SEASONAL NITROGEN DYNAMICS AND LONG-TERM CHANGES IN SOIL PROPERTIES UNDER THE MUCUNA/MAIZE CROPPING SYSTEM ON THE HILLSIDES OF NORTHERN HONDURAS

A Dissertation
Presented to the Faculty of the Graduate School
of Cornell University
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy

by
Bernard Louis Triomphe
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Bernard Louis Triomphe, Ph.D
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In the wet lowland hillsides of Northern Honduras, thousands of small farmers have been spontaneously developing and adopting throughout the past 20 years a no-tillage cropping system, which consists of a rotation between a rainy-season, spontaneously reseeding mucuna (*Mucuna spp.*) and a dry-season maize (*Zea mays*). The present study provides an exploratory analysis of some of the major agroecological processes which shape this system, including short-term nitrogen cycling and long-term trends in soil chemical and physical properties. To this end, an agronomic monitoring was conducted in farmers' fields during two consecutive cycles in four villages, in which maize yields and yield components, mucuna biomass, soil properties and farmers practices were recorded. Long-term trends were detected via a chronosequence scheme.

By the time a mucuna crop is slashed, it has typically accumulated 10 to 12 t.ha^{-1} of dry-matter and 250 to 350 kg.ha^{-1} of nitrogen in its above-ground biomass. The mucuna mulch decomposes rapidly after slashing, occasioning a marked peak of inorganic nitrogen in the soil profile. Farmers take advantage of this pattern by planting maize just after slashing. The mucuna itself recycles a significant share of the nitrogen it needs. Sustained maize yields of 3 to 4 t.ha^{-1} (double those obtained without using mucuna) are commonly achieved, with hardly any need for and response to nitrogen fertilizer.

In the long-run, the mucuna system not only protects the soil from erosion, but also contributes to a general improvement in soil fertility over time in most cases. No soil acidification or other forms of soil degradation take place. Soil organic matter increases markedly in the first five cm of the soil profile. Levels of exchangeable Ca or Mg have a tendency to increase throughout the soil profile, whereas levels of available phosphorus remain stable. Finally, steady-state infiltration and porosity also increase significantly over time.

In spite of its satisfactory agronomic performance, the future of the mucuna system is uncertain, as the income-generation capacity of the rotation is relatively low. Increasing yields, making use of mucuna as forage or feed, and diversifying the production at the farm level while maintaining the multiple benefits associated with the mucuna system seem necessary to avoid its gradual abandonment. More generally, the wider diffusion of ecologically-sound slash-and-mulch systems, and also the understanding and application of the key principles of mulch farming to agroecological environments less favorable than Northern Honduras are among the many challenges lying ahead.

DINAMICA DE NITROGENO Y CAMBIOS A LARGO PLAZO EN LAS PROPIEDADES DEL SUELO BAJO LA ROTACIÓN MUCUNA/MAÍZ EN LAS LADERAS DEL NORTE DE HONDURAS

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En las laderas húmedas del norte de Honduras. miles de pequeños agricultores han ido desarrollando y adoptando espontáneamente durante los últimos veinte años un sistema de cultivos de labranza zero. consistiendo en una rotación de un cultivo de maiz (*Zea mays*) sembrado durante la estación seca y un cultivo de mucuna (*Mucuna spp*) en la estación lluviosa El presente estudio provee un análisis de algunos de los procesos agroecológicos actuando en este sistema. incluyendo el reciclage de nitrógeno a lo largo del ciclo del maiz y las tendencias a largo plazo en propiedades químicas y físicas del suelo Para este fin. se llevó a cabo un monitoreo agronómico durante dos ciclos consecutivos en parcelas de agricultores en cuatro comunidades. durante el cual se midieron los rendimientos de maiz y sus componentes. la biomasa de mucuna. las propiedades del suelo y las practicas de los agricultores. Las tendencias a largo plazo se detectaron mediante un esquema de cronosecuencias

Al momento de chapiarlo. el cultivo de mucuna ha acumulado de 10 a 12 t ha^{-1} de materia seca y entre 250 y 350 kg.ha^{-1} de nitrógeno en su biomasa aerea. El mantillo de mucuna se descompone rapidamente despues de chapiar. induciendo un marcado incremento en la disponibilidad del nitrógeno mineral en el perfil del suelo Los agricultores aprovechan esta situación para sembrar maiz justo despues de chapiar La mucuna recicla gran parte del nitrogeno que va acumulando Rendimientos sostenidos de 3 a 4 t ha^{-1} de maiz (el doble de los obtenidos sin usar mucuna) son comunmente alcanzados. sin necesidad de aplicar fertilizante nitrogenado La respuesta al mismo es muy débil aunque variable entre parcelas y años

A largo plazo. la rotación mucuna/maiz permite proteger el suelo contra la erosión. a la vez que contribuye a mejorar la fertilidad del suelo a través de los años en la mayoria de los casos No se observa acidificación del suelo o otras formas de degradación del mismo Los niveles de materia organica aumentan marcadamente en los primeros 5 cm del perfil de suelo. y los contenidos de Ca y Mg intercambiables tienden a aumentar en todo el perfil El fósforo disponible se mantiene estable Finalmente. las tasas de infiltración y la porosidad del suelo tambien aumentan a lo largo de los años.

A pesar de sus buenas caracteristicas agronómicas. la permanencia de la rotacion esta en dudas. ya que los ingresos derivados de su uso son relativamente bajos Para evitar su abandono gradual. parece necesario aumentar los rendimientos. usar mucuna como fuente de forrage o diversificar la producción a nivel de la finca. tratando sin embargo de no perder los beneficios multiples asociados con el uso de este sistema de cultivos De forma mas general. la difusión de sistemas ecologicamente viables basados en el uso de coberturas vivas y mantillos. asi como el entendimiento y la aplicacion de los principios claves de los mismos en ambientes agroecologicos menos favorable que el litoral atlántico de Honduras. forman parte de los muchos retos que quedan por afrontar.

BIOGRAPHICAL SKETCH

Born a while ago. raised in Strasbourg (France ..) for many years, he acquired early on some of the skills apparently necessary to prosper in a family of 7 lively but quarrelsome siblings Convinced by the example of his parents that acquiring a college education was after all a reasonable way to approach life, he decided to study agronomy, thus escaping a strong family tradition of literary-oriented careers. An early sabbatical year spent traveling in Africa and sharing the lives of humble people opened his eyes to new cultures and created a lasting impulse to do whatever he could to justify returning to sunny climates and fragile rural societies. His wishes were fulfilled beyond expectations: in the past decade. he has lived successively in West Africa, Mexico. Honduras. and exotic Central New York, each stay offering countless opportunities to discover new people. intriguing ideas and old personal shortcomings

Exhausted after more than five years of laborious work on his Ph.D.. and at last armed with serious degrees. moderate knowledge, and questionable wisdom. Bernard will continue his journey on this planet. trying to ascertain why he was ever born, and how best to enjoy life and share its joys and pains with others

A Don Jose Maria Ayala
y los agricultores de San Francisco de Saco

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Nobody should doubt that this Ph.D. is in many respects a tribute to the vision and help I garnered from many people, several of whom I certainly forgot to mention here.

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I was very fortunate to have among my fellow graduate students in SCAS, past or present, not only seasoned professionals from whom judicious advise could always be obtained, but also excellent friends on whom to rely during the tough times Cornell distributes around so lavishly: Ken Schlather, Julie Lauren, Beverly McIntyre, Arturo Aguirre-Gomez, Alejandro Mateos, Diego de Lozada. My gratitude to Ken is immense even though he won't admit it: this dissertation and his author would not have gone far without his (and Donna's) constant, patient and generous behind-the-scene support.

To the farmers of hilly Northern Honduras, my appreciation and admiration is boundless. Not only have they "invented" the mucuna/maize rotation, but they have also contributed tremendously to its diffusion beyond their own communities. Indeed, this study is a pale reflection of their collective wisdom and achievements, or, as they would certainly prefer to see it, of God's generosity to them. Among those who have so patiently listened to my questions, opened their fields and experience to my stubborn inquiries, and welcome me in their hearts and homes, I wish to express my deepest gratitude and respect to Don Jose Maria Ayala, his wife Doña Lola and their (many) children. Numerous others in San Francisco de Saco and elsewhere were equally essential in making my stay at their side an unforgettable professional and human experience: Don Antonio Ayala and his family, Don Jose Maria Galdamez, his wife Doña Pastora, Doña Ester and the whole family (including the grand-children!), Don Juan Rivera and family, Don Andres Lainez and family, Don Jacobo Castellanos and his wife, Don Antonio Morales and family, Martir Andrade, Obed Serrano and his wife, the late Don Anselmo Mejia, Don Chepe Alfaro, and many, many others still.

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I am also very grateful to Ings. Manuel Lopez y Oscar Espinal, professors in the Soils Department at CURLA/UNAH (Centro Universitario Regional del Litoral Atlántico de la Universidad Nacional Autónoma de Honduras), for welcoming me in their laboratory, and for having participated in various phases of this project. David Ashby, Carmen de Brooks and Leonel Castillo from the Research Department of the Standard Fruit Company in La Ceiba helped tremendously with laboratory analyses. Ing Orly García and Inga. Angela Munguia, of the Secretaria de Recursos Naturales have both done their best to support my efforts. Ings. Rafael Meza, Oscar Robles, Guillermo Rosales, Pedro Baca, Maria Gricel Navarro, Christian Alix and Denis Buteau, of P.D.B.L. (Proyecto de Desarollo del Bosque Latifoliado) have made my collaboration with their project both extremely fruitful and enjoyable. Gricel and Christian know that my debt with them goes much beyond their professional help in this study. Sally Humphries and Hector Barreto (CIAT-Hillsides), and Daniel Buckles (then at CIMMYT) have generously shared with me first-hand data on the mucuna system and the Atlantic littoral.

Roland Bunch and Milton Flores constantly forced me to scrutinize my scientific approach for its contribution to the improvement of farmers' lives. certainly, I fell short of their expectations, but I hope that one day I or another scientist will surprise them.

In France, several people from CIRAD were instrumental in defending my research project at a moment when budgets were easily cut. I wish to thank especially Cl. Charreau, D. Picard, F. Ganry, P. Siband, J. Pichot, and also R. Oliver, who took personally responsibility "pour la gloire" of an impressive amount of laboratory work.

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Last but not least, I want to thank my parents Robert and Micheline for they have given me unconditional love and support, a rare ingredient in my life. It was certainly crucial for the completion of this thesis, and will continue to be so in my future endeavors.

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Chapter 1

INTRODUCTION

Many small farmers throughout Latin America operate under dire socioeconomic conditions (de Janvry, 1981) Several key interrelated structural constraints are usually recognized as contributing to this situation: (1) restricted access to land, as a result of very uneven land distribution, (2) limited access to agricultural inputs and commodity markets, linked among other causes to inadequate communication infrastructure and lack of disposable income, (3) high rates of population growth, spurring a growing pressure on the natural resources, and (4) a rapid disappearance of remaining virgin forested land, which up to now have provided a relative measure of alleviation for many households in search of decent standards of living (Breslin, 1987).

In hillside or mountain environments, additional constraints must be included in the previous list. One of them is the high transaction costs associated with many economic activities which take place in a context of broken topography and geographical isolation of many communities. This translates into lower or erratic fluxes of information, services or goods being exchanged between households living in the hillsides and the society at large Another one is the relative fragility of the physical environment, and in particular the high potential levels of erosion and other forms of degradation accompanying the economic exploitation of natural resources via logging, agriculture or cattle rising

Under such challenging conditions, it is hardly surprising that farmers have not been able to respond very successfully to the growing stresses imposed on rural societies (Collins, 1986) For the most part, they have had no choice but to continue extensive cropping practices such as land fallowing or slash-and-burn agriculture. Whereas these practices had long been adequate (Nye and Greenland, 1960), greatly shortened fallow periods and low cash-income generation capacity nowadays threaten the survival of entire farming communities

For those concerned with the conservation of natural resources and/or the well-being of rural populations, a vital question is what can be done to alleviate some of the constraints mentioned above, and help households living from small-scale agriculture achieve a more sustainable path (Peters and Neuenschwander, 1988, Wijewardene and Waidyanatha, 1989, Villachica *et al.*, 1990, Robison and McKean, 1992; Bandy *et al.*, 1993, Garrity and Khan, 1994) Clearly, successful strategies will have to address in one way or another the root of these problems, which lie largely outside agriculture *sensu stricto* in that sense, it would be foolish to entertain the illusion that there can be sustainable agricultural practices or systems without a sustainable society at large (Castallenet, 1994). Whatever the progress made on this latter level, a definite requirement from an agricultural viewpoint is to at least devise durable means of exploiting the one resource most easily degraded destroyed or lost in the productive process, particularly in a hillside environment. the soil itself.

1.1 IN SEARCH OF ALTERNATIVES TO THE DILEMMA OF HILLSIDE FARMING

On account of the intrinsic fragility of hillsides, many dispute the notion that they should ever be farmed. The fact that this study focuses on a successful hillside cropping system by no means constitutes an act of active advocacy for farming hillsides But as hillside colonization is an inescapable reality, understanding how to minimize the resulting damage is a legitimate concern.

There have been a great many successful experiences, most centuries or even millennia old, about conserving soil in hillside environments, including engineering approaches (e.g terracing) and agronomic approaches (e.g. agroforestry or rotations with cover crops) (Siebert and Lassoie, 1991). The former were commonly practiced in Europe or Asia for example centuries ago, but their high initial and maintenance cost and high requirement in terms of social control make them hardly appropriate for most present-day situations Agroforestry systems proposed by present-day scientists (Nair, 1989; Fernandes *et al.*, 1993), even though they appear attractive theoretically, have been very sparingly adopted up to now outside areas where similar or related practices were already in use (Budowski, 1985; Garrity, 1993). This lack of adoption can be explained at least partly because of the high labor requirements of these systems, and the delayed or minimal impact they have on productivity or income generation

On the other hand, no-till slash-and-mulch systems (systems in which a natural or introduced vegetation is slashed and used as a mulch for the following crop) have been adopted in several regions throughout the tropics (Thurston, 1994). They do not require heavy initial investments and can produce tangible benefits in the short-term, including erosion and pest control, improved nutrient cycling and water use, and reduced labor use (Lal, 1975; Monegat, 1991). Of special interest are systems including legumes as the mulched species, because the nitrogen released by the legume upon decomposition helps boost non-legume crop yields significantly Thus farmers depend less, or not at all, on applications of costly nitrogen fertilizer, an advantage shared by rotations including green manures (de Sornay, 1916; Pieters, 1927. Yost *et al.*, 1985. Lathwell, 1990. Buresh and de Datta, 1991). These rotations seem particularly suited to the humid tropics (Buckles and Barreto, 1995), as production of biomass which will be left in place competes little with the production of economically more valuable biomass such as grain, forage or fuel In spite of their many qualities, legume-based slash-and-mulch systems are still very poorly documented in the scientific literature (Sanchez, 1994), even though related agroecosystems have been studied extensively (Huntington *et al.*, 1985. Ladd and Amato, 1985. Yost *et al.*, 1985, Glover and Beer, 1986, Pichot *et al.*, 1987, IRRI. 1988, Yost and Evans, 1988, Sanchez *et al.*, 1989; van der Heide and Hairiah.

1989; Palm and Sanchez, 1990; Sarrantonio, 1991; Smyth *et al.*, 1991; Kang and Mulongoy, 1992, Mulongoy and Akobundu, 1992, Haggar and Beer, 1993, Thurston, 1994)

1.2 TAPPING FARMERS' KNOWLEDGE AND EXPERIENCES

While science-based agricultural research is to be credited for huge successes in raising agricultural output, many scientists fail to realize that small, uneducated farmers also successfully experiment and innovate on their own initiative (Johnson, 1972; Brammer, 1980, Richards, 1985). By definition, farmers' mode of experimentation is not equivalent to scientific inquiry, as it relies heavily on empirical, locally validated experience Hence it may not generate knowledge in a form easily accessible to outsiders or extrapolable to other regions/farmers. Nevertheless, many insights were gained in the past and many more that could still be gained from assessing what farmers did or do to address key issues related to crop or environmental management. For example, farmers' in-depth understanding of numerous wild plants and their relationships to the environment might provide invaluable guidelines for developing sustainable farming practices (Richards, 1985, Sinclair *et al.*, 1993).

An important task for researchers then is to devise efficient ways of tapping this knowledge. An added challenge is to contribute simultaneously to the strengthening of farmers' capacity to generate new ideas and practices (empowerment may be the keyword Bunch, 1982), given that traditional mechanisms of knowledge generation are fast eroding, in the wake of the crisis affecting rural societies.

Documentation of farmers' knowledge and practices, a needed first step in this process, can take several forms: from mainly journalistic accounts of what is being done (e g (Flores, 1987) to in-depth diagnostic studies trying to identify constraints, benefits or farmers' conceptual frameworks (Richards, 1985; Bentley, 1989; Bellows, 1992, Sinclair *et al.*, 1993, Solomon and Flores, 1994) In all cases, it is important to get away from gratuitous opinion and propaganda-loaded accounts about indigenous systems and knowledge bases and towards a rigorous understanding of the principles they rely on, their shortcomings and potential for extrapolability outside of their original context

1.3 WHY STUDY THE MUCUNA SYSTEM? RESEARCH OBJECTIVES

Given the above context, the very existence of the mucuna/maize rotation practiced by thousands of farmers throughout the humid tropics of Meso America (Buckles, 1995), and particularly in the hillsides of Northern Honduras, seemed to provide a good opportunity to document *in situ* the agronomic performance and conceptual underpinnings of an indigenous slash-and-mulch cropping system reportedly successful in terms of productivity, sustainability and adoptability.

Briefly, the mucuna/maize rotation is a yearly rotation/intercrop between a rainy season mucuna (*Mucuna spp.*) grown as a cover crop and a dry season maize (*Zea mays*) planted in the slashed mucuna mulch. The mucuna volunteers in the maize crop from seeds left unharvested in the mulch. This rotation has been adopted massively among hillside farmers of Northern Honduras (Flores, 1987; Avila Nájera and López P., 1990, Buckles *et al.*, 1992). The fact that adoption had taken place *spontaneously* and *on a regional scale* indicated that the system was apparently providing satisfactory answers to important macro- and micro-level constraints. Unlike many innovations conceived by agricultural scientists, literally anybody seemed to be able to adopt the mucuna system, without the need for costly capital investments, incentive packages or formal training sessions. Also, the mucuna system seemed 'sustainable' (a fashionable though poorly defined notion) as some farmers were said to have been using the rotation for 15 to 20 years without running into any noticeable agronomic problem. Furthermore, the system seemed reasonably productive with reported maize yields (based on farmers' *interviews*) ranging from 2 to 3 $t.ha^{-1}$, which is about double the Honduran average maize yield of 1.4 $t\ ha^{-1}$ (CIMMYT, 1994).

The patterns of adoption made the mucuna system well-suited to a long-term analysis: the rotation had been introduced long enough to allow a reasonable assessment of what changes had taken place. Swift et al. (1991) consider one decade as the minimum relevant scale for long-term studies. It also took place recently enough in the region so that farmers still remember fairly precisely in which year they started using it.

Also, there are many organizations (particularly NGOs) which, lured perhaps by the success of the mucuna/maize rotation, have developed active programs of diffusion of mucuna seed and mucuna-based systems all over Mexico, Central America and in Africa (Bunch, 1990, CIDICCO, 1991; Buckles, 1993; Versteeg *et al.*, 1993, Arellanes, 1994, Loaiza, 1994). Yet these groups for the most part did not appear to possess a strong technical basis for recommending mucuna, and in particular did not rely on solid quantitative agronomic evidence about how these systems work (not even maize yields or mucuna biomass had been *measured* in farmers' fields under the mucuna system in the Atlantic littoral of Honduras by the time this study was initiated).

Under the circumstances, it seemed both desirable and necessary to document and quantify the behavior and performance of the mucuna system, and in particular to detect any problems associated with its use before it was transferred indiscriminately as a new miracle technology. In-depth documentation of an actual cropping system also seemed to provide an opportunity to learn useful conceptual and practical lessons about the functioning of generic slash-and-mulch cropping systems.

A short-term study could not comprehensively cover the broad spectrum of issues associated with the mucuna system. Hence, a number of choices had to be made to restrict the scope of the research. Specifically, our research objectives included the following:

(1) document the overall features of the mucuna system (practices, productivity, etc.),
(2) detect long-term trends in soil fertility under continuous use of this rotation,
and (3) analyze some of the key components of the nitrogen cycle.

1.4 KEY METHODOLOGICAL CHOICES

1.4.1 On-farm research

Several reasons dictated our decision to conduct the study on-farm. First, working on-station was not even an option, as no experiment station had been established in the hillsides of the Atlantic littoral, and because it seemed hardly possible to reproduce the mucuna system on-station in its various dimensions. On the other hand, we were interested in sampling the diverse agroecological conditions existing on a regional level. Also, it appeared necessary to explore the mucuna system in a broad fashion, with the objective of identifying the actual influence on the performance of the mucuna system of as many factors and conditions as possible (Sébillotte, 1987). In addition, we wanted to tackle management of the rotation by the farmers as a central issue, in a bottom-up rather than top-down manner (Rhoades and Booth, 1982, Chambers *et al.*, 1990, Legal, 1995). Overall, our approach was very similar in essence to conducting an agronomic diagnosis of the mucuna system (Byerlee *et al.*, 1991), with the belief that this was a necessary step before being able to choose relevant issues for more in-depth disciplinary research.

1.4.2 Chronosequence approaches

Detecting long-term trends was one of our declared objectives. Because many effects induced by the continuous use of a crop rotation are cumulative over time, and hardly detectable in the short-term, it was felt that short-term experiments would not yield the type of empirical evidence we were hoping to document. In particular, we were interested in detecting any *potential negative trend* induced by the use of the mucuna rotation, such as soil acidification or the building-up of pests or diseases. On the other hand, the absence of any downward trend or a positive trend in soil properties would be a proof of the agronomic sustainability of the mucuna system.

Given that long-term experiments or historical databases on the mucuna system did not exist, the only practical alternative was to adopt an *indirect approach*, namely a *chronosequence* or *space-for-time substitution scheme* (Pickett, 1988). In such an approach, trends over time are inferred from an instantaneous comparison of fields with different cropping history, which in the case of the mucuna rotation corresponded to varying number of years of continuous use of the rotation.

From the beginning, it was clear that this approach had intrinsic weaknesses, as risks of confusion were potentially large and independent testing of the conclusions were not possible within the study. On the other hand, the potential validity of the conclusions appeared enhanced by the possibility of using a relatively large sampling base (a consequence of the wide adoption of the mucuna rotation), something rarely encountered in long-term studies. Also, it seemed worthwhile to evaluate in a case study fashion the potential usefulness and limitations of chronosequence approaches, as they may be one of the few tools available to evaluate long-term impacts without having to wait many years for obtaining an answer, and without needing the resources and institutional commitment required by long-term experiments (Pieri, 1989; Johnston and Powlson, 1994; Steiner, 1995).

1.5 OUTLINE OF THE VARIOUS CHAPTERS

Materials and methods common to all chapters are presented in chapter two, including an overview of the main agroecological and socioeconomic features of Northern Honduras. Chapter three offers a general overview of the mucuna system, from a brief history of the mucuna system in Northern Honduras to an examination of its management by farmers, as well as a summary of the main constraints and benefits associated to its use. Chapter four analyses the seasonal dynamics of the mucuna system during the maize cycle season, and particularly aspects pertaining to mucuna biomass accumulation and decomposition as well as nitrogen cycling. Chapter five examines the long-term changes over time in soil chemical and physical properties induced by the continuous use of the mucuna/maize rotation, as well as the consequences of these changes on crop productivity. A general discussion of major agronomic and socioeconomic issues pertaining to the performance, future and extrapolability of the mucuna system is presented in chapter six alongside an evaluation of several methodological issues. Finally, chapter seven summarizes the main findings of the thesis.

Chapter 2

MATERIALS AND METHODS

This chapter presents an overview of the regional context and the methodological framework adopted in this study. This includes a conceptual analysis of chronosequence approaches, the criteria for the selection of our various research sites, their main characteristics and a description of the key features of the agronomic survey conducted in farmers' fields. A brief overview of the measurements related to nitrogen cycling and long-term evaluation of the soil fertility is also given, although most of the details are presented within the respective chapters devoted to these issues (Chapters 4 and 5)

2.1 THE HILLSIDES OF THE ATLANTIC LITTORAL OF HONDURAS

Major characteristics of the environment (national, local) in which farmers using the mucuna/maize rotation operate are briefly described in this section, as they contribute to a better understanding of some of the peculiarities of this cropping system

2.1.1 Smallholder agriculture in Honduras

Like most of Central America. Honduras is a country dominated by rolling to steep hillsides. It is also one of the poorest countries in Latin America, with a GDP per capita of less than $600 in 1991 (World Bank, 1993). The Honduran economy is heavily dependent on traditional agricultural exports such as coffee and bananas, and shrimp more recently. Land distribution in the country is very uneven, a situation typical of Central and Latin America as a whole (de Janvry, 1981, de Janvry and Garcia, 1992). As much as 90% of the arable land is owned by 10% of the farming population (Secplan, 1989 in Buckles and Sain, 1995). The better lands (flatter, easily accessible) have been monopolized by the wealthiest landowners (most of them engaged in extensive livestock production), as well as by a number of multinational companies (such as United Fruit or Standard Fruit) growing banana and other export-oriented crops on large industrial plantations since the turn of the century. Small farmers mainly dedicated to hillside maize and bean production constitute the vast majority of the farming population: in 1987, 70 to 80% of the Honduran maize and/or bean producers had farms smaller than five hectares (Curry Zavalo, 1993). In spite of low productivity levels (1.4 t.ha-1 on average for maize CIMMYT, 1994), their contribution to the national grain output is significant, reaching about 40% of the maize and 60% of the beans produced in Honduras (Lindarte and Benito, 1991)

Given the poor economy and restricted access to land, standards of living for most rural households are very low: malnutrition is common among children, infant mortality rates are high, and actual access to education or other services is minimal (Humphries, 1994)

This situation has motivated many families to migrate out of their home regions in the hope of improving their lot, or simply surviving. In addition to rural-to-urban migrations (Tegucigalpa and San Pedro Sula receiving the bulk of these migrants), there is also a steady flow of migrants who opt to try farming in the Northern Coast (Breslin, 1987, Szaraz and Irias, 1993; Humphries, 1994), where land is still available, and where rainfall is abundant, unlike much of Honduras (Zuñiga A., 1990).

2.1.2 The socioeconomic environment in the Atlantic littoral region

The discussion will now focus on the part of the North Coast known as the Atlantic littoral of Honduras (Figure 2 1) The terms Northern Honduras, North Coast or Atlantic littoral will be used interchangeably to refer to a relatively narrow strip running approximately West to East for about 200 km, from Tela to Tocoa (Figure 2 1) Administratively speaking, this area includes the Departments of Atlantida and the Western part of the Department of Colon.

Historically, the Atlantic littoral has been notorious for its large export-oriented industrial plantations located on the flat lowlands, alongside extensive ranching concentrated in the hands of a few. Most of the hillsides and the whole mountain range remained scarcely populated until at least the 50s, and primarily under virgin moist tropical forest (Szaraz and Irias, 1993; Buckles and Sain, 1995). Since the early 1960s, the Atlantic littoral has become an active agricultural frontier, receiving scores of poor, spontaneous migrants from other regions of Honduras who settled for the most part in the hillsides (Breslin, 1987, Szaraz and Irias, 1993). In parallel to hillside colonization, there has been in recent years a marked expansion of extensive livestock operations in many flat areas and in moderately-sloped hillsides as well. It was estimated that fifty-five percent of the total land area in the Atlantic littoral was under pastures in 1988, vs only 15% under annual cropping (Buckles and Sain, 1995). Livestock expansion may not be the direct cause for the accelerated deforestation (Nicholson *et al.*, 1995), however it is contributing to pushing the poorest farmers ever higher in the mountain (Humphries, 1994) As land availability decreases and land prices increase, landless newcomers or young households have no choice but to settle in the steeper hillsides of the "Nombre de Dios" mountain range, which they cannot do without clearing the primary forest still found at higher elevations (Szaraz and Irias, 1993, Humphries, 1995).

Figure 2.1 Location of the Atlantic littoral in Honduras and Central America

Public or private investments for the benefit of rural communities have been very limited. The only large-scale development project operating in the region, the Proyecto de Desarollo del Bosque Latifoliado (P.D.B.L. or Broadleaf Forest Development Project, co-financed by CIDA-Canada), has been in operation since the late 1980s, but has reached relatively few people and communities. Indeed, churches of varied denominations are in many cases the only institutions reaching the general population. Year-round accessible roads are rare in the hillsides and public transportation on the existing ones very limited. Very few communities have access to electricity or primary health care centers. Services such as rural credit or extension are non-existent or inaccessible for most farmers (Giasson *et al.*, 1990; PDBL, 1991; PDBL, 1994). Finally, the average levels of formal education and training remain very low, and many farmers are functionally illiterate (Humphries, 1994)

2.1.3 Agroecological environment in the Atlantic Coast of Honduras

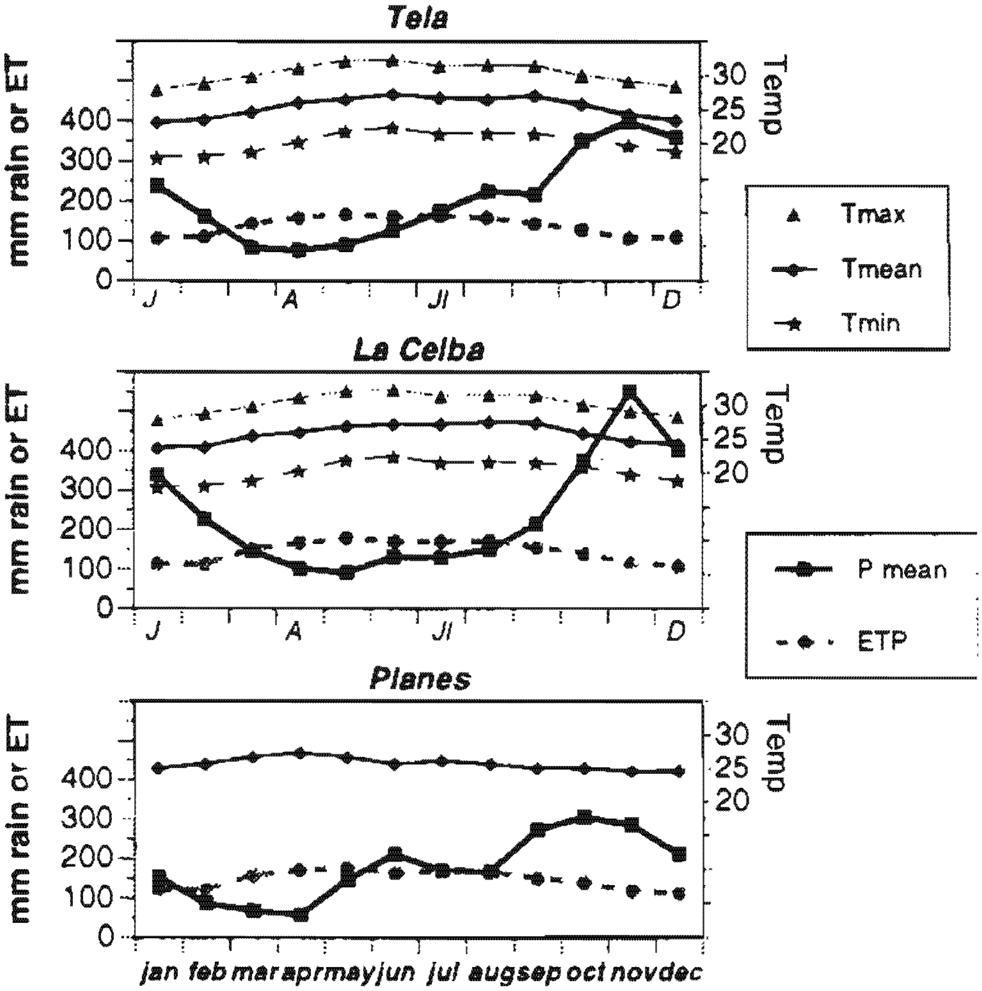
2.1.3.1 Topography

The Atlantic littoral is made up of three contrasting natural regions the mountain range "Nombre de Dios", culminating at almost 2500 m above sea level, the narrow (less than 30 km wide) fertile littoral plain bordering the Caribbean sea and running parallel to the mountain, and an intermediate hillside area constituting a buffer zone between the plain and the mountain proper (PDBL, 1991).

Whereas the plain is very flat, dissected only by rivers originating in the mountain, the Sierra has extremely steep slopes, as it rises abruptly above the plain. In the hillsides, topography is mixed but largely dominated by irregular rolling landforms with slopes ranging typically between 20% and 100% (PDBL, 1991). Another important feature of the landscape is that many of the slopes are precariously stabilized, making massive or localized landslides relatively common during the periods of intense rainfall

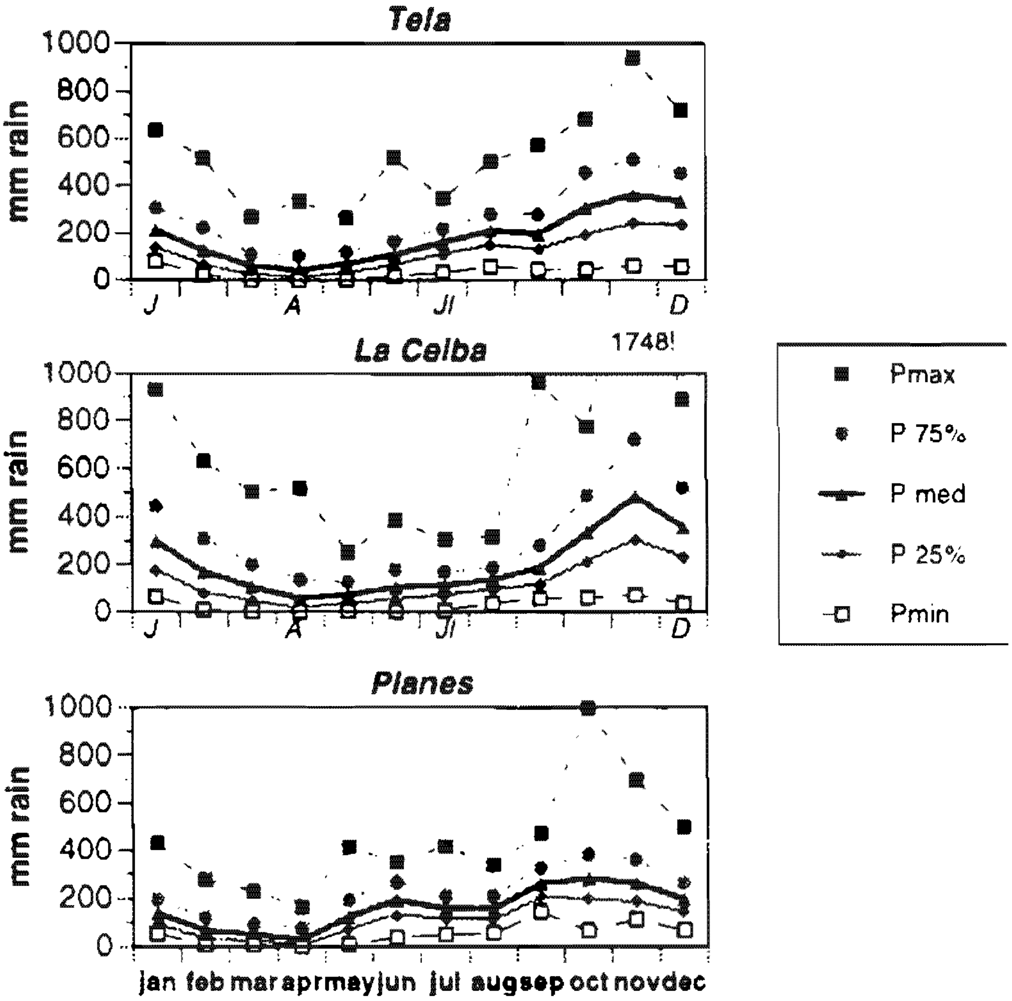
2.1.3.2 Climate

Excluding the higher mountain range, the climate in the Atlantic littoral is typical of the humid lowland tropics (van Wambeke, 1992). Rainfall is abundant and reaches 2500 to 3000 mm.year^{-1} on average. It has a tendency to increase with elevation, in response to orographic factors (the mountain Nombre de Dios is the first obstacle encountered by the moisture-laden winds from the Caribbean; Zuñiga A., 1990). There are also local "dry spots" where rainfall drops to less than 2000 mm.year^{-1}, such as the Jutiapa area



Monthly averages calculated on 38 years data (Data from Hargreaves, 1980)
Average minimum and maximum temperatures based on 12 years data collected at one single site (Escuela Agricola J.F. Kennedy, 10 m a.s.l., near La Ceiba).

Figure 2.2: Average monthly rainfall, evapotranspiration and temperature in the Atlantic littoral of Northern Honduras



Rainfall frequency distribution calculated on 38 years data. Data from Hargreaves, 1980

Figure 2.3 Frequency distribution of monthly rainfall in the Atlantic littoral of Honduras

Distribution of the rain throughout the year is roughly bimodal (Figure 2.2). There is typically a long rainy season from May to January, peaking at 300 to 500 mm month^{-1} towards the end of the year, and a short, drier season (known as summer or "verano") between February and May (50 to 150 mm.month^{-1}) (Hargreaves, 1980). *Daily* rainfall in excess of 100 to 200 mm is not uncommon between September and December, leading to monthly totals of 1000 mm or more (Figure 2.3). Occasionally, the dry season extends over 4 to 5 months, although isolated rains fall irregularly here and there even during the drier summers. Also, because the soil profile contains usually between 200 and 300 mm of stored water at the onset of the dry season from the heavy rainfall received by the end of the rainy, many crops or natural vegetation can resist drought periods 4 to 6 weeks long with little negative consequences.

Average annual temperature is about 26°C at sea level, with little variation year-round: the coolest month being January (24°C), and the hottest May (28°C) (Figure 2.2). Similarly, average diurnal variations are limited to about 10-12°C even in January, average minimum temperatures do not drop below 15 to 17 °C, while in May, average maximum temperatures do not exceed 30 to 32°C (Figure 2.2). Average temperatures get lower as elevation increases however.

Evapotranspiration as calculated by Hargreaves (1980) (Figure 2.2) remains moderate during the rainy season (about 3 to 4 mm.day^{-1}), it increases however during the dry season (reaching about 5 mm day^{-1} between March and May).

Excluding occasional hurricanes and other tropical storms (fairly common in the Caribbean), winds remain moderate on average, although they can occasionally become strong enough during the dry season to provoke damage to agricultural crops.

2.1.3.3 Soils

Soils in the littoral plain, mainly Tropic Fluvaquents and associated alluvial soils (van Es *et al.*, 1992), are very fertile and among the most coveted in the region. Similarly, even though their overall fertility is inferior to what is found in the plain, soils in the hillsides present fairly favorable properties for agriculture if it were not for their steepness and susceptibility to erosion. The most common are Ultic Hapludalfs, Typic Dystropepts and Typic Hapludults, Tropohumults and Tropohudults (Bryant, pers.com., Rosales S. and Sanchez A., 1990). They typically developed from an igneous metamorphic, mafic parent rock material (Simmons, 1969 ; Bryant, pers com.). Most of these soils are relatively deep (> 60-80 cm in most cases), present mildly acidic pHs (around 6) and have good levels of exchangeable bases to a depth of 60 cm or more, usually from 10 to more than 20 cmoles(+).kg^{-1} (Table 2.1).

Table 2.1 Typical ranges for selected soil properties in four sites in the hillsides of Northern Honduras

Property	Depth	Sn Fco	Mangas	Cuero	Piedras
Organic C (%)	0-10	2.1-2.7	2.4-3.2	2.4-3.2	2.6-3.4
Organic N (%)	0-10	0.20-0.28	0.24-0.32	0.25-0.33	0.27-0.35
pH water	0-10	5.7-6.3	6.0-6.8	5.6-6.4	5.8-6.5
	30-60	5.6-6.0	6.0-6.8	5.3-5.9	5.2-6.1
Exch.Ca+Mg	0-10	8-18	20-30	6-14	10-18
(cmol(+) kg^{-1})	30-60	10-22	20-30	3-8	7-17
Avail P (Morgan) (ppm)	0-10	0-4	4-10	0-3	0-3
Sand %	0-10	40-55	30-50	40-60	?
Clay %	0-10	15-30	20-35	15-25	?
Clay %	30-60	20-40	25-40	20-30	?
Typical soil depth [1]	---	> 80 cm	> 80 cm	60 cm	60-80 cm

[1] no obstacle (physical or chemical) to root colonization up to this depth

2.1.4 Implications for hillside farming

Perhaps the most obvious conclusion of this brief overview is that the hillsides of the Atlantic littoral are well-endowed with at least three of the major ingredients of a potentially successful smallscale agriculture, namely available land (even if only by renting it), relatively good soils and favorable climate. The rainfall pattern allows the completion of two rainfed cropping cycles annually: the first (called summer or primavera) coincides with the steady return of rains in June-July whereas the second (called winter or postrera) starts anywhere between November and January and coincides with the last part of the rainy season and the bulk of the dry season.

The very possibility of planting a winter cycle puts the farmers of Northern Honduras in the position to exploit an advantageous market niche for their winter maize harvests. In effect, because most of Honduras and Central America only produces summer maize, there is a strong seasonality of maize prices on the market, which reach their peak around May-June of each year (Buckles *et al.*, 1992, Buckles and Sain, 1995). Farmers of the North Coast are thus able to capture a price 50% to 100% higher for their winter maize compared to the price farmers producing summer maize can fetch.

Beside annual crops, a variety of perennials can also be successfully planted, such as cocoa, coffee, African palm, citrus, and a large range of fruit trees (PDBL, 1991). Also, it is usually possible to maintain pastures green and growing year-round. The risk of total crop failure due to lack of rainfall is relatively small even during the winter cycle, a situation in sharp contrast to other much drier regions of Honduras. Indeed, excess rainfall may be more of a problem, as it can cause significant yield losses during the primavera cycle by favoring fungal diseases of maize such as *Stenocarpella maydis, S. macrospora and Fusarium moniliforme* (del Rio and Castaño-Zapata, 1993, cited in Buckles and Sain, 1995). Overall however, agricultural risk whatever its causes is fairly limited. asked about the frequency of "bad" years, farmers estimated it at less than 2 years out of 10, and many actually disputed the very idea that there were bad years at all.

On the other hand, the high risk of erosion created by steep slopes and high rainfall erosivity (Mikhailova, 1995) coupled with the poor economic infrastructure and great poverty of most rural households qualify the hillsides of the Atlantic littoral as marginal environments vis-à-vis agricultural production and economic development.

Approximately 30% of hillside households have comfortable revenues linked to their better access to land (Buckles and Sain, 1995). Lacking experience, access to markets and capital to deal with other alternatives or to purchase inputs, the remaining 70% of hillside farmers, like most other Honduran farmers (Lindarte and Benito, 1991; Curry Zavalo, 1993) grow small quantities (1 to 3 hectares per household) of maize, beans and sometime rice both for home consumption and as cash crops. Even in the smallest farms, it is frequent to sell more than 50% of the winter maize production, whereas summer maize is more likely to be kept for home consumption (Humphries, 1994, Buckles and Sain, 1995). Other agricultural activities contribute to income generation. For example, many farmers cultivate small quantities of cocoa or coffee, usually as part of their home gardens. Small-scale pig or chicken rising is also frequent, although periodic epidemics make it a risky enterprise. About 15% of all households, usually those who can afford to have pasture land close to the existing roads, exploit small herds of dual-purpose cows, usually less than 10-20 heads. In some communities, logging of the primary forest still provides significant revenues, although the long-term sustainability of this activity on a regional scale remains problematic (Szaraz and Irias, 1993; Humphries, 1995). Finally, many individuals, particularly in the poorest households, engage in occasional or seasonal off-farm activities to complement their revenues, from wage labor to petty trading and craft work (Buckles and Sain, 1995).

2.1.5 Importance of the mucuna/maize rotation in Northern Honduras

In the early 90s, the mucuna/maize rotation was being used by approximately two thirds of the small hillside farmers of the Atlantic littoral of Honduras (or 10,000 farmers), up from less than 10% just a decade earlier (Buckles *et al.*, 1992). As it was becoming a major avenue for producing maize in the region, the mucuna system has significantly displaced other alternatives, in particular the traditional fallow/summer maize rotation

(Sain and Matute, 1993) However, even farmers having adopted the mucuna/maize rotation keep growing maize under alternatives systems, if only as back-up options, making the mucuna system only one among several maize-based cropping systems.

In the traditional fallow/maize rotation, once the initial clearing of the forest has taken place, a field is typically left in fallow for several years (usually at least three) after every phase of cultivation, and the corresponding vegetation is slashed and burnt at the end of the dry season (April-May). After one or two consecutive maize cycles, the field is reverted to fallow because soil fertility has declined markedly while weed control has become arduous. In this system, yields are typically modest (1 to 2 $t.ha^{-1}$ for maize, 1 $t.ha^{-1}$ or less for beans). A significant proportion of farmers also plant maize in the *postrera* (winter) cycle in a slash-and-mulch system (the fallow vegetation is slashed but not burnt: Humphries, 1994). Another common alternative consists of planting maize as a way of introducing or renovating a pasture: the maize cycle follows a degraded pasture (invaded by bushes and unpalatable annuals) or a woody fallow and allows a new pasture to be established, taking advantage of the favorable growing conditions created for the maize crop. Even though many farmers do not possess pastures themselves, they may be in a situation to use this system by borrowing land from a wealthier farmer eager to improve his pastures.

2.2 CHRONOSEQUENCE SCHEMES

Because chronosequence schemes are both rare in cropping system studies and potentially ambiguous, the following paragraphs detail the considerations to keep in mind when constructing a chronosequence.

2.2.1 Prerequisites

To conduct a chronosequence approach, a number of prerequisites must be met

(1) a clear definition of the object (system) undergoing long-term transformations must be adopted, both in terms of its constituents (elements of the system) and its geographical extension (boundaries). This task is made difficult by the fact that, unlike what is the case in experimental long-term studies, a chronosequence cannot be isolated from the real world, but only observed in its natural environment.

(2) a sizable spatial variability with respect to the history of the potential individual components of the chronosequence must exist in the area selected for the study. The variability should allow the adoption of as fine a time step as possible (Pickett, 1988)

(3) a "reasonable" way of dating the individual components of the chronosequence should exist. The more precise the dating, the better the resolution of the study.

(4) the selection of fields to be included in the chronosequence should be made from among as large a pool of potential candidates as possible, in order to screen out those presenting factors or conditions which would tend to confound the historical analysis

2.2.2 Steps

If the above requirements are met, the conduction of the actual chronosequence is relatively straightforward. It involves 3 main steps.

(1) Selection of the individual components of the chronosequence

In this step, the cropping history and main characteristics of potential individual components are recorded and scrutinized. Much of the work consists in identifying factors that would violate the basic assumptions of the chronosequence (see further). The end product is a sample of components which, pulled together on a unified time axis, make up a discrete, instantaneous **representation** of the cropping system under study at different moments of its historical evolution

(2) Selection of variables which will document the assumed changes over time

Given the nature of the cropping system represented in the chronosequence, a set of variables must be selected that will provide information on either the mechanism(s) of differentiation of this system over time or at least its effects, and also on the main factors and conditions which would tend to interfere with the above mechanism and create background noise Whenever possible, variables allowing the testing of the assumptions associated with the use of a chronosequence approach should be included as well

(3) Data collection over an adequate time frame

The only remaining task at this point is to engage in the data collection itself, taking care that the proper time frame is adopted. A major concern should be that specific conditions during the period of data collection do not interfere with the detection of long-term trends this may take place when the amplitude of the seasonal or year to year variations in measured parameters is similar to or even larger than the variation associated with the long-term evolution itself

2.2.3 Major assumptions

Clearly, the construction process described earlier relies on several assumptions First and foremost, **singleness of cause** must be assumed to explain the evolution each component of the chronosequence has been subjected to. In other words, one has to assume that the alleged mechanism of differentiation over time was identical, or at least similar enough among the various fields to have induced similar effects in every case.

A corollary is that the **effects** associated with this mechanism are assumed to be **distinguishable** from (1) effects produced by other mechanisms likely to affect simultaneously the selected fields over the same time period, or from (2) differences in initial conditions of the fields prior to the introduction of the rotation under study.

A third assumption involves the **positioning of the individual fields on the time axis**, for which it must be assumed that a standard, unambiguous yardstick for measuring time can be found which will be applicable to all fields

2.2.4 Limitations of chronosequence approaches

a) Hypothesis-generation vs. hypothesis-testing

The assumptions listed above are difficult to test without having at hand independent historical evidence about both the process being studied and about the various fields which make up the chronosequence, the lack of which is precisely one of the main justifications for using such an approach in the first place. Hence, trends detected via a chronosequence approach should be considered mainly as a quick way of **generating educated hypotheses** about the behavior of a system over time (Pickett, 1988) No validation of theses hypotheses is possible without their independent testing, a task which requires alternate approaches (such as long-term experiments or perhaps simulation modeling).

b) The inescapable variability associated with on-farm observational studies

Chronosequence schemes are subjected to the same general constraints found in all observational studies: risk of confusion of effects created by external sources of interference, high intrinsic variability of the data, etc. Hence a cautious attitude should be adopted when interpreting or extrapolating the results Also, the predictive power which can be derived from chronosequence approaches is limited (at best, very large predictive intervals would be obtained)

2.3 SITE SELECTION

Our objective was to understand the mucuna/maize rotation both with respect to its overall agronomic characteristics and to its long-term behavior We also wanted to explore the role of geographic factors in inducing a sizable variability in environmental conditions and farmers' practices, given that the adoption of the mucuna/maize rotation had taken place over a fairly extended region (Figure 2 4) It was therefore necessary to select farming communities (sites) possessing as long a history of adoption of the rotation as possible on one hand, but yet typical if not representative of the region. A further requirement is that we wanted to construct complete chronosequences of the mucuna rotation *within each site*, in an attempt to maximize the intra-site comparability of fields of various ages. Also, it appeared desirable to gather detailed information on relatively few sites and fields, rather than proceed to a more superficial coverage of many fields. in-depth coverage would facilitate the exploration of the mechanisms at work in the mucuna system. Finally, the sampling scheme had to integrate the constraints related to site and field accessibility, rather significant ones in a hillside environment.

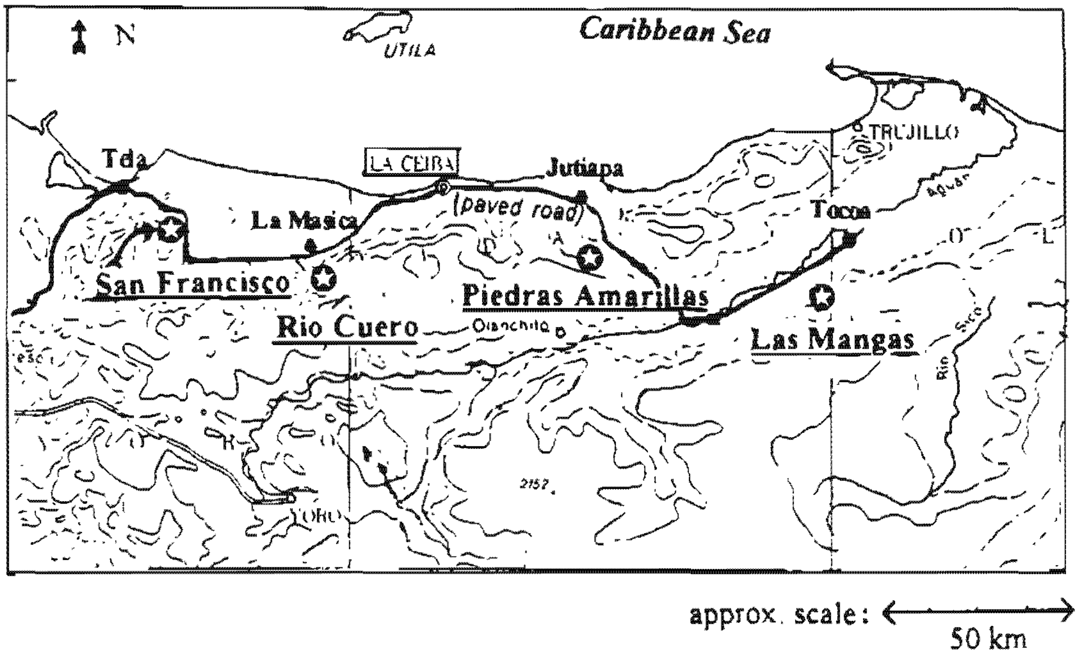


Figure 2.4 Location of the various sites selected for the study of the mucuna/maize rotation in the Atlantic littoral of Honduras

Our solution to the above dilemma was to choose a *main research site*, on which much of the time- and equipment-intensive data collection was conducted (Table 2.2), and *three secondary sites*, used to evaluate the regional validity of the main findings about biomass production, maize yields and long-term trends. Together, these four sites (Figure 2.4) covered the main apparent factors of differentiation among communities in terms of rainfall, soil fertility, patterns of migration, and distance from a paved road, this last factor being *de facto* a good proxy for many socioeconomic factors, such as intensity of deforestation, market-orientation of the agricultural production, etc. (Table 2.3).

Table 2.2: Studies conducted in San Francisco de Saco

Study or component	92/93	93/94	Methodology
Chronosequence	35 fields	12 fields	see text and Table 2.4
Agronomic monitoring	20 fields	15 fields	see text and Table 2.5
Mucuna biomass dynamics	--	Oct-May	periodic sampling, quadrats
Inorganic nitrogen dynamics	Dec-Apr	Oct-Jun	periodic sampling, KCl extracts
Fertilizer experiments	3 fields	12 fields	2^2 RCB design, N and P
Within-field variability in soil chem. properties and yields	--	4 fields	sampling of shoulder, backslopes and footslopes
Infiltration & macroporosity	--	7 fields	infiltrometers, undisturbed cores, sand table
Water & temperature monitoring[1]	--	3 fields	TDR, tensiometers, thermistors
Variability of field-level yields	30 fields		farmers' interviews

[1] Results not reported in this dissertation

San Francisco de Saco (SFS), our main research site, lies towards the Western tip of the Atlantic littoral, 17 km South-East of Tela (Figure 2.4). Conveniently located less than one kilometer from the main road Tela-La Ceiba, this community was chosen because it had been one of the first to adopt the mucuna rotation on a large scale, some 20 years ago. Many mucuna fields of all ages were clustered close to each other less than 40 minutes by foot from the village center. Also, contact with farmers had already been established by the Agricultural Research Division of the Ministry of Agriculture, which had initiated on-farm trials in the community.

Table 2.3 Selected characteristics of the four research sites selected in the Atlantic littoral of Northern Honduras

Item	San Francisco de Saco	Las Mangas	Rio Cuero	Piedras Amarillas
Approx. location (cf. Figure 2.4)	17 km SE of Tela	15 km SW of Tocoa	10 km South of La Masica	15 km SE of Jutiapa
Accessibility [1]	1 km, very easy	9 km; difficult to very dif.	8 km; fair to difficult	12 km; easy to fair
Elevation (fields) [2]	50-200 masl	300-400 masl	300-400 masl	200-350 masl
Rainfall mm	2500-3000	2000-2500	2500-3000	<2000
Soil fertility	fair to good	very good	fair	fair
Virgin forest left	< 10% area	> 70% area	> 70% area	little?
Immigration [3]	low (to US)	active	very active	moderate?
Standards of living [4]	regular-good	low	low	low-regular
Mucuna use (92) [5] - oldest fields. - typical range.	everybody > 15 years 6-8 years	> 50% (?) 10 years 3-5 years	≈ 60% 6 years 1-3 years	< 50% (?) 12 years 3-5 years

[1] distance from a paved road & relative difficulty of reaching the village center. [2] for fields selected in the study; [3] arrival of people from other communities (in SFS, males tend to emigrate temporarily to the US). [4] quality of housing, nutrition, etc.; [5] first line: diffusion of mucuna in the community (approx. % of farmers using it)

The other three sites were selected among the ten watersheds chosen by a Canado-Honduran Forestry development project, the P.D.B.L. (Proyecto de Desarollo del Bosque Latifoliado) to promote the sustainable use of forest resources (Szaraz and Irias. 1993) Las Mangas (MG). 20 km South-West of Tocoa (Figure 2.4), was our second most studied site again, adoption of the mucuna rotation was relatively ancient in the community (12 years). It was also famous for its very rich soils and good yield potential. Access to the community was difficult however, as it was located one hour away from a dirt road, by a treacherous mule path crossing a capricious river. Piedras Amarillas (PIE), in the heart of the drier Jutiapa area, located 12 km away from the paved road, had a 12-year history of mucuna adoption. Rio Cuero (CUE), 8 km South of La Masica by a tough dirt road was a watershed with a more recent history of mucuna use (7 years only in 1993), and was undergoing a rapid process of colonization/deforestation

(Humphries, 1994. PDBL, 1994). In each of these sites, collaboration with farmers was secured via the resident extension agent assigned to the area by the P.D.B.L.

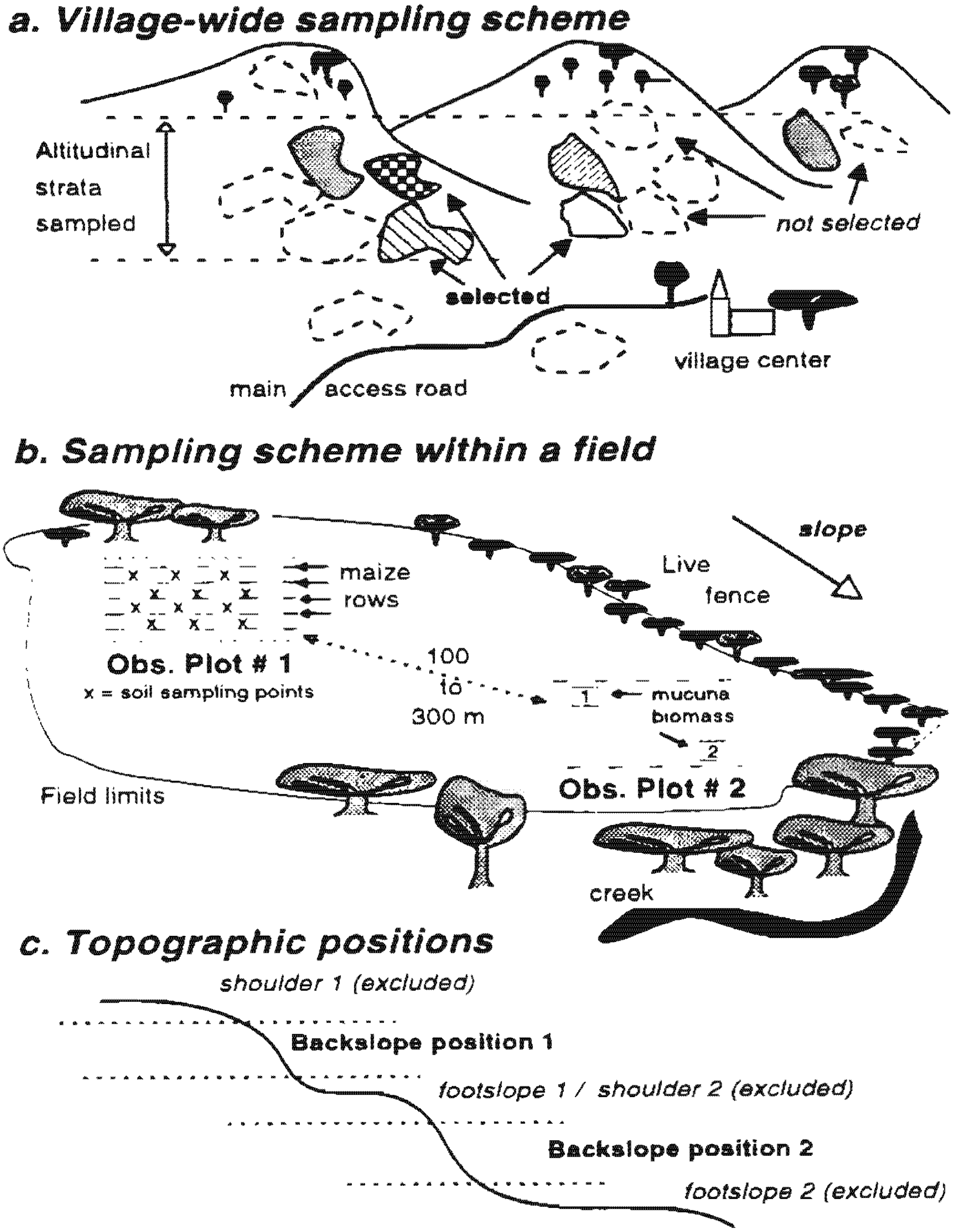
2.4 GENERAL AGRONOMIC SURVEY

Agronomic surveys focusing on the maize cycle were conducted during two consecutive years (year 1, winter 92/93, and year 2, winter 93/94) in the four villages described above to document the main features of the mucuna/maize cropping system with respect to farmers' practices, maize yield levels and relationships between yields and soil chemical properties. Limited data collection was extended over the 94/95 cycle in SFS and CU thanks to a collaboration with the CIAT-Hillside project.

Between 10 and 20 farmers' fields were selected in each village (35 in San Francisco de Saco). These fields were not selected randomly, as the major criteria for selection was time spent in the mucuna/maize rotation. Other restrictions were placed on field selection as well to make variability more manageable. For example, only a narrow altitudinal strata (approximately 100 to 150 m wide) was explored within each village, so as to avoid potential rainfall and temperature gradients (Figure 2.5.a). Also, fields with either too moderate (< 25-30%) or too steep slopes (> 70%) were discarded from the selection. Neighboring fields (located on the same landform) were selected whenever possible to maximize similarities in geomorphological background (Figure 2.5.a).

To facilitate the comparison among fields, measurements were made on small (10 m x 10 m) observation plots systematically located on linear backslopes positions within each field (Figure 2.5.c), thus avoiding the variability usually associated with topographic position in hillside environments (Ruhe, 1960 in Hall and Olson, 1991), as well as the typical within-field heterogeneity induced by farmer's management (1972, Milleville, 1976). These plots, not the fields, represented the basic observation units on which all data analysis was made, unless otherwise specified. Within-field heterogeneity was explored by selecting two backslope positions in each field, distant from one another by 100 to 200 m on average (Figure 2.5.b). Representativeness of backslope positions was analyzed by quantifying the differences in soil properties between backslopes, shoulders and footslopes in four fields in San Francisco de Saco (Appendix B).

Table 2.4 presents the data collection protocol common to all four villages, which included data on farmers' practices, mucuna biomass (year 2 only for all sites except SFS), yield and yield components, and soil chemical properties. Farmers' practices (dates of main operations, quantities and type of inputs used, rating of the success of the operation) were established at the field level by interview with the field owners. In addition, a recapitulative survey of field past cropping history, farmers' experiences with and rationale in using and managing the mucuna/maize rotation was conducted at the end of the second year. To this effect, individual and collective interviews were conducted using a mixture of closed and open-ended questions (see survey instruments in Appendix A).


a. Village-wide sampling scheme

b. Sampling scheme within a field

c. Topographic positions

Figure 2.5: Sampling scheme for field and plot selection (a) field selection within a site. (b) observation plot selection within a field, (c) topographic positions

Table 2.4: Data collection common to all sites selected in Northern Honduras (chronosequence and general agronomic study)

Item	Type[1]	Scale[2]	Methodology
Plant data:			
- mucuna biomass	Q, A	Plot	quadrats, dry matter, nutrient content
- maize yields	Q	Plot	3 10-meter rows, shelling, moisture
Environmental data:			
- rainfall	Q	Village	daily rainfall (village level)
Soil data			
- chemical properties	A	Plot	0-10, 10-30, 30-60 cm: composite sample
Farmers' practices			
- mucuna management	I	Field	individual & collective interviews
- dates of practices	I	Field	1-2 interviews with field owner during
- input & labor use	I	Field	or at end of maize cycle
- cropping history	I	F, V	(see format in Appendix A)

[1] A analytical, Q quantitative, V visual estimate, I interview; [2] F field, V village

2.5 AGRONOMIC MONITORING

In two villages (San Francisco de Saco and Las Mangas), the plots were further subjected to an agronomic monitoring conducted during two consecutive years in SFS (20 fields in year 1, 15 in year 2), and during 93/94 only in MG (15 fields).

Briefly, agronomic monitoring consists of multiple visits made at key moments of the cropping cycle at the level of the observation plots selected in each field (Manichon and Sébillotte, 1973, Jouve, 1985, Byerlee *et al.*, 1991). Agronomic monitoring is a flexible tool easily adaptable to the actual objectives of the study and to the resources available to the researcher. It allows a meaningful analysis of yield-limiting factors by taking advantage of within-field variability to explore a range of agronomic situations (Crozat *et al.*, 1986) in a quasi-experimental fashion (Gras, 1981).

In this study, visits took place at the time of mucuna slashing, at 15 and 30 days after maize planting, at flowering and at maize harvest During each visit, measurements were made on a combination factors and conditions likely to influence maize yield elaboration (Fleury *et al.*, 1982; Fleury, 1991) These included farmers' practices, environmental factors (rainfall, incidence of weed, pests and diseases, soil fertility), and maize response to these factors and conditions (plant growth, mineral nutrition, yield and yield components) (Table 2 5) A special effort was made to pinpoint the dates of the practices at the plot level, which included direct observations and a semi-successful attempt at having farmers record their practices on specially-designed journals

Table 2 5: Data collection for agronomic monitoring conducted in San Francisco de Saco and Las Mangas

Item	Freq [1]	Type [2]	Methodology
Plant data			
- mucuna biomass	S	Q, A	quadrats, dry matter, nutrient content
- maize yield	S	Q	4 central rows, shelling
- plant height	M	Q	extended leaves then panicle leaf height
- develop stage	M	Q	number of leaves or % silking
- nutritional status	S	A	ear leaf analysis at flowering
- min. deficiencies	M	V	% plants affected by specific symptoms
- rooting patterns	S	V	profile observation (selected fields)
Environmental data			
- Pests and diseases	M	V	% plants affected by specific symptoms
- weed pressure	M	V	relative cover 0-10 scale + main weeds
- rainfall	M	Q	daily rainfall (village level)
Soil data			
- chemical prop	S	A	0-10, 10-30, 30-60 cm; composite sample
Farmers' practices			
- dates of practices	M	V,I	direct observation + periodic interview
- input use	M	I	with field manager (plot and field level)

[1] Frequency of visits M multiple, S once during the season. [2] A analytical, Q quantitative, V visual estimate, I interview. *All data collected at the level of observation plots unless otherwise specified*

2.6 YIELD AND YIELD COMPONENTS

Maize yields were measured in each observation plot by harvesting three 10-meter rows (general survey) or the four central rows (agronomic monitoring plots), or more rarely a fixed area of 30 m^2 in case planting had not been done in rows. Total number of plants, number of harvested ears, proportion of damaged ears as well as ear fresh weight (to the nearest 100 g) were determined in the field. A random sub-sample of approximately 20 to 25 ears was taken in each plot, and analyzed for grain moisture content (Farmex Portable Grain moisture sampler) and shelling coefficient. Specific kernel weight was evaluated by counting and weighing duplicate 100-grain samples.

Maize yield for each observation plot was expressed as the product of the following series of *yield components* (Navarro Garza, 1984; Fleury, 1991)

$$\text{Yield} = NP * NE * NK * W1K \qquad (1)$$

in which yield represents measured maize yield in kg ha^{-1}, NP Number of harvested maize plants per unit area, NE the number of harvested ears per plant, NK the number of kernels per ear, and W1K the average weight of each kernel. Each factor in the equation was measured independently, except NK, which was calculated based on other components and equation (1)

2.7 MUCUNA BIOMASS

Measurements were made just prior to slashing time (December of each year precise date for each field as a function of individual farmers' management) In 1992, 40 observation plots (2 plots per field) were sampled (SFS only), 100 plots in 1993 (4 villages), and an additional 35 in 1994 (SFS and CU: CIAT, 1995). In each village, the aboveground total biomass was determined by harvesting 2 to 4 quadrats (2.25 m^2 each) per observation plot Total biomass was separated into easily distinguishable fractions. green mucuna, live weed material, and litter (this latter being simply all dead organic matter, whatever its stage of decomposition). Further sub-categories were made in December 93 and 94, for pods and vines, respectively A composite sub-sample was taken from each fraction in every observation plot for dry-matter and nutrient determination

2.8 NITROGEN CYCLING

Nitrogen cycling was studied in San Francisco de Saco only. Soil inorganic nitrogen content was measured up to a depth of 60 cm between December and April in year 1, and between October and June in year 2 Mucuna biomass was measured monthly in year 2 by quantifying monthly biomass accumulation between October to December and its apparent decomposition was followed between December and May. Maize mineral status was estimated from ear leaf total nutrient content at flowering, and grain total N and P content was determined at harvest in a limited number of fields

A factorial nitrogen x phosphorus fertilizer experiment was established in farmers' fields in SFS and MG (year 2 only for MG) to evaluate the possibility that nitrogen (or phosphorus) limited maize yields in well-established mucuna fields. The design consisted of a 2^2 RCB factorial, with 2 levels of N: 0 (mucuna mulch only) and 50 kg ha^{-1} of N-urea, applied 40 days after planting, and 2 levels of P: 0 (mucuna mulch only) and 60 kg ha^{-1} of P as triple superphosphate, applied at planting. Other details are given in chapter 4

2.9 SOIL FERTILITY MEASUREMENTS

Composite soil samples (12 to 15 sub-samples) were taken in every observation plot with a 2-cm diameter tube auger in March 1993 from 3 depths: 0-10 cm, 10-30 cm and 30-60 cm, air-dried and sieved at 2 mm. All the above samples (sampling A) were analyzed for pH (1:2 water), P and exchangeable bases (extracted with a Morgan solution), Al and exchangeable acidity and micronutrients in the Cornell Nutrient Analytical Laboratory. A separate sample (sampling B) was collected in March 1994 in 17 fields in San Francisco de Saco from the 2.5-5 cm depth, and analyzed for pH, P (Olsen Dabin III), exchangeable bases and total CEC at the soil natural pH (cobaltihexammine method Fallavier *et al.*, 1985) in CIRAD analytical laboratory in Montpellier (France)

Soil organic matter (C, N and natural abundance of C13 and N15) was measured for the top horizon of the A samples by mass spectrometry. Organic carbon distribution in the soil profile (Walkey and Black, Nelson and Sommers, 1982) was determined by collecting composite samples by 2.5 cm increments, from 0 to 15 cm depth (as part of sampling B). A limited number of these samples was further subjected to both a chemical (Egoumenides, 1989) and a physical fractionation scheme (Feller, 1994) in an attempt to evaluate the dynamics of specific fractions of soil organic matter over time

Texture (Bouyoucos method Gee and Bauder, 1986) was analyzed for all A samples. In SFS, non-ponding infiltration rates were determined for a subsample of 7 fields, using portable rainfall simulators/infiltrometers (Ogden *et al.*, 1996). Macroporosity (measured on the same fields and positions for which infiltration measurements were made) was determined on undisturbed soil cores collected at two depths: 1-8.5 cm and 11-18.5 cm using a suction table (suctions applied varied from 0 to -10 kPa) (Topp *et al.*, 1993). Other details about soil fertility measurements can be found in chapter 5.

2.10 DATA ANALYSIS

A variety of techniques was used to analyze the data collected in this study. Simple two or three-way contingency tables, t-tests of the significance of differences among sample means, or one-way or two-way ANOVAs were routinely used to analyze the results. For the analysis of the fertilizer experiments, GLM procedures which allowed for the analysis of unbalanced designs (use of Type III sums of squares: Littel *et al.*, 1991) were used due to small differences in experimental design among fields and to the presence of missing data. In a few cases, envelope curve techniques (Siband and Wey, 1994) were used to identify the likelihood that a given factor had been limiting the level of a response variable.

Most long-term trends were detected via qualitative graphical analysis (with time as the X coordinate), in keeping with the high variability of the data and the relatively small sample sizes involved (Federer, pers. com.). Whenever possible, the graphical analysis was however formalized by fitting simple or multiple regressions in which time (measured in years of use of the mucuna rotation) was the or one of the independent predictors of the specific response variable being described (see details in chapter 5).

Chapter 3

AN OVERVIEW OF THE MUCUNA/MAIZE CROPPING SYSTEM

Slash-and-mulch systems (Thurston *et al.*, 1994) combine no-tillage practices with the use of consequent mulches of natural fallow vegetation or of planted legumes created for the benefit of a succeeding crop. Were they better documented, and their underlying principles clarified, it would become possible to improve them and also to extrapolate them outside the environments where they have been found to perform especially well, i.e. mostly the humid tropics (Buckles and Barreto, 1995).

A first step is to document farmers' present management strategies of slash-and-mulch systems. Understanding farmers' practices is pivotal because these latter integrate at the field level both the environmental and socioeconomic constraints affecting these systems and because any attempt at modifying their performance will necessarily involve modifying the way they are managed (Sébillotte, 1982; Sébillotte, 1987, Legal, 1995).

Such an analysis is provided in this chapter. After briefly summarizing mucuna biology, farmers' practices are examined, along with maize yields. This description of the rotation will serve as an introduction to and reference for subsequent chapters.

3.1 THE MUCUNA/MAIZE CROPPING SYSTEM

3.1.1 Biology of mucuna

Mucuna, sometimes still referred to as *Stizolobium* in the literature, is the generic name given to a number of closely related species from the genus *Mucuna*, including *M. deeringiana*, *M. utilis*, *M. pruriens* and *M. aterrima* among others (Duke, 1981). In addition to an apparent confusion in the taxonomy, precise identification at the species level has not always been conducted. As this is indeed the situation for the mucuna grown in Northern Honduras, it appears preferable to use the generic name *Mucuna spp.* rather than to arbitrarily refer to a specific species. Furthermore, farmers actually distinguish several sub-classes of mucuna, on the basis of seed color (from shiny black to creamy white to mottled, this latter being by far dominant) and growth habit, the black-seeded mucuna being apparently slightly more precocious than the others. This differentiation does not however lead farmers to exploit the differences between sub-types, as all mucuna types are harvested in bulk irrespective of their type and replanted together.

In all cases, the mucuna grown in Northern Honduras is an aggressive, vigorously climbing, nitrogen-fixing annual legume producing lengthy vines (several meters long) and abundant foliage. A typical canopy may stand as tall as 1 m above the soil surface, and typical levels of above-ground biomass range from 5 to more than 12 t.ha^{-1} on a dry-matter basis. Mucuna sheds significant quantities of leaves before reaching maturity: they decay gradually in a litter layer which they form below the actively growing mucuna. Most mucuna roots are very superficial, and only a few roots tapping deep horizons can be found per square meter (Hairiah, 1992; personal observations).

The mucuna cycle can last from 100 to 300 days, depending on the elevation and planting date. As all mucuna fields observed in Northern Honduras initiate flowering around the same time in early to mid-October irrespective of their planting date, it would appear that mucuna is photoperiodic, responding to shorter daylengths. Mucuna dies naturally after having produced seed, approximately 45 to 60 days after flowering. Pod production is variable depending on the environmental conditions but can easily reach more than 2 t ha^{-1} especially if mucuna can find its way up trees, stalks or similar opportunities to climb.

Mucuna is well-known for its nematicide effects when used in rotation with a number of commercial crops (Acosta *et al.*, 1991, Kloepper *et al.*, 1991; Marban-Mendoza *et al.*, 1992) although it is not itself immune to a number of nematode species (Duke, 1981). In addition, it also seems to possess a notable allelopathic activity which may help it suppress competing plants (Aguilar, 1984). Mucuna seeds contain levadopa, a toxic chemical for insects and humans alike if ingested in high doses (Duke, 1981, Ravindran and Ravindran, 1988), which makes it necessary to process the seed adequately if mucuna seed is to be used in human nutrition (CIDICCO, 1993; Osei-Bonsu *et al.*, 1995). This chemical toxicity may also explain why mucuna has few problems with insect pests (Duke, 1981).

As a general statement, this legume is well adapted to the humid tropical lowlands, with a maximum elevation around 1500 m.a.s.l. It tolerates fairly well a number of abiotic stresses, from drought to low soil fertility, including soil acidity (Hairiah, 1992).

3.1.2 Origin of the rotation

The details of how mucuna seed was introduced in Northern Honduras were described in Buckles (1995). What follows is an overview of this account.

Mucuna seed was originally introduced in Central America in the 1920s from the south-eastern US (where it had been massively grown as a feed/green manure since the late 1800s) by the United Fruit company who used it to feed the mules working in the banana plantations. From there, it was introduced in the Polochic valley, Guatemala in the 1930s, as a soil-improving and forage crop. Small-scale farmers in the valley started adopting it in the 50s, on account of its effects on weed control and labor use. Mucuna seed then diffused into Western Honduras, and was most probably introduced in the North Coast in the early 70s by migrant farmers originating from these regions.

Once in the Atlantic littoral region, the mucuna system diffused slowly first (decade of the 70s and early 80s) while during the 80s, the rate of adoption increased to reach 5% annually (Buckles *et al.*, 1992). The system was diffused by word of mouth and seed circulation from farmer to farmer without any institutional support. Vigorous migratory movements in the region probably contributed greatly to the rapid spread of the system. Conversely, certain communities have remained impervious to the system, which may result from lower-than-average rates of immigration (Humphries, 1994).

History of mucuna management is much more uncertain than history of the seed itself According to our own surveys conducted in San Francisco de Saco, one of the first communities to adopt the mucuna/maize rotation, the seed was introduced in the early to mid-70s, but it is not until several years later that a few farmers started planting it in their maize fields, after having observed the effects that an unmanaged, spontaneously reseeding mucuna was having on maize and other vegetation grown near by. Farmers' claim that management guidelines did not come along with the seed is striking: appropriate practices seemed to have evolved *locally* from a careful observation of mucuna ecology, and a fast, lucky trial-and- error process which taught farmers what were the most successful management options

In terms of the reasons behind the adoption, one key informant explained it by the need to find alternatives for maize production in the hillsides as farmers were gradually pushed uphill by the expansion of large-scale livestock operations, and away from the more fertile lowlands they used to have access to in the past. Also, the strong seasonality in maize market prices may have acted as a powerful incentive (Buckles *et al.*, 1992) Both these mechanism would constitute excellent illustrations of the theory of induced innovations (Hayami and Ruttan, 1985).

3.1.3 Typical management of the mucuna system

In this section, we describe the most typical practices adopted by farmers in the Atlantic littoral to manage the mucuna/maize rotation Indications will be given whenever significant deviations from this norm exist locally or regionally Also, the rationale for the various practices is given both in terms of farmers' own explanations and in terms of the probable agroecological processes involved.

3.1.3.1 General calendar

The mucuna system is an annual rotation (or perhaps more precisely a case of relay intercropping: Vandermeer, 1989) between a "dry-season" maize grown between December and May, and a wet-season mucuna crop grown from February to December (Flores, 1987) The dying mucuna is slashed in December (Figure 3.1) and used thereafter as a mulch for the succeeding maize crop, planted through the mulch immediately after slashing. Mucuna reseeds itself spontaneously during the maize cycle from February onward via seeds left unharvested in the mulch, and aggressively takes control over the maize field around harvest time (April to June), using maize stalks as support

From that moment up to the next slashing in December, the field can be considered to be under a short-term mucuna fallow, as no other operations are performed. Figure 3.1 summarizes the calendar, whereas Figure 3.2 offers a photographic illustration of some of the main phases of the mucuna rotation.

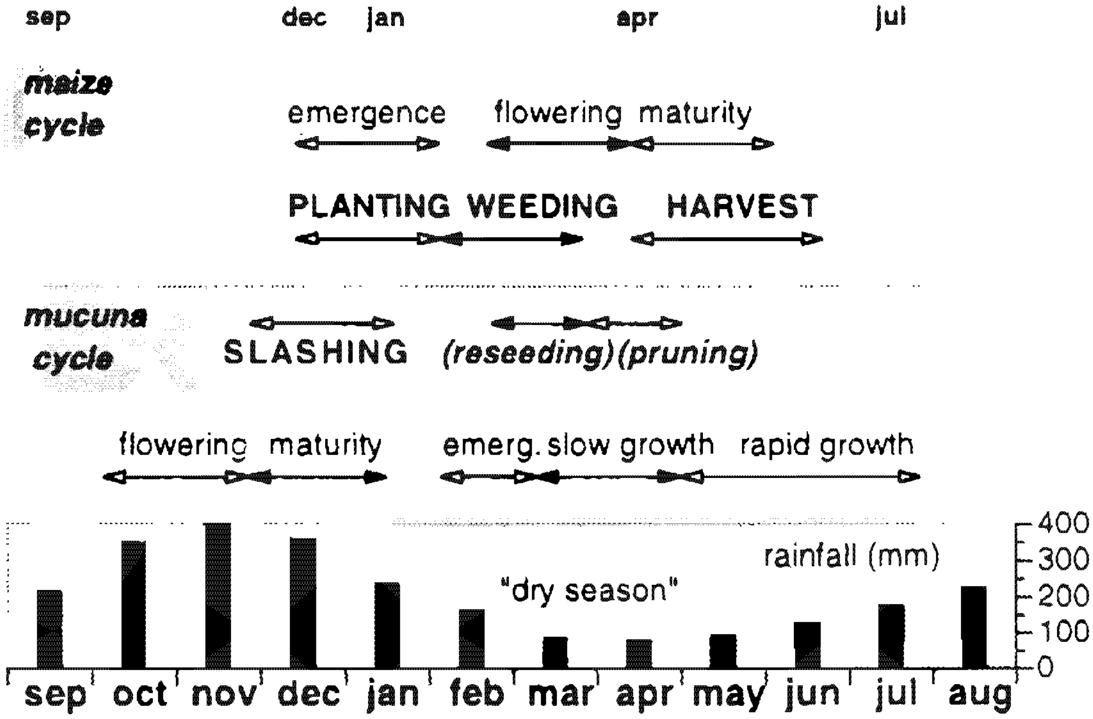


Figure 3.1: Calendar of the maize/mucuna rotation. Arrows indicate periods during which most farmers do a given practice.

3.1.3.2 Mucuna establishment and reseeding

3.1.3.2.1 Initial establishment

Most farmers will introduce mucuna in a field during the course of a winter maize cycle. Mucuna seed usually consists of a mixture of seed types (see 3.1.1), and is dibble-sticked 40 to 60 days after maize planting in the maize interow, 2 to 3 seeds per hole, in holes 1 to 2 meters apart. The quantity of seed needed per ha varies from farmer to farmer but ranges from 10 to 15 kg.ha^{-1}. In the absence of a seed market, farmers use seed collected from established mucuna fields or obtained from a neighbor.

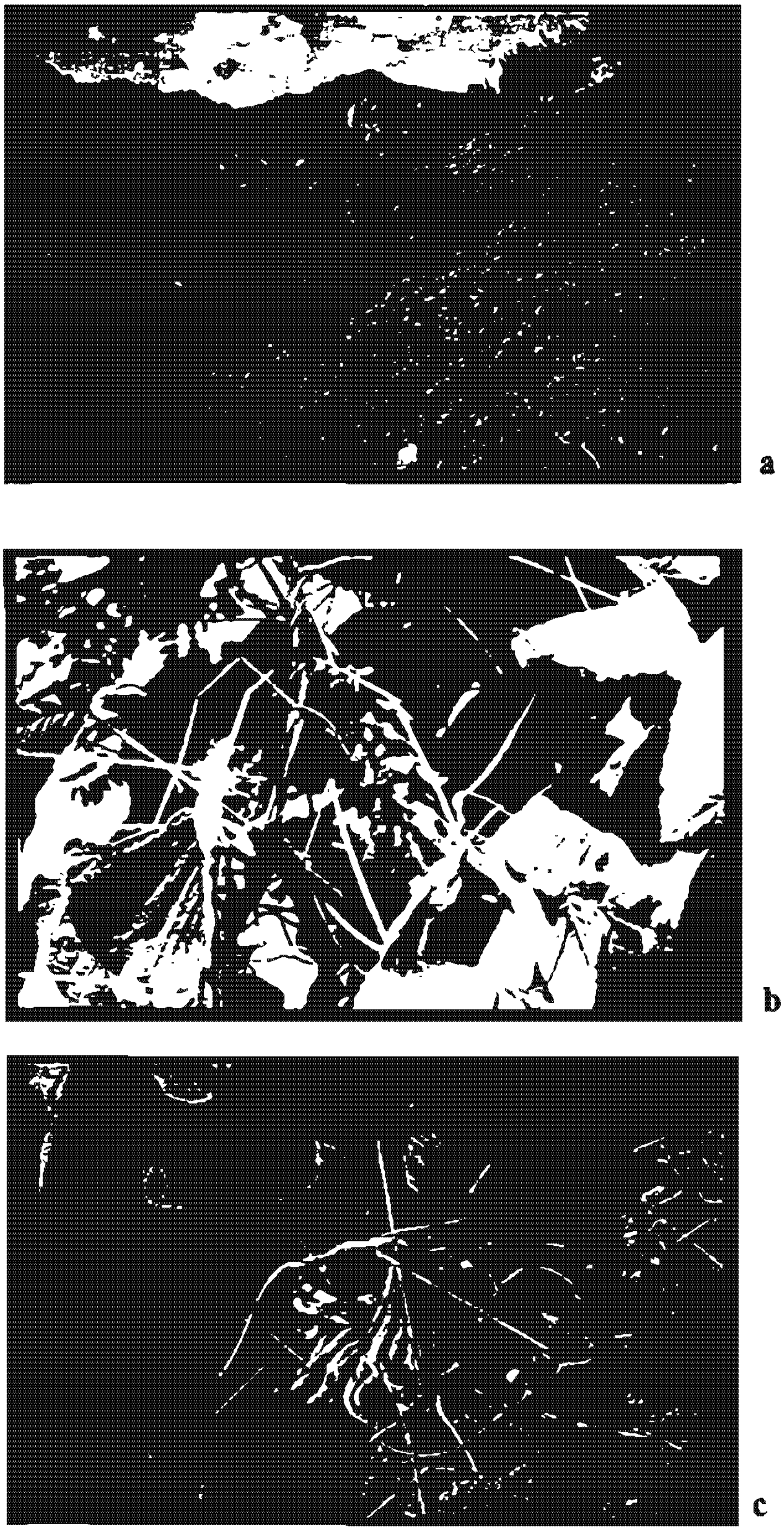


Figure 3.2.a: Photographic illustration of the mucuna/maize rotation:
(a) mucuna stand in November, (b) mucuna flower (c) young mucuna pods

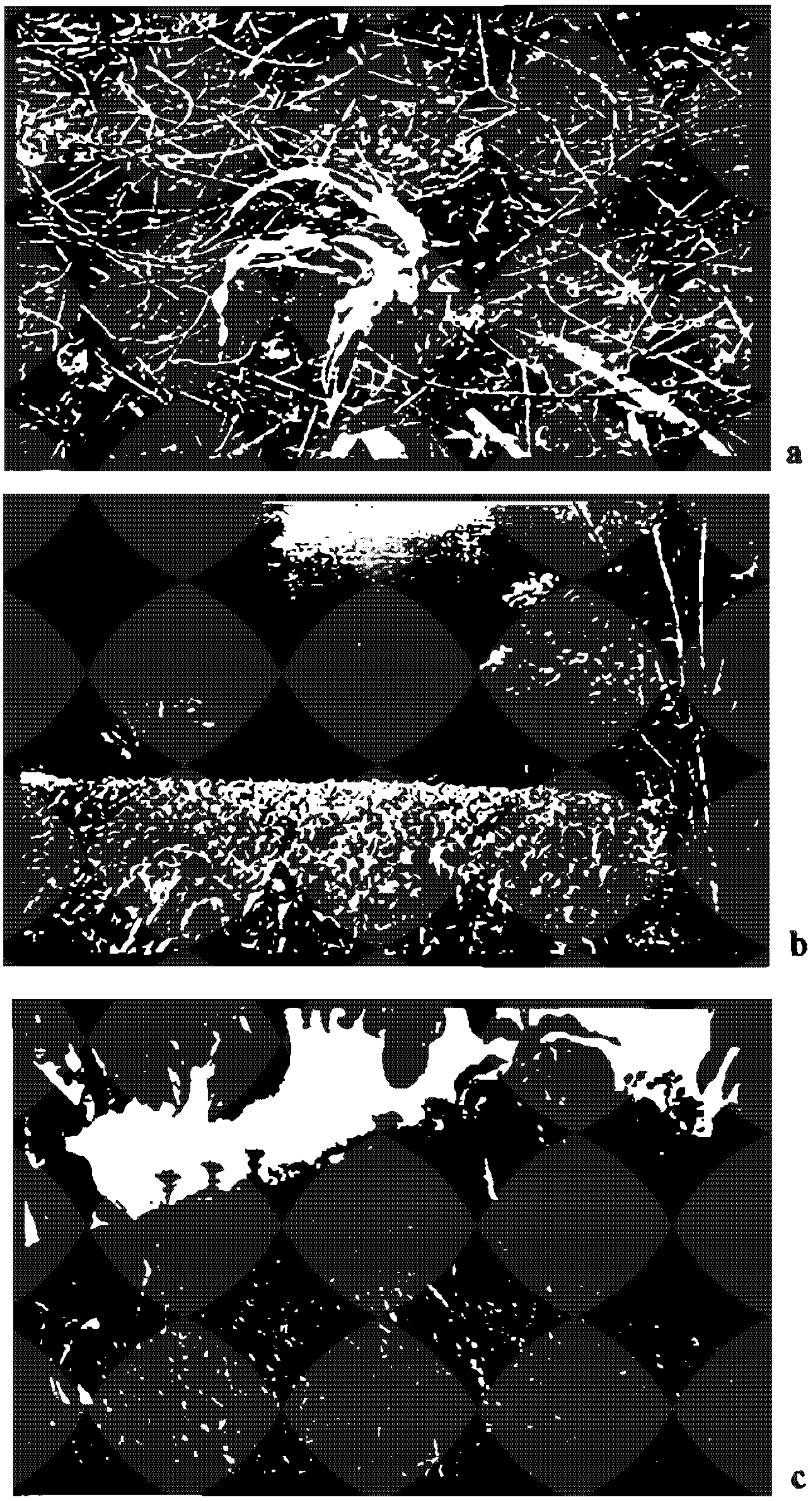


Figure 3.2.b: Photographic illustration of the mucuna/maize rotation: (a) maize growing in mucuna mulch, (b) maize 50 d.a.p., (c) mucuna growing on dry maize stalks around harvest time

Variations to this scheme include farmers broadcasting mucuna seed in their maize fields (apparently as a means of saving on labor; but success rate seems markedly inferior to the planted method), and farmers establishing mucuna directly after a fallow (very rare).

According to most farmers, it usually takes one to two years after the first planting for mucuna to become fully established in a given field, and it is not rare that farmers will repeat the planting the second year in spots where mucuna did not establish properly the first time.

3.1.3.2.2 Annual re-establishment

The vast majority of farmers take advantage of the ability of mucuna to reseed itself naturally, a mechanism similar to what Myers and Wagger described for Crimson Clover for example (1991). Reseeding succeeds provided farmers don't slash mucuna before enough viable pods are produced. The pods left unharvested at slashing time eventually mature in the mulch. Upon desiccation, they burst open, projecting seeds around, which ensures their fair distribution in the field. A few farmers also spread pods around at slashing. Frequently, they also let small quantities dry on rocks or trees whenever they plan to need seed for replanting or establishing a new "abonera". Farmers have observed that mucuna produces much more seed whenever it has managed to climb on trees or rocks; conversely, dense mucuna stands seem to yield only moderate amounts of pods and seeds, probably as a result of insufficient light penetration in the canopy.

Farmers often complement natural reseeding by replanting mucuna in spots where it didn't reestablish itself. Conversely, mucuna reseeds itself so successfully certain years and starts to grow vigorously so early in the season that farmers will thin the emerging mucuna plants and slightly "prune" them, in order to delay their re-establishment, thus avoiding the taking over of the field by mucuna before harvest time.

On average, the resilience of mucuna is truly remarkable: in 14 years of relying on natural reseeding, farmers of SFS have never been obliged to replant their mucuna fields from new seed. Only in the improbable case of a complete failure of the mucuna cycle (i.e. hardly any viable seed produced), coupled with extremely unfavorable conditions for seed germination would farmers consider replanting the whole field. Such a situation happened during the winter 93/94 in SFS, but seed production from the sparse mucuna stand reaching maturity in December 94 was so plentiful that most farmers didn't need to replant after all.

Interestingly, the success of natural reseeding seems to have implications on the long-term purity of the mucuna stand. When farmers don't help mucuna reestablish itself, spots devoid of mucuna start appearing in the field, which are promptly colonized by aggressive weeds which compete fiercely with mucuna. Such seems to have been at least partially the case with *Rottboellia cochinchinensis*, presently a major pest in certain areas of Northern Honduras (Sharma and Zelaya, 1986, Munguia, 1992).

3.1.3.3 Slashing

Farmers' major action vis-à-vis the mucuna crop consists of slashing it manually when it reaches maturity and starts to die naturally. Slashing involves cutting loosely the soft mucuna cover with a machete, with the help of a wooden hook used to pull up mucuna from the ground or rocks. Interestingly, farmers do not try to cut mucuna very finely, probably because that would tend to induce high rates of destruction of pods, and because this would increase labor costs. However, some farmers indicate the importance of spreading the slashed mucuna material evenly on the field surface, to ensure adequate soil cover and uniform maize growth. Slashing of mucuna requires far less labor than slashing of an arbustive fallow: about 10 days per hectare vs. about 18, respectively.

If the year has been favorable to rat proliferation (a cyclical pest, apparently not restricted to mucuna fields), farmers will tend to work in teams of 3-5 people, slashing the mucuna in such a way that rats are gradually pushed into hiding in an increasingly smaller, carefully isolated "island", from which it is easy (and fun) to kill whole scores of them by obliging them to run away into the open, where watchful machete holders are awaiting them. An efficient rat control during slashing will usually translate into tolerable losses of maize seed or seedlings later on, and vice versa.

There is quite a range of slashing dates within a given community or even within a given field, but all farmers are careful to slash mucuna only after it has produced viable pods. The other end of the spectrum is determined by farmers' perception of how late they can afford to plant a winter maize cycle without running too great a risk of exposure to drought later in the season. Obviously, all factors influencing access to labor, be it from the household or hired, will necessarily impinge on the actual slashing dates.

3.1.3.4 Maize planting

Most farmers prefer to plant maize as soon as possible after they have slashed mucuna, thus avoiding some of the competition provided by actively growing weeds. In practice, the interval slashing-planting ranges from a few days to a few weeks, reflecting once more the farmer's ability to mobilize labor. Interestingly, many farmers will proceed with planting as they advance in their slashing: one or two days of slashing, followed by planting the corresponding area, before continuing the slashing further.

Planting is achieved by dibble-sticking the maize seeds through the mulch and into the soil. Planting densities and seed type vary among farmers: the most common strategy involves planting 3-4 seeds per hole, in rows 80-100 cm apart, with an intra-row spacing of 50-80 cm. Seeds are frequently treated against a variety of insect predators (particularly ants), using an array of home recipes, or pesticides such as Malathion. Sometimes farmers use pregerminated seed, to hasten emergence and provide young maize seedlings with a competitive edge vis-a-vis weeds. Local genotypes (Olotillo, Tuza morada, Raque) reproduced on the farm are usually preferred: these are tall materials (more than 3 m final height in many cases), producing abundant leaves (23-25 in total) and green biomass, having a good husk cover, maturing in approximately 120 days (65 to 75 days to silking), and with a yield potential of 4-5 tons.ha^{-1} (as determined from the best yields recorded). Introgression of improved germplasm into the local genotypes is probable, as farmers sometimes plant commercial cultivars side-by-side. The open-pollinated variety Honduras Planta Baja is the major commercial cultivar that farmers have had access to. it is of a shorter stature (2 to 2.5 m) and higher yield potential (5-6 t.ha^{-1}) than local genotypes, but provides poor husk protection, a reason for which some farmers do not like it, as its conservation during long-term storage is uncertain. Up to now, hybrids are practically unknown in hillside maize production.

3.1.3.5 Weeding

Weeding is a key practice for determining the fate of both maize and mucuna. It keeps weeds from diverting nutrients and light from the growing maize crop, and it creates the window necessary for the successful natural reseeding of mucuna in a relatively weed-free environment. Farmers usually perform one to two weedings at 20-30 days after planting for the first one, and at 30-40 d.a.p. for the second.

There are marked differences across villages in terms of weeding strategies. In Las Mangas for example, farmers weed their plots entirely manually with a long hoe ("azadon") and only once during the maize cycle. In San Francisco de Saco or Rio Cuero on the other hand, most farmers weed their maize twice or even 3 times, using a combination of hand weeding with a short hooked machete ("pando") and chemical control (Paraquat for the most part, applied via back sprayers). Those keen on chemical control are careful not to apply 2-4D, or apply it very cautiously, as it can easily kill the emerging mucuna. Chemical control allows big savings in labor use: 1-2 man-days vs. 8-10 for a manual control. However, its effectiveness varies widely, depending on doses and product used, and on development stage of the weed population at the time of control. From a nutrient-cycling perspective, both manual and chemical weed control have fairly similar effects, as weeds are left to dry on the surface in both cases (see chapter 4).

Many of the observed differences across sites reflect differences in farmers' place of origin (use of culturally specific tools: Pando vs. Azadon for example), access to commercial inputs (SFS is located on the edge of a paved road, whereas MG is relatively isolated) and more importantly perhaps, the nature of the weed population farmers are facing. For example, the heavy investment consented by farmers in SFS is intended to keep itchgrass (*Rottboelia cochinchinensis)* under control at least until around maize flowering. Itchgrass (appropriately called "Invasor" or "Walking weed" locally) is a notoriously noxious grass weed (Holm *et al.*, 1977; Fisher *et al.*, 1985; Bridgemohan and Brathwaite, 1989) which has spread widely in the community since the early to mid-80s. Although it constitutes an increasingly serious problem throughout Northern and Central Honduras (Sharma and Zelaya, 1986), *Rottboelia* is not yet ubiquitous in the hillsides of the Atlantic littoral (Munguia, 1992).

Even with the advent of *Rottboellia* , manual weed control in mucuna plots requires significantly less labor than in non-mucuna plots (from 25% to more than 50% less according to farmers' estimates), for a number of reasons. First, mucuna gradually eliminates most weed species over the years, especially broadleaves, by preventing many of them from germinating, by outcompeting those which do emerge or by some unspecified allelopathic action (Aguilar, 1984). Also, according to farmers, weeds which manage to survive in a mucuna system are rooted much more superficially, owing to the presence of the mulch layer, and furthermore, the topsoil is looser (see chapter 5), and also wetter hence weed plants are easy to pull out during a manual weeding.

Mucuna itself can behave partly as a weed certain years (cf. earlier) but this is not a frequent occurrence, nor is it generalized within a given field The labor involved in controlling it is minimal (less than 1-2 man-days per hectare)

3.1.3.6 Fertilization

Most farmers surveyed outside SFS don't apply any commercial fertilizer to their maize, citing cost, availability or difficult access as strong deterrents. Many also consider that the mucuna mulch provides enough nutrients to satisfy maize nutritional requirements they describe with manifest delight the deep green color of the maize plants in the mucuna system as a proof of their good health, something confirmed by foliar analysis (chapter 4).

In SFS however, almost half of the farmers use small doses of urea (25 to 50 kg ha^{-1}) surface-applied from 40 to 60 d.a.p., a finding similar to what was reported in Buckles et al (1992). Farmers using it do not necessarily apply it every year, nor do they always broadcast it over their entire field. Furthermore, it seems to be applied preferentially in young mucuna fields, or in fields without mucuna Effects of this fertilization on maize yields remain unclear (see further, and also chapter 4)

A few farmers in SFS report having used occasionally a complex fertilizer (12-24-12 or 15-15-15 NPK) with encouraging results, but this seems more related to coincidental availability of this product than to a deliberate strategy to supply P and K

3.1.3.7 Maize harvest

Depending on planting date and elevation, maize reaches physiological maturity sometimes between mid-April and early June. Most farmers harvest their crop (ears only stover is left entirely in place) almost immediately after maturity has been reached, to capture the best possible price on the local market and also to avoid the summer rains of June-July which would make it difficult to obtain a dry and disease-free grain suitable for sale or long-term storage

Some farmers bend ("dobla") the maize plants over (under the ear) shortly before harvest as a way to avoid lodging, facilitate harvest (ear insertion height on local cultivars is frequently more than 2 m), and protect it from bird damage. Whenever this is done, mucuna benefits markedly from better light interception, but it is doubtful that this is an explicit objective of the bending, as a grown mucuna makes harvesting more tedious

3.1.3.8 Beyond harvest: the mucuna fallow

After harvest, the field is literally abandoned to the mucuna crop and its associated weed suite for a full six months, until it is time to slash again. A few weeks after harvest, mucuna has usually managed to tear down all standing maize stalks, and has achieved full canopy closure, even when density was low at the time of reestablishment, thanks to its extensive network of vines. Mucuna fields are not grazed, nor used for any purpose during this time. Indeed, mucuna is grown for the sole purpose of protecting the soil and enhancing soil fertility to the benefit of the maize crop, making it akin to a short-term improved fallow. Even farmers possessing livestock do not allow it to graze the mucuna. nor do they feed it

3.1.3.9 Miscellaneous

Many farmers in San Francisco and Las Mangas use *Gliricidia sepium* as a live fence around their mucuna fields and pastures. The main reason cited for the choice of this leguminous tree is its very fast growth and capacity to provide posts heavily used for fencing pastures in particular. The trees are usually pruned at the beginning of the maize cycle. and the prunings left in place, adding significant biomass and nutrients to the mucuna mulch on the field edges.

3.1.4 Variability in management and its causes

There are a number of minor differences from field to field and across years in the way the mucuna/maize rotation is managed by different farmers The most notable ones involve timing of slashing/planting operations and also the choice and timing of weed control These differences seem to take place in response to specific local environmental conditions. such as actual timing of mucuna maturity, intensity of rainfall at the time of slashing or weed pressure Production constraints at the household level may also influence practices for which labor or cash availability is critical, such as hiring of wage labor. or purchase of herbicides. but these aspects were not tackled in this study. They would however need to be considered carefully in the perspective of proposing changes to the present practices. which will probably affect differentially farms in function of their specific constraints and resources (Capillon and Sébillotte, 1982; Harrington and Tripp. 1984)

Interestingly. farmers do not appear to modify their management strategies as the mucuna system ages. old mucuna fields are treated in much the same way as are young mucuna fields. notwithstanding small adjustments in maize densities which reflect the perceived enhancement of soil fertility over the years (see chapter 5).

3.2 MAIZE YIELDS AND YIELD COMPONENTS IN THE MUCUNA SYSTEM

Maize is the only harvested output in the mucuna system, and is both the staple in farmers' diet and a major source of income. Hence the ability of the mucuna rotation to yield a good maize crop is a key criterion by which to judge its performance

3.2.1 Regional & local variability

There was a sizable variability among sites with respect to maize yields measured during the 93/94 cycle (Table 3.1 p. 41). In all documented cases, yields for fields without mucuna were consistently about half those obtained when maize was planted after a summer mucuna fallow. In the higher-yielding sites (San Fco and Las Mangas), the majority of yields were in the range 2.5 to 4.5 t ha^{-1}, a good level considering that maize cultivars were mostly landraces, that plant densities remained relatively low (Table 3.2 below) and that external inputs were sparingly applied (not at all in the case of Las Mangas). In both sites, the best yields measured were close to 6 t.ha^{-1}, indicating the high yield potential of the mucuna/maize rotation. These sites also had favorable soil chemical characteristics (Table 2.1). In Piedras Amarillas and Rio Cuero, actual yields and yield potential (as indicated by the best yields) were lower on average, something consistent with lower intrinsic soil fertility (Rio Cuero) or lower rainfall (case of Piedras Amarillas) and also sub-optimum management (low plant densities, late planting dates)

Table 3.2 Maize yield components with and without mucuna in selected sites and cycles

site & year	rotation	yield t ha^{-1}	dens (thous.)	Near /plant	N Kern. /ear	Weight 1 ear (g)	N Kern. /m2	Weight 1 K (mg)
Sn Fco 93	no muc	1.9	26.9	0.79	296	89	636	300
	w/ muc	3.3	33.0	0.84	378	120	1065	315
Mangas 93	no muc	2.5	30.3	0.76	302	113	692	376
	w/ muc	4.5	36.9	0.90	446	140	1483	315
Cuero 94	no muc [1]	1.4	26.5	0.66	264	80	463	302
	w/ muc	1.9	27.3	0.82	303	91	685	298

[1] one observation plot only

Across all sites, higher yields levels were significantly associated with higher plant densities (Table 3.2 and Figure 3.3 a). The relationship was even stronger with indicators of favorable conditions of plant growth, such as the number of ears per plant or number of kernel per ears (Navarro Garza, 1984; Fleury, 1991) (Table 3.2, Figure 3.3 b and 3.3.c). There was no differences between high and low yielding plots during the grain filling stage, as all plants exhibited kernels of approximately the same specific weight.

Table 3.1: Maize yields with and without mucuna in several sites in the hillsides of Northern Honduras, cycles 92/93 and 93/94

a. 92/93 cycle

SITE	(n)[1]	average	s.d.	min	max.
SAN FRANCISCO		(t/ha)			
- checks w/o mucuna	4	1.9	0.6	1.3	2.8
- mucuna fields	46	3.3	1.0	1.0	4.9
LAS MANGAS					
- checks w/o mucuna	2	2.5	0.2	2.3	2.6
- mucuna fields	26	4.5	0.8	3.0	6.0
PIEDRAS AMARILLAS					
- mucuna fields	11	2.3	0.8	0.9	3.3

b. 93/94 cycle

SITE	(n)[1]	average	s.d.	min	max.
San Francisco		(t/ha)			
- checks w/o mucuna	10	2.0	0.4	1.1	2.5
- mucuna fields	50	3.5	1.0	2.2	5.4
LAS MANGAS					
- checks w/o mucuna	4	1.4	0.8	0.3	2.1
- mucuna fields	29	3.1	1.0	0.8	4.6
RIO CUERO					
- checks w/o mucuna	1	1.4	---	---	---
- mucuna fields	18	1.9	0.8	0.6	3.5
PIEDRAS AMARILLAS					
- mucuna fields	16	2.5	0.6	1.3	3.7

number of samples

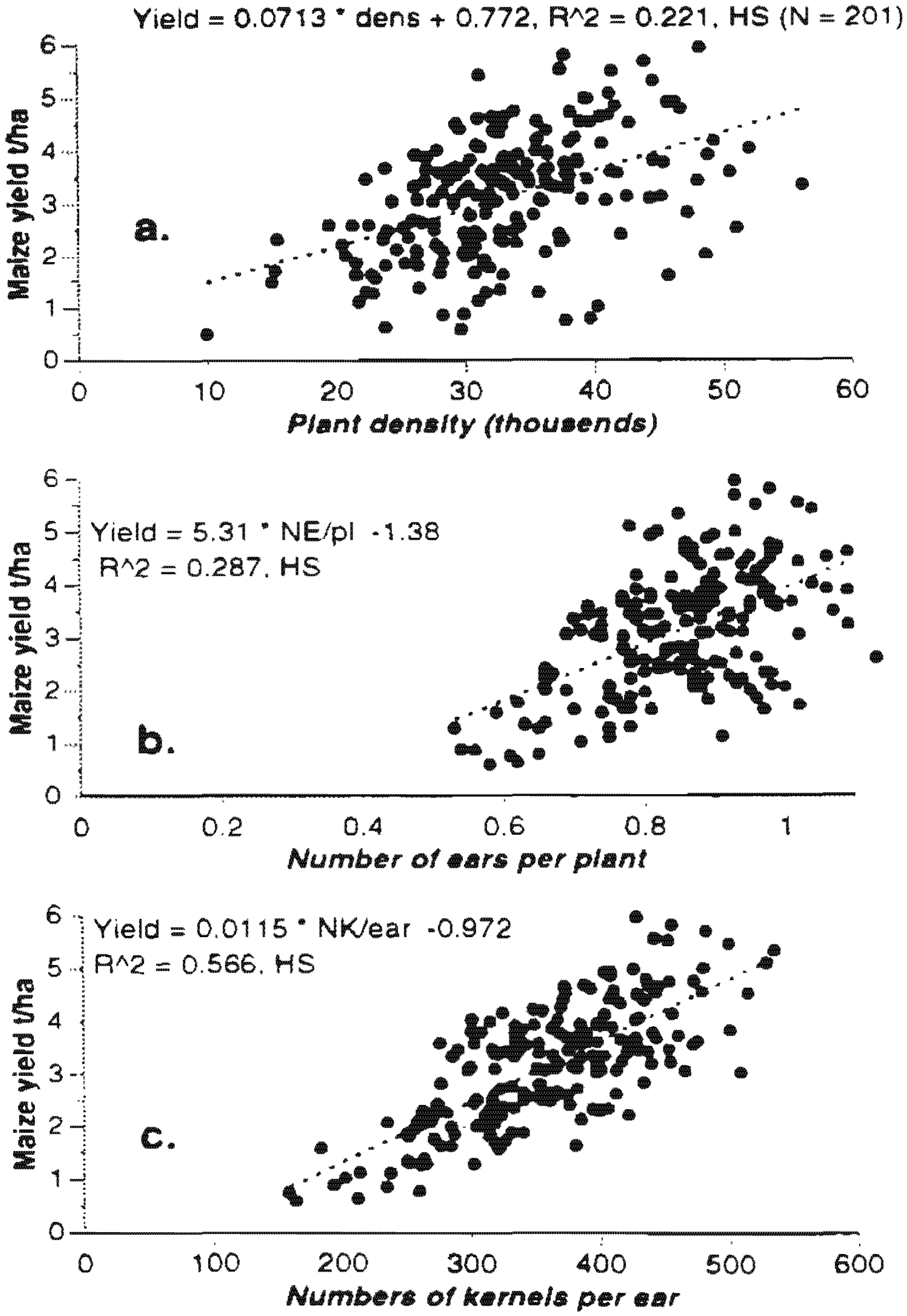


Figure 3.3 Relationship between maize yields and yield components across sites and years. Northern Honduras (a) plant density, (b) number of ears per plant, (c) number of kernels per ear

3.2.2 Year-to-year variability

The 92/93 and 93/94 cycles differed markedly with respect to the distribution of the rains received during the maize cycle (Figure 4.04, chapter 4). Whereas rainfall was abundant in 92/93 throughout the cycle, it was very scarce in the second-half of the 93/94 cycle, and late-planted maize fields suffered significantly from drought. This is especially apparent in Las Mangas (Table 3.1), where average yields dropped by 1.4 t ha^{-1} in mucuna fields between the 2 cycles (this drop is not however a direct measure of year-to-year variability in a given field, because fields sampled differed from one cycle to the next). Conversely, maize yields remained stable in San Francisco de Saco and in Piedras Amarillas (Table 3.1). For San Francisco de Saco, this may be attributed to the fact that most farmers had managed to plant before Christmas, thus allowing their maize crop to avoid much of the drought stress by tapping into the large amounts of stored water (in many cases, more than 200 to 250 mm for the 0-60 cm soil profile, see Figure 4.09, chapter 4).

Maize yields for fields without mucuna apparently followed the same pattern as for mucuna fields. But these figures do not reflect the fact that near complete crop failures occurred in a number of fields without mucuna in 93/94, whereas nearby mucuna fields planted around the same date had acceptable yields.

3.2.3 Plot vs. whole field yield estimates

The maize yields reported above were measured on small observation plots (two only in each field), and cannot pretend to provide an accurate estimate of commercial yields at the field level. Indeed, crop-cut yield data usually overestimate commercial yields at the field level by as much as 15 to 20% (Poate, 1988). Evidence that this is indeed the case in our study comes from a comparison between our measured data and yield data collected via interview with the farmers of these very same fields right after the 93 harvest: whereas the estimated average yield was 3.1 t.ha^{-1} based on our measurements, it was 2.3 t.ha^{-1} according to farmers' declarations.

Other reports based on farmers' declarations show somewhat similar evidence. If there is little doubt in our mind that yield levels reported by Buckles et al. (1992) are abnormally low (average yields of mucuna fields would be less than 1.5 t.ha^{-1}), those reported by Avila and Lopez (1990) (around 2.7 t.ha^{-1} for mucuna fields on a regional basis, and half that for fields without mucuna) and Humphries (1994) (1.7 t.ha^{-1} in Rio Cuero in 93/94), are consistent with our own findings (2-4 t.ha^{-1} on a regional basis and 1.9 t.ha^{-1} in Rio Cuero in 93/94).

The practical significance of the discrepancies between measured and declared yields should be kept in mind From an agronomic perspective, measured data are both more accurate and more useful, as they were collected from the exact same physical areas on which all other measurements (such as mucuna biomass or soil chemical properties) were made, and hence direct causal relationships can be inferred relatively safely From a socioeconomic perspective, measured yields should probably be corrected by about 20% to obtain figures suitable for a realistic analysis of production costs or income

3.3 MAIN BENEFITS AND CONSTRAINTS ASSOCIATED WITH THE MUCUNA/MAIZE ROTATION

From a qualitative viewpoint, many of the characteristics of the mucuna/maize rotation can be examined in terms of major practical benefits or constraints, even though it is not possible at this stage to establish a precise ranking of their actual contribution to the agronomic or economic success of the rotation

3.3.1 Main benefits

The main benefits (many of them interdependent) associated with the use of the mucuna/maize rotation *and perceived by farmers* can be summarized as follows

1 It requires little labor both for its initial establishment in the field and for its maintenance, because of the ability of mucuna to reseed itself spontaneously Compared to a traditional maize/fallow rotation, labor requirements are actually decreased, because slashing of an herbaceous mucuna stand is much easier than slashing a fallow containing trees and shrubs

2 It allows farmers to take advantage of the best cropping season for maize (usually sufficient, but not excessive rains, reliance on abundant stored water from the previous rainy season, healthier maize and better harvest conditions, better market price)

3 The vegetation (mucuna or maize residues) is never burned, and the soil is protected year-round from direct exposure to rainfall (hence less potential for erosion, and also conditions favorable for an intense biological activity)

4 Upon decomposition, the mucuna mulch provides large quantities of nitrogen and other nutrients to a succeeding maize crop The mulch helps conserve water in the soil profile, which provides a buffering capacity against drought stress, especially in dry years

5 The mulch and the mucuna fallow help control weeds

6 Maize yields levels are doubled compared fields without mucuna Furthermore, yields start increasing in the first year after mucuna has been introduced (no delay in response, as in the case in many agro-forestry systems or terracing works)

7 The mucuna system allows continuous cultivation of the same field year after year, without a need for fallow periods.

Most of these benefits are associated with intrinsic properties and characteristics of slash-and-mulch cropping systems (Bunch, 1994, Thurston *et al.*, 1994) Some however (# 2 and partly #1) are specific to the environment of the Atlantic littoral or the ecology of the mucuna plant, and hence, may not be extrapolable to other mulch systems or outside the Atlantic littoral region

3.3.2 Main constraints

Among the disadvantages mentioned by farmers (but not consistently confirmed by in-depth observations and discussion with farmers), one should mention localized landslides possibly favored by the use of mucuna (see discussion in chapter 5), proliferation of rats and snakes which may particularly appreciate the protection offered by the mucuna cover, and finally, the high opportunity cost of having to leave the field under a mucuna fallow for the duration of the wet season (Buckles *et al.*, 1992)

Almost unanimously, farmers consider these constraints to be very minor ones compared to the wealth of benefits that the mucuna system brings

3.4 CONCLUSIONS

The mucuna/maize rotation is a good example of a low-external input, no-tillage cropping system whose management is intimately interwoven with and dependent on natural ecological processes stemming from mucuna biology Its main features include slashing without burning the mucuna stand at its physiological maturity, dibble sticking of maize in the mucuna mulch, reliance of the natural reseeding of mucuna for its re-establishment, and an untouched mucuna fallow extending over 6 months during the main rainy season (Table 3.3 and Figure 3.1)

Farmers' practices throughout the Atlantic littoral match closely the uniform "technical sequence" or general model of crop management (Cerf and Sébillotte, 1988) described above The extent to which practices differ among fields, sites and years represents what could be called tactical adjustments to fluctuating agroecological or intra-household factors and conditions rather than inherently distinct management strategies

From its key characteristics, the mucuna system appears to be very close to what may be considered an ideal cropping for hillside farming in this type of environment It combines some of the most desirable traits from both a scientist's perspective (resource conservation, nutrient recycling, good productivity: Sanchez, 1994) and from the user's standpoint (low investment, fast return, compatibility with existing knowledge base Bunch, 1982; Buckles *et al.*, 1992; Bunch, 1993). Perhaps the most eloquent proof of the desirability of such a system consists of its spontaneous adoption by small farmers of Northern Honduras (at the impressive rate of 66% on a regional basis cf Buckles *et al.*, 1992). Or as farmers put it simply, mucuna is a God's blessing.

Table 3.3 Main farmers' practices in the mucuna/maize rotation. Northern Honduras

Practices	Early -Late dates	Criteria	Input used	Observations
SLASHING	mid Nov late Jan	pod maturity/ avoid drought	machete	
MAIZE PLANTING	late Nov early Feb	slashing	dibble stick. local seed	
WEED CONTROL	5 d a p [1] - 60 d.a p	weed growth. labor avail	machete, hoe or herbicide	1 or 2 controls
(MUCUNA RESEEDING) [2]	mid Feb mid Mar	(if deficient natural reseeding)	seed from previous cycle	rarely done
(FERTILIZATION)	40 d a p 60 d.a p	(cash availability perceived need)	Urea (25 to 60 of N kg.ha^{-1})	not used at all in some villages
HARVEST	mid April mid June	household needs market prices	----	

[1] d.a p = days after planting the maize. [2] parentheses denote a practice not done by the majority of farmers

Chapter 4

NITROGEN CYCLING IN THE MUCUNA/MAIZE ROTATION

4.1 INTRODUCTION

A distinctive feature of the mucuna/maize rotation (hereafter referred to as the mucuna system) is the year-round presence of a thick mulch layer on the soil. The nature and behavior of this mulch layer makes the system share many of the characteristics of natural ecosystems possessing litter layers, such as tropical forested ecosystems (Budelman, 1988). Compared to a natural system however, the dynamics of the mucuna system is radically altered to accommodate a commercial crop, and the management and behavior of mucuna in the rotation can be equated roughly with that of an improved, short-term fallow whose main function is to help maintain and build up soil productivity for the benefit of the maize crop (Sebillotte, 1985). Among the many effects of mucuna on the succeeding maize crop (see chapter 3), improved mineral nutrition constitutes undoubtedly a major aspect, and one for which quantitative evidence coming from tropical slash-and-mulch cropping systems is still rare, even though numerous studies have dealt with related agroecosystems (Huntington *et al.*, 1985, Ladd and Amato, 1985, Yost *et al.*, 1985, Glover and Beer, 1986, Pichot *et al.*, 1987, IRRI, 1988, Yost and Evans, 1988, Sanchez *et al.*, 1989; van der Heide and Hairiah, 1989; Palm and Sanchez, 1990, Sarrantonio, 1991, Smyth *et al.*, 1991, Kang and Mulongoy, 1992, Mulongoy and Akobundu, 1992, Haggar and Beer, 1993, Thurston, 1994).

The objective of this chapter is therefore to provide baseline information about nutrient cycling in the mucuna/maize cropping system practiced in Northern Honduras, with a strong emphasis on nitrogen dynamics. The main issues considered here include quantification of organic inputs, pace and timing of nitrogen accumulation in the legume and subsequent patterns of release by the mulch and uptake by the maize crop. Of particular interest are (1) the synchronization of mucuna decomposition with maize uptake, and (2) nitrogen imbalances in the system, potentially created by large amounts of nitrogen inputs added through the mucuna biomass (supply side), compared to the relatively modest outputs achieved via maize harvest (demand side).

The chapter will present a general framework for analyzing annual inputs and outputs of biomass in the mucuna system, followed by a discussion of biomass and nutrient accumulation by the mucuna crop, as well as mucuna litter decomposition. There follows an analysis of the dynamics of inorganic nitrogen in the soil profile during the maize cycle. Finally, maize response to nitrogen present in the litter or applied as fertilizer is examined. The discussion highlights the significance of these findings for understanding the processes at work in the mucuna system and its implications in terms of management by farmers and crop performance.

4.2 MATERIALS & METHODS

The general framework for the study was reported in chapter 2. This section deals only with the specifics related to nitrogen cycling.

4.2.1 Evaluation of mucuna biomass accumulation

Measurements were made mainly just prior to slashing time (December of each year; precise date for each field as a function of individual farmers' management). In 1992, 40 observation plots (2 plots per field) were sampled (SFS only), 100 plots in 1993 (4 villages), and an additional 35 in 1994 (SFS and CU/CIAT, 1995). In each village, the above-ground total biomass was determined by harvesting 2 to 4 quadrats (2.25 m^2 each) per observation plot for sampling dates up to December. Total biomass was separated into various fractions, easily recognizable by eye: green mucuna, live weed material, and litter (this latter being simply all dead organic matter, whatever its stage of decomposition) (Figure 4.01). In December 93 and 94, further sub-categories were made for pods and vines, respectively.

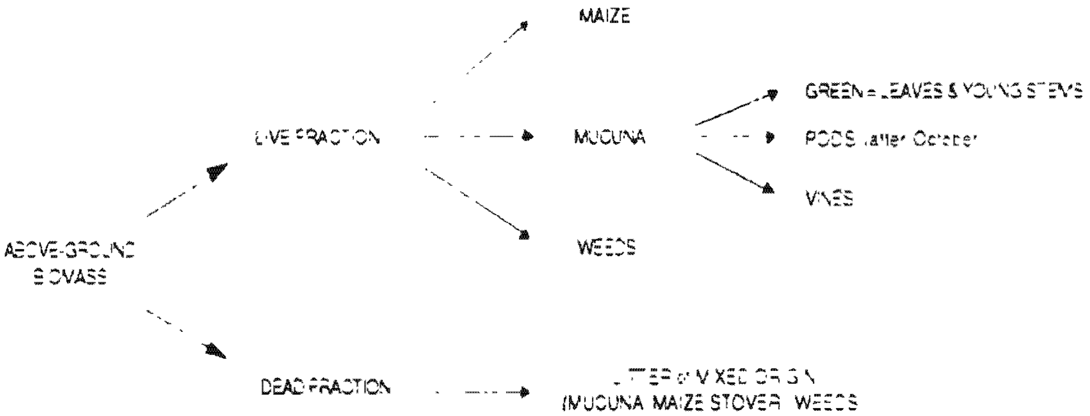


Figure 4.01 Compartments of the above-ground biomass in the mucuna system, Northern Honduras

Additionally, a periodic assessment of mucuna biomass accumulation from October to December 93 was conducted in SFS only using the above methodology in 7 plots, whereas apparent mucuna mulch decomposition was followed from December 93 to

May 94 in 18 plots, also in SFS (in this later case, quadrat size was 1 m^2, and there was only one litter fraction and occasionally one weed fraction). At each date and in each village, a composite sub-sample was taken from each fraction in every observation plot for dry-matter and nutrient determination. Samples were oven-dried at 60 °C for 48 hours minimum, ground in a Wiley mill # 4, and analyzed by ICP after dry-ashing for total nutrient content (P, K, Ca, Mg, B, Cu, Fe, Zn) and by micro-Kjeldahl for total N content at the Standard Fruit Laboratory in La Ceiba, Honduras. C, N and isotope (^{13}C, ^{15}N) content was furthermore determined by using a Europa Scientific Roboprep C/N analyzer coupled to a Tracermass mass spectrometer (Europa Scientific, Crewe, Cheshire, England) at Cornell. Because results for total nitrogen differed according to the method used, a regression equation ($R^2 = 0.92$) was developed to allow the conversion of results obtained by one method into the other.

4.2.2 Evaluation of maize response to N-urea and P-TSP

A nitrogen x phosphorus fertilizer experiment was established to investigate the response of maize to fertilizer applied in well-established mucuna fields (i.e. fields several years into the rotation). It consisted of a simple 2^2 RCB factorial, with 2 levels of N, 0 (mucuna mulch only) and 50 kg ha^{-1} of N-urea, applied 40 days after planting, and 2 levels of P, 0 (mucuna mulch only) and 60 kg ha^{-1} of P-TSP, applied at planting. For both N and P, the fertilizer was incorporated into the soil, in a hole a few cm away from each hill.

In 92/93, the trial was planted in 3 fields in San Francisco de Saco, whereas in 93/94, it was established in 8 fields in SFS (different from those chosen the previous year), as well as in 3 fields in Las Mangas. There were 2-3 replications per field, spread out over the field in order to adapt to the broken topography. Particular attention was given to weed pressure in 92/93: all blocks were duplicated to offer a contrast between weed-free vs. farmer-controlled weed environments; in 93/94, all 11 fields were kept reasonably weed-free. In all cases, individual plot size was 30-40 m^2, and the harvested area comprised the 4 central rows of each plot. Trial establishment and maintenance was done in collaboration with the various field owners.

4.2.3 Monitoring of inorganic nitrogen dynamics during the maize cycle

The monitoring was done in the soil profile of most check plots (without fertilizer application) of the above trials in SFS only: in each year, a total of 14 individual plots were sampled. In 92/93, sampling started in December and ended in April, for a total of 7 sampling dates, whereas in 93/94, sampling started in December and ended in June, for a total of 9 sampling dates. An additional 7 plots (2 of which were common to the general monitoring, whereas the others were located in neighboring fields) were sampled monthly between October and December of 1993 in conjunction with the biomass accumulation study. Samples were taken from 3 depths: 0-10 cm (0-15 cm in 92/93), 10-

30 cm (15-30 in 92/93) and 30-60 cm, sieved to approximately 2-4 mm in fresh, extracted with 2M KCl (20 g of soil to 100 ml of KCl), filtered, and stored frozen immediately after extraction. The extracts were analyzed colorimetrically (Keeney and Nelson, 1982) using an AutoAnalyzer for both NO_3 (modified Griess-Ilosvay method) and NH_4 (Indophenol Blue method) at Cornell at the end of the experimental work. The colorimetric procedure was calibrated against a standard steam distillation procedure (Keeney and Nelson, 1982). Inorganic N content was converted to kg.ha^{-1} using bulk density figures collected for each field (see chapter 5).

4.2.4 Determination of maize nutrient uptake

The main indicator used to reflect maize mineral status was ear leaf total nutrient content at flowering. For each observation plot or experimental treatment, a sample of 15-20 healthy ear leaves was taken from plants in the silking stage. Samples were oven-dried at 60°C for 48 hours, the central leaf section ground in a Wiley mill, and analyzed for total nutrient content by ICP in a manner similar to that used for mucuna samples.

Maize total N and P content at harvest was analyzed colorimetrically on grain and stover samples taken from the N*P experimental treatments (93/94 cycle only), following a wet digestion with H_2SO_4 and salicylic acid (Novozamsky *et al.*, 1974, 1983).

4.3 ANNUAL DYNAMICS OF ABOVE-GROUND BIOMASS AND NITROGEN

In the mucuna/maize rotation, all or most of the nutritional requirements of the maize crop are met via *in situ* production and management of mucuna biomass, which upon decomposition provides the maize crop with an array of nutrients, chief among them nitrogen. Understanding the complex processes of biomass accumulation and decomposition affecting release of nutrients by a mucuna cover is a necessary step to better take advantage of them, and possibly to manipulate them in a direction more suitable to farmers' interests.

Thus, this section will first analyze the general trends in above-ground biomass and nitrogen dynamics over the year, and their relation to availability of inorganic nitrogen in the soil profile during the maize cycle. Management options for meeting maize nitrogen requirements will then be analyzed by determining the effects of limited additions of N or P fertilizer on maize production.

4.3.1 The various phases of the mucuna/maize rotation

4.3.1.1 Main components of the above-ground biomass

Above-ground biomass in the mucuna/maize rotation includes several key components whose relative importance (in terms of dry-matter and nutrients) depends on the particular phase of the rotation (Figure 3.1 chapter 3).

As a first simplification, the above-ground biomass can be divided into live and dead components (Figure 4.01). The live fraction comprises either growing mucuna (from June to December) or growing maize and its accompanying weeds (between December and May). Its biomass content varies widely during the year, following the various phases of the mucuna/maize rotation. Interestingly, under the present-day management, farmers do not remove any biomass other than the maize ears from their mucuna fields: maize stover is left in place, and mucuna is not grazed nor harvested as forage or grain.

The dead fraction consists of a dead mulch or **litter layer** *sensu stricto*, which completely covers the soil surface year-round. Components of the litter include a dynamic mixture of decaying mucuna parts, decaying weeds slashed by farmers during the maize cycle or suffocated by mucuna during the summer, and rotting maize stover. The biomass content in this layer is always high, contributing consistently over 50% of the total above-ground biomass found in a mucuna field at any given time. It reaches its highest levels after slashing of mucuna and again following maize stover incorporation into the litter.

4.3.1.2 The litter layer

4.3.1.2.1 Functions of the litter

The constantly renewed litter sitting above the soil profile fulfills many important functions, all of which contribute to the performance and behavior of the rotation in both the short- and long-term. Chief among them is its role in controlling erosion, as it cushions the impact of water drops (chapter 5). At the same time, it helps regulate water flow in and out of the profile, by favoring infiltration over run-off (chapter 5) and by slowing down evaporation. It contributes strongly to nutrient cycling, both by providing the needed substrates for decomposition and by offering an adequate habitat for the decomposing flora and fauna. It also provides the environment in which mucuna will reseed itself. Simultaneously, it influences markedly weed dynamics by altering conditions for weed emergence and by providing those which manage to compete against mucuna or maize with plentiful nutrients and water.

4.3.1.2.2 Factors affecting biomass accumulation and decomposition

The maintenance of the litter layer over time is the result of two opposite sets of processes, litter formation on one hand and litter decomposition on the other. Among the former, maize, weed and mucuna management by farmers codetermine the quantitative levels of addition to the litter as well as its timing, in interaction with environmental conditions regulating plant growth. Each of the three main components added to the litter has distinct initial properties vis-à-vis decomposition. For example, mucuna material has typically high N content and low C:N ratio, and includes very leafy, easily decomposable material, whereas the opposite is true for maize stover. Weeds have a composition and behavior depending on the species involved and the precise timing of their incorporation in the litter.

Conversely, decomposition processes, even though they probably fluctuate markedly in response to periodic additions of fresh material to the litter, seem only moderately affected by management. They are largely under the influence of environmental factors such as moisture and temperature (Jenkinson, 1981). These two factors continually interact to modify the microclimate of the litter layer, and its ability to undergo decomposition.

4.3.2 Biomass and nutrient content at slashing

Because slashing of the mucuna crop constitutes the pivotal moment of the mucuna rotation, we will now turn our attention to two fundamental aspects of slashing, namely the quantity of biomass present at that moment, and its composition. It should be noted that in the following presentation, easily recognizable pieces of maize stover (from the previous maize cycle) were systematically excluded from the sampling process, out of an initial (unwarranted) assumption that only neo-formation of litter during the mucuna cycle was important for understanding cycling processes: this methodological flaw probably brings about an average underestimation of above-ground biomass of roughly 0.5 to 1 ton of DM ha^{-1}. This omission is rather insignificant in terms of nitrogen (in the order of 1% or less of the total nitrogen content).

4.3.2.1 Total biomass content

For all four villages sampled in December 1993, the levels of total above-ground biomass fell in a relatively narrow range of 10 to 12.5 t.ha^{-1} on a dry-matter basis (Table 4.01). Statistically speaking, these differences were highly significant, with San Francisco presenting the highest biomass production. In the two sites for which data is available, the year-to-year variability was moderate (Table 4.02), although biomass was significantly lower in December 92 compared to the two following cycles in San Francisco de Saco. The largest differences however occurred *among fields* within the same year and site, leading to statistical differences among fields in 3 of the four villages. For example, in San Francisco, individual field minimas dropped to less than 7 t.ha^{-1}, whereas maximas exceeded 15 t.ha^{-1} (Table 4.01). The *within-field variability* was low on average (not statistically significant), although in a few cases differences of several t.ha^{-1} were found between observation plots within a single field.

Given the diverse soil and climatic conditions represented by the four sites and three years sampled in this study, biomass production across sites and years appears relatively stable (overall coefficient of variation less than 15%). This result probably stems from a combination of factors. First, total biomass includes a strong semi-permanent litter component, which is only partly influenced by seasonal fluctuations in climate and plant growth. Also, the length of the mucuna cycle (8 months minimum) probably allows the mucuna/weed stand to compensate for any temporal stress which would transiently reduce growth. Finally, expressing productivity on the basis of total biomass usually reduces apparent variability, as this latter is more likely to affect specific components, and particularly pod production.

Table 4.01: Above-ground biomass (t.ha-1) and its various fractions (in %) present in mucuna fields at slashing in four sites, Northern Honduras, 12/93

(each cell represents the average for the site, followed by its standard deviation)

		t.ha^{-1}			% of total biomass			
site	(n)	total biomass	Min.	Max	green[1]	pods[2]	vines[3]	litter[4]
Sn Fco	32	12.4 ± 2.1 *a*[5]	7.0	16.3	11 ± 5	6 ± 4	14 ± 4	69 ± 6
Mangas	29	11.0 ± 1.4 *b*	8.8	13.9	10 ± 5	24 ± 6	22 ± 4	45 ± 8
Cuero	21	10.7 ± 1.6 *b*	8.6	14.5	15 ± 6	7 ± 5	18 ± 5	60 ± 8
Piedras	19	11.3 ± 1.9 *ab*	8.6	16.2	15 ± 5	13 ± 7	19 ± 5	53 ± 8
Average	*101*	*11.4 ± 1.9*	*7.0*	*16.3*	*12 ± 6*	*13 ± 9*	*18 ± 5*	*57 ± 12*

[1] leafy material and tender vines. [2] pods include immature seeds. [3] old stems, partly lignified and possibly about to start rooting. [4] dead material, including freshly shed leaves; [5] means followed by the same letter in one column do not differ significantly according to Tukey's test at the 10% family rate

Table 4.02 Inter-annual variability in biomass production of mucuna fields at slashing time in San Francisco de Saco, Northern Honduras

		t. DM.ha^{-1}			% of total		t. DM.ha^{-1}	kg/ha
Year	(n)[1]	Tot. Biomass[2,5]	Min	Max	Litter	pods	Live Weeds	N total
1992	44	10.8 ± 2.3 *b*	6.1	15.9	61	?	(0.0)[3]	263 ± 75
1993	32	12.4 ± 2.1 *a*	7.0	16.3	69	6	(0.0)	313 ± 65
1994	22	12.6 ± 2.7 *a*	8.6	17.0	64	16	(0.6)	?[4]
Average	98	11.7 ± 2.5	6.1	17.0	64	10	---	284 ± 75

[1] number of plots sampled. [2] average ± standard deviation. [3] parentheses indicate only few plots had weeds, or quantities per plot were insignificant; [4] lab data not available. [5] means followed by the same letter in one column do not differ significantly according to Tukey's test at the 10% family rate

In order to reflect morphological and functional differences among the various components of the live fraction, the slashed mucuna material was subdivided into three sub-fractions: green material (mucuna leaves and fine stems), mucuna pods, and mucuna vines (i.e. partly lignified stems). Live weeds were almost always insignificant at slashing time (weeds present at the end of the maize cycle get incorporated in the mulch/litter layer, after being outcompeted by mucuna).

The proportions of these various sub-fractions were also relatively stable (10-15 % for green material, and 14-22 % for vines). Pod production however was quite variable both between and within sites: pods constituted as little as 6% of the total biomass and as much as 24% for a given site (the range was wider for comparisons among fields). This variability occurred both across sites and across years (Tables 4.01 and 4.02).

The litter (dead) fraction constituted on average close to 60% of the total dry weight, or 5 to 9 t.ha. Thus, the annual December slashing added only 4 to 6 tons of DM.ha of *fresh* material to the pre-existing litter (roots add probably another 1-2 t of fresh dry matter however: Lathwell, 1990, Hairiah, 1992)

4.3.2.2 Characteristics of the various biomass fractions

The various fractions discussed above presented fairly similar characteristics across sites in terms of their N content and C:N ratios (Table 4.03). The pods were richer in nitrogen than any other fraction (about 3% on average), whereas the vines were the poorer (less than 2%), translating into C:N ratios greater than 20. The litter fraction presented relatively high though variable within-site levels of nitrogen, about 2.65% on average, with consequently low C:N ratios of 16 to 18. This fact, along with a δ^{13}C value (Mariotti, 1991) close to -26 tends to prove that the litter fraction at slashing time was heavily dominated by the contributions made by the mucuna crop, a C3 plant, rather than by maize stover (a C4 plant with a δ^{13}C value close to -13), or by C4 grass weeds which predominate in numerous mucuna fields across Northern Honduras (*Rottboellia cochinchinensis* in the case of SFS). Conversely, when mucuna does not reesta-blish itself properly in a field (as was the case during the 94 summer cycle), the biomass found at the following slashing comprises a much higher proportion of weeds, yielding lower N content (less than 2%) and δ^{13}C values for the litter fraction (-15 to -20)

Table 4.03 Selected characteristics of the various biomass fractions found in mucuna fields at slashing time, Northern Honduras. 12/93

site	*Property*	green[1]	pods[2]	vines[3]	litter[4]
Sn Fco	*(sample size)*	(14)	(14)	(14)	(32)
	total N %	2.77	3.02	2.00	2.62
	C:N ratio	17.0	14.9	22.9	16.8
	$\delta^{13}C$	-26.8	-25.2	-26.3	-25.5
Las Mangas	*(sample size)*	(9)	(9)	(9)	(19)
	total N %	2.92	2.97	1.74	2.68
	C:N ratio	15.7	15.2	25.9	16.2
	$\delta^{13}C$	-26.8	-25.7	-26.6	-25.8
Rio Cuero	*(sample size)*	(5)	(4)	(4)	(13)
	total N %	2.65	2.88	2.09	2.68
	C:N ratio	16.9	15.0	21.2	16.7
	$\delta^{13}C$	-26.8	-25.1	-26.1	-24.9
Piedras Amar	*(sample size)*	(3)	(3)	(3)	(10)
	total N %	3.83	3.14	2.02	2.65
	C:N ratio	11.9	14.0	22.2	16.6
	$\delta^{13}C$	-25.8	-24.0	-25.2	-24.2

[1] leafy material and tender vines; [2] pods include immature seeds. [3] old stems, partly lignified and possibly about to start rotting. [4] dead material, including freshly shed leaves

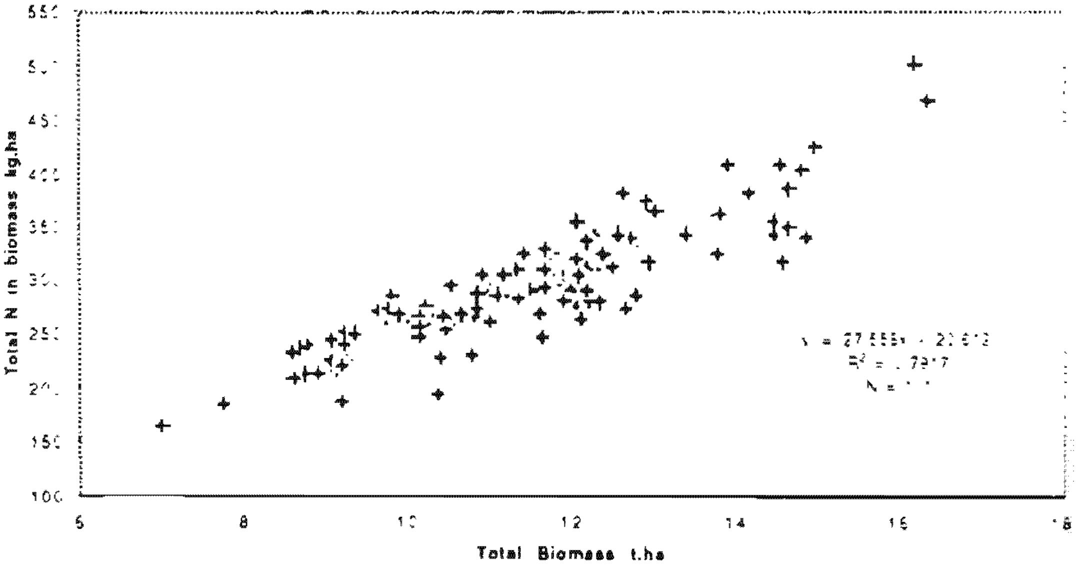
4.3.2.3 Nitrogen content

Total nitrogen content in the above-ground biomass for the different sites is presented in Table 4.04. As was the case for total biomass, total N content was rather similar among sites, and reached almost 300 kg ha^{-1} on average. Again, the major source of variability was among fields: in SFS for example, N content dropped to as little as 100 kg ha^{-1} in one field, and conversely reached almost 500 kg ha^{-1} in another.

Table 4.04 Nitrogen (kg ha^{-1}) present in above-ground biomass at slashing time in mucuna fields in four sites, Northern Honduras. 12/93

site	(n)	green N [1]	pods N [2]	vines N [3]	litter N [4]	**total N**	litter N %
				in kg ha^{-1}			*% of total N*
Sn Fco	32	39 ± 19	20 ± 13	36 ± 10	221 ± 55	**316 ± 67**	70 ± 7
Mangas	29	29 ± 17	78 ± 20	[illegible]3 ± 8	128 ± 34	**278 ± 41**	46 ± 8
Cuero	21	41 ± 14	21 ± 13	37 ± 11	173 ± 51	**272 ± 52**	63 ± 9
Piedras	19	58 ± 21	46 ± 22	42 ± 14	163 ± 50	**310 ± 60**	52 ± 8
Mean	*101*	40 ± 20	42 ± 30	39 ± 11	174 ± 59	**295 ± 58**	58 ± 13

[1] leafy material and tender vines. [2] pods include immature seeds. [3] old stems, partly lignified and about to start rotting; [4] dead material, including freshly shed leaves. *Each cell represents the average for the site followed by its standard deviation.*



(Each symbol corresponds to one plot)

Figure 4.02 Relationship between total nitrogen in the above-ground mulch and biomass levels, Northern Honduras, December 1993

Total N was more dependent on biomass levels than on N content in the various fractions, as shown in Figure 4 02 p. 56: the overall R2 across sites for the relationship between total nitrogen and total biomass reaches 0.8 (N= 101), and all sites presented a similar relationship, with the exception perhaps of Las Mangas, where the relationship between the two variables was slightly looser (R2 closer to 0 6, data not shown)

Because of the quantitative dominance of the litter fraction, and its relatively high N content, almost 60% of the nitrogen present at slashing is found *in the litter*, and not in the live fractions The pod fraction comprises a low percentage of total N on average, except in Las Mangas, where it reached almost 25% of the total N, in keeping with the high proportion of pod biomass Because mucuna typically reseeds itself, most of this "pod N" is probably not available however for subsequent recycling via decomposition.

4.3.2.4 Other nutrients

While nitrogen was of primary interest in this study, the mucuna biomass accumulated other key nutrients Table 4.05 displays the average levels of phosphorus, potassium, calcium and magnesiumpresent at slashing (in kg.ha^{-1}), and the proportion of them found in the litter

Table 4.05. Nutrients other than nitrogen found in the above-ground biomass of mucuna fields at slashing time in various sites, Northern Honduras. 12/93

Nutrient	Sn Fco	Mangas	Cuero	Piedras	*Average*
total P kg ha^{-1}	18 ± 6[1]	28 ± 5	14 ± 2	19 ± 4	20 ± 7
% P in litter	58 ± 9	31 ± 7	51 ± 11	39 ± 8	45 ± 14
total K kg ha^{-1}	82 ± 21	114 ± 24	98 ± 16	113 ± 17	100 ± 24
% K in litter	27 ± 7	11 ± 3	19 ± 6	13 ± 5	18 ± 9
total Ca kg ha	159 ± 45	130 ± 23	111 ± 22	134 ± 34	140 ± 37
% Ca in litter	78 ± 5	62 ± 9	72 ± 7	66 ± 6	70 ± 10
total Mg kg.ha^{-1}	32 ± 7	22 ± 4	22 ± 4	26 ± 5	26 ± 7
% Mg in litter	67 ± 8	45 ± 8	54 ± 9	54 ± 8	56 ± 12

[1] each cell represents the average over all fields sampled in each site, followed by its standard deviation. Sample size: 32, 29, 21 and 19 for Sn Fco, Mangas, Cuero and Piedras respectively

Even though there was a sizable variability among sites, the mucuna "complex" accumulated significant quantities of all of these nutrients, and especially calcium (140 kg ha on average) and potassium (100 kg ha^{-1}). Even phosphorus was found at levels roughly sufficient to supply the requirements of a maize crop. The distribution of these nutrients in the above-ground biomass differed for each nutrient: if most of the Ca (70%) was found in the litter, most of the K (82%) was in live fractions (and particularly the vine fraction), with intermediate situations for P (45% in litter) and Mg (56% in litter).

4.3.3 Seasonal behavior of the mucuna cover

We will now examine in more detail how a mucuna crop accumulates dry-matter and nutrients in the first place, and then releases both upon decomposition.

4.3.3.1 Mucuna biomass accumulation during the rainy season

There are two main phases during the mucuna cycle: the vegetative phase, lasting from February/March (mucuna re-seeding) to early October, and the reproductive phase, from October to December, at which moment mucuna starts to die naturally, even when slashing does not take place. Climatically speaking, the vegetative phase spans the dry-season and the first half of the rainy season, whereas the reproductive phase takes place during the peak of the rainy season (Figure 3.1 chapter 3).

4.3.3.1.1 From mucuna re-establishment to flowering

After reseeding itself in February-March, mucuna grows relatively slowly under the shade provided by a fully developed maize crop. Also, it has to withstand either farmers' attempts at keeping it from competing too strongly with maize in wet years (see chapter 3), or alternatively extremely dry and hot conditions if the winter cycle is drier than usual. Finally, weeds not controlled by farmers may also compete heavily for light, nutrients and water with the young mucuna plants. It is usually not until after maize harvest and the return of rains (by end of May - early June) that conditions become favorable to mucuna rapid growth, leading within a few weeks to full canopy closure. By mid-summer, a typical field presents a relatively uniform, dense mucuna stand, given that maize stover has been pulled down and incorporated to the litter by aggressively growing mucuna vines using the stalks as support. Weeds have usually been reduced to a marginal presence by that time, since mucuna gradually overcompetes most of those present at the end of the maize cycle.

Mucuna starts flowering in early to mid-October, apparently in response to shorter days (it is not clear yet how strictly photoperiodic mucuna is). At this point, a typical mucuna field has "accumulated" about 10 t.ha^{-1}, with close to 40% (i.e. 4 t.ha^{-1}) in the live mucuna fraction, and slightly more than 60% in the litter layer (Table 4.06).

Table 4.06: Accumulation of dry-matter and nitrogen in the above-ground biomass of mucuna fields San Francisco de Saco, 10/93 to 12/93

(each figure represents the mean of 7 plots, followed by its standard deviation)

Component	sampling date [1]			rates kg .ha^{-1}.day^{-1} [2]		
	October	*November*	*December*	*Oct Nov*	*Nov Dec*	*Oct Dec*
Total biom. t ha^{-1}	10.1 ± 1.4	12.0 ± 2.2	14.2 ± 1.2	58 ± 81	88 ± 128	71 ± 30
"live" biom t.ha^{-1}	3.7 ± 0.8	3.3 ± 0.9	4.3 ± 0.9			
litter biom t.ha^{-1}	6.4 ± 1.1	8.7 ± 1.5	9.9 ± 1.6			
total N kg.ha^{-1}	289 ± 54	334 ± 62	367 ± 51	1.3 ± 1.9	0.8 ± 4.4	1.3 ± 1.3
litter N kg ha^{-1}	167 ± 35	235 ± 43	256 ± 49			

[1] actual dates 10/15/93. 11/15/93 and variable in Dec. as a function of actual timing of slashing by each farmer; [2] linear rates were calculated for individual plots. using actual sampling dates

4.3.3.1.2 Towards maturity. biomass and nutrient accumulation beyond flowering

Total biomass increased from 10 t.ha^{-1} in mid-October (early flowering) to 12 t ha^{-1} one month later. and 14 t.ha^{-1} after another 3 weeks to a month (Table 4.06), giving average apparent growth rates of 58 and 88 kg.ha^{-1}.day^{-1} respectively for these two periods (note however high variability in the figures). Dry-matter accumulation seemed to affect the litter layer more than the live fractions: in mid-November, the live fraction had apparently dropped from 3.7 t ha^{-1} in mid-October to 3.3 t.ha^{-1}, or less than 30% of the total biomass present. There was however an increase in live biomass at slashing time (+ 1 t.ha^{-1} between mid-November and slashing time), matching closely the biomass found in the pods (0.8 t.ha^{-1}). The observed increase affecting the litter fraction (from 6.4 t.ha^{-1} in mid-October to 8.7 t.ha^{-1} to almost 10 t.ha^{-1} at slashing) may indicate that even though mucuna does not die massively until it is slashed, it however starts decaying before or soon after flowering, by shedding leaves and stopping maintenance of its extensive vine network.

The overall accumulation of nitrogen by the mucuna complex matched closely the trends observed for total biomass. Total N for all fractions increased from 289 kg ha^{-1} in mid-October to 334 kg ha^{-1} in mid-November and 367 by slashing time, with an overall rate of accumulation of about 1.3 kg N .ha^{-1}.day^{-1}. Again, the situation differed markedly for each fraction: whereas the live fraction did not apparently accumulate any N during the two-month period (from 122 to 99 and then up again to 111 kg ha^{-1}, thanks to the N found in the pods), the litter fraction did gain 68 kg and then 21 kg.ha^{-1}, for a total of 89 kg ha^{-1} over the entire period.

This gain is probably due to the transfer of biomass from the live to the litter fraction and would account for the observed fluctuations of the C:N ratio of the litter fraction: from almost 20 in mid-October to 18 in mid-November and less than 16 by December. This trend seems consistent with the incorporation to the litter of low C:N ratio leafy mucuna material (via leaf shedding). This situation may have important implications for nutrient release and recycling, which would start significantly *before* mucuna slashing, and follow closely the addition of fresh, nitrogen-rich material to the litter layer, at a moment when abundant rainfall favors its rapid decomposition.

4.3.3.2 Mulch decomposition during the dry season

Once farmers have slashed the mucuna stand, decomposition is the major process affecting the litter layer. Data presented in Table 4.07 show decomposition trends over the period December 93 to May 94, much drier than what is typical for the region. They represent apparent rather than actual rates of decomposition, because periodic samplings over time of unconfined material make it impossible to separate out the decomposition of the litter per se from its renewal via fresh biomass of weeds added during weed control operations (cf. 5.3.1).

Table 4.07: Apparent decomposition of the litter present in mucuna fields at various times after slashing, San Francisco de Saco, 12/93 to 5/94

Variables	Sampling date[1]			avg. rates in kg.ha^{-1}.day^{-1}	
	early 12/93	early 3/94	late 5/94	Dec-Mar[2]	Mar-May
biomass left (t.ha^{-1})[3]	12.6 ± 1.8	8.6 ± 2.2	10.6 ± 2.2	45.2 ± 40.0	-25.2 ± 44.5[4]
total N left (kg ha^{-1})[3]	316 ± 63	198 ± 50	235 ± 67	1.3 ± 1.1	-0.5 ± 1.2[4]

[1] actual sampling date varies by field. [2] linear rates were calculated individually for each field based on actual sampling date. [3] Apparent biomass/N, because litter/N at any date represents a mixture of litter/N already present at slashing and newly added litter/N via weedings: see text. [4] minus sign indicates an apparent gain in biomass/N between the two sampling dates. *Each value represents the mean of 18 plots*

Litter biomass appeared to drop at first, from 12.6 t.ha^{-1} at slashing time to 8.6 t ha^{-1} in early March, corresponding to a loss of approximately 45 kg .ha^{-1}.day^{-1}. From March to end of May, total biomass present in the litter layer seemed to increase, reaching 10.6 t.ha^{-1}. Although it may be an artifact stemming from sampling procedures, this increase may also happen as a result of weed control practices during the February-March period: slashing the weeds or drying them out with Paraquat (see chapter 3) does actually contribute new biomass to the litter layer.

Analysis of *in situ* labeling provided by natural abundance ^{13}C values (Balesdent *et al.*, 1988) supports this interpretation. Weed populations in many fields are dominated by a C4 grass (*Rottboelia cochinchinensis*), giving rise to a distinctive average δ^{13}C value of -17‰ for the weed biomass (as measured in May), quite different from the δ^{13}C values for the mucuna material (around -25 to -26‰). Assuming that the litter at any date is a simple mixture of weeds and mucuna material, it becomes possible to estimate the proportion of each of these two fractions in the litter by equating the observed δ^{13}C of the mixed litter to a weighted average of the δ^{13}C of the two materials.

Arithmetically, this is equivalent to resolving the following system of simultaneous equations for any field and sampling date i.

$$\begin{cases} Wi + Mi = 1 & (1) \\ d_{w,i}\,(Wi) + d_{mu,i}\,(Mi) = d_{m,i} & (2) \end{cases}$$

in which Wi and Mi represent the weed and mucuna fractions respectively at date i ($0 \le Wi, Mi \le 1$), and $d_{w,i}$, $d_{mu,i}$ and $d_{m,i}$ correspond to the δ^{13}C signatures of the weed, mucuna and mixture biomass respectively for the same date in each field. Assuming constant δ^{13}C signatures for the weed and mucuna fractions over time, we can get these values from weed and biomass samples taken in December for the mucuna fraction (because it is supposedly exempt of any subsequent contamination by weeds) and May for the weed fraction (only date at which weeds were sampled).

Based on the above equations, estimates of how much of the original litter or nitrogen were left at the various sampling dates, or how much weed biomass there was were calculated (Table 4.08). According to these calculations, the original mucuna litter decomposed relatively fast from December to early March, losing 43% by weight during this period, at an average rate of 61 kg .ha^{-1}.day^{-1}, and much more slowly afterwards, losing only an additional 6% of the original litter, at an average rate of 7 kg ha^{-1}.day^{-1} (Table 4.08). Weeds controlled by farmers contributed significant quantities of new litter during the maize cycle: by end of May, they seemed to represent almost 40% of the litter found (4 t ha^{-1} out of a total litter of 10.6 t.ha^{-1}), and this figure does not include the biomass of live weeds, which can range anywhere between 0.5 to 4 tons of DM .ha

Table 4.08: Estimated litter and nitrogen left in mucuna fields at various times after slashing, San Francisco de Saco, Northern Honduras, 12/93 to 5/94

	Sampling date[1]			avg. rates in kg.ha^{-1} day^{-1}	
Variables	early 12/93	early 3/94	late 5/94	Dec-Mar[2]	Mar-May
$\delta^{13}C$ litter[3]	-25.7 ± 2.0	-24.2 ± 2.3	-22.6 ± 2.0	--	--
Est original litter left (t ha^{-1})[4]	12.6 ± 1.8	7.2 ± 2.2	6.6 ± 2.6	60.9 ± 38.8	6.8 ± 35.1
Est weed in litter	(none)	1.4 ± 1.4	4.0 ± 2.3	--	--
Est orig Nitrogen left (kg ha^{-1})[4]	316 ± 63	176 ± 52	171 ± 66		
Est N released	--	140 ± 94	(5 ± 76)	1.6 ± 1.1	0.1 ± 0.9

[1] actual sampling date varies by field. [2] linear rates were calculated individually for each field based on actual sampling date. [3] weighted average (by biomass) of $\delta^{13}C$ for the various fractions constituting the litter. [4] original refers to litter or nitrogen already present at slashing; see text for assumptions made. *Each figure represents the mean of 18 plots.*

Clearly some of the assumptions are not very satisfactory: decaying maize leaves also contribute to the renewal of litter biomass; also, weed population in a given field may change over the growing season as a result of weed control hence weeds don't necessarily present a constant $\delta^{13}C$ signature over time. However, the calculations seem to yield *average* results consistent with the actual environmental conditions observed *in situ*: rainfall was abundant between December and mid-February, allowing moisture levels (and hence potential and actual decomposition rates) to remain high in the litter layer. Rains stopped thereafter, creating an extremely dry, hot litter layer, unsuitable for active decomposition, as illustrated by the visible presence of undecomposed leafy mucuna material.

The situation in terms of nitrogen was very similar to the one for biomass: total N (in kg. ha^{-1} for the entire litter) dropped sharply between December and March, from 316 to 198 kg.ha , to increase again to 235 kg.ha^{-1} by late May, in parallel to the apparent biomass increase (Table 4.07). Using the same calculations reported previously (with an additional assumption about constant N content of the weed fraction), nitrogen remaining in the original mucuna fraction can be derived (Table 4.08): it dropped from 316 to 176 in early March to 171 kg ha^{-1} in late May, corresponding to rates of 1.6 and 0.1 kg .ha^{-1}.day^{-1} respectively over these two intervals. About 140 kg.ha^{-1} of N seemed to have been released by the litter on average in the first 80 days following slashing, and less than 5 kg.ha^{-1} in the following 80 days (note however the huge variability associated with both estimates) These calculations do not include however the nitrogen released upon break-down of the weed fraction.

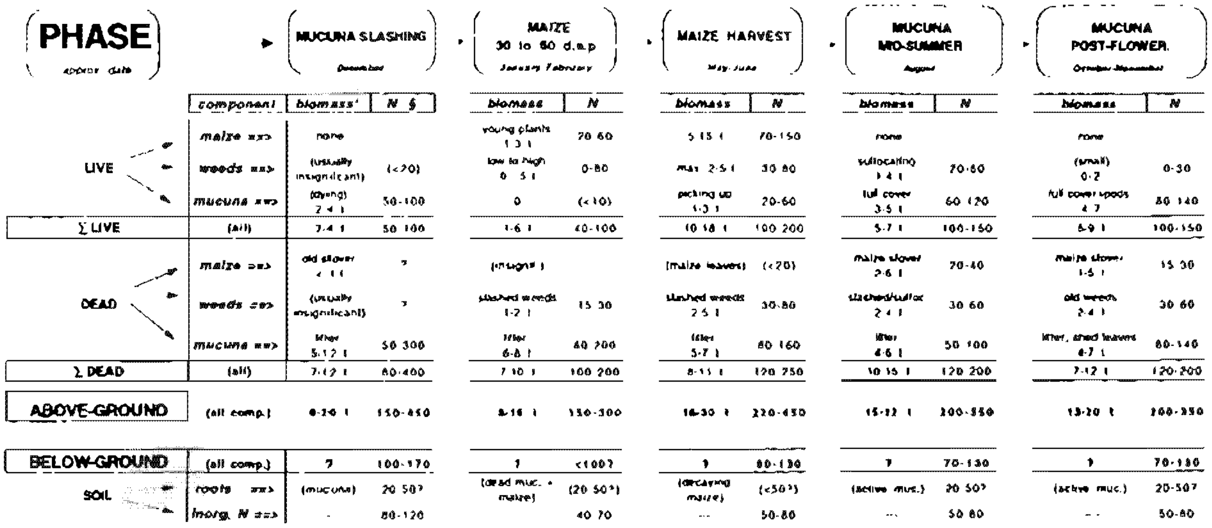
It is probable that these crude figures, obtained in a very dry cycle, represent lower-than-average estimates of the N released in a typical (i.e. wetter) winter cycle, especially after March, as there are usually at least a few significant rains However, the behavior in two phases (fast then slow release) seems consistent with what has been observed for the decomposition of green manures (Bouldin, 1988)

4.3.4 Summary of mucuna dynamics

Above-ground biomass present in a mucuna field was quite variable depending on the specific phase of the mucuna/maize rotation considered, in terms of its origin (mucuna vs weeds vs maize), its absolute levels (which can vary from 7-8 t ha^{-1} to about 30 t.ha^{-1}), its composition and its seasonal dynamics, which entailed periods of active accumulation and simultaneous decomposition Figure 4 03 summarizes our present understanding of the dynamics of the overall cycle A key feature of the mucuna system resides in the year-long presence of a dynamic litter layer periodically renewed by addition of fresh biomass, as well as actively undergoing decomposition at virtually all times (i e not only after slashing), environmental conditions allowing.

Trends observed for nitrogen matched closely the movements affecting biomass dynamics There were considerable amounts of nitrogen present at all times in the biomass (and especially in the litter): the accumulation seemed to reach a peak at slashing, with average values around 300 kg.ha^{-1}. After slashing, there seemed to be a relatively fast though highly variable release of N by the decomposing litter, which even in a dry year reached 140 kg ha^{-1} on average.

The previous analysis didn't deal with the fate of the released N: there are several possible sinks for it, from the atmosphere (via volatilization) to microbial biomass, soil solution and plant uptake We will now examine these two latter aspects in more detail



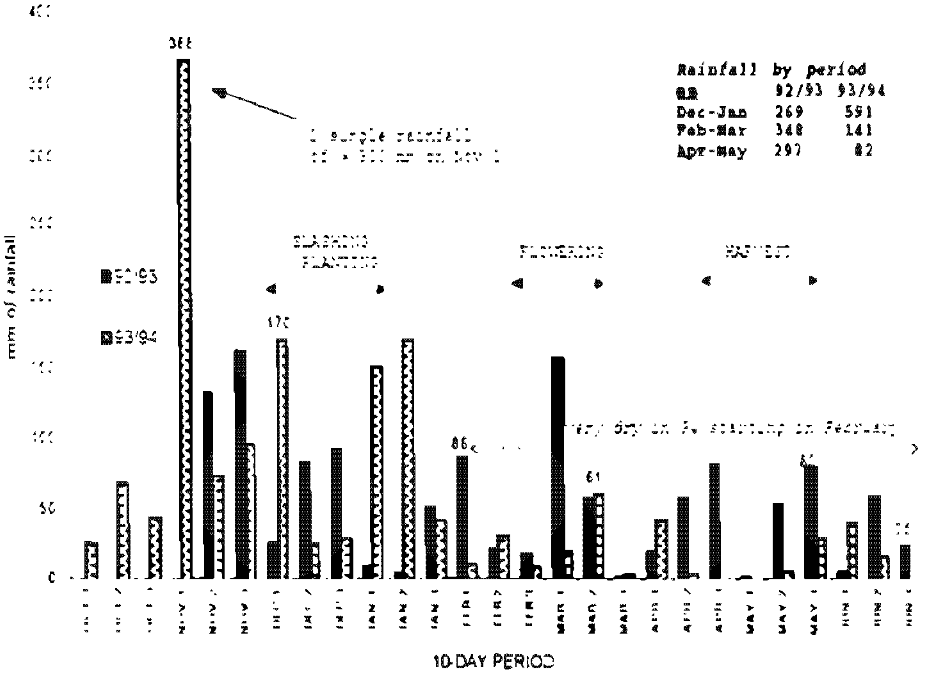
PHASE (approx. date)	component	MUCUNA SLASHING (December) biomass*	N §	MAIZE 30 to 60 d.a.p (January-February) biomass	N	MAIZE HARVEST (May-June) biomass	N	MUCUNA MID-SUMMER (August) biomass	N	MUCUNA POST-FLOWER. (October-November) biomass	N
LIVE	*maize*	none		young plants 1-3 t	20-60	5-15 t	70-150	none		none	
	weeds	(usually insignificant)	(<20)	low to high 0-5 t	0-80	max 2-5 t	30-80	suffocating 1-4 t	20-60	(small) 0-2	0-30
	mucuna	(dying) 2-4 t	50-100	0	(<10)	picking up 1-3 t	20-60	full cover 3-5 t	60-120	full cover+pods 4-7	80-140
∑ LIVE	(all)	2-4 t	50-100	1-6 t	40-100	10-18 t	100-200	5-7 t	100-150	6-9 t	100-150
DEAD	*maize*	old stover < 1 t	?	(insignif.)		(maize leaves)	(<20)	maize stover 2-6 t	20-40	maize stover 1-5 t	15-30
	weeds	(usually insignificant)	?	slashed weeds 1-2 t	15-30	slashed weeds 2-5 t	30-80	slashed/suffoc. 2-4 t	30-60	old weeds 2-4 t	30-60
	mucuna	litter 5-12 t	50-300	litter 6-8 t	80-200	litter 5-7 t	80-160	litter 4-6 t	50-100	litter, shed leaves 4-7 t	60-140
∑ DEAD	(all)	7-12 t	80-400	7-10 t	100-200	8-11 t	120-250	10-15 t	120-200	7-12 t	120-200
ABOVE-GROUND	(all comp.)	8-20 t	150-450	8-16 t	150-300	18-30 t	220-450	15-22 t	200-350	13-20 t	200-350
BELOW-GROUND	(all comp.)	?	100-170	?	<100?	?	80-130	?	70-130	?	70-130
SOIL	*roots*	(mucuna)	20-50?	(dead muc. + maize)	(20-50?)	(decaying maize)	(<50?)	(active muc.)	20-50?	(active muc.)	20-50?
	inorg. N	-	80-120		40-70	---	50-80	---	50-80	--	50-80

Notes: * *typical range for biomass content (in t of DM ha⁻¹)* § *typical range for nitrogen content (in kg.ha⁻¹)*
? *unknown or poorly known quantity*

Figure 4.03: Schematic representation of the seasonal dynamics of biomass and nitrogen in various compartments of the mucuna system, Northern Honduras

4.4 NITROGEN DYNAMICS IN THE SOIL-MAIZE SYSTEM

The main objective of this section is to gain some understanding about the relation between N supply by the decaying litter / soil organic matter and N demand and uptake by the maize crop (in terms of quantities and synchronization). The analysis is based on data from a periodic sampling of the soil profile in well-established mucuna fields at bi-weekly or monthly intervals during or before two consecutive, highly contrasting maize cycles (in terms of amount of rainfall see Figure 4.04), as well as on a point assessment of maize total nitrogen uptake All fields sampled were located within a radius of less than 1 km (chapter 2), and hence can be assumed to have been subjected to approximately the same environmental conditions (rainfall, temperature in particular)



Each bar represents the sum of daily rainfall over 10-day periods, collected in a rain gauge installed locally. Periods started the 1st, 11th and 21st of each month.

Figure 4 04 Rainfall (mm) during the 92/93 and 93/94 winter cycles, San Francisco de Saco, Northern Honduras

Several considerations should be kept in mind in interpreting these data. (1) most probably, a fraction of the nitrogen released by the litter never entered the soil profile: it was recycled directly in the litter layer by the existing fauna and by maize and weed roots growing in it or at the interface between the litter and the soil proper, (2) the sampling recovered both the N released by the decomposing litter and the N mineralized from the soil organic matter, with no way of differentiating these two sources, (3) since the sampling took place in fields with actively growing maize or weeds, the inorganic N recovered from the soil solution corresponds to what was left after plant uptake, (4) the fact that sampling did not proceed deeper than 60 cm does not imply that inorganic nitrogen did not occasionally move beyond that depth, and (5) there are reasons to believe that inorganic N tells only part of the story about N release and dynamics in a mulch system: organic N probably plays a significant role as well in N transport and availability for subsequent plant uptake.

4.4.1 Temporal patterns of inorganic N

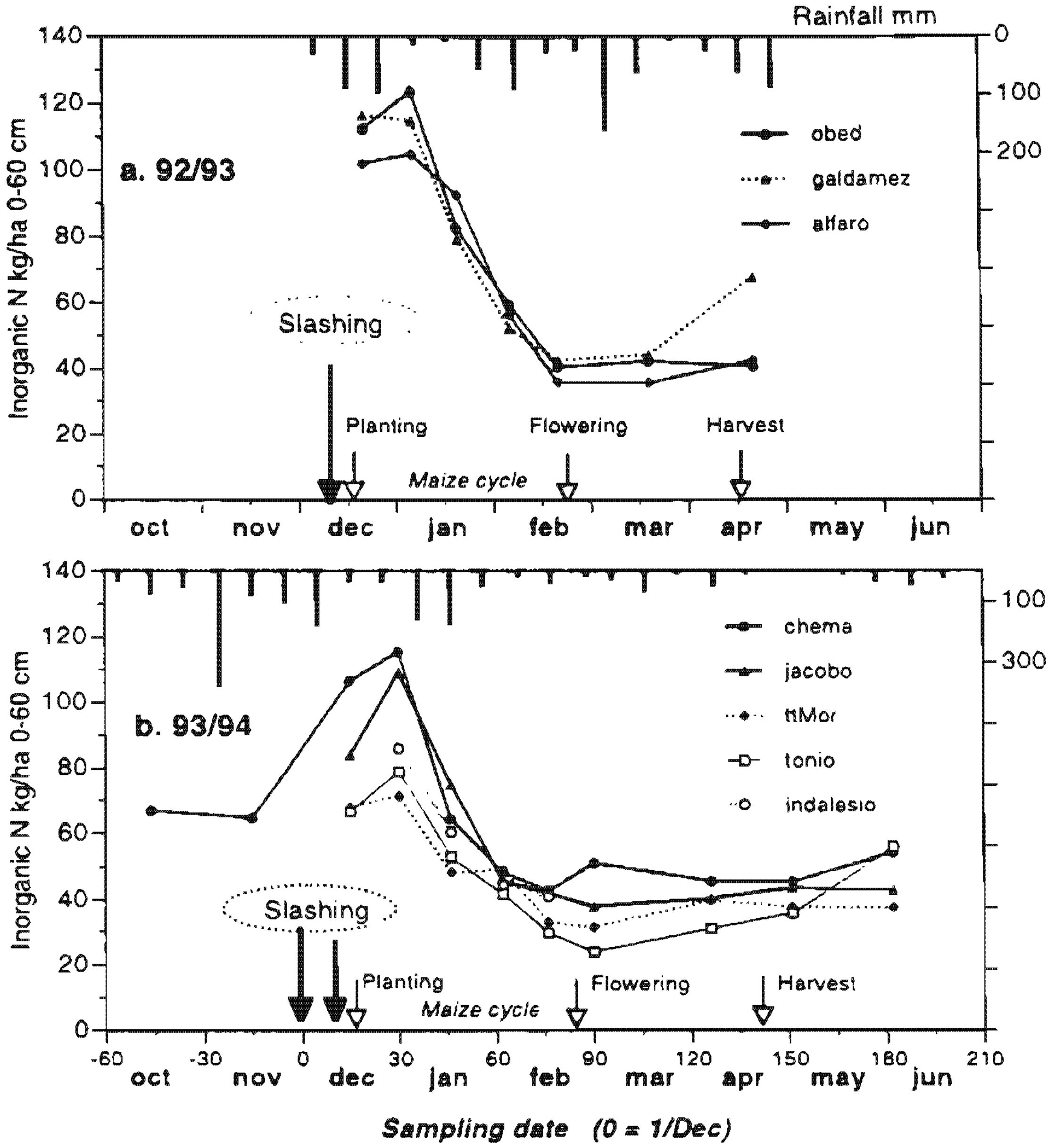
4.4.1.1 Overall dynamics for the entire soil profile

Figures 4.05a & b show the general temporal patterns exhibited by inorganic N (Ni) over the 92/93 and 93/94 maize cycles for a number of well-established mucuna fields (more than 5 years of continuous use of the mucuna/maize rotation). Data are presented in kg.ha^{-1} of Ni (sum of NO_3-N and NH_4-N) for the entire 0-60 cm profile.

Several features are apparent from these figures.

a) all fields displayed a relatively homogeneous behavior with respect to when Ni was highest and how fast it changed with time. The similarity of pattern both within and between years illustrates the homogeneity of management across fields, and also the influence of environmental factors and conditions in shaping N mineralization processes.

b) each year, there was a marked peak of inorganic nitrogen approximately 30 days after slashing, followed by a rapid decrease over the next 3 to 4 weeks. Maximum observed levels of Ni reached values close to 100 kg.ha^{-1} for both years (max. observed 115, min. 70). They never dropped below 30 to 50 kg.ha^{-1} of inorganic N even during the period of maximum maize uptake.



Rainfall in mm by 10-day period, drawn at the mid-point of each period. Inorganic N = sum of NH_4-N and NO_3-N for the 0-10 (0-15 in 92/93), 10-30 (15-30 in 92/93) and 30-60 cm horizons. Each point represents the average of 3 (93/94) or 4 replications (92/93). Slashing refers to the approximate date for manual cutting of the mucuna material, thereafter left to decompose on the soil surface. Planting, Flowering and Harvest refer to approximate dates for the maize cycle.

Figure 4.05 Dynamics of inorganic nitrogen (in kg.ha^{-1}) in the 0-60 cm soil profile of well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1992/93 and 1993/94

c) synchronization between nitrogen release by the decaying mucuna mulch and uptake by the maize crop seemed satisfactory, as maize is planted immediately after slashing. The sharp decrease observed in the levels of available inorganic N between days 30 and 80 (92/93) or 90 (93/94), during which period 60 to 80 kg.ha^{-1} of inorganic N disappeared, coincided with periods of intense crop uptake (see later). In addition to maize, weeds are also likely to have benefited from the high levels of available Ni, especially in the first few weeks following slashing, when maize was growing slowly.

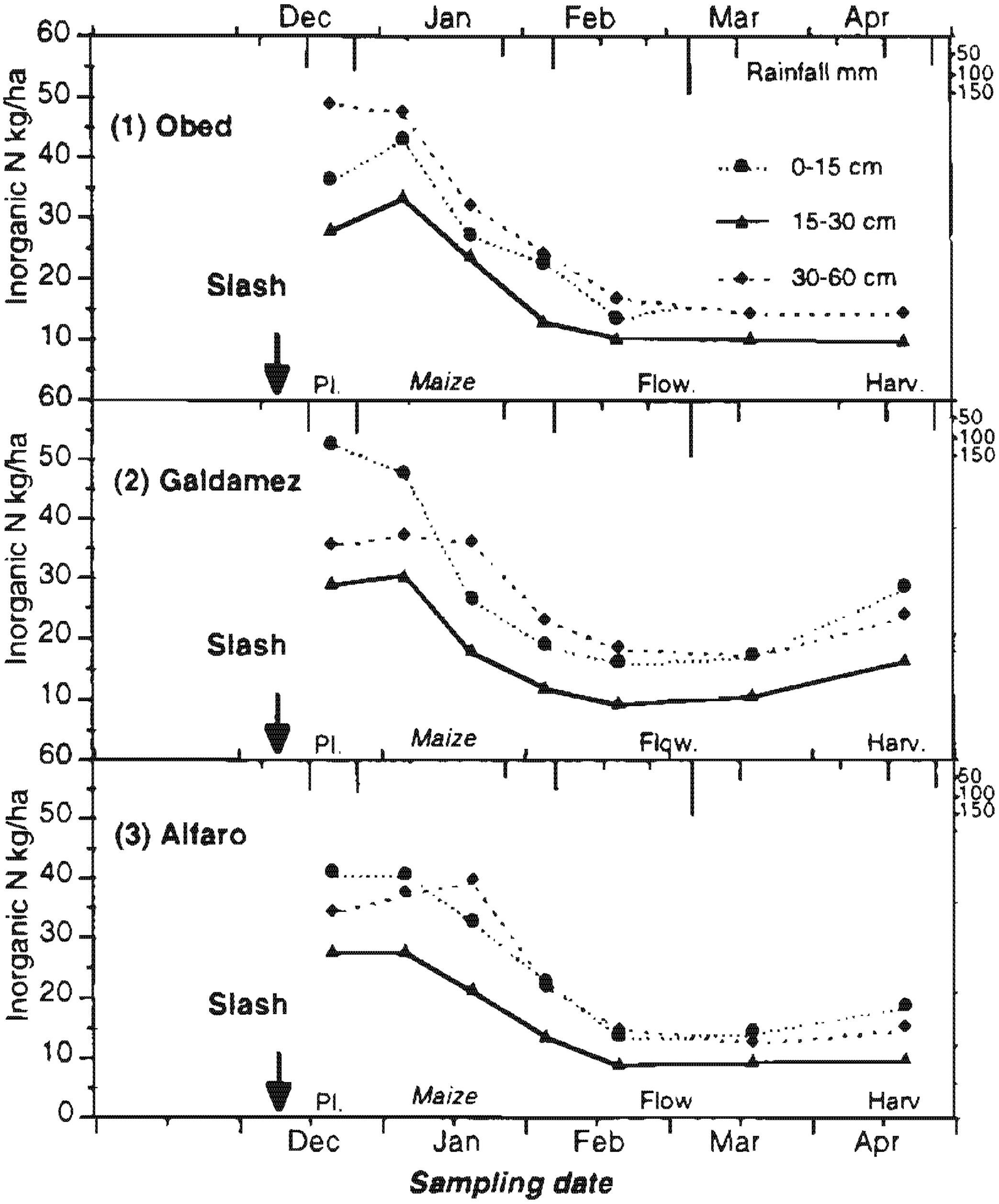
d) there was a sizable pool of Ni (40 kg ha^{-1} or more) available in the profile even outside the maize cycle. This is especially evident from the 93/94 data (Figure 4.05b), which covered a larger time span (from October to June). The slight increase in Ni observed towards the end of the maize cycle for both years probably coincided approximately with reduced uptake by the maize/weed complex as well as with the occasional return of rains after a relatively dry period (particularly in 94). Likewise, the relatively high levels of Ni (around 60 to 70 kg ha^{-1}) found in the profile in October-November (i.e. well before slashing) tend to indicate that active decomposition is taking place in the litter layer / SOM complex during the main thrust of the rainy season, while mucuna is still growing actively. This trend is consistent with the observed increase in litter biomass during this period (see section 4.3.3.1.2 above).

4.4.1.2 *Distribution of inorganic N by horizon*

Figures 4.06, 4.07 and 4.08 display the levels of inorganic N for individual fields/years by horizon. Three horizons were sampled: 0-10 or 0-15 cm (horizon 1); 10-30 cm or 15-30 cm (horizon 2), and 30-60 cm (horizon 3). They present alternative ways of looking at the same information: in Figure 4.06, it is presented in kg.ha^{-1}, with the horizon as the central focus. Figure 4.08 is similar, except that it is based on concentrations (in ppm) rather than on kg.ha^{-1}. Finally, in Figure 4.07, the focus is on selected sampling dates.

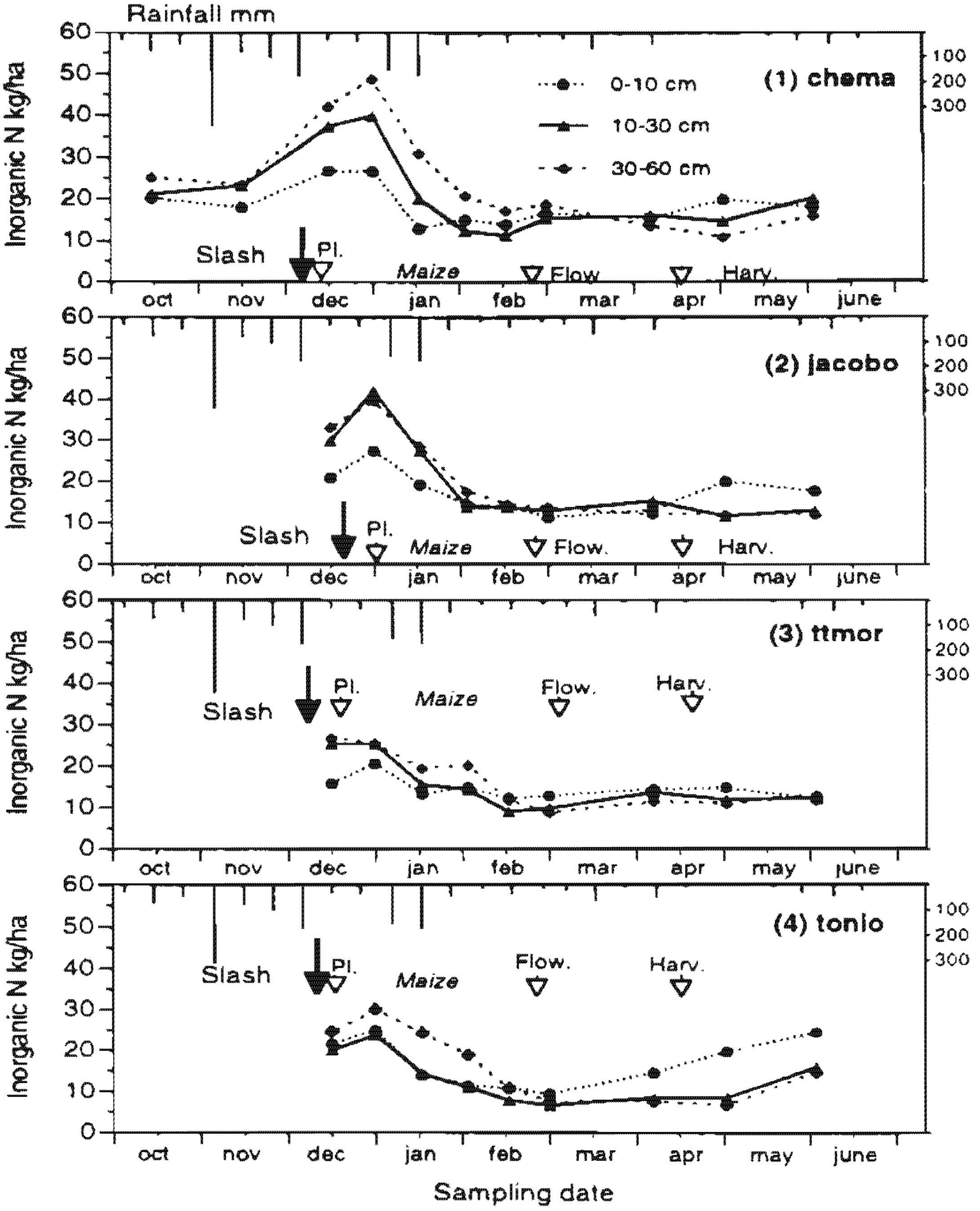
In all cases, it can be seen that all three horizons presented the same temporal pattern described in 4.4.1. The apparent difference between the two cycles with respect to the levels of N present in the first and second horizons (greater for hor 1 in 92/93, whereas the reverse is true for 93/94, at least for the first 3-4 sampling dates) are mainly related to changes in the sampling scheme: in 92/93, sampling was done on the 0-15 and 15-30 cm horizons, whereas in 93/94, it was done on 0-10 and 10-30 cm.

As the season progresses (i.e. maize going from emergence to flowering: 3 first sampling dates), the profile is gradually depleted of its Ni at all depths (Figure 4.07). For all fields, the sampling date closer to maize flowering (mid-February) exhibited the lowest levels of available Ni, in synchrony with maximum rates of nitrogen uptake by the maize crop. Towards the end of the maize cycle, availability of Ni tended to increase again, especially in the top horizon, which became the main contributor to total inorganic N; even in 93/94 its share reached around 50% of the total N found in the profile.



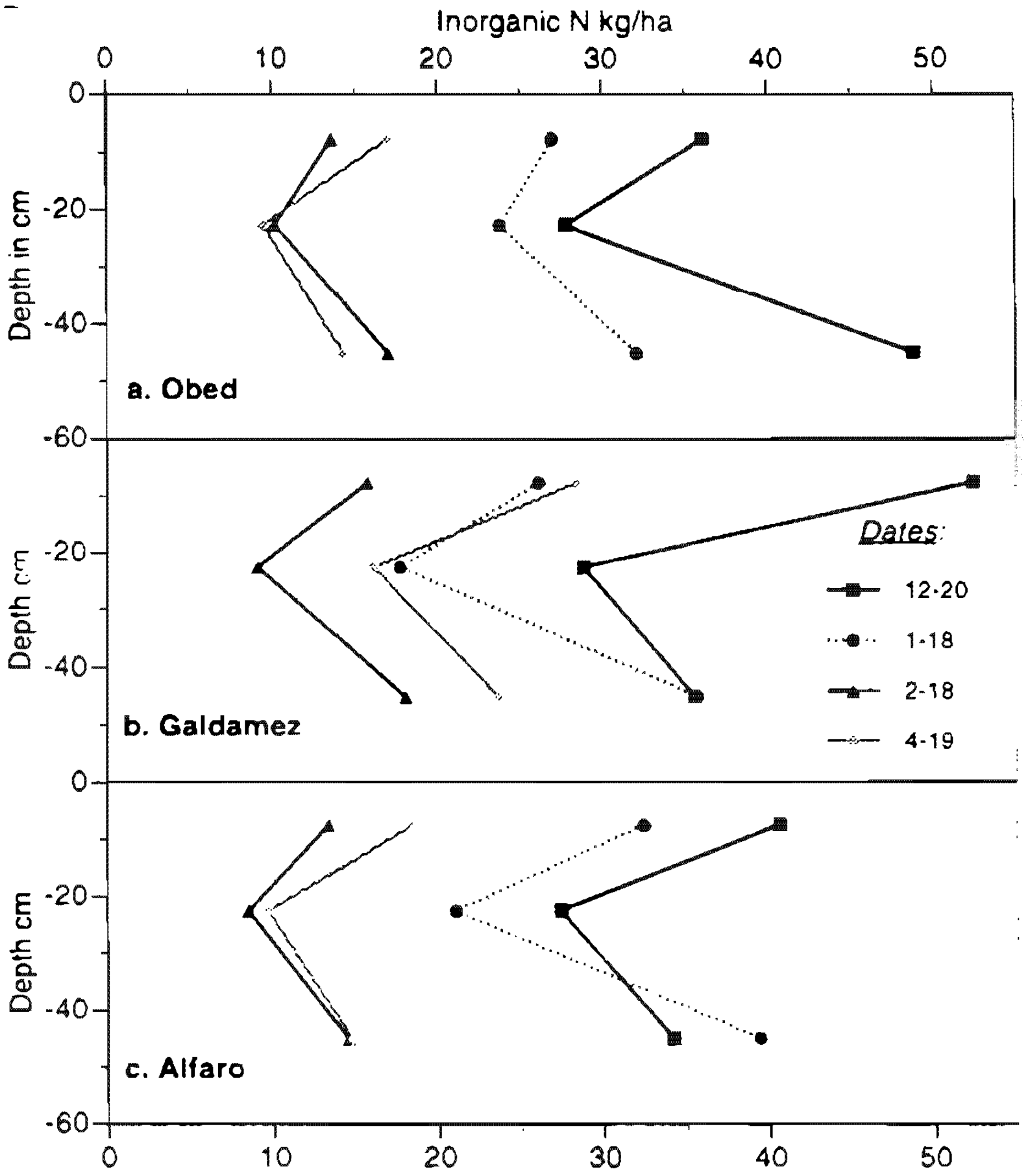
Each point represents the average of 4 replications. Pl., Flow., Harv. refer to maize planting, flowering and harvest respectively. Other details cf. notes at bottom of Figure 4.05.

Figure 4.06.a: Seasonal dynamics of inorganic nitrogen (in kg.ha^{-1}) by horizon for individual well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1992/93



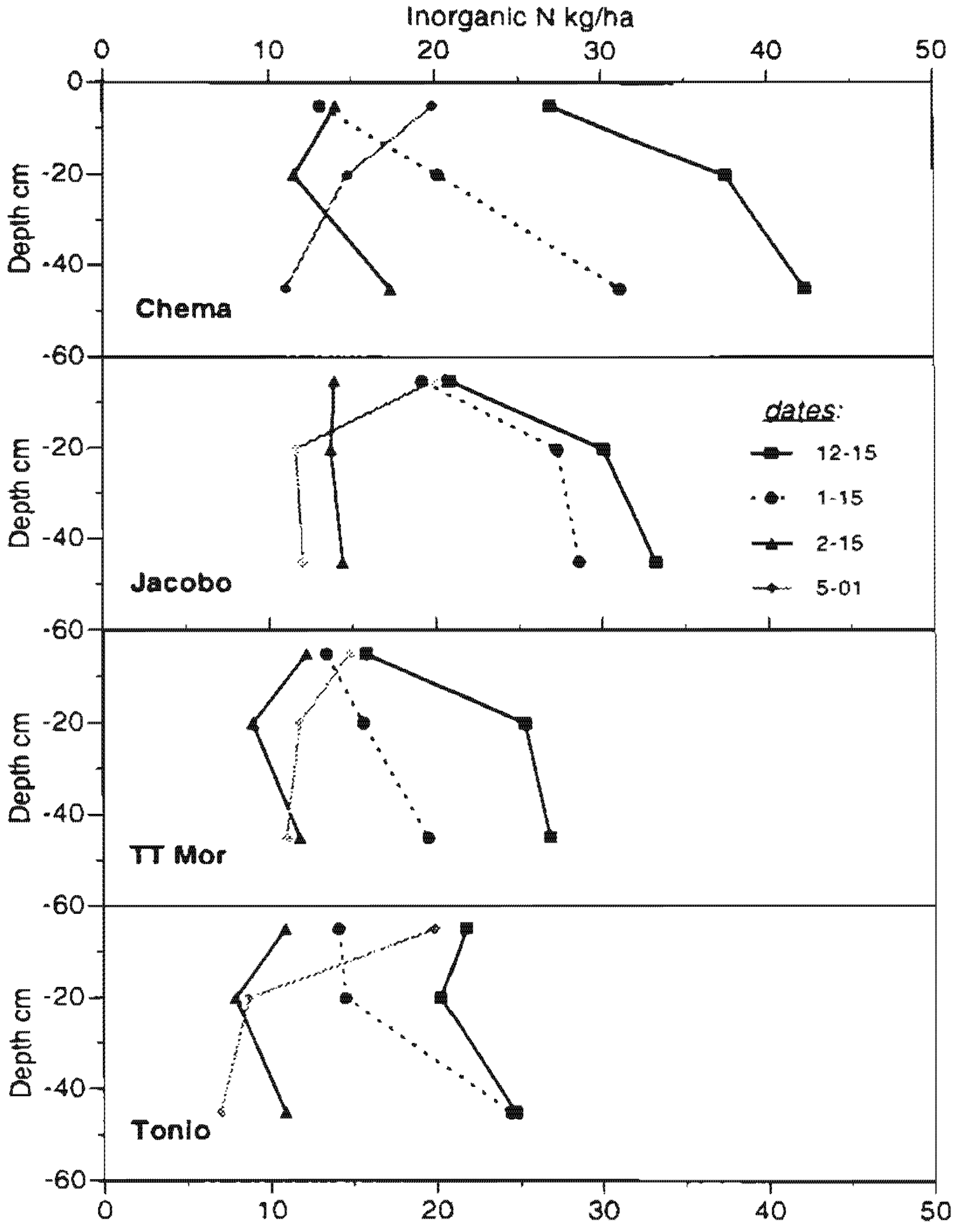
Each point represents the average of 3 replications. Pl., Flow., Harv. refer to maize planting, flowering and harvest respectively. Other details: cf. notes at bottom of Figure 4.05

Figure 4 06.b Seasonal dynamics of inorganic nitrogen (in kg.ha^{-1}) by horizon for individual well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1993.94



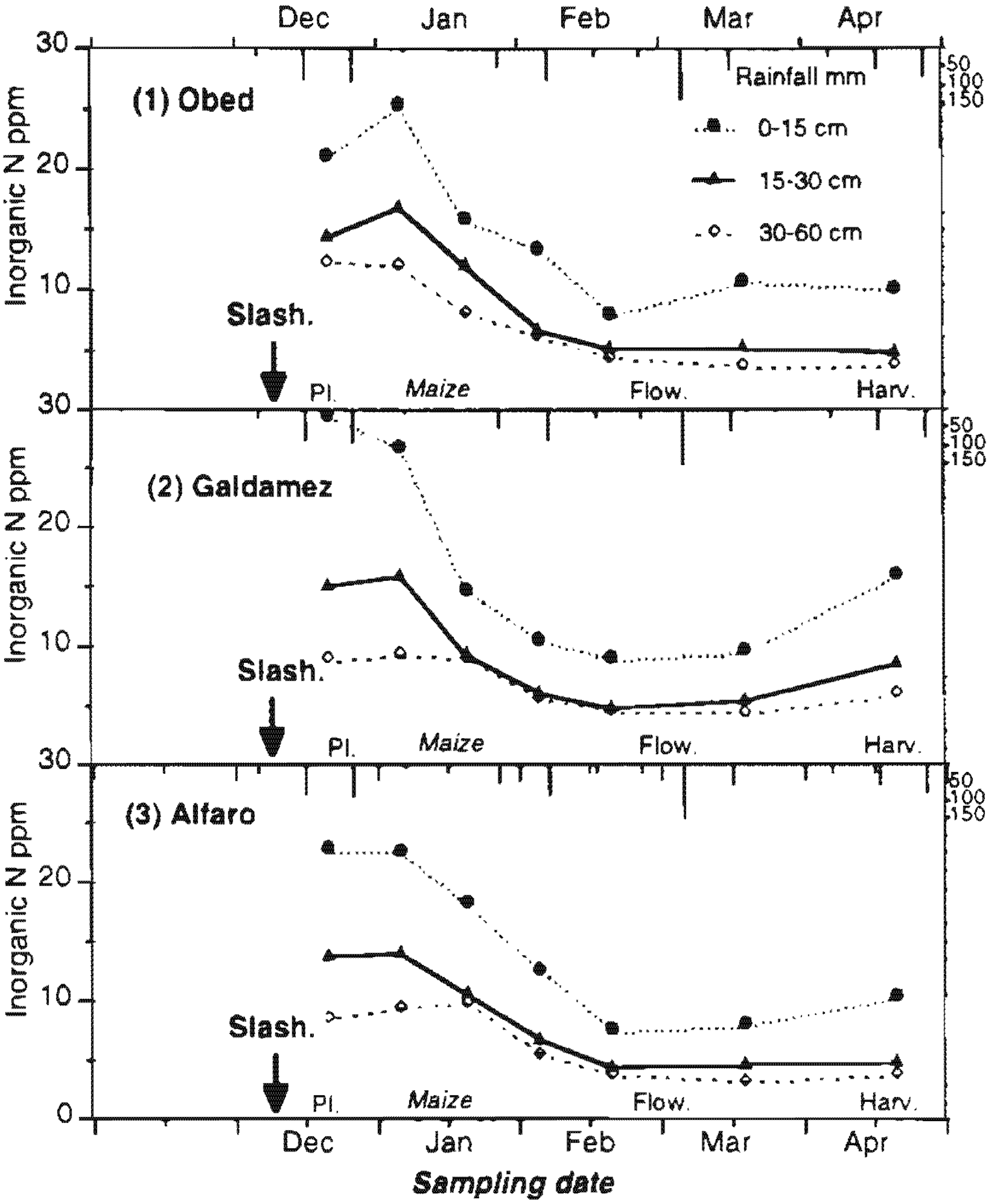
Each point represents the average of 4 replications. Symbols are drawn at the mid-point of each horizon 7.5, 22.5 and 45 cm Other details: cf. notes at bottom of Figure 4.05

Figure 4.07.a: Inorganic N (in kg.ha^{-1}) at various depths in the soil profile for selected sampling dates in well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1992/93



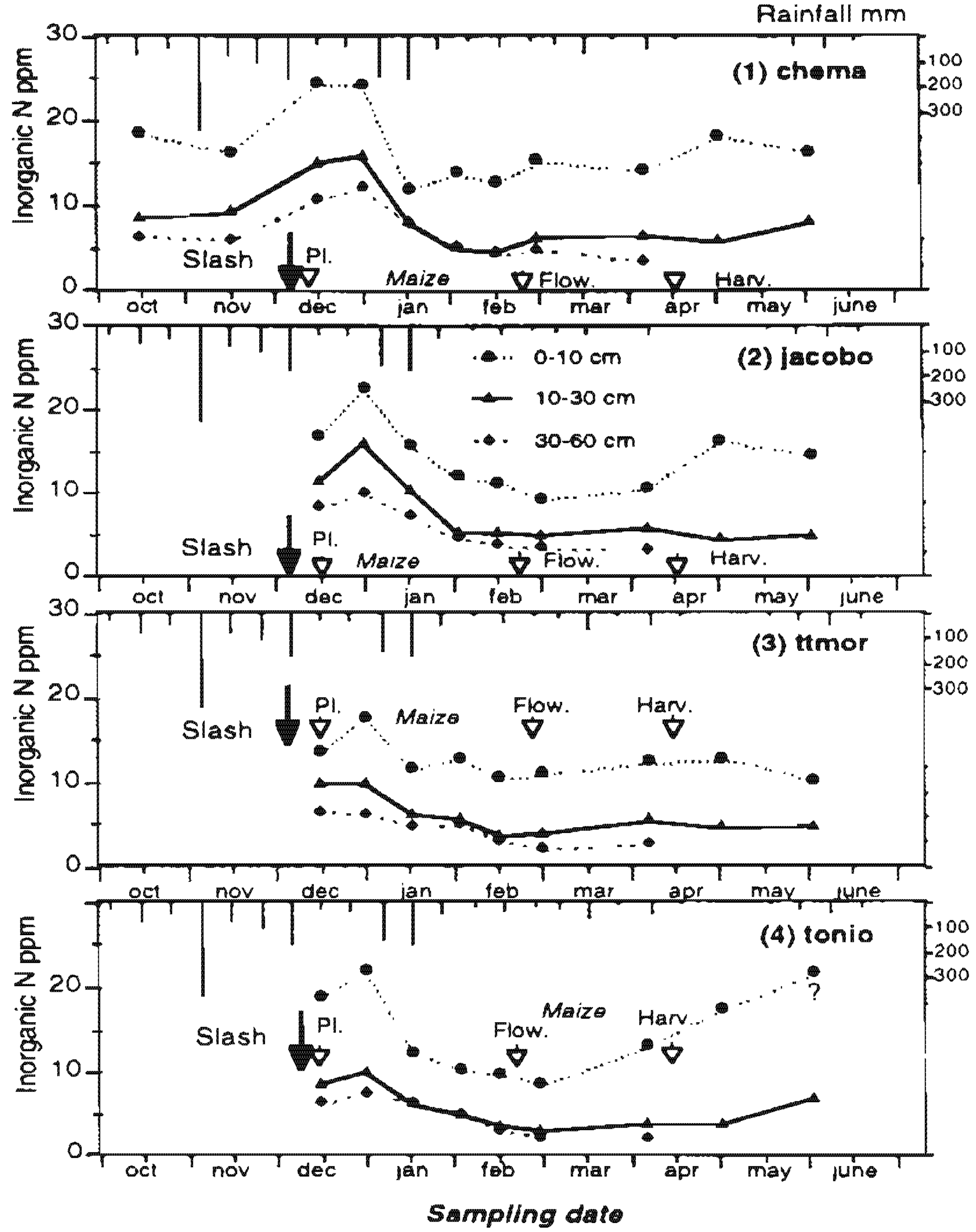
Each point represents the average of 3 replications. Symbols are drawn at the mid-point of each horizon: 5, 20 and 45 cm. Other details: cf. notes at bottom of Figure 4.05

Figure 4.07.b: Inorganic N (in kg.ha^{-1}) at various depths in the soil profile for selected sampling dates in well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1993/94



Each point represents the average of 4 replications. P, F, and H refer to maize planting, flowering and harvest respectively. Other details: cf. notes at bottom of Figure 4.05

Figure 4.08.a: Seasonal dynamics of inorganic nitrogen (in ppm) by horizon for individual well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1992/93



Each point represents the average of 3 replications. Pl., Flow., and Harv. refer to maize planting, flowering and harvest respectively. Other details: cf. notes at bottom of Figure 4.05.

Figure 4.08.b Seasonal dynamics of inorganic nitrogen (in ppm) by horizon for individual well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1993/94

The dynamics affecting the first horizon over time and the observed difference between the upper and lower horizons probably reflects the influence of maize / weed uptake. Roots would preferentially deplete the inorganic N of the superficial horizons. Once this uptake is less active, inorganic N again would tend to accumulate in the soil surface.

For concentrations (Figure 4.08), there was a strong gradient in the order: hor. 1 > hor. 2 > hor. 3, a situation typical of a no-till system with a litter. Concentrations in horizon 1 frequently exceeded 20 to 25 ppm after slashing, and decreased gradually thereafter to levels around 10 ppm. Peaks were less pronounced with depth: less than 15 ppm in horizon 2, and less than 10 ppm in horizon 3. Later in the season, both horizons exhibited low, fairly constant levels of inorganic N around 5 ppm. Decreased concentrations over time may be due to relative availability of substrate for decomposition, and also moisture content in the soil profile (Figure 4.09). In both years, there was a highly significant correlation between the concentration of Ni and the gravimetric soil moisture content (R^2 between 0.4 and 0.5 for over 300 samples).

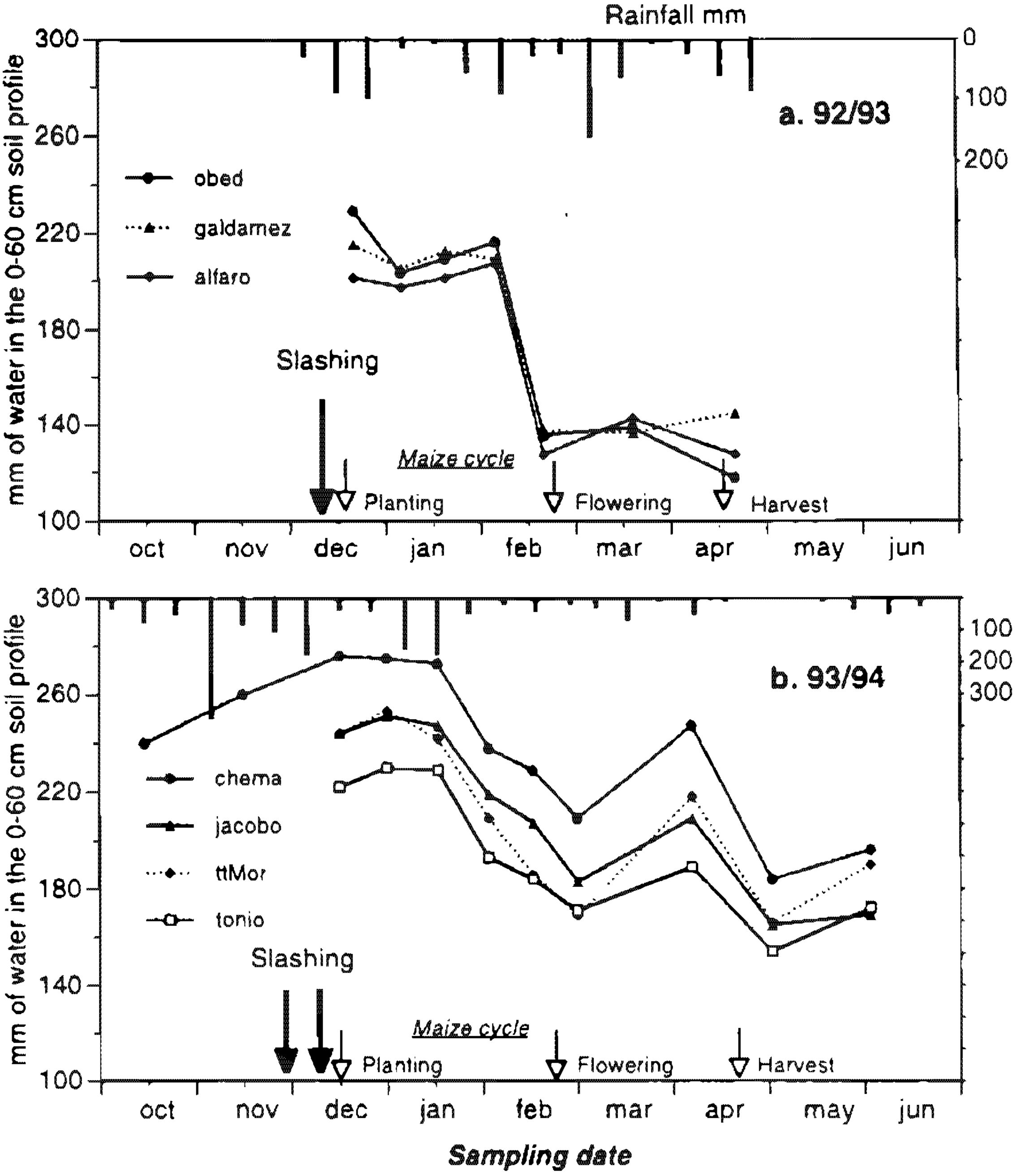
4.4.1.3 Forms of inorganic N

In the above presentation, inorganic N was analyzed by summing the various forms of inorganic N: NO_3-N, NO_2-N and NH_4-N. It is commonly assumed that most of the inorganic N in the soil solution is in the form of NO_3-N. However this was not always the case in this study: it seemed to depend in part on the sampling date and on the horizon (Figure 4.10). NH_4-N can represent close to 50% of the total inorganic N on given sampling dates, even in the 0-10 cm horizon, and on average (over all sampling dates and years), tended to be higher proportionally at lower depths and perhaps also at lower moisture contents (30 to 35% NH_4-N in horizons 2 and 3 vs. 18 to 23% in horizon 1) (Figure 4.10). Influence of sample handling on these variations was not determined, although it may have played a significant role (Fruci, 1995).

4.4.2 Sources of inorganic N

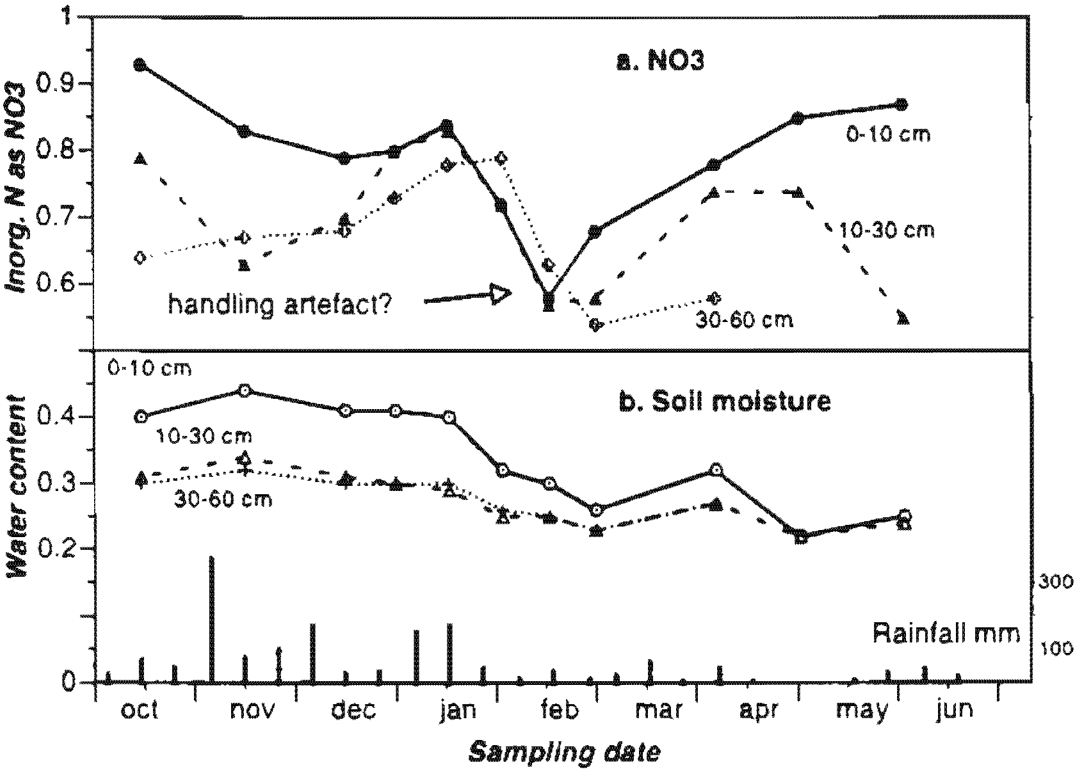
4.4.2.1 N released by the decomposing litter

As described in section 4.3.3.2, the decomposing litter alone appeared to have released about 100 kg.ha^{-1} during the first 80 days after slashing (this value differs from the one reported in Table 4.08 because it was calculated only on the fields monitored for Ni). How much of this N found its way in the soil solution remains a matter of speculation, as it may have been volatilized (Costa *et al.*, 1990) or immobilized by the fauna inhabiting the litter, or simply intercepted by plant roots at the litter/soil interface before ever entering the soil profile (Schlather, 1996).



Each point represents the average of 3 (93/94) or 4 replications (92/93). Water content was measured gravimetrically and converted to mm using bulk density figures collected by horizon for each field

Figure 4.09: Seasonal dynamics of water content (in mm) in the 0-60 cm soil profile of well-established mucuna fields during the winter maize cycle, San Francisco de Saco, Northern Honduras



Each point represents the average of 12 replications. Gravimetric moisture contents shown for interpretative purposes.

Figure 4.10: Changes in the relative proportion of NO_3-N vs. total Inorganic N in different horizons of the soil profile of well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1993/94 cycle

Given the large amounts of N incorporated in the litter at slashing time (section 4.3.2), it is reasonable to suspect however that the peak of inorganic N observed in the profile (section 4.4.1) derived mostly from the decomposition of this fresh organic matter. For the 92/93 cycle, no apparent relationship was found however between the amounts of N in the above-ground biomass and N in the profile, perhaps because the range of variation was very narrow for the total N in the profile (Figure 4.11a). Interestingly, for the 93/94 cycle, a tight correlation (R2 = 0.76, significant at the 1% level) was found between the N present in the green and vine fractions combined on one hand, and the maximum level of inorganic N measured in the profile (Figure 4.11b). No trend was found when considering the relationship between total N in the litter or N in the dead fraction alone and the maximum N found in the profile. These findings may indicate that it is the most recently slashed material which contributes the most to the flush of inorganic N in the profile, whereas the oldest, semi-permanent litter would rather contribute to the baseline level of inorganic N found in the profile throughout the year.

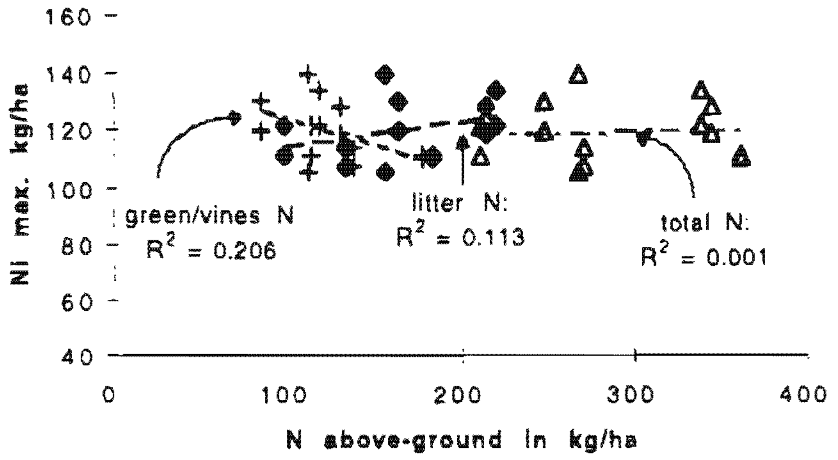
4.4.2.2 N released by the mineralization of soil organic nitrogen

An estimate of N mineralized from soil organic matter during the maize cycle can be derived by estimating mineralization rates for the organic N stored in the soil profile. For a humid tropical climate, and considering that on average, the moisture content of the various horizons remained favorable to mineralization from December until at least early March, mineralization rates in the 0-10 cm horizon may reach 1 to 1.5% of the N present for this 3-month period (based on a 4-6% annual rate). Given that well-established mucuna fields averaged 0.27% total N in the 0-10 cm horizon, this translates into about 30 to 45 kg ha^{-1} of N mineralized over the period. Similar types of considerations for the 10-30 and 30-60 cm horizons yielded the figures presented in Table 4.09. Summing the contributions of the different horizons, nitrogen mineralized within the 0-60 cm profile from the soil organic nitrogen pool alone could contribute in the order of 50 to 75 kg ha^{-1} of inorganic N between early December and early March, thus adding significantly (as much as 50%?) to the levels of N released by the decaying litter.

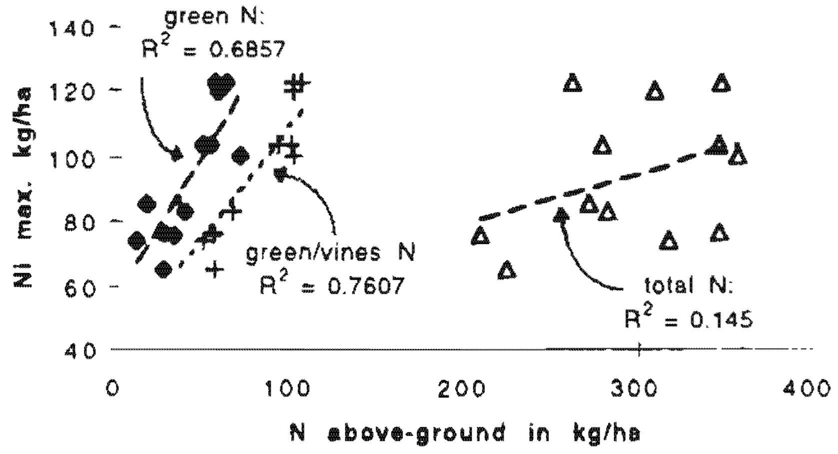
Table 4.09. Estimates of N mineralized from soil organic matter
between December and February

Horizon	N% average	Min. rate (3 months)	Bulk density	N mineralized kg.ha^{-1} / 3 months
0-10 cm	0.27	1-1.5%	1.15	30-45
10-30 cm	0.12	0.5-0.75%	1.25	15-23
30-60 cm	0.06	0.2%	1.34	5
0-60 cm	---	----	----	50-75

a. 92/93 cycle



b. 93/94 cycle



Each point represents a single replication Regression lines and R-square values based on LS simple linear regression for N= 12 observations.

Figure 4 11: Relationship between nitrogen found in various fractions of the mucuna litter and the maximum amount of inorganic nitrogen found in the soil profile during the winter cycle for several well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1993/94

4.4.2.3 Inorganic vs. organic N

Assessing the contribution of organic N to the amounts of N present in the soil solution is especially relevant given the existence above the soil profile of a litter layer continuously releasing new decomposition products upon breakdown of dead organic matter (Yu *et al.*, 1994). A limited analysis of 30 soil extracts for both inorganic N and total N showed that on average, inorganic N did not constitute more than 45% of the N found in the soil extracts. There were sizable differences among horizons and dates (the proportion of Ni seemingly higher for the upper horizon, and lower as profile was drier) but data is too scarce to test the consistency of these trends. Could the organic N constitute a pool of reserve N in the soil solution, in equilibrium with Ni consumed by plant uptake? Does this organic N move freely down the profile? Further studies are needed to verify the general validity and significance of these issues.

4.4.3 N uptake by plants

Not considering here N uptake by the re-establishing mucuna, maize and also weeds are the two major plant competitors for access to the N found in the soil profile.

4.4.3.1 N uptake by maize

It was not possible to follow maize uptake throughout the growing season (destructive sampling is not welcome in on-farm settings). Data on nitrogen content was however collected at harvest, allowing a crude approximation of N present at various growth stages, by assuming that the nitrogen uptake curve over time was of the form

$$\frac{a}{1+b*e^{-ct}},$$

where a represents the maximum level of uptake, t is time (in days) and b and c are fitting parameters which determine how fast the plateau is reached (Hunt, 1982). The resulting figures, calculated for a range of values of final N uptake determined at harvest are presented in Table 4.10.

These figures, even though they probably underestimate actual uptake by maize (N uptake by the root system for example is not taken into account), reflect closely however the fast uptake of N typical of a maize crop between 30 and 80 days after planting.

Table 4 10 Estimates of cumulative above-ground N uptake by a maize crop at various moments during its cycle, using a logit function

days after planting →	10	30	45	60	80	100	120
N uptake [1] 85 kg.ha^{-1}	0.5	5 8	26	62	82	85	(85)
N uptake 100	0.6	6 8	30	73	97	100	(100)
N uptake 115	0.8	8	35 5	84	111	115	(115)
typical range [2]	<1	5-9	24-40	56-92	74-122	75-125	75-125

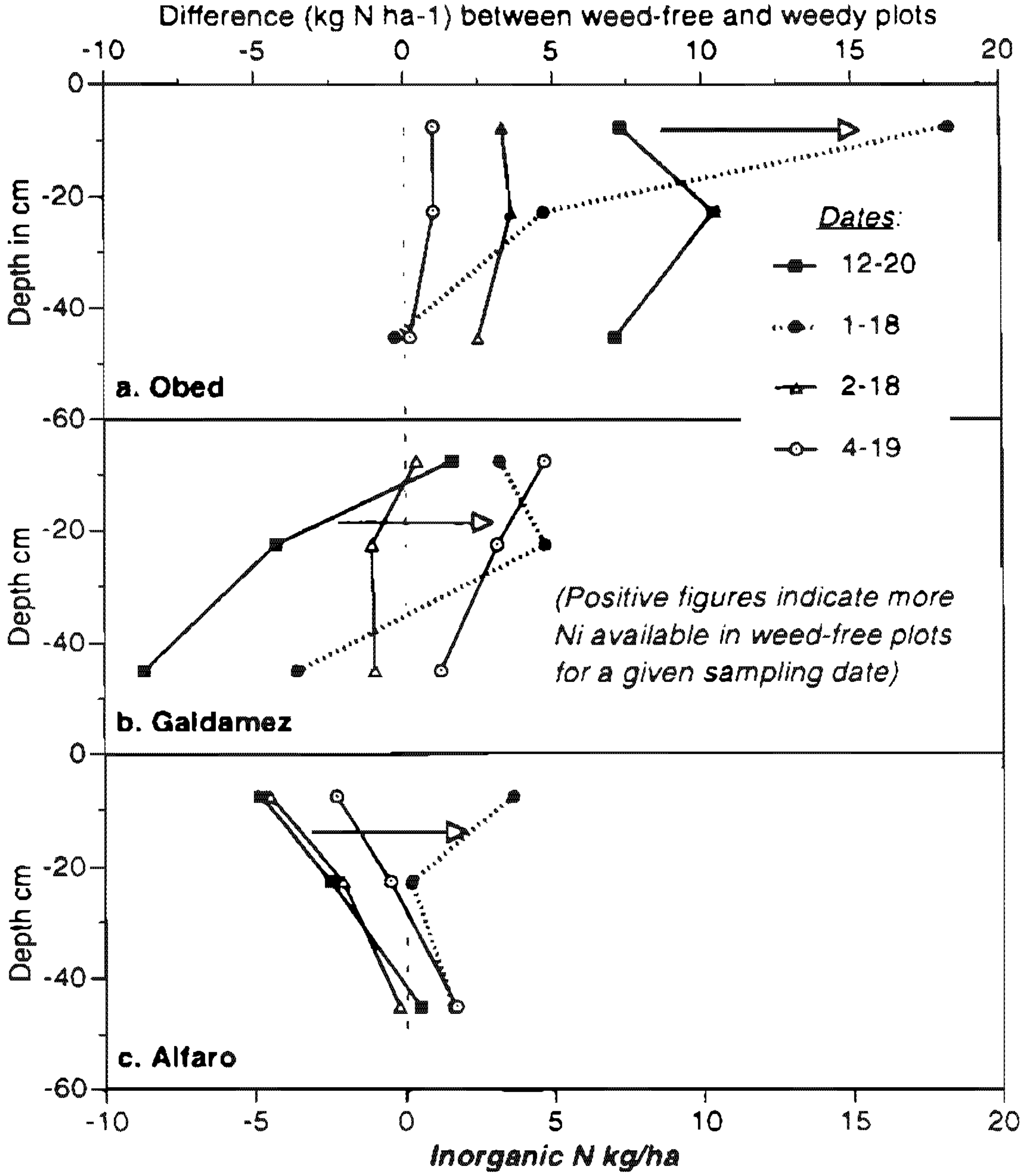
[1] total N content of the maize crop measured at harvest
[2] calculated by reducing or adding 10% to the range obtained for three lines above it

4.4.3.2 N uptake by weeds

Weeds constitute another important though variable source of uptake (see 4 3 1). N found in weeds can account from less than 15-20 kg ha^{-1} (rather weed-free fields with less than 1 t ha^{-1} of accumulated weed dry-matter) to more than 60 kg.ha^{-1} (fields having accumulated as much as 4 t ha^{-1} of DM before weeds were controlled)

Weeds tend to affect the availability of inorganic N in the soil profile Using experimental data from the 92/93 cycle, a consistent trend was detected for weed-free plots to exhibit higher values of Ni in the profile (and especially the first horizon) one month after maize planting, compared to corresponding weedy plots (Figure 4.12). This increase coincided with a period of rapid weed growth in the weedy plots without much simultaneous maize N uptake (see Table 4 10). There was a concomitant increase in water availability in the profile (data not shown), showing that weeds also competed for water uptake

Interestingly, because of the way weeds are controlled (slashed manually or desiccated via Paraquat application), most of the N they take up can be expected to be recycled later during the growing season (Lambert and Arnason, 1989) Even though this might come too late for maize (particularly if the winter is very dry), this temporary trapping of N could play a significant role in protecting this nitrogen against leaching early in the maize growing season, when this latter is unable yet to take it up, but when rains are still frequent and heavy.



Each point represents the difference between the inorganic N found in weed-free vs. farmer-weeded check plots of an on-farm fertilizer trial. Arrows indicate trend observed during initial 30-40 days of the maize cycle.

Figure 4.12: Influence of weeds on the amount of inorganic N present at selected sampling dates and at various depths in the soil profile of well-established mucuna fields, San Francisco de Saco, Northern Honduras, 1992/93

4.4.3.3 Synchronization of plant uptake with N release

As noted earlier, N availability in the profile seemed to be well in phase with the nutritional demand of a growing maize crop. The decline in inorganic N (between 60 and 80 kg.ha^{-1}) between days 30 and 80 (Figure 4.07) after maize planting coincided with an uptake of 60 and 100 kg ha^{-1} by the growing maize (Table 4.10). If root and weed uptake were further taken into consideration however, it would appear that the accumulation of N by the corn/weed complex exceeded the measured decrease of Ni in the profile by as much as 40 to 60 kg ha^{-1}. Probably the organic N in the profile (litter + soil) continued to mineralize and furnish the N needed by the crop. Also, if some N were taken up by maize or weeds without ever entering the profile (because of direct root interception in the litter layer for example), then plant uptake would be greater than the uptake estimated by considering only the inorganic N pool found in the soil solution.

4.4.4 Synthesis: understanding nitrogen dynamics in the mucuna system

Throughout the preceding sections, we have presented separate pieces of evidence dealing with various aspects of the nitrogen cycle. We now turn to a combined analysis of this information, in order to get an overall picture of nitrogen dynamics in the mucuna/maize rotation.

4.4.4.1 N budgets

Putting most of the preceding figures side by side, approximate nitrogen budgets were calculated at various moments during the maize cycle for four different fields (Table 4.11). The various terms taken into consideration include the above-ground litter, the maize crop, weeds and the inorganic N found in the 0-60 cm soil profile (the level of which reflects both the mineralization of the litter and of the soil organic nitrogen). Linear interpolations were used to *estimate* data for which no direct measurements were available at specific dates. Excluded from the balance sheets however is the change in organic N storage, because no reliable estimates were available at the individual field level: hence these budgets are partial at best.

The N unaccounted for (obtained by difference between the total N for a given date and total N at slashing) is a measure of how well the above representation (and measurement) of the various N pools holds (Legg and Meisinger, 1982). Positive amounts indicate either overestimation of one or several terms, or an underestimation of the total nitrogen at slashing. Negative figures point towards potential N losses from the system (via volatilization, or leaching) or towards the existence of other N pools: roots, microbial biomass or soil organic nitrogen.

Overall, the budgets presented in Table 4.11 appear to offer reasonable approximations, as the N unaccounted for represents relatively small amounts (often a few % of the total N at slashing, with maximum deviations of 10 to 20%). In other words, the various components taken into consideration in calculating these budgets (litter, crop and weeds, inorganic N in the profile) seem to represent the most important ones, with little room for losses or other forms of N immobilization (e.g. the omission of storage of organic N seems a minor one). There is a tendency however for more negative figures to be found towards the middle of the maize cycle, whereas positive ones are found around harvest

Table 4.11: Estimated nitrogen budgets (in kg ha^{-1}) at several moments during the maize cycle, San Francisco de Saco, winter 1993/94

(Each value represents the mean of three replications)

Date	litter N[1]	Maize N[2]	weed N[3]	soil Ni[4]	Total N	***N unacc.***[5]
a. Chema						
slashing	335	0	0	90	425	
30 dap	284	7	30	96	417	***- 8***
50 dap	255	45	10	54	363	***-61***
70 dap	225	90	20	45	380	***-45***
Harvest	272	100	41	45	458	***33***
b. Jacobo						
slashing	299	0	0	80	379	
30 dap	264	7	30	75	376	***- 4***
50 dap	244	47	10	45	346	***-34***
70 dap	224	94	20	39	377	***- 2***
Harvest	217	105	46	42	411	***31***
c. TTMor						
slashing	238	0	0	68	306	
30 dap	234	6	30	48	318	***12***
50 dap	231	41	10	46	329	***22***
70 dap	229	83	20	32	364	***57***
Harvest	204	92	33	38	368	***61***
d. Tonio						
slashing	312	0	0	67	379	
30 dap	284	7	30	53	374	***- 5***
50 dap	266	47	10	39	362	***-17***
70 dap	248	94	15	26	384	***5***
Harvest	253	105	17	33	408	***29***

[1] total N found in above-ground biomass (sum of live + dead fractions), measured
[2] total N in above-ground maize biomass, estimated using a logit function, except for harvest measured. [3] total N in weed biomass, estimated except for harvest, measured
[4] inorganic nitrogen as measured in 0-60 cm soil profile;
[5] N unaccounted for, calculated for each date i as, total N (date i) - total N (slashing)

4.4.4.2 Leaching of N

In a nitrogen-rich environment, subjected to abundant rainfall, leaching of N represents a likely fate for N released by the decomposing litter/soil, and the calculations obtained for the above N budgets did not rule out the possibility of it playing a role. Following an approach developed by Jones (1975), apparent leaching rates (in mm mm^{-1} of rainfall) were estimated by calculating for each field the average depth of the inorganic N for the various sampling dates, and regressing it against the cumulative amount of rainfall received. The results of these calculations showed that in both cycles (92/93 and 93/94), there was no apparent downward movement of Ni (the rates calculated were indeed slightly *negative*, which would indicate an apparent upward movement in the soil profile).

This indirect evidence, combined with the indications coming from the N budgets, and with the evidence from the inorganic N monitoring, tends to indicate that leaching is probably not a very significant source of nitrogen loss in the mucuna system, at least during the maize cycle. Further evidence is however required, especially concerning the importance of profile drainage at different moments during the year, what proportion of this drainage would occur through macro-pore flow, and how variable it might be among years.

4.4.4.3 N stored or otherwise immobilized

Besides plant uptake, there are two likely sinks for N released by the decomposition of litter and SOM: either the soil/litter biota, or the soil organic matter itself. No data is available on the former, although it may be expected that microbial biomass in particular should demonstrate a strong seasonality, in response to the increased availability of substrate produced by slashing. In all likelihood, the turnover of this N should be relatively fast (Duxbury *et al.*, 1989), and hence net release of some of it is possible even within the maize cycle, still in time for subsequent plant uptake.

With respect to soil organic matter, evidence of its long-term role as a sink is given by the general positive trend observed for soil organic nitrogen values measured in the 0-10 cm horizon (see chapter 5): from about 0.2% in check fields where no mucuna has ever been grown to more than 0.3% for old mucuna fields. The gradual increase observed over the years corresponds to an overall storage of approximately 50 to 80 kg.ha^{-1} of N per year on average. There is some evidence however of the system reaching an equilibrium level after about 10 years in the rotation. How much of this yearly storage would occur during the maize cycle itself remains unclear.

4.4.4.4 Recycling of N vs. N2 fixation

An interesting issue is to determine how much N merely cycles through vs. how much is newly incorporated into the system every year. Disregarding losses via leaching and volatilization, and assuming stable levels of the microbial pools of nitrogen across years, there are two mechanisms by which annual N cycles are kept open: nutrient removal via harvest (grain only), and long-term storage in soil organic matter (at least until the system reaches near-equilibrium) Each term representing approximately between 50 and 80 kg ha^{-1}.year^{-1}, a total of 100 to 160 kg.ha^{-1}.year^{-1} of nitrogen must be obtained from an external source. Some N may enter via rainfall or non-symbiotic fixation (perhaps 20-30 kg.ha-1 .yr-1: Wetselaar and Ganry, 1982), but most probably the bulk of it is provided via symbiotic N2 fixation by the mucuna crop itself. Until direct, in situ measurements are made, it appears reasonable to estimate that a mucuna crop must fix anywhere between 70 and 130 kg ha^{-1} of N per cycle.

Conversely, as much as 200 to 300 kg.ha^{-1} of N, or about 2/3 of the total N would be recycled through the system every year. The mucuna crop (and to a much lesser extent, weeds) would appear to be a primary candidate for scavenging any available nitrogen, because of the large biomass it accumulates, the amount of time it has to accomplish this task (almost 6 months as the sole or major crop), and also because the conditions are highly favorable to mineralization and litter decomposition during this period. In addition, one could expect mucuna to rely as much as possible on the ample supply of inorganic N in the environment rather than to incur the high energetic cost associated with fixing all the nitrogen it needs (Giller and Wilson, 1991)

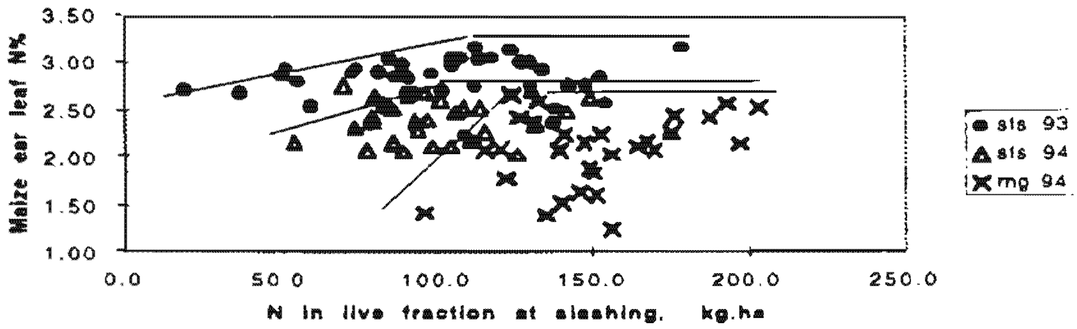
4.5 MAIZE RESPONSE TO NITROGEN

After looking at nitrogen cycling from a biological perspective, a remaining issue is to determine to what extent maize yields seem to depend on how much nitrogen is present in the soil-plant system. The two main inputs in terms of nitrogen are the various mucuna biomass fractions constituting the litter found on the soil surface on one hand, and the soil organic nitrogen, both of which release N upon mineralization in a gradual fashion Nitrogen fertilizer can constitute a third source for those farmers willing or able to invest in such a costly input (as a matter of fact, 40% of them do on a regional basis Buckles *et al*., 1992 and also chapter 3) Fertilizer can at best add flexibility in managing the mucuna system, as it has the potential to almost instantaneously increase N availability for plant uptake beyond what is "naturally" released by the soil/litter organic complex It could thus contribute towards achieving higher yield goals, for which ample N supply must be provided during critical stages of the crop growth, irrespective of its source (organic or chemical) On the other hand, given the large quantities of organic N found in the mucuna system, adding even more N to the system could well constitute a wasteful use of precious cash and labor resources, as well as a potential door open to subsequent leaching in the environment.

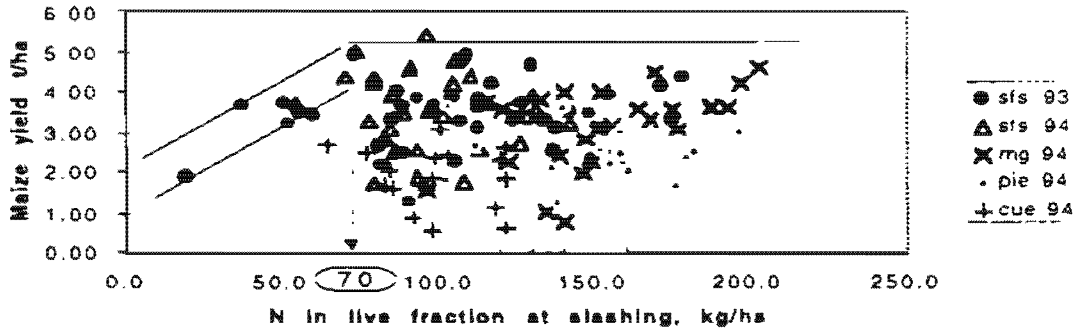
4.5.1 Maize response to the nitrogen accumulated by mucuna at slashing

Figure 4.13 displays the relationships between maize ear leaf N concentrations at silking or maize yields and nitrogen found in the live biomass accumulated at slashing time (Figures 4.13 a and b, respectively) and between the two former (Figure 4.13.c)

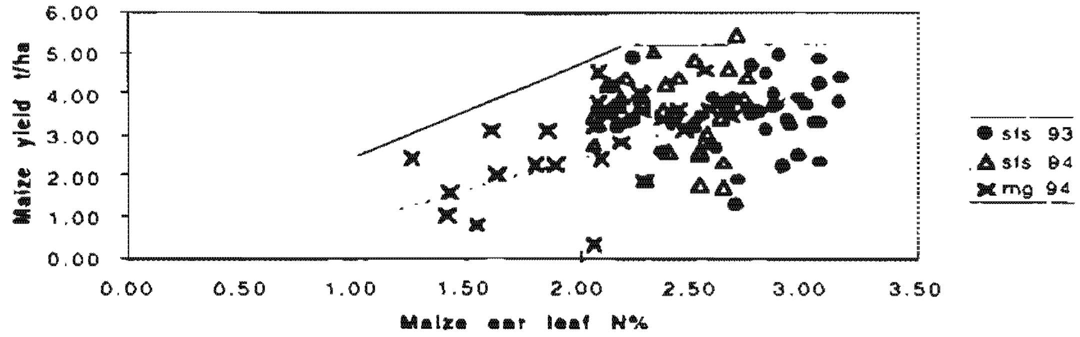
a. Relationship between maize ear leaf concentration (%) at silking and nitrogen in the live biomass fraction



b. Relationship between maize yields ($t.ha^{-1}$) and nitrogen in the live biomass fraction



c. Relationship between maize yields ($t.ha^{-1}$) and maize ear leaf N (%) at silking



sfs = San Francisco, mg = Las Mangas, cue = Rio Cuero, pie = Piedras Amarillas

Figure 4.13: Maize response to nitrogen found in the litter, Northern Honduras, cycles 92/93 and 93/94

Since maize yields didn't depend solely on nitrogen supply, and N in the litter is at best an indication of potential, not actual N supply), background variability is very high. making interpretation difficult Nevertheless there were highly significant differences between sites in terms of maize ear leaf concentrations (Figure 4 13.a), with San Francisco presenting the highest values (2.6% on average vs. 2.08% for Las Mangas, $p < 0.001$). Highly significant differences ($p < 0.001$) were also found between years in the same site: in 93, maize appeared to have achieved a better nutritional status vis-à-vis nitrogen (average N% = 2.81) compared to 94 (average N% = 2.41). These differences didn't reflect however differences in potentially available N, as similar ranges of nitrogen in the live fraction were encountered in both sites.

The relationship between maize ear leaf concentrations and maize yields (Figure 4 13c) is slightly clearer, with a weak tendency for yields to increase in response to corresponding increases in maize ear leaf concentrations One way of going beyond the high variability is to adopt an envelope curve approach, whereby points lying at the border of the data cloud are used to detect the theoretically-known potential response curve (see Siband and Wey, 1994) Applied to Figure 4 13b (with the necessary caution warranted by the few points involved), it can be inferred that nitrogen supply might possibly have been limiting if less than 70 $kg.ha^{-1}$ were present in the live fraction (which. translates into levels of total biomass at slashing below 8 $t.ha^{-1}$). Above this threshold. maize yields seemed to reach a plateau around 5 to 5.5 $t.ha^{-1}$ Prolongation of the envelop to hypothetical situations with zero N in the live fraction produces yield levels without mucuna biomass input in the 1 to 2.5 $t.ha^{-1}$ range, something consistent with actual check yields observed in fields not planted to mucuna (chapter 3). A roughly similar interpretation can be developed in the case of Figure 4.13 a. threshold levels (if they exist at all) appear to differ however for each site/year

Most of the mucuna fields presented however levels largely above the 70 kg ha^{-1} threshold mentioned earlier, while also exhibiting yields much below the alleged plateau (2-3 $t.ha^{-1}$ compared to 5 $t.ha^{-1}$). Therefore, it can be inferred that factors other than potential nitrogen supply are likely to have been limiting. Overall, the lack of a clear trend in the figures indicates that potential nitrogen supply did not apparently limit maize yields.

4.5.2 Maize response to added nitrogen fertilizer

We will now turn to an examination of the additional response to fertilizer nitrogen exhibited by maize grown in the mucuna system. By additional, it is meant that nitrogen added as fertilizer was managed not as a replacement to the N provided by the decomposing mucuna litter, but as a complement to this organic source.

4.5.2.1 Reminder about experimental settings

This issue was addressed via simple, replicated on-farm experiments in which the effect of a single, moderate dose of N-urea (50 $kg.ha^{-1}$) applied 40 days after planting in well-established mucuna fields was compared to the yield obtained solely on the basis of nutrients provided by the decomposing mucuna litter.

It should be noted that the trial design also included addition of phosphorus (applied at planting at a rate of 60 $kg.ha^{-1}$ of $TSP-P_2O_5$) as a test of whether P could constitute a significant limiting factor of maize yields in a situation where N was assumed to be readily available. There was no significant effect of P in Las Mangas (Table 4.14), even though it was consistent across years in Sn Fco ($P < 0.05$: Table 4.12, 4.13). In all cases, the yield increase was fairly small (betwee 0 and 0.4 $t.ha^{-1}$), indicating probably that P availability in the mulch layer was sufficient to provide for maize P requirements (see also chapter 5). Furthermore it did not interact with the response to nitrogen, therefore it will not be discussed further in this chapter.

The trials were conducted during two consecutive cycles (cf. earlier rainfall data: Figure 4.04), and included a total of 14 different fields, 11 of which were clustered close to each other in one site (San Francisco de Saco), and 3 were in another site more than 160 km east of the first one (Las Mangas, 93/94 only). Data losses were important the first year, due to heavy damage by winds. In 93/94, one field was excluded from the analysis, because of severe plant stand deficiencies. Disparities in planting densities among the remaining fields (as a result of farmers' involvement in the planting of the trial, or as in Las Mangas, because of losses due to *Phyllophaga spp.*) prompted that plant density be used as a covariable in the analysis of variance (Neter *et al.*, 1985). Also, missing data (92/93) and slight imbalances in design (93/94) compelled the use of Type III sums of squares on SAS (Littel *et al.*, 1991).

4.5.2.2 Maize response to nitrogen fertilizer

Variability in response among and also within fields (from one block to another) was important (Tables 4.12.a, 4.13.a and 4.14.a), given rise to sums of squares for the block factors far greater than any other sum of squares. In practical terms, it reflects the fact that whereas certain fields/blocks did not respond at all to N (or very weakly), others responded sharply (yield increase of about 1 t/ha were obtained in a few blocks). Three of the 10 analyzable fields in 93/94 (3 in Sn Fco, none in Las Mangas) showed a statistically significant response to N when analyzed individually (at a level varying between 1% and 8%), whereas seven did not respond apparently (reflecting partly the low power of these experiments).

Table 4.12 Yield response of a maize crop to the application of fertilizer in well-established mucuna fields, San Francisco de Saco, cycle 92/93

a Treatment means across weed treatments [1] (response expressed as yield increase over the treatment without fertilizer)

Treat	Alfaro [2]	Galdamez [3]	Obed [4]	Site mean [5]
No fert.	3.67	4.31	3.35	3.80 ± 0.72
+N	0.03 *ns* [6]	0.02 *ns*	0.02	0.02 ± 0.56
+P	0.25 *ns*	0.07 *ns*	-0.03	0.09 ± 0.90
+N+P	0.34 *ns*	0.17 *ns*	1.26	0.45 ± 0.64

[1] see text. [2] mean of 3 reps.; [3] mean of 2 reps.; [4] 1 rep. only. [5] mean ± std.dev.. [6] statistical significance for individual ANOVA. ns not significant

b ANOVA Table across fields

Source	DF	Sum Squares[1]	Mean Square	F value	Pr > F
weed [2]	1	1.4734	1.4734	1.5	0.25
block(weed)	9	8.8319	0.9813		
N	1	0.3346	0.3346	1.76	0.21
P	1	0.9244	0.9244	4.87	0.04
N*P	1	0.2631	0.2631	1.39	0.26
trat*weed	3	0.0335	0.0112	0.06	0.98
error term [3]	21	3.9856	0.1898		

[1] Type III sum of squares (SAS) to accommodate missing data. [2] main plot factor at two levels, farmer-weed control vs. weed-free (tested against the main plot MS, line below); [3] coef. var. = 12%

Table 4.13 Yield response of a maize crop to the application of fertilizer in well-established mucuna fields, San Francisco de Saco, cycle 93/94

a Treatment means, San Francisco de Saco (response expressed as yield increase over the treatment without fertilizer, uncorrected for density effects)

Treat	Chema[1]	Jacobo[1]	TTMo[1]	Tonio[1]	Indal[2]	Martir[2]	Negrito[2]	Site mean[3]
0 fert	4.06	3.94	3.43	4.15	3.34	4.93	4.13	3.98 ± 0.60
+N	0.89 *s5*[4]	0.40 *s1*	0.76 *s5*	0.50 *ns*	0.58 *ns*	0.45 *ns*	0.70 *ns*	0.61 ± 0.59
+P	0.25 *ns*	0.24 *s5*	0.30 *ns*	0.42 *ns*	--	--	--	0.22 ± 0.66
+N+P	0.85 *ns*	0.99 *ns*	0.77 *ns*	0.79 *ns*	0.53	0.72	1.56	0.87 ± 0.71

[1] mean of 3 reps. [2] mean of 2 reps (+P treatment omitted in these fields). [3] mean ± std dev.; [4] statistical significance for individual ANOVA ns not significant, s5 and s1 signif. at the 5% and 1% level, respect

b ANCOVA Table across fields

Source	DF	Sum Squares[1]	Mean Square	F value	Pr > F
farm	7	20.3895	2.9128	16.04	<0.01
block(farm)	12	5.2722	0.4393	10.84	0.02
N	1	3.8083	3.8083	29.09	<0.01
P	1	0.8758	0.8758	4.26	0.03
N*P	1	0.0029	0.0029	1.11	0.90
plant density [2]	1	0.5757	0.5757	11.61	0.08
error term [3]	48	8.7164	0.1816		

[1] Type III sum of squares (SAS) to accommodate unbalanced design and missing data.
[2] used as covariable. [3] coef. var. = 10%

Table 4.14: Yield response of a maize crop to the application of fertilizer in well-established mucuna fields, Las Mangas, cycle 93/94

a Treatment means (response expressed as yield increase over the treatment without fertilizer, uncorrected for density effects)

Treat.	Amaya [1]	Hernan [1]	Albar [1]	Site mean[2]
No fert	3.32	3.15	3.15	3.21 ± 0.82
+N	0.75 *ns* [3]	0.47 *ns*	0.28 *ns*	0.53 ± 0.82
+P	0.07 *ns*	0.31 *s5*	0.82 *ns*	0.40 ± 1.02
+N+P	0.29 *ns*	0.59 *s10*	0.47 *ns*	0.42 ± 0.42

[1] mean of 3 reps.; [2] mean ± std.dev.; [3] statistical significance for individual ANOVA: ns not significant, s10 and s5 signif. at the 10% and 5% level, resp

b ANCOVA Table across fields

Source	DF	Sum Squares[1]	Mean Square	F value	Pr > F
farm	2	0.6574	0.3287	1.92	0.17
block(farm)	6	17.2024	2.8671	16.71	<0.01
N	1	1.0434	1.0434	6.08	0.02
P	1	0.0023	0.0023	0.01	0.91
N*P	1	0.2265	0.2265	1.32	0.26
plant density [2]	1	0.8267	0.8267	4.82	0.04
error term [3]	23	3.9465	0.1716		

[1] Type III sum of squares (SAS) to accommodate unbalanced design and missing data; [2] used as covariable; [3] coef. var. = 12%

When considering the average response by site, a comparison between Tables 4.12 and 4.13 shows that response to N was markedly different among cycles. In 92/93 (a relatively wet winter cycle: Figure 4.04), there was no significant response to nitrogen ($p = 0.21$, no yield increase on average). Conversely, in 93/94 (a rather dry cycle), overall response to nitrogen was significant in both Sn Fco and Las Mangas ($p < 0.01$ and $p = 0.02$ respectively), reaching almost 0.5 t.ha^{-1} on a regional basis. The same differential behavior was observed for maize nutritional status vis-à-vis nitrogen: visual symptoms of N deficiencies, almost absent in 93, were widespread in 94, and ear leaf N concentrations at silking were significantly lower in 94 compared to 93 (cf. 5.1), as well as significantly affected by the application of fertilizer (2.31% without N vs. 2.50 with N in 93/94, $p < 0.0001$).

The fact that fertilizer would be advantageous in a relatively dry year may appear paradoxical. But it is hardly surprising if one considers the rainfall pattern and the soils prevalent in Northern Honduras, allowing winter maize to start growing with a soil profile holding up to 300 mm of stored water (hence there is water for at least a good month of consumption, assuming an evapotranspiration of about 5 mm.day-1: Hargreaves, 1980). Moreover, it is also a consequence of the ability of a mulched profile to conserve this stored water efficiently (Steiner 1994).

4.5.2.3 Possible causes of the differential response to N among sites and years

The marked variability detected in maize response to nitrogen (confirmed further by the results obtained in a series of 15 nitrogen fertilizer trials conducted in Sn Fco and Rio Cuero during the 94/95 cycle: Barreto, pers. com.) invites to question the underlying cause or causes, which would make a given mucuna field or block respond to fertilizer nitrogen. Given the data set assembled in this study, it was only possible to try to explain the *yield increase* observed upon N fertilization (adjusted for plant density, as suggested by the significant effect of density in the analysis of covariance) as a function of potential explanatory variables such as maize yield levels and nitrogen status in the plant, interval between slashing and planting, N inputs from the various fractions composing the litter at slashing times, soil inorganic and organic N levels and also the rainfall received during the maize cycle.

No satisfactory multiple regression using yield increase as the dependent variable could be devised (maximum R^2 around 0.20), demonstrating that there does not appear to exist *in our data* one or several overwhelming factors related to response to added nitrogen. A qualitative sense for what could influence the response was therefore conducted by analyzing the values taken by a selection of these variables for three incremental classes of response to nitrogen (from no response to response higher than 0.7 t.ha^{-1}) (Table 4.15).

This rough analysis yielded statistically significant differences (at a level of 10% or less) between fields belonging to class 0 (no response) on one hand vs. fields belonging to classes 1 and 2 (moderate and high response, respectively) on the other hand. In particular, fields presenting the highest maize yield levels, highest maize nitrogen status and highest soil organic N levels appear not to have responded to added nitrogen fertilizer. Interestingly, these fields have been on average cropped for more time in the mucuna system than the ones responding more markedly to fertilizer (10 years for the former vs 7 for the latter). Conversely, there were no differences among classes with respect to the amount of nitrogen found in the various mucuna fractions, or to the amount of rainfall received during the maize cycle (either during the initial part of the cycle, or during the period of rapid growth).

Table 4.15: Selected variables associated with three classes of yield increases measured in individual experimental blocks upon application of 50 kg.ha^{-1} of Urea-N, Northern Honduras, cycles 92/93 and 93/94.

Each value represents the average for the class followed by its standard deviation, number of samples, 11, 17 and 8 for class 1, 2 and 3 respectively

Data	unit	class 1 (< 0.3 t.ha^{-1})	class 2 (0.3 - 0.7 t.ha^{-1})	class 3 (≥ 0.7 t.ha^{-1})
Average yield increase [1]	t.ha^{-1}	-0.18 ± 0.34	0.43 ± 0.11	0.90 ± 0.14
Yield w/o nitrogen [2]	t.ha^{-1}	4.41 ± 0.47	3.32 ± 0.58	3.74 ± 0.48
Soil total N% (0-10 cm)	%	0.28 ± 0.04	0.24 ± 0.04	0.25 ± 0.02
ear leaf N% at silking	%	2.73 ± 0.40	2.36 ± 0.41	2.42 ± 0.17
N total at Slashing [3]	kg.ha^{-1}	309 ± 57	268 ± 34	297 ± 35
N green at Slashing [4]	kg.ha^{-1}	38 ± 17	31 ± 18	40 ± 23
N litter at Slashing [5]	kg.ha^{-1}	183 ± 68	161 ± 39	190 ± 48

[1] calculated for each block as (avg. yield w/ nitrogen - avg. yield w/o nitrogen). [2] average yield of the block for treatments in which no nitrogen was applied. [3] total N in above-ground biomass at slashing time; [4] N in green fraction (leaves + tender stems) [5] N in dead fraction

4.6 DISCUSSION

After analyzing mucuna and nitrogen dynamics, and maize response to nitrogen, it is possible to examine the overall dynamics of the mucuna system over a year

4.6.1 How does the mucuna system work?

At the heart of the mucuna system lies the mucuna crop: acting alternatively as a major collector (when growing) or supplier (when decomposing) of nutrients, its natural seasonal dynamics dictates the major features of the mucuna system. Figure 4.03 (page 63) presents a schematic view of this dynamics for a number of key phases of the cycle and for the various compartments or fractions identified throughout the analysis. live fraction (maize, weeds, mucuna) or dead (litter) fraction. The multi-layered structure of the mucuna system is a key to understanding its dynamics. At any given moment in time, there are always at least two distinct layers (or compartments) functioning in concert. One layer is constituted by the growing, live biomass (in effect, a crop/weed mixture), which can accumulate nutrients, under the driving force of photosynthesis. Depending on the precise phase of the cycle, the crop is either mucuna or maize and its associated weeds (Figure 4.03). Whereas maize function in the system is relatively straightforward, the function of the growing mucuna is more complex, ranging from controlling existing weeds to recycling or fixing N to shielding the underlying litter or soil from direct exposure to the heavy rains of the major rainy season.

The other layer corresponds to a semi-permanent "dead" litter layer serving (together with the first few centimeters of soil proper) as a major provider of nutrients for the growing biomass. The litter originates from the natural or farmer-induced decay of mucuna, maize or weed biomass. Its continuous presence and multiform activity throughout the year makes it a prime regulator of nutrient fluxes, acting both as a substrate for decomposition and as an almost ideal habitat for the host of decomposing flora and fauna which thrives in this micro-environment protected from brutal variations in temperature and moisture.

4.6.2 Nutrient cycles

The dynamic relationship between nutrient release by the litter and simultaneous nutrient uptake by the growing crops determines the yearly partitioning of nutrients between the various sinks: levels of nutrient exportations via maize harvest (typically in the range 50 to 80 kg ha^{-1}), levels of temporary immobilization by the various decomposers (e.g. microorganisms) or "pure" scavengers of nitrogen (e.g. weeds, maize), levels of long-term storage in the soil organic matter (perhaps more than 50 kg.ha^{-1}.$year^{-1}$) and finally, levels of losses by leaching or volatilization (apparently relatively small).

The mucuna system appears to recycle large quantities of nutrients throughout the year. For a dry cycle like 93/94, it was estimated that more than 200 kg.ha^{-1} of nitrogen were recycled, a magnitude which ranges it alongside a number of natural forestry or agroforestry ecosystems (Vitousek and Sanford, 1986). As in natural ecosystems, the losses of nitrogen not related to crop exports (i.e. leaching, volatilization) seem relatively limited at least for the conditions under which data were gathered. Losses by leaching may be higher in very wet winter cycles, during which decomposition is probably fairly active.

and profile drainage consequent and the possibility of significant losses by volatilization after slashing cannot be ruled out.

Beside recycling, acquisition of external N2 (via symbiotic fixation) remains important in balancing the nitrogen budget, contributing perhaps between 80 and 150 kg.ha^{-1} of nitrogen per annum in well-established mucuna fields. Whether fixation could actually be relatively more important in the early years following mucuna introduction in a field, to drop subsequently to maintenance levels once a significant pool of recyclable N has been constituted, remains unknown.

4.6.3 Fertilizer use

Organic nitrogen supply in the mucuna system is roughly adequate to meet the demand of a moderately yielding maize crop without the need for adding external nitrogen fertilizer, particularly when mucuna has been used for many years in the same field.

But because overall environmental conditions strongly influence the processes of nutrient accumulation and release in the mucuna system, the mucuna litter remains a somewhat irregular supplier of nutrients to the maize crop. It was shown that the drier the cycle, the more limited the supply to a succeeding maize crop. This observation is hardly surprising, given that N supply in a mucuna field is primarily the result of the complex break-down of organic forms of N (found in the litter or in the soil: see section 4.4), a process which is in turn influenced by fluctuating environmental conditions before or during the maize cycle (Jenkinson, 1981).

Hence supplemental N fertilization may have a small role to play in boosting maize yields in dry years. But until reasonably accurate and practical ways of predicting nutrient release by the litter can be derived (by incubating mucuna material for example: Quintana *et al.*, 1988), trying to advise farmers with respect to where, when and how much N to apply will probably remain a fairly futile exercise.

An interesting issue is to consider what would happen if farmers were trying to aim for higher yields than what they are presently getting in the mucuna system (say 5-6 t ha instead of 3-4), as a way of obtaining additional income (or to free up land for other purposes than growing maize: see chapter 6). Even though the first stage would probably involve using improved germplasm and increasing plant densities, there is a good chance that a higher-yielding maize crop would require instantaneous nitrogen supply above the typical supplying capacity of the mucuna litter. Under these conditions, supplemental nitrogen fertilization might have a bigger role to play than what was mentioned earlier. Whether a maize crop could respond to fertilizer nitrogen above the single 50 kg.ha^{-1} dose tested in this study remains to be determined: preliminary evidence (Barreto, pers. com.) does seem to indicate that certain field might respond to doses of 100 kg ha^{-1}, but the variability among fields seems very high. On the other hand, testing the potential response to other nutrients such as P, Mg, or Zn might also prove useful in the long-run. In all these fertilizer studies, placement of fertilizer would also need to be addressed, as it has been shown elsewhere (Schlather, 1996) that nutrient uptake directly in the litter layer may be significant.

In addition to examining direct response of a maize crop to fertilizer, other approaches should be employed. One would be to test whether applying fertilizer to the mucuna crop itself could boost its productivity (biomass and/or nutrient accumulation), with a subsequent benefit for the maize crop. This strategy would particularly make sense in fields where mucuna does not grow very well "naturally", or during the first one or two cycles following its introduction in a field, in order to help its fast establishment. Another avenue for inquiry would be to test alternatives for slashing the mucuna, with the objective of increasing subsequent nutrient release by the decomposing litter. For one thing, it could be worthwhile to try advancing the timing of slashing (which would require that an area of the field be set aside for mucuna seed production), with the hope that the proportion of fast-decaying live material may increase. Another test could involve the actual slashing technique itself, and in particular the size of the cuttings. It could be expected that a finer slashing size (if achievable without increasing labor use too much) would possibly promote faster litter decomposition (Jenkinson, 1981).

4.6.4 Benefits and constraints to the maize crop

A maize crop benefits in many ways from the environment and general dynamics of a mucuna system. First, the system seems fairly stable over time, allowing respectable yield levels (usually between 2 and 4 t.ha^{-1}) to be obtained every year. In particular, drought stress appears to be avoided or at least much diminished, thanks to the effect of the mulch layer on water conservation (Steiner, 1994; see chapter 5). With enough water around, nutrients (nitrogen, but also phosphorus, potassium, calcium, magnesium, etc.) are made readily available in good synchronization with the period of major crop uptake (Myers, 1988). In addition to providing nutrients, the mucuna system creates a relatively trouble-free environment for maize because most weeds (with the notable exception of *Rottboelia cochinchinensis*) have a hard time flourishing in this system, either because mucuna physically prevents them from germinating/emerging or from surviving very long during its cycle, or because they are easier to control, thanks to a shallow rooting in the litter layer/soil interface itself. And pests and diseases of maize or mucuna seem to be fairly minor in the system, permitting continuous cultivation of maize without running into disasters or having to invest in pesticides.

There are a number of minor constraints however. One is the tight coupling of maize planting with slashing. Until alternatives are found (via introduction of mucuna or maize germplasm of different maturity classes for example), there is a very limited window for choosing a planting date (in practice, it is restricted to a 6-week period starting in early December). Also, it is unclear at this venture if maize could be planted successfully at any other time during the year, without negating most of the advantages associated with the mucuna system as it presently works. Another problem is the tough competition provided certain years to the growing maize crop by a fast re-establishing mucuna.

obliging farmers to curb its growth via pruning. Finally, the year-to-year, hardly predictable (up-to-now at least) variability in the pace at which nutrients are made available via decomposition may be seen as a constraint, especially if it turns out that achieving high maize yields becomes more and more part of farmers' agenda.

4.6.5 Farmers' practical knowledge about nutrient dynamics

Evidence from the inorganic N monitoring showed that by deliberately planting maize almost immediately after slashing, farmers were placing their crop in a good position to take advantage of the flush of Ni entering the profile, in effect reaching an almost ideal synchronization of the crop demand with the environmental offer. Other considerations than nutrient availability constrain the choice of a slashing/planting date: slashing has to be delayed until viable seeds are produced (see chapter 3), and the interval during which it is desirable to slash is born out on the other end by the need to avoid possible drought or weed competition. Given these constraints, one could claim that farmers contented themselves with cleverly patterning their management according to the ecology of mucuna, without trying to modify its basic parameters

With regard to N fertilizer, many farmers don't use it at all when growing maize in rotation with mucuna, even though it is generally available locally, and its use is not unknown to them (chapter 3). When asked about their rationale for (not) using nitrogen fertilizer, many stated very clearly that a major reason (even before considering cash availability) for not applying urea to their maize in rotation with mucuna was because "it didn't need it". In effect, they consider mucuna as an *in situ* (green) manure, which *replaces* external fertilizer: it is no coincidence that the local name for mucuna is "frijol de abono", or fertilizer bean. Conversely, farmers readily recognized that maize planted without mucuna did respond markedly to nitrogen fertilizer applications.

Hence it appears that even though they did not formally experiment much with mucuna decomposition patterns and/or fertilization, many farmers in Northern Honduras have for the most part already integrated the bulk of the practical knowledge related to these issues in their management of the mucuna system. Under these conditions, researchers and extensionists interested in contributing something useful to users of the mucuna system should focus their attention and resources to novel aspects not yet part of today's management, such as perhaps alternative slashing techniques or the means of increasing yield levels.

4.7 CONCLUSIONS

Throughout this chapter, we have alternatively examined the mucuna system from a biological perspective, deciphering its dynamics over time, and through a much more practical viewpoint, looking at maize yields levels in relation to nitrogen inputs in the system.

Perhaps the most important conclusion so far is that the mucuna system represents a working example of how to exploit the properties and dynamics of a "natural" ecosystem for the benefit of commercial maize production (Gliessman *et al.*, 1981). In particular, farmers devised a way to optimize mucuna management to derive substantial nutritional benefits for their maize crop. They achieve this result by letting mucu accumulate *in situ* the biomass and nutrients needed for the succeeding dry winter maize cycle, which are then gradually released during the decomposition of the mucuna mulch created by slashing and maintained by a deliberate decision not to burn it The reliance on mucuna N2-fixing and recycling abilities in effect practically eliminates the need for costly, impractical (in a hillside context) external fertilizer, without compromising yield levels, and without incurring significant nutrient losses to the environment.

It is difficult however to claim that the mucuna system is primarily an elegant way of providing and recycling nutrients Beside nutritional aspects, there are a host of other benefits associated with the use of mucuna, which all contribute significantly to the success of the rotation they include reduced labor use, pest control, soil conservation and soil fertility build-up (see chapter 5). There are differences among farmers and locations regarding the degree to which the mucuna system is helping them accomplish these various goals For example, not all mucuna fields accumulate quite enough biomass and nutrients to satisfy all maize nutritional requirements. Similarly, management decisions (from the timing of slashing/planting to the choice of planting densities or the timeliness of weed control), do affect how much farmers take advantage of the production potential that the mucuna system creates in their fields.

But the fact is, without the nutritional benefits, the performance of the mucuna system would undoubtedly be much less satisfactory.

Chapter 5

LONG-TERM CHANGES IN SOIL FERTILITY UNDER THE MUCUNA/MAIZE ROTATION

5.1 INTRODUCTION

Scant evidence exists in the scientific literature which firmly demonstrates on the basis of whole-farm data that slash-and-mulch cropping systems do indeed constitute a viable, productive *long-term* option for continuous cultivation without concomitant degradation of the resource base (Sanchez, 1994). On one hand, agreed-upon, unambiguous indicators which would clearly document the processes (and effects thereof) at work during the long-term evolution of complex systems are barely emerging, following the recent interest in sustainability issues (Harrington, 1992). A long-time favorite such as the characterization of soil organic matter remains open to widely divergent methodological inquiries and data interpretations (Duxbury *et al.*, 1989; Swift and Woomer, 1993). And determining threshold levels of organic matter in the soil profile which would cause a system to become unsustainable, or defining in analytical terms the main attributes of a healthy soil from its individual properties and finding appropriate ways of measuring them are still more proclaimed goals than actual possibilities (e.g. Kay, 1990; Doran and Parkin, 1994). The rough criteria which have been proposed up to now remain mostly empirical, and very qualitative when authors venture to tackle the whole field level at all: maintenance of "high" levels of soil organic matter, or "good" structure, or achievement of sustained yields over time (Swift *et al.*, 1991), etc. They are furthermore more suited for identifying what went wrong *a posteriori* (Johda, 1994), than for identifying in a predictive fashion what precisely should be accomplished, and how.

On the other hand, the historical databases required to investigate the long-term behavior of cropping systems are fairly costly and logistically difficult to assemble. The lack of resources and frequent instability typical of most research institutions in the developing world makes long-term experiments and historical time-series, the two major tools for long-term studies, even rarer and also much harder to interpret, when they exist at all, than similar studies conducted or available in developed countries (Pieri, 1989; Steiner, 1995). Notwithstanding the potential for using properly calibrated computer models to simulate the behavior of complex systems over time (Jones *et al.*, 1993; Uehara, 1994; Young, 1994), the only alternative at hand with the capacity to deliver rapidly some of the much-needed quantitative evidence about long-term trends consists of using indirect approaches such as chronosequences. A chronosequence allows inferences to be made about the suspected evolution over time of a system by comparing at a given time a set of fields assumed to represent successive historical states of the system. This space-for-time substitution scheme is common practice in ecology (Pickett, 1988) and soil genesis studies, because the time frame involved (typically hundreds to millions of years) precludes experimental approaches. It is much rarer however though not unknown in cropping systems studies (Staley *et al.*, 1988; Feller *et al.*, 1991, Kleinman, 1995), probably because conditions favorable to the proper use of such schemes are difficult to find, and also because this approach entails a fair level of assumptions and risk of failure, with the potential to undermine the very significance of the results

Under these conditions, the objective of this chapter is two-fold. First, the chronosequence approach itself is scrutinized, and methodological considerations and guidelines are developed with a view to provide a better appreciation for such approaches. Secondly, a case study is presented wherein long-term trends in soil fertility under the mucuna/maize cropping system in Northern Honduras are analyzed using a chronosequence approach

5.2 MATERIALS AND METHODS

Many of the specifics about the study area, the mucuna/maize cropping system, or the general agronomic measurements can be found in chapters two and three

5.2.1 Reconstitution of field history

Dating of the individual fields making up the chronosequence was facilitated by the fact that the mucuna system has been adopted relatively recently by the farmers of Northern Honduras. most of them introduced it sometime during the 1980s, with the oldest reported adoption taking place in the mid-70s (Buckles *et al.*, 1992). Hence, even though there were no written records of adoption, it was possible to use farmers' ***oral recollections*** about when they had introduced the mucuna rotation in their fields. In spite of its associated constraints, oral history has been recognized as a valid methodological approach for investigating contemporary events, especially in circumstances where written evidence is scarce (Dunaway and Baum, 1984).

A first step consisted of selecting villages with at least 5 years of adoption of the mucuna system, in order to allow a meaningful exploration of long-term effects. Potential sites were selected along an East-West transect representing a broad range of agroecological and socioeconomic conditions typical of the Atlantic littoral region of Northern Honduras. Out of 10 villages initially considered, only 6 were selected for further study, based on the results of collective semi-structured interviews. In each of the 6 villages, individual interviews were conducted with farmers whose fields span the entire range of adoption dates detected during the collective interview. Check fields (no adoption of the mucuna system) were included in each village to provide a basis for comparisons with mucuna fields. Cropping history was reconstituted starting with the rotation followed prior to the adoption of the mucuna system, and going as far back as the last significant fallow period preceding adoption whenever possible. It should be noted that reconstitution was hampered by the fact that Northern Honduras is an active migratory area, with a fast turnover of farmers and field ownership. Cropping history was carefully scrutinized for disqualifying events which would threaten the validity of the assumptions listed previously (examples of such events include burning of the field, transitory abandonment of the rotation, cattle invasion, etc.) Also, particular care was taken to detect within-field heterogeneity in history, leading the way to the independent sampling of several plots within the same field whenever appropriate (see survey instrument in Appendix A.1). After one year, 2 of the 6 villages were discarded completely from the study, owing mainly to insufficient confidence in the quantitative data collected (see below), as well as for logistical reasons. At the end of the two-year field study, a second historical survey, both collective and individual, was conducted in most of the fields of the 4 remaining villages to cross-check the results of the initial surveys, and to fill information gaps about various aspects of the mucuna system, including potential changes in management which would have taken place as time spent in the rotation increased (see survey instruments for final survey in Appendices A.2 and A.3)

5.2.2 General sampling scheme

Independent chronosequences were constructed in each of the four villages. To minimize variability not related to field history, care was taken to select neighboring fields whenever possible, with the objective of matching their geomorphological backgrounds and properties. Also, only fields located within a narrow altitudinal stratum (typically less than 200 m between low- and high-lying fields) were selected in each village (see Figure 2.5). Furthermore, it was decided not to work at the scale of whole fields (Milleville, 1972, Moormann and Kang, 1978), but rather to focus on small, uniform observation plots (10 x 10 m²) selected on linear backslope topographical positions (Ruhe, 1960 in Hall and Olson, 1991). Representativeness of the chemical properties of backslope positions was nevertheless examined by comparing them to those measured for a number of footslopes and shoulder positions in 4 fields. Two observation plots were selected in each field, as a way of accounting for potential within-field heterogeneity. Slope in the observation plots was kept as much as possible within the range 25% to 70%, representing the most typical conditions under which farmers grow maize on the hillsides.

The distribution of fields and observation plots according to the adoption date of the mucuna system is presented in Table 5.1. The range of field/plot ages explored by each chronosequence depended on the particular village: only in one site (San Francisco) did the chronosequence include fields as old as 15 years. Conversely, in one site (Cuero), the oldest field had been no more than 7 years in the mucuna rotation.

Table 5.1. Field/plot sample composition for each chronosequence of the mucuna/maize rotation, Northern Honduras

(Each pair of values indicates the number of fields plots sampled for a given category)

site	Total # of fields/plots[1]	check fields[2]	1-2 years	3-4 years	5-7 years	8-10 years	≥ 11 years	avg. years w/ muc[3]
Sn Fco	55/101	8/15	9/14	5/ 9	11/19	13/26	9/18	7.8
Mangas	40/ 62	8/10	6/ 9	7/11	14/25	4/ 6	1/ 1	5.3
Cuero	32/ 32	6/ 6	8/ 8	13/13	5/ 5	---	---	3.4
Piedras	11/ 22	1/ 2	2/ 4	2/ 4	3/ 6	1/ 2	2/ 4	5.7
Region[4]	138/217	23/33	25/35	27/37	33/55	18/34	12/23	6.2

[1] including fields/plots sampled more than once; [2] maize fields where mucuna was never planted. [3] average time (in years) sampled *plots* have been in the mucuna system. [4] combined sample over the 4 sites

5.2.3 Soil fertility measurements

5.2.3.1 Chemical properties

Composite samples (12 to 15 sub-samples) were taken in every observation plot at each of the four sites with a 2-cm diameter tube auger in March 1993 (March 1994 in a few cases) from 3 depths: 0-10 cm, 10-30 cm and 30-60 cm, air-dried and sieved at 2 mm. All these samples (hereafter referred to as "sampling A") were analyzed for pH (1:2 water), P, Al, exchangeable bases and micronutrients (extracted with Morgan's solution), and exchangeable acidity (barium chloride/triethalonamine extract) in the Cornell Nutrient Analysis Laboratory (Cornell Nutrient Analysis Laboratory, 1989). A separate sample (hereafter referred to as "sampling B") was collected in March 1994 in 17 fields in San Francisco de Saco from the 2.5-5 cm depth, and analyzed for pH, P (Olsen Dabin III), exchangeable bases and total CEC at the soil natural pH (cobaltihexammine method Fallavier *et al.*, 1985) in CIRAD analytical laboratory in Montpellier (France).

5.2.3.2 Soil Organic Matter

Characterization of soil organic matter was approached in several ways. First, all 0-10 cm 1993 or 1994 samples, and a subset of the 10-30 cm samples were analyzed for organic C, total N and stable isotopes (^{13}C, ^{15}N) content using a Europa Scientific Roboprep C/N analyzer coupled to a Tracermass mass spectrometer (Europa Scientific, Crewe. Cheshire, England). Also, organic carbon distribution in the soil profile was determined by collecting composite samples from 36 observation plots (17 fields) by 2.5 cm increments (from 0 to 15 cm depth, as part of sampling B). On these air-dried samples, organic C was determined by a classic Walkey and Black procedure (Nelson and Sommers. 1982). A subset of these samples (3 complete 0-15 cm profiles from check plots or young mucuna fields, and 3 profiles from old mucuna fields) was further subjected to two fractionation schemes: one chemical by acid hydrolysis (Stewart *et al.*, 1963; Egoumenides, 1989), and one physical (Feller *et al.*, 1991; Feller, 1994). The physical fractionation consisted of a ball-assisted, mechanical water dispersion, followed by the separation of two fractions by wet sieving fine (< 50µ) and coarse (50-2000 µ). Total C and N was determined for each fraction using an automated C/N analyzer

5.2.3.3 Physical properties

All 1993 samples were analyzed for texture using the Bouyoucos method (Gee and Bauder. 1986). Granulometry for sample B was determined following aggregate destruction by an ultrasonic treatment

Infiltration was measured in 7 fields (sampling C) covering the entire chronosequence in San Francisco in January 1994, using portable rainfall simulators/infiltrometers calibrated to deliver a constant 100 mm.hour^{-1} via small capillary drip tubes on an area of 25 x 25 cm2 (Ogden *et al.*, 1996). Eight positions were selected in each field (4 backslopes, 4 shoulders). in each position, infiltration was measured in a pair-wise fashion, with or without mulch, this latter condition being created by gently removing the mulch present above the soil. A Tecktronics cable tester was coupled to the infiltration measurement to evaluate initial wetness of the upper profile as well as water storage in the 0-5 cm layer after one hour of rainfall application.

Macroporosity was determined for the same fields and positions (sampling C) using a sand table methodology (Ball and Hunter, 1988; Topp *et al.*, 1993). Suctions applied ranged from 0 (fully saturated sample) to -10 kPa (100 cm of waterhead), corresponding to pore sizes between 15 and 390 µm. The undisturbed cores used for this study (6.7 cm diameter x 7.5 cm height) were collected from two depths, 1-8.5 cm and 11-18.5 cm, using a hammer-driven core sampler. Bulk density was determined on the same samples by oven-drying the cores for 48 hours at 110 °C (Blake and Hartge, 1986)

5.2.4 Other measurements

To be able to relate of soil properties to plant response and crop management factors, data was collected in each observation plot on mucuna biomass production and nutrient content at slashing time, maize yield and yield components, and farmers' practices (see details in chapters 2 and 3). Also, slope, orientation and approximate elevation were determined for each observation plot, as a way of controlling for a few commonly encountered sources of variability in hillside environments

From the onset of the study, logistical constraints dictated that data collection be limited to selected soil chemical and physical properties. Consequently, soil properties such as soil structure and soil biological properties were left undocumented.

5.2.5 Data analysis

Data was analyzed for trends associated with the length of time individual observation plots had been in the mucuna rotation. Plots were grouped in six age classes as follows class 0 for plots without mucuna; class 1 for plots in their first or second year into the rotation (establishment phase); class 2 for plots in their third or fourth year, class 3 for plots between their fifth and seventh year, class 4 for plots between their eighth and tenth year; and finally class 5 for old mucuna fields with 11 years or more into the rotation. Age classes rather than actual years were used first of all because they better reflect the degree of precision attached to the determination of field history (see section 5.3.1) Also, interpretation is easier, because age classes are agronomically more meaningful than individual years. For example, farmers recognize that it takes one to two years to get mucuna properly established in a field, and hence class 1 represents the establishment phase of the rotation As time passes, differences from one year to the next are less and less pronounced, and hence lumping together 3 or more years becomes justified Finally, because sample size based on individual years was frequently very small, and furthermore very heterogeneous, grouping together several consecutive years allows for more accurate averages, and more solid comparisons between classes

Most long-term trends in soil fertility were detected qualitatively, by plotting a given soil property against time spent in the mucuna/maize rotation (the latter being some times referred to as the *age* of the field). Statistical tools such as analysis of variance, multiple regression or mean separation were applied whenever possible, although resolution of most tests was low given the high levels of variability found in the data and the small sample sizes involved As pointed out in chapter 2, chronosequences are most useful at generating hypotheses, not at testing them. Also, because data collection was at the same time more intensive and better controlled in San Francisco de Saco than in any other site, the subsequent analyses will emphasize these results, using the other three sites as a way of evaluating the general validity of the findings.

A word of caution is necessary about the general interpretation of trends in a chronosequence We will hereafter infer long-term trends by comparing among them the average or individual values measured on the plots making up the various age classes, *assuming that the chronosequence is a valid way of identifying these trends, whether or not this is indeed true* The potential bias introduced in the analysis varies with each site and age class, as they have been obtained independently from each other, and hence may each (mis)represent the typical trajectory of the mucuna/maize rotation over time in their own peculiar way. Also, it should be kept in mind that the plots without mucuna, which are conceptually the equivalent of a check treatment in a controlled experiment, do *not* however represent a fixed set of initial conditions First, the limited number of check plots included in this study precluded their further stratification into sub-classes corresponding to different lengths of the previous fallow for example. Consequently, check plots may exhibit low soil fertility (as could be expected in plots submitted to repeated cycles of mulchless farming, or extensively grazed by cattle) as well as good soil fertility if fallowing balanced the decline in fertility due to previous cropping for example (Nye and Greenland, 1960). Hence, a significant variability for any soil property measured on check plots as well as carrying over to young mucuna plots may be expected above and beyond that stemming from the very nature of observational studies

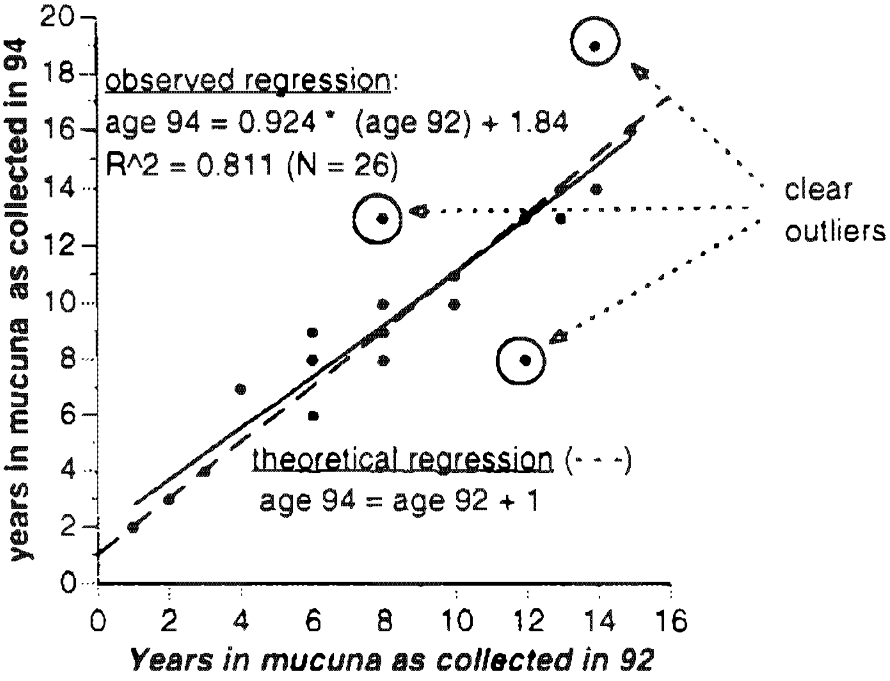
5.3 SCRUTINIZING THE CHRONOSEQUENCE SCHEME IN SAN FRANCISCO DE SACO

Because chronosequences are potentially ambiguous tools, we will examine in this section some of the inner construction of the chronosequence in the one site (San Francisco de Saco) for which the most detailed information was collected

5.3.1 Reliability of the recollection of field cropping history

Farmers' somewhat volatile recollections of cropping history and interview internal mechanics frequently cause data on cropping history to lack accuracy (Bartlett, 1932, Cutler III, 1970, Hoffman, 1974). To minimize this potential source of error, two interviews on cropping history were conducted with field owners, one at the onset of the study (November 1992) and one towards the end (July 1994). Comparative results for the length of time that fields had been in the mucuna rotation are presented in Figure 5.1 The regression on 26 fields is highly significant ($R2 = 0.81$, and $R2 = 0.93$ excluding the 3 clear outliers) and reflects correctly the fact that mucuna fields 'aged' between the two surveys Indeed, the regression does not differ significantly from the *expected* regression, assuming recollections were perfectly accurate from the start (age in 94 = age in 92 + 1), indicating that on average, farmers kept an accurate account of field history There are however a few obvious outliers (Figure 5.1), corresponding to fields whose declared age did change markedly from one survey to another

The conclusion is that while reasonably accurate, our dating of the different fields is approximate, not exact. Hence, analyzing the chronosequence in terms of age classes (comparing young mucuna fields to medium-aged to old mucuna fields) seems as legitimate as doing it in terms of individual years (1 year old vs. 5 vs. 12).



(Each point represents the results of a double interview for one field)

Figure 5.1: Comparative results of two successive recollections of field cropping history, San Francisco de Saco, 1992 and 1994 interview data

5.3.2 Cropping history prior to the establishment of the mucuna rotation

Initial conditions (Pickett, 1988), and particularly *cropping history prior to the establishment of a given rotation* (Sébillotte, 1989) can be of overwhelming influence in creating durable differences among the various components of a chronosequence. It is likely for example that a field presently without mucuna might potentially have been exposed to more degrading conditions (erosion particularly) over the past 10 years than what was the case for a similar field 10 years ago, by the simple fact that more years of mulchless annual cultivation have passed.

Evidence that past cropping history is not entirely similar between check plots and older mucuna fields is presented in Table 5.2. Many check plots have had one or more cycles of annual cropping prior to the cycle in which the sampling took place, whereas none of them was under medium or long-term fallow, contrary to a number of the older mucuna fields. Also, the proportion of fields which were used as pastures in the recent past is higher for the check plots than for any other group of fields. Overall however, the differences in prior history do not appear to be very large If not for the high frequency of previously cropped fields found in the check plots, the chi-square test would not detect any significant differences among age classes in their respective frequencies for the various precedents, meaning that all age classes are roughly equivalent in terms of their 'pre-mucuna' cropping history

Hence it can be concluded that the chronosequence scheme used in this study may present a slightly skewed picture of the trends over time, as the check plots (and to a lesser extent the more recent mucuna fields) present probably slightly more degraded conditions than the conditions prevailing in fields which entered the rotation 10 or 15 years ago In other words, our chronosequence analysis would have a built-in tendency to slightly *exaggerate* the effects of the mucuna rotation, based on cropping history alone

5.3.3 Ahistorical sources of variability

Most of the potential differences not related to cropping history (like those attached to topographic position or elevation) were *a priori* excluded from our sampling scheme Still, because we were dealing with a heterogeneous hillside environment, factors such as slope or orientation could have confused the historical analysis.

Table 5.2: Cropping history (by age class) of the fields selected for the chronosequence study prior to the onset of the mucuna/maize rotation, San Francisco de Saco Northern Honduras ($\chi 2 = 37.6$ with 25 df, significant at the 5% level)

class	# of fields	annual crops [1]	pastures [2]	short-term fallows [3]	med.-term fallows[4]	long-term fallows[5]	misc. [6] fallows
no muc	8	4	3	1	--	--	--
1-2 yrs	8	--	2	4	1	1	--
3-4 yrs	3	--	2	--	--	1	--
5-7 yrs	10	--	3	1	1	3	2
8-10 yr	13	--	4	5	1	1	2
≥ 11 yr	9	--	2	2	1	3	1
all fields	51	4	16	13	4	9	5

[1] maize (winter and/or summer) grown for one or more years prior to present cycle. [2] long-term pastures including degraded pastures (bushy vegetation regrowth). [3] 1 or 2 years of fallow. [4] 3-4 years of fallow. [5] 5 to 10 years of fallow. [6] undetermined duration of fallow, or special cases (wild banana and Guava fallows)

Indeed, check plots and to a lesser extent young mucuna plots were located on smoother slopes than all other plots on average (Table 5.3), a condition which could have affected the intensity of past erosion processes for example (with check plots being *less* susceptible to erosion than other plots). Differences in plot orientation were less pronounced (Table 5.3), although there was a tendency for check plots and young mucuna plots to have more of a Northern orientation whereas mucuna plots with more than 3 years into the rotation had a more South-Eastern one. Altogether, these differences appear to be relatively minor, and should not be a significant cause of noise in the chronosequence analysis

Table 5.3: Orientation and slope of the plots making up the chronosequence by age class, San Francisco de Saco, Northern Honduras

		<----- orientation of the plot [1]-------->				<--- slope ---->	
class	sample size	NE (0-90°)	SE (90-180°)	SW (180-270°)	NW (270-0°)	avg slope %	std dev slope
no muc	14	29%	29%	7%	36%	29	10
1-2 yrs.	12	67%	17%	0%	17%	38	22
3-4 yrs.	9	22%	56%	0%	22%	43	8
5-7 yrs	17	29%	47%	6%	18%	44	11
8-10 yr.	20	5%	75%	15%	5%	43	18
≥ 11 yr.	16	31%	50%	19%	0%	47	9
all fields	88	28%	48%	9%	15%	41	15

[1] figures represents the proportion of plots in each age class presenting a given orientation. NE = North-East. SE = South-East. SW = South-West. NW = North-West. Line Sum = 100%

5.3.4 Influence of topographic position on soil chemical properties

As indicated earlier, our sampling was limited to backslope topographic positions as a way of reducing potential sources of confusion. A limited study was however conducted in 4 fields to detect the representativeness of the backslopes compared to other commonly found positions such as footslopes or shoulders. Results indicated that there were no overall systematic trend in soil chemical properties associated with topographic position for the first two horizons (0-10 cm and 10-30 cm). For properties such as exchangeable Al and K, there were significant differences among positions but the ranking obtained was field-specific. For the deepest horizon (30-60 cm), exchangeable Al, Ca and Mg were higher for backslopes than for the other positions, although the differences were only moderate (0.33 vs. 0.12 vs 0.18 cmol(+) of Al, and 15.7, 11.7 and 13.5 meq of Ca for backslopes, footslopes and shoulders respectively)

Overall, the lack of consistency, or the limited extent of the few differences detected, indicates that backslope positions did not represent a soil chemical environment significantly different from that of other topographic locations, allowing cautious extrapolation of the chronosequence analysis based on backslope positions to the whole field.

5.3.5 Summary

By scrutinizing the very construction of the chronosequence in one site, we have been able to gain a better sense for the potential caveats associated with its use. For one thing, age of the different fields is known only approximately. Also, initial conditions found in the check plots included in this study such as cropping history, slope or orientation appear to differ from those existing in fields where adoption of the mucuna rotation took place a decade or so ago. This might have had or still have an unknown impact on some of the soil properties measured in this study.

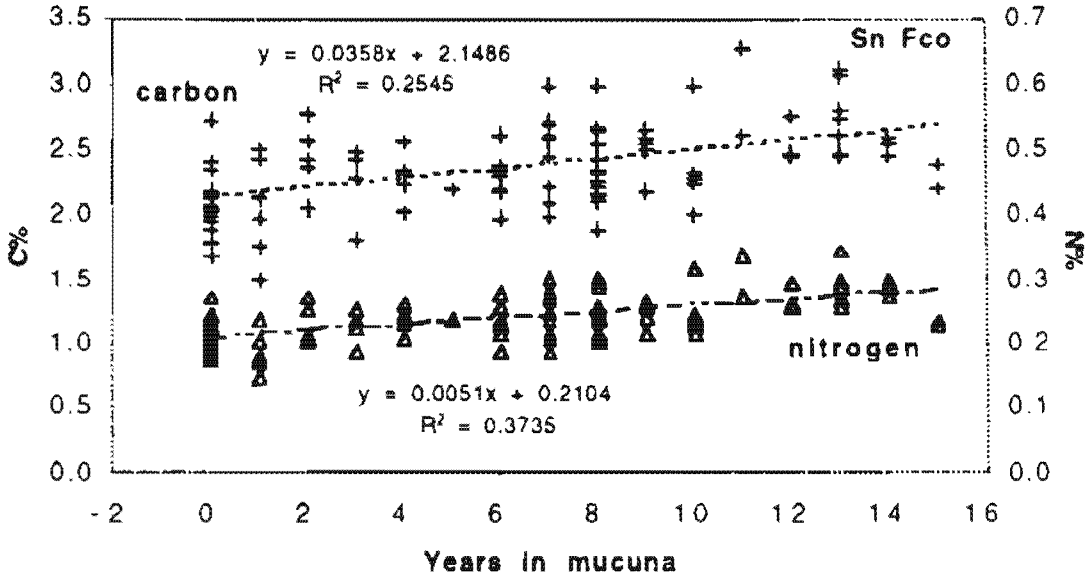
These findings are quite natural for an observational study, in which the experimental structure (i.e. the chronosequence scheme) is *superimposed* on a reality that lends itself only imperfectly to this manipulation. This does not invalidate our approach, it is however a reflection of the limits and risks such an approach entails, which have to be taken into account when interpreting and extrapolating the results of our study.

5.4 CHANGES IN SOIL ORGANIC MATTER

5.4.1 Overall changes in the 0-10 cm horizon

Changes over time in C and N content as well as in the C:N ratio of the 0-10 cm horizon (sampling A) are presented in Figure 5.2 for Sn Fco at the level of individual observation plots. As expected, the variability within each age class is high, but the trends exhibited by C and N content are sufficiently consistent to be statistically significant. In terms of averages, C% content increased from 2.11% to 2.5% over 11 years, an overall increase of 20% (1.7% yearly). The change in N content is stronger, from 0.21% to 0.28%, a 30% increase (2.5% yearly). This differential between the pace of N and C accumulation in the upper profile explains the slight decrease in the C:N ratio from 10 to 9.5.

On a regional basis, the tendencies observed in Sn Fco are not entirely confirmed in other sites. In a site such as Mangas, no change in C or N content appears to have taken place over time, whereas in Cuero, the changes seemed quite dramatic even after only 7 years in the mucuna rotation (Figure 5.3). Also, the levels of C or N found in the check plots vary significantly across sites, reflecting undoubtedly differences in edaphoclimatic conditions and perhaps also differences in agricultural history at the village level (the fact that San Francisco exhibited the lowest levels of both elements appears consistent both with its lower elevation and oldest human settlement).



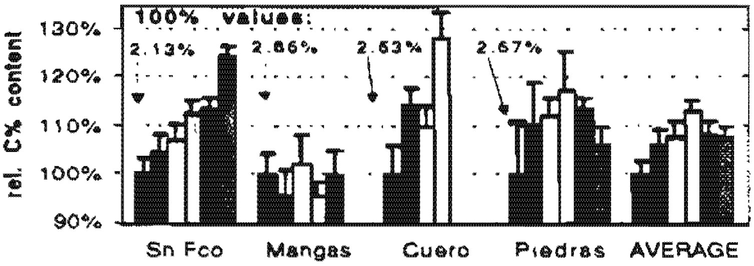
Each point represents one observation plot. Dotted lines represent LS regression lines

Figure 5 2 Changes in total C and N content of the 0-10 cm horizon over time under the influence of the mucuna system, San Francisco de Saco, Northern Honduras

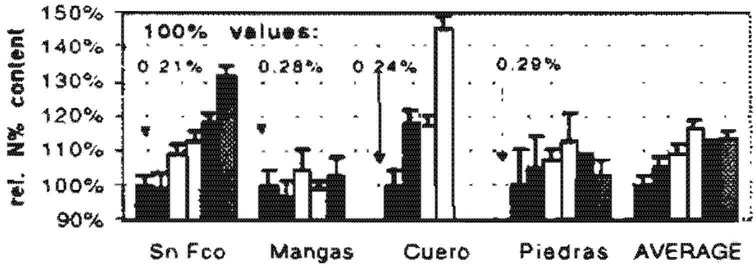
In all cases, no site exhibited a tendency for the older mucuna plots to have less C or N than the check plots Stated in a conservative way, it can be said safely that the mucuna rotation appears to allow conservation of the initial stocks of C and N in spite of continuous annual cultivation.

The fact that observed trends agree closely with agronomic theory (increase in the upper horizons, no change below) strengthens our contention that the chronosequence constructed in San Francisco de Saco is indeed a reasonable representation of the long-term behavior of the mucuna system.

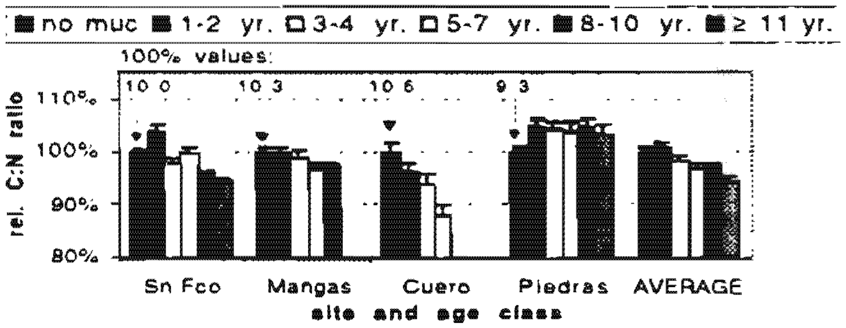
a. Changes in C% content



b. Changes in N% content



c. Changes in C:N ratio



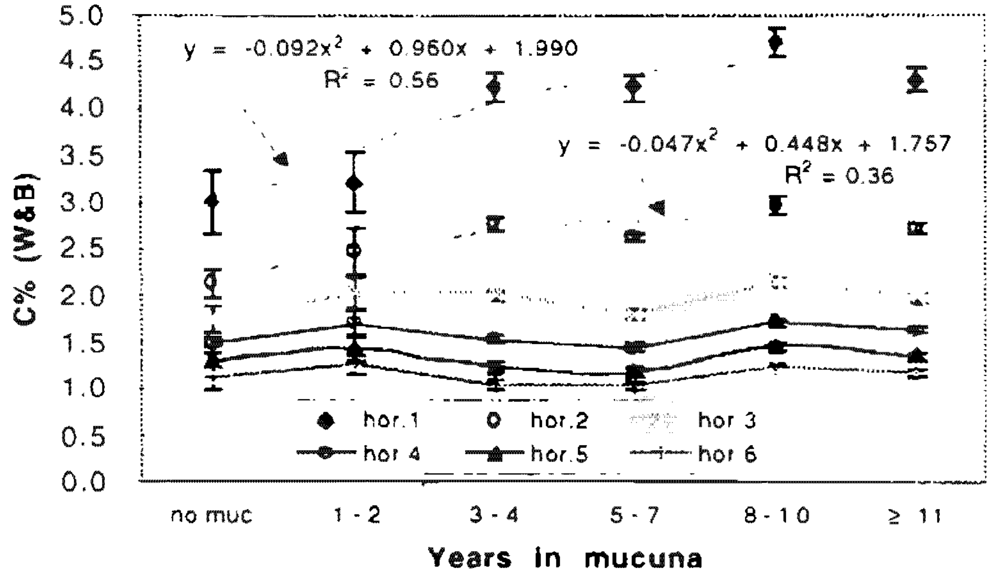
Each bar represents the average for a given age class and site, topped by it standard error.

Figure 5.3: Changes in total C and N content of the 0-10 cm horizon over time under the influence of the mucuna/maize rotation in four sites, Northern Honduras.

5.4.2 Distribution of SOM in the upper soil profile

In a no-tillage cropping system, changes in soil fertility are expected to affect mainly the top centimeters of the soil profile (Follett and Peterson, 1988, Barreto, 1989, Dalal *et al.*, 1991) To verify this in the case of the mucuna system soil samples were collected by 2.5 cm increments in the upper 15 cm of soil profile (sampling B). Figure 5 4 shows that it is indeed in the first 5 cm of soil profile that changes in carbon content were significant, and especially in the 0-2.5 cm layer, for which the relative increase reached about 50% over a decade (from 3% to 4.5%). For the 2.5-5 cm layer, the increase over the same period reached 40%, with a peak value of 2.8%. In both cases, it was possible to fit a second-degree polynomial to the data (R2 = 0.56 for the first layer, R2 = 0 36 for the second both regressions are highly significant).

The fact that the quadratic term is significant in these regressions would tend to indicate that there is a leveling-off of the carbon accumulation after about 9-10 years of rotation, as an equilibrium is reached (see 5.5 4). Conversely, no apparent increases were detected for layers between 7.5 cm and 15 cm, for which all plots presented fairly uniform C contents regardless of their age



Vertical bars represent standard errors. Hor. 1 = 0-2.5 cm, Hor. 2 = 2.5-5 cm, Hor.3 = 5-7.5 cm, Hor.4 = 7.5-10 cm, Hor.5 = 10-12.5 cm, Hor.6 = 12.5-15 cm

Figure 5.4 Changes in the distribution of organic C by 2.5 cm increment in the first 15 cm of soil profile over time under the influence of the mucuna/maize rotation, San Francisco de Saco, Northern Honduras

5.4.3 SOM pools

Although the above assessment reflected overall changes in terms of total C or N content, it didn't differentiate among the various fractions which make up total soil organic matter (Duxbury *et al.*, 1989; Christensen, 1992). Both a classical chemical fractionation scheme based on acid hydrolysis (Stewart *et al.*, 1963), and a physical one (after Feller, 1994), probably more satisfactory, as it relates conceptually to soil architecture (McGill and Myers, 1987, Christensen, 1992), were used to examine this latter issue. In this latter case, two fractions were distinguished: a fine fraction (particles < 50 µ) and a coarse fraction (particles > 50 µ). Detailed results are presented in Appendix D.1.

In a first step, only extremes of the chronosequence were contrasted, i.e. fields without mucuna or with one year into the rotation (hereafter referred to globally as check plots), vs. old mucuna fields: 14 to 16 years of continuous mucuna rotation (Table 5.4).

Table 5.4. Comparison of soil profiles of old and young mucuna fields vis-à-vis two methods of fractionation of soil organic matter, San Francisco de Saco, Northern Honduras, 1994.

← chemical → ← ------ physical fractionation ------------→

Age class	hori-zon	Nhd [1]	Nhnd /Nhd [2]	C% fine [3]	C% coarse [4]	C fine repart [5]	N% fine [3]	N% coarse [4]	N fine repart [5]
0-1 years	0-5	588	1.79	2.74	1.27	79%	0.280	0.082	85%
	10-15	390	1.52	1.41	0.32	90%	0.173	0.035	91%
≥ 14 years	0-5	965	1.79	3.34	3.39	80%	0.365	0.267	84%
	10-15	513	1.45	1.42	0.61	91%	0.191	0.050	95%

[1] hydrolizable distillable nitrogen. [2] ratio of hydrolizable non-distillable to hydrol. distil. nitrogen. [3] C% or N% in the fraction < 50 µm; [4] C% or N% in the fraction > 50 µm; [5] %C (%N) in fine fraction as a percent of C (N) in the sum of the fine and coarse fractions. *Each cell represents the mean of 6 values.*

The chemical fractionation scheme did not pick up any differential behavior between the various fractions distinguished by the acid digestion (Table 5.4). The physical fractionation on the other hand showed that the fine and coarse fractions behaved differently over time (Table 5.4 and Appendix D.1). Due to a confounding effect of texture on the results however, it remains unclear whether the change affected preferentially the coarse or the fine fraction. A preferential increase in the coarse fraction may indicate the accumulation of relatively free organic matter (perhaps even organic debris) at or very close to the soil surface. Conversely, a preferential increase in the fine fraction as observed when limiting the analysis to mucuna fields less than 10 years old (Appendix D 1) would indicate the formation of relatively stable organic matter, as it is intimately bound to the mineral fraction (Tisdall and Oades, 1982).

5.4.4 Rates of changes in SOM

The actual dynamics of change in carbon and nitrogen content over time can be expressed in terms of mean rates of changes for the 0-10 cm horizon in the four villages, either on a relative basis (%) or on an absolute basis (kg of C or N per hectare) (Table 5.5). The calculations are somewhat imprecise, as they were based on average values obtained for C and N content for each age class (see formula on top of next page).

Table 5.5 Annual rates (relative and absolute) of changes in carbon and nitrogen content of the 0-10 cm soil profile in four sites in the mucuna/maize rotation, Northern Honduras

For each cell, the first line is expressed as percent change, whereas the second is on a mass basis (gain of C or N in kg/ha/year for the horizon. A negative sign indicates an apparent decrease)

	carbon content			*nitrogen content*		
site	mean rate [1]	max rate [2]	min. rate [2]	mean rate [1]	max rate [2]	min rate [2]
Sn Fco	1.9% (436)	5.9% (1376)	-1.0% (-253)	2.5% (58)	3.5% (83)	1.2% (32)
Man-gas	0.6% (185)	3.2% (965)	-2.6% (-842)	0.9% (27)	3.9% (116)	-2.2% (-68)
Cuero	4.9% (1369)	9.6% (2673)	-1.8% (-572)	7.8% (206)	12.4% (327)	-0.6% (-20)
Pie-dras	0.5% (161)	5.3% (1546)	-1.9% (-618)	0.3% (9)	2.8% (90)	-1.6% (-59)
all sites	*2.0%* *(538)*	*5.5%* *(1493)*	*0.1%* *(- 24)*	*2.9%* *(75)*	*5.0%* *(135)*	*0.5%* *(09)*

[1] mean rate refers to apparent average annual rate of change in C or N content since the introduction of mucuna in each site. [2] maximum and minimum rates observed between any two consecutive age classes (from class n to class n+1)

Rates in Table 5.5 were calculated according to the formula $\frac{Y_n - Y_{n-1}}{t_n - t_{n-1}} * \frac{A}{Y_{n-1}}$,

where Y_n is the average C or N% of class n ($n \in \{1, 5\}$), t_n is the average age of the age class, and A = 1 for rates in %, and A = mass of soil for rates in $kg.ha^{-1}$.

Estimated rates differ markedly among sites, from a low of 0.5% in Piedras, to a high of nearly 5% in Rio Cuero. This latter seems rather improbable, because mucuna does not appear to produce sufficient biomass to generate the physical quantities of carbon or nitrogen that these rates would imply, if, following Larson et al. (1972), one considers that about 10% of the carbon present in returned residues eventually ends up in the profile. Applying such an estimate to the Rio Cuero case, about 25 to 30 t of biomass would have been needed annually (cf. mucuna biomass is about 40 to 45% carbon), vs an actual 10 to 12 $t.ha^{-1}$. The average across sites however seems to provide a value (538 $kg.ha^{-1}$ of C) at least roughly consistent with biomass production. Similarly, the mean annual rate of accumulation of nitrogen (75 $kg.ha^{-1}$) seems a reasonable figure. Interestingly, the maximum annual rates of change calculated between consecutive age classes were generally obtained in the first few years following the introduction of the mucuna rotation, while the minimum rates (some seemingly negative) were generally observed for the oldest mucuna fields. This evidence may again indicate that the mucuna system is reaching an equilibrium state 8 to 10 years after its introduction in a given field.

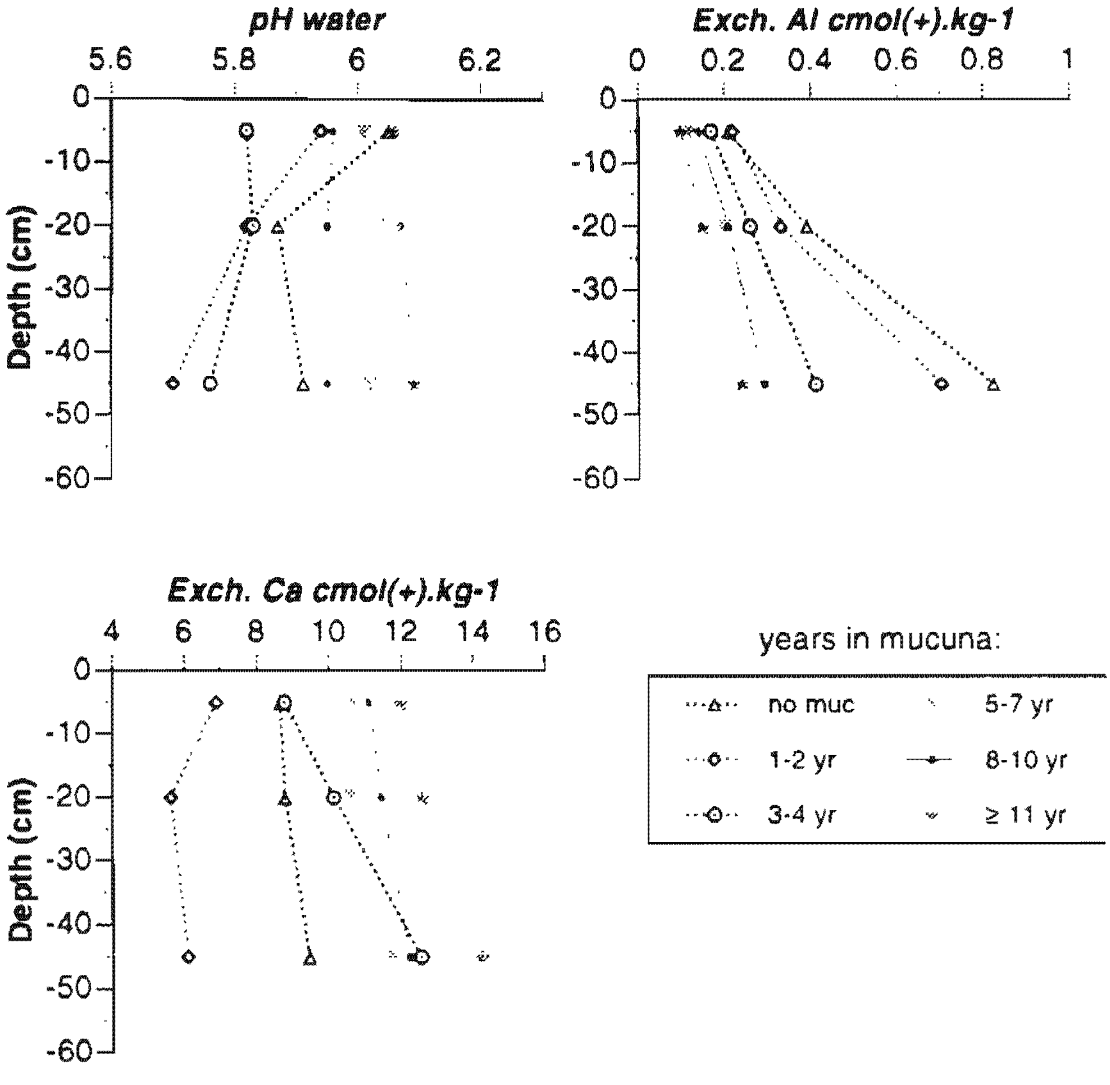
5.5 CHANGES IN SOIL CHEMICAL PROPERTIES

5.5.1 pH, exchangeable Ca and Mg, and soil acidity

At the very inception of this study, it was hypothesized that in a wet tropical environment, potential imbalances between an ample supply of nitrogen by the mucuna biomass and moderate uptake by the maize crop might rapidly induce significant nitrogen leaching along with its accompanying cations, leading eventually to soil acidification (Bouldin, 1989; Cahn *et al.*, 1993).

Soil test results for both pH and exchangeable Ca and Al do not however present any evidence to support these fears (Figure 5.5 and 5.6). In San Francisco de Saco, after 15 years of continuous use of the mucuna rotation, pH appears to have remained fairly constant in the entire soil profile (up to 60 cm), with even a slight (not significant) tendency for pH to increase over time (Figure 5.5). There were significant differences in pH among sites (from a low site average of 5.7 in Cuero, to a high of 6.5 in Mangas), but not among age classes (Figure 5.6 a).

Levels of exchangeable Ca (Table 5.6 and Figure 5.6 b) and Mg appear to have increased over time at all depths in 3 out of 4 sites. Piedras was the only site with no consistent trend over time, whereas in San Francisco, the increase was particularly clear ($p < 0.001$).



Each point represents the age class average for each horizon.

Figure 5.5: Changes in pH, exchangeable Ca and Al over time in the 0-60 cm soil profile under the influence of the mucuna/maize rotation, San Francisco de Saco, Northern Honduras.

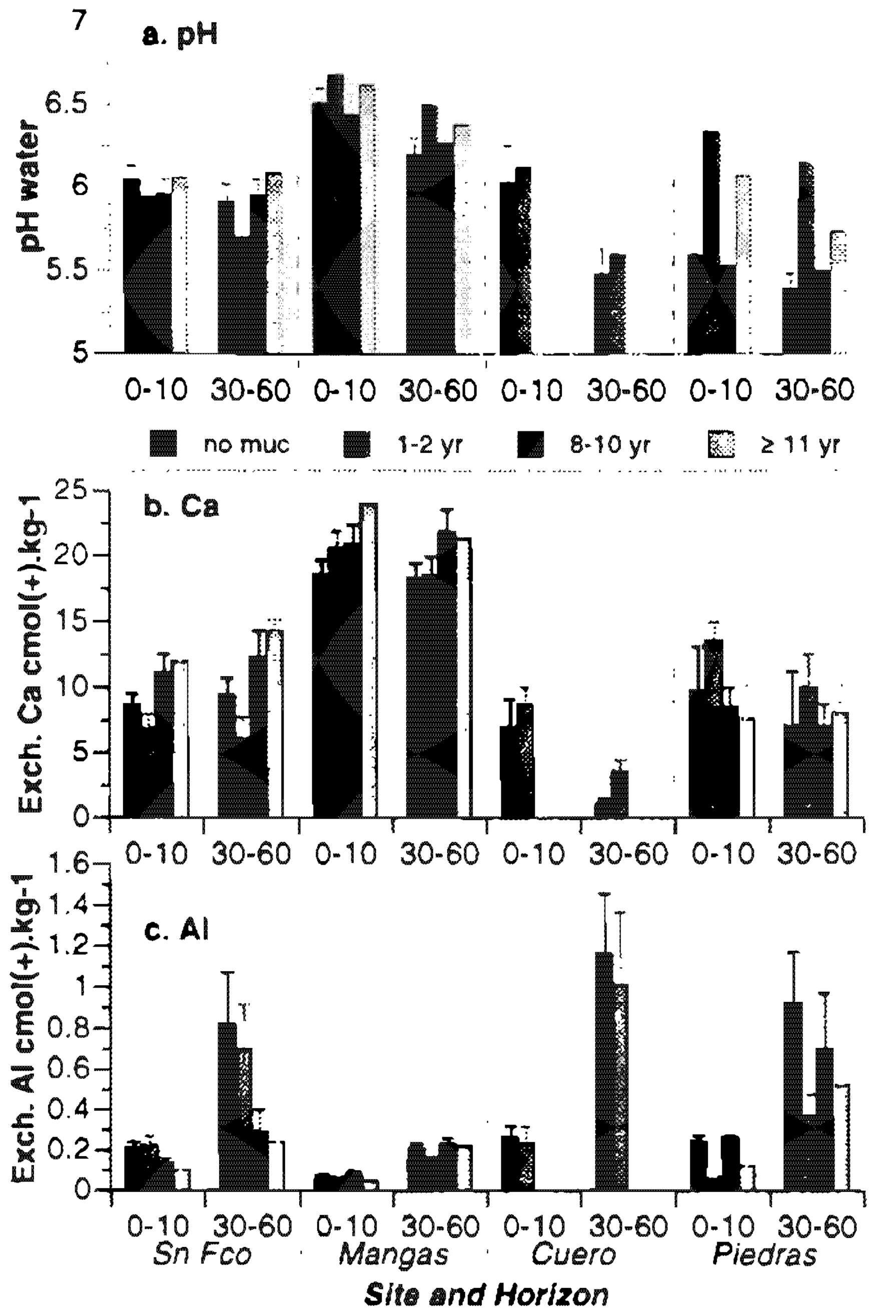


Figure 5.6 Changes in pH, exchangeable Ca and Al over time in the 0-10 and 30-60 cm horizons in four sites under the influence of the mucuna/maize rotation, Northern Honduras

Table 5.6 Changes in exchangeable Ca and Mg content (in cmol(+) kg^{-1}) over time in the 0-10 cm horizon in four sites, Northern Honduras

element	site[1]	no muc	1-2 yrs	3-4 yrs	5-7 yrs	8-10 yrs	≥ 11 yrs
Exch. Ca	sfs	8.7	6.9	8.8	10.7	11.1	12.0
	mg	18.6	20.6	19.4	18.9	20.9	(23.9)[2]
	cu	6.9	8.7	7.5	8.4	--	--
	pi	9.8	13.6	11.8	10.2	8.5	7.6
Exch Mg	sfs	2.9	2.1	3.3	3.4	3.7	3.9
	mg	4.1	4.5	4.3	3.9	5.3	(5.7)[2]
	cu	1.8	2.2	2.2	2.7	--	--
	pi	2.6	4.4	4.0	3.5	3.0	3.2

[1] sfs = Sn Fco. mg = Mangas. cu = Cuero. pi = Piedras; [2] one sample only in Mangas for this age class

This increase, also observed in other mulched systems (Lal, 1989, Hulugalle *et al.*, 1990) may be attributed to the large yearly additions of calcium and magnesium via the mucuna biomass (reaching more than 150 kg ha^{-1} year^{-1} for Ca, or the equivalent of more than 0.6 cmol(+) of Ca if applied to the 0-10 cm horizon). How and from what source does the mucuna crop mobilize this Ca remains a matter of speculations. Also, the fact that the increase apparently affected all depths would indicate that cations (and hence accompanying anions such as nitrates: Cahn *et al.*, 1993) do migrate down the profile over time (but not necessarily out of it), as there does not seem to exist a source of Ca or Mg capable of supplying them to the soil profile other than the litter.

Given the pH and exchangeable bases values, it was logical to find very low levels of exchangeable Al throughout the soil profile (Figure 5.5c). The few cases in which Al concentrations were high were associated with instances of low pH, low base status, something not uncommon in Cuero, but almost absent in the other sites (Figure 5.6c).

The absence of soil acidification is consistent with the observations made in Chapter 4, which indicated that whereas availability of potentially leachable Ni was high during the maize cycle, inorganic N leaching was seemingly fairly small.

5.5.2 Other exchangeable bases

In all sites, levels of exchangeable K were roughly similar and seemed to remain fairly stable over time, around 0.2 to 0.4 cmol(+).kg^{-1}.

Exchangeable sodium was not analyzed in this study, except on a limited number of samples (sampling B, San Francisco de Saco). As for potassium, levels seemed roughly stable, remaining close to 0.5 to 1 cmol(+).kg^{-1}. These high levels may indicate that the soils are fairly young, having had little time to weather (Oliver, pers. com.)

5.5.3 Phosphorus

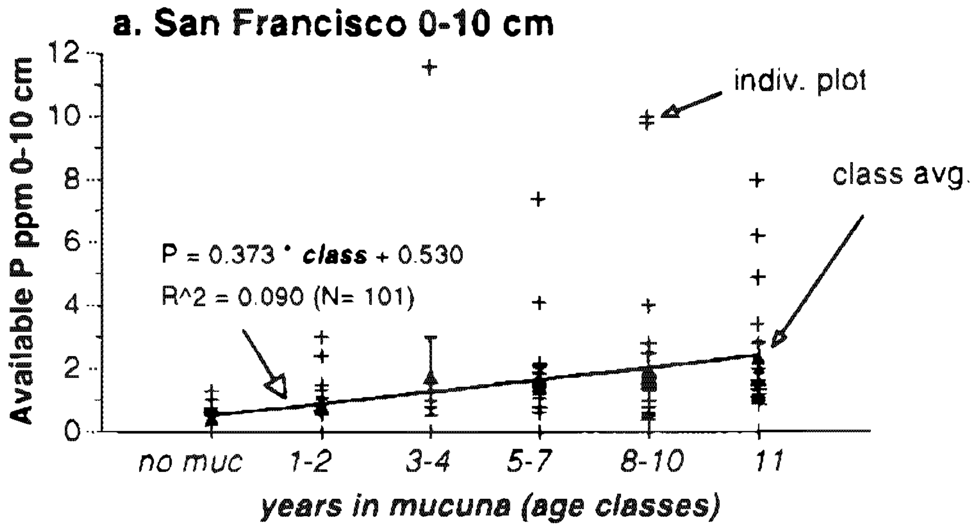
Together with nitrogen, phosphorus is a very common limiting factor in crop production throughout the tropics, and in systems including a legume as the N source, it freequently becomes a major obstacle to the obtention of sustained yields over long periods of time (Schlather, 1996). Hence maintaining an adequate supply of available P over time is a critical concern in the mucuna system.

Results with an Olsen extraction on a small number of samples (San Francisco only) indicated that P availability seemed to have remained fairly constant over time, with levels around 15 to 20 ppm in the upper soil profile (data not shown). There was however a sizable variability among sites when trends were examined using a Morgan extraction (Figure 5.7). In San Francisco de Saco, there seemed to be a consistent yet small increase in P availability over time in the 0-10 cm horizon ($P < 0.003$), although all values were very low (average for the site less than 2 ppm) (Figure 5.7.a). In Las Mangas, the P levels were markedly higher than in any other site (average about 7 ppm) and seemed to remain stable over time. In Cuero, there was a small, but not significant decrease over time, whereas in Piedras, no consistent tendency could be detected (Figure 5.7b)

Pooling these different pieces of evidence together, it can be concluded in a conservative manner that P availability seems to remain fairly stable over time in the mucuna system, in spite of yearly exports (via harvest) amounting to approximately 15 to 20 kg ha^{-1} year^{-1}. As for all other nutrients, decomposition of the mucuna biomass is a major source of available P: yearly additions of P via the above-ground biomass reach about 15 to 20 kg.ha^{-1} (chapter 4)

5.5.4 Other nutrients

Table 5.7 presents the results obtained for the changes in micronutrient content (Fe, Zn, Cu, Mn) over time in the various sites. Even though the average levels of each nutrient were variables among sites, there was no consistent tendency detected over time within each site. Here again, a safe conclusion would be to conclude at the stability of availability of the micronutrients in the mucuna system



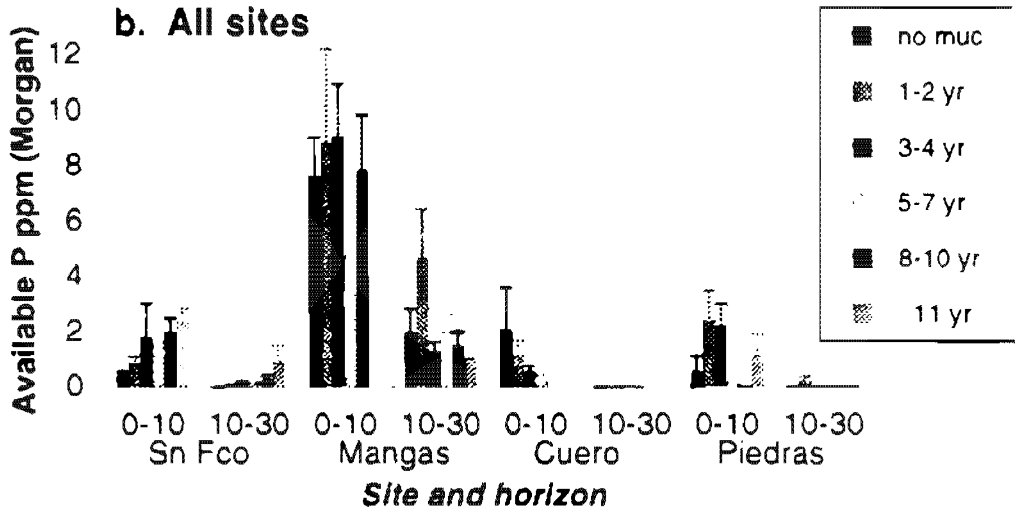


Figure 5.7. Changes in levels of available P (Morgan) over time under the influence of the mucuna/maize rotation, Northern Honduras. a 0-10 cm horizon, San Francisco de Saco, b. 0-10 and 10-30 cm horizons, all sites

Table 5.7: Changes in micronutrient content over time in the 0-10 cm horizon in four sites, Northern Honduras

element	site	no muc	1-2 yrs	3-4 yrs	5-7 yrs	8-10 yrs	≥ 11 yrs
Fe	sfs	1.9	1.5	2.1	1.5	2.1	1.5
ppm	mg	0.5	0.5	0.6	0.5	0.7	(0.0) [1]
	cu	0.7	1.1	1.3	0.7	--	--
	pi	2.4	0.6	0.4	0.5	5.2	1.7
Mn	sfs	41	78	55	63	76	75
ppm	mg	46	33	42	43	71	(49) [1]
	cu	103	75	85	103	--	--
	pi	14	27	37	35	20	29
Zn	sfs	0.6	1.7	0.9	1.4	1.4	1.2
ppm	mg	0.5	0.8	0.8	0.6	0.6	(0.1) [1]
	cu	0.7	0.9	0.8	1.6	--	--
	pi	0.8	1.7	4.0	2.8	0.4	0.6

[1] one sample only in Mangas for this age class

5.5.5 Summary

A conservative conclusion from this examination of changes in soil chemical properties is that the continuous use of the mucuna system is not accompanied by a depletion of the available nutrients in the soil profile, at least within the time frame adopted for this study (10 to 15 years). This maintenance of the resource base (or increase, in the case of Ca or Mg) occurred in spite of consequent yearly exportations of nutrients in the maize harvest. In the case of phosphorus, exports amounted to approximately 15 to 20 $kg.ha^{-1}.year^{-1}$ (average P content of the grain 0.53%, average maize yields of 3-4 $t.ha^{-1}$). Hence, there has to be a mechanism allowing the mobilization/extraction of non-available nutrients from the soil matrix. The mucuna crop is a prime candidate for fulfilling this function, via the capture of nutrients in its biomass. It has been demonstrated elsewhere (Schlather, 1996) that fallow species (including mucuna, which is a special case of fallow), can extract unavailable P.

5.6 CHANGES IN SOIL PHYSICAL PROPERTIES

Historical trends were analyzed for one site only (San Francisco de Saco), and for a subsample only (sampling C, made up of 7 fields) of the fields analyzed for chemical properties or soil organic matter. As could be expected for soil physical properties measured on a micro-scale, within-field variability was fairly high, creating a high level of background noise in the analysis (see Horowitz, 1995). For example, time to run-off for a given field varied from a few minutes to not detected after an hour of infiltration, whereas bulk density could vary by as much as 30% within a given field. This situation, combined with the limited sample size (one to two fields only for each age class) and geographical coverage makes the analysis presented below akin to a semi-qualitative assessment of the changes over time.

5.6.1 Soil erosion

No quantitative assessment of soil erosion was conducted. Some general comments are in order however, given the overwhelming importance of soil erosion in hillside farming.

The characteristic signs of erosion at the field scale were virtually absent even in the oldest mucuna fields (more than 15 years of continuous cultivation). Gullies or rills were seldom observed, except for very localized areas where rill erosion seemed more a result of marginal management errors than anything else. Also, the upper horizon did not present the typical enrichment in coarse material associated with significant surface run-off (Foster *et al.*, 1985). And the chemical analyses (section 5.5) demonstrated there was no depletion of nutrients over time, and that the upper profile was accumulating actively organic matter, and was comparatively much richer in nutrients than the underlying horizons, observations which all point to the absence of active erosion.

On a larger scale, small creeks collecting water at the bottom of slopes cultivated in the mucuna rotation remained very clear even during or after intense rains, in contrast to what could be observed in neighboring unprotected slopes, for which the sediment load was usually high.

There is one issue however for which evidence is more difficult to interpret. As much as 40% of farmers interviewed by Buckles et al. (1992) reported that the mucuna system might induce localized landslides in areas of very steep slopes (superior to 60-70%). Discussion with farmers confirmed that such landslides occur once in a while (not every year) during the peak of the rainy season (anytime between September and November), under very heavy rainfall conditions (several hundred mm in a few days: see Figure 3.3). A possible explanation would include a combination of the heavy weight of the wet mucuna biomass, a loosening of the upper soil profile as a result of the shallow rooting habits of the mucuna plant, and/or a state of supersaturation of the soil resulting from increased infiltration (see later), inducing a lower shear strength and higher overburden weight (Van Es, pers. com.). Some farmers also indicated that landslides might result from the lack of deep rooting or anchoring caused by the substitution of the traditional bush-fallow rotation for one with a fairly shallow-rooted species such as mucuna. The fact that mucuna can effectively suufocate trees if left unpruned (in much the same way as it suffocates weeds) may contribute to this phenomenon.

But these alleged mechanisms are not completely convincing. A first argument consists in recognizing that the landscape in the mountains of Northern Honduras appears to be geologically very young, having not yet fully stabilized. Hence there are numerous areas where mass redistribution continues to take place "spontaneously", and sectors of abrupt slopes are among the prime candidates for being affected by this gravity-driven redistribution process (whether such a landscape should ever be subjected to large scale cultivation is definitely a relevant question). Also, one could argue that when quantities of water pouring on any landform reach hundreds of mm in a few hours or days, something dramatic is poised to happen, and the actual role of the mucuna cover in causing a landslide is probably insignificant compared to the role played by the sheer masses of water obliged to find their way downhill. This may explain why, landslides when they take place affect lands under all kinds of land use, from virgin forest to pastures to fields cultivated without mucuna, without obvious preferential impact on any one category of land use. This could clearly be seen in November 93 when 400 to 700 mm fell in a 15 hour period on October 31st, causing countless landslides in the hillsides.

In all cases, the issue seemed important enough to warrant addressing it in a general survey of the mucuna system conducted in the summer of 94. Farmers were specifically asked about the occurrence of landslides in their fields prior to and after the introduction of the mucuna rotation. Of 34 fields having suffered from landslides (out of a total of 44 fields included in the survey), 62% (21) had had similar problems before mucuna was ever introduced. Furthermore, only 1/3 of the farmers did incriminate mucuna in the occurrence of landslides. Perceptions varied strongly from village to village: in Piedras, where landslides are common, farmers coincided in blaming mucuna for making things worse, whereas in San Francisco de Saco, where landslides are rare, most experienced mucuna users actually vehemently opposed this view.

In summary, it is fair to say that globally, the mucuna system is extremely efficient at preventing erosion damage, thanks to the creation and year-round maintenance of a thick mulch protecting the entire soil surface from the direct impact of rain drops and its consequences. With regard to the landslide issue, evidence remains inconclusive in either direction, and further assessment is needed.

5.6.2 Bulk density & macroporosity

5.6.2.1 Bulk density

Bulk density was measured at three depths: 1-8.5 cm, 11-18.5 cm and 41-48.5 cm (this latter sampling in conjunction with inorganic N monitoring: see chapter 4). As a preliminary step, the relationship between gravimetric moisture content at the time of sampling and bulk density must be considered briefly, as these two variables were strongly related (Figure 5.8): the r-square reached 0.7 on 75 samples for horizon 1, and 0.43 for horizon 2 ($p < 0.001$ in both cases). Measured bulk density values were consistently *lower* under high moisture content (i.e. shortly after a good rain), and vice versa. This may be related to the marked tendency for soils in San Francisco de Saco to shrink or swell in response to dry or wet moisture conditions, respectively. In a swollen state, measured bulk density values would tend to be lower, and higher when shrunk, a condition further reinforced by the fact that large visible cracks were systematically avoided during sampling. As clay composition or soil organic matter content were not analyzed on the cores, and as sampling could not be redone, this hypothesis remains untested, and it is not possible to rule out a measurement artifact.

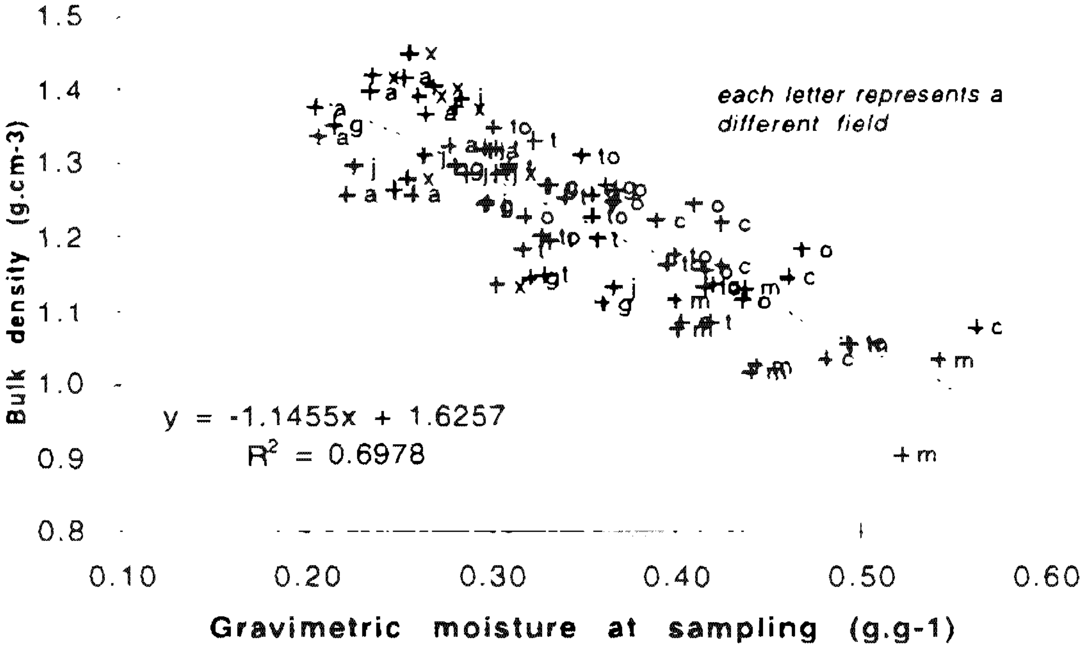


Figure 5.8: Relationship between gravimetric moisture at sampling and bulk density in the 0-10 cm horizon, San Francisco de Saco, Northern Honduras.

With respect to the effect of time in the mucuna rotation, it was found that for all three horizons sampled, average bulk density values at the field level tended to decrease over time (Table 5.8). In the first horizon, bulk density dropped sharply from an initial value of 1.35 to about 1.20 in old mucuna fields (the regression of bulk density on years in mucuna was highly significant, with $p < 0.01$). For the lower horizons, the drop was smaller: from 1.40 to about 1.32 in horizon 2 (NS) and from 1.45 to 1.37 in the third horizon ($p < 0.04$). These trends are consistent with the measured increase in soil organic matter content over time, and also with the qualitative increased "looseness" or "softness" of the upper profile reported by farmers.

Table 5.8 Changes in bulk density over time for the 0-10 cm and 10-20 cm horizons in the mucuna/maize rotation, San Francisco de Saco, Northern Honduras

horizon	0-10 cm	10-20 cm	40-50 cm
no mucuna	1.36 ± 0.145	1.41 ± 0.065	
1-2 years	1.32 ± 0.066	1.32 ± 0.072	1.45 ± 0.022
4-7 years	1.20 ± 0.075	1.32 ± 0.124	1.40 ± 0.067
8-11 years	1.28 ± 0.083	1.37 ± 0.066	1.42 ± 0.076
≥ 12 years	1.20 ± 0.091	1.33 ± 0.064	1.37 ± 0.070

Each value represents the average for a given age class and depth, followed by its standard deviation

5.6.2.2 Macroporosity

Regardless of what happened to the total porosity (as reflected in the bulk density figures), shifts in the distribution of pores of different sizes may take place as a result of mucuna use. This hypothesis was examined by quantifying the porosity associated with pore sizes ranging from a diameter of 0.395 mm for the largest to about 0.015 mm for the smallest. The study was conducted in the same fields and approximate positions within each field for which infiltration was measured.

Reflecting the changes in bulk density, total porosity increased over time, especially in the 0-10 cm horizon. Furthermore, there was an initial increase both in the porosity above 15 µm and above 133 µm following the introduction of the mucuna rotation (from less than 8% of the soil volume to about 10%, and from about 3% to about 5% respectively), after which the values obtained remained virtually stable (Table 5.9, Figure 5.9). For the second horizon, with the exception of one one-year old mucuna field presenting a higher porosity than any other field, porosity was essentially identical for all fields, and quite high in all cases. The same data can also be analyzed in terms of the *relative* pore size distribution for the various fields and age classes. In both horizons, the porosity above 133 µm increased from about 40-42% to about 55% of the porosity above 15 µm, whereas conversely, the porosity between 15 and 133 µm decreased from 58-60% to 45%.

Table 5.9: Changes in soil porosity over time, San Francisco de Saco

(values expressed in % soil volume occupied by each pore size class)

pore class → Age class	*horizon 0-10 cm* total poros [1]	 pores ≥ 15 [2]	 pores ≥ 133 [2]	 pores ≥ 395 [2]	*horizon 10-20 cm* total poros	 pores ≥ 15	 pores ≥ 133	 pores ≥ 395
no mucuna	49.0%	7.6%	3.2%	1.0%	47.0%	9.5%	3.8%	1.4%
1-2 years	50.7%	10.3%	5.6%	2.2%	50.5%	11.5%	6.2%	2.1%
4-8 years	54.7%	9.7%	5.2%	1.5%	50.3%	10.7%	5.7%	2.2%
≥ 12 years	54.6%	9.4%	5.3%	2.2%	49.7%	8.6%	4.7%	1.9%

[1] total porosity based on bulk density values
[2] soil volume occupied by *all* pores greater than 15, 133 and 395 µm, respectively

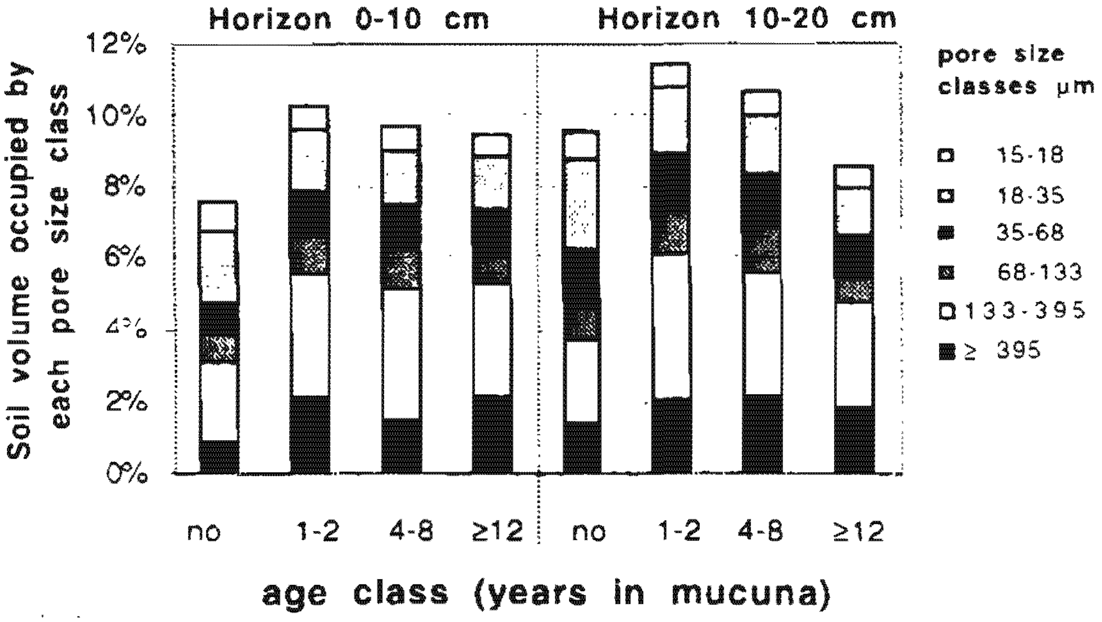


Figure 5.9: Changes in macroporosity (pores > 15 µm) over time in the 0-10 and 10-20 cm horizons under the influence of the mucuna/maize rotation. San Francisco de Saco, Northern Honduras

It should be noted that the only check plot sampled in this study was probably not very representative of the usual conditions found in fields without mucuna: it had been in long-term pasture (likely to induce a certain compaction of the upper horizon) rather than in arbustive fallow. Hence the apparent increase in porosity associated with the largest pore sizes might not be widely extrapolable. What however is most striking is that the mucuna rotation appears to allow the *maintenance* of a extensive array of large pores, without any tendency for degradation of this favorable architecture over time.

5.6.3 Infiltration

Of the various variables measured during the infiltration study, *steady-state infiltration rate* is the parameter most directly related to a intrinsic profile property (Hillel, 1982). It was observed that these rates increased markedly with time spent in the mucuna/maize rotation (Figure 5.10), even though variability within and between fields was quite high (see also Horowitz, 1995).

Most other variables related to the infiltration process (such as run-off rates or time to run-off) depend on the measurement protocol, and particularly the choice of a rainfall intensity (about 100 mm hr^{-1}) and hence their meaning cannot be easily extrapolated. Besides time spent in the mucuna rotation, a number of factors and conditions *unrelated to plot history or rainfall rate* may potentially influence infiltration rates in this study. we considered slope, topographic position (shoulder vs. backslope), presence or absence of a surface mulch (this latter condition being created artificially immediately prior to the application of water), and initial upper profile wetness as possible codeterminants of infiltration rates. Average values taken by these variables for the different ages included in the sample of fields are presented in Table 5.10.

Of the possible codeterminants of infiltration rates unrelated to plot history, only topographic position and initial profile wetness were found to have a detectable influence (Table 5.11). Steady-state infiltration was slightly but consistently higher (about 7 mm hr^{-1}) for shoulder positions compared to backslope ones. Similarly, drier initial conditions in the upper profile (found particularly, but not exclusively, in the unmulched check plots) led to increased infiltration, as a result of increased capacity for water intake in the profile. Conversely, neither the local slope (measured at the exact site when the infiltrometers were installed) nor the presence of a surface mulch at the time of measurement seemed to affect infiltration rates.

With respect to the mulch, the fact that it presents a very open architecture makes it a fairly improbable barrier to infiltration compared to the soil proper. Also, one would need to take into consideration the actual orientation of mulch fragments on a micro-scale to account for its effect on water penetration. The lack of effect of slope is somewhat surprising, but it could be a consequence of the very small scale used for the measurement (area of infiltration smaller than 0.1 m^2), unsuitable for the detection of the influence of macro-scale factors such as slope.

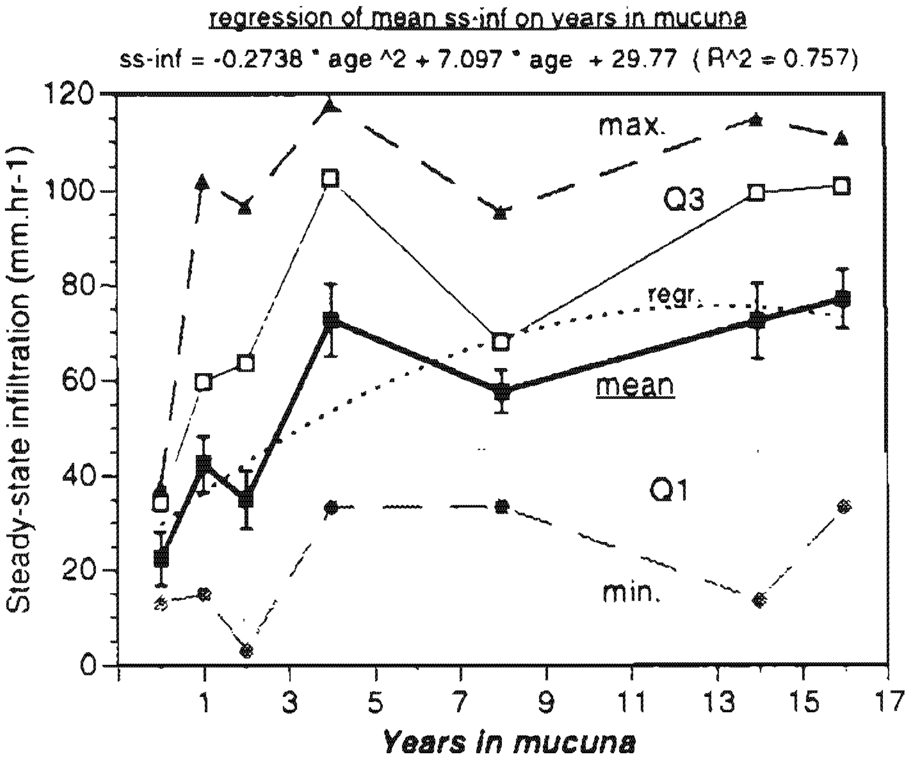


Figure 5.10 Changes in steady-state infiltration rates over time under the influence of the mucuna/maize rotation, San Francisco de Saco, Northern Honduras

Table 5.10. Changes in infiltration and related variables over time in the mucuna system. San Francisco de Saco, 1994

Each cell represents the average for the age class, followed by its standard deviation

Variable	no mucuna (N=8)	1-2 years (N=40)	4-8 years (N=34)	≥ 12 years (N=32)
steady-state infilt. (mm.hr^{-1})	22.5 ± 11.4	37.1 ± 28.7	65.0 ± 26.0	74.9 ± 28.2
slope (%) [1]	16% ± 5%	37% ± 15%	36% ± 8%	40% ± 9%
time runoff (mm)	06 41 ± 01·17	09 25 ± 25·49	29 23 ± 47.47	27 33 ± 45 27
initial vol. soil moisture [2]	0.21 ± 0.03	0.34 ± 0.08	0.34 ± 0.05	0.35 ± 0.06
storage 0-5 cm (mm) [2]	9.2 ± 2.8	4.2 ± 2.1	4.4 ± 2.0	4.3 ± 1.7

[1] measured on the exact spot where infiltration took place. [2] determined on the 0-5 cm horizon by TDR probe readings taken before and after infiltration water was applied

Table 5.11 Multiple Regression of the steady-state infiltration rate (mm.hr^{-1}) in the mucuna/maize rotation against various predictors, San Francisco de Saco, Northern Honduras (N= 110, R-square = 0.523, $p < 0.0001$)

Predictor	coefficient	Std. Dev	t-value	Prob
constant	14.00	6.23	2.25	0.027
years in mucuna	2.22	0.38	5.83	<0.001
topographic position [1]	7.34	4.33	1.70	0.093
time to runoff (mn)	0.382	0.055	6.95	<0.001
mm water stored in the 0-5 cm hor	3.51	1.03	3.42	0.001

[1] categorical variable, backslope = 0, shoulder = 1

Unsurprisingly, time to run-off had a strong relationship with infiltration rates (Table 5.11). As the profile was able to absorb water without entering into run-off mode, the observed steady-state infiltration rate was higher. No measured characteristic could be found in our data that would "explain" time to run-off more than marginally (best R-square less than 0.1), although both length of time in mucuna and slope seemed to have a significant, though very small influence.

Once all these factors have been accounted for, the "real" influence of time spent in the mucuna system on infiltration and run-off rates can be assessed more precisely. It was found that on average, infiltration rates increased by 2 to 3 mm.hr^{-1} for each year spent in the mucuna rotation (Table 5.11). Over fifteen years, this lead to a increase of more than 30 mm hr^{-1}, which corresponds approximately to a doubling of the initial rates measured in no or young mucuna situations. Conversely, run-off rates (at 100 mm.hr^{-1} rainfall intensity) decreased by about 2 mm.hr^{-1}.yr^{-1} on average, from 72 mm hr^{-1} in no mucuna fields to a low 26 mm.hr^{-1} in old mucuna fields.

From a mechanistic viewpoint, one may expect to find a relatively strong relationship between steady-state infiltration and porosity. Indeed, the general trend in bulk density over time was consistent with the trend in the infiltration data (infiltration increasing as bulk density decreased, and hence total porosity increased). However, no significant relationship was found between infiltration rates and levels of macroporosity *measured on the same sites* (Figure 5.11), reflecting either measurement shortcomings, or possibly, the fact that macroporosity was high enough in all situations not to have constituted a significant limitation to infiltration. On the other hand, factors more related to pore continuity than to pore size may play an important role. No-till mulched systems induce high levels of earthworm and other soil/litter biota activity, which can contribute to the maintenance of a dense network of channels and pores connecting the subsurface to the open atmosphere (Hulugalle *et al.*, 1994; Lavelle *et al.*, 1994).

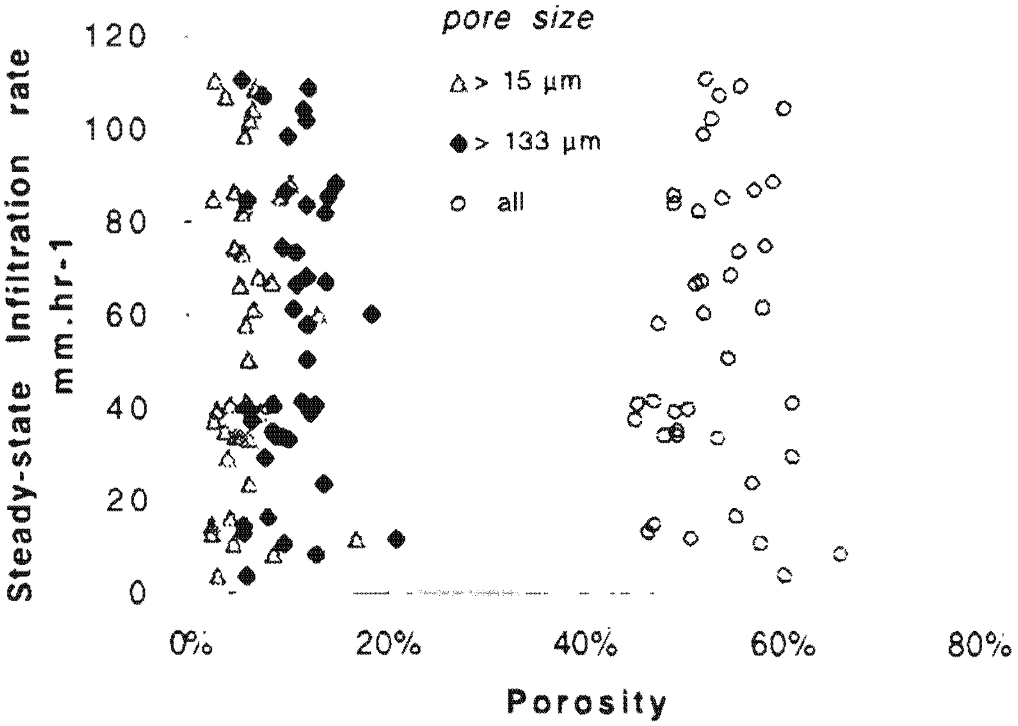


Figure 5.11: Steady-state infiltration (mm hr^{-1}) in relation to porosity in the 0-10 cm horizon, San Francisco de Saco, Northern Honduras.

5.6.4 Summary

Several soil physical properties were measured in a limited number of fields representing the mucuna rotation at different ages The mucuna system induced significant improvements in infiltration rates over time. Although the conditions under which these measurements were made do not represent very realistically what would happen under natural rainfall at the landscape level, the trends detected probably have a number of practical consequences in terms of water balance and water circulation at the field level (see discussion in section 5.8)

Soil porosity also appeared to have increased globally (as measured by bulk density) while macropores were maintained or slightly increased Finally, while erosion was not measured, there was however converging qualitative evidence to indicate that it was nonexistent in most mucuna fields. The only apparent problem, localized landslides occurring in certain sites after particularly heavy rains, do not seem to represent an issue specifically related to the use of the mucuna system.

5.7 CROP PRODUCTIVITY AND FARMERS' EVALUATION OF LONG-TERM CHANGES

Does maintenance or perhaps increase in soil fertility (as measured on a number of soil fertility components) translate into increased crop (maize or mucuna) productivity? This question was addressed by looking at trends in maize yields or mucuna biomass production as time spent in the mucuna rotation increases. Farmers' own evaluation of the long-term changes in soil fertility will also be presented, as a supplementary way of assessing the validity of our analytical findings.

5.7.1 Changes in average maize yields and yield components over time

Table 5.12 presents the average trends observed for maize yields in each site in the different age classes

There are four main conclusions that can be drawn from these figures.

(1) average maize yield levels varied markedly by site (from a low of less than 2 t ha^{-1} in Rio Cuero to a high of 4.4 in Las Mangas in 1993). The ranking seems to reflect at least partially the difference in general soil fertility (pH, availability of exchangeable bases in particular).

(2) maize yields in the presence of mucuna were almost doubled those obtained without mucuna (Rio Cuero constituted an exception, with an increase of 40% only, but the study in this site included only one check plot).

(3) once the mucuna rotation is well-established (more than 3 years), yields seemed to remain fairly constant over time. In particular, there was no apparent tendency for yields to decline over time

(4) maize yields have a tendency to be more stable in the older mucuna fields: the standard deviation across sites in fields 8 years or older dropped from 1.5 t ha^{-1} in younger mucuna fields to 0.73 t.ha^{-1} in 92/93, and from 1.0 to 0.7 in 93/94.

Table 5.12. Changes in average maize yields (t.ha^{-1}) as a function of the duration of the mucuna rotation, Northern Honduras, 1992/93 and 1993/94 winter cycles

a. Cycle 92/93

site	Data	no mucuna	1-2 years	3-4 years	5-7 years	8-10 years	≥ 11 years
	sample size	*4*	*7*	*4*	*14*	*21*	*15*
Sn Fco	yield	1.9 **b**	2.2 **b**	3.7 **a**	3.0 **ab**	3.5 **a**	3.6 **a**
	sample size	*2*	*5*	*9*	*11*	*1*	*0*
Mangas	yield	2.5 **b**	4.2 **a**	4.2 **a**	4.9 **a**	(4.4)	--

b. Cycle 93/94

site	Data	no mucuna	1-2 years	3-4 years	5-7 years	8-10 years	≥ 11 years
	sample size	*10*	*2*	*5*	*3*	*10*	*10*
Sn Fco	yield	2.0 **b**	3.3 **ab**	3.7 **a**	2.7 **ab**	3.6 **a**	3.4 **a**
	sample size	*4*	*3*	*6*	*12*	*4*	*4*
Mangas	yield	1.4 **b**	1.8 **ab**	3.1 **a**	3.2 **a**	3.9 **a**	3.1 **a**
	sample size	*1*	*6*	*6*	*6*	*0*	*0*
Cuero	yield	(1.4)	2.2 **ns**	2.0 **ns**	1.7 **ns**	--	--
	sample size	*0*	*0*	*6*	*2*	*2*	*6*
Piedras	yield	--	--	2.2 **b**	1.6 **b**	2.8 **ab**	3.0 **a**

Figures followed by the same letter on the same line are not different according to Tukey's test at the 10% family rate.

Differences in plant density can help explain the apparent yield drop in fields 5 to 7 years into the rotation (cycles 92/93 and 93/94), and also the fact that old mucuna fields did not outyield the medium-term ones in 92/93. The fact that plant densities were lower in check plots than in fields planted to mucuna is probably a consequence of farmers' deliberate adaptation to perceived soil fertility (see 5.7.3). Together, years in mucuna and plant stand were significant predictors of yield levels in a multiple regression approach in all sites/years with the exception of Cuero (Table 5.13). Based on the slope of the equations obtained in the various cases, it can be concluded that on average, every additional year in mucuna yields an extra 50 to 170 kg.ha^{-1} of maize, whereas every additional 5,000 plants harvested yields between 250 and 500 kg.ha^{-1} of maize

Table 5.13: Multiple regression of maize yields on years in mucuna and plant densities. Northern Honduras, 92/93 and 93/94.

(In parenthesis, significance level for each regression coefficient)

year & site	years in mucuna (kg/ha/yr)[1]	plant stand (kg/ha/000)[1]	Multiple R-square	F value	d f error
93 SFS	92 (0.1%)	54 (<0.1%)	0.373	18.45 (<0.1%)	62
93 MG	169 (0.5%)	101 (<0.1%)	0.625	20.84 (<0.1%)	25
94 SFS	50 (10%)	47 (1%)	0.309	8.26 (0.1%)	37
94 MG	169 (0.2%)	-28 (27%)	0.320	7.05 (0.3%)	30
94 CUE	-58 (54%)	65 (22%)	0.127	1.16 (34%)	16
94 PIE	104 (0.9%)	0 (99%)	0.428	4.87 (2.6%)	13

[1] partial coefficients in regression ***Maize yield = a + b (years) + c (plant stand)***

Other maize yield components (Table 5.14) provide an additional way of analyzing the effect of soil fertility on crop productivity (Fleury *et al.*, 1982). Indicators of favorable growing conditions prior to flowering such as the number of ears per plant, or number of kernels per ear (Navarro Garza, 1984; Fleury, 1991) demonstrate a significant improvement with time in mucuna for the 92/93 cycle. The situation is not as clear-cut however for the 93/94 cycle.

From a qualitative view point, the apparently greater stability provided by the mucuna rotation in the face of adverse climatic conditions is perhaps especially striking. During the drier-than-usual 93/94 cycle, many maize fields suffered from drought stress, and in some villages, yields in fields without mucuna dropped to very low levels (less than 1 t.ha^{-1}, or even complete crop failure), whereas nearby fields planted to mucuna around the same time were faring reasonably well (2 t.ha^{-1} or more). The implied improved access to water by maize in mucuna fields can be ascribed to a combination of reduced evaporation and better infiltration (see section 5.6 above).

Table 5.14: Changes in maize yield components over time in the mucuna/maize rotation. San Francisco de Saco, cycles 92/93 and 93/94

a. cycle 92/93

Component	no mucuna (N=4)	1-2 yrs (N=5)	3-4 yrs (N=4)	5-7 yrs (N=14)	8-10 yrs (N=21)	≥ 11 yrs (N=15)
maize yield (t ha^{-1})	1.9 **b**	2.2 **b**	3.7 **a**	3.0 **ab**	3.5 **a**	3.6 **a**
plant dens (000)	26.9 **ab**	26.1 **b**	39.8 **a**	34.4 **ab**	33.7 **ab**	32.3 **ab**
N ear/plant	0.79 **ab**	0.72 **b**	0.79 **ab**	0.79 **b**	0.86 **ab**	0.91 **a**
N Kernels/ear	296 **b**	366 **ab**	382 **ab**	351 **ab**	388 **a**	391 **a**
Weight 1 K. (mg)	300 **ns**	312 **ns**	307 **ns**	308 **ns**	322 **ns**	315 **ns**
N..Kernels/m2	636 **b**	842 **ab**	1225 **a**	960 **ab**	1106 **a**	1138 **a**
Weight 1 ear (g)	89 **b**	116 **ab**	117 **ab**	110 **ab**	125 **a**	124 **ab**

b. cycle 93/94

Component	no mucuna (N=10)	1-2 yrs (N=2)	3-4 yrs (N=5)	5-7 yrs (N=3)	8-10 yrs (N=10)	≥ 11 yrs (N=10)
maize yield (t ha^{-1})	2.0 **b**	3.3 **ab**	3.7 **a**	2.7 **ab**	3.6 **a**	3.4 **a**
plant dens (000)	25.0 **b**	39.4 **a**	36.9 **ab**	27.0 **ab**	31.4 **ab**	38.6 **a**
N ear/plant	0.87 **ns**	0.88 **ns**	0.84 **ns**	0.84 **ns**	0.92 **ns**	0.89 **ns**
N.Kernels/ear	321 **ns**	326 **ns**	336 **ns**	347 **ns**	368 **ns**	351 **ns**
Weight 1 K. (mg)	321 **ns**	299 **ns**	356 **ns**	355 **ns**	348 **ns**	306 **ns**
N Kernels/m2	678 **b**	1121 **ab**	1075 **a**	795 **ab**	1051 **a**	1163 **a**
Weight 1 ear (g)	103 **ns**	98 **ns**	120 **ns**	124 **ns**	127 **ns**	108 **ns**

Figures followed by the same letter on the same line are not different according to Tukey's test at the 10% family rate.

5.7.2 Changes in average mucuna biomass production over time

Mucuna production, a hidden output from the farmers' perspective, may potentially be affected by enhanced soil conditions, which in turn would influence maize productivity. The evidence is not entirely clear however (Table 5.15). For the 92/93 cycle, the young mucuna fields included in the study produced significantly less biomass than other mucuna fields, but this was not observed in 93/94. In two sites however (San Francisco and Piedras), the highest biomass production was obtained in the oldest mucuna fields. A fairly similar situation was observed with respect to nitrogen accumulation.

5.7.3 Farmers' evaluation of long-term changes

Farmers using the mucuna rotation were asked to compare yields they could reasonably hope to get before using mucuna and after it was firmly established in their fields. In the most extreme cases, farmers reported that mucuna had helped tripled yields or even reclaim what they considered fields too poor to produce a maize crop. On the other hand, some farmers reported no changes at all or only very minor yield increases. Averaged across sites, the reported yield gain reached 70%, from about 1.5 t.ha^{-1} to 2.6 t.ha^{-1} (it is not the place here to analyze the discrepancy between yield data obtained via surveys vs. measured in the field; see chapter 3 and Poate, 1988).

It is also interesting to note that an overwhelming majority of farmers (43 out of 46) considered that the soil quality of their fields had improved qualitatively (soil was judged "better" or "much better" by equal proportions of them) upon introduction of mucuna. Many of them claim to deliberately use higher plant densities in mucuna fields, as they feel that the soil is capable of producing more. And no farmer ever reported a degradation. In collective interviews conducted at the village level, farmers were explicitly asked to consider any negative behavior or characteristic which would start to affect mucuna fields with the passing of time, but they could not identify any single specific instance of such behavior (not even the famed landslides seem to affect preferably old mucuna fields). Another solid indication is given by the higher sale or rental values fetched by land in mucuna compared to average farm land: the increase can reach 50% to70% (Buckles *et al.*, 1992; Humphries, 1994).

Altogether, mucuna farmers are extremely satisfied with the agronomic results associated with mucuna use. A final proof is perhaps that none of them has ever abandoned a mucuna field for *agronomic* reasons (the few cases reported were related to issues of land tenure or to changes of land use).

Table 5.15 Changes in average above-ground mucuna biomass production (t.ha^{-1}) and nitrogen content (kg ha^{-1}) over time in the mucuna/maize rotation, Northern Honduras, 1992/93 and 1993/94 winter cycles.

a. Cycle 92/93

site	Data	1-2 years	3-4 years	5-7 years	8-10 years	≥ 11 years
	sample size	*3*	*3*	*9*	*16*	*13*
Sn Fco	total biomass (t.ha^{-1})	6.9 **b**	10.4 **ab**	11.2 **a**	11.0 **a**	11.2 **a**
	total N (kg ha^{-1})	112 **b**	246 **ab**	276 **a**	263 **a**	289 **a**

b. Cycle 93/94

site	Data	1-2 years	3-4 years	5-7 years	8-10 years	≥ 11 years
	sample size	*2*	*5*	*3*	*10*	*10*
Sn Fco	total biomass (t ha^{-1})	12.2 **ab**	12.8 **ab**	11.8 **ab**	11.8 **b**	14.2 **a**
	total N (kg ha^{-1})	296 **ab**	320 **ab**	314 **ab**	286 **b**	377 **a**
	sample size	*3*	*6*	*12*	*4*	*4*
Mangas	total biomass	10.9 **ns**	10.8 **ns**	11.0 **ns**	11.6 **ns**	10.9 **ns**
	total N	261 **ns**	294 **ns**	272 **ns**	291 **ns**	276 **ns**
	sample size	*6*	*6*	*6*	*0*	*0*
Cuero	total biomass	10.6 **ns**	10.4 **ns**	11.5 **ns**		
	total N	267 **ns**	255 **ns**	301 **ns**		
	sample size	*0*	*5*	*2*	*2*	*6*
Piedras	total biomass		10.7 **ns**	10.7 **ns**	10.1 **ns**	12.3 **ns**
	total N		293 **ns**	299 **ns**	271 **ns**	351 **ns**

Figures followed by the same letter on the same line are not different according to Tukey's test at the 10% family rate.

5.8 DISCUSSION AND CONCLUSIONS

After looking at individual soil properties, it is now possible to examine the general significance of the apparent trends associated with the continuous use of the mucuna system Again, this discussion will that our main methodological tool (i.e the chronosequence approach) did indeed yield valid insights about the time trend.

5.8.1 Infiltration and water balance in the mucuna system

A key consequence of higher infiltration rates and porosity relates to the induced increase in both profile recharge and water holding capacity. The two former mean more water is available to the maize crop and to support biological activities such as decomposition and mineralization. This may be particularly important during winter cycles with a marked dry season, and would be even more so in drier environments than Northern Honduras, in which water balance becomes a critical parameter in crop production

More infiltration may also induce higher drainage rates under certain circumstances This would in turn affect the downward movement of nitrates and exchangeable cations, an outcome consistent with the observed increase in Ca content at depth (see 5.5.1). An evaluation of the fraction of water subjected to preferential flow would be needed however to judge the leaching risk associated with increased infiltration (Bouma, 1991)

Consequences of decreased run-off rates and intact porosity on erosion should not be underestimated. As run-off is reduced, the erosive action of rainfall is also drastically decreased. Also, as the mucuna system provides a 100% cover of the soil surface year-round, even occasional high levels of runoff do not translate directly into high erosion or soil structure degradation (such as surface sealing Bielders and Baveye, 1995), as runoff water flows on top of or in the mulch layer rather than over a bare surface

5.8.2 Mechanisms of change

While this study documented significant changes in soil properties, processes and mechanisms driving these changes remained largely undocumented. What role play deep mucuna roots and mycorhizae in recycling nutrients and/or making them available year after year (Rosemeyer and Gliessman, 1992). Perhaps one has to look also at the significance of the uptake taking place directly in the litter layer (Schlather and Duxbury, 1994), as evidenced qualitatively by both the impressive amount of mucuna roots found in this layer, and by the numerous maize roots lying directly at the soil/litter interface

On the other hand, soil fauna feeding on the litter and the soil organic matter play certainly a key role in bringing fresh organic matter into the soil matrix and eventually in maintaining or increasing the stock of soil organic matter And as hypothesized earlier, they may contribute greatly to the maintenance of a network of continuous pores

5.8.3 Is the mucuna/maize rotation sustainable?

Perhaps it is time to restate the challenge of continuous cultivation in fragile environments when long-term fallowing cannot be relied on anymore as a means of periodically restoring soil fertility. A major threat in many of these situations (and specially in hillside context) is a rapid decline of soil fertility associated with heavy losses of nutrients and soil caused by erosion and mining of the resource base without restitutions. As soil fertility declines, and noxious weeds start competing strongly with crops, crop yields drop and farming becomes rapidly both very tedious and unprofitable, leading to abandonment of the fields. This is the background against which to judge the achievements of the mucuna system.

The analysis of long-term changes conducted in this chapter provided ample evidence to conclude that after 10 to 15 years of continuous use of the mucuna/maize rotation, the system was doing very well overall. Perhaps the clearest sign of success is that maize yields were actually as high or even higher in old mucuna fields compared to young ones, and on average about double those obtained in check plots not planted to mucuna. From an environmental viewpoint, a number of positive results were observed, which were fairly consistent across sites, in spite of sizable differences among sites in initial soil conditions and in rates at which changes were seemingly taking place (perhaps an artifact stemming from the differences in the construction of each chronosequence).

For one thing, there was practically no active erosion in the mucuna fields, thanks to the protective cover provided by the mucuna biomass throughout the year (erosion rates were not quantified however). Soil organic content (carbon and nitrogen in particular) increased markedly over time, especially in the upper 5 cm of the soil profile. No signs of soil acidification were detected, something congruent with the efficient cycling of nutrients (particularly nitrogen) reported in Chapter 4. Soil physical properties such as porosity and infiltration were maintained or improved. Also, even though no measurements were made, biological activity in the mucuna fields seemed qualitatively improved, as a host of arthropods, earthworms, and fungi could be found at or close to the interface between the mulch layer and the soil matrix.

Hence, from a strictly agroecological perspective, the mucuna system seems indeed sustainable over at least fifteen years, at a reasonably high level of productivity (about 2-4 $t.ha^{-1}.year^{-1}$ in its present management). Clearly, conserving or even improving the resource base does not in itself guarantee the global sustainability of a cropping system, (Humphries, 1994, chapter 6; Kleinman, 1995). But the mucuna system offers at least farmers the option of continuing if they wish to do so. Should they decide to shift to another land use, fields which have been in the mucuna system for several years do not present restrictive factors frequently associated with degraded agricultural soils (low fertility, high weed or pest pressure, compaction, etc.): they are probably in an ideal condition to guarantee the successful implementation of any other crop, pasture or tree-based system.

Chapter 6

GENERAL DISCUSSION

This chapter offers an open discussion of major agronomic and socioeconomic issues related to the use and performance of the mucuna/maize rotation. The objective is to explore issues which have a direct impact on how the mucuna system could be improved, why improving it is necessary, and more generally what is the probability that this or similar systems may play a positive role in the long-term improvement of farmers' standards of living and in the simultaneous conservation of fragile environments.

This analysis relies on interpretations presented in chapters 3, 4 and 5, as well as on discussion with and writings of social scientists who all have an intimate knowledge of the mucuna system, such as D. Buckles, S. Humphries and G. Sain. I have also used qualitative insights gained through my extended interactions, formal and informal, with many mucuna users and other specialists in the Atlantic littoral.

6.1 AGRONOMIC PERFORMANCE OF THE MUCUNA/MAIZE ROTATION

As was demonstrated in earlier chapters, the mucuna system is a fairly successful cropping system: this study did not detect significant flaws from an agronomic viewpoint, considering the resources farmers using the rotation have access to. But from a socioeconomic perspective (see 6.2), higher average yields would make the system much more attractive to present-day users. The best yields observed in farmers' fields 5-6 t ha^{-1} vs. a regional average of 2-3 t ha^{-1} prove that this can be achieved. Management issues to consider if average yields are to be increased are discussed below.

6.1.1 Importance of and latitude in the choice of a slashing date

Deciding on a slashing date is perhaps the single most important decision a farmer has to make in the yearly management of his mucuna field. The decision is constrained by two quite distinct factors: on one hand, farmers must wait until rains taper off and mucuna has produced viable pods and seeds, while on the other, they have to avoid the risk of a potentially severe drought stress during the subsequent maize cycle. Additional considerations relate to the synchronization of maize uptake with the release of inorganic nitrogen following mucuna slashing: it was shown that the sooner after slashing that planting occurs, the more nitrogen would be potentially recovered by a maize crop (chapter 4). Finally, weed dynamics must be considered: the weed-free conditions created by slashing do not last very long, especially when *Rottboellia* or other grasses are present, as these species benefit as much as maize from the favorable growth conditions offered by the mucuna system (see later).

Under the circumstances, it becomes clear that (1) as long as farmers rely on natural reseeding, there is a relatively narrow window for planting (December/early January) during which most factors and conditions are compatible with the reproduction of the mucuna system, and (2) the choice of a planting date cannot be considered independently from the choice of the slashing date, as the timing of slashing has strong implications on the environmental conditions a maize crop will find.

The issue of replanting mucuna every year (instead of natural reseeding) is worth examining briefly. Besides the organizational and labor issues (collecting and storing seeds, finding the necessary labor, etc.) that such a move would imply, it remains unclear what exact benefit(s) would accrue from doing so. Would the added flexibility in deciding on a slashing/planting date be advantageous in terms of nitrogen cycling (by being able to slash a 'greener' mucuna), or positioning of the maize cycle? Controlling mucuna stand could also increase biomass production, leading to increase nutrient availability, and provide more options for a successful weed management (see later). Also, inasmuch as different mucuna germplasm (different maturity classes, selected for specific insect resistance or lesser amounts of levadopa in the seed, etc.) were to be introduced, replanting would be almost a requirement. On the other hand, it may add a new risk, i.e. that of failing to reestablish mucuna properly, something which if it happened would probably have dramatic consequences on the following maize cycle.

6.1.2 Cultivar and plant density

Many of the higher yields recorded in this study were obtained by farmers using second or third generations of an improved open-pollinated cultivar (Honduras Planta Baja), rather than local genotypes. Additionally, plant density in these plots was also higher than average (above 40,000 plants/ha vs. about 31,000) (see also chapters 3 and 5). The practical significance of these two observations combined should not be underestimated. A major difference between improved and local genotypes relates to plant height: closer to 2-2.5 m for the former, and frequently above 3 m for the latter. Reduced plant height makes the maize plants less susceptible to lodging while also allowing planting at higher densities. Conversely, increasing the density at which local cultivars are planted may increase lodging rather than maize yields.

As both mineral nutrients and water are readily available in the mucuna system, there seems to be room for the introduction of improved germplasm, including hybrids, planted at relatively high densities (50,000 or more). This should significantly boost maize yields in mucuna fields, at the cost of a modest increase in cash expenses, corresponding to the cost of buying commercial seed, which can be found throughout the Atlantic littoral.

In all cases, the evidence available, alongside farmers' own perceptions about how to increase yields in the mucuna system suggest that there would be much to be gained from on-farm tests of improved germplasm and higher plant stands. Simultaneously, efforts to improve farmers' strategies for seed selection should be undertaken.

6.1.3 Weed control and the Mucuna rotation: the *Rottboellia* puzzle

Being hardly a km away from the main axis of dissemination of *Rottboellia cochinchinensis* (Munguia, 1992), San Francisco de Saco has been an unfortunate and certainly unwilling witness of the damage this obnoxious weed can produce. That *Rottboellia* would be a "perfect" companion to the mucuna system must be explained briefly. First the environment of a mucuna field is highly favorable to a grass weed like *Rottboellia*: most other weeds (and especially broadleaves) have been de facto eradicated over the years by mucuna itself. Furthermore, nutrients, light and water are largely available, especially just after slashing, when maize is growing very slowly. Also, farmers' casual control over mucuna re-establishment allows gaps to develop in the mucuna stand. Finally, *Rottboellia* can complete its cycle in a very short time, producing massive amounts of seed with an excellent longevity (Bridgemohan *et al.*, 1991).

Farmers in San Francisco de Saco recognize that the cost of weed control has increased markedly in response to the presence of *Rottboellia*, while maize yields have probably dropped significantly (perhaps by as much as 0.5 $t.ha^{-1}$ on average?). Under the circumstances, two questions of great practical significance come to mind: (1) can farmers not yet affected by a *Rottboellia* invasion protect their fields against a future invasion? and (2) what can farmers already affected do about it? In both cases, answers are not straightforward. It seems next to impossible to establish and enforce quarantine-like standards strict enough to limit the diffusion of *Rottboellia* seed on a regional scale. Also, constant movements of population and animals (including birds!) in the region make it probable that *Rottboellia* seed will reach more and more sites in the near future. And unless farmers are both knowledgeable and extremely prompt at eradicating any *Rottboellia* stand that may appear community-wide (whether in cropped fields, fallows, along paths, [illegible] pastures), chances are that Rottboellia will indeed invade many fields. With respect to the second question, experiences reported in the literature do not give great cause for optimism: expensive chemical control or tillage seem to be the only methods that work, whereas mulches have apparently failed (Fisher *et al.*, 1985; Bridgemohan and Brathwaite, 1989). Antunez *et al.* (1994) have shown that systematic replanting of mucuna (instead of relying exclusively on natural reseeding) may help reduce the population of *Rottboellia* in mucuna fields, but the departure and added cost this would represent vis-à-vis current practices makes it an unlikely candidate for adoption (see 6.1.1 page 140). Perhaps one should accept that as *Rottboellia* continues its colonization of the hillsides of Northern Honduras, it will probably be an unavoidable part of the mucuna system. As many farmers perceive it, the added cost and inconvenience its presence implies is a small price to pay compared to the great benefits derived from the use of mucuna. Besides, it may actually play some useful role in helping with nutrient recycling (Lambert and Arnason, 1989, chapter 4).

6.1.4 Other pest and diseases

Our study has not focused on these issues, although they are undoubtedly important in a disease-prone humid tropical environment. Two distinct aspects are involved. the health of the maize crop, and that of the mucuna crop.

Maize in the mucuna system appears to suffer very little from economically significant incidences of pest and diseases. Among the few cases observed, there was a localized instance of damage by *Phyllophaga sp.* which affected two fields in Las Mangas. Losses of seed or seedlings due to rodents or birds in the days after planting were at time significant, prompting many farmers to replant the affected areas. On the other hand, it was observed that birds had selected a field without mucuna rather than an adjacent mulched plot (both planted the same day), perhaps because it was much easier for them to retrieve the seeds in the mulchless plot. Overall, maize health in mucuna fields around planting time seems quite satisfactory (Arneson, pers. com.). Later during the cycle, significant incidences of *Spodoptera sp.* are more ubiquitous throughout the entire region, particularly in 93/94. Its effect on maize yields has not been determined however. Losses due to ear diseases were almost always insignificant at harvest time: less than 1% of the total harvest by weight in nearly all cases, something in sharp contrast to what is observed for maize planted during the rainy season (Buckles and Sain, 1995). Of all sources of losses, post-harvest losses incurred in long-term storage (6-7 months or more) may well constitute the most serious issue, even though their quantitative impact has not been measured. These losses are related to management of the harvest (absence of pre-storage screening of infected ears, inadequate storage conditions) and environmental factors such as the high levels of ambient moisture.

For the mucuna crop, losses of biomass or pods due to pests and diseases also appear marginal, possibly owing partly to mucuna chemical composition (Duke, 1981). Farmers have reported isolated instances of what may be viral diseases (locally known as "hielo" Bentley, 1991), but up to now, the Atlantic littoral has been a relatively disease-free environment for mucuna.

As a general statement, pests and diseases appear to constitute a minor concern in the mucuna/maize rotation, probably as a combined result of mucuna's own biology, favorable rotational effects and control of a number of soil-borne pathogens allowed by the presence of a mulch (Galindo *et al.*, 1983, Abawi and Thurston, 1994). Whether this will continue to be the case in the future remains a matter of speculation however. A particular concern involves the probably fairly narrow genetic basis of the mucuna grown in the Atlantic littoral, owing to its common origin and autogamous habits (Duke, 1981, Buckles, 1995). This combined with its widespread use would place the mucuna system in a very weak position in the case of a sudden appearance in the region of a major pest or disease for which mucuna would present no resistance. Under the circumstances, strategies which would widen the genetic basis of mucuna, or increase biodiversity by introducing other legumes should be considered in the future.

6.1.5 Soil erosion and soil fertility

We will not elaborate on this important aspect of the mucuna system, as it was the focus of chapters 4 and 5. Its ability to protect the soil against erosion in the long-run is certainly one of its most striking features, and leaving aside the issue of landslides, it does not seem there is much room for improving this aspect of the system. The mucuna system provides and recycles nutrients (nitrogen obviously but others as well, such as phosphorus and calcium) in a fashion quite favorable to the maize crop, making it as efficient as the best agroforestry systems (Kang and Mulongoy, 1992; Haggar and Beer, 1993). It maintains or improves chemical, physical and biological soil properties in the long-run.

As yet there are no systematic studies which define conditions under which response to fertilizer will be obtained. It was shown however that limited additions of nitrogen fertilizer could boost maize yields by as much as 0.7 to 0.8 t ha^{-1} under certain conditions (chapter 4). As pointed out earlier, changing varieties and plant stand may be necessary conditions for the mucuna system to achieve its full potential. But yield increases may not occur consistently unless nutrients are added at a pace or in quantities above the environmentally-dependent supplying capacity of the mucuna mulch. Alternatively, any change in mucuna management that would increase mucuna biomass production or mucuna decomposition rates may increase nutrient availability for the subsequent maize crop, thus making fertilizer additions less necessary. Provided proper ways of determining in which situation to use fertilizer are devised, the risk of failing to boost yields should be limited, as soil water is relatively available in the mucuna system even in dry years. A cost/benefit analysis factoring the steep transportation costs of fertilizer (from commercial supplier to community to field itself) needs to be conducted on this issue.

6.2 SOCIOECONOMIC ISSUES

Understanding the impact that socioeconomic conditions have on both the extrapolability of the mucuna system and also its future existence in the Atlantic littoral may contribute to defining realistic lines of agronomic inquiries about the system.

6.2.1 Who can adopt the mucuna system?

Considering the desirability of using cropping systems similar to the mucuna/maize rotation in other regions, a key question is who is likely to adopt such an innovation. Evidence available from the Atlantic littoral underlines several important issues with respect to the patterns of adoption of the mucuna system:

(1) adoption was greater among farmers possessing or exploiting relatively large acreages compared to smaller farmers (respective farm size: 12 ha vs. 5 ha). However farm size per se was not an absolute constraint to adoption: 56% of farmers with less than 1.65 ha had also adopted the mucuna system (Buckles *et al.*, 1992).

(2) there was a positive relationship between adoption and the form of land tenure. Those with legally titled land or at least with secure access to it were more likely to adopt the mucuna/maize rotation than those with precarious access to land (Buckles *et al.*, 1992). The latter are reluctant to use mucuna because they can promptly lose access to the field in which they would plant it. However, it was observed in San Francisco de Saco that a number of farmers had planted mucuna in land rented to them, with the blessing or even under the strict recommendation of the landowner, keen on preserving or improving his capital. Finally, some farmers may use the mucuna rotation simply because they rent out fields in which it is already planted (Humphries, 1994).

(3) there is a marked relationship between local availability of land for annual cropping and adoption of the mucuna system (Buckles *et al.*, 1992). In effect, many of the smallest landowners appear to plant and use mucuna on their own land because they can have access to land for *rental* during the summer cycle, while their own field is under mucuna fallow. Conversely, were no land available for growing summer maize, many farmers would hesitate to commit their only field to a summer mucuna fallow (there are cases of farmers planting a summer maize in their mucuna fields because of lack of other options).

6.2.2 Opportunity cost of land and land use intensification

How intensive can or should land use be in the mucuna system? The preceding sections touched on this key issue, which surfaces in many discussions about the potential and limitations of slash-and-mulch systems. The mucuna system represents a significant step towards intensification compared to the traditional fallow/maize rotation (Buckles *et al.*, 1992), as farmers are able to cultivate the same field year after year while preserving its future capacity to produce. But the short-term imperative of generating always more income makes the 6-month long mucuna fallow appear an increasingly unaffordable luxury, all the more so as population pressure increases, land availability decreases and more attractive short-term land uses emerge. Transposed to areas of land shortages and shorter growing cycles (200 days or less), it appears necessary to devise more intensive land uses (Buckles and Barreto, 1995), by relying on intercropping rather than on rotational schemes, or by using legumes with an immediate economic value as food or as feed (see for example Solomon and Flores, 1994). Alternatively, inclusion in the rotational or intercropping scheme *or elsewhere on the farm* of high value-added production seems highly desirable.

There is however another side to the issue of land use intensity when dealing with fragile hillsides. Increasing land use intensity may place undue pressure on hillsides towards producing more than what is safe in such erosion-prone environments. This would in turn expose society at large to very high potential risks related to off-site effects (Harrington, 1994): gradual loss of sources of drinkable water for the cities, silting-up of hydroelectric dams, episodic dramatic damage in the flatlands, or mass migration of bankrupt farmers towards the city or the national parks, to cite a few typical symptoms.

associated with failed hillside management. Therefore, promoting (or preserving) a more benign, less intensive use of land in the hillsides may constitute a desirable social goal, and economic incentives could perhaps be created to help reach this goal. This collective contribution towards ensuring a responsible management of hillsides would ideally compensate farmers for abiding to a less intensive land use. Far from being a subsidy, it would explicitly acknowledge that a production system should be valued according to its total productivity (Harrington, 1994): not only short-term physical yields but also long-term sustainability and a clean environmental record. Conversely, the absence of such a financial mechanism would be a *de facto* admission that if small hillside farmers are not willing or capable of absorbing the entire cost associated with environmental conservation, it will probably not happen. Unless, as discussed by Humphries (1994), coercive enforcement of environmental protection policies is put in place, which would create great social tensions and cost society significant resources. There is definitely a price to pay off or on-site for environmental conservation (or the lack of it).

6.2.3 Comparative profitability of the mucuna system

The absolute profitability of the mucuna system is only relevant in comparison to various alternatives available to farmers to invest their resources or generate disposable income. In this section, the mucuna system will be compared mainly to the traditional maize/fallow system, a logical choice given the context in which the mucuna rotation developed. But as farmers are not restricted to maize production, we will also attempt to position the mucuna system vis-à-vis alternatives such as bean or livestock production.

Agronomists have routinely favored the yearly return per unit of land as the standard yardstick to measure profitability, but this choice may not reflect the various strategies behind farmers' technical choices, nor the appropriate time horizon, especially for rotational cropping systems extending over several cycles. In manual agriculture for which labor is likely to be as or more limiting than land availability, return per unit of labor may be a more meaningful measure of profitability. On the other hand, if availability of capital or cash is a crucial factor, return per unit capital may be more telling. In all cases, it would have been highly desirable to evaluate the mucuna system from *all* three perspectives, but data currently available does not provide insight on more than one, and rarely two of these criteria simultaneously.

Sain et al. (1994) have compared the mucuna system to the traditional fallow/maize over a six-year period, thus taking into account the actual dynamics of these two rotations over time. They estimated that the profitability per unit of *land* was superior in the mucuna system only *after* the first three years (considered the investment period) had elapsed, whereas returns to *labor* became superior from the second year onward. They concluded that as the mucuna system had diffused very rapidly in the Atlantic littoral, it was probably the superior return to labor which had triggered adoption, something consistent with farmers' own evaluation of the system. These results were however based on unrealistically low yield estimates for both systems (see chapter 3, section 3 2 3), the mucuna system being particularly penalized. I would contend that if more accurate yield values were used in the calculations, the mucuna system would come out ahead of the traditional one from the very first year on both land and labor counts.

Humphries (1994) compared the costs and benefits per unit of land over one cycle only of the mucuna system, a mucunaless slash-and-mulch winter maize system, and the slash-and-burn summer maize system, using yield data from Rio Cuero very comparable to our own estimates obtained in this community. The mucuna system provided net profits 52% higher than those derived from the winter slash-and-mulch system, whereas the summer maize cultivation was returning a small loss. The profitability of bean production was estimated to be three times (summer beans) to four times (winter beans) greater than that of the maize/mucuna system: \$300-400/ha vs \$100/ha. However risk of bean crop failure was greater as well, and risk of environmental degradation was very high, particularly for summer beans. Calculations derived from data based on the higher whole-field yields obtained by farmers in San Francisco de Saco (Matute, pers. com.) showed that summer maize production was once again not profitable, whereas the mucuna system allowed profits of \$300/ha similar to those obtained with summer bean production in Rio Cuero, and about four times as profitable as winter slash-and-mulch maize production. With even better average yields (3.2 t ha^{-1} instead of 2.7 t ha^{-1}), farmers can pocket as much as \$400/ha by growing maize in the mucuna system.

In a further analysis, Humphries (1994) estimated that a farmer with only three milking cows could realize yearly profits as high as those obtained by a typical hillside producer of maize and beans (three ha of maize, of which two in the mucuna system, and 1 ha of beans over the two bean cycles), with less efforts and risk, but on more land however than this latter (because productivity of pastures is low). Tabasco chile peppers sold to a near-by factory was by far the best income-generating enterprise (\$2000/ha or seven times the profits of summer beans, 20 times those of the mucuna system) but capital costs and risk of crop failure were extremely high. Buckles and Sain (1995) estimated that a farmer managing a herd of 10 cows can generate an income 10 times higher than a day laborer working 200 days during the year. For his part, Flores (1993) concluded from a comparison of the mucuna system to a mechanized fertilizer-based system, both being used on flat cooperative land, that although the latter provided farmers with 18% higher net profit per ha, the return per unit capital invested was 30% higher for the mucuna system. He also observed that the way expenses were incurred in the two systems was radically different: in the mucuna system, 52% of the cost went back to local farmers in the form of wage labor, whereas in the mechanized system, 71% of the expenses ended up paying for inputs and services bought from outside.

In conclusion, a number of comments can be made:

(1) undoubtedly, the mucuna system is the most profitable way of producing maize in the hillsides, from the view point of return to labor, land and cash expenditures. Furthermore, this source of income is both relatively stable and sustainable over time

(2) profitability of bean production, either summer or winter, can be greatly superior to that of the mucuna system, particularly if maize yields remain moderate (2 t.ha^{-1} or less), but risks are greater (environmental, crop failure).

(3) if farmers can access enough land and/or capital to buy and maintain even a few cows, and have an easy way to market milk or cheese, the income from raising livestock is equal and many times superior to that from annual cropping, at a lower cost in labor and at a very small risk.

(4) if capital is freely available, and farmers are willing/capable of taking big risks, high-value crops such as Tabasco chile peppers can produce incomes an order of magnitude higher than those derived from maize or beans. The issue remains however to know how many farmers it would take to saturate this type of small-niche market.

6.2.4 An economic future for the mucuna system?

A key issue for the future of the mucuna system is whether a typical household of 6 to 10 people can live decently on income derived mainly from the cultivation of maize (or beans), as it has been the case up to now. Assuming the average acreage in mucuna/maize to be two hectares, and that in summer beans to be 0.6 ha (Buckles and Sain, 1995), and allowing the highest levels of profits for both crops ($400/ha, see 6.2.3), the total disposable income (once costs of production, including household labor, are paid for) would be about $1000 *in a favorable year*, i.e. a meager $100 to $160 per capita. This disappointing economic result may explain why some farmers (those who have a choice at least) have started to abandon or reduce their use of the mucuna system, in spite of its unchallenged agronomic merits. Under present-day economic hardships and growing cash needs, it simply does not pay enough to grow and sell maize for a living, even at the higher-than-average market price fetched by a winter harvest.

The preceding argument constitutes perhaps one of the strongest reasons for looking at ways that farmers could twist the rotation towards better income-generating capacity, *without loosing the major agronomic benefits attached to its present management*. Effective strategies for doing so should contemplate boosting average maize yields towards 5-6 t.ha^{-1} (i.e. double their present level: see 6.1), giving economical uses to mucuna biomass and seeds (such as feeding livestock) so that the mucuna fallow would no more be "wasted" time, or introducing high value-added crops such as fruit or timber trees (ramboutan, mahogany) *in* or *outside* mucuna fields, which would simultaneously add diversity and perhaps even durability to hillside mucuna-maize farming. Another avenue would be to devise a mechanism by which society at large would contribute to the income derived from using environmentally-friendly practices (see 6.2.2).

Even though our discussion has focused heavily on what may be done to increase the income-generation capacity of the mucuna system itself, it should be clear that any alternative that would bring about a sustainable increase in income *at the farm level* would be welcome. I would argue that perhaps the 'best' role of the mucuna system may be to allow the achievement of durable food security by hillside farmers and communities, as they would rely on a productive, environmentally-friendly, low-risk system to produce what they need for home consumption on a relatively small acreage. On the remainder of the farm, other sustainable systems based on annual crops, agroforestry, perennials, cattle rising, or harvesting of forest products may contribute to income generation as efficiently, or more efficiently, than the mucuna system or a modification thereof. In other words, diversification and astute exploitation of market niches and/or of the few comparative advantages of hillside environments may be a better bet than a blind belief in the unlimited wonders of the mucuna system.

6.3 EXTRAPOLABILITY OF THE FINDINGS OUTSIDE NORTHERN HONDURAS

In this section, we will distinguish what in the success of the mucuna system appear to be adaptations and performances specific to the Honduran Atlantic littoral context from what appear to be principles or features of any slash-and-mulch system whose validity encompasses a broad range of environments and circumstances. Although it may appear somewhat arbitrary, we will distinguish between agroecological and socioeconomic factors and conditions, in the belief that such dichotomy will help separate the technical feasibility of slash-and-mulch systems from their actual adoptability by farmers.

6.3.1 Behavior and performance specific to Northern Honduras

The Atlantic littoral is endowed with fertile, largely undegraded soils, and abundant rainfall, thus creating conditions favorable to a rapid initial establishment of the mucuna crop in a field, a high level of annual biomass production and a relatively risk-free, high-yielding maize cycle. Such conditions, even though they occur elsewhere are relatively rare in Central America (Buckles and Barreto, 1995). In that sense, the 'natural' domain of *direct* agroecological extrapolability of the mucuna system is rather limited. Interestingly, spontaneous adoption of mucuna-based systems very similar to the one in place in Northern Honduras has already taken place in these regions throughout Central America and Mexico (Carter, 1969; Gutierrez *et al.*, 1985, Garcia-Espinosa *et al.*, 1994, Buckles and Barreto, 1995; Buckles and Perales, 1995, Guerrero *et al.*, 1995).

How well mulch systems may perform in drier environments is unclear. On one hand, there is little doubt that mulching can contribute greatly to reducing evaporation (Lal, 1975, Steiner, 1994), and to improving the water balance through greater infiltration rates (see chapter 5). On the other hand, producing *in situ* the biomass needed to achieve a reasonable soil cover might in itself be a challenge when water availability is limited, and when there are competing uses for any available biomass (fodder, fuel) (Scopel, 1994). Whether a mulch layer could intercept or immobilize a fraction of the rainfall thus prevented it from reaching the soil and increasing evaporation is debatable

Assuming the presence of 5 $t.ha^{-1}$ of mulch absorbing 5 times its weight in water, the maximum potential interception would be less than 2.5 mm, a rather negligible amount

In all cases, the general tendency for lower levels of biomass production seems inevitable (less than 5 $t.ha^{-1}$ of legume biomass vs. more than 10 $t.ha^{-1}$ in humid environments) Interestingly, mucuna itself, as well as *Dolichos lablab* or *Canavalia ensiformis* have proved among the best-growing legumes in semi-arid climates such as Southern Sinaloa. Mexico (Loaiza, 1994) Conversely, many studies have documented the negative effects that a legume intercrop could have on the yield of a companion maize crop when it was planted less than 40 to 50 days after maize planting (Zea *et al.*, 1991, Barreto, 1994). A solution to this dilemma might be to plant the legume at the end of the wet season, as several legumes species have been shown to survive well a prolonged dry season (Lobo Burle *et al.*, 1992) This planting scheme avoids the risk associated with early intercropping as well as the high opportunity cost implied by a biennial rotational scheme (one year of legume followed by a commercial crop the next year).

Influence of initial soil fertility alone has not been assessed, but it seems reasonable to expect that this would also lower levels of legume biomass production in the first years of establishment, at least until legume-derived nutrients could start being recycled actively. This would in turn affect the rates of accumulation of carbon and nitrogen On the other hand, the mulch layer may shield the crop from many constraints associated with the soil proper. Schlather and Duxbury (1994) have shown that bean plants avoided P deficiency typical of Andosols by growing roots which take up available P directly in the mulch layer

Agroecological features are only a partial determinant of the success of the mucuna/maize rotation Among socioeconomic factors, a key role was apparently played by the low opportunity cost of land associated to the moderate pressure existing (until recently at least) on hillsides land resources. As land saturation and competition for access to available land increase, adoption of a relatively extensive rotation such as the mucuna system appears less likely (Humphries, 1994, Buckles and Barreto, 1995), or, as noted earlier, can actually provoke its abandonment

The role of regional migration patterns does not appear essential to the success of the mucuna system, although it most probably shaped the spatio-temporal patterns of adoption (rate of adoption and number of communities impacted by the adoption). Similarly, the existence of a market niche (maize prices 50% higher for winter maize than for summer maize Buckles *et al.*, 1992; chapter 2) seems more of an added incentive than a determining factor in adoption, as many farmers were already producing winter maize before adopting the mucuna system.

6.3.2 Principles which seem extrapolable

Clearly, many beneficial agronomic effects associated with the presence of a consequent mulch layer are not specific to the Atlantic littoral of Honduras or to the mucuna system. In many contexts, erosion control (or the lack of it) is the cornerstone of any intent at permanent productive agriculture The almost perfect erosion control brought about by the combination of no-tillage and continuous mulching of the soil surface in the mucuna system proves the potential of cover crops to substitute for costly erosion control works. An associated benefit involves water circulation and storage in a mulched soil profile Mulching improves the water balance by acting both on water entry into the profile (via higher infiltration rates) and on water exit (via reduced evaporation), the net benefit being that crops are less susceptible to the impact of prolonged droughts Another major benefit derives from the ability of a cropping system including cover-crops to durably extract and mobilize nutrients (nitrogen, phosphorus, calcium, etc) through the periodic growth and restitution of large quantities of biomass. Substrate abundance coupled to the creation of a suitable habitat, promotes the development of a vigorous soil/mulch biota, which becomes a major mediator in the recycling of nutrients. Recycled nutrients contribute both to increased crop yields in the short-term and long-term improvement of soil fertility (by staying or becoming more available in the root zone) Similar effects, whose magnitude depends more perhaps on mulch quantity than on its actual composition. have been reported for all sorts of annual or perennial legume mulches (Lal. 1975, Okigbo and Lal, 1982; Wade and Sanchez, 1983, Kamara. 1986. Tomar *et al.*, 1992; Haggar and Beer, 1993), mixed fallow mulches (Galindo *et al.*. 1983. Schlather and Duxbury, 1994) or for mulches made of crop residues (Larson et al . 1972. Fukuoka, 1978, Alberts and Neibling. 1994, Schomberg *et al* , 1994).

The fact that mulched systems are in essence labor-saving is also well-documented (e g Lorenz and Errington. 1991) It stems from the replacement of a hard-to-cut shrub or tree fallow by an annual regrowth of mainly leafy, easily slashed vegetation, as well as by the decrease in weed growth induced by the presence of a mulch.

One striking characteristic of the mucuna system is the reliance by farmers on spontaneous ecological processes to optimize the management of the system and reduce the environmental and production risks. Trying to extrapolate this point, one may contend that any cropping system poorly in phase with such processes will probably entail inherently higher levels of potential mismanagement, as one or several key practices may not have a very sound ecological basis. Examples of such problems include summer bean production or livestock grazing in hillsides, two land uses which frequently lead to high rates of environmental degradation or crop failure (Humphries, 1994)

How much of the instant success of the mucuna rotation with new users is due to its nearly immediate effect on maize productivity is debatable. Bunch (1982; 1993) considers these short-term benefits to be especially important in motivating individuals and communities in adopting a new technology. Certainly, this acts as a powerful incentive to convince skeptical farmers that "something good is going on". Conversely, the absence of short-term benefits may jeopardize the adoption of otherwise sound technical alternatives. such as agro-forestry cropping systems

Another important aspect of the mucuna system is that it is a multi-purpose innovation, in the sense that the introduction of one single "technology" (the mucuna fallow) provides answers to many simultaneous constraints, from soil conservation to weed control, nutrient input or labor use. Whereas it has been demonstrated that farmers have a tendency to adopt new "external" technology in a step-wise fashion rather than in packages (Byerlee and Hesse de Polanco, 1986), the concept of a single multi-purpose technology is perhaps an alternative model to be followed in the design of sustainable cropping systems (Francis, 1993), much in the same way that agroforesters have come to recognize the necessity of multi-purpose trees.

Last but not least, farmers' complete control over the technological agenda seems a necessary ingredient for a successful technology. The usual constraints linked to the need for external capital, training or complex information all but disappear in the case of the mucuna system, as it relies strongly on farmers' past experiences and empirical knowledge (Buckles *et al.*, 1992; Holt-Gimenez and Pasos Cedeño, 1994).

6.4 CRITICAL EVALUATION OF THE METHODOLOGICAL CHOICES

6.4.1 On-farm research techniques

Because the mucuna/maize rotation had been adopted by thousands of farmers in the Atlantic littoral, and in the absence of precise hypotheses about the system, an on-farm research scheme seemed fully justified to decipher this cropping system. A wide array of tools was used, including farmers' interviews (collective or individuals), agronomic monitoring, yield and biomass crop-cut surveys, on-farm experiments, and an assortment of soil sampling activities. The study developed at several levels: the region, the village, the field and the observation plot. A key concern throughout was to create a sample scheme allowing for reasonably fair inferences in spite of the high variability typically associated with hillside environments and manual agriculture. For that reason, it was decided to shield our study from the influence of factors such as elevation (only a narrow range of elevations was permitted within each village), slope (slopes lower than 25-30% and higher than 70% were excluded), and topographic position (only linear backslope positions were selected). An effort was made to control soil type, but it was only partly successful. Sampling scheme was purposive rather than random, as a major criterion for field selection was field cropping history with respect to the introduction of the mucuna/maize rotation.

In retrospect, it can be said that variability remained very high in spite of the precautions taken, and this translated into a number of situations for which no conclusions could be reached. This may stem from insufficient efforts to construct our survey in the form of a quasi-experimental protocol (Gras, 1981), and to identify factors and conditions to be used as explanatory covariables in the interpretation. Conduction of an initial exploratory survey of the mucuna system would certainly have helped designing a better study. Also, a better balance between a purely observational attitude (as was the case in the agronomic monitoring) and a more experimental inquiry (in which specific treatments are imposed, as was the case with the fertilizer trials) would have probably yielded more clean-cut answers. Similarly, the balance between an in-depth "mechanistic" exploration of a few carefully-chosen fields and a coverage broad enough to satisfy the statistical requirements of extrapolability of the conclusions was not satisfactory: too few sites were selected for attaining the latter, and too few observations were made to achieve the former. This frustrating result may be an unavoidable consequence of the relatively broad objectives assigned to the study.

Given the mixed results outlined above, a legitimate question is whether the benefits associated with agronomic monitoring are worth the heavy time commitment such an activity implies. There is undoubtedly great value in establishing a routine that will oblige the researcher to be present and observe fields at several moments during the growing season. These visits allow an intuitive understanding or at least an appreciation to develop for what is taking place in the field, something that no amount of statistical manipulation of data will ever allow. Perhaps involving more heavily the farmers themselves in the agronomic monitoring would constitute a viable improvement over an agronomic monitoring conducted exclusively by the researcher.

With respect to the various levels at which this study developed, one could regret that few bridges were created allowing the passage of one level to the other. For example, no quantification of the relative importance of backslope positions was done, and it is similarly difficult to evaluate the representativeness of the four villages studied within the Atlantic littoral region. This relative flaw stems from the fact that the various scales were integrated in the survey on the go, without considering the implications that such a move would create in terms of sampling strategies and conceptual framework (cf. the discussion of hierarchical models in Lavelle *et al.*, 1993).

6.4.2 Chronosequence approach

Our foray into long-term effects was based on the use of a chronosequence approach, or a space-for-time substitution following the terminology of Pickett (1988). Even though it was impossible to test the conclusions within the framework of this study, it seems fair to state that our approach was successful in our main research site (San Francisco de Saco) insofar as it was possible to select geographically close-by plots with contrasting cropping histories and we were able to scrutinize carefully the historical information by repeated contact with the farmers. The insights obtained under such conditions appear to be globally consistent with agronomic experience gained elsewhere, something which confers an indisputable solidity to our conclusions. When the chronosequence scheme was applied more rapidly however, results were mixed. In particular, it became difficult to know whether to trust the trends detected, or to question the construction of the chronosequence.

It seems than any researcher considering a chronosequence approach should be conscious of the high requirements in terms of data quality and quantity. Possible confounding factors should be excluded from the sample as much as possible, or controlled for by characterizing them as covariables, and large samples should be constituted, allowing potentially for ex-post stratifications of the initial sample These requirements disqualify chronosequences from being considered low-cost alternatives to direct long-term studies, even though their ability to deliver conclusions and working hypotheses in a relatively short time frame remains very attractive

It appears desirable to use empirical chronosequence approaches in conjunction with both mechanistic modeling and simulation at the level of the whole-field soil-plant system (Jones *et al.*, 1993), and carefully designed field studies focusing on suspected mechanisms and processes of change. By combining empirical data with explicit hypotheses about mechanisms, the quality of the construction of the chronosequence itself could be assessed, and specific hypotheses about the nature and quantity of the changes taking place could be tested (Cassman *et al*, 1995). Also, simulation and field trials would allow one to explore the effect of factors or factor levels other than those encountered in farmers' fields (Uehara, 1994) Such a combined approach would require however that enough baseline information be available at the *onset* of the study to select and calibrate an appropriate simulation model (Addiscott, 1993), and to design meaningful experimental treatments

6.4.3 Soil fertility measurements

In general, the variables chosen in this study seemed to constitute pertinent indicators of temporal changes at the scale of the maize cycle (inorganic nitrogen) or the decade (soil carbon and nitrogen, exchangeable bases, infiltration). A number of improvements could however be made. For one thing, it seems necessary to include a characterization of biological properties, at least in terms of overall activity at key moments of the mucuna cycle, as this is a critical area where changes seem to be taking place over time. Measurements and sampling protocols should also reflect the fact that much of the system's dynamics is related to the functioning of the litter layer/upper soil profile. For example, it seems necessary to characterize decomposition directly in the litter layer, perhaps by using appropriate litter bags and ion-specific resin bags techniques to follow nutrient accumulation at the base of the litter layer rather than only in the soil Dynamics of organic nitrogen should be evaluated concurrently with that of inorganic N, as it may play an important role in the redistribution of nitrogen in the system. Weed dynamics seem to deserve special attention as one important mechanism for nutrient recycling (Lambert and Arnason, 1989). Soil sampling should distinguish clearly the first 5 cm of soil profile from lower depths.

Conceptually, it seems also necessary to analyze soil fertility from a more holistic perspective, by focusing on the overall processes affecting soil quality (Doran and Parkin, 1994, Pankhurst, 1994) at the level of the entire soil/litter/plant system rather than on static, individual variables whose interrelationships remain unknown. A careful examination of the various scales at which soil fertility is determined would certainly be needed. in this study, we focused on small 10x10 m^2 observation plots (a rather arbitrary unit), whereas "natural" superior scales (e.g. landscape) or inferior ones (soil aggregates) were ignored, in spite of their potential importance in determining specific processes (McGill and Myers, 1987; Lavelle *et al.*, 1993).

Chapter 7

SUMMARY AND CONCLUSIONS

Three interdependent objectives were delineated at the onset of this study: (1) document the main features of the mucuna/maize rotation practiced by farmers in the hillsides of Northern Honduras, (2) detect long-term trends in soil properties under continuous use of this rotation, and (3) understand nitrogen cycling in such a system.

7.1 MAIN FEATURES OF THE MUCUNA SYSTEM

The mucuna/maize rotation is a low external input, no-tillage rotation between a summer mucuna fallow and a winter maize crop. It presents radical contrasts compared to other ways of growing maize. Compared to a typical maize/fallow system, the medium- or long-term fallow with trees or shrubs is replaced with a short-term herbaceous fallow. Whereas for the tree fallow, burning is perhaps almost a necessity, the mucuna fallow is not burned. simple sun-drying for a couple of days reduces the mass of slashed material to a litter layer no more than a few cm thick, easy to walk over, and fast-decomposing under the usual environmental conditions prevailing during the maize cycle.

Compared to conventional input-based maize production on the other hand, the mucuna system is characterized by its reliance on no-tillage (a necessity in steep hillsides), and by a very modest use of external inputs (none in many cases, and at most light doses of herbicide and nitrogen fertilizer). Organic inputs are large however, in the form of slashed mucuna and weed biomass and crop residues. Farmers' practices are integrated with and dependent on the natural ecology of the mucuna crop. Slashing of mucuna takes place at about the same time as mucuna would die naturally, and farmers rely on spontaneous reseeding for its re-establishment. Maize nutritional requirements are mostly met by the nutrients released upon decomposition of the mucuna mulch, which in Northern Honduras seems to be controlled mostly by moisture availability.

Management of the mucuna rotation appeared fairly uniform across fields and sites throughout the Atlantic littoral of Honduras, in spite of local fluctuations in soils, rainfall, slashing/planting dates or weed management strategies. This has two important implications. First, the effects of the rotation on the physical environment in a given site can be assigned mainly to the number of years spent in the rotation, not to differences in management. And second, the conclusions about mechanisms and limitations reached in selected sites and fields can be readily extrapolated to the mucuna system as a whole.

Selection of a slashing date by the farmer was shown to constitute the key management option in the mucuna system, as it also determined planting dates and relative availability of nutrients for the maize crop. However, as long as natural reseeding remains the favored option to ensure reestablishment of mucuna (and as long as there is no usable variability in mucuna germplasm maturity class), there is a relatively narrow window for slashing mucuna and planting maize, from late November to mid-January

This study documented the mostly positive consequences of the way in which mucuna or maize were managed, given the overall constraints under which most farmers operate. Long-term trends in soil fertility were positive and yields were satisfactory, at least compared to other alternatives for producing maize in the hillsides (2 to 4 t.ha^{-1} with mucuna vs less than 2 t.ha^{-1} without). There are however a number of concerns One is weed control. Aggressive annual grasses such as *Rottboellia cochinchinensis* will likely prosper in the mucuna system, although a stricter control by farmers over mucuna re-establishment might mitigate its negative impact. Another concern involves the need to provide hillside farmers with a better income-generation capacity in the future Even though planting basic grains is certainly not the best avenue for generating income, use of the mucuna system could relatively easily lead to maize yields of 5 to 6 t ha^{-1} in many well-established mucuna fields, given the high soil fertility and water availability But achieving high yields would imply increasing plant densities significantly above present stands (around 30,000 plants/ha), which in turn would probably require a shift away from tall local landraces susceptible to lodging, and towards improved germplasm.

7.2 NITROGEN CYCLING

A partial study of nitrogen cycling confirmed the extremely dynamic nature of a mucuna stand Periods of net accumulation of biomass and nitrogen (i.e when mucuna is growing) alternate with periods of net mineralization (after mucuna has been slashed), although there is overlap between these two processes At any given time, there is always at least some vegetation actively growing, and some recently-formed litter decomposing

Large amounts of nitrogen are cycled in the mucuna system every year. An average of more than 300 kg.ha^{-1} of nitrogen could be found in the above-ground biomass of mucuna at slashing. Following slashing, there was a marked increase in the quantity of inorganic nitrogen found in the soil profile (from 50-60 kg.ha^{-1} before slashing up to 120 kg.ha^{-1} in the 0-60 cm profile). This peak had mostly disappeared after 4 to 6 weeks, under the combined influence of maize and weed uptake. It was estimated that a maize crop yielding about 4 t.ha^{-1} accumulated around 100 kg ha^{-1} in its above-ground biomass whereas weeds could mobilize up to 50 kg.ha^{-1} before they were controlled, and even more than this after farmers had stopped controlling them. A fraction of the nitrogen, perhaps as much as 50 to 80 kg.ha^{-1} on average appeared to be stored in the newly-formed soil organic matter every year There was no evidence that losses of nitrogen by either leaching or volatilization were playing an important role in the mucuna system

Considering the availability of inorganic N in the soil profile on one hand, and the quantities of nitrogen exported via maize harvest or stored in the soil on the other hand, it was argued that yearly biological nitrogen fixation by the mucuna crop was probably of minor importance compared to the ability of the mucuna system to recycle nitrogen via the activity of mucuna, weeds, maize and the soil/litter biota. This latter would account for about 200 kg.ha^{-1} vs. no more than about 100 kg.ha^{-1} for biological fixation.

Based on the results of a series of N x P fertilizer trials, it was concluded that use of chemical fertilizers in the mucuna system was for the most part unnecessary, as the abundant mucuna mulch (more than 10 t.ha^{-1} of above-ground biomass on a dry-matter basis in most cases) provided quantities of nitrogen, potassium, and phosphorus (about 300 kg.ha^{-1}, 100 and 20 kg ha^{-1} on average respectively) well above or at least equal to the nutritional requirements and exportations of a maize crop. However, and especially if maize yields are to be increased, supplemental N fertilization might provide the maize crop with access to inorganic N above the limited *instantaneous* supplying capacity of the mulch, which vary markedly in response to environmental conditions. In a relatively wet cycle, this supply was adequate to meet maize nitrogen requirements (no response to added nitrogen was observed). Conversely, in a drier cycle, supply by the mulch was reduced, and a significant response to nitrogen fertilizer was obtained. There was however a sizable variability in the amplitude of the response, which remains largely misunderstood at this moment.

7.3 LONG-TERM TRENDS IN SOIL PROPERTIES

By using a chronosequence approach consisting of a comparison among fields having been subjected to the mucuna rotation for various lengths of time, from never to more than 15 years of continuous use, a number of important conclusions were reached.

First, there were no signs of active soil erosion in mucuna fields. the dense mucuna canopy protects the soil surface during the period of intense rains (numerous single rains above 100 mm) and there is a continuous litter layer year-long. The potential role of mucuna in favoring localized landslides on very steep slopes remains to be elucidated however. This near-perfect, low-cost soil erosion control is certainly a major contributor to the agroecological sustainability of the mucuna system in an erosion-prone environment.

Not only is soil conserved, but soil fertility seems to increase over time in many fields. In our main research site, levels of soil organic matter increased by as much as 30 to 50% in the upper soil profile (first 5 cm). Levels of exchangeable calcium and magnesium increased throughout the soil profile (sampled to a depth of 60 cm), probably as a result of mucuna' ability to accumulate these nutrients (150 kg.ha^{-1} of calcium were present on average at slashing time in the above-ground biomass). Although the large amounts of nitrogen mineralized by the mucuna mulch seemed to create a potential risk for gradual soil acidification, no such trend was detected.

Soil physical properties also showed positive trends: steady-state infiltration rates appeared to increase markedly over time with the use of the mucuna rotation, whereas total porosity increased, especially in the upper profile. Old mucuna fields had as many or more large pores as fields where no mucuna had been grown.

Finally, even though biological activity was not measured, there was abundant qualitative evidence to indicate that the litter layer and upper soil profile were the site of intense biological activity from a variety of fungi, arthropods and earthworms, among other organisms.

7.4 THE QUEST FOR SUSTAINABILITY IN HILLSIDES

Two central questions regarding the mucuna/maize cropping system are (1) is it sustainable? and (2) can it (or its principles) be extrapolated to other regions or environments?

I would answer yes to both questions, with the following restrictions. Sustainability cannot be judged only by the fine agroecological performance of the mucuna system (Harrington, 1992). The capacity to produce a marketable surplus beyond the household food consumption requirements is essential to guarantee household survival and development. The mucuna system, while undoubtedly superior to other alternatives, hardly generates more than subsistence income. This stems from a combination of the low market price of maize, and the small areas cultivated by most farmers. If a fraction of mucuna biomass were used as a forage crop, or mucuna seed were partially collected for supplementing pig rations, many households could probably increase their profits. Perhaps a better solution would be to ***intensify maize production*** on a small area under the mucuna/maize system (thus meeting the objective of food security cherished by many farmers) while engaging in other environmentally-friendly, high value-added productions ***on the remainder of the farm***. Alternatives may include introducing livestock together with improved pastures (thus bypassing the need for large landholdings), or planting vegetables, fruit trees or timber species with a good market value. If this were to happen, the farm-wide adoption of the mucuna system observed presently would be a necessary, transitory phase on the way to diversified, sustainable farming.

With respect to extrapolability, areas of the humid tropics (not necessarily hillsides) with a short dry season and relatively low pressure on land could benefit most from a direct transfer of the mucuna system. However, a number of principles are valid in numerous other environments. Combining no-tillage, mulching and crop rotations to control erosion, weeds and other pests, to supply nutrients, to optimize water use and to maintain or rebuild soil fertility over time is undoubtedly critical. As rainfall becomes less abundant however, accumulating enough biomass to produce these various effects becomes an important issue. A number of alternatives for maintaining a minimum soil cover exist. In extreme cases, it has been shown that even a modest 2 t ha^{-1} of crop residues used as mulch may offer advantages compared to clean cultivation (Scopel, 1994; Unger, 1994). Other worthwhile features of the mucuna system include the reliance by farmers on natural ecological controls and processes to optimize crop management, the low cost (in capital, labor and information) and short-term benefits associated with the introduction of a legume fallow, and the control farmers exercise on the technology

7.5 ESTABLISHING A RESEARCH AGENDA ON MULCH-BASED AGRICULTURE

The principles embodied in the mucuna system are hardly new, even though they have not been widely documented in the conventional agronomic literature of the past 40 years (Sanchez, 1994). The mucuna system is one of numerous successful slash-and-mulch cropping systems, some centuries old, developed by farmers throughout the tropics (Thurston, 1994): other examples include the Frijol Tapado system used extensively in Costa Rica (Bellows, 1992; Araya V. and Gonzalez M., 1994), or the maize-chinapopo (*Phaseolus coccinus*) found in the highlands of Honduras (Solomon and Flores, 1994). In spite of their merits, these systems are no panacea for smallholder agriculture, given the acute pressures on the resource base observed in most tropical countries. The capacity of slash-and-mulch systems to withstand intensification without losing the agronomic benefits they entail remains uncertain (Buckles and Sain, 1995)

Few resources have been devoted to study and improve these systems, considered by many scientists to be marginal, archaic or hopelessly low-output This is not necessarily the case however Schlather (1996) was able to increase bean yields three-fold in the Frijol Tapado system by broadcasting moderate doses of P fertilizer in the mulch. Also, the on-going shift away from chemical-input based agriculture and towards more environmentally-sound forms of farming in developed countries (Sanchez, 1994) constitutes a *de facto* validation of many of the same principles at work in tropical slash-and-mulch cropping systems. Throughout the tropics however, governments and public institutions have been very slow at integrating the principles of sustainable agriculture in their routine actions, in part because of the weakness of the actors involved, and because political structures have been hardly responsive to the needs and concerns of poor households living in marginal environments Hence the fight to value and promote sustainable agriculture has been mostly the domain of relatively small non-governmental organizations not prepared to conduct the research needed to accompany farmers in their efforts to innovate and adapt their practices to rapidly changing circumstances.

In many ways, small resource-poor farmers are still ahead of the scientific community in having devised durable ways of farming difficult environments. It is my deepest belief that if more scientific studies were conducted on the agronomic processes conducive to a more sustainable agriculture, alongside a systematic documentation of farmers' past and present experiences in this area, much useful conceptual and practical knowledge may be gathered that would add to what scientists and farmers have already formalized about these issues

There is an infinite array of topics that need to be addressed from a variety of angles and disciplines. For example, changes in soil biology (from soil biota composition to rates of various microbial activities) needs to be examined in relation to the establishment of a quasi-perennial mulch or litter layer on the soil surface. Similarly, soil structure (structural stability, aggregate distribution, etc.) and its relationship to crop root development and uptake patterns would need to be assessed to understand the significance for the soil-plant system of the detailed changes in individual soil properties from a functional perspective. Water balances and their relationship to short- and long-term nutrient balances and crop growth also need to be determined. Another line of inquiry would be to modify experimentally (and via computer simulation) existing slash-and-mulch systems in order to determine the actual plasticity of their performance in response to changes in a number of important factors and conditions, such as initial soil conditions, rates of annual biomass inputs, available rainfall and its distribution, length of the fallow cycle, levels of nutrient exportations by harvest, etc.

Similar amounts of research should also be dedicated to socioeconomic issues such as understanding farmers' decision-making about the use and adoption of sustainable technologies, boosting the profitability of small-scale production systems by means of intensification and diversification, or devising practical methods for quantifying the total productivity of a cropping system (Steiner *et al.*, 1995), among other topics.

In all these studies, using and formalizing farmers' present knowledge, perceived constraints and objectives seems a necessary starting point, to avoid investing scarce resources in topics or areas with little potential for generating a positive impact on farmers' practices and standards of living. This also implies that a systemic, interdisciplinary and participatory approach to research on sustainable agriculture and slash-and-mulch systems should be used, without which all the typical caveats associated with scientist-driven disciplinary research will plague this promising field of study.

APPENDIX

APPENDIX A: SURVEY INTRUMENTS

A.1) INITIAL SURVEY OF FIELD CROPPING HISTORY (11/92)

Agricultor ______________________________
Localidad ________________________ AMI __________
Ubicacion Parcela ______________________________

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1 Cuantos años tiene esta parcela de tener frijol de abono? ____________
(Si no es abonera pasar a la pregunta # 5)

2 Siempre fue Ud el dueño de esta parcela desde que se establecio la abonera? ____
Si no: identificar quien era el dueño anterior y ir a hablar con el.

3 Al establecer la abonera, sembró toda la parcela en FA el mismo año?

Si no: hacerse explicar donde empezo primero, y donde se sembro cada año (dibujar puede ser util.)

4 Se perdio alguna vez la abonera desde que la establecio?

Si si: Cuando? ____________ Razones (Quema/Sequia/ganado/etc.) __________

5 Antes de establecer la abonera (la milpa), que rotacion habia tenido esta parcela?
____
(Distinguir bien si era guamil (de cuantos años?), potrero, o si se habia cultivado en continuo)

6 Antes de establecer la abonera (o hoy mismo, si no tiene FA), como era la tierra en esta parcela (buena/regular/mala)? ____________________

7. Que tanto ha mejorado la situacion con el FA? __________________
Rendimiento/mz antes: ______ ahora: _________ (unidad __________)

8 Tiene Ud algun problema en esta parcela en relacion con la tierra (erosion, derrumbes,)? ____

9 Hoy dia, observa Ud alguna diferencia importante de una parte a otra dentro de la parcela en cuanto a como se ve la tierra, o como crece la milpa?

(Si si: hacerse explicar donde y a que se debe la diferencia)

A.2) FINAL SURVEY ON CROPPING HISTORY AND MANAGEMENT OF THE MUCUNA/MAIZE ROTATION (7/94)

Agricultor: ________________________________ Aldea: ____________

Parcela ________________ Area total: ______ manzanas

Fecha Encuesta: _____/_______/94

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1. Historial parcelas muestreadas

1.1 ¿En que año se sembró frijol de abono en esta parcela? ___________

(# de veces que se chapió el FA) [si no es abonera, pasar directamente a la pregunta 1.5]

1.2 ¿Sembró FA a un solo tiempo en toda la parcela tal como la tiene hoy? _______

Si no, hacerse explicar los # años de siembra, con ref. a los cuadros de monitoreo:

cuadro 1, año ____ cuadro 2, año: ____ cuadro 3, año: ______

Si la parcela no pertenecia al agricultor al momento de establecer la abonera, indicar con quien obtener esta información (Don ______________) en la aldea

1.3.a ¿Se dio bien el FA en esta parcela desde el primer año en que se sembró? ______

Si no: ¿Cuantos años para que se establezca bien? ______

1.3.b ¿Hubo años durante los cuales la abonera no desarollo bien? ____ **¿cuales?** ____

1.4. ¿Alguna vez se perdio totalmente o bastante la abonera desde que se sembró? ___

Años _____ Razones: **Quema** - **Sequia** - **Ganado** - **Plagas** - **Cambio cultivo** - **Otros**

_____ **Quema** - **Sequia** - **Ganado** - **Plagas** - **Cambio cultivo** - **Otros**

¿Que hizo para reestablecer la abonera? **Nada**, se compuso solo - resembró por **partes** - **todo**

1.5 Antes de sembrar FA en esta parcela (o antes de este ciclo, para los testigos), ¿que cultivaba?

a. nada, era montaña que no habia sido jamas cultivado

b. nada, era un guamil que tumbé para sembrar FA (en milpa o directamente?)

c. habia sembrado maiz de primavera - postrera cada año desde hace __ años

d. habia sido potrero desde hace ___ años

1.6 ¿Cuando es la ultima vez que quedó enguamilado esta parcela? _____

¿cuantos años continuos se quedó enguamilado? _______

¿Quemó el guamil despues de tumbarlo? ____ ¿Sacó troncones? _____

1.7 Antes de sembrar FA, ¿como era la tierra en esta parcela? **Buena** - **Regular** - **Mala**

Niveles de rendimiento alcanzados sin FA (rango): _________ cargas en oro-tuza/mz

1.8 Desde que sembró FA, ¿como ha cambiado la tierra? **mucho mejor - mejor igual - peor**

Niveles de rendimiento alcanzados con FA (rango) ________ cargas en oro-tuza /mz.

1.9 ¿Ha observado problemas de erosión / lavado de tierra o derrumbes en esta parcela

a. antes de haber sembrado FA? ______________________________

b. despues de haber sembrado FA? ____________________________

Si si en b.: en su opinion, estos problemas se deben al FA? _____ (hacerse explicar)

1.10 ¿Como considera Ud. las partes donde teniamos las estacas comparado con lo demás de la parcela (la pregunta se refiere a la calidad de tierra)? **mejor - mas o menos similar - mas peor**

(si existe diferencia entre cuadros, mencionar por separado cada cuadro!)

2. Postrera 93/94

2.1 Fecha aprox. de chapia (semana/mes) inicio: __________ duración: ________

¿Algún problema con la chapia? ______________________________

2.2. Fecha aprox. de siembra (semana/mes): inicio ________ duración. ________

Clase de maiz ____________ semilla. **Propia - Vecino - Comprada afuera**

¿Algun problema con la siembra? ______________________________

2.3 ¿Fertilizo? ___ Si si. producto: _____ dosis/mz. ____ area total abonado ___

2.4 ¿Cuantas limpias hizo? ________ ¿Cuando? **1ra.** _____ **2a.** ____ **3a** _____

Usó veneno para las limpias? ____ ¿**producto**? ____________ ¿**cual limpia**? ____

¿Considera que hizo las limpias a buen tiempo? **1ra**: ____ **2da** _____ **3a** _______

¿Logro controlar bien el zacate o el monte? ______________________________

2.5. ¿Cual es su opinión sobre esta postrera? **Muy buena - Buena - Regular - Mala**

¿Que es lo que le faverecio este ciclo? ______________________________

¿Que es lo que le perjudico?. ______________________________

2.6 ¿Cuanto sacó Ud __________ cargas /mz **O** __________ cargas/toda la parcela
en la parcela? **Unidad** ¿en tuza o en oro? __________

2.7. Todavia se acuerda Ud. de cuanto sacó de esta misma parcela en años anteriores.

¿hace 1 año (postrera 93)? ______ cargas / mz o ___ cargas / toda la parc.

¿hace 2 años (postrera 92)? _____ cargas / mz. o ___ cargas / toda la parc

¿hace 3 años (postrera 91)? ______ cargas / mz o ___ cargas / toda la parc

[**unidad**. cargas en tuza o en oro?]

3. Manejo de la abonera y del maíz en abonera

3.1 **Forma de sembrar FA** (lo mas comun para el agricultor)

¿en la milpa (invierno? postrera?) o directamente despues de tumbar guamil? _____
¿cuantas libras de FA por manzana? _______ regado o sembrado? _____
¿Distancia entre macanazos: ______ x _____ (¿en cuadro o surceado? ________)
semillas/golpe _____ clase de semilla: ______________

3.2 Una vez sembrado, como hace para que se resiembre el FA de un año para otro?
a. dejar que nazca solo b. resembrar por **partes** c. resembrar **todo** cada año

3.3 Chapia

¿epoca mas común para chapiar? ____________________ (ej: mediados de dic.)
¿criterio para decidir de empezar la chapia? ______________________________
¿algunas técnicas especiales que emplea Ud.:
* para controlar ratones? ______________________________
* para distribuir las vainas? ______________________________
* otras particularidades: ______________________________

3.4 Siembra de maíz (lo más habitual)

* ¿cuanto tiempo espera despues de la chapia? ______________________
* ¿siembra surqueado? ______ distancias de siembra. _______ x ________
* semillas/ macanazo. ______ maiz hinchado? ___ curado? ____
* siembra con cabulla? ______ con mozos? ______
* clases de maiz que acostumbra sembrar en abonera? __________________
* compra semilla de fuera o es propia? ______________________
* hay diferencia entre la forma de sembrar en aboneras y donde no hay FA? ___
Si hay, hacersela explicar (distancia de siembra, clase de maiz, fecha, etc.)'

3.5 Limpias

a ¿cuantas limpias hace en general durante la postrera? ________________
b. (llenar el cuadro siguiente, usando los codigos correspondientes para cada limpia)

	1ra limpia	*2da limpia*	*3ra limpia*
¿cuando? (en dds)	________	________	________
¿como? (ver codigos)	________	________	________

1a solo con azadon **1b**: solo con pando **1c**. machete **2**: solo gramoxone
3. solo 2-4 D **4**. gramox. y 2-4 D **5** manual y gramoxone **6** manual y 2-4 D

c Zacates o monte más dificiles de controlar
1 ________________ 2. ________________
3 ________________

d ¿Puede llegar el FA a perjudicar el maiz cuando se desarolla bastante? __________
¿Si si, como hace para evitar este problema? ______________________________

3.6 ¿Hay diferencias entre la **forma** de limpiar en parcelas donde hay FA comparado con parcelas donde no hay? __________ Si si, explicar (# limpias, # jornales/limpia, uso venenos, etc.)

3.7 (solo para agricultores que tienen Z. Invasor en su parcela)

* ¿desde cuando tiene Invasor en la parcela? __________
* ¿a que se debe la aparición del Invasor en su opinión? ____________________
* ¿ha tenido que cambiar su formar de limpiar desde que tiene Invasor? ____

Si si: explicar la diferencia entre antes y ahora. ____________________________

3.8 **Fertilización**

a. ¿Acostumbra abonar el maiz aún en abonera? ____________________

b. Si si ¿Todos los años? __________
¿Cuando? (dds) ______________________________
Producto: ______________________ Dosis/mz ____________________

c. Si no es todos los años
¿criterio para decidir abonar? ____
¿influye en algo la edad de la abonera? __________________________________

d. Si no abona del todo **razones** (no necesita/costo/otro) __________________________

3.9 Antes de sembrar FA en la parcela donde teniamos las estacas, ¿ya habia sembrado FA en otra parte? ______________ ¿En que año lo sembró por primera vez? __________

3.10 Alguna vez ha dejado de cultivar FA en una parcela donde lo habia sembrado? ___

Si si ¿despues de cuantos años de tenerlo? ______________________________
¿por que razon? ____

3.11 a. ¿Cultiva maiz de postrera sin FA? ________ ¿cuantas manzanas? ________
b. ¿Cultiva maiz de primavera sin FA? _______ ¿cuantas manzanas? ________

3.12 a ¿Cada año cultiva mas o menos la misma cantidad de maiz de postrera? ______
Si no: rango de area y razones de variacion. ______________________________________
¿para que fin? (gasto, venta, seguridad) ______________________________________

3.12.b ¿Cada año cultiva mas o menos la misma cantidad de maiz de primavera? _____
Si no: rango de area y razones de variación ______________________________________
¿para que fin? (gasto, venta, seguridad) ______________________________________

A.3) COLLECTIVE SURVEY (VILLAGE LEVEL) ABOUT CROPPING HISTORY & MANAGEMENT OF THE MUCUNA/MAIZE ROTATION (7/94)

1. ¿Antes de empezar a sembrar FA en esta aldea. acostumbraban no quemar?

2. ¿Antes de empezar a sembrar FA, acostumbraban sembrar maiz de postrera?

3. ¿Antes de empezar a sembrar FA, cual era la rotación mas común que seguían Uds. en sus parcelas de maiz?

4. ¿Aproximadamente que proporción de agricultores usan FA hoy dia en la aldea?

5. ¿Hay alguna diferencia entre las clases de tierra en las parcelas de los primeros que empezaron a sembrar FA comparado con los que solo lo adoptaron desde hace poco tiempo (fertilidad. pendiente. distancia de la aldea, etc)?

6 ¿Hay diferencias en la forma de trabajar una milpa en abonera comparado con una milpa donde no se ha sembrado FA? (Distinguir bien ciclos de primavera y de postrera)

[primero dejar que contesten libramente. despues preguntar por tema: siembra (fechas. densidad, clase de maiz), control malezas. fertilización]

7. ¿Hay diferencias en la forma de trabajar en aboneras viejas vs. jovenes?

8 Empezando cuando uno siembra FA en una parcela por primera vez y observando como va cambiando la situación al pasar los años:

   a ¿cuantos años seguidos se puede decir que van subiendo los rendimientos hasta estabilizarse?

   b ¿Habrá algun momento en que los rendimientos empiezan a bajar?

   c ¿Aparecerán problemas al cabo de cierto numero de años que no se observarian normalmente en parcelas sin FA o en aboneras jovenes?

9 Entre los primeros años en que empezaron a sembrar FA en esta aldea y hoy. considerando la experiencia que han ganado poco a poco con este cultivo, pueden Uds acordarse de haber cambiado en algun aspecto su forma de trabajar con FA?

[dejar que contesten libramente, despues preguntar especificamente sobre forma y epoca de establecer FA, formas y epocas de chapia, formas de manejar el FA que va naciendo solo. # y epocas de limpias]

10 ¿Hay gran diferencia de un año para otro en cuanto a cantidad de follaje/bejuco/vainas que produce el FA al momento de la chapia? Si si: ¿a que se deben estas diferencias segun Uds ?

11 ¿Que tan rapido logra el FA ahogar las malezas despues de la tapizca?
¿Que tan variable es de un año para otro?

12 ¿Hay clases de tierra donde según su experiencia no se da bien el FA? [Si si: hacerse describir sus caracteristicas y averiguar si otros cultivos se dan bien en estas tierras]

13. ¿Tiene el FA algunas desventajas serias?

14. ¿Tiene el FA algunas desventajas leves?

15. ¿Que hacen o podrian hacer Uds. para superar estos problemas?

16. ¿Que tendria que hacer un agricultor en su parcela para tener niveles de produccion aún superiores a los que se dan presentemente en aboneras?

17.a ¿Que clase de experimentos han realizado Uds. por cuenta propia para mejorar su forma de trabajar en aboneras?

b. ¿Que resultados han obtenido?

18. ¿Es rentable producir maiz en abonera?

19. ¿Cual es el nivel minimo de producción/mz. para pagar los costos?

20. ¿Como compara la ganancia que uno puede sacar de una manzana de maiz con FA comparado con (1) una manzana de maiz sin FA? (2) una manzana de potrero junto con sus vacas? (3) una manzana de frijol de comer? (4) una manzana de cacao? (5) algun otro cultivo?

21. ¿Puede ganar lo suficiente uno al cultivar maiz con FA para no tener que ir a trabajar a la ciudad? a EE UU? ¿Que dicen los jovenes al respecto?

22. Sabemos bien que la producción no es la misma de un año a otro. En esta comunidad, y con la experiencia de todos Uds., ¿podrian decirnos aproximadamente el numero de años buenos, regulares y malos que va a haber en 10 años respecto a la **producción** de maiz? Para cada clase de año, ¿que tanto podria sacar Ud. de sus parcelas en postrera y en primavera?

a. ¿# años **buenos**? ___/10 Prod. **post** ___ cargas/mz Prod. **prim** ___ cargas

Razones ______________________________

b. ¿# años **regulares**? ___/10 Prod. **post** ___ cargas/mz Prod. **prim** ___ cargas

Razones ______________________________

b. ¿# años **malos**? ___/10 Prod. **post** ___ cargas/mz Prod. **prim** ___ cargas

Razones ______________________________

e. Ejemplos de años que en los 20 ultimos años han sido:

muy buenos: __________ buenos: __________
regulares: __________ malos: __________

23. ¿Hay fechas de siembra (en postrera) mas favorables que otras en esta comunidad?

APPENDIX B: REPRESENTATIVENESS OF BACKSLOPE POSITIONS

Soil samples used in this study came almost exclusively from observation plots located in backslope topographic positions (chapter 2, section 2.3 and 2.4 page 25 & following, chapter 5, section 5.3.4, page 142; see also Figure 2.5.c. page 31) A limited study was conducted in four fields in San Francisco de Saco to determine whether soil chemical properties of backslopes were different from that of either shoulder or footslope positions Selected results are presented in Table B.1 (next page)

Even though there are a number of statistical differences among topographic positions, trends are not consistent among farms Hence, it can be concluded that backslope positions selected in this study exhibited soil properties typical if not representative of soil properties at the whole field level

Table B.1: Variability of soil properties as a function of the topographic position in four fields, San Francisco de Saco

		<	*farmer*		>		<	*stat. signif.*[1]	>
property	*pos.*[2]	*chema*	*galdamez*	*obed*	*tonio*	***average***	*farm*	*pos.*	*farm*pos.*
0-10 cm									
pH	S	6.25	6.27	6.16	5.98	**6.16**	ns	ns	ns
	B	6.26	6.25	5.94	5.97	**6.09**			
	F	6.34	6.20	6.34	6.11	**6.25**			
Ca meq	S	11.4	15.2	14.2	9.0	**12.5**	ns	ns	ns
	B	17.5	14.4	14.4	13.0	**14.8**			
	F	10.9	11.5	14.4	12.6	**12.3**			
Al meq	S	0.07	0.12	0.20	0.46	**0.21**	<0.001	0.004	<0.001
	B	0.09	0.08	0.16	0.17	**0.13**			
	F	0.09	0.18	0.20	0.17	**0.16**			
K meq	S	0.19	0.10	0.10	0.27	**0.17**	0.02	ns	0.118
	B	0.23	0.13	0.17	0.14	**0.17**			
	F	0.22	0.10	0.11	0.10	**0.13**			
P ppm	S	4.6	0.2	0.0	0.0	**1.2**	0.014	ns	ns
	B	2.3	1.7	1.2	4.4	**2.4**			
	F	4.6	0.0	0.0	0.0	**1.1**			
30-60 cm									
pH	S	6.38	6.24	6.14	6.03	**6.20**	0.021	ns	ns
	B	6.05	6.23	6.06	5.79	**6.02**			
	F	6.31	6.58	6.09	5.93	**6.22**			
Ca meq	S	16.6	14.2	13.4	10.0	**13.5**	0.076	0.005	ns
	B	17.3	16.0	15.2	14.6	**15.7**			
	F	12.3	11.5	12.3	11.2	**11.8**			
Al meq	S	0.27	0.08	0.11	0.25	**0.18**	ns	0.017	ns
	B	0.22	0.22	0.40	0.48	**0.34**			
	F	0.20	0.07	0.10	0.14	**0.12**			
K meq	S	0.07	0.21	0.19	0.36	**0.21**	0.042	<0.001	0.001
	B	0.08	0.04	0.08	0.08	**0.07**			
	F	0.14	0.33	0.17	0.13	**0.20**			
P ppm	S	0.0	1.4	0.7	1.2	**0.8**	0.143	<0.001	0.039
	B	0.0	0.0	0.0	0.0	**0.0**			
	F	0.4	0.6	0.5	0.0	**0.4**			

[1] probability that the farm, topographic position or interaction term are significant in the ANOVA for each soil property (3 reps per position and per farm; ns not significant)

[2] S = shoulder positions, B = backslope positions, F = footslope positions

APPENDIX C.1: BIOMASS AND NUTRIENT CONTENT AT SLASHING 12/92

FARMER	YEARS IN MUCUNA	REP	SLASHING DATE	Biomass t/ha gr. bm	M. bm	tot. bm	M%	Nitrogen kg/ha gr. N	M. N	tot. N	M. N%	P kg/ha tot. P	M. P%	K kg/ha tot. K	M. K%	Ca kg/ha tot. Ca	M. Ca%	Mg kg/ha tot. Mg	M. Mg%
MARCO HERNANDEZ	10	1	12/03/92	6.32	8.53	14.86	0.58	171	229	400	0.57	28.2	0.57	106	0.38	199	0.67	47	0.67
MARCO HERNANDEZ	10	2	12/02/92	3.87	6.45	10.32	0.64	109	159	268	0.59	21.3	0.44	69	0.41	141	0.71	27	0.70
MARCO HERNANDEZ	10	3	12/02/92	5.88	9.07	14.95	0.61	175	223	398	0.56	31.7	0.57	106	0.38	206	0.68	40	0.65
MARCO HERNANDEZ	10	4	12/02/92	5.38	6.64	12.02	0.55	160	163	323	0.50	25.7	0.52	89	0.39	153	0.63	37	0.67
CALISTRO ANDRADE	6	1	12/03/92	4.14	4.63	8.76	0.53	123	128	251	0.51	15.5	0.45	67	0.21	170	0.65	20	0.58
CALISTRO ANDRADE	6	2	12/03/92	2.70	4.13	6.83	0.60	82	140	222	0.63	17.0	0.56	64	0.31	112	0.76	16	0.66
JULIO MEJIA	13	1	12/10/92	4.06	6.39	10.45	0.57	113	129	242	0.54	17.6	0.49	96	0.39	130	0.65	23	0.56
JULIO MEJIA	13	2	12/10/92	4.18	4.88	9.06	0.54	113	130	243	0.53	15.6	0.53	101	0.37	118	0.67	17	0.59
ORLANDO PALOMO	8	1	12/06/92	5.91	6.22	12.12	0.51	137	132	269	0.49	19.5	0.48	151	0.45	124	0.53	30	0.57
ORLANDO PALOMO	8	2	12/06/92	4.53	5.08	9.60	0.53	102	137	239	0.57	11.5	0.57	84	0.43	110	0.71	20	0.60
DON JACOBO CASTELLANO	6	1	12/13/92	5.87	6.01	11.88	0.51	147	169	316	0.53	17.0	0.39	93	0.23	189	0.61	31	0.50
DON JACOBO CASTELLANO	6	2	12/13/92	6.33	8.60	14.93	0.58	152	211	363	0.58	15.9	0.49	83	0.25	198	0.65	41	0.54
DON JUAN RIVERA	13	1	12/12/92	3.57	9.80	13.37	0.74	104	252	356	0.71	21.3	0.65	67	0.46	225	0.78	31	0.73
DON JUAN RIVERA	13	2	12/12/92	3.81	5.42	9.23	0.59	99	98	198	0.50	16.7	0.49	69	0.33	160	0.65	23	0.59
DON JUAN RIVERA	13	3	12/12/92	2.43	5.14	7.57	0.68	52	90	142	0.63	9.8	0.63	104	0.70	?	?	13	0.56
ANTONIO MORALES "GORON"	4	1	12/05/92	5.58	6.25	11.83	0.53	142	135	277	0.49	16.0	0.43	?	?	144	0.66	25	0.64
ANTONIO MORALES "GORON"	4	2	12/05/92	4.69	6.10	10.79	0.57	108	94	202	0.47	15.6	0.39	78	0.21	158	0.57	27	0.48
DON CHEMA ENRIQUE	14	1	12/06/92	5.57	7.46	12.98	0.57	126	182	308	0.59	18.7	0.49	87	0.18	187	0.72	35	0.57
DON CHEMA ENRIQUE	14	2	12/06/92	4.00	7.28	11.28	0.65	107	80	187	0.43	15.4	0.32	65	0.23	177	0.74	30	0.70
ANTONIO AYALA	5	1	12/12/92	3.70	7.60	11.30	0.67	93	155	248	0.63	14.7	0.67	82	0.57	123	0.67	30	0.66
ANTONIO AYALA	5	2	12/12/92	3.35	8.73	12.08	0.72	73	205	278	0.74	15.4	0.68	78	0.45	166	0.77	28	0.75
ANTONIO MALDONADO	10	1	12/13/92	3.17	7.33	10.50	0.70	86	243	330	0.74	15.5	0.57	84	0.47	184	0.77	27	0.69
ANTONIO MALDONADO	10	2	12/13/92	4.82	7.31	12.13	0.62	134	202	337	0.60	17.6	0.51	76	0.37	197	0.68	33	0.58
DON CEPITO	14	1	12/12/92	4.21	7.68	11.90	0.65	105	217	322	0.67	16.7	0.60	67	0.39	186	0.75	36	0.67
DON CEPITO	14	2	12/12/92	3.51	7.02	10.53	0.67	88	185	274	0.68	13.4	0.58	56	0.29	151	0.75	27	0.67
"NEGRITO" RIVERA	12	1	12/05/92	4.98	6.25	11.22	0.56	130	128	258	0.50	19.2	0.54	139	0.52	116	0.61	27	0.59
"NEGRITO" RIVERA	12	2	12/05/92	5.66	6.56	12.22	0.54	154	209	363	0.58	26.7	0.54	129	0.34	?	?	30	0.62
ANTONIO GARCIA	2	1	12/16/92	3.38	4.34	7.72	0.56	90	78	169	0.46	8.0	0.43	92	0.31	87	0.48	16	0.45
ANTONIO GARCIA	2	2	12/16/92	1.66	6.14	7.80	0.79	50	180	230	0.78	12.1	0.71	66	0.57	105	0.85	19	0.78
MARVIN MALDONADO	1	1	12/10/92	3.57	2.52	6.10	0.42	74	47	120	0.39	5.8	0.27	69	0.23	53	0.42	17	0.45
MARVIN MALDONADO	1	2	12/10/92	1.08	5.80	6.88	0.84	20	64	84	0.75	2.7	0.65	48	0.73	37	0.81	11	0.85
MARIO ANDRADE	6	1	12/17/92	3.95	6.97	10.92	0.64	88	158	246	0.64	14.7	0.57	109	0.56	126	0.69	29	0.64
MARIO ANDRADE	6	2	12/17/92	3.97	9.00	12.98	0.69	91	230	321	0.72	19.0	0.66	77	0.40	207	0.77	38	0.72
ANTONIO MORALES	8	1	12/16/92	3.71	5.07	8.78	0.58	81	108	189	0.57	14.7	0.66	93	0.74	113	0.61	27	0.51
ANTONIO MORALES	8	2	12/16/92	2.62	5.88	8.50	0.69	56	102	158	0.65	5.7	0.52	41	0.50	79	0.71	22	0.63
TEYO MORALES	8	1	12/16/92	2.50	6.85	9.35	0.73	60	181	240	0.75	12.6	0.65	60	0.65	89	0.73	21	0.60
TEYO MORALES	8	2	12/16/92	1.84	4.57	6.40	0.71	37	115	152	0.75	4.8	0.57	31	0.46	60	0.76	14	0.66
DON CHEPE ALFARO	10	1	12/10/92	4.65	5.28	9.93	0.53	113	98	211	0.47	16.8	0.51	81	0.48	104	0.54	21	0.55
DON CHEPE ALFARO	10	2	12/10/92	5.84	6.47	12.30	0.53	138	133	271	0.49	22.6	0.54	158	0.36	144	0.58	27	0.59
DON CHEPE ALFARO HIJO	7	1	12/24/92	4.65	9.23	13.89	0.66	112	156	268	0.58	15.6	0.47	104	0.59	156	0.67	33	0.58
ORFILIO SERRANO	6	1	12/03/92	4.55	6.85	11.40	0.60	130	215	344	0.62	19.4	0.56	?	?	180	0.78	34	0.68
ORFILIO SERRANO	6	2	12/03/92	3.44	7.37	10.81	0.68	85	164	248	0.66	11.9	0.55	51	0.40	128	0.71	28	0.67
DON CHEMA GALDAMEZ	15	1	12/13/92	4.45	7.52	11.97	0.63	118	221	339	0.65	21.5	0.60	82	0.44	208	0.74	25	0.67
DON CHEMA GALDAMEZ	15	2	12/13/92	6.50	6.44	12.94	0.50	178	184	362	0.51	25.6	0.45	86	0.34	210	0.61	48	0.48

APPENDIX C.2: BIOMASS AND NUTRIENT CONTENT AT SLASHING 12/93

			biomass in tons DM/ha					nitrogen (adjusted)						phosphorus		potassium		calcium		magnesium	
site	farmer	trat	gr biom	pods bm	vines bm	litter bm	total bm	green N	pods N	vines N	litter N	total N	% N M	total P	% P M	total K	% K M	total Ca	% Ca M	total Mg	% Mg M
sfs	chema	1	2.41	0.84	2.23	8.25	12.94	60.8	5.3	43.3	212.0	317.5	0.67	16.9	0.54	83.9	0.19	178.0	0.77	34.0	0.61
sfs	chema	2	2.16	0.92	1.81	7.84	12.73	40.4	27.5	41.9	210.6	340.4	0.62	17.4	0.46	85.8	0.10	164.8	0.71	33.2	0.61
sfs	chema	3	1.94	0.60	2.13	7.60	12.27	52.5	17.3	45.8	227.0	342.6	0.66	17.2	0.58	82.3	0.22	184.8	0.75	30.2	0.65
sfs	abel	1	1.43	1.13	0.86	11.07	14.50	33.1	30.9	15.6	276.8	356.4	0.78	18.2	0.63	67.2	0.33	144.2	0.84	43.5	0.83
sfs	abel	2	2.87	0.45	1.92	9.34	14.58	66.3	12.4	34.7	203.0	317.3	0.64	18.5	0.56	65.0	0.20	105.8	0.74	37.8	0.64
sfs	juan ves	1	1.58	0.16	2.11	8.32	12.17	46.7	5.0	41.9	214.5	307.5	0.70	15.6	0.54	78.5	0.20	154.8	0.73	28.7	0.64
sfs	juan ves	2	1.48	0.09	2.12	7.45	11.07	48.5	2.6	42.1	198.4	291.6	0.68	15.8	0.54	76.0	0.17	145.4	0.71	26.3	0.60
sfs	ii mor	1	1.17	1.00	1.50	6.48	10.12	28.0	30.1	27.0	163.4	240.5	0.66	13.7	0.52	61.3	0.18	127.0	0.78	25.4	0.64
sfs	ii mor	2	1.77	0.60	1.40	6.39	10.16	32.4	21.1	23.9	118.6	196.0	0.60	10.3	0.49	58.8	0.28	84.4	0.69	22.0	0.61
sfs	ii mor	3	1.13	0.85	1.64	7.01	10.74	29.6	27.8	30.8	147.6	231.0	0.62	12.5	0.45	52.9	0.17	108.3	0.73	26.5	0.58
sfs	jacobo	1	2.03	0.21	1.40	8.07	11.76	67.6	7.0	29.7	272.8	377.1	0.68	18.9	0.55	91.2	0.26	188.1	0.87	32.2	0.70
sfs	jacobo	2	2.10	0.07	2.24	7.49	11.89	61.6	2.4	45.9	193.8	304.0	0.54	16.2	0.51	104.7	0.27	168.2	0.75	37.7	0.60
sfs	jacobo	3	1.56	0.07	2.15	6.54	10.31	52.1	2.4	44.1	171.8	272.4	0.64	18.1	0.51	80.2	0.23	164.4	0.74	27.5	0.57
sfs	indalesio	1	1.18	1.31	1.80	7.75	12.04	26.3	37.0	35.4	167.5	278.6	0.65	14.9	0.52	62.8	0.23	124.7	0.78	29.2	0.66
sfs	indalesio	2	0.71	1.17	2.12	8.29	12.28	13.6	35.1	35.1	228.6	312.6	0.75	17.2	0.58	88.3	0.27	130.0	0.84	27.8	0.78
sfs	negrito	1	1.27	0.63	2.21	10.14	14.26	45.1	27.1	59.0	293.6	424.7	0.69	29.4	0.57	113.3	0.22	236.4	0.80	35.8	0.65
sfs	negrito	2	1.10	0.44	1.31	9.65	12.50	38.6	14.3	37.2	283.3	373.4	0.76	26.1	0.63	82.7	0.29	156.7	0.70	29.7	0.71
sfs	mario a	1	1.08	0.27	1.90	7.82	11.08	31.6	6.6	38.7	210.2	268.2	0.73	16.9	0.65	54.5	0.33	169.6	0.80	37.1	0.63
sfs	mario a	2	1.22	0.62	2.00	8.34	12.17	35.9	19.4	40.6	217.5	313.4	0.69	18.1	0.60	57.6	0.25	166.1	0.78	34.4	0.56
sfs	lorno ey	1	0.65	0.55	0.98	8.64	10.82	18.0	14.6	14.7	211.3	258.6	0.80	12.4	0.60	53.3	0.37	128.2	0.86	31.5	0.78
sfs	lorno ey	2	1.04	0.34	1.51	10.46	13.39	31.1	11.2	30.0	270.6	343.0	0.78	18.8	0.72	77.8	0.40	103.2	0.86	38.4	0.73
sfs	lorno ey	3	0.39	1.00	1.97	11.13	14.49	10.0	20.3	30.0	264.0	344.0	0.77	18.0	0.60	80.3	0.33	171.0	0.84	39.1	0.80
sfs	galdamez	1	2.13	0.63	2.31	11.24	16.34	70.3	20.1	57.9	320.0	468.3	0.66	41.8	0.57	83.2	0.23	271.9	0.70	48.7	0.62
sfs	galdamez	2	1.91	1.18	1.66	10.07	14.80	63.1	37.0	41.0	261.7	402.9	0.66	28.1	0.55	103.0	0.35	104.7	0.75	37.6	0.58
sfs	lorno gel	1	2.34	0.50	1.83	7.57	12.34	57.0	14.8	35.1	173.4	281.1	0.62	13.0	0.52	132.1	0.74	114.7	0.68	26.4	0.63
sfs	lorno gel	2	1.35	0.05	1.90	9.73	13.03	33.6	1.6	34.4	285.3	364.5	0.81	17.4	0.78	97.5	0.28	153.1	0.84	26.0	0.76
sfs	marvin mal	1	0.28	1.75	1.37	4.68	7.76	5.8	37.8	27.4	115.3	186.2	0.63	7.7	0.45	64.8	0.20	58.4	0.80	16.3	0.72
sfs	marvin mal	2	0.08	0.60	0.55	5.76	7.01	1.8	18.1	10.8	133.8	164.5	0.81	5.9	0.68	33.7	0.36	58.5	0.82	13.5	0.84
sfs	chapito	1	0.89	0.77	1.34	11.64	14.64	25.2	24.0	33.4	303.8	386.3	0.79	21.3	0.71	85.2	0.43	187.0	0.84	36.5	0.77
sfs	chapito	2	1.77	0.47	1.16	11.06	14.16	36.2	29.7	28.8	266.7	361.0	0.76	19.6	0.68	75.6	0.31	196.8	0.82	34.2	0.74
sfs	lorno mal	1	1.30	1.77	2.04	8.55	14.66	34.4	51.6	39.1	223.5	348.6	0.64	20.4	0.54	105.3	0.21	165.6	0.76	31.1	0.64
sfs	lorno mal	2	1.35	0.69	1.90	8.53	13.77	35.8	28.8	16.4	225.0	326.0	0.69	18.4	0.62	101.8	0.32	173.7	0.76	28.6	0.68
mg	eduvigen c	1	0.61	3.27	1.72	3.18	8.78	18.9	98.3	33.1	92.0	242.4	0.38	27.5	0.27	118.0	0.08	98.7	0.59	18.2	0.35
mg	eduvigen c	2	0.91	2.21	2.63	4.71	10.47	28.3	84.5	50.7	100.6	255.4	0.43	33.2	0.27	131.4	0.10	118.8	0.59	16.1	0.40
mg	jorge castron	1	1.37	2.10	2.24	4.50	10.21	42.9	70.7	47.5	122.7	278.7	0.44	29.8	0.29	134.3	0.10	134.0	0.64	18.5	0.39
mg	jorge castron	2	1.86	1.82	2.98	3.34	9.21	33.1	61.3	56.6	91.0	242.0	0.36	38.7	0.20	137.8	0.07	110.2	0.65	18.7	0.34
mg	francisco paz	1	1.89	3.34	2.12	2.45	11.00	27.2	62.5	36.8	115.0	262.5	0.44	26.2	0.31	96.0	0.08	133.1	0.67	25.0	0.41
mg	francisco paz	2	1.54	2.06	1.74	3.35	9.13	28.6	31.7	36.3	86.7	[illegible]	0.40	22.3	0.26	85.7	0.07	115.5	0.55	20.3	0.35
mg	antonio ruiz	1	0.31	1.82	2.68	4.69	9.50	6.2	59.4	49.9	100.2	215.7	0.46	26.1	0.30	80.7	0.12	104.6	0.63	16.9	0.43
mg	antonio ruiz	2	0.81	2.01	3.02	4.16	9.25	16.2	85.6	38.6	107.6	228.1	0.47	24.5	0.30	88.1	0.10	106.1	0.62	18.0	0.39
mg	jose mora	1	0.75	3.19	2.15	5.31	11.42	20.8	100.5	34.7	171.6	326.7	0.52	24.8	0.36	118.7	0.12	146.4	0.72	18.0	0.53
mg	jose mora	2	1.56	3.08	2.26	5.00	11.89	43.1	87.3	35.7	121.5	287.5	0.41	25.6	0.29	131.0	0.08	133.3	0.60	19.0	0.45
mg	adolfo cont	1	2.39	2.33	2.38	5.17	12.50	82.6	75.7	45.5	128.1	316.9	0.41	32.3	0.35	141.3	0.20	155.6	0.58	25.5	0.47
mg	adolfo cont	2	2.45	2.90	2.09	2.76	10.19	84.1	86.0	42.5	47.5	260.1	0.28	25.8	0.10	126.7	0.10	107.4	0.40	18.4	0.28
mg	jose corti	1	1.18	2.84	2.56	5.43	12.01	35.2	84.3	51.5	123.3	292.3	0.42	32.2	0.12	148.8	0.13	133.5	0.61	21.0	0.44
mg	jose corti	2	1.99	2.37	2.48	4.88	11.66	56.0	69.5	40.6	120.6	293.7	0.41	29.0	0.26	146.1	0.10	135.2	0.54	23.2	0.46
mg	antonio her	1	1.78	1.22	2.71	4.04	9.75	62.1	36.6	55.3	114.1	266.1	0.43	29.4	0.20	123.6	0.08	116.6	0.67	23.0	0.44
mg	antonio her	2	1.92	2.61	3.12	3.85	11.50	53.0	73.7	70.0	94.6	291.3	0.37	25.1	0.21	172.0	0.09	101.5	0.47	24.7	0.30
mg	antonio her	3	0.56	1.32	2.41	5.76	10.04	15.3	36.4	42.6	166.7	263.0	0.63	18.4	0.46	74.6	0.10	131.2	0.74	24.4	0.59
mg	anastacio	1	0.49	3.24	2.69	5.78	12.20	13.5	78.3	61.7	143.6	282.9	0.51	29.0	0.36	108.3	0.11	155.0	0.66	21.6	0.44
mg	anastacio	2	0.80	3.34	2.41	2.59	9.05	27.3	95.2	41.2	61.3	245.0	0.33	24.1	0.21	105.7	0.07	91.8	0.47	17.0	0.36

APPENDIX C.2 (cont.)

			<- biomass in tons DM/ha ->					nitrogen (adjusted)						phosphorus		potassium		calcium		magnesium	
site	farmer	year	gr biom	pods bm	vines bm	litter bm	total bm	grain N	pods N	vines N	litter N	total N	% N M	total P	% P M	total K	% K M	total Ca	% Ca M	total Mg	% Mg M
mg	anastacio	3	0.51	2.83	2.54	6.31	12.18	15.0	82.6	40.8	153.4	291.8	0.53	28.9	0.37	110.2	0.11	135.8	0.64	25.6	0.52
mg	juan burgos	1	0.56	3.17	2.60	5.59	11.92	17.1	82.0	40.2	149.6	288.9	0.53	35.2	0.27	115.0	0.11	145.4	0.68	26.7	0.56
mg	juan burgos	2	0.88	3.38	2.49	5.06	11.81	18.8	83.4	38.6	131.9	272.7	0.49	37.5	0.31	118.3	0.11	146.6	0.66	22.8	0.47
mg	benigno amaya	1	0.78	4.16	2.38	6.65	13.89	18.1	140.2	44.0	206.5	408.7	0.51	37.4	0.38	127.1	0.08	185.2	0.72	26.4	0.50
mg	benigno amaya	2	0.85	3.12	2.15	6.05	12.19	20.5	104.9	39.7	169.1	338.4	0.50	33.7	0.39	109.9	0.12	165.2	0.71	21.6	0.48
mg	cristino cas	1	0.76	2.96	2.04	6.81	12.57	21.8	86.3	40.3	195.4	343.8	0.57	26.9	0.40	98.4	0.17	165.2	0.75	31.0	0.58
mg	cristino cas	2	0.80	1.67	2.11	4.90	9.48	25.5	54.7	41.6	149.5	271.3	0.55	20.2	0.35	81.7	0.13	130.2	0.71	27.0	0.55
mg	juan alb	1	0.91	2.90	1.99	6.31	12.12	28.3	71.1	33.1	136.0	268.5	0.50	35.8	0.37	98.0	0.14	125.4	0.63	21.3	0.50
mg	juan alb	2	0.49	2.61	2.05	7.47	12.62	15.8	73.5	34.1	154.1	277.6	0.55	27.3	0.30	81.0	0.09	128.2	0.75	17.1	0.57
mg	juan alb	3	0.54	2.53	2.45	6.31	11.83	16.1	71.7	37.7	123.9	249.4	0.50	29.6	0.41	92.1	0.16	115.6	0.64	17.0	0.52
cu	manuel var 0	1	2.83	0.34	1.43	7.41	12.00	71.7	21.6	27.4	166.5	287.5	0.54	12.3	0.31	109.8	0.10	139.5	0.76	21.0	0.56
cu	manuel var 1b	1	1.47	0.68	2.14	4.77	9.05	39.5	19.7	41.4	126.8	227.4	0.56	13.4	0.50	106.1	0.22	94.0	0.67	18.3	0.42
cu	manuel var 1a	2	1.48	0.54	3.33	6.02	11.37	39.8	15.7	64.4	170.9	290.8	0.59	17.6	0.55	124.8	0.14	123.4	0.86	22.8	0.40
cu	manuel var 2a	1	1.18	0.83	2.15	6.39	10.56	31.7	24.7	41.6	168.6	266.5	0.63	13.8	0.51	91.8	0.12	101.3	0.72	21.1	0.51
cu	manuel var 2a	2	1.13	0.63	1.60	5.90	9.25	30.5	1.0	37.5	146.8	215.8	0.76	12.9	0.64	72.7	0.22	97.0	0.76	17.5	0.57
cu	manuel var 3a	1	1.38	1.31	2.38	8.74	13.81	37.1	30.0	44.4	240.6	352.1	0.66	18.1	0.53	138.1	0.30	151.8	0.78	34.0	0.64
cu	manuel var 3a	2	1.41	0.25	1.55	7.63	10.84	38.0	7.4	41.6	189.5	276.5	0.69	14.8	0.67	89.5	0.16	125.3	0.76	20.4	0.52
cu	manuel var 5a	1	1.57	1.11	1.23	6.52	10.43	42.7	32.7	21.9	170.0	267.3	0.63	12.0	0.43	91.8	0.23	99.3	0.73	22.0	0.59
cu	manuel var 5a	2	0.90	0.69	2.03	6.78	10.40	24.8	20.0	39.3	145.6	229.7	0.64	11.8	0.57	99.6	0.21	111.3	0.78	25.3	0.64
cu	nino lopez	1	1.79	0.33	2.12	5.47	9.71	34.7	9.8	41.0	168.7	254.2	0.56	12.2	0.54	69.3	0.17	104.5	0.73	20.0	0.53
cu	nino lopez	2	1.63	0.21	1.03	7.13	10.00	43.6	8.7	37.4	217.6	307.3	0.72	14.2	0.60	83.7	0.21	128.5	0.77	23.2	0.56
cu	manuel dC	1	2.60	0.66	2.00	3.05	8.60	77.8	19.2	38.8	75.3	211.1	0.36	11.6	0.24	112.0	0.08	84.8	0.47	18.3	0.30
cu	manuel dC	2	1.79	0.86	1.38	7.25	11.27	34.6	21.9	36.5	190.5	283.5	0.66	14.6	0.55	96.6	0.22	98.8	0.72	23.5	0.58
cu	miguel carb 4a	1	1.17	0.54	1.62	8.01	11.35	31.6	15.8	35.3	229.1	311.8	0.73	14.9	0.63	96.1	0.28	170.6	0.80	24.4	0.64
cu	miguel carb 4a	2	2.22	0.35	1.73	10.25	14.57	59.7	9.6	33.4	304.6	407.7	0.75	17.9	0.63	95.0	0.18	155.3	0.78	30.1	0.65
cu	miguel carb 1a	1	1.32	1.03	1.01	7.30	10.66	35.5	30.1	19.5	185.4	270.5	0.69	12.9	0.37	80.3	0.33	94.6	0.76	21.5	0.64
cu	miguel carb 1a	2	1.64	0.38	0.84	5.80	8.66	52.1	8.7	16.3	160.4	237.6	0.66	11.7	0.57	49.0	0.21	84.5	0.71	18.2	0.61
cu	luis carb	1	1.27	0.15	2.38	5.47	9.26	36.6	4.9	50.3	130.6	222.4	0.54	11.3	0.48	87.6	0.12	86.9	0.69	21.7	0.47
cu	luis carb	2	1.16	1.05	1.28	4.80	8.10	24.2	50.4	23.3	80.0	177.9	0.48	11.1	0.35	104.5	0.20	74.0	0.74	16.0	0.48
cu	rosendo dC	1	1.24	1.28	2.19	7.35	12.06	37.0	41.1	43.4	198.4	320.9	0.82	18.5	0.49	107.0	0.16	127.7	0.72	28.2	0.54
cu	rosendo dC	2	1.50	1.10	2.36	5.16	10.13	45.6	30.0	42.2	150.4	268.2	0.56	15.1	0.41	83.4	0.08	108.8	0.83	22.4	0.48
pm	samuel cavi	1	1.80	1.61	1.44	6.91	11.76	66.5	55.8	28.7	192.8	339.7	0.57	20.8	0.43	114.7	0.19	148.2	0.71	37.1	0.69
pm	samuel cavi	2	1.64	2.14	1.92	6.68	12.38	38.3	66.6	38.2	151.6	327.3	0.49	20.6	0.35	121.1	0.10	134.3	0.87	28.0	0.58
pm	don aladio 5a	1	2.90	0.90	1.63	5.76	11.19	84.8	29.1	36.3	147.6	308.1	0.48	20.0	0.42	116.3	0.11	138.8	0.50	26.2	0.48
pm	don aladio 5a	2	2.84	0.70	1.86	6.30	11.68	82.8	27.7	38.8	170.8	330.4	0.53	21.2	0.45	116.6	0.15	171.7	0.80	27.4	0.51
pm	don aladio 4a	1	2.21	0.49	1.21	4.67	8.58	77.6	15.8	24.6	116.8	234.7	0.50	13.4	0.35	82.8	0.12	85.4	0.54	21.7	0.54
pm	don aladio 4a	2	1.66	0.75	1.68	5.57	9.65	58.7	24.4	33.4	156.8	272.4	0.58	14.2	0.45	83.3	0.17	120.1	0.87	23.8	0.58
pm	luis alf cavi	1	1.40	1.65	1.76	6.83	11.65	48.2	53.3	35.0	174.2	311.0	0.56	18.0	0.38	120.7	0.24	125.1	0.80	28.4	0.59
pm	luis alf. cavi	2	1.22	1.05	1.20	6.35	9.81	45.1	33.7	25.5	184.0	288.3	0.64	13.8	0.41	75.4	0.11	120.7	0.75	24.4	0.67
pm	rafael cavi	1	1.55	2.88	1.45	4.27	10.15	54.5	92.0	28.7	83.9	259.1	0.32	18.0	0.18	128.0	0.14	80.6	0.56	21.7	0.42
pm	magdo 10a	1	1.81	1.13	3.35	9.88	16.18	47.1	40.3	73.8	342.4	503.5	0.64	31.8	0.52	130.5	0.14	218.1	0.75	38.2	0.60
pm	magdo 10a	2	1.28	0.35	2.84	7.63	12.08	44.3	11.2	56.4	193.7	305.7	0.63	17.8	0.51	115.5	0.28	155.6	0.73	28.2	0.63
pm	magdo 12a	1	1.98	1.45	2.05	5.89	11.37	43.3	42.8	53.5	146.3	285.7	0.51	14.8	0.38	132.6	0.07	121.4	0.65	23.4	0.51
pm	magdo 12a	2	0.73	1.29	1.70	5.95	9.67	75.5	41.5	35.6	121.6	274.2	0.63	15.6	0.46	86.7	0.15	108.8	0.75	22.0	0.62
pm	rodolfo gut 12	1	2.55	1.18	3.24	5.50	12.47	76.4	37.6	83.0	127.7	356.6	0.50	20.0	0.36	126.5	0.08	173.0	0.62	50.0	0.46
pm	rodolfo gut 12	2	2.56	1.73	2.56	5.81	12.64	83.6	55.5	50.8	185.5	375.4	0.40	25.3	0.39	137.8	0.08	161.3	0.80	28.8	0.44
pm	rodolfo gut 2	1	1.36	1.48	2.06	4.98	9.88	47.7	46.6	41.3	133.8	269.4	0.50	17.0	0.36	105.4	0.17	113.9	0.83	27.8	0.52
pm	rodolfo gut 2	2	1.74	2.06	1.53	5.19	10.52	61.3	66.2	30.4	138.9	296.8	0.47	19.1	0.33	113.2	0.11	118.4	0.64	24.0	0.55
pm	rigoberto b	1	0.78	2.18	2.71	5.19	10.86	27.4	70.3	53.1	135.4	286.4	0.48	19.0	0.33	121.8	0.10	113.8	0.67	24.2	0.51
pm	rigoberto b	2	0.83	2.40	2.59	3.53	9.35	29.1	77.2	51.4	94.6	252.2	0.37	17.6	0.25	120.3	0.07	89.8	0.58	20.5	0.41

APPENDIX C.3: BIOMASS DYNAMICS 10/93 to 5/94

A. BIOMASS ACCUMULATION October to December 1993

		BIOMASS in t D.M./ha					Nutrient content kg/ha					Nitrogen content %			
FARMER	DATE	B green	B pods	B vines	B litter	B total	N tot	P tot	K tot	Ca tot	Mg tot	%N gr	%N lit	%N vine	%N pod
CHEMA AY 1	10/14/93	3.57			5.44	8.96	243	14	77	120	27	2.64	2.57	-	
CHEMA AY 2	10/14/93	3.85			7.86	11.71	359	21	130	190	33	3.43	2.60	-	
CHEMA GALD	10/15/93	3.71			5.38	9.09	232	16	82	145	28	3.00	2.24	-	-
CHEPITO BA 1	10/15/93	2.80			7.49	10.29	263	15	69	135	27	3.47	2.21	-	-
CHEPITO BA 2	10/15/93	5.16			7.07	12.23	366	24	160	157	32	3.43	2.68	-	-
TONIO MAL 1	10/14/93	3.66			5.05	8.70	291	18	80	152	26	3.77	3.03	-	-
TONIO MAL 2	10/14/93	3.05			6.60	9.66	264	15	66	157	30	3.17	2.56	-	-
CHEMA AY 1	11/17/93	2.49			6.98	9.48	273	13	50	149	27	2.84	2.87	-	-
CHEMA AY 2	11/17/93	3.76			10.74	14.50	447	25	110	229	41	3.42	2.96	-	-
CHEMA GALD	11/16/93	3.49			7.71	11.20	310	24	86	178	32	2.92	2.71	-	-
CHEPITO BA 1	11/16/93	2.85			8.52	11.36	321	18	78	176	30	2.27	3.00		-
CHEPITO BA 2	11/16/93	2.80			7.28	10.07	282	17	64	136	24	3.06	2.66		-
TONIO MAL 1	11/16/93	5.03			10.30	15.33	368	20	111	197	39	2.94	2.33	-	-
TONIO MAL 2	11/16/93	2.74			9.28	12.02	315	16	76	170	37	3.26	2.43		
CHEMA AY 1	11/30/93	2.33	0.04	2.18	8.06	12.61	309	16	82	174	33	2.52	2.57	1.55	3.14
CHEMA AY 2	11/30/93	2.25	0.91	1.85	8.03	13.04	345	17	88	169	34	2.80	2.69	2.31	2.68
CHEMA GALD	12/14/93	2.13	0.63	2.34	10.97	16.07	461	31	93	267	48	3.30	2.85	2.47	3.21
CHEPITO BA 1	12/15/93	0.82	0.79	1.42	10.85	13.88	366	20	94	185	35	2.35	2.61	2.46	3.12
CHEPITO BA 2	12/15/93	1.39	0.66	1.10	11.93	15.07	407	21	77	211	36	2.85	2.68	2.49	3.12
TONIO MAL 1	12/15/93	1.27	1.79	2.13	8.79	13.97	332	20	105	156	30	2.65	2.34	1.52	2.62
TONIC MAL 2	12/15/93	1.38	0.98	1.82	10.43	14.62	346	19	104	186	31	2.65	2.36	1.52	2.22

B. BIOMASS DECOMPOSITION December 1993 to May 1994

FARMER	DATE	B green	B pods	B vines	B litter	B total	N tot	P tot	K tot	Ca tot	Mg tot	%N green	%N lit	%N vine	%N pod
CHEMA AY 1	11/30/93	2.33	0.04	2.18	8.06	12.61	309	16	82	174	33	2.52	2.57	1.55	3.14
CHEMA AY 2	11/30/93	2.25	0.91	1.85	8.03	13.04	346	17	88	169	34	2.80	2.69	2.31	2.68
CHEMA AY 3	11/30/93	1.98	0.62	2.17	7.64	12.41	346	17	84	166	35	2.71	2.58	2.15	2.97
DON JACOBO 1	12/08/93	2.12	0.16	1.56	8.95	12.83	357	20	97	207	35	3.33	2.78	1.59	3.26
DON JACOBO 2	12/08/93	1.65	0.06	2.11	6.15	10.26	262	14	97	144	28	2.94	2.56	2.55	3.56
DON JACOBO 3	12/08/93	1.49	0.06	2.06	6.98	10.58	283	18	88	171	28	3.35	2.66	2.23	3.52
T T MOR 1	12/03/93	1.57	1.00	1.80	7.34	11.51	282	16	69	146	27	2.40	2.53	1.81	3.10
T T MOR 2	12/03/93	1.79	0.77	1.30	7.18	11.04	208	11	56	91	24	1.83	1.86	1.71	2.64
T T MOR 3	12/03/93	1.01	0.64	1.54	7.00	10.49	224	12	50	106	26	2.54	2.03	1.88	2.92
TONIO AYALA 1	12/14/93	0.59	0.54	0.67	8.85	10.64	271	12	53	128	32	2.86	2.48	1.62	3.24
TONIO AYALA 2	12/14/93	0.85	0.34	1.47	10.81	13.51	347	19	76	156	36	2.87	2.56	2.05	3.28
TONIC AYALA 3	12/14/93	0.40	0.64	1.86	10.17	13.37	318	17	85	158	36	2.77	2.38	2.05	2.83
OBED SER 1	11/30/93	1.54	1.06	0.80	10.01	13.41	329	17	65	151	40	2.31	2.50	1.81	2.75
OBED SER 2	11/30/93	3.49	0.48	1.95	10.31	16.23	354	21	95	218	42	2.31	2.18	1.81	2.75
INDALESIO 1	12/08/93	1.04	1.30	1.84	6.87	11.04	255	14	79	113	37	2.22	2.35	1.86	2.83
INDALESIO 2	12/08/93	0.65	1.18	2.00	9.16	13.02	335	18	88	141	30	1.55	2.76	1.64	3.11
CHEMA GALD 1	12/14/93	2.12	0.65	2.33	10.97	16.07	461	31	93	267	48	3.30	2.85	2.47	3.21
CHEMA GALD 2	12/14/93	2.02	1.11	1.62	10.14	14.88	405	25	103	196	38	3.30	2.61	2.41	3.21
CHEMA AY 1	03/03/94				6.47	6.47	157	6	7	85	16	-	2.43	-	
CHEMA AY 2	03/03/94				7.69	7.69	201	8	12	114	19		2.62		
CHEMA AY 3	03/03/94				8.30	8.30	242	6	10	127	27		2.92		
DON JACOBO 1	03/03/94				6.44	6.44	164	8	20	86	15		2.55		
DON JACOBO 2	03/03/94				9.78	9.78	236	10	15	137	25		2.41		
DON JACOBO 3	03/03/94				11.11	11.11	245	12	27	152	27		2.22	-	
T T MOR 1	03/04/94				11.38	11.38	255	11	11	130	24		2.22	-	
T T MOR 2	03/04/94				10.70	10.72	165	6	14	85	21		1.85		
T T MOR 3	03/04/94				11.27	11.27	236	10	18	127	26		2.12		
TONIO AYALA 1	03/04/94				11.59	11.56	271	10	12	131	27	-	2.34	-	
TONIO AYALA 2	03/04/94				10.65	10.65	264	11	17	132	26	-	2.48		
TONIO AYALA 3	03/04/94				8.95	8.95	161	7	14	81	17	-	2.13		
OBED SER 1	03/04/94				9.36	9.36	164	7	7	72	16	-	1.76	-	
OBED SER 2	03/04/94				8.31	8.31	223	9	6	135	25	-	2.68	-	
INDALESIO 1	03/03/94				6.26	6.26	137	6	14	61	13	-	2.19		
INDALESIO 2	03/03/94				5.37	5.37	115	4	11	52	11	-	2.13		
CHEMA GALD 1	03/11/94				5.66	5.66	126	7	12	72	15		2.22		
CHEMA GALD 2	03/11/94				6.34	6.34	150	8	12	66	15		2.36	-	
CHEMA AY 1	05/24/94	0.34			11.62	11.96	305						2.63		
CHEMA AY 2	05/24/94	0.59			12.86	13.45	332						2.58		
CHEMA AY 3	05/24/94	0.12			7.87	7.99	177						2.25		
DON JACOBO 1	05/25/94	0.19			6.13	6.32	211						2.31		
DON JACOBO 2	05/25/94	0.29			8.23	8.52	194						2.35		
DON JACOBO 3	05/25/94	0.14			11.77	11.90	246						2.25		
T T MOR 1	05/25/94	0.11			7.31	7.41	143						1.96		
T T MOR 2	05/25/94	0.00			6.66	6.66	167						1.72		
T T MOR 3	05/25/94	0.04			11.64	11.68	302						2.59		
TONIO AYALA 1	05/25/94	0.03			8.08	8.10	172						2.13		
TONIO AYALA 2	05/25/94	0.12			10.80	10.92	291						2.69		
TONIO AYALA 3	05/25/94	0.00			14.33	14.33	297						2.07		
OBED SER 1	05/25/94	0.16			16.64	16.79	188						1.17		
OBED SER 2	05/25/94	0.31			9.15	9.46	213						2.33		
INDALESIO 1	05/24/94	0.30			10.70	10.66	179						1.67		
INDALESIO 2	05/24/94	0.67			10.34	11.01	216						2.29		
CHEMA GALD 1	05/24/94	0.04			14.85	14.89	378						2.54		
CHEMA GALD 2	05/24/94	0.08			6.05	6.13	222						2.43		

APPENDIX C.4: INORGANIC N MONITORING 92/93

(N values in ppm)				depth 0-15 cm			depth 15-30 cm			depth 30-60 cm			grav moisture content		
date	FARMER	rep	weed	[NO3]	[NH4]	N-inorg	[NO3]	[NH4]	N-inorg	[NO3]	[NH4]	N-inorg	hor 1 %	hor 2 %	hor 3 %
n1	OBED	1	yes	12.0	7.1	16.1	7.6	3.8	11.4	5.6	5.5	11.1	0.35	0.33	0.27
n2	OBED	1	yes	16.4	7.1	23.6	9.3	11.0	20.3	7.3	5.1	12.4	0.33	0.23	0.24
n3	OBED	1	yes	?	?	?	8.4	3.9	12.3	5.1	2.9	8.0	0.33	0.27	0.26
n4	OBED	1	yes	8.6	2.0	10.6	4.5	0.5	5.0	4.9	0.8	5.7	0.37	0.27	0.24
n5	OBED	1	yes	5.5	1.0	6.5	2.4	1.2	3.6	2.8	0.7	3.5	0.22	0.17	0.15
n6	OBED	1	yes	15.1	1.0	16.1	4.9	1.7	6.7	2.3	0.7	3.0	0.26	0.20	0.18
n7	OBED	1	yes	no sampling											
n1	OBED	1	no	14.3	8.0	22.3	5.6	8.5	14.1	4.3	9.2	13.5	0.41	0.25	0.30
n2	OBED	1	no	19.4	4.2	23.5	10.4	5.6	16.0	6.3	3.8	10.2	0.35	0.28	0.31
n3	OBED	1	no	15.2	1.4	16.6	6.7	2.4	9.1	4.8	1.7	6.5	0.34	0.29	0.31
n4	OBED	1	no	13.5	1.7	15.2	6.1	1.9	8.0	5.5	1.0	6.5	0.38	0.29	0.29
n5	OBED	1	no	6.1	0.9	7.0	3.0	1.8	4.8	4.1	1.4	5.5	0.20	0.16	0.19
n6	OBED	1	no	6.1	0.6	6.6	2.3	1.5	3.8	1.9	1.2	3.2	0.20	0.16	0.17
n7	OBED	1	no	no sampling											
n1	OBED	2	yes	11.5	7.3	18.7	7.9	3.7	11.6	6.1	5.6	11.8	0.34	0.28	0.22
n2	OBED	2	yes	22.4	4.5	26.9	9.3	4.7	14.0	?	?	?	0.35	0.20	0.21
n3	OBED	2	yes	9.7	0.7	10.4	6.4	3.0	9.4	5.4	2.9	8.3	0.24	0.20	0.23
n4	OBED	2	yes	11.3	1.0	12.3	5.1	0.9	6.0	5.0	0.8	5.8	0.29	0.24	0.22
n5	OBED	2	yes	6.1	1.3	7.4	2.4	2.6	5.0	3.1	1.3	4.4	0.19	0.18	0.16
n6	OBED	2	yes	9.7	0.6	10.3	2.6	2.1	4.7	2.4	2.1	4.4	0.21	0.17	0.17
n7	OBED	2	yes	8.7	0.9	9.6	2.8	1.8	4.6	2.1	1.5	3.6	0.18	0.16	0.16
n1	OBED	2	no	13.9	10.0	24.0	8.8	10.7	19.5	6.2	6.8	13.0	0.41	0.30	0.29
n2	OBED	2	no	20.9	5.5	26.4	12.2	5.1	17.4	8.4	4.7	13.0	0.32	0.26	0.27
n3	OBED	2	no	24.0	1.5	25.5	11.8	5.7	17.5	5.7	4.0	9.7	0.34	0.29	0.30
n4	OBED	2	no	13.7	1.2	14.9	5.9	1.1	7.0	4.5	2.1	6.6	0.37	0.30	0.28
n5	OBED	2	no	9.3	1.4	10.7	5.9	1.6	7.5	3.1	0.6	3.7	0.27	0.18	0.18
n6	OBED	2	no	9.1	0.5	9.6	3.0	2.1	5.1	1.8	2.0	3.8	0.20	0.17	0.16
n7	OBED	2	no	8.8	1.4	10.2	3.2	1.9	[illegible]	1.8	1.9	3.6	0.16	0.15	0.14
n1	GALDAMEZ	1	yes	15.4	18.5	33.9	7.0	11.3	18.2	4.2	5.4	9.6	0.31	0.24	0.26
n2	GALDAMEZ	1	yes	20.5	6.7	27.2	11.0	4.3	15.3	6.7	3.8	10.5	0.35	0.22	0.22
n3	GALDAMEZ	1	yes	12.2	1.5	13.7	6.9	2.6	9.5	4.7	2.8	7.5	0.28	0.25	0.26
n4	GALDAMEZ	1	yes	7.9	0.4	8.3	4.6	1.2	5.7	3.9	2.1	6.1	0.32	0.25	0.25
n5	GALDAMEZ	1	yes	6.2	1.4	7.6	3.5	0.7	4.3	2.1	1.6	3.7	0.19	0.18	0.16
n6	GALDAMEZ	1	yes	7.8	0.6	8.3	3.7	1.5	5.2	2.0	1.3	3.3	0.17	0.15	0.16
n7	GALDAMEZ	1	yes	12.1	1.1	13.2	4.8	2.3	7.1	2.5	3.9	6.4	0.21	0.18	[illegible]
n1	GALDAMEZ	1	no	16.6	16.1	32.7	5.9	8.4	14.3	3.9	3.8	7.7	0.25	0.27	0.24
n2	GALDAMEZ	1	no	21.4	6.4	27.7	9.5	4.8	14.3	7.1	4.2	11.3	0.34	0.26	0.23
n3	GALDAMEZ	1	no	11.2	0.9	12.2	9.0	2.2	11.3	5.9	3.0	8.9	0.29	0.26	0.28
n4	GALDAMEZ	1	no	6.9	0.6	7.5	3.5	1.1	4.6	2.3	1.4	3.7	0.32	0.26	0.26
n5	GALDAMEZ	1	no	6.6	0.7	7.3	3.4	0.7	4.1	2.3	1.5	3.8	0.19	0.17	0.17
n6	GALDAMEZ	1	no	7.1	0.3	7.4	3.6	1.0	4.6	2.5	1.6	4.1	0.20	0.16	0.17
n7	GALDAMEZ	1	no	13.9	1.1	14.9	6.2	1.0	7.2	2.5	1.7	4.2	0.22	0.17	0.17
n1	GALDAMEZ	2	yes	12.1	11.7	23.8	5.3	8.7	14.0	4.5	5.7	10.2	0.34	0.26	0.34
n2	GALDAMEZ	2	yes	20.0	3.4	23.4	10.5	4.4	14.9	5.3	3.4	8.7	0.34	0.27	0.26
n3	GALDAMEZ	2	yes	12.6	1.1	13.7	4.7	1.8	6.4	5.8	5.3	11.1	0.30	0.26	0.30
n4	GALDAMEZ	2	yes	11.3	0.4	11.7	4.5	2.3	6.8	3.9	2.4	6.3	0.35	0.28	0.27
n5	GALDAMEZ	2	yes	8.0	1.7	9.7	4.8	1.0	5.8	3.0	2.4	5.4	0.21	0.17	0.21
n6	GALDAMEZ	2	yes	4.9	0.8	5.7	3.1	1.5	4.7	2.5	2.1	4.6	0.19	0.16	0.18
n7	GALDAMEZ	2	yes	14.3	1.5	15.8	5.5	2.6	8.1	2.1	2.9	5.0	0.21	0.16	0.16
n1	GALDAMEZ	2	no	13.3	13.6	26.9	5.9	7.6	13.5	?	?	?	0.37	0.27	0.26
n2	GALDAMEZ	2	no	24.0	4.2	28.2	14.4	4.1	18.4	4.4	2.0	6.4	0.34	0.25	0.25
n3	GALDAMEZ	2	no	17.4	1.5	18.9	6.5	1.1	6.6	6.3	1.7	7.9	0.32	0.26	0.27
n4	GALDAMEZ	2	no	13.0	1.0	14.0	5.8	1.0	6.8	4.4	1.9	6.3	0.36	0.26	0.19
n5	GALDAMEZ	2	no	8.9	1.6	10.5	4.6	0.1	4.7	3.7	1.2	4.9	0.19	0.19	0.17
n6	GALDAMEZ	2	no	11.7	1.0	12.7	5.1	1.9	7.0	2.6	2.3	4.9	0.22	0.17	0.19
n7	GALDAMEZ	2	no	17.7	1.7	19.4	8.6	2.5	11.2	4.1	3.7	7.8	0.23	0.18	0.18
n1	ALFARO	1	yes	16.1	14.5	30.6	7.9	7.8	15.7	5.0	3.9	8.9	0.35	0.27	0.27
n2	ALFARO	1	yes	?	?	?	9.7	3.9	13.6	6.1	2.4	8.5	0.36	0.25	0.26
n3	ALFARO	1	yes	10.7	6.4	17.1	6.4	3.9	10.2	4.9	2.6	7.5	0.30	0.25	0.26
n4	ALFARO	1	yes	13.6	3.7	17.3	4.3	1.3	5.7	3.8	1.0	4.8	0.35	0.20	0.24
n5	ALFARO	1	yes	8.8	2.9	11.8	4.4	1.6	6.0	2.8	0.5	3.3	0.19	0.18	0.17
n6	ALFARO	1	yes	5.9	2.2	8.2	2.7	1.6	4.3	2.0	0.8	2.8	0.22	0.18	0.18
n7	ALFARO	1	yes	11.5	1.4	[illegible]	4.2	1.0	5.2	2.6	0.6	3.6	0.18	0.17	0.16
n1	ALFARO	1	no	11.6	8.7	20.5	7.2	6.3	13.5	5.0	3.9	9.0	0.32	0.23	0.25
n2	ALFARO	1	no	12.0	10.7	22.7	8.5	6.1	14.6	7.2	3.2	10.5	0.27	0.22	0.22
n3	ALFARO	1	no	9.0	5.0	14.0	6.2	3.1	9.2	5.2	2.1	7.3	0.25	0.23	0.23
n4	ALFARO	1	no	5.1	2.3	7.4	4.2	1.2	5.4	4.2	0.8	5.0	0.29	0.25	0.24
n5	ALFARO	1	no	4.3	1.8	6.1	3.1	1.1	4.2	3.2	0.2	3.4	0.17	0.17	0.16
n6	ALFARO	1	no	3.4	1.7	5.1	2.5	2.1	4.7	1.7	0.7	2.4	0.22	0.18	0.16
n7	ALFARO	1	no	4.1	1.4	5.5	3.9	1.7	5.6	1.8	1.9	3.7	0.18	0.16	0.14
n1	ALFARO	2	yes	12.5	4.5	17.0	?	?	?	?	?	?	0.34	0.26	0.24
n2	ALFARO	2	yes	15.3	6.6	21.9	9.9	4.0	13.9	7.7	4.2	11.9	0.25	0.17	0.24
n3	ALFARO	2	yes	?	?	?	4.8	2.5	7.4	7.5	3.3	10.8	0.21	0.21	0.22
n4	ALFARO	2	yes	3.9	1.6	5.5	2.1	1.1	3.3	2.6	0.4	3.0	0.24	0.22	0.21
n5	ALFARO	2	yes	3.8	1.9	5.7	1.9	0.6	2.6	1.4	0.2	1.7	0.16	0.16	0.14

APPENDIX C.4 (cont.)

n6	ALFARO	2	yes	5.0	2.7	7.7	1.8	2.2	4.0	1.6	0.8	2.5	0.21	0.19	0.18
n7	ALFARO	2	yes	8.3	1.1	9.4	2.4	1.8	4.3	1.7	1.7	3.4	0.17	0.17	0.16
n1	ALFARO	2	no	12.1	11.3	23.4	6.8	7.2	14.0	4.2	4.3	8.5	0.34	0.25	0.23
n2	ALFARO	2	no	15.8	8.0	23.8	10.0	4.8	14.8	5.7	3.3	8.9	0.31	0.27	0.26
n3	ALFARO	2	no	6.2	5.3	11.6	4.7	4.8	9.6	4.5	3.8	8.3	0.27	0.23	0.25
n4	ALFARO	2	no	3.5	2.4	5.9	2.1	1.3	3.4	3.7	1.6	5.3	0.31	0.25	0.23
n5	ALFARO	2	no	4.3	1.6	6.2	1.9	1.0	2.9	2.0	0.8	2.8	0.19	0.16	0.15
n6	ALFARO	2	no	4.8	3.7	8.5	2.2	4.3	6.6	1.7	2.9	4.6	0.20	0.17	0.19
n7	ALFARO	2	no	9.8	1.7	11.5	2.9	2.7	5.6	1.6	2.0	3.6	0.19	0.16	0.17
n1	ALFARO	3	yes	13.0	11.1	24.1	5.4	7.5	12.9	4.3	3.8	8.1	0.30	0.24	0.15
n2	ALFARO	3	yes	18.0	6.9	24.9	8.1	6.1	14.2	4.5	3.9	8.3	0.35	0.27	0.27
n3	ALFARO	3	yes	10.8	6.1	16.9	7.0	6.8	13.9	5.1	5.5	10.6	0.33	0.30	0.32
n4	ALFARO	3	yes	19.0	3.0	22.0	7.9	2.6	10.5	5.0	1.8	6.8	0.36	0.32	0.31
n5	ALFARO	3	yes	5.8	3.2	9.0	3.3	2.3	5.6	4.6	1.4	5.9	0.19	0.17	0.18
n6	ALFARO	3	yes	6.0	3.6	9.6	1.3	2.3	3.6	2.1	1.5	3.7	0.19	0.16	0.17
n7	ALFARO	3	yes	8.5	1.6	10.1	2.9	2.5	5.4	1.5	2.0	3.4	0.18	0.15	0.16
n1	ALFARO	3	no	9.0	10.5	15.8	4.6	7.2	11.8	3.9	4.5	8.3	0.32	0.25	0.21
n2	ALFARO	3	no	14.0	3.5	17.5	7.5	4.0	11.5	4.9	2.9	7.9	0.27	0.22	0.23
n3	ALFARO	3	no	17.3	14.1	31.4	5.1	7.8	12.9	6.9	7.6	14.5	0.29	0.24	0.25
n4	ALFARO	3	no	15.2	0.8	16.0	9.2	2.0	11.2	5.6	1.8	7.4	0.33	[illegible]	0.27
n5	ALFARO	3	no	5.1	1.0	6.1	3.0	0.9	3.9	3.8	0.8	4.6	0.15	0.14	[illegible]
n6	ALFARO	3	no	7.5	0.6	8.3	2.9	1.3	4.2	2.1	0.7	2.8	[illegible]	0.20	[illegible]
n7	ALFARO	3	no	6.5	[illegible]	7.7	[illegible]	0.8	2.5	2.1	2.2	4.3	[illegible]	[illegible]	[illegible]

APPENDIX C.5: INORGANIC N MONITORING 93/94 (ppm)

1) october and november sampling

			depth 0-10 cm			depth 10-30 cm			depth 30-60 cm			grav. moisture content		
date	FARMER	rep	[NO3]	[NH4]	N-min	[NO3]	[NH4]	N-min	[NO3]	[NH4]	N-min	hor 1	hor 2	hor 3
oct	maldon	1	15.7	0.6	16.5	6.5	1.3	7.7	4.7	2.1	6.8	0.36	0.28	0.28
oct	maldon	2	12.5	1.7	14.3	5.7	2.9	8.6	2.4	2.5	4.9	0.36	0.30	0.28
oct	galdamez	1	10.8	2.2	13.0	5.3	1.5	6.8	2.9	1.7	4.5	0.28	0.24	[illegible]
oct	chema	1	15.4	1.2	16.6	6.0	1.6	7.6	3.0	2.8	5.8	0.39	0.31	[illegible]
oct	chama	2	18.7	1.5	20.2	7.4	1.9	9.3	5.2	1.6	6.8	0.41	0.30	[illegible]
oct	chepito	1	13.1	2.3	15.4	6.6	0.7	7.4	4.7	1.1	5.9	0.33	0.26	0.26
oct	chepito	2	13.2	1.8	14.9	6.4	1.0	7.4	4.7	1.3	6.0	0.31	0.27	0.28
nov	maldon	1	9.2	2.3	11.4	5.4	2.1	7.5	3.2	1.1	4.3	0.40	0.31	0.31
nov	maldon	2	12.6	1.7	14.3	5.1	2.3	7.3	3.2	1.6	4.8	0.42	0.33	0.32
nov	galdamez	1	12.0	2.2	14.2	4.8	1.0	5.8	3.3	0.7	4.0	0.39	0.30	0.31
nov	chema	1	13.4	1.7	15.0	5.7	4.2	9.9	3.5	3.2	6.7	0.42	0.33	0.32
nov	chema	2	12.5	3.8	16.3	5.8	2.8	8.6	4.2	0.9	5.1	0.45	0.34	0.32
nov	chepito	1	12.3	1.2	13.6	7.1	0.9	8.0	5.1	1.2	6.3	0.39	0.31	0.30
nov	chepito	2	11.6	3.8	15.6	6.8	2.5	9.3	5.4	0.9	6.3	0.39	0.32	0.32

2) 93/94 monitoring

			depth 0-10 cm			depth 10-30 cm			depth 30-60 cm			grav moisture content		
date	FARMER	rep	[NO3]	[NH4]	N-min	[NO3]	[NH4]	N-min	[NO3]	[NH4]	N-min	hor 1	hor 2	hor 3
m1	chema	1	15.0	8.0	23.0	11.6	4.2	15.8	8.2	2.5	10.7	0.46	0.36	0.35
m2	chema	1	19.9	3.4	23.3	11.6	2.4	14.2	11.4	3.3	14.7	0.46	0.36	0.35
m3	chema	1	9.8	2.4	12.2	5.6	0.8	6.4	6.6	1.4	8.1	0.45	0.35	0.34
m4	chema	1	10.7	1.8	12.6	3.2	1.5	4.7	3.8	1.0	4.9	0.38	0.31	0.31
m5	chema	1	?	?	?	2.4	1.6	4.0	2.0	2.6	4.6	0.37	0.31	0.30
m6	chema	1	12.8	4.0	16.8	3.8	2.0	5.8	?	?	?	0.32	0.26	0.26
m7	chema	1	15.1	3.2	18.4	6.2	0.8	7.0	2.0	0.8	2.8	0.36	0.33	0.33
m8	chema	1	18.0	5.0	23.0	3.5	2.1	5.7	no deep sampling			0.24	0.25	
m9	chema	1	18.8	1.4	20.2	5.0	3.0	8.0	no deep sampling			0.26	0.26	
m1	chema	2	20.0	0.8	20.8	10.0	4.0	14.0	9.3	3.9	13.3	0.46	0.35	0.35
m2	chema	2	19.0	5.0	24.0	15.0	3.5	18.5	8.0	4.3	12.3	0.48	0.35	0.34
m3	chema	2	9.1	1.3	10.4	8.1	2.0	10.1	5.2	1.6	6.8	0.46	0.34	0.34
m4	chema	2	13.5	2.7	16.1	3.3	1.8	5.1	4.0	2.2	6.3	0.44	0.31	0.30
m5	chema	2	8.5	4.2	12.6	2.5	2.2	4.7	1.7	1.8	3.5	0.37	0.29	0.26
m6	chema	2	12.9	3.3	16.3	4.3	3.6	7.9	2.1	2.9	5.0	0.34	0.28	0.27
m7	chema	2	19.5	4.4	23.9	5.6	1.5	7.1	2.2	1.8	4.0	0.40	0.32	0.32
m8	chema	2	?	?	?	3.0	3.0	6.0	no deep sampling			0.25	0.24	
m9	chema	2	16.7	1.8	18.5	4.2	3.9	8.1	no deep sampling			0.26	0.26	
m1	chema	3	19.8	9.4	29.2	8.8	6.2	15.0	4.9	2.8	7.7	0.47	0.33	0.33
m2	chema	3	20.0	5.4	25.4	10.7	4.2	14.8	6.3	3.3	9.6	0.43	0.33	0.34
m3	chema	3	10.7	2.2	12.9	6.3	1.4	7.7	5.5	3.0	8.5	0.45	0.34	0.34
m4	chema	3	10.0	2.6	12.6	2.9	2.1	5.0	3.4	1.1	4.5	0.36	0.28	0.30
m5	chema	3	6.9	5.7	12.6	2.5	2.5	5.0	2.3	2.5	4.9	0.35	0.28	0.26
m6	chema	3	8.8	3.7	12.5	2.8	2.0	4.8	2.5	1.9	4.4	0.28	0.25	0.28
m7	chema	3	?	?	?	3.5	1.8	5.4	1.6	1.9	3.5	0.33	0.31	0.30
m8	chema	3	7.6	5.1	12.8	3.3	2.6	5.8	no deep sampling			0.23	0.24	
m9	chema	3	9.2	1.5	10.7	2.7	2.8	5.5	no deep sampling			0.24	0.24	
m1	jacobo	1	13.6	3.0	16.6	7.4	2.7	10.1	?	?	?	0.41	0.31	0.30
m2	jacobo	1	20.0	2.5	22.5	10.2	2.4	12.6	6.5	3.3	9.9	0.43	0.31	0.29
m3	jacobo	1	12.6	2.7	15.3	9.1	1.2	10.2	7.0	2.1	9.1	0.44	0.31	0.29
m4	jacobo	1	8.6	2.2	10.8	3.6	1.0	4.6	3.8	1.2	5.0	0.35	0.26	0.27
m5	jacobo	1	8.2	5.6	13.8	3.0	2.5	5.5	1.4	1.4	2.8	0.32	0.26	0.25
m6	jacobo	1	6.6	2.7	9.3	3.3	2.0	5.3	2.0	2.0	4.0	0.27	0.24	0.24
m7	jacobo	1	7.3	2.4	9.7	4.4	1.0	5.4	?	?	?	0.30	0.26	0.25
m8	jacobo	1	18.0	1.4	19.4	4.6	0.5	5.1	no deep sampling			0.25	0.22	
m9	jacobo	1	9.4	1.9	11.3	2.5	4.0	6.5	no deep sampling			0.25	0.22	
m1	jacobo	2	16.5	3.5	20.0	11.4	4.8	16.2	6.6	3.2	9.8	0.38	0.31	0.31
m2	jacobo	2	20.0	3.2	23.2	16.0	4.2	20.2	7.5	2.9	10.3	0.41	0.32	0.31
m3	jacobo	2	?	?	?	8.9	2.3	11.2	4.7	0.6	5.3	0.42	0.30	0.31
m4	jacobo	2	9.9	2.6	12.5	3.8	2.1	5.9	2.8	1.2	4.0	0.31	0.26	0.28
m5	jacobo	2	6.5	1.9	8.4	2.6	1.7	4.3	2.4	2.1	4.5	0.30	0.26	0.26
m6	jacobo	2	8.4	3.0	11.4	3.3	1.6	4.9	2.0	1.8	3.8	0.22	0.27	0.25
m7	jacobo	2	?	?	?	6.0	0.7	6.7	1.7	1.3	3.0	0.29	0.26	0.26
m8	jacobo	2	16.0	3.0	19.0	3.0	0.6	3.6	no deep sampling			0.18	0.20	
m9	jacobo	2	15.6	1.6	17.2	2.5	1.5	4.0	no deep sampling			0.21	0.23	
m1	jacobo	3	11.3	3.0	14.3	5.3	2.6	7.9	4.2	2.5	6.7	0.37	0.29	0.27
m2	jacobo	3	18.0	3.5	21.5	12.2	3.0	15.2	7.0	2.5	9.4	0.41	0.32	0.27
m3	jacobo	3	13.4	2.8	16.2	7.4	2.2	9.6	5.3	1.7	7.0	0.40	0.31	0.27
m4	jacobo	3	9.0	3.2	12.2	3.1	2.1	5.2	2.9	1.1	4.1	0.32	0.28	0.26
m5	jacobo	3	8.1	3.7	11.8	2.7	3.1	5.8	1.8	1.6	3.4	0.32	0.26	0.24

APPENDIX C.5 (cont.)

			depth 0-10 cm			depth 10-30 cm			depth 30-60 cm			grav moisture content		
date	FARMER	rep	[NO3]	[NH4]	N-min	[NO3]	[NH4]	N-min	[NO3]	[NH4]	N-min	hor 1	hor 2	hor 3
m6	jacobo	3	5.2	1.8	6.9	2.4	2.1	4.5	1.2	1.2	2.4	0.23	0.22	[illegible]
m7	jacobo	3	9.6	2.0	11.6	3.4	1.9	5.2	1.3	1.6	3.0	0.31	0.27	0.24
m8	jacobo	3	9.4	0.9	10.4	3.8	0.7	4.5	no deep sampling			0.20	0.21	
m9	jacobo	3	12.9	1.9	14.8	2.4	1.9	4.3	no deep sampling			0.22	0.25	
m1	timor	1	10.0	1.8	11.8	6.4	2.4	8.8	4.8	1.6	6.4	0.40	0.27	0.26
m2	timor	1	16.8	4.4	21.2	9.0	1.8	10.8	6.0	1.5	7.6	0.43	0.29	0.28
m3	timor	1	9.1	2.8	11.9	4.3	0.6	5.0	3.2	1.0	4.2	0.42	0.27	0.29
m4	timor	1	7.5	3.6	11.1	3.5	1.1	4.6	3.8	1.0	4.8	0.32	0.24	0.23
m5	timor	1	6.1	6.7	12.7	2.1	1.2	3.3	1.4	0.8	2.1	0.28	0.22	0.20
m6	timor	1	7.1	3.7	10.8	3.0	1.0	4.0	0.8	0.5	1.3	0.22	0.18	0.19
m7	timor	1	9.6	2.7	12.3	5.0	1.0	6.0	1.1	0.5	1.6	0.33	0.28	0.25
m8	timor	1	17.0	1.0	18.0	3.4	0.8	4.2	no deep sampling			0.22	0.19	
m9	timor	1	11.8	1.4	13.2	2.7	1.8	4.5	no deep sampling			0.26	0.23	
m1	timor	2	11.3	3.6	14.9	9.0	3.1	12.1	4.0	2.6	6.6	0.40	0.31	0.30
m2	timor	2	14.1	3.1	17.2	7.8	3.2	10.9	3.8	1.4	5.2	0.44	0.32	0.32
m3	timor	2	7.2	0.9	8.0	5.1	1.6	6.8	3.3	2.7	6.0	0.43	0.32	0.31
m4	timor	2	8.5	6.3	14.8	4.2	2.5	6.7	2.8	0.8	3.7	0.35	0.27	0.28
m5	timor	2	5.3	4.6	9.9	1.7	1.5	3.2	2.6	0.9	3.5	0.30	0.23	0.21
m6	timor	2	6.9	4.1	10.9	2.9	2.1	5.0	1.3	1.9	3.1	0.27	0.23	0.22
m7	timor	2	?	?	?	3.3	2.5	5.9	1.3	3.2	4.5	0.33	0.28	0.28
m8	timor	2	10.8	0.7	11.5	3.4	1.6	5.0	no deep sampling			0.24	0.22	
m9	timor	2	5.6	1.5	7.1	2.0	2.0	4.0	no deep sampling			0.25	0.24	
m1	timor	3	10.8	2.9	13.7	5.6	3.1	8.7	3.8	2.7	6.5	0.44	0.33	0.31
m2	timor	3	11.1	2.9	14.0	6.0	1.9	7.9	3.9	1.6	5.5	0.44	0.30	0.29
m3	timor	3	13.0	1.3	14.3	5.4	1.0	6.4	3.4	0.5	3.9	0.44	0.29	0.29
m4	timor	3	8.1	3.9	11.9	3.5	1.9	5.4	4.7	1.5	6.1	0.33	0.25	0.33
m5	timor	3	5.5	2.9	8.4	2.0	2.0	4.0	1.7	1.2	2.9	0.34	0.27	0.34
m6	timor	3	?	?	?	1.5	1.0	2.5	1.2	0.9	2.1	0.24	0.21	0.22
m7	timor	3	?	?	?	2.8	1.4	4.2	1.2	1.1	2.3	0.33	0.28	0.27
m8	timor	3	7.6	0.6	8.3	3.6	1.0	4.5	no deep sampling			0.24	0.23	
m9	timor	3	?	?	?	3.4	2.6	5.9	no deep sampling			0.29	0.26	
m1	tonio	1	13.0	3.7	16.7	5.3	2.5	7.8	4.1	1.6	5.7	0.39	0.29	0.36
m2	tonio	1	15.6	6.1	21.7	7.0	2.8	9.8	6.2	3.0	9.2	0.40	0.29	0.31
m3	tonio	1	7.6	1.0	6.6	5.5	2.6	8.1	5.2	1.4	6.6	0.43	0.30	0.29
m4	tonio	1	6.5	3.6	10.2	4.0	2.0	6.0	4.3	0.9	5.2	0.31	0.25	0.24
m5	tonio	1	3.0	4.6	7.6	1.2	2.0	3.2	2.1	0.5	2.6	0.30	0.23	0.21
m6	tonio	1	2.9	3.6	6.4	1.2	1.8	3.0	0.9	0.5	1.3	0.26	0.22	0.22
m7	tonio	1	7.0	2.6	9.6	1.3	0.6	2.1	1.1	0.3	1.5	0.30	0.25	0.24
m8	tonio	1	13.7	3.6	17.3	2.3	1.6	3.9	no deep sampling			0.22	0.22	
m9	tonio	1	15.4	4.5	19.9	2.2	3.9	6.1	no deep sampling			0.25	0.23	
m1	tonio	2	20.0	4.3	24.3	7.0	2.0	9.0	4.6	1.5	6.1	0.40	0.28	0.27
m2	tonio	2	19.0	6.0	25.0	8.2	1.3	9.6	5.1	1.0	6.2	0.40	0.28	0.28
m3	tonio	2	13.7	3.1	16.7	3.4	0.4	3.8	3.8	0.2	3.9	0.40	0.26	0.25
m4	tonio	2	6.8	3.6	10.4	3.2	0.6	3.8	3.5	0.5	4.0	0.32	0.24	0.26
m5	tonio	2	6.1	6.4	12.5	1.8	1.2	3.0	1.4	1.3	2.7	0.30	0.22	0.26
m6	tonio	2	6.9	3.3	10.2	1.4	1.1	2.4	1.4	1.2	2.6	0.25	0.21	0.23
m7	tonio	2	14.6	3.6	18.2	3.2	0.3	3.5	1.1	0.3	1.4	0.29	0.23	0.23
m8	tonio	2	?	?	?	2.7	0.1	2.8	no deep sampling			0.21	0.19	
m9	tonio	2	16.6	1.4	18.1	5.5	1.7	7.2	no deep sampling			0.27	0.22	
m1	tonio	3	12.1	3.4	15.5	?	?	?	4.5	1.9	6.4	0.37	0.25	0.29
m2	tonio	3	14.0	4.6	18.6	7.6	2.6	10.3	5.2	1.7	6.9	0.38	0.26	0.29
m3	tonio	3	10.0	1.5	11.5	4.5	1.6	6.1	5.7	1.7	7.4	0.39	0.27	0.30
m4	tonio	3	6.5	3.2	9.6	3.5	0.7	4.2	4.0	0.7	4.7	0.27	0.23	0.25
m5	tonio	3	4.4	3.9	8.3	2.0	1.6	3.6	2.4	0.4	2.8	0.25	0.21	0.25
m6	tonio	3	4.7	3.6	8.3	1.3	1.6	2.9	1.0	0.6	1.7	0.26	0.22	0.22
m7	tonio	3	8.0	2.9	10.8	3.0	2.0	5.0	1.4	1.3	2.7	0.28	0.23	0.25
m8	tonio	3	?	?	?	3.2	0.6	4.1	no deep sampling			0.16	0.19	
m9	tonio	3	24.0	2.2	26.2	4.3	2.6	6.9	no deep sampling			0.22	0.21	
m1	indalesio	1	no sampling											
m2	indalesio	1	10.6	3.2	13.8	10.8	2.8	13.6	8.3	2.5	10.8	0.29	0.24	0.26
m3	indalesio	1	6.0	0.8	6.8	8.2	0.6	8.8	4.4	2.0	6.4	0.29	0.23	0.26
m4	indalesio	1	4.5	2.1	6.6	3.3	0.9	4.3	7.2	1.2	8.4	0.23	0.19	0.24
m5	indalesio	1	3.5	1.9	5.5	2.9	0.8	3.7	6.7	0.8	7.5	0.23	0.22	0.25
m6	indalesio	1	no further sampling in this block											
m1	indalesio	2	no sampling											
m2	indalesio	2	7.8	2.3	10.1	7.0	0.5	7.5	8.2	2.0	10.3	0.29	0.23	0.26
m3	indalesio	2	6.7	2.0	8.7	6.1	0.3	6.4	7.0	1.4	8.4	0.27	0.23	0.27
m4	indalesio	2	3.8	1.4	5.2	1.7	0.0	1.7	5.2	0.5	5.7	0.21	0.19	0.23
m5	indalesio	2	4.4	3.1	7.5	1.1	0.3	1.5	4.0	1.0	5.0	0.27	0.21	0.23
m6	indalesio	2	no further sampling in this block											

APPENDIX C.6: FERTILIZER EXPERIMENTS 92/93

treatment i.d						yield components							ear leaf		Plant
						t/ha	thous			g		g			final
Farmer	bloc	weed	treat	N	P	yield	dens	NEar/pl.	NK/ear	W1ear	NK/m2	W1K	N%	P%	height
ALFARO	1	0	1	0	0	4.31	34.4	1.06	431.2	118.4	1569	[illegible]	3.15	0.29	242.0
ALFARO	1	0	2	1	0	4.13	35.7	0.95	453.2	121.4	1541	26.8	3.21	0.33	264.8
ALFARO	1	0	3	0	1	4.85	37.0	1.03	444.8	127.4	1693	28.7	3.19	0.35	281.8
ALFARO	1	0	4	1	1	4.22	37.0	1.00	401.7	114.2	1482	28.4	3.24	0.34	271.2
ALFARO	1	1	1	0	0	4.45	40.9	0.87	449.4	124.9	1601	27.8	3.31	0.28	267.3
ALFARO	1	1	2	1	0	4.34	36.7	0.92	439.3	128.5	1483	29.3	3.23	0.30	265.7
ALFARO	1	1	3	0	1	5.33	40.8	1.00	492.3	131.1	2002	26.6	3.26	0.33	295.6
ALFARO	1	1	4	1	1	5.06	37.5	0.98	441.4	137.4	1625	31.1	3.24	0.32	286.9
ALFARO	2	0	1	0	0	3.69	32.5	0.94	416.9	121.4	1267	29.1	2.51	0.32	276.3
ALFARO	2	0	2	1	0	3.34	32.4	0.91	392.8	113.2	1158	28.8	2.51	0.27	261.6
ALFARO	2	0	3	0	1	2.54	30.4	0.88	364.3	95.1	974	26.1	2.41	0.30	268.8
ALFARO	2	0	4	1	1	3.43	30.0	1.11	407.7	103.1	1355	25.3	2.54	0.31	281.3
ALFARO	2	1	1	0	0	3.25	31.0	0.95	381.3	109.7	1130	28.8	2.48	0.28	278.1
ALFARO	2	1	2	1	0	3.59	27.6	1.00	475.9	129.5	1320	27.2	2.55	0.22	303.6
ALFARO	2	1	3	0	1	3.26	30.1	0.86	431.5	125.6	1119	29.1	2.53	0.28	284.9
ALFARO	2	1	4	1	1	4.00	28.8	1.03	451.9	135.1	1339	29.9	2.48	0.27	275.8
ALFARO	3	0	1	0	0	2.66	46.1	0.58	361.5	99.0	971	27.4	2.17	0.22	277.9
ALFARO	3	0	2	1	0	3.10	40.2	0.76	431.1	102.0	1311	23.7	2.32	0.21	287.1
ALFARO	3	0	3	0	1	3.64	39.0	0.84	396.1	110.8	1302	28.0	2.64	0.25	314.3
ALFARO	3	0	4	1	1	3.33	29.8	0.92	402.8	120.9	1108	30.0	2.39	0.25	296.8
ALFARO	3	1	1	0	0	lost!							2.51	0.24	335.6
ALFARO	3	1	2	1	0	lost!							2.62	0.24	333.1
ALFARO	3	1	3	0	1	lost!							2.71	0.27	341.7
ALFARO	3	1	4	1	1	lost!							2.56	0.27	338.3
GALDAMEZ	1	0	1	0	0	lost!							3.06	0.29	326.7
GALDAMEZ	1	0	2	1	0	3.89	30.9	0.99	424.1	127.1	1299	30.0	3.09	0.28	299.2
GALDAMEZ	1	0	3	0	1	lost!							3.13	0.30	318.0
GALDAMEZ	1	0	4	1	1	lost!							3.09	0.27	304.0
GALDAMEZ	1	1	1	0	0	3.87	34.5	0.92	413.7	122.6	1305	29.6	2.93	0.29	312.3
GALDAMEZ	1	1	2	1	0	lost!							2.98	0.25	314.9
GALDAMEZ	1	1	3	0	1	4.30	28.1	0.98	448.0	155.8	1237	34.8	3.04	0.34	318.7
GALDAMEZ	1	1	4	1	1	4.05	31.9	1.01	437.0	125.3	1412	28.7	3.04	0.30	337.1
GALDAMEZ	2	0	1	0	0	4.26	32.5	0.99	431.3	131.8	1392	30.6	3.16	0.27	306.6
GALDAMEZ	2	0	2	1	0	4.45	34.1	0.97	476.3	134.3	1579	28.2	3.04	0.29	323.0
GALDAMEZ	2	0	3	0	1	lost!							2.88	0.28	311.9
GALDAMEZ	2	0	4	1	1	lost!							3.11	0.30	320.8
GALDAMEZ	2	1	1	0	0	4.80	32.8	0.96	446.7	151.6	1413	33.9	3.06	0.31	328.9
GALDAMEZ	2	1	2	1	0	4.64	33.9	1.01	433.5	135.2	1487	31.2	3.07	0.30	305.3
GALDAMEZ	2	1	3	0	1	4.45	33.5	0.99	409.6	135.0	1351	33.0	3.08	0.29	318.6
GALDAMEZ	2	1	4	1	1	4.92	33.1	0.98	459.3	152.4	1484	33.2	2.99	0.31	296.2
OBED	1	0	1	0	0	lost!							3.01	0.33	281.0
OBED	1	0	2	1	0	lost!							3.14	0.29	279.7
OBED	1	0	3	0	1	lost!							3.23	0.29	276.5
OBED	1	0	4	1	1	lost!							3.25	0.37	246.6
OBED	1	1	1	0	0	lost!							3.24	0.36	263.8
OBED	1	1	2	1	0	lost!							3.23	0.35	247.6
OBED	1	1	3	0	1	lost!							3.09	0.30	274.3
OBED	1	1	4	1	1	lost!							3.38	0.31	266.8
OBED	2	0	1	0	0	2.71	27.7	0.92	335.1	106.6	853	31.8	3.04	0.25	231.4
OBED	2	0	2	1	0	3.04	35.4	0.80	371.8	107.0	1056	28.8	3.08	0.26	241.7
OBED	2	0	3	0	1	3.19	37.3	0.79	347.9	112.0	1030	32.2	2.83	0.27	244.8
OBED	2	0	4	1	1	4.27	35.9	0.99	378.7	120.8	1339	31.9	2.88	0.30	243.9
OBED	2	1	1	0	0	3.98	35.7	0.88	424.8	126.4	1337	29.7	3.21	0.29	284.0
OBED	2	1	2	1	0	3.71	35.8	0.95	357.7	109.3	1213	30.5	3.06	0.24	280.0
OBED	2	1	3	0	1	3.45	33.6	0.92	348.6	111.7	1077	32.1	3.40	0.31	266.2
OBED	2	1	4	1	1	4.85	33.3	1.04	460.7	139.0	1594	30.2	3.16	0.31	281.9

APPENDIX C.7: FERTILIZER EXPERIMENTS 93/94

treatment i.d							yield components						
site	Farmer	rep	Treat.	N	P	t/ha yield	thous. dens	NEar/pl.	NK/ear	W1ear	NK/m2	(15%) W1K	ear leaf N%
sis	DON CHEMA AYALA	1	1	0	0	4.58	35.7	0.92	411	139	1351	33.9	2.43
sis	DON CHEMA AYALA	1	2	1	0	5.39	40.0	0.98	383	137	1504	35.8	2.54
sis	DON CHEMA AYALA	1	3	0	1	5.16	36.3	0.90	420	158	1377	37.6	2.58
sis	DON CHEMA AYALA	1	4	1	1	4.80	39.1	0.98	350	128	1336	36.5	2.39
sis	DON CHEMA AYALA	2	1	0	0	3.94	36.5	0.81	350	119	1162	34.1	2.79
sis	DON CHEMA AYALA	2	2	1	0	4.56	36.3	0.91	375	139	1244	37.1	2.92
sis	DON CHEMA AYALA	2	3	0	1	3.93	36.9	0.86	351	128	1115	36.3	2.66
sis	DON CHEMA AYALA	2	4	1	1	5.23	38.9	0.98	411	139	1570	33.9	2.58
sis	DON CHEMA AYALA	3	1	0	0	3.67	38.1	0.90	335	107	1150	32.1	2.34
sis	DON CHEMA AYALA	3	2	1	0	4.87	39.7	0.91	376	134	1361	35.7	2.64
sis	DON CHEMA AYALA	3	3	0	1	3.82	38.2	0.88	352	115	1181	32.5	2.21
sis	DON CHEMA AYALA	3	4	1	1	4.70	38.8	0.95	397	129	1460	32.5	2.50
sis	DON JACOBO	1	1	0	0	4.00	36.5	0.90	315	122	1032	38.7	2.22
sis	DON JACOBO	1	2	1	0	4.51	38.9	0.87	417	137	1405	32.8	2.36
sis	DON JACOBO	1	3	0	1	4.08	34.8	0.95	339	122	1125	36.1	2.03
sis	DON JACOBO	1	4	1	1	5.12	36.7	0.98	426	145	1525	34.0	2.60
sis	DON JACOBO	2	1	0	0	4.23	35.7	0.80	349	131	1121	37.6	2.24
sis	DON JACOBO	2	2	1	0	4.86	36.4	0.88	420	152	1347	36.2	2.44
sis	DON JACOBO	2	3	0	1	4.63	35.6	0.91	395	145	1280	36.7	2.16
sis	DON JACOBO	2	4	1	1	5.03	35.4	0.93	405	152	1324	37.6	2.26
sis	DON JACOBO	3	1	0	0	3.60	34.2	0.86	390	123	1149	31.5	2.22
sis	DON JACOBO	3	2	1	0	3.66	37.6	0.87	323	114	1051	35.3	2.02
sis	DON JACOBO	3	3	0	1	3.82	38.8	0.78	380	127	1144	33.6	2.06
sis	DON JACOBO	3	4	1	1	4.62	37.6	0.98	392	127	1447	32.3	2.07
sis	T T MORALES	1	1	0	0	3.79	37.8	0.84	309	120	984	39.0	2.16
sis	T T MORALES	1	2	1	0	4.47	36.7	0.90	394	136	1296	34.4	2.64
sis	T T MORALES	1	3	0	1	4.07	37.4	0.90	357	122	1204	34.1	2.20
sis	T T MORALES	1	4	1	1	4.02	38.2	0.79	394	134	1189	34.2	2.51
sis	T T MORALES	2	1	0	0	3.43	35.1	0.81	328	122	926	37.2	2.16
sis	T T MORALES	2	2	1	0	4.10	39.4	0.88	330	117	1149	35.3	2.56
sis	T T MORALES	2	3	0	1	3.14	37.1	0.82	267	102	811	38.2	2.01
sis	T T MORALES	2	4	1	1	4.51	40.4	0.87	346	129	1215	37.4	2.48
sis	T T MORALES	3	1	0	0	3.08	36.1	0.81	358	107	1041	29.9	2.10
sis	T T MORALES	3	2	1	0	4.00	39.1	0.8[illegible]	337	116	1155	34.5	2.34
sis	T T MORALES	3	3	0	1	3.99	36.7	0.93	364	115	1245	31.5	2.03
sis	T T MORALES	3	4	1	1	4.09	36.9	0.84	404	134	1251	33.1	2.48
sis	TOÑO AYALA	1	1	0	0	3.73	38.1	0.81	337	116	1045	34.5	2.3[illegible]
sis	TOÑO AYALA	1	2	1	0	4.51	40.1	0.86	338	131	1173	38.7	2.6[illegible]
sis	TOÑO AYALA	1	3	0	1	3.75	39.2	0.90	316	105	1117	33.1	2.64
sis	TOÑO AYALA	1	4	1	1	4.83	37.4	0.92	379	140	1308	36.9	2.56
sis	TOÑO AYALA	2	1	0	0	4.55	39.8	0.95	374	121	1415	32.4	2.28
sis	TOÑO AYALA	2	2	1	0	5.03	39.0	0.93	413	141	1494	34.1	2.29
sis	TOÑO AYALA	2	3	0	1	5.55	38.8	0.96	414	149	1545	35.9	2.37
sis	TOÑO AYALA	2	4	1	1	4.56	38.5	0.96	344	122	1265	35.6	2.61
sis	TOÑO AYALA	3	1	0	0	4.17	38.2	0.96	325	113	1191	34.7	2.32
sis	TOÑO AYALA	3	2	1	0	4.40	37.1	0.87	389	135	1252	34.8	2.49
sis	TOÑO AYALA	3	3	0	1	4.40	36.0	0.89	385	138	1228	35.8	2.45
sis	TOÑO AYALA	3	4	1	1	5.43	36.1	0.94	451	160	1536	35.5	2.61
sis	INDALECIO MEJIA	1	1	0	0	3.59	37.9	0.86	353	111	1154	31.4	2.41
sis	INDALECIO MEJIA	1	2	1	0	3.85	36.5	0.91	328	116	1093	35.4	2.87
sis	INDALECIO MEJIA	1	4	1	1	4.02	34.4	0.97	391	122	1304	31.3	2.74
sis	INDALECIO MEJIA	2	1	0	0	3.09	41.0	0.89	298	85	1088	28.4	2.56
sis	INDALECIO MEJIA	2	2	1	0	3.98	46.0	0.88	310	98	1254	31.6	2.99
sis	INDALECIO MEJIA	2	4	1	1	3.73	42.4	0.86	302	103	1101	34.1	2.86
sis	OBEL SERRANO	1	1	0	0	1.73	15.3	1.02	327	112	508	34.4	2.64
sis	OBEL SERRANO	1	2	1	0	1.90	15.6	0.98	378	129	581	34.1	2.83
sis	OBEL SERRANO	1	4	1	1	1.47	13.4	0.98	340	118	448	34.8	2.77
sis	OBEL SERRANO	2	1	0	0	2.62	19.5	1.13	367	121	809	33.1	2.[illegible]3
sis	OBEL SERRANO	2	2	1	0	2.02	16.7	1.18	343	102	677	29.8	2.92
sis	OBEL SERRANO	2	4	1	1	2.03	16.9	0.94	399	130	633	32.6	2.6[illegible]

APPENDIX C.7 (cont.)

						t/ha	thous					(15%)	ear leaf
site	Farmer	rep	Treat.	N	P	yield	dens	NEar/pl.	NK/ear	W1ear	NK/m2	W1K	N%
sis	NEGRITO RIVERA	1	1	0	0	3.60	50.6	0.72	276	98	1008	35.5	2.37
sis	NEGRITO RIVERA	1	2	1	0	5.58	45.5	0.86	414	142	1628	34.2	2.74
sis	NEGRITO RIVERA	1	4	1	1	6.43	49.9	0.89	386	149	1708	38.6	2.63
sis	NEGRITO RIVERA	2	1	0	0	4.65	40.6	0.86	373	132	1302	35.3	2.66
sis	NEGRITO RIVERA	2	2	1	0	4.07	34.3	0.92	343	129	1078	37.5	3.00
sis	NEGRITO RIVERA	2	4	1	1	4.94	37.6	0.89	366	147	1222	40.2	2.60
sis	MARTIR ANDRADE	1	1	0	0	4.40	32.3	0.94	435	143	1323	32.8	2.44
sis	MARTIR ANDRADE	1	2	1	0	5.43	32.5	0.99	441	169	1425	38.2	2.63
sis	MARTIR ANDRADE	1	4	1	1	6.08	33.4	0.96	436	159	1405	36.4	2.71
sis	MARTIR ANDRADE	2	1	0	0	5.45	31.2	1.04	500	169	1616	33.8	2.70
sis	MARTIR ANDRADE	2	2	1	0	5.33	31.8	0.94	446	180	1327	40.3	2.73
sis	MARTIR ANDRADE	2	4	1	1	6.21	36.3	1.00	474	172	1719	36.3	2.81
mg	ANASTACIO AMAYA	1	1	0	0	3.97	35.0	0.99	364	115	1262	31.6	2.28
mg	ANASTACIO AMAYA	1	4	1	0	4.31	35.2	1.02	513	120	1835	23.4	2.26
mg	ANASTACIO AMAYA	1	3	0	1	4.09	36.3	0.95	372	116	1285	31.3	2.01
mg	ANASTACIO AMAYA	1	2	1	1	4.03	38.0	0.95	383	111	1380	29.1	2.12
mg	ANASTACIO AMAYA	2	1	0	0	3.95	41.7	0.92	321	103	1227	32.2	2.32
mg	ANASTACIO AMAYA	2	2	1	0	4.50	44.0	0.98	383	104	1657	27.1	2.57
mg	ANASTACIO AMAYA	2	3	0	1	3.24	42.0	0.87	285	85	1040	29.9	1.95
mg	ANASTACIO AMAYA	2	4	1	1	3.25	39.8	0.90	345	91	1239	26.3	2.34
mg	ANASTACIO AMAYA	3	1	0	0	2.04	32.1	0.82	296	75	778	25.5	2.12
mg	ANASTACIO AMAYA	3	2	1	0	3.68	41.4	0.88	309	98	1122	31.9	1.72
mg	ANASTACIO AMAYA	3	3	0	1	2.85	42.7	0.85	254	76	919	30.0	2.06
mg	ANASTACIO AMAYA	3	4	1	1	3.25	45.5	0.92	213	67	886	31.5	2.11
mg	JUAN ALBARENGA	1	1	0	0	3.20	42.9	0.82	288	90	1017	31.1	2.34
mg	JUAN ALBARENGA	1	2	1	0	3.55	37.3	0.85	283	111	892	39.3	2.54
mg	JUAN ALBARENGA	1	3	0	1	4.47	46.5	0.93	313	102	1351	32.5	2.88
mg	JUAN ALBARENGA	1	4	1	1	3.52	34.3	0.84	324	116	940	35.9	2.84
mg	JUAN ALBARENGA	2	1	0	0	3.17	32.6	0.90	300	108	883	35.9	2.82
mg	JUAN ALBARENGA	2	2	1	0	3.11	29.7	0.87	321	118	831	36.8	2.58
mg	JUAN ALBARENGA	2	3	0	1	3.77	40.2	0.93	281	98	1051	35.1	2.52
mg	JUAN ALBARENGA	2	4	1	1	3.74	34.9	0.93	311	114	1008	36.7	2.83
mg	JUAN ALBARENGA	3	1	0	0	3.08	33.2	0.87	303	108	870	35.5	2.26
mg	JUAN ALBARENGA	3	2	1	0	3.63	33.8	0.90	338	118	1033	35.0	2.42
mg	JUAN ALBARENGA	3	3	0	1	3.67	40.2	0.89	335	102	1203	30.4	2.58
mg	JUAN ALBARENGA	3	4	1	1	3.59	34.1	0.92	337	113	1058	33.6	2.52
mg	ANTONIO HERNANDEZ	1	1	0	0	3.50	51.1	0.86	269	79	1174	29.5	2.25
mg	ANTONIO HERNANDEZ	1	2	1	0	4.41	44.5	0.88	420	113	1641	26.9	2.55
mg	ANTONIO HERNANDEZ	1	3	0	1	4.61	53.2	0.93	333	93	1639	28.0	2.26
mg	ANTONIO HERNANDEZ	1	4	1	1	4.79	49.5	0.88	405	110	1765	27.1	2.43
mg	ANTONIO HERNANDEZ	2	1	0	0	4.13	36.2	0.91	404	124	1339	30.7	2.19
mg	ANTONIO HERNANDEZ	2	2	1	0	4.48	40.8	0.96	358	109	1408	30.4	2.45
mg	ANTONIO HERNANDEZ	2	3	0	1	4.39	40.9	1.01	336	106	1389	31.5	2.11
mg	ANTONIO HERNANDEZ	2	4	1	1	3.82	45.3	0.87	362	96	1428	26.4	2.11
mg	ANTONIO HERNANDEZ	3	1	0	0	1.82	45.4	0.68	222	57	685	25.6	1.41
mg	ANTONIO HERNANDEZ	3	2	1	0	1.98	38.3	0.80	249	61	768	24.4	2.22
mg	ANTONIO HERNANDEZ	3	3	0	1	1.38	46.2	0.50	146	34	338	23.6	1.44
mg	ANTONIO HERNANDEZ	3	4	1	1	2.62	44.9	0.81	305	66	1116	21.6	1.81

APPENDIX D.1: FRACTIONATION RESULTS

Note: This appendix presents data summarized in chapter 5, section 5.4.3, page 114

Changes induced by the use of the mucuna system may not affect all fractions or *pools* of the total soil organic matter similarly (Duxbury *et al.*, 1989). To examine this possibility, two parallel approaches were used: a classical chemical fractionation scheme based on acid hydrolysis (Stewart *et al.*, 1963), and a physical one (after Feller, 1994), this latter being probably more satisfactory, as it relates conceptually to soil architecture, for which size of the aggregates is of prime importance (McGill and Myers, 1987, Christensen, 1992) In this case, two fractions were distinguished: a fine fraction (particles < 50 µ) and a coarse fraction (particles > 50 µ)

In a first step, only extremes of the chronosequence were contrasted, namely fields without mucuna or only one year into the rotation (hereafter referred to globally as check plots), vs old mucuna fields: 14 to 16 years of continuous mucuna rotation (Table 5.4 page 148).

The chemical fractionation scheme did not pick up any differential behavior between the various fractions distinguished by the acid digestion: Nhd (nitrogen hydrolizable distillable), Nnh (nitrogen non-hydrolizable), and Nhnd (nitrogen hydrolizable non-distillable). Old mucuna fields presented a marked increase in N content in all fractions compared to check plots, and this increase was especially strong in the upper layers, and marginal at greater depth (Figure D 1)

The physical fractionation showed that the fine and coarse fractions behaved differently over time (Figure D 2) The coarse fraction seemed to accumulate C and N much more rapidly over time than the fine fraction: the relative increase in C content of the coarse fraction reached 250% in the first 2 5 cm, compared to 30% for the fine This may indicate the accumulation of relatively free organic matter (perhaps even organic debris) at or very close to the soil surface However, the relative distribution of C between the coarse and fine fraction (as a percent of total C in the layer) was not affected by this differential increase, because old mucuna fields exhibited a higher proportion of fine fraction than young ones for all depth increments (0 to 15 cm) (Figure D 3) This textural gradient is somewhat puzzling, although it would be relatively consistent with the hypothesis mentioned in 5.3.2, i e. that young mucuna fields, having been subjected to more cycles of unmulched cropping than old ones, may have suffered some erosion damage over the years, while the old mucuna fields did not Alternatively, it may reflect a built-in bias in the construction of the chronosequence, older mucuna fields presenting a heavier texture than young ones.

In a second step, the whole chronosequence, not only the extremes, was considered, but limiting the analysis to the 2 5-5 cm layer (the first layer was not selected to bypass any bias potentially associated with the unavoidable mixing of organic debris together with the soil proper when sampling this layer)

Again, the chemical fractionation did not discriminate markedly among the various fractions, as they all presented gradual increases over time of a similar magnitude. Focusing only on mucuna fields younger than 10 years (thus avoiding the textural gradient mentioned earlier), the physical fractionation showed that it was the fine fraction, not the coarse one where most of the increase in C or N content was taking place (Figure D 4). This would indicate the formation of relatively stable organic matter, as it is intimately bound to the mineral fraction (Tisdall and Oades, 1982).

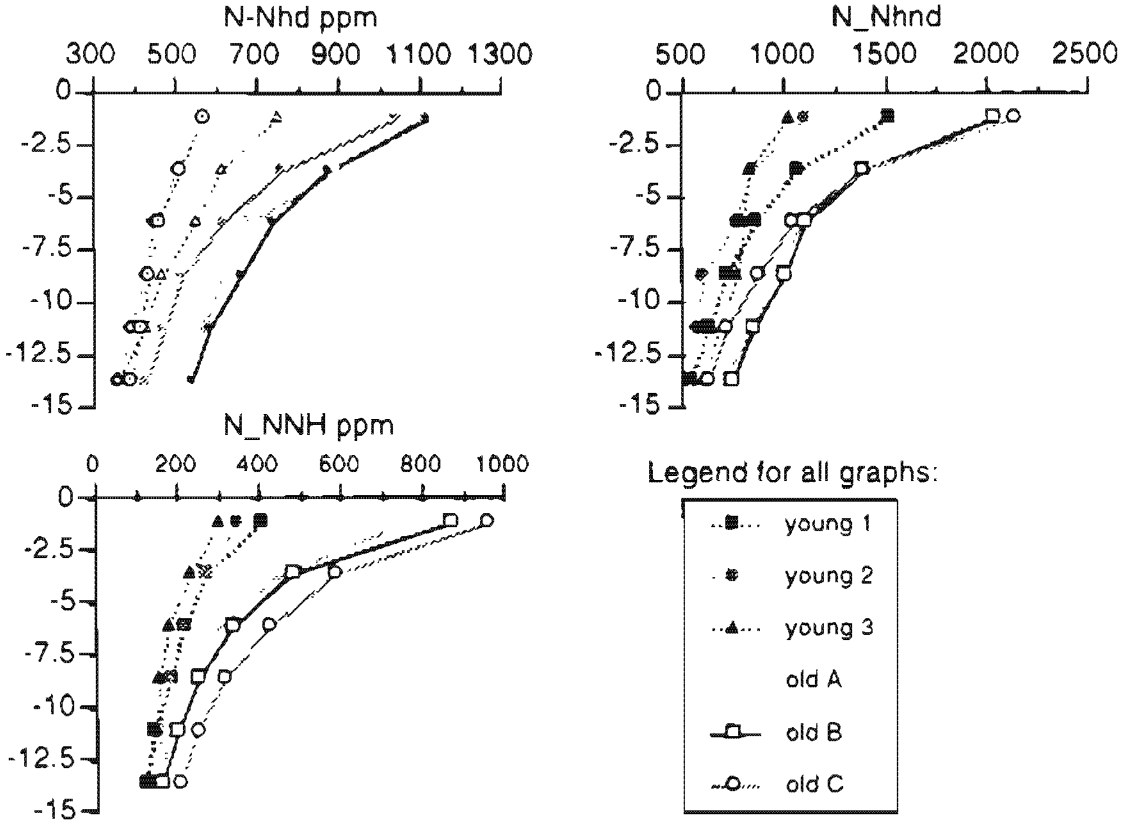

Figure D 1: Nitrogen content of chemical fractions of soil organic matter in the 0-15 cm soil profiles of old vs. young mucuna fields, San Francisco de Saco, Northern Honduras

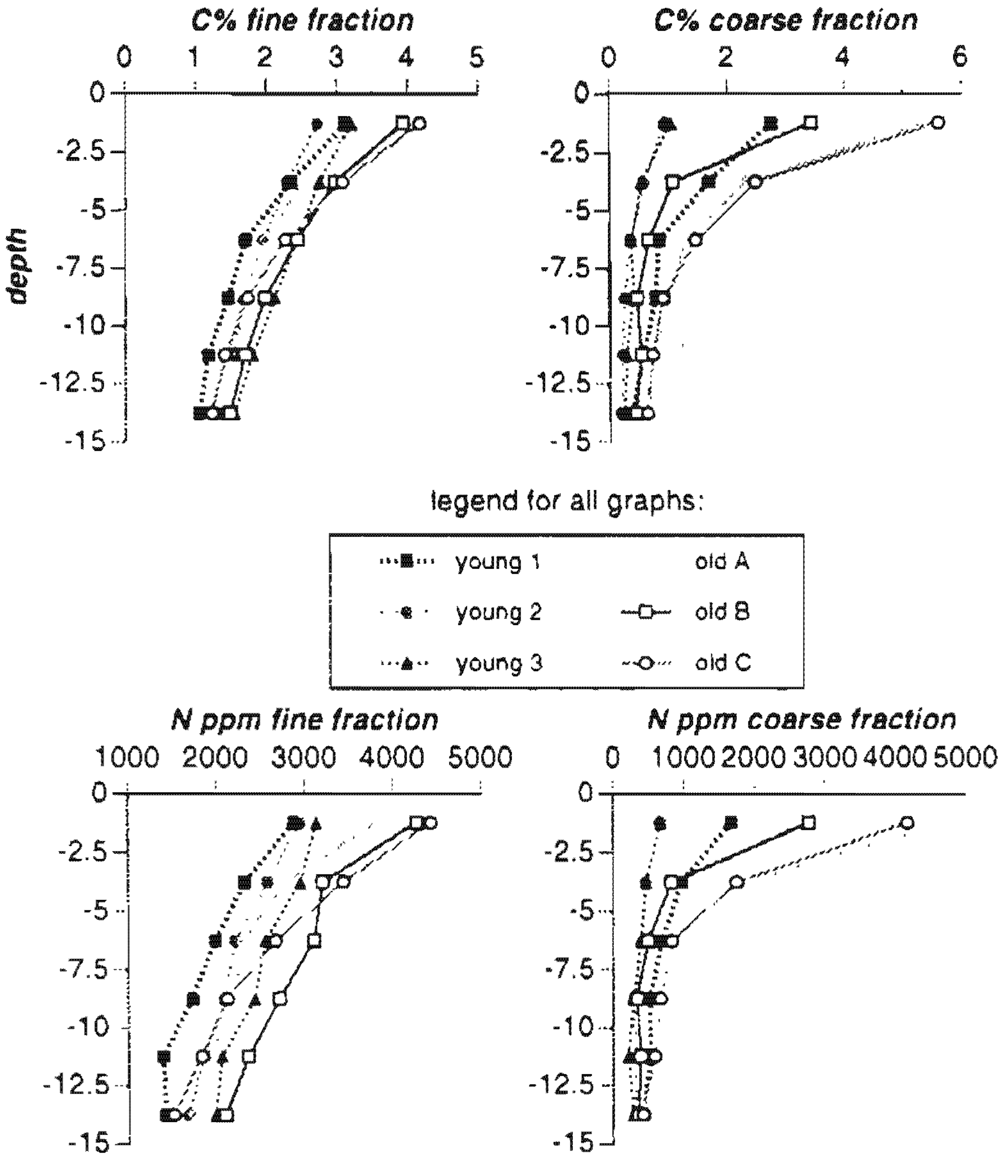

Figure D.2: Absolute C and N content of two physical fractions of soil organic matter in the 0-15 cm soil profiles of old vs. young mucuna fields. San Francisco de Saco, Northern Honduras

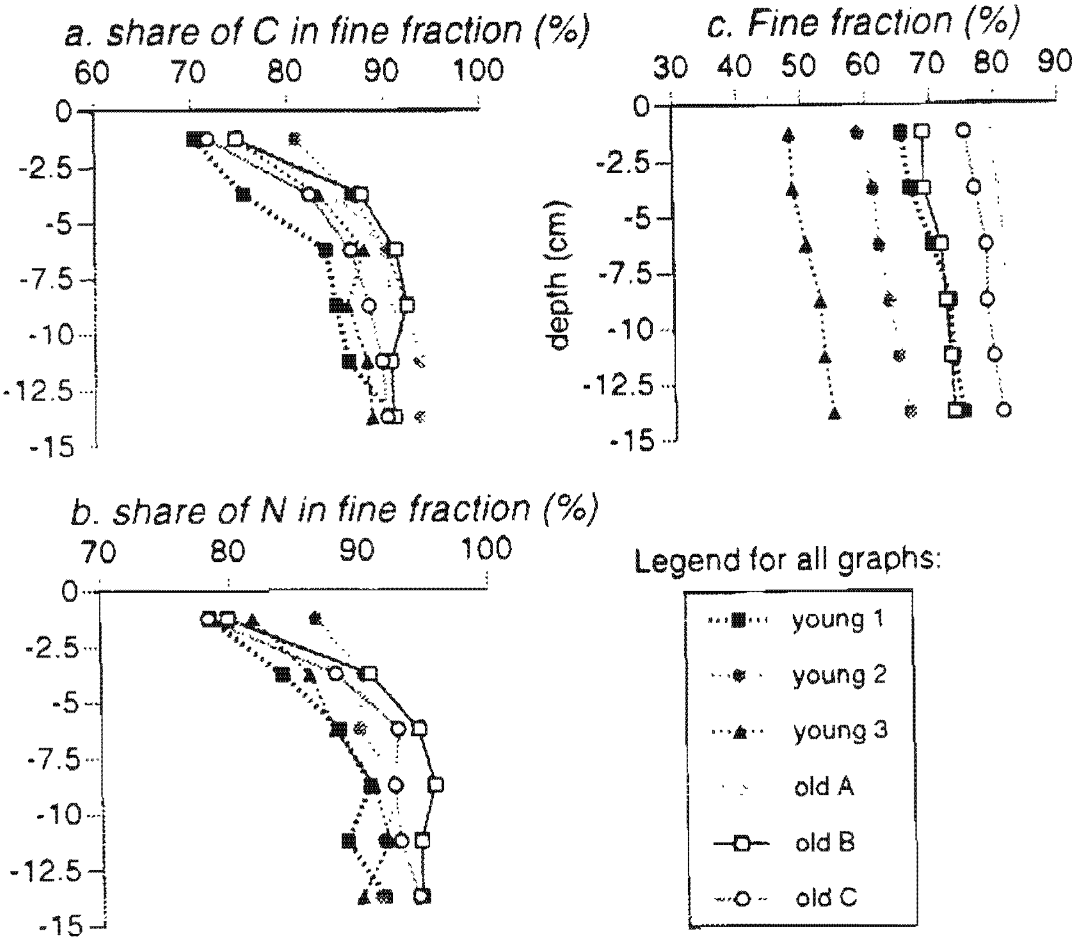

Figure D 3. Relative contribution in terms of C and N content of two physical fractions of soil organic matter in the 0-15 cm soil profiles of old vs young mucuna fields. San Francisco de Saco, Northern Honduras

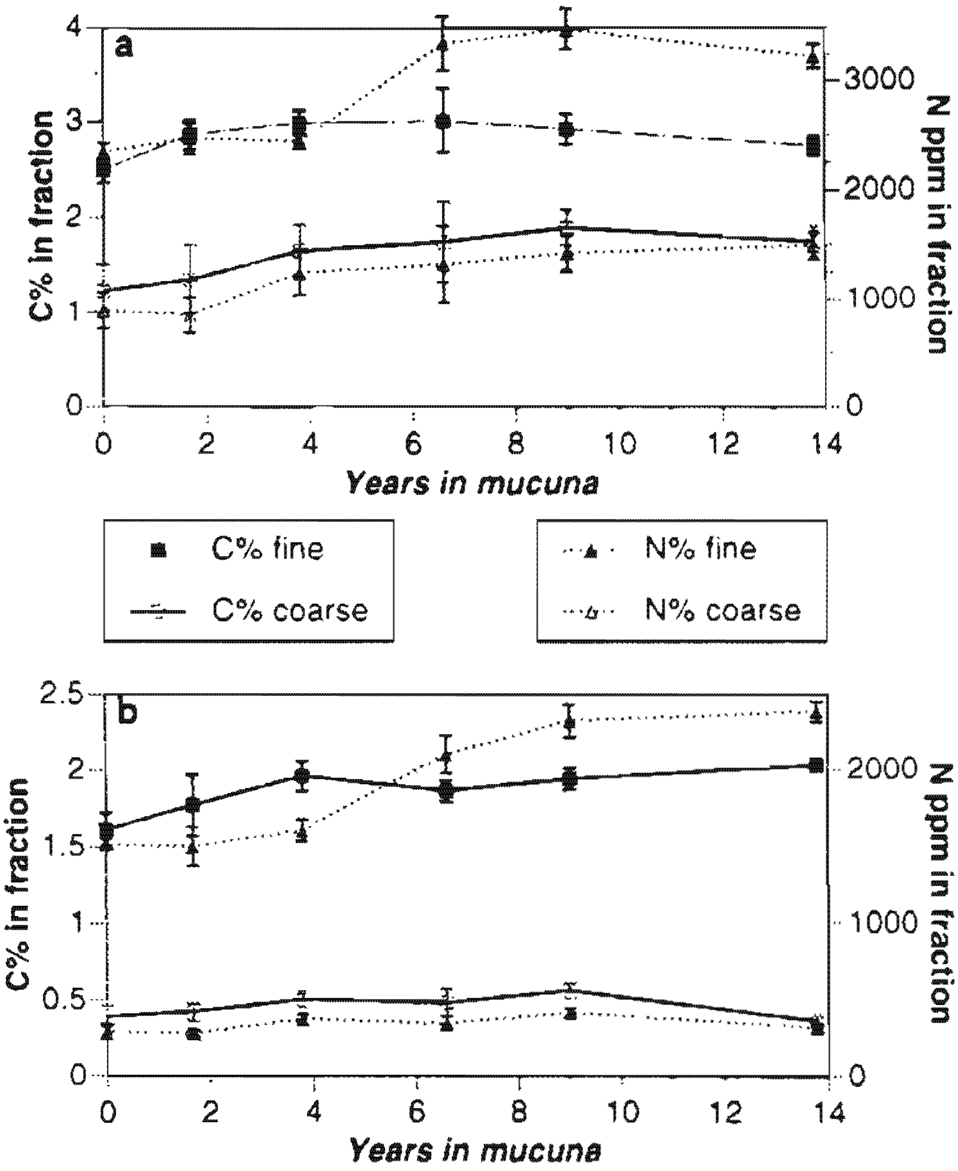

Figure D 4: Changes affecting the C and N content of two physical fractions of soil organic matter in the upper soil profile (2.5-5 cm) over time under the influence of the mucuna/maize rotation. San Francisco de Saco, Northern Honduras a absolute changes in each fraction. b weighted contribution of each fraction

APPENDIX D.2.a: CHEMICAL & PHYSICAL FRACTIONS 0-15 cm

				exchangeable bases (cobalt method)						texture					carbon	P	
				meq	meq	meq	meq	meq		%	%	%	%	%	%	ppm	
ID	hor	avg depth	years muc	Ca	Mg	K	Na	CEC	base sat	clay	fine silt	coarse silt	fine sand	coarse sand	C	P Olsen	pH cobalt
1a1	1	-1.25	0	13.07	4.86	0.45	1.31	21.89	90%	27.8	18.2	7.4	25.3	21.3	2.97	23.3	6.24
1a2	2	-3.75	0	11.48	4.43	0.33	0.90	19.31	89%	29.9	14.8	8.0	25.7	21.6	1.96	19.7	5.88
1a3	3	-6.25	0	10.43	4.27	0.25	0.78	17.97	88%	32.8	17.1	7.6	22.7	19.7	1.42	11.9	5.53
1a4	4	-8.75	0	10.48	4.33	0.17	0.70	17.98	87%	32.3	16.8	6.1	23.3	19.4	1.16	10.4	5.43
1a5	5	-11.25	0	10.66	4.46	0.19	0.69	18.27	88%	32.8	16.3	7.3	22.6	19.0	0.99	13.3	5.35
1a6	6	-13.75	0	10.81	4.63	0.16	0.71	18.37	89%	34.2	17.4	7.2	22.6	16.6	0.79	7.4	5.31
2a1	1	-1.25	0	1.84	1.03	0.31	0.25	5.01	68%	31.7	11.6	8.6	21.3	26.8	1.93	19.0	4.81
2a2	2	-3.75	0	1.19	0.66	0.40	0.52	4.40	63%	32.5	12.5	7.9	20.3	26.7	1.54	15.1	4.66
2a3	3	-6.25	0	0.85	0.52	0.44	0.66	3.89	64%	33.2	12.7	7.8	21.4	24.9	1.08	21.6	4.76
2a4	4	-8.75	0	0.75	0.46	0.21	0.38	3.69	49%	36.0	13.2	7.2	19.3	24.4	1.29	16.2	4.53
2a5	5	-11.25	0	0.70	0.46	0.37	0.51	3.44	60%	36.9	15.2	6.5	21.0	20.3	0.98	12.5	4.69
2a6	6	-13.75	0	0.71	0.45	0.17	0.28	3.32	49%	35.6	17.4	6.8	16.1	22.5	0.92	14.2	4.49
3a1	1	-1.25	1	3.51	1.51	0.25	0.33	7.64	73%	24.1	12.4	5.5	21.2	36.8	2.06	19.2	4.92
3a2	2	-3.75	1	2.56	1.10	0.29	0.43	6.38	69%	22.9	11.6	5.2	20.5	39.6	1.59	26.1	4.91
3a3	3	-6.25	1	2.05	0.89	0.30	0.42	5.59	65%	22.8	13.5	5.0	19.0	39.7	1.27	21.1	4.83
3a4	4	-8.75	1	1.76	0.78	0.24	0.30	5.50	56%	24.0	13.5	5.0	19.4	36.0	1.16	17.6	4.63
3a5	5	-11.25	1	1.81	0.79	0.33	0.43	5.92	57%	25.6	13.1	6.5	22.1	32.7	1.09	11.7	4.83
3a6	6	-13.75	1	1.60	0.74	0.17	0.23	5.14	53%	26.3	13.0	5.3	20.9	34.4	0.89	16.6	4.76
14a1	1	-1.25	14	15.16	[illegible]	0.29	0.80	25.13	89%	40.7	22.6	12.6	17.5	6.5	3.43	19.3	[illegible]
14a2	2	-3.75	14	13.25	5.51	0.22	0.65	21.69	91%	41.2	22.7	10.4	18.2	7.6	2.31	16.0	5.22
14a3	3	-6.25	14	13.07	5.55	0.15	0.49	21.35	90%	42.5	20.5	12.1	17.7	7.2	1.79	28.2	[illegible]
14a4	4	-8.75	14	12.50	5.73	0.12	0.94	22.20	91%	41.1	24.0	10.7	17.3	6.9	1.46	9.9	5.26
14a5	5	-11.25	14	14.51	6.13	0.11	0.65	23.37	91%	41.9	22.5	12.5	17.1	6.0	1.22	10.0	5.16
14a6	6	-13.75	14	15.29	6.43	0.09	0.74	25.07	90%	43.5	22.8	11.2	16.1	6.6	[illegible]	[illegible]	5.26
15a1	1	-1.25	15	14.97	5.63	0.02	0.32	23.96	89%	33.7	10.8	13.7	14.6	27.1	3.72	27.8	5.52
15a2	2	-3.75	15	12.63	4.80	0.23	0.32	20.33	88%	35.8	15.0	8.3	18.1	21.8	2.36	12.6	5.39
15a3	3	-6.25	15	12.23	4.67	0.16	0.33	19.26	90%	38.0	17.1	6.2	15.4	21.3	1.84	13.7	5.36
15a4	4	-8.75	15	12.42	4.70	0.13	0.52	20.03	89%	37.9	18.4	6.6	16.5	[illegible]	[illegible]	16.2	[illegible]
15a5	5	-11.25	15	12.51	4.66	0.10	0.21	19.99	88%	33.6	7.7	22.4	20.4	[illegible]	1.35	9.7	[illegible]
15a6	6	-13.75	15	12.44	4.61	0.08	0.18	19.62	88%	[illegible]	14.4	11.4	16.0	[illegible]	[illegible]	9.3	[illegible]
17a1	1	-1.25	16	18.94	[illegible]	0.24	0.59	28.43	91%	31.6	16.5	9.6	[illegible]	[illegible]	4.35	27.7	[illegible]
17a2	2	-3.75	16	15.47	4.72	0.17	0.83	22.66	94%	29.4	16.5	11.0	21.6	[illegible]	2.62	17.6	6.12
17a3	3	-6.25	16	14.94	4.12	0.10	0.63	[illegible]	93%	28.9	12.8	18.5	20.7	[illegible]	[illegible]	14.5	[illegible]
17a4	4	-8.75	16	14.67	3.76	0.10	0.47	20.72	93%	[illegible]	15.1	11.5	21.2	20.6	1.54	16.9	5.92
17a5	5	-11.25	16	15.16	3.53	0.07	0.61	20.86	93%	26.6	18.5	[illegible]	22.8	22.1	[illegible]	14.4	[illegible]
17a6	6	-13.75	16	15.89	3.43	0.09	0.61	21.12	95%	32.7	18.6	[illegible]	19.6	[illegible]	[illegible]	13.5	5.97
1b2	2	-3.75	0	11.77	4.10	0.44	0.62	17.73	97%	31.2	14.2	7.4	19.6	27.6	2.22	[illegible]	5.66
2b2	2	-3.75	0	1.93	0.98	0.46	0.54	4.71	84%	39.1	13.8	8.3	16.0	20.9	1.93	19.2	[illegible]
3b2	2	-3.75	1	2.91	1.20	0.31	0.36	5.30	90%	[illegible]	10.2	6.5	25.4	36.5	1.53	18.0	[illegible]
4a2	2	-3.75	2	5.32	2.97	0.66	0.64	10.65	90%	46.2	14.1	6.3	19.3	14.2	2.29	11.3	5.45
4b2	2	-3.75	2	5.75	2.27	0.67	0.76	11.15	85%	37.0	11.0	20.1	16.6	15.4	[illegible]	12.6	[illegible]
5a2	2	-3.75	2	1.61	0.94	0.41	0.30	3.66	84%	35.5	12.5	6.6	19.3	25.9	[illegible]	16.6	[illegible]
5b2	2	-3.75	2	1.56	0.92	0.42	0.29	4.27	75%	42.5	12.4	6.4	17.8	[illegible]	2.54	11.2	4.56
6a2	2	-3.75	3	6.97	3.44	0.93	1.97	16.06	95%	33.5	14.9	7.7	19.1	24.6	2.36	24.6	[illegible]
6b2	2	-3.75	4	10.74	3.96	0.52	1.51	17.35	96%	[illegible]	15.9	6.4	[illegible]	[illegible]	[illegible]	[illegible]	5.92
7a2	2	-3.75	4	11.03	4.67	0.31	0.72	17.70	94%	34.0	19.7	6.8	18.7	18.8	[illegible]	[illegible]	4.76
7b2	2	-3.75	4	13.98	3.76	0.35	0.91	18.97	100%	30.9	18.5	7.8	21.6	21.2	2.65	15.9	5.87
7c2	2	-3.75	4	10.70	3.90	0.31	0.51	15.93	97%	30.0	15.2	5.7	18.4	30.7	2.34	17.0	5.03
14c2	2	-3.75	5	12.75	5.63	0.22	0.78	20.85	93%	41.2	18.6	8.1	16.9	13.2	2.34	13.6	5.47
10a2	2	-3.75	7	12.66	5.18	0.43	1.09	18.51	99%	31.2	15.8	5.5	20.2	27.3	2.24	16.4	5.35
10b2	2	-3.75	7	17.96	6.40	0.31	1.28	26.65	98%	44.6	21.0	9.3	16.9	8.0	2.45	14.4	5.65
9a2	2	-3.75	7	7.60	2.15	0.47	0.70	11.29	97%	19.0	8.8	5.3	26.3	37.5	2.67	[illegible]	5.36
9b2	2	-3.75	7	10.87	3.23	0.66	1.27	16.39	98%	27.0	15.2	6.6	17.3	34.0	2.35	20.6	5.62
11a2	2	-3.75	9	[illegible]	4.02	[illegible]	1.19	18.89	100%	31.9	16.5	6.6	16.9	26.0	[illegible]	19.6	5.54
11b2	2	-3.75	9	13.48	5.61	0.40	0.73	20.42	99%	35.2	14.0	5.9	18.9	26.1	2.66	14.9	[illegible]
11c2	2	-3.75	9	14.64	5.66	0.29	0.62	21.65	98%	35.9	16.9	[illegible]	[illegible]	24.1	2.76	16.9	[illegible]
12a2	2	-3.75	9	13.31	4.18	0.27	1.05	19.12	98%	40.9	22.0	[illegible]	[illegible]	10.9	2.62	16.4	5.43
12b2	2	-3.75	9	13.87	[illegible]	[illegible]	0.82	19.29	98%	37.1	19.6	10.3	22.9	10.1	2.75	23.1	[illegible]
8a2	2	-3.75	9	12.64	4.69	0.56	1.74	19.66	100%	36.1	18.4	6.7	18.6	20.0	2.56	15.3	[illegible]
8b2	2	-3.75	9	10.49	4.35	0.27	1.06	16.33	97%	33.9	15.4	8.4	14.0	28.3	2.33	14.6	[illegible]
8c2	2	-3.75	9	10.96	[illegible]	0.43	1.01	16.61	99%	32.9	16.8	6.0	17.6	28.5	2.17	[illegible]	[illegible]
13a2	2	-3.75	11	14.85	4.08	0.32	0.42	20.92	94%	39.4	22.7	11.4	16.4	10.1	2.36	23.2	5.36
13b2	2	-3.75	11	[illegible]	4.63	[illegible]	0.44	19.42	94%	39.4	22.1	10.6	[illegible]	6.5	2.12	15.6	5.45
16a2	2	-3.75	13	[illegible]	[illegible]	0.42	1.10	17.26	92%	36.6	18.5	[illegible]	17.6	22.2	2.22	[illegible]	[illegible]
16b2	2	-3.75	13	[illegible]	[illegible]	[illegible]	0.84	15.87	91%	27.3	14.3	6.9	[illegible]	[illegible]	2.45	[illegible]	5.66
14b2	2	-3.75	14	13.44	5.37	0.33	0.67	21.17	93%	43.4	20.7	[illegible]	16.3	9.2	2.45	[illegible]	[illegible]
15b2	2	-3.75	15	[illegible]	4.59	0.22	0.24	19.26	89%	37.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17b2	2	-3.75	16	16.64	5.96	0.29	0.68	26.41	89%	39.3	19.3	[illegible]	[illegible]	[illegible]	2.44	[illegible]	5.54

APPENDIX D.2.a (cont.)

				nitrogen	chemical fractions					physical fractions					
				ppm	ppm	ppm	ppm	ppm		%	%	%	ppm	%	ppm
		pH	pH	N					Nhnd	fract.	fract.	C in	N in	C in	N in
ID	hor	water	KCl	total	N_Nhd	N Nhl	N NNH	Nhnd	/Nhd	<50µ	>50µ	F<50µ	F<50µ	F>50µ	F>50µ
1a1	1	6.32	5.60	2548	750	2262	406	1512	2.01	65.6	31.0	3.12	2680	2.76	1670
1a2	2	6.18	5.31	1895	616	1680	272	1064	1.73	66.9	30.2	2.35	2320	1.69	970
1a3	3	6.16	5.02	1615	549	1411	218	862	1.57	70.3	26.5	1.70	1990	0.65	690
1a4	4	6.11	4.83	1381	470	1187	185	717	1.52	73.0	24.5	1.46	1730	0.78	520
1a5	5	6.09	4.72	1185	426	1053	143	627	1.47	73.4	23.9	1.18	1400	0.58	500
1a6	6	6.04	4.66	1045	358	896	120	536	1.50	74.9	22.5	1.05	1420	0.37	420
2a1	1	5.49	4.57	2016	571	1680	347	1109	1.94	58.9	39.9	2.73	2950	0.95	670
2a2	2	5.71	4.34	1699	504	1344	274	840	1.67	61.2	37.0	2.30	2580	0.59	460
2a3	3	5.78	4.54	1475	448	1210	213	762	1.75	62.0	37.0	1.95	2210	0.36	410
2a4	4	5.48	4.29	1307	426	1030	179	605	1.42	63.5	35.1	1.67	2090	0.25	290
2a5	5	5.40	4.33	1213	392	963	157	571	1.46	64.9	33.7	1.54	1850	0.22	320
2a6	6	5.20	4.15	1129	358	896	151	538	1.50	66.5	32.3	1.31	1660	0.20	320
3a1	1	5.78	4.85	1951	571	1590	305	1019	1.78	48.3	50.2	3.20	3130	1.05	670
3a2	2	5.86	4.72	1596	515	1344	232	829	1.61	48.7	49.8	2.75	2950	0.55	460
3a3	3	5.87	4.59	1503	459	1254	179	795	1.73	50.7	44.9	2.42	2550	0.37	390
3a4	4	5.76	4.51	1409	437	1210	157	773	1.77	52.8	45.0	2.12	2430	0.42	280
3a5	5	5.79	4.53	1297	414	1098	146	683	1.65	53.3	44.5	1.81	2160	0.29	210
3a6	6	5.62	4.47	1146	392	986	126	594	1.51	54.6	42.6	1.55	1990	0.28	280
14a1	1	5.95	5.34	3627	1098	3046	764	1949	1.78	78.9	15.5	3.35	3620	3.41	4670
14a2	2	5.92	4.88	2837	896	2397	454	1501	1.68	80.6	15.2	2.51	2770	2.31	1660
14a3	3	5.91	4.69	2137	683	1770	302	1086	1.59	81.4	13.8	1.99	2300	1.28	1020
14a4	4	6.31	4.77	1753	616	1546	235	930	1.51	82.0	13.3	1.66	2190	1.04	900
14a5	5	6.07	4.66	1596	571	1411	182	840	1.47	83.7	12.3	1.47	1920	0.75	740
14a6	6	6.27	4.61	1428	493	1187	154	694	1.41	84.6	10.6	1.20	1740	0.57	480
15a1	1	6.19	5.17	3929	1120	3158	871	2038	1.82	69.0	26.8	3.94	4270	3.44	2770
15a2	2	6.12	5.03	2725	874	2262	482	1389	1.59	69.1	27.3	2.97	3210	1.16	820
15a3	3	6.11	4.94	2259	739	1837	333	1098	1.46	71.7	25.7	2.44	3100	0.66	490
15a4	4	6.15	4.94	1848	661	1658	255	997	1.51	72.0	25.4	1.92	2712	0.47	340
15a5	5	6.08	4.85	1661	582	1434	202	851	1.46	72.9	24.7	1	2260	0.53	390
15a6	6	6.03	4.71	1447	538	1277	160	739	1.38	73.4	24.2	1.4	2101	0.44	360
17a1	1			3883	1042	3181	963	2139	2.05	75.5	22.1	4.2	4430	5.61	4170
17a2	2	6.33	5.54	2697	762	2150	588	1389	1.82	77.0	20.4	3.08	3436	2.49	1140
17a3	3	6.48	5.38	2025	616	1658	426	1042	1.69	76.7	19.2	2.27	2610	1.47	630
17a4	4	6.36	5.27	1615	515	1389	316	874	1.70	78.7	19.6	1.73	2122	0.91	670
17a5	5	6.52	5.29	1391	470	1167	249	717	1.62	79.7	18.4	1.41	1630	0.73	590
17a6	6	6.52	5.24	1251	426	1053	207	627	1.47	81.0	16.8	1.23	1511	0.64	420
1c2	2	6.31	5.29	2156	750	1904	356	1154	1.54	66.50	31.20	2.68	2260	1.69	1390
2c2	2	5.85	4.66	2156	627	1658	347	1030	1.64	64.10	34.00	2.43	2200	0.93	660
3c2	2	6.09	4.81	1568	493	1344	204	851	1.73	45.70	52.30	2.32	2170	0.59	490
4a2	2	6.05	5.20	2081	672	1770	356	1098	1.63	70.70	27.30	2.66	2080	1.88	1060
4c2	2	6.43	5.38	2651	851	2128	510	1277	1.50	75.50	22.70	3.15	2420	2.79	1550
5a2	2	5.61	4.66	2165	627	1770	366	1142	1.82	60.30	36.30	2.95	2590	0.88	360
5c2	2	5.52	4.57	2641	784	2262	470	1478	1.89	65.40	33.10	3.44	2710	1.42	410
6a2	2	6.38	5.63	2231	739	1926	330	1187	1.61	59.10	38.80	3.12	2460	1.31	660
6c2	2	6.38	5.50	2212	750	1882	260	1131	1.51	64.00	33.50	2.72	2450	1.16	1040
7a2	2	5.76	4.62	2389	739	2016	339	1277	1.73	74.10	23.40	2.65	2190	0.14	1640
7b2	2	6.12	5.22	2753	856	2195	507	1389	1.72	73.70	26.80	3.28	2640	2.51	1630
7c2	2	5.93	4.90	2333	739	2016	389	1277	1.73	60.90	36.90	3.19	2490	1.13	810
14c2	2	6.24	5.03	2651	862	2106	448	1243	1.44	76.00	20.70	2.56	3120	1.71	1610
10a2	2	6.16	5.08	2147	739	1814	372	1075	1.45	64.80	32.20	2.67	3120	1.38	950
10c2	2	6.34	5.10	2613	851	2173	476	1322	1.55	82.70	13.80	2.33	2830	3.36	2570
9a2	2			2063	638	1770	375	1131	1.77	39.50	58.80	4.2	4260	1.28	640
9b2	2	6.31	5.34	2203	694	1859	367	1165	1.68	61.00	36.50	3.34	3420	2.69	640
11a2	2	6.25	5.21	2819	907	2330	526	1422	1.57	62.70	34.30	3.22	4250	2.11	1420
11b2	2	5.60	4.71	2669	862	2218	521	1355	1.57	62.40	34.30	3.4	3920	1.76	1240
11c2	2	5.93	4.79	2893	896	2374	510	1478	1.65	67.30	29.40	2.94	3790	1.78	1250
12a2	2	6.09	5.06	2707	829	2195	535	1366	1.65	76.40	20.50	1.88	3230	2.67	2770
12c2	2	6.12	5.18	2893	918	2330	518	1411	1.54	71.00	26.20	2.85	3480	2.29	2120
8a2	2	6.31	5.40	2651	851	2195	470	1344	1.58	68.50	28.50	2.87	2510	[illegible]	1450
8b2	2	6.46	5.27	2417	750	1994	409	1243	1.66	63.80	34.50	3.08	3410	2.22	860
8c2	2	6.36	5.28	2511	750	1994	470	1243	1.66	63.10	34.50	3.18	3350	1.22	1000
13a2	2	6.56	5.05	2613	818	2038	456	1221	1.49	82.70	13.60	2.47	2870	2.2	1620
13c2	2	6.13	5.06	2240	717	1814	392	1098	1.53	79.70	16.50	2.35	2660	1.95	1730
16a2	2	6.37	5.32	2352	773	1949	395	1176	1.52	65.90	31.40	2.94	3160	1.21	990
16c2	2	6.46	5.51	2735	829	2218	504	1389	1.68	61.30	36.00	3.31	3970	1.3	1160
14b2	2	6.14	5.11	2619	930	2307	487	1376	1.48	79.20	17.20	2.6	3510	1.6	1760
15c2	2	5.92	4.94	2622	851	2128	445	1277	1.50	75.40	21.60	2.62	3100	1.80	1380
17c2	2	6.26	5.11	2632	829	2106	456	1277	1.54	72.80	23.20	2.6	3391	1.95	1760

APPENDIX D.2.b: SOIL ORGANIC CARBON (Walkey & Black) 0-15 cm

sample I.D.				*% C*					
parc.	**rep**	**ID #**	**age**	**hor.1**	**hor.2**	**hor.3**	**hor.4**	**hor.5**	**hor.6**
1	1	1a	0	3.33	2.04	1.60	1.34	1.06	0.90
1	2	1b	0	3.83	2.49	2.15	1.69	1.67	1.43
2	1	2a	0	2.24	1.78	1.49	1.33	1.16	1.02
2	2	2b	0	2.66	2.28	1.83	1.60	1.45	1.16
3	1	3a	1	2.53	1.85	1.47	1.39	1.18	1.03
3	2	3b	1	2.16	1.73	1.49	1.28	1.12	1.08
4	1	4a	2	3.40	2.57	2.16	1.77	1.38	1.26
4	2	4b	2	4.22	3.28	2.58	2.03	1.64	1.44
5	1	5a	2	3.03	2.36	2.00	1.78	1.56	1.25
5	2	5b	2	3 92	3.01	2.59	2.08	1.82	1.61
6	1	6a	3	4.32	2.78	2.18	1.72	1.44	1.23
6	2	6b	4	3.79	2.45	2.09	1.56	1.24	1.10
7	1	7a	4	4.07	2.84	2.06	1.48	1.24	1.05
7	2	7b	4	4.65	2.95	1.83	1.44	1.11	1.00
7	3	7c	4	4.35	2.82	1.97	1.54	1.21	0.89
8	1	8a	9	4.92	2.97	2.12	1.70	1.38	1.21
8	2	8b	9	4.45	2.76	1.97	1.62	1.49	1.27
8	3	8c	9	4.59	2.46	2.31	1.82	1.63	1.25
9	1	9a	7	3.99	2.55	1.65	1.35	1.02	0.97
9	2	9b	7	4.13	2.59	1.88	1.40	1.21	0.96
10	1	10a	7	4.02	2.49	1.74	1.49	1.19	1.05
10	2	10b	7	4.75	2.78	1.94	1.51	1.27	1.19
11	1	11a	9	5.39	3.29	2.40	1.85	1.53	1.30
11	2	11b	9	3.98	2.96	2.33	1.86	1.51	1.19
11	3	11c	9	5.10	3.23	2.09	1.73	1.43	1.22
12	1	12a	9	4.93	2.99	2.04	1.63	1.45	1.31
12	2	12b	9	4.43	3.06	2.01	1.63	1.35	1.27
13	1	13a	11	5.01	2.77	2.04	1.67	1.46	1.31
13	2	13b	11	4.02	2.46	1.75	1.54	1.19	1.10
14	1	14a	14	3.95	2.67	1.93	1.62	1.38	1.09
14	2	14b	14	4.23	2.65	1.87	1.63	1.36	1.24
14	3	14c	5	4.26	2.66	1.88	1.52	1.29	1.08
15	1	15a	15	4.23	2.76	2.11	1.72	1.45	1.22
15	2	15b	15	3.97	2.64	1.94	1.50	1.21	1.07
16	1	16a	13	4.01	2.52	1.84	1.59	1.40	1.22
16	2	16b	13	4.05	2.85	2.20	1.85	1.60	1.37
17	1	17a	16	4.92	3.10	2.31	1.77	1.34	1.21
17	2	17b	16	4.79	2.75	1.98	1.54	1.30	1.10

APPENDIX D.3: SOIL CHEMICAL PROPERTIES ACROSS SITES

site	year	ID #	farmer	rep	years mucuna	horizon 0-10 cm pH	C%	N%	C:N	P ppm	K meq	Ca meq	Mg meq	Al meq	Fe ppm	Mn ppm
s1	94	B-T34	Manuel	4	0	5.30	1.90	0.20	9.65	0.0	0.40	1.58	0.78	0.48	2.0	47.1
s1	94	B-T31	Manuel	2	0	6.42	1.70	0.18	9.63	0.0	0.40	1.76	0.87	0.38	3.4	49.7
s1	93	b-443	CARLOS MALDONAD	[illegible]	0	6.05	2.73	0.27	10.08	0.0	0.48	7.72	3.12	0.13	0.7	58.5
s1	93	b-476	DON JACOBO-check	1	0	5.94	1.97	[illegible]	10.37	0.6	0.02	10.61	3.94	0.15	2.3	69.6
s1	94	B-T01	Raul Morales	1	0	6.46	2.17	0.21	10.16	0.8	0.20	10.87	3.75	0.17	2.0	20.5
s1	94	B-T07	Doña Chinda A	1	0	6.34	2.35	0.23	10.21	1.3	0.34	10.68	3.09	0.16	1.3	20.3
s1	94	B-T13	Doña Chinda B	1	0	6.31	2.04	0.20	10.13	1.0	0.27	10.70	2.77	0.16	2.3	21.1
s1	94	B-T19	Juancito Rivera	1	0	6.11	2.01	0.20	10.22	0.0	0.23	6.58	2.78	0.19	2.4	26.0
s1	94	B-T28	Chema Galo check	1	0	sample lost										
s1	93	b-446	CARLOS MALDONAD	2	0	5.77	2.40	0.24	10.16	0.0	0.43	5.70	2.48	0.25	1.1	93.1
s1	93	b-479	DON JACOBO-check	2	0	6.11	2.19	0.22	9.96	1.3	0.16	10.82	3.48	0.13	1.9	120.4
s1	94	B-T04	Raul Morales	2	0	6.20	2.08	0.21	9.87	0.0	0.17	10.73	3.75	0.17	1.6	26.6
s1	94	B-T10	Doña Chinda A	2	0	6.18	1.80	0.18	10.19	0.7	0.30	8.88	2.63	0.30	3.3	16.7
s1	94	B-T16	Doña Chinda B	2	0	6.28	2.07	0.21	9.89	0.6	0.29	12.97	2.92	0.17	2.0	11.9
s1	94	B-T22	Juancito Rivera	2	0	6.25	2.14	0.22	9.57	0.0	0.19	8.64	3.31	0.15	1.4	41.5
s1	94	B-T28	Chema Galo. check	2	0	6.10	2.40	0.25	9.80	0.0	0.15	11.82	3.36	[illegible]	1.3	9.3
s1	93	b-279	MARVIN MALDONAD	1	1	5.88	2.51	0.24	10.45	0.6	0.30	10.05	3.93	0.15	[illegible]	43.3
s1	93	b-434	M.A. ANDRADE	1	1	6.39	2.14	0.20	10.46	3.0	0.64	9.40	[illegible]	0.12	1.2	44.2
s1	93	b-455	BERNABE VAZQUEZ	1	1	6.34	1.99	0.18	11.09	2.4	0.12	8.82	1.83	0.09	1.2	23.0
s1	94	B-E3[illegible]	Indalesio Mejia	1	1	5.26	1.76	0.17	10.21	0.6	0.14	3.07	1.26	0.26	2.0	204.6
s1	93	b-282	MARVIN MALDONAD	2	1	6.04	2.45	0.24	10.25	1.3	0.21	10.75	3.95	[illegible]	1.1	[illegible]
s1	94	B-E4[illegible]	Indalesio Mejia	2	1	5.54	1.55	0.15	10.13	0.7	0.16	3.09	[illegible]	[illegible]	1.9	[illegible]
s1	93	b-273	ANTONIO GARCIA	1	2	5.91	2.42	0.21	11.52	0.0	0.21	4.97	2.74	0.19	1.2	[illegible]
s1	93	b-407	ADAM ANDRADE	1	2	5.97			9.63	0.0	0.79	6.64	2.61	0.21	1.8	[illegible]
s1	93	b-475	TONIO MADRID	1	2	5.98	2.07	0.20	10.13	1.5	0.14	10.11	2.45	[illegible]	2.2	46.4
s1	94	B-M11	Marvin Maldonado	1	2	6.43	2.37	0.21	11.24	0.0	0.63	4.97	2.44	[illegible]	0.4	22.2
s1	93	b-473	TONIO MADRID	2	2	6.09				1.5	0.19	16.38	[illegible]	[illegible]	1.8	57.9
s1	94	B-M01	Manuel	2	2	5.50	2.06	0.21	9.77	0.0	0.40	1.72	0.69	[illegible]	2.7	[illegible]
s1	94	B-M13	Marvin Maldonado	2	2	6.45	2.77	0.26	10.81	0.0	0.87	4.95	1.77	[illegible]	1.3	51.2
s1	94	B-M04	Manuel	4	2	5.39	2.57	0.27	9.49	0.0	0.41	1.65	0.75	0.60	2.1	56.6
s1	93	b-249	ANTONIO AYALA	1	3	5.74	2.49	0.25	9.85	1.0	0.10	15.62	5.15	[illegible]	6.0	52.0
s1	94	B-M07	Toño Garcia	1	3	6.13	2.29	0.22	10.19	0.0	0.38	8.20	3.14	[illegible]	[illegible]	14.5
s1	93	b-252	ANTONIO AYALA	2	3	5.95	1.82	0.19	9.58	1.0	0.12	12.54	[illegible]	[illegible]	2.0	56.4
s1	93	b-276	ANTONIO GARCIA	2	3	5.76	2.43	0.24	10.24	0.0	0.41	5.10	[illegible]	[illegible]	[illegible]	[illegible]
s1	94	B-E28	Toño Ayala	1	4	5.38	2.24	0.23	9.71	0.0	0.12	9.95	2.75	0.36	2.3	[illegible]
s1	93	b-452	SANTOS VASQUEZ	2	4	5.82	2.32	0.24	9.45	0.8	0.17	8.32	2.26	[illegible]	[illegible]	42.3
s1	94	B-E31	Toño Ayala	2	4		2.57	0.26	9.78	11.6	0.14	[illegible]	3.16	[illegible]	0.8	[illegible]
s1	94	B-M19	Toño Garcia	2	4	6.20	2.03	0.21	9.73	0.0	0.29	9.58	3.60	0.12	1.2	16.9
s1	94	B-E34	Toño Ayala	3	4	5.56	2.34	0.25	9.55	1.6	0.15	9.81	3.36	[illegible]	2.1	[illegible]
s1	94	B-E[illegible]	Chema Ayala	3	5	5.92	2.20	0.24	9.21	1.3	0.13	11.59	4.54	0.16	[illegible]	[illegible]
s1	93	b-2[illegible]	CALISTRO ANDRAD	1	6	6.47	2.20	0.23	9.57	4.1	0.26	15.85	3.24	[illegible]	[illegible]	76.5
s1	93	b-237	TONIO MORALES Cor	1	6	6.15	2.19	0.22	10.05	2.1	0.25	12.29	3.14	[illegible]	2.0	39.3
s1	93	b-4[illegible]	DON JUAN BIDES	1	6	6.21	2.62	0.26	10.16	0.0	0.66	8.47	2.29	[illegible]	[illegible]	46.[illegible]
s1	93	b-456	JUAN VAZQUEZ	1	6	6.04	2.39	0.23	10.26	1.2	0.10	9.69	[illegible]	0.09	[illegible]	43.[illegible]
s1	93	b avg	obed	1	6	5.94	2.33	0.24	9.79	1.1	0.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
s1	93	b-2[illegible]	CALISTRO ANDRAD	2	6	6.00	2.63	0.28	9.39	7.4	0.41	15.24	2.61	[illegible]	1.6	[illegible]
s1	93	b-24[illegible]	TONIO MORALES Cor	2	6	6.10	1.98	0.19	10.45	1.2	0.23	5.74	[illegible]	[illegible]	2.7	[illegible]
s1	93	b-467	JUAN VAZQUEZ	2	6	6.07	2.35	0.23	10.17	1.5	0.17	6.61	2.32	[illegible]	[illegible]	[illegible]
s1	93	b-avg	obed	2	6	6.03	2.39	0.24	10.16	0.8	[illegible]	[illegible]	[illegible]	[illegible]	2.2	41.6
s1	93	b-222	JACOBO CAST	1	7	6.20	2.11	0.21	10.05	1.4	0.16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
s1	93	b-431	ANDREZ LAINEZ	1	7	5.92	2.22	0.19	11.72	0.0	0.22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
s1	93	b-461	SANTIAGO SUAZO	1	7	6.02	2.70	0.27	10.05	1.9	0.19	[illegible]	4.24	[illegible]	[illegible]	[illegible]
s1	94	B-E43	Obed Serrano	1	7	5.32	2.60	0.28	9.36	2.2	0.25	[illegible]	[illegible]	0.09	[illegible]	19.2
s1	93	b-225	JACOBO CAST	2	7	6.05	2.45	0.24	10.21	0.8	0.15	[illegible]	3.77	[illegible]	1.6	91.6
s1	93	b-434	ANDREZ LAINEZ	2	7	6.00	2.60	0.25	10.39	0.0	0.21	6.47	1.37	0.14	0.9	140.5
s1	93	b-464	SANTIAGO SUAZO	2	7	5.88	2.72	0.28	9.66	2.1	0.21	9.56	2.73	0.15	1.4	63.2
s1	94	B-E46	Obed Serrano	2	7	5.85	2.01	0.22	9.26	0.6	0.19	11.39	4.70	0.23	1.8	42.9
s1	93	b-avg	Alfaro	3	7	6.10	2.99	0.30	9.90	1.6	0.15	13.17	5.41	0.12	2.0	91.6
s1	93	b-216	ORLANDO PALOMO	1	8	6.15	2.99	0.30	9.97	4.0	0.06	12.23	4.12	0.07	1.2	98.3
s1	93	b-265	MARTIR ANDRADE	1	8	5.86	2.43	0.25	9.78	1.4	0.11	11.69	3.80	0.13	2.7	41.2
s1	93	b-291	ANTONIO MORALES	1	8	5.94	2.32	0.25	9.15	1.0	0.06	15.19	4.40	0.15	2.4	36.6
s1	93	b-297	TEYO MORALES	1	8		2.33	0.26	8.97	2.8	0.17	10.69	2.81	0.06	0.9	18.3
s1	93	b-410	DON ANSELMO MEJ	1	8	6.03	2.44	0.24	10.37	0.5	0.43	6.06	2.41	0.12	1.3	126.1
s1	93	b-416	JESUS ENRIQUE	1	8	6.17	2.12	0.21	9.89	9.8	0.27	8.26	2.89	0.07	0.7	36.6
s1	93	b-422	INDALESIO Old	1	8	6.60	1.90	0.20	9.30	0.4	0.10	3.98	1.78	0.22	1.9	97.0
s1	93	b-425	JUANCITO RIVERA	1	8	5.82	2.55	0.29	8.67	0.0	0.17	10.49	[illegible]	0.13	2.1	68.3
s1	93	b-219	ORLANDO PALOMO	2	8	6.17	2.67	0.29	9.21	0.6	0.16	10.45	[illegible]	0.06	[illegible]	93.3
s1	93	b-288	MARTIR ANDRADE	2	8	5.98	2.28	0.25	9.10	1.0	0.10	10.31	3.68	0.14	[illegible]	[illegible]
s1	93	b-294	ANTONIO MORALES	2	8	5.70	2.22	0.24	9.17	[illegible]	0.10	12.63	5.06	[illegible]	4.6	[illegible]
s1	93	b-300	TEYO MORALES	2	8	5.78				[illegible]	0.14	13.25	[illegible]	[illegible]	[illegible]	72.5
s1	93	b-413	DON ANSELMO MEJ	2	8	6.22				0.0	[illegible]	[illegible]	2.46	[illegible]	1.6	65.0
s1	93	b-419	JESUS ENRIQUE	2	8	6.16	2.18	0.21	10.28	10.0	0.33	7.99	[illegible]	[illegible]	[illegible]	43.9
s1	93	b-428	JUANCITO RIVERA	2	8	5.90	2.66	0.30	8.80	0.5	[illegible]	9.55	[illegible]	[illegible]	[illegible]	45.6
s1	94	B-E[illegible]	Jacobo	1	9	5.93	2.66	0.27	9.98	1.6	[illegible]	[illegible]	4.09	[illegible]	1.6	[illegible]

APPENDIX D.3 (cont. 1/5)

					years	horizon 0-10 cm										
site	year	ID #	farmer	rep	mucuna	pH	C%	N%	C:N	P ppm	K meq	Ca meq	Mg meq	Al meq	Fe ppm	Mn ppm
s1	94	B-E19	T.T. Morales	1	9	5.69	2.65	0.26	9.81	2.8	0.17	11.02	3.34	0.13	1.5	111.6
s1	94	B-E13	Jacobo	2	9	6.85	2.56	0.24	10.56	1.6	0.12	9.42	3.63	0.10	0.9	166.2
s1	94	B-E22	T.T. Morales	2	9	5.36	2.60	0.27	9.72	1.3	0.13	12.62	4.65	0.32	3.4	100.2
s1	94	B-E16	Jacobo	3	9	5.79	2.19	0.21	10.19	1.7	0.14	9.29	3.62	0.12	1.2	120.6
s1	94	B-E25	T.T. Morales	3	9	5.55	2.51	0.27	9.39	1.4	0.13	13.44	4.97	0.22	2.9	115.2
s1	93	b-255	ANTONIO MALDONA	1	10	5.84	2.29	0.25	9.34	0.8	0.19	13.29	3.72	0.12	2.9	56.1
s1	93	b-avg	Alfaro	1	10	6.18	3.00	0.32	9.36	1.8	0.15	13.85	4.49	0.13	1.9	55.3
s1	93	b-251	MARCO HERNANDEZ	2	10	6.21	2.26	0.23	9.83	2.5	0.10	13.25	5.15	0.08	0.9	47.2
s1	93	b-258	ANTONIO MALDONA	2	10	6.10	2.03	0.22	9.42	0.5	0.09	12.62	4.10	0.11	2.0	47.4
s1	93	b-avg	Alfaro	2	10	5.98	2.32	0.24	9.64	2.5	0.19	14.95	4.95	0.14	2.2	66.9
s1	93	b-437	JULIAN ENRIQUE	1	11	6.00	3.28	0.34	9.70	1.3	0.41	11.05	3.28	0.05	0.3	47.9
s1	93	b-440	JULIAN ENRIQUE	2	11	6.11	2.60	0.27	9.48	8.0	0.45	12.24	3.50	0.06	0.8	39.4
s1	93	b-267	"NEGRITO" RIVER	1	12	6.06	2.48	0.26	9.44	1.6	0.20	11.43	4.00	0.08	1.3	48.6
s1	93	b-449	SANTOS VASQUEZ	1	12	6.02	2.76	0.30	9.29	0.0	0.32	6.24	1.53	0.19	0.5	92.2
s1	93	b-270	"NEGRITO" RIVER	2	12	6.15	2.46	0.26	9.46	6.2	0.46	10.07	2.91	0.07	1.1	40.0
s1	93	b-210	JULIO MEJIA	1	13	5.74	2.46	0.26	9.46	1.5	0.20	10.38	3.00	0.14	2.5	59.7
s1	93	b-228	JUAN RIVERA	1	13	6.31	3.11	0.30	10.37	4.9	0.19	15.67	4.15	0.05	0.5	35.9
s1	93	b-243	CHEMA AYALA	1	13	6.66	2.74	0.29	9.38	1.0	0.19	12.33	4.95	0.16	3.4	95.3
s1	93	b-213	JULIO MEJIA	2	13	6.93	2.61	0.27	9.67	2.8	0.26	9.94	2.60	0.15	1.9	32.5
s1	93	b-231	JUAN RIVERA	2	13	5.96	2.48	0.26	9.54	3.4	0.23	12.80	3.61	0.11	2.3	51.3
s1	93	b-246	CHEMA AYALA	2	13	6.14	3.06	0.35	8.80	1.2	0.20	13.46	4.59	0.07	1.6	106.3
s1	93	b-234	JUAN RIVERA	3	13	5.84	2.81	0.29	9.65	2.0	0.29	11.44	3.26	0.12	2.1	95.7
s1	93	b-261	CHEPITO	1	14	6.09	2.59	0.29	9.04	1.1	0.16	12.33	4.37	0.08	1.2	82.9
s1	94	B-E01	Chema Ayala	1	14	5.73	2.45	0.27	9.01	1.6	0.15	13.43	5.09	0.14	1.9	145.8
s1	93	b-264	CHEPITO	2	14	5.99	2.56	0.29	8.81	0.9	0.05	11.82	3.98	0.11	1.6	51.6
s1	94	B-E04	Chema Ayala	2	14	5.76	2.60	0.30	8.68	1.4	0.22	12.74	5.18	0.09	0.9	161.8
s1	93	b-avg	Galdamez	1	15	6.22	2.21	0.23	9.61	2.0	0.15	14.71	5.22	0.08	1.5	72.3
s1	93	b-avg	Galdamez	2	15	6.27	2.40	0.24	10.19	1.5	0.10	14.00	5.00	0.08	1.6	87.2
mg	93	mg-001	ANASTACIO AMAYA	1	0	6.23	2.71	0.26	10.42	8.7	0.28	16.66	3.47	0.09	1.1	68.3
mg	93	mg-004	ADOLFO CONTRERAS	1	0	6.74	2.88	0.27	10.65	13.1	0.26	21.66	4.13	0.06	1.0	44.0
mg	93	mg-007	EDUVIGES CASTRON	1	0	6.66	2.91	0.29	9.86	6.1	0.24	23.46	3.69	0.07	1.1	43.6
mg	93	mg-010	JORGE CASTRON	1	0	7.07	3.66	0.37	9.89	11.6	0.51	22.15	3.46	0.04	0.4	18.2
mg	93	mg-013	HUMBERTO RODRIGUEZ	1	0	6.71			9.44	15.0	0.36	22.44	4.58	0.09	0.3	53.1
mg	94	MG-M06	Juan Albarenga check	1	0	6.32	2.73	0.25	10.71	2.3	0.31	16.06	4.15	0.07	0.4	63.1
mg	94	MG-M12	Francisco Paredes T	1	0	6.54	2.81	0.27	10.64	6.6	0.44	14.51	4.96	0.06	0.1	29.6
mg	94	MG-M03	Antonio Ruiz	1	0	6.41	2.29	0.21	10.67	6.9	0.34	15.60	3.68	0.08	0.2	29.3
mg	94	MG-M09	Juan Albarenga check	2	0	6.17	3.06	0.30	10.27	3.1	0.28	17.90	4.49	0.10	0.5	54.2
mg	94	MG-M15	Francisco Paredes T	2	0	6.27	2.56	0.25	10.31	2.6	0.28	15.31	4.08	0.06	0.2	52.1
mg	93	mg-016	ADOLFO CONTRERAS	1	1	7.14	2.97	0.28	10.68	1.4	0.43	23.67	4.70	0.05	0.5	27.7
mg	93	mg-019	JORGE CASTRON	1	1	6.94	2.80	0.28	10.15	21.7	0.32	27.73	4.17	0.06	0.9	26.0
mg	94	MG-M36	Juan Burgos	1	1	6.29	3.07	0.30	10.39	5.4	0.35	17.58	5.21	0.03	0.1	28.6
mg	94	MG-M39	Juan Burgos	2	1	6.23	1.92	0.19	10.06	7.2	0.30	16.39	4.29	0.06	0.3	35.7
mg	93	mg-022	JORGE CASTRON	1	2	6.38	3.09	0.31	10.08	2.1	0.25	18.97	5.28	0.11	1.0	36.0
mg	93	mg-025	NARCISO RIVAS	1	2	6.38	2.90	0.29	10.09	6.3	0.36	22.61	4.70	0.06	0.6	56.6
mg	93	mg-028	HUMBERTO RODRIGUEZ	1	2	7.16	2.51	0.23	10.69	1.1	0.36	17.27	4.47	0.03	0.3	23.3
mg	94	MG-M21	Antonio Ruiz	2	2	6.89	2.71	0.27	10.24	25.6	0.39	20.17	3.04	0.05	0.1	28.5
mg	93	mg-031	EDUVIGES CASTRON	1	3	6.73	2.90	0.30	9.61	10.5	0.34	24.40	4.22	0.08	0.7	55.1
mg	93	mg-034	PASCUAL MARTINEZ	1	3	6.97	2.62	0.26	10.99	23.1	0.40	17.46	4.55	0.07	0.7	27.6
mg	93	mg-037	MIGUEL ARGUETA	1	3	6.65	2.84	0.30	9.60	1.6	0.34	14.20	2.96	0.05	0.7	19.4
mg	94	MG-M24	Benigno Amaya	1	3	6.46	4.10	0.40	10.28	8.4	0.29	23.46	4.81	0.05	0.0	51.5
mg	94	MG-M27	Benigno Amaya	2	3	6.47	3.96	0.40	9.92	13.8	0.32	22.03	3.66	0.07	0.8	39.4
mg	93	mg-040	ANASTACIO AMAYA	1	4	6.22	2.41	0.25	9.75	10.4	0.46	13.29	2.87	0.08	0.6	45.5
mg	93	mg-046	CRISTINO CASTRON	1	4	6.78	2.68	0.25	10.76	5.0	0.17	27.52	6.76	0.12	0.7	30.1
mg	93	mg-052	CONSTANTINO NAVARR	1	4	6.55	2.38	0.24	10.00	14.2	0.37	22.74	4.54	0.06	0.6	51.6
mg	93	mg-043	ANASTACIO AMAYA	2	4	6.05	2.44	0.23	10.43	5.4	0.30	14.81	4.97	0.11	1.1	63.1
mg	93	mg-049	CRISTINO CASTRON	2	4	6.39	3.02	0.30	10.16	3.7	0.34	17.61	4.90	0.05	5.4	26.2
mg	93	mg-055	CONSTANTINO NAVARR	2	4	6.27	2.63	0.26	10.41	3.2	0.32	15.58	3.10	0.06	0.8	52.7
mg	93	mg-058	CRISTINO CASTRON	1	5	6.14	2.70	0.25	10.63	2.1	0.14	19.26	5.83	0.09	0.6	59.6
mg	93	mg-061	PASCUAL MARTINEZ	1	5	6.46	2.70	0.27	9.97	12.8	0.58	17.76	4.29	0.06	0.3	47.0
mg	93	mg-064	ANTONIO HERNANDEZ	1	5	6.07	2.02	0.20	10.18	1.2	0.35	15.26	4.27	0.12	1.2	60.6
mg	94	MG-E01	Amaya	1	5	6.22	3.45	0.34	10.12	14.3	0.45	14.27	3.17	0.05	0.0	46.5
mg	94	MG-M01	Cristino Castron	1	5	6.31	3.16	0.29	11.05	2.2	0.25	19.69	6.43	0.06	0.0	56.6
mg	94	MG-E04	Amaya	2	5	6.39	2.31	0.24	9.45	15.2	0.51	16.08	2.64	0.05	0.0	34.2
mg	94	MG-M03	Cristino Castron	2	5	6.20			9.23	0.0	0.00	19.26	0.00	0.16	0.6	27.1
mg	94	MG-E08	Amaya	3	5	6.10	2.64	0.26	10.26	4.7	0.34	14.25	6.03	0.09	0.3	63.4
mg	93	mg-067	JOSE RIVERA	1	6	6.56	2.62	0.27	9.61	8.7	0.41	17.80	3.46	0.10	1.0	37.8
mg	93	mg-070	ARMANDO GALVEZ	1	6	7.60	2.46	0.25	10.03	1.1	0.44	25.66	2.14	0.09	0.0	26.0
mg	93	mg-073	HUMBERTO RODRIGUEZ	1	6	6.50	2.51	0.27	9.14	5.1	0.35	25.80	5.94	0.08	0.6	28.5
mg	94	MG-E23	Hernandez	1	6	6.15	2.57	0.25	10.42	2.0	0.43	12.39	3.64	0.04	[illegible]	12.5
mg	94	MG-M18	Antonio Ruiz	1	6	6.43	3.56	0.36	9.66	5.3	0.27	21.59	4.36	0.03	[illegible]	31.4
mg	93	mg-076	HUMBERTO RODRIGUEZ	2	6	6.89	3.12	0.32	9.79	1.3	0.45	30.06	5.39	0.07	[illegible]	51.6
mg	94	MG-E26	Hernandez	2	6	5.99	2.60	0.25	10.21	2.3	0.37	12.74	3.83	0.05	0.3	3.8
mg	94	MG-E29	Hernandez	3	6	5.94	3.00	0.30	10.15	0.4	0.12	13.45	4.41	0.08	0.5	5.6
mg	93	mg-079	ADOLFO CONTRERAS	1	7	6.46	3.42	0.33	10.29	9.3	0.47	24.78	3.66	0.08	1.2	60.3

APPENDIX D.3 (cont. 2/5)

					years	horizon 0-10 cm										
site	year	ID #	farmer	rep	mucuna	pH	C%	N%	C:N	P ppm	K meq	Ca meq	Mg meq	Al meq	Fe ppm	Mn ppm
mg	93	mg-085	JOSE CONTRERAS	1	7	6.88	2.85	0.29	9.86	1.3	0.36	23.26	3.19	0.04	0.3	25.2
mg	93	mg-091	ISMAEL URBINA	1	7	6.19	2.39	0.23	10.19	1.1	0.36	13.68	4.00	0.08	1.0	80.7
mg	94	MG-E11	Albarenga	1	7	6.11	2.51	0.25	9.98	6.9	0.30	22.08	4.05	0.08	0.2	38.8
mg	93	mg-082	ADOLFO CONTRERAS	2	7	6.17	2.91	0.30	9.64	4.2	0.36	21.45	3.55	0.09	1.3	77.2
mg	93	mg-088	JOSE CONTRERAS	2	7	6.39	2.50	0.27	9.27	1.1	0.25	16.73	4.06	0.15	1.4	76.7
mg	93	mg-094	ISMAEL URBINA	2	7	6.04	2.76	0.26	10.58	1.2	0.27	9.61	3.20	0.07	0.9	54.1
mg	94	MG-E15	Albarenga	2	7	6.06	2.35	0.23	10.05	5.8	0.29	24.31	4.63	0.09	0.4	55.8
mg	94	MG-E19	Albarenga	3	7	6.11	2.51	0.25	10.06	8.9	0.50	20.91	3.45	0.09	0.7	24.8
mg	93	mg-097	HUMBERTO RODRIGUEZ	1	8	6.64	3.26	0.33	9.85	15.9	0.45	24.78	5.72	0.06	0.4	56.4
mg	93	mg-100	HUMBERTO RODRIGUEZ	2	8	6.50	2.80	0.28	8.91	8.8	0.42	24.52	5.60	0.06	0.4	73.7
mg	93	mg-103	FRANCISCO PAREDES	1	10	6.38	2.73	0.27	10.11	8.5	0.40	23.16	6.42	0.19	1.3	59.1
mg	93	mg-109	ISMAEL URBINA	1	10	6.36	3.28	0.32	10.22	1.2	0.37	18.40	4.59	0.09	1.0	95.6
mg	93	mg-112	JOSE RIVERA	1	10	6.54	2.71	0.27	9.99	4.7	0.52	12.77	2.69	0.05	0.4	65.2
mg	93	mg-106	FRANCISCO PAREDES	2	10	6.27	2.33	0.23	10.14	7.8	0.27	21.95	6.55	0.09	0.9	73.3
mg	94	MG-M30	Francisco Paredes 10	1	11	6.62				22.8	0.55	23.94	5.66	0.05	[illegible]	49.1
cu	93	cu-001	MANUEL VARELA 0 a	1	0	5.50	2.94	0.26	11.29	1.1	0.39	5.16	1.53	0.34	2.0	98.3
cu	93	cu-004	VICTOR CRUZ	1	0	6.00	2.17	0.22	9.85	0.4	0.29	4.01	1.54	0.26	0.8	161.[illegible]
cu	93	cu-007	ISMAEL DELCID	1	0	5.90				0.0	0.51	5.11	1.46	0.49	0.7	152.2
cu	93	cu-010	RUBEN PEREZ	1	0	7.05	2.77	0.26	10.54	9.7	0.24	17.75	3.11	0.06	0.4	35.4
cu	94	cu-01	Victor Cruz check	2	0	5.82	2.65	0.26	10.38	0.5	0.37	3.97	1.50	0.16	[illegible]	133.4
cu	94	cu-04	Cheque del Cid check	2	0	5.93	2.13	0.20	10.85	0.6	0.44	5.46	1.45	0.22	1.5	39.5
cu	93	cu-013	MANUEL VARELA 1 a	1	1	6.25				1.5	0.42	10.13	1.91	0.16	1.2	94.5
cu	93	cu-016	MIGUEL CARBALLO	1	1	6.21	3.02	0.28	10.96	0.0	0.41	7.56	1.89	0.16	[illegible]	97.4
cu	93	cu-019	SANTOS PEREZ	1	1	6.85				4.3	0.36	15.81	2.63	[illegible]	2.5	8[illegible]
cu	94	cu-34	Ismael del Cid	2	1	5.74	2.86	0.28	10.33	0.0	0.49	4.71	1.94	0.44	2.2	99.3
cu	94	cu-19	Manuel Varela 0a	2	1	5.20	2.59	0.25	10.31	0.2	0.46	2.76	1.20	0.63	4.3	54.9
cu	93	cu-022	MANUEL VARELA 2 a	1	2	6.24	3.38	0.32	10.42	1.0	0.46	7.51	2.86	0.10	[illegible]	178.[illegible]
cu	93	cu-025	RAMON GONZALES 2 a	1	2	6.34	2.74	0.28	9.64	2.3	0.31	10.25	2.96	0.11	[illegible]	52.2
cu	94	cu-07	Miguel Carballo 1a	2	2	6.09	3.01	0.30	9.95	0.0	0.54	9.19	2.19	0.11	0.9	14.[illegible]
cu	94	cu-22	Manuel Varela 1a	2	2	5.79	2.64	0.27	9.95	0.0	0.46	6.27	1.66	0.73	[illegible]	24.[illegible]
cu	93	cu-028	MANUEL VARELA 3 a	1	3	6.15	2.69	0.29	9.34	0.0	0.33	6.67	1.73	0.11	[illegible]	[illegible]
cu	93	cu-031	RENE LOPEZ	1	3	5.89	2.81	0.25	11.48	1.4	0.28	5.19	1.15	0.31	2.1	[illegible]
cu	93	cu-034	LUIS CARBALLO	1	3	5.65	2.24	0.23	9.60	1.1	0.12	5.07	1.65	0.28	3.3	82.4
cu	93	cu-037	GREGORIO ORELLANA	1	3	6.25	2.88	0.28	10.14	1.8	0.36	7.46	1.66	0.12	[illegible]	65.[illegible]
cu	94	cu-25	Manuel Varela 2a	2	3	6.05	3.73	0.34	10.85	0.0	0.50	8.85	2.97	0.12	5.5	16.9
cu	93	cu-040	MIGUEL CARBALLO	1	4	5.87	2.89	0.30	9.67	0.5	0.40	5.30	1.61	0.31	1.2	87.3
cu	93	cu-043	SANTOS PEREZ	1	4	6.19	2.45	0.25	9.83	0.6	0.16	10.62	2.11	0.17	1.0	41.7
cu	93	cu-046	JULIAN MANCIA	1	4	5.72	2.70	0.27	10.01	0.8	0.19	8.49	2.14	0.30	2.1	109.9
cu	93	cu-049	JUAN C PEREZ	1	4	6.27	2.94	0.31	9.58	0.0	0.32	10.49	3.34	0.12	1.5	108.4
cu	93	cu-052	RAMON GONZALEZ 4 a	1	4	6.16	3.18	0.33	9.72	0.5	0.16	11.44	3.62	0.16	[illegible]	101.6
cu	94	cu-13	Rene Lopez	2	4	5.95	2.88	0.28	10.39	0.0	0.41	5.33	2.01	0.22	[illegible]	[illegible]
cu	94	cu-16	Luis Carballo	2	4	5.67	2.13	0.23	9.26	0.8	0.30	5.55	1.90	0.24	2.9	72.4
cu	94	cu-28	Manuel Varela 3a	2	4	5.65	2.74	0.29	9.43	0.0	0.38	7.03	2.43	0.13	1.9	63.4
cu	93	cu-055	MANUEL VARELA 5 a	1	5	6.15	3.38	0.36	9.25	0.7	0.19	10.78	3.82	[illegible]	[illegible]	203.[illegible]
cu	94	cu-10	Miguel Carballo 4a	2	5	5.85	3.02	0.33	9.30	0.0	0.58	7.53	2.42	0.12	[illegible]	19.6
cu	93	cu-058	ROSENDO DELCID	1	6	5.56	2.85	0.32	8.99	0.7	0.26	4.90	1.19	0.32	[illegible]	[illegible]
cu	94	cu-31	Manuel Varela 5a	2	6	5.92	3.90	0.39	10.00	0.0	0.21	11.24	4.07	0.13	1.8	61.5
cu	94	cu-37	Rosendo del Cid	2	7	5.80	3.13	0.34	9.13	0.7	0.35	7.77	1.63	0.16	1.5	60.6
pi	93	pi-001	Delio Ramirez	1	0	5.59	2.37	0.26	9.17	1.1	0.41	13.13	3.78	0.21	1.4	9.[illegible]
pi	93	pi-004	Delio Ramirez	2	0	5.58	2.97	0.32	9.34	0.0	0.15	6.40	2.39	0.27	1.4	16.6
pi	93	pi-007	Rafael Castellanos	1	2	6.43	2.87	0.31	9.39	0.9	0.37	14.40	4.67	0.07	1.6	29.3
pi	93	pi-013	Rodolfo Gutierrez	1	2	6.26	3.68	0.38	9.61	5.6	0.42	16.14	4.36	0.07	[illegible]	33.3
pi	93	pi-010	Rafael Castellanos	2	2	6.43	2.70	0.27	9.96	1.3	0.46	14.07	4.93	0.06	0.4	36.6
pi	93	pi-016	Rodolfo Gutierrez	2	2	6.23	2.55	0.26	9.87	1.7	0.29	9.59	3.51	0.07	0.6	10.4
pi	93	pi-019	Eladio Castellano	1	3	6.38	3.21	0.32	10.03	2.3	0.72	14.60	4.35	0.05	0.4	16.5
pi	93	pi-022	Eladio Castellano	2	3	6.31	3.00	0.31	9.75	4.4	0.80	13.99	4.57	0.04	0.2	32.5
pi	93	pi-043	Samuel Castellanos	1	4	6.34	2.67	0.29	9.37	0.7	0.58	8.94	3.61	0.06	0.6	52.1
pi	93	pi-046	Samuel Castellanos	2	4	6.35	3.10	0.33	9.51	1.3	0.40	9.58	3.65	0.06	1.5	52.6
pi	93	pi-025	Luis Alfonso Cast	1	5	6.55	3.78	0.41	9.25	0.5	0.74	12.17	3.53	0.06	0.4	13.1
pi	93	pi-031	Clementino Mendez	1	5	5.86	2.78	0.27	10.28	0.0	0.58	7.81	2.46	0.21	0.7	62.4
pi	93	pi-028	Luis Alfonso Cast	2	5	6.30	2.98	0.32	9.42	0.0	0.87	9.96	4.24	0.06	0.6	15.[illegible]
pi	93	pi-034	Clementino Mendez	2	5	6.18	4.04	0.40	10.02	0.8	0.10	12.37	2.91	0.13	0.7	35.[illegible]
pi	93	pi-037	Santos Segovia	1	6	6.17	2.51	0.26	9.52	0.6	0.53	8.18	3.93	0.07	0.4	42.1
pi	93	pi-040	Santos Segovia	2	6	6.28	2.72	0.29	9.26	0.8	0.58	10.60	3.73	0.06	0.3	24.7
pi	93	pi-055	Victor Vazquez	1	8	5.49	2.96	0.31	9.59	0.0	0.22	6.44	2.20	0.31	6.5	16.[illegible]
pi	93	pi-058	Victor Vazquez	2	8	5.57	3.10	0.31	9.86	0.0	0.41	10.62	3.76	0.21	3.9	21.6
pi	93	pi-061	Victor Vazquez	1	11	5.83	2.84	0.30	9.36	0.7	0.40	9.50	2.94	0.14	2.2	48.9
pi	93	pi-064	Victor Vazquez	2	11	5.65	2.91	0.32	9.12	0.0	0.35	10.99	3.36	0.16	2.9	[illegible]
pi	93	pi-049	Rodolfo Gutierrez	1	12	6.53	2.57	0.26	9.98	2.6	0.44	10.09	3.18	0.09	[illegible]	6.3
pi	93	pi-052	Rodolfo Gutierrez	2	12		3.03	0.31	9.81		0.39	[illegible]	3.45	0.08	[illegible]	7.3

APPENDIX D.3 (cont. 3/5)

years			horizon 10-30 cm					horizon 30-60 cm			
mucuna	Zn ppm	Cu ppm	pH	P ppm	Ca meq	K meq	Al meq	pH	Ca meq	K meq	Al meq
0	0.3	0.0	5.42	0.0	0.86	0.34	0.66	5.51	0.48	0.43	1.21
0	0.6	0.0	5.49	0.0	0.84	0.36	0.48	5.48	0.54	0.27	1.36
0	1.8	0.0	5.41	0.0	4.42	0.18	0.38	5.12	2.93	0.06	2.47
0	0.9	0.1	5.76	0.0	11.77	0.04	0.24	5.76	12.85	0.04	0.28
0	0.1	0.4	6.14	0.0	14.09	0.12	0.26	6.45	15.62	0.07	0.32
0	0.0	0.0	6.09	0.0	10.57	0.20	0.34	6.08	12.71	0.14	0.32
0	0.0	0.0	5.94	0.0	10.73	0.15	0.29	5.81	11.09	0.15	0.55
0	0.8	0.0	6.25	0.0	6.83	0.18	0.27	6.40	8.54	0.14	0.32
0			6.17	0.0	9.51	0.12	0.18	6.38	12.37	0.09	0.23
0	1.3	0.0	4.99	0.0	3.29	0.13	1.15	4.99	1.86	0.07	3.95
0	1.7	0.1	6.02	0.0	12.10	0.02	0.22	6.06	10.69	0.05	0.18
0	0.1	0.0	6.18	0.1	12.17	0.09	0.25	6.34	13.58	0.06	0.29
0	0.0	0.3	5.69	0.0	9.59	0.23	0.79	5.84	12.03	0.13	0.62
0	0.0	0.0	6.34	0.0	13.44	0.22	0.27	6.13	14.38	0.14	0.40
1	0.3	0.0	6.07	0.0	8.10	0.14	0.24	6.04	8.99	0.10	0.33
1	0.4	0.0	5.88	0.0	12.24	0.07	0.23	6.13	12.75	0.06	0.35
1	1.5	0.0	5.62	0.0	7.74	0.12	0.27	5.45	6.97	0.13	0.38
1	3.4	0.0	6.00	0.0	6.91	0.40	0.24	5.96	5.31	0.22	0.49
1	0.6	0.2	5.80	0.0	7.50	0.06	0.24	5.75	8.27	0.02	0.24
1	2.6	0.0	5.26	0.0	1.92	0.08	0.29	5.17	2.67	0.05	0.35
1	0.9	0.0	5.95	0.0	11.98	0.09	0.23	6.01	12.24	0.04	0.26
1	4.7	0.3	5.37	0.0	1.72	0.14	0.27	5.37	2.14	0.07	0.19
2	2.1	0.1	5.45	0.5	3.22	0.16	0.33	5.83	1.71	0.12	2.88
2	2.6	0.0	5.53	0.0	2.96	0.26	0.48	5.88	1.63	0.15	1.19
2	0.6	0.1	6.17	0.6	11.24	0.06	0.11	6.34	13.08	0.04	0.13
2	0.7	0.0	6.73	0.0	3.39	0.55	0.27				
2	1.0	0.1	5.76	0.0	16.13	0.06	0.34	5.61	18.19	0.05	0.35
2	0.9	0.0	5.53	0.0	0.81	0.26	0.49	5.56	0.53	0.26	0.67
2	1.4	0.1	6.71	0.0	2.80	0.00	0.21				
2	0.6	0.3	5.60	0.0	0.55	0.36	0.85	5.39	0.51	0.21	1.07
3	0.4	0.0	5.70	0.0	14.60	0.06	0.37	5.83	17.37	0.04	0.50
3	0.8	0.0	6.34	0.0	7.27	0.18	0.18				
3	0.5	0.1	6.33	0.0	12.52	0.05	0.18	6.01	14.34	0.02	0.22
3	3.0	0.0	5.47	0.0	2.76	0.16	0.24	5.29	2.06	0.14	0.43
4	0.7	0.0	5.53	0.8	9.82	0.09	0.56	5.65	10.14	0.04	1.00
4	0.6	0.0	5.76	0.0	9.04	0.05	0.26	5.82	15.27	0.03	0.29
4	0.8	0.0	6.15	0.0	13.46	0.09	0.10	6.52	17.26	0.10	0.17
4	0.2	0.0									
4	1.2	0.0	5.63	0.0	11.63	0.10	0.23	5.63	16.53	0.09	0.26
5	2.9	0.0	5.96	0.0	12.76	0.06	0.14	5.86	15.34	0.04	0.25
6	0.4	0.0	6.55	0.7	9.40	0.15	0.11	6.59	10.14	0.12	0.13
6	0.7	0.1	6.07	0.0	14.86	0.09	0.16	6.06	17.00	0.05	0.24
6	0.8	0.0	6.16	0.0	3.51	0.33	0.32	6.12	3.03	0.30	0.41
6	1.3	0.1	6.09	0.0	9.29	0.04	0.14	6.03	10.74	0.02	0.23
6	0.9	0.0	5.96	0.0	16.79	0.06	0.29	5.67	17.36	0.04	0.40
6	0.7	0.1	6.06	1.7	9.55	0.22	0.14	6.27	13.26	0.13	0.22
6	0.5	0.2	6.00	0.0	9.86	0.11	0.22	6.01	12.16	0.07	0.26
6	1.3	0.1	6.00	0.0	8.67	0.06	0.15	5.85	10.49	0.13	0.24
6	0.4	0.0	6.05	0.0	12.20	0.05	0.26	5.93	13.23	0.04	0.31
7	1.5	0.0	6.24	0.0	11.37	0.06	0.13	6.06	13.07	0.04	0.25
7	2.3	0.0	5.29	0.0	2.84	0.09	0.18	5.54	2.26	0.06	0.46
7	1.2	0.0	6.02	0.0	12.07	0.09	0.21	6.09	13.43	0.05	0.25
7	0.2	0.0	6.41	0.0	18.72	0.13	0.18	6.55	19.58	0.08	0.26
7	1.0	0.0	6.03	0.0	11.12	0.06	0.16	6.01	12.30	0.03	0.25
7	7.3	0.1	5.94	0.0	4.10	0.09	0.15	5.87	4.46	0.07	0.31
7	1.6	0.1	5.83	0.0	7.31	0.08	0.22	5.81	8.56	0.04	0.28
7	0.0	0.0	6.22	0.0	10.81	0.13	0.36	5.89	10.80	0.14	0.65
7	1.0	0.1	6.06	0.1	14.05	0.07	0.19	6.02	15.33	0.05	0.28
8	1.3	0.1	6.02	0.0	10.35	0.16	0.14	5.78	13.58	0.06	0.33
8	0.8	0.0	5.91	0.0	12.76	0.06	0.17	6.03	15.50	0.03	0.27
8	0.6	0.0	6.01	0.0	16.11	0.03	0.29	6.04	17.37	0.01	0.38
8	0.5	0.0	6.17	0.0	13.31	0.04	0.18	6.18	14.46	0.05	0.23
8	2.4	0.0	5.94	0.0	4.27	0.27	0.19	5.77	3.49	0.16	0.22
8	0.9	0.0	6.19	2.0	8.42	0.10	0.13	6.18	9.94	0.06	0.21
8	2.0	0.0	5.44	0.0	3.56	0.04	0.36	5.21	4.26	0.01	0.84
8	0.7	0.1	6.95	0.0	12.41	0.06	0.19	6.11	14.04	0.02	0.29
8	2.4	0.0	6.08	0.0	8.74	0.07	0.07	6.11	8.00	0.05	0.12
8	0.7	0.1	5.97	0.0	15.64	0.05	0.20	6.08	16.88	0.02	0.26
8	0.9	0.2	5.72	0.0	14.56	0.05	0.39	5.78	8.91	0.18	0.19
8	1.0	0.1	5.84	0.0	16.45	0.05	0.54	5.62	18.08	0.06	0.51
8	4.9	0.0	6.05	0.0	4.25	0.25	0.09	6.21	2.97	0.16	0.24
8	1.1	0.0	6.30	3.1	7.13	0.19	0.12	6.26	7.43	0.16	[illegible]
8	0.9	0.2	5.90	0.0	8.62	0.03	0.14	5.90	10.64	0.00	0.27
9	2.0	0.4	6.02	0.0	12.09	0.10	0.12	5.98	12.62	0.06	[illegible]

APPENDIX D.3 (cont. 4/5)

years			*horizon 10-30 cm*					*horizon 30-60 cm*			
mucuna	Zn ppm	Cu ppm	pH	P ppm	Ca meq	K meq	Al meq	pH	Ca meq	K meq	Al meq
9	1.7	0.0	5.78	0.0	11.06	0.10	0.22	5.81	13.27	0.08	0.23
9	1.8	0.0	5.99	0.0	9.72	0.07	0.13	5.95	12.64	0.06	0.22
9	1.4	0.0	5.47	0.0	13.68	0.08	0.53	5.34	14.30	0.07	0.70
9	1.7	0.0	5.80	0.0	9.11	0.10	0.18	5.88	13.91	0.06	0.21
9	2.3	0.0	5.66	0.0	14.29	0.10	0.26	5.70	14.78	0.08	0.28
10	0.8	0.0	5.87	0.0	14.53	0.08	0.18	6.05	14.51	0.03	0.22
10	0.8	0.1	6.07	0.1	14.04	0.06	0.16	6.23	14.90	0.04	0.20
10	0.6	0.0	6.27	0.9	13.34	0.04	0.12	6.31	14.57	0.02	0.18
10	0.6	0.0	6.19	0.0	13.27	0.04	0.18	6.12	13.81	0.02	0.26
10	0.7	0.0	5.99	0.2	16.57	0.09	0.18	6.00	16.82	0.06	0.23
11	1.7	0.1	5.93	0.0	8.19	0.19	0.14	5.87	9.43	0.09	0.25
11	0.8	0.0	5.97	2.0	13.96	0.21	0.14	6.08	17.21	0.10	0.20
12	2.0	0.4	6.19	0.0	10.99	0.11	0.12	5.90	12.63	0.05	0.25
12	1.7	0.0	6.02	0.0	4.81	0.15	0.13	6.15	3.91	0.11	0.25
12	0.9	0.2	6.18	1.1	7.31	0.19	0.10	6.20	7.55	0.11	0.16
13	0.7	0.1	5.94	0.0	11.28	0.08	0.20	6.13	12.40	0.06	0.19
13	0.6	0.0		11.2	20.93	0.10	0.08	6.36	14.74	0.05	0.16
13	1.6	0.1	5.75	0.0	14.17	0.10	0.26	5.87	16.45	0.05	0.37
13	0.5	0.0	6.11	0.0	9.95	0.13	0.19	6.29	12.57	0.07	0.22
13	[illegible]	0.0	6.04	0.5	13.01	0.11	0.14	6.07	14.47	0.06	0.23
13	0.9	0.1	6.26	0.0	14.48	0.10	0.13	6.29	17.15	0.06	0.25
13	1.6	0.1	6.27	0.7	12.72	0.14	0.13	6.08	18.49	0.08	0.26
14	1.0	0.0	6.23	0.0	12.76	0.06	0.15	6.07	16.32	0.02	0.31
14	2.9	0.5	5.71	0.0	16.25	0.09	0.16	5.67	19.74	0.07	0.26
14	0.9	0.0	6.09	0.0	13.48	0.06	0.18	6.07	15.10	0.03	0.29
14	1.6	0.0	6.00	0.0	14.05	0.10	0.11	6.05	16.56	0.07	0.19
15	0.8	0.0	6.23	0.0	14.53	0.07	0.13	6.25	15.77	0.04	0.22
15	0.7	0.0	6.29	0.1	13.79	0.05	0.13	6.22	16.24	0.02	0.22
0	0.8	0.2	6.15	1.7	18.65	0.09	0.14	5.65	15.76	0.06	0.37
0	0.5	0.1	6.51	3.0	19.67	0.12	0.11	6.32	21.70	0.07	0.21
0	0.6	0.1	6.55	1.2	21.50	0.09	0.12	6.34	21.45	0.03	0.23
0	0.5	0.0	6.82	2.1	17.69	0.22	0.08	6.27	17.44	0.12	0.24
0	0.2	0.0	6.94	9.1	25.24	0.25	0.13	6.89	25.82	0.13	0.14
0	1.0	0.0	6.23	0.0	16.75	0.17	0.15	6.09	19.72	0.12	0.22
0	0.2	0.1	6.32	0.0	12.56	0.19	0.11	6.13	12.56	0.06	0.23
0	0.2	0.0	6.28	2.5	15.93	0.20	0.12	6.32	15.99	0.15	0.14
0	0.6	0.0	6.05	0.0	17.94	0.10	0.19	6.06	14.91	0.07	0.16
0	0.4	0.0	6.08	0.0	15.23	0.13	0.13	5.97	17.06	0.06	0.21
1	0.5	0.0	7.08	15.5	21.32	0.17	0.07	7.30	22.58	0.09	0.13
1	0.6	0.0	6.74	3.6	25.91	0.07	0.11	6.64	25.59	0.03	0.19
1	0.6	0.0	6.14	1.2	16.94	0.11	0.11	6.07	16.99	0.08	0.15
1	0.4	0.0	6.28	3.7	18.06	0.13	0.09	6.27	18.13	0.13	0.10
2	0.8	0.0	6.04	0.0	13.85	0.09	0.21	5.81	12.62	0.05	0.29
2	1.1	0.1	6.43	3.2	22.17	0.13	0.10	6.42	20.09	0.12	0.15
2	1.2	0.0	7.05	8.1	14.73	0.17	0.05	6.75	15.76	0.09	0.09
2	0.9	0.6	6.87	2.0	16.66	0.16	0.07	6.74	15.98	0.11	[illegible]
3	0.8	0.1	6.77	2.3	23.83	0.21	0.12	6.37	22.36	[illegible]	0.28
3	1.1	0.0	6.64	2.2	15.02	0.17	0.14	6.33	14.54	0.09	[illegible]
3	1.5	0.0	6.58	0.0	11.01	0.08	0.09	6.36	10.34	[illegible]	[illegible]
3	0.7	0.0	6.48	1.1	23.06	0.12	0.06	6.44	[illegible]	0.09	0.14
3	0.5	0.4	6.43	1.8	21.53	0.13	0.08	6.13	21.54	0.09	0.16
4	0.9	0.0	6.24	3.0	11.98	0.20	0.09	6.27	12.96	[illegible]	0.14
4	0.3	0.0	6.62	0.9	27.34	0.04	0.19	6.53	27.56	0.04	[illegible]
4	0.7	0.1	6.43	2.3	21.66	0.10	0.12	6.34	22.77	0.06	[illegible]
4	1.0	0.0	6.05	0.7	15.29	0.09	0.18	6.25	11.55	0.09	[illegible]
4	0.7	0.0	6.24	0.0	19.39	0.08	0.16	6.74	18.48	0.04	0.26
4	0.8	0.0	6.05	0.0	15.58	0.15	0.11	6.20	19.60	0.09	0.25
5	0.9	0.0	6.06	0.7	20.83	0.07	0.20	6.63	22.42	0.02	0.27
5	1.0	0.0	6.39	1.3	16.64	0.05	0.12	6.12	12.79	[illegible]	0.24
5	1.0	0.1	6.06	0.0	13.21	0.06	0.19	6.57	16.00	0.03	0.24
5	0.7	0.0	6.08	3.6	12.11	0.24	0.06	6.50	17.67	[illegible]	0.06
5	0.1	0.0	6.13	0.0	19.01	0.08	0.10	6.07	12.04	0.12	0.16
5	0.6	0.0	6.41		16.17	0.28	0.04				
5	0.0	0.1	6.25	1.1	13.00	0.26	0.07				
5	0.9	0.0	5.98	0.8	13.67	0.16	0.18				
6	0.5	0.1	6.62	1.5	17.72	0.16	0.12	6.76	17.86	0.08	0.15
6	0.7	0.0	7.23	2.1	17.35	0.26	0.10	6.72	15.58	0.17	0.26
6	0.3	0.1	6.32	0.0	26.46	0.06	0.14	6.92	26.96	0.02	0.27
6	0.2	0.0	6.25	0.0	12.02	0.17	0.06	5.96	16.52	0.04	0.16
6	0.2	0.0	6.60	0.8	20.90	0.12	0.06	6.62	19.27	0.08	[illegible]
6	0.8	0.2	6.92	8.5	29.57	0.15	0.14	6.26	27.44	[illegible]	0.16
6	0.3	0.0	6.03	0.0	12.90	0.21	0.09				
6	0.1	0.0	6.08	0.0	12.96	0.06	0.16				
7	0.6	0.0	6.36	2.7	24.29	0.07	0.10	6.21	25.69	0.07	0.19

APPENDIX D.3 (cont. 5/5)

years			horizon 10-30 cm					horizon 30-60 cm			
mucuna	Zn ppm	Cu ppm	pH	P ppm	Ca meq	K meq	Al meq	pH	Ca meq	K meq	Al meq
7	1.5	0.0	6.86	11.8	21.20	0.20	0.07	6.66	21.13	0.19	0.15
7	0.9	0.0	6.11	0.0	16.46	0.13	0.19	5.91	16.68	0.04	0.35
7	0.3	0.0	6.26	7.2	23.01	0.18	0.08	6.28	23.71	0.11	0.13
7	1.0	0.1	6.08	0.6	22.24	0.12	0.13	6.15	21.99	0.07	0.23
7	0.5	0.0	7.13	0.0	17.31	0.06	0.19	6.17	18.69	0.06	0.26
7	1.0	0.0	5.80	0.0	6.97	0.08	0.14	5.75	10.81	0.07	0.30
7	0.5	0.0	6.11	1.3	24.79	0.10	0.14	6.03	24.83	0.08	0.20
7	0.2	0.2	6.03	3.3	22.04	0.19	0.13	6.07	23.08	0.13	0.16
8	0.5	0.0	6.63	0.6	26.95	0.11	0.14	6.51	27.18	0.07	0.33
8	0.6	0.0	6.50	1.0	23.81	0.11	0.09	6.38	26.11	0.07	0.19
10	0.2	0.0	6.41	2.8	24.99	0.17	0.15	6.35	24.69	0.12	0.25
10	0.8	0.2	6.25	0.4	16.04	0.11	0.12	6.12	15.23	0.07	0.19
10	0.9	0.0	6.37	0.8	11.83	0.30	0.10	6.21	12.22	0.19	0.15
10	0.9	0.0	6.19	3.3	21.90	0.09	0.15	6.05	25.79	0.08	0.22
11	0.1	0.0	6.56	1.0	21.34	0.15	0.08	6.38	21.37	0.12	0.22
0	1.1	0.1	4.79	0.0	2.03	0.12	1.37	4.84	0.84	0.09	2.56
0	1.3	0.1	5.91	0.0	2.36	0.07	0.36	5.93	1.66	0.07	0.79
0	1.1	0.0	5.56	0.0	2.32	0.24	0.64	5.41	1.93	0.09	0.86
0	0.4	0.0	6.22	0.0	10.62	0.04	0.31	5.73	0.30	0.08	0.55
0	0.5	0.0	5.69	0.0	1.67	0.14	0.34	5.48	0.66	0.06	0.97
0	0.2	0.0	5.62	0.0	3.03	0.17	0.57	5.51	1.76	0.12	1.22
1	1.9	0.2	5.91	0.0	3.58	0.19	0.36	5.65	2.68	0.10	0.54
1	1.1	0.0	5.65	0.0	3.54	0.19	0.54	5.33	1.37	0.09	2.54
1	0.7	0.1	6.56	0.0	9.41	0.18	0.21	5.86	7.17	0.17	0.50
1	0.6	0.0	5.44	0.0	2.62	0.28	0.74	5.27	1.16	0.14	2.40
1	0.7	0.0	4.93	0.0	1.03	0.19	2.13	5.04	0.48	0.07	2.80
2	1.2	0.0	6.12	0.0	4.21	0.25	0.20	5.95	2.61	0.17	0.29
2	0.4	0.0	6.15	0.0	8.02	0.13	0.28	5.81	7.87	0.09	0.36
2	0.6	0.5	5.97	0.0	6.07	0.40	0.17	5.61	3.66	0.05	0.52
2	0.8	0.0	5.58	0.0	3.10	0.18	0.43	5.52	2.41	0.08	0.59
3	1.5	0.0	6.09	0.0	5.58	0.15	0.30	5.79	4.22	0.06	0.53
3	0.7	0.0	5.49	0.0	2.17	0.19	0.43	5.29	1.53	0.16	0.57
3	0.8	0.0	5.86	0.0	3.70	0.04	0.30	5.68	2.32	0.02	0.33
3	0.7	0.0	6.13	0.0	3.55	0.26	0.32	5.62	1.77	0.16	0.65
3	0.3	0.0	5.85	0.0	4.31	0.24	0.24	5.56	2.70	0.09	0.52
4	1.0	0.0	5.56	0.0	3.66	0.26	0.46	5.15	1.80	0.10	1.25
4	0.3	0.0	5.95	0.0	6.47	0.07	0.50	6.69	4.51	0.07	0.66
4	1.5	0.0	5.70	0.0	6.28	0.07	0.33	5.26	3.68	0.06	1.66
4	1.0	0.1	6.07	0.0	7.90	0.15	0.28	5.71	6.80	0.09	0.55
4	0.9	0.0	6.18	0.0	9.46	0.06	0.29	5.96	7.33	0.03	0.47
4	0.6	0.0	5.67	0.0	2.43	0.19	0.41	5.31	0.90	0.15	1.11
4	0.2	0.2	5.94	0.0	4.10	0.10	0.25	5.66	2.55	0.07	0.42
4	1.7	0.0	5.65	0.0	5.09	0.20	0.25	5.55	3.84	0.12	0.62
5	2.1	0.1	6.20	0.0	8.23	0.06	0.19	5.83	4.30	0.03	0.46
5	2.1	0.0	5.78	0.0	4.15	0.31	0.22	5.67	2.74	0.15	0.45
6	0.9	0.0	5.69	0.0	3.06	0.15	0.41	5.59	2.74	0.10	0.47
6	1.1	0.0	6.03	0.0	8.63	0.07	0.11	6.71	6.82	0.04	0.24
7	1.7	0.0									
0	0.4	0.0	5.07	0.0	3.83	0.04	0.97	5.30	2.83	0.05	1.16
0	1.3	0.1	5.53	0.0	10.31	0.13	0.65	5.46	11.25	0.11	0.67
2	1.7	0.0	6.26	0.0	15.89	0.17	0.21	6.16	13.07	0.08	0.32
2	1.7	0.0	6.50	0.7	11.52	0.16	0.12	6.48	14.97	0.10	0.26
2	2.8	0.1	6.31	0.0	11.19	0.24	0.13	6.25	8.56	0.20	0.21
2	0.7	0.0	6.02	0.0	6.69	0.19	0.23	5.72	3.36	0.09	0.69
3	1.6	0.0	6.21	0.0	11.34	0.32	0.12	6.11	9.83	0.21	0.33
3	3.6	0.0	5.91	0.0	10.67	0.38	0.09	5.87	10.11	0.29	0.16
4	4.5	0.0	5.83	0.0	5.15	0.30	0.28	4.95	3.69	0.14	1.36
4	6.2	0.1	6.94	0.0	7.10	0.29	0.19	5.04	4.84	0.12	0.89
5		0.0	6.39	0.0	8.23	0.26	0.16	5.95	5.78	0.13	0.41
5	0.7	0.0	5.18	0.0	4.25	0.02	0.77	5.09	2.26	0.02	4.29
5	4.1	0.0	6.10	0.0	7.03	0.40	0.19	5.65	5.72	0.28	0.53
6	1.2	0.0	6.04	0.0	7.78	0.02	0.17	5.19	4.63	0.05	0.64
6	4.5	0.0	5.96	0.0	6.92	0.26	0.15	5.76	4.14	0.14	0.35
6	3.2	0.0	5.92	0.0	7.88	0.31	0.15	5.67	6.10	0.22	0.57
8	0.2	0.0	5.50	0.0	5.28	0.05	0.52	5.35	4.44	0.03	0.69
8	0.5	0.0	5.56	0.0	10.30	0.19	0.36	5.65	9.79	0.06	0.51
11	0.6	0.0	5.81	0.0	7.72	0.23	0.33	6.75	7.53	0.11	0.45
11	0.4	0.0	5.94	0.0	11.46	0.17	0.30	5.01	11.08	0.07	0.36
12	0.5	0.0	6.01	0.0	6.76	0.16	0.30	5.65	2.21	0.24	1.01
12	0.9	0.1	6.61	0.0	13.15	0.07	0.11	6.50	11.40	0.04	0.76

APPENDIX D.4: INFILTRATION DATA

field	years muc	site ID	topog pos	with surface mulch									surface mulch removed								
				slope	h:mm:ss time r off	deliv rate	mm r off	mm inf rat	steady state run off	steady state infilt	init wetness	mm store	slope	time roff	deliv rate	mm r off	mm inf rat	steady state run off	steady state infilt	init wetness	mm store
manual	0	2	Back										11%	0:08:30	65.0	15.2	49.8	57.0	38.0	0.17	12.1
manual	0	3	Back										22%	0:05:30	115.2	87.1	30.9	102.0	13.2	0.22	7.8
manual	0	1	Back										19%	0:06:30	81.0	46.9	34.1	57.0	24.0	0.23	8.0
manual	0	4	Back										13%	0:06:15	86.8	58.8	32.5	72.0	14.8	0.21	10.8
mdalesso	1	A	Back	36%	0:03:30	95.0	61.1	33.9	69.0	26.0	0.36	2.7	28%	0:03:00	72.8	65.8	8.0	75.0	15.0	0.34	3.8
mdalesso	1	B	Back	44%	0:03:35	80.7	37.4	43.9	48.0	32.7	0.30	5.9	45%	0:13:00	109.5	5.7	104.1	7.2	102.3	0.30	5.7
mdalesso	1	H	Back	37%	0:03:30	102.2	68.4	39.4	75.6	31.6	0.29	5.6	33%	0:02:00	106.5	67.8	40.8	69.6	36.9	0.33	3.5
mdalesso	1	G	Back	39%	0:03:15	98.0	71.5	26.5	79.2	18.8	0.27	3.7	36%	0:03:00	117.1	43.4	75.1	57.0	60.1	0.26	3.8
mdalesso	1	D	Show	33%	0:02:30	88.6	59.6	31.8	63.0	25.6	0.24	4.9	39%	0:06:30	89.5	25.5	64.5	31.8	57.7	0.28	5.8
mdalesso	1	C	Show	28%	0:04:40	88.0	27.1	58.9	37.8	47.0	0.33	4.7	18%	0:03:45	83.4	57.0	30.0	60.0	23.4	0.38	2.5
mdalesso	1	F	Show	47%	0:01:40	101.6	76.8	27.3	84.0	17.6	0.26	5.8	41%	0:04:00	103.4	32.8	69.5	38.4	65.0	0.25	7.1
mdalesso	1	E	Show	22%	0:06:30	88.0	18.7	69.3	25.8	62.2	0.28	5.4	18%	0:02:00	143.2	77.0	68.7	84.0	59.2	0.26	8.4
manual +	2	1	Back	20%	0:07:30	99.3	41.1	58.9	51.0	48.3	0.28	6.4	18%	0:07:45	92.5	16.8	75.5	24.0	68.5	0.29	4.8
manual +	2	2	Back	15%	0:07:20	80.3	24.4	57.8	33.0	47.3	0.27	4.9	30%	0:04:30	87.6	55.3	34.9	66.6	21.0	0.23	7.5
manual +	2	4	Back	9%	2:00:00	80.6	0.0	80.6	0.0	80.6	0.20	7.5	17%	2:00:00	84.0	0.0	84.0	0.0	84.0	0.22	7.8
manual +	2	3	Back	24%	0:04:00	102.9	61.0	44.7	66.0	36.9	0.28	5.0	17%	0:11:30	108.9	11.1	98.7	12.0	96.9	0.28	7.0
marvin	2	C	Back	42%	0:03:45	102.0	35.3	66.7	45.0	57.0	0.41	3.9	46%	0:02:00	99.3	85.3	15.4	95.4	3.9	0.41	3.4
marvin	2	E	Back	47%	0:03:00	105.5	72.0	35.8	75.6	29.9	0.41	3.2	58%	0:01:30	113.0	91.7	21.8	95.4	17.6	0.43	2.2
marvin	2	A	Back	53%	0:01:00	92.5	73.7	19.9	84.0	8.5	0.39	3.1	53%	0:01:30	118.0	105.1	12.9	109.2	8.8	0.41	2.6
marvin	2	H	Back	53%	0:02:30	92.0	78.9	13.1	82.2	9.8	0.44	0.9	48%	0:01:30	88.1	80.7	10.4	80.0	6.0	0.43	0.9
marvin	2	F	Show	58%	0:01:45	104.0	87.6	16.4	93.0	11.0	0.45	0.4	49%	0:01:00	103.5	89.4	17.0	100.2	3.3	0.42	2.5
marvin	2	B	Show	54%	0:02:45	112.8	65.8	44.7	76.2	36.6	0.40	3.4	51%	0:03:00	100.6	28.5	77.0	28.8	71.8	0.40	2.7
marvin	2	D	Show	46%	0:01:00	100.0	84.2	19.8	83.4	16.6	0.40	2.2	48%	0:02:00	96.4	81.5	16.2	91.2	5.2	0.39	3.4
marvin	2	G	Show	55%	0:02:00	105.0	33.9	71.1	39.0	66.0	0.44	1.4	51%	0:01:30	86.6	76.5	11.3	83.0	7.2	0.44	1.8
tonio	4	D	Back	25%	2:00:00	86.0	0.0	86.0	0.0	86.0	0.29	5.7	38%	0:04:38	111.3	20.0	91.9	23.5	87.8	0.33	5.3
tonio	4	B	Back	34%	2:00:00	117.9	0.0	117.9	0.0	117.9	0.34	5.2	22%	2:00:00	100.0	0.0	100.0	0.0	100.0	0.28	6.2
tonio	4	F	Back	35%	0:07:00	98.0	57.0	41.0	64.5	33.5	0.37	2.8	52%	0:02:50	118.0	76.7	41.3	84.3	33.7	0.35	5.0
tonio	4	G	Back	35%	0:03:51	97.0	31.1	65.9	38.1	58.9	0.31	6.6	47%	0:01:55	103.5	56.9	48.5	60.6	42.9	0.34	5.7
tonio	4	A	Show	27%	0:04:20	100.0	26.6	73.4	29.2	70.8	0.31	6.7	22%	0:38:26	104.0	1.2	102.8	3.6	100.2	0.25	8.4
tonio	4	E	Show	45%	0:03:00	95.0	52.8	42.2	58.0	37.0	0.34	3.9	31%	0:02:14	103.0	55.6	47.4	60.5	42.5	0.34	4.1
tonio	4	C	Show	37%	0:04:30	119.0	12.5	106.5	14.5	104.5	0.25	7.0	34%	2:00:00	104.8	0.0	104.8	0.0	104.8	0.37	2.9
tonio	4	H	Show	36%	0:02:00	113.0	62.3	50.7	69.6	43.4	0.38	2.4	34%	2:00:00	103.5	0.0	103.5	0.0	103.5	0.38	3.9
chad	8	CH	Back	40%	0:01:30	93.1	39.6	55.7	44.4	48.9	0.25	7.4	32%	0:03:30	98.4	48.3	53.1	59.4	39.0	0.33	5.9
chad	8	HG	Back	42%	0:03:00	90.5	38.8	53.6	39.6	50.9	0.42	2.6	33%	0:03:00	92.8	28.5	66.1	37.2	55.6	0.42	2.2
chad	8	D	Back	54%	0:46:15	65.5	0.5	65.0	1.8	63.7	0.36	3.5	51%	0:01:30	78.7	25.0	45.4	45.0	33.7	0.32	4.6
chad	8	J	Back	46%	0:02:00	105.7	54.2	57.1	49.2	56.5	0.40	0.8	42%	0:01:45	118.2	61.4	62.3	69.0	49.2	0.38	1.1
chad	8	C	Show	32%	0:05:30	83.0	43.7	39.3	48.0	35.0	0.41	1.9	23%	0:01:30	132.0	41.4	69.8	73.8	58.2	0.35	2.9
chad	8	E	Show	37%	0:02:00	101.3	41.2	62.7	48.0	53.3	0.31	4.5	31%	2:00:00	88.1	0.0	88.1	0.0	88.1	0.37	4.0
chad	8	7	Show	31%	0:02:30	91.5	34.9	57.1	40.8	50.7	0.40	7.7	26%	0:03:00	91.9	42.7	51.1	44.8	47.5	0.42	1.8
chad	8	6	Show	35%	0:04:15	91.9	43.7	49.7	49.8	42.1	0.35	5.7	15%	0:03:00	101.3	10.8	92.7	11.4	91.9	0.40	3.9
chad	8	5	Show	38%	2:00:00	95.8	0.0	95.8	0.0	95.8	0.23	7.8	43%	0:09:00	103.0	14.8	88.2	21.0	82.0	0.29	6.2
chema	14	B	Back	45%	0:45:02	98.3	16.6	84.5	14.8	83.5	0.40	3.7	36%	0:15:15	97.3	2.5	95.0	4.0	93.3	0.40	3.7
chema	14	D	Back	63%	0:06:36	116.2	4.1	112.3	6.0	110.2	0.40	3.5	41%	0:15:45	87.5	[illegible]	87.3	0.4	87.1	0.30	6.7
chema	14	H	Back	35%	[illegible]	97.8	75.8	27.9	80.0	20.0	0.38	2.5	37%	0:02:00	88.0	[illegible]	17.5	74.3	13.7	0.44	1.0
chema	14	F	Back	50%	2:00:00	98.7	0.0	98.7	0.0	98.7	0.34	4.5	44%	0:03:06	94.7	41.6	55.7	83.4	51.3	0.40	6.1
chema	14	A	Show	33%	[illegible]	[illegible]	56.0	46.1	61.5	41.5	0.40	3.7	32%	0:02:45	104.0	55.1	48.9	63.3	40.7	0.40	3.5
chema	14	C	Show	36%	2:00:00	100.0	0.0	100.0	0.0	100.0	0.42	1.9	33%	0:08:00	124.9	7.0	118.1	10.0	114.9	0.40	3.7
chema	14	E	Show	40%	[illegible]	90.5	21.6	68.5	23.4	67.1	0.43	1.7	25%	2:00:00	103.0	0.0	103.0	0.0	103.0	0.40	4.1
chema	14	G	Show	26%	[illegible]	87.5	25.2	62.8	29.0	58.5	0.34	7.4	29%	0:06:55	101.3	16.6	85.0	23.0	78.3	0.33	6.3
gald	16	CH	Back	52%	0:06:07	106.0	42.6	63.4	50.0	56.0	0.34	4.8	44%	0:05:58	115.1	27.6	87.9	40.0	75.1	0.26	7.9
gald	16	HC	Back	22%	0:05:24	109.5	65.0	47.6	76.0	33.5	0.30	3.4	28%	2:00:00	101.5	0.0	101.5	0.0	101.5	0.35	4.1
gald	16	E	Back	50%	0:01:30	124.0	55.1	68.9	67.0	57.0	0.20	7.2	50%	0:02:50	98.0	28.0	70.0	31.7	66.8	0.32	3.6
gald	16	A	Back	55%	0:03:30	112.0	20.9	91.1	24.5	87.5	0.34	3.6	51%	0:02:30	103.1	22.1	81.5	23.0	80.3	0.39	2.8
gald	16	F	Show	51%	0:17:00	113.0	2.0	111.0	2.6	110.4	0.27	4.8	50%	2:00:00	111.0	0.0	111.0	0.0	111.0	0.79	5.4
gald	16	G	Show	36%	0:05:00	101.0	10.6	90.4	11.7	89.3	0.33	6.6	19%	0:02:00	104.0	56.8	47.2	65.0	39.0	0.35	4.4
gald	16	B	Show	40%	0:03:30	102.6	[illegible]	66.9	40.0	62.6	0.37	3.3	45%	0:02:35	100.3	30.8	70.0	41.0	59.3	0.40	2.9
gald	16	D	Show	80%	0:27:30	101.6	[illegible]	100.2	1.4	99.6	0.33	3.8	57%	2:00:00	105.0	0.0	105.0	0.0	105.0	0.26	5.9

APPENDIX D.5: MAIZE YIELDS AND YIELD COMPONENTS (ALL SITES)

year	site	Farmer	rep	age	Planting	t/ha yield	thous. dens	Wear/pl	WK/ear	g Wiear	WK/m2	mg WIK
93	sf	CARLOS MALDONADO	1	0		1.58	23.1	0.74	322	93	550	26.8
93	sf	CARLOS MALDONADO	2	0		1.32	22.4	0.78	252	75	442	29.9
93	sf	DON JACOBO -check	1	0		2.81	30.5	0.84	353	110	903	31.2
93	sf	DON JACOBO -check	2	0		1.97	31.6	0.80	257	78	651	30.3
93	sf	MARVIN MALDONADO	1	1	01/05/93							
93	sf	MARVIN MALDONADO	2	1	12/24/92	1.88	25.4	0.78	341	95	675	27.9
93	sf	M.A. ANDRADE LUPE	1	1		0.50	10.0					
93	sf	BERNABE VAZQUEZ	1	1	12/05/92	1.50	15.0					
93	sf	ANTONIO GARCIA	1	2	01/01/93	1.30	31.7	0.53	303	76	506	25.8
93	sf	ADAN ANDRADE	1	2	12/20/92	3.07	32.6	0.69	399	136	899	34.1
93	sf	TONIO MADRID	1	2	12/26/92	3.68	30.0	0.77	444	169	1020	36.1
93	sf	TONIO MADRID	2	2	12/26/92	3.55	36.2	0.85	343	110	1108	32.1
93	sf	ANTONIO AYALA	1	3	12/23/92	3.92	46.9	0.79	335	101	1298	30.2
93	sf	ANTONIO AYALA	2	3	12/23/92	4.94	46.3	0.95	408	119	1695	29.2
93	sf	ANTONIO GARCIA	2	3	01/01/93	3.74	33.2	0.81	461	136	1247	30.6
93	sf	SANTOS VAZQUEZ JR	2	4	12/24/92	2.21	30.9	0.66	324	108	662	33.4
93	sf	CALISTRO ANDRADE	1	6	12/12/92							
93	sf	CALISTRO ANDRADE	2	6	12/11/92	2.22	28.0	0.78	312	102	683	32.4
93	sf	ANTONIO MORALES	1	6	12/18/92	3.56	29.4	0.95	385	128	1169	33.3
93	sf	ANTONIO MORALES	2	6	12/18/92	4.86	41.7	0.89	438	131	1519	32.2
93	sf	OBED SERRANO	1	6	12/17/92							
93	sf	OBED SERRANO	2	6	12/17/92	3.36	33.6	0.86	364	114	1074	31.4
93	sf	JUAN BIDES	1	6	12/16/92	0.90	29.9	0.54	194	55	319	28.5
93	sf	JUAN VAZQUEZ	1	6	12/08/92	3.04	31.9	0.74	398	129	935	32.4
93	sf	JUAN VAZQUEZ	2	6	12/08/92	3.47	28.6	0.74	454	162	971	35.7
93	sf	DON JACOBO CASTEL	1	7	12/14/92	3.50	22.4	1.07	423	146	1012	34.6
93	sf	DON JACOBO CASTEL	2	7	12/14/92	3.11	26.4	0.94	383	125	952	32.7
93	sf	DON CHEPE ALFARO	3	7	01/06/93	3.15	42.6	0.71	379	105	1137	27.7
93	sf	ANDRES LAINEZ	1	7	12/22/92	0.77	37.8	0.61	159	34	365	21.2
93	sf	ANDRES LAINEZ	2	7	12/22/92	3.44	48.1	0.72	337	99	1163	29.5
93	sf	SANTIAGO SUAZO	1	7	12/13/92	2.81	35.4	0.77	354	103	963	29.2
93	sf	SANTIAGO SUAZO	2	7	12/13/92	3.78	45.5	0.77	369	111	1291	30.2
93	sf	ORLANDO PALOMO	1	8	12/14/92	2.57	25.3	0.90	353	112	809	33.7
93	sf	ORLANDO PALOMO	2	8	12/13/92							
93	sf	MARTIR ANDRADE	1	8	01/07/93	3.69	23.9	1.01	428	152	1036	35.6
93	sf	MARTIR ANDRADE	2	8	01/04/93	4.53	29.4	1.06	515	145	1612	28.2
93	sf	ANTONIO MORALES	1	8	01/09/93	2.68	26.7	0.78	368	129	764	35.2
93	sf	ANTONIO MORALES	2	8	01/09/93	3.57	29.5	0.89	472	137	1235	29.3
93	sf	TEYO MORALES	1	8	01/15/93	3.45	32.2	0.62	376	132	994	34.7
93	sf	TEYO MORALES	2	8	01/06/93	3.68	36.6	0.77	427	131	1215	30.5
93	sf	DON ANSELMO MEJIA	1	8	12/29/92	3.41	33.0	0.79	353	131	919	37.1
93	sf	DON ANSELMO MEJIA	2	8	12/29/92	3.22	32.0	0.74	368	137	868	37.1
93	sf	JESUS ENRIQUE	1	8	12/20/92	3.34	37.1	0.79	334	114	975	34.2
93	sf	JESUS ENRIQUE	2	8	12/20/92	3.61	28.1	0.87	399	147	977	36.8
93	sf	INDALESIO MEJIA	1	8	12/24/92	1.65	31.6	0.70	382	139	879	28.5
93	sf	JUANCITO RIVERA	1	8	12/26/92	3.37	38.2	0.88	322	112	1278	31.6
93	sf	JUANCITO RIVERA	2	8	12/26/92	3.48	39.6	0.88	317	111	1101	31.6
93	sf	MARCO HERNANDEZ	1	10	12/03/92	4.19	49.4	0.79	356	117	1296	[illegible]
93	sf	MARCO HERNANDEZ	2	10	12/03/92	4.93	45.8	0.82	434	133	1497	32.9
93	sf	MARCO HERNANDEZ	3	10	12/03/92	3.35	56.2	0.70	286	66	1117	31.0
93	sf	MARCO HERNANDEZ	4	10	12/03/92							
93	sf	ANTONIO MALDONADO	1	10	12/23/92	4.03	27.9	1.04	428	139	1240	32.5
93	sf	ANTONIO MALDONADO	2	10	12/23/92	3.35	26.1	0.94	404	137	992	33.8
93	sf	DON CHEPE ALFARO	1	10	12/14/92	4.74	38.3	0.99	454	125	1716	27.6
93	sf	DON CHEPE ALFARO	2	10	12/10/92	3.19	31.0	0.91	398	113	1124	28.3
93	sf	JULIAN ENRIQUE	1	11	12/19/92	3.87	33.0	0.90	363	130	1085	35.7
93	sf	JULIAN ENRIQUE	2	11	12/19/92	4.13	32.0	0.94	424	142	1179	35.1
93	sf	"NEGRITO" RIVERA	1	12	12/27/92	4.69	41.2	0.87	388	131	1387	33.8
93	sf	"NEGRITO" RIVERA	2	12	12/24/92	3.94	26.2	1.06	365	141	1073	36.7
93	sf	SANTOS VAZQUEZ JR	1	12		2.33	37.7	0.67	315	92	795	29.4
93	sf	JULIO MEJIA	1	13	12/12/92	3.66	31.4	0.98	379	119	1166	31.4
93	sf	JULIO MEJIA	2	13	12/12/92							
93	sf	DON JUAN RIVERA	1	13	12/15/92	3.90	27.3	1.09	410	132	1215	32.1
93	sf	DON JUAN RIVERA	2	13	12/15/92	3.71	29.3	0.98	374	130	1071	34.7
93	sf	DON JUAN RIVERA	3	13	12/31/92	3.25	28.3	0.74	455	155	956	34.0
93	sf	DON CHEMA ENRIQUE	1	13	12/20/92	3.77	35.0	0.88	391	131	1158	31.5
93	sf	DON CHEMA ENRIQUE	2	13	12/19/92	3.31	38.1	0.86	385	122	1259	26.3
93	sf	DON CHEPITO	1	14	12/24/92	2.31	30.3	0.87	411	87	1156	21.9
93	sf	DON CHEPITO	2	14	12/24/92	2.50	30.9	0.88	362	92	974	25.8
93	sf	DON CHEMA GALDAME	1	15	12/17/92	4.88	31.3	0.95	431	139	1271	30.2

APPENDIX D.5 (cont. 1/2)

year	site	Farmer	rep	age	Planting	yield	dens	Near/pl	NK/ear	Wlear	NK/m2	WlK
93	sf	DON CHEMA GALDAME	2	15	12/17/92	4.50	33.0	0.98	429	139	1385	32.5
93	mg	ADOLFO CONTRERAS	1	0	12/18/92	2.31	33.0	0.66	263	106.4	571	40.4
93	mg	EDUVIGES CASTRON	1	0	12/17/92	2.65	27.6	0.86	342	118.8	813	34.6
93	mg	ADOLFO CONTRERAS	1	1	12/14/92	3.64	28.8	0.79	476	159.2	1085	33.5
93	mg	JORGE CASTRON	1	1	12/26/92	3.84	30.5	0.81	501	156.9	1239	31.3
93	mg	JORGE CASTRON	1	2	12/26/92	3.96	34.2	0.90	398	131.3	1227	33.0
93	mg	NARCISO RIVAS	2	2	12/28/92	5.96	48.3	0.93	429	139.8	1925	32.6
93	mg	HUMBERTO RODRIGUE	1	2	12/16/92	3.79	33.5	0.81	441	151.9	1191	34.5
93	mg	EDUVIGES CASTRON	2	3	12/17/92	5.56	37.5	1.02	442	147.8	1686	33.5
93	mg	PASCUAL MARTINEZ	1	3	12/14/92	3.91	33.2	0.98	400	124.9	1299	31.2
93	mg	MIGUEL ARGUETA	1	3	01/12/93	3.11	35.9	0.92	319	96.7	1053	30.3
93	mg	ANASTACIO AMAYA	1	4	01/06/93	5.10	41.3	0.78	529	165.1	1696	31.2
93	mg	ANASTACIO AMAYA	2	4	01/06/93	5.01	39.4	0.82	480	157.4	1544	32.8
93	mg	CRISTINO CASTRON	1	4	12/26/92	3.46	32.9	0.78	430	134.9	1109	31.4
93	mg	CRISTINO CASTRON	2	4	12/26/92	3.04	29.2	0.77	509	136.1	1152	26.7
93	mg	CONSTANTINO NAVAR	1	4	01/01/93	4.56	39.1	0.91	479	134.6	1701	28.1
93	mg	CONSTANTINO NAVAR	2	4	01/01/93	4.15	40.7	0.84	456	126.7	1559	27.8
93	mg	CRISTINO CASTRON	1	5	12/24/92	4.65	33.1	0.98	445	146.2	1442	32.9
93	mg	PASCUAL MARTINEZ	1	5	12/15/92	3.85	38.2	0.97	340	105.7	1260	31.1
93	mg	ANTONIO HERNANDEZ	2	5	12/21/92	5.69	44.0	0.93	480	145.5	1961	30.3
93	mg	JOSE RIVERA	1	6	12/19/92	5.81	37.8	0.98	456	158.2	1692	34.7
93	mg	ARMANDO GALVEZ		6	12/09/92	4.36	32.8	0.97	416	141.4	1324	34.0
93	mg	HUMBERTO RODRIGUE	1	6	12/15/92	5.34	44.7	0.85	535	141.6	2033	26.5
93	mg	HUMBERTO RODRIGUE	2	6	12/15/92	4.80	46.8	0.66	436	119.9	[illegible]	27.5
93	mg	ADOLFO CONTRERAS	1	7	12/14/92	4.67	32.2	0.99	436	146.4	1398	33.6
93	mg	ADOLFO CONTRERAS	2	7	12/14/92	5.00	39.6	0.93	426	136.0	1567	31.9
93	mg	JOSE CONTRERAS	1	7	12/26/92	5.52	41.5	0.96	453	141.4	1811	31.2
93	mg	JOSE CONTRERAS	2	7	12/26/92	4.77	33.9	0.98	473	143.6	1571	30.4
93	mg	HUMBERTO RODRIGUE	1	8	12/16/92	4.44	29.7	1.02	405	145.7	1229	36.4
94	sf	JUANCITO RIVERA	1	0	1/17/94	1.29	22.9	0.65	261	88.0	387	33.7
94	sf	JUANCITO RIVERA	2	0	1/17/94	2.06	30.6	0.88	319	77.3	864	24.3
94	sf	DON JACOBO -check	1	0		2.24	20.5	0.94	423	119.1	815	28.2
94	sf	DON JACOBO -check	2	0		2.15	24.8	0.87	366	103.0	790	28.1
94	sf	DOÑA CHINDA, milp	1	0	12/26/93	2.34	15.5	0.98	395	156.1	600	39.5
94	sf	DOÑA CHINDA, milp	2	0	12/26/93	2.02	20.8	0.95	311	109.6	614	35.2
94	sf	DOÑA CHINDA, milp	1	0	12/26/93	2.52	24.0	0.85	356	125.4	729	35.2
94	sf	DOÑA CHINDA, milp	2	0	12/26/93	2.01	30.1	0.69	305	97.2	634	31.9
94	sf	PAUL MORALES, che	1	0	01/03/94	2.09	29.9	1.00	239	79.3	715	33.2
94	sf	PAUL MORALES, che	2	0	01/03/94	1.14	31.1	0.91	214	66.8	606	31.2
94	sf	INDALECIO MEJIA	1	1	12/10/93	3.59	37.9	0.86	353	110.9	1154	31.4
94	sf	INDALECIO MEJIA	2	1	12/10/93	3.09	42.0	0.89	298	84.7	1113	28.4
94	sf	TOÑO GARCIA	1	3	12/29/93	1.78	30.0	0.62	272	101.6	506	37.4
94	sf	TOÑO AYALA	1	4	12/16/93	3.73	38.1	0.81	337	116.2	1045	34.5
94	sf	TOÑO AYALA	2	4	12/16/93	4.55	39.8	0.95	374	121.0	1419	32.4
94	sf	TOÑO AYALA	3	4	12/16/93	4.17	38.2	0.96	325	112.8	1191	34.7
94	sf	TOÑO GARCIA	2	4	12/29/93	4.40	36.4	0.88	372	146.4	1192	39.3
94	sf	DON CHEMA AYALA	3	5	12/06/93	3.67	36.1	0.92	335	[illegible]	1113	33.1
94	sf	JUAN VASQUEZ	1	7	12/23/93	2.61	21.3	0.87	375	144.5	694	38.5
94	sf	JUAN VASQUEZ	2	7	12/23/93	1.89	21.6	0.75	332	119.3	538	35.9
94	sf	OBEL SERRANO	1	8	12/01/93	1.73	15.3	1.02	327	112.4	518	34.4
94	sf	OBEL SERRANO	2	8	12/01/93	2.62	19.5	1.15	367	121.5	823	33.1
94	sf	DON JACOBO	1	9	12/14/93	4.00	36.5	0.90	335	122.8	1100	36.7
94	sf	DON JACOBO	2	9	12/14/93	4.23	35.7	0.90	349	131.5	1121	37.6
94	sf	DON JACOBO	3	9	12/14/93	3.60	34.2	0.86	392	123.6	1149	31.5
94	sf	T.T. MORALES	1	9	12/15/93	3.79	37.8	0.84	309	120.5	984	39.0
94	sf	T.T. MORALES	2	9	12/15/93	3.43	35.1	0.81	328	122.0	926	37.2
94	sf	T.T. MORALES	3	9	12/15/93	3.08	36.1	0.81	358	106.8	1041	29.9
94	sf	MARTIR ANDRADE	1	9	01/03/94	4.40	32.3	0.94	435	142.7	1323	32.8
94	sf	MARTIR ANDRADE	2	9	01/03/94	5.45	31.0	1.04	500	168.9	1616	33.8
94	sf	MARCO A. ANDRADE	1	11	12/28/93	2.77	34.1	0.83	332	103.0	937	31.0
94	sf	MARCO A. ANDRADE	2	11	12/28/93	3.44	27.0	0.92	438	141.9	1095	32.4
94	sf	NEGRITO RIVERA	1	13	12/18/93	3.60	50.6	0.72	276	97.5	1008	35.3
94	sf	NEGRITO RIVERA	2	13	12/18/93	4.65	40.6	0.66	373	131.5	1000	35.3
94	sf	DON CHEMA AYALA	1	14	12/06/93	4.58	35.7	0.92	411	139.3	1351	33.9
94	sf	DON CHEMA AYALA	2	14	12/06/93	3.94	36.5	0.91	350	119.1	1162	34.1
94	sf	CHEPITO BARRERA	1	15	01/05/94	2.83	47.3	0.85	277	73.9	1117	26.7
94	sf	CHEPITO BARRERA	2	15	01/05/94	2.54	51.1	0.78	305	79.4	1216	26.0
94	sf	CHEMA GALDAMEZ	2	16	12/27/93	2.35	32.8	0.97	334	65.1	1063	19.5
94	sf	CHEMA GALDAMEZ	1	16	12/27/93	3.25	29.9	1.09	417	109.3	1359	26.2
94	mg	ANTONIO RUIZ chec	1	0	1/28/94	1.36	32.8	0.61	251	65.3	504	26
94	mg	ANTONIO RUIZ chec	2	0	1/28/94	2.09	36.3	0.75	269	80.2	733	29.8

APPENDIX D.5 (cont. 2/2)

year	site	Farmer	rep	age	Planting	yield	dens	Near/pl	NK/ear	W/ear	NK/m2	W1K
94	mg	FRANCISCO PAREDES	1	0	01 10 94	1.88	31.5	0.75	251	78.9	591	31.4
94	mg	JUAN ALBARENGA c	1	0	01/10/94	0.34	56.0	0.28	101	27.1	161	26.7
94	mg	JUAN BURGOS	1	1	1/27/94	1.03	40.3	0.71	203	38.4	578	19.0
94	mg	JUAN BURGOS	2	1	1/27/94	0.80	39.7	0.65	260	56.0	674	21.5
94	mg	ANTONIO RUIZ	2	2	12/15/93	3.59	31.7	0.99	429	113.9	1351	26.6
94	mg	BENIGNO AMAYA	1	3	12/10/93	4.61	31.1	1.09	393	139.7	1327	35.5
94	mg	BENIGNO AMAYA	2	3	12/10/93	3.36	30.6	0.88	395	127.3	1055	32.3
94	mg	EDUVIGES CASTRON	1	4	01/17/94	3.11	44.4	0.80	352	96.7	1249	27.5
94	mg	EDUVIGES CASTRON	2	4	01/17/94	2.02	48.7	0.66	285	71.9	913	25.2
94	mg	JORGE CASTRON	1	4	1/15/94	2.43	42.2	0.66	274	92.5	756	33.8
94	mg	JORGE CASTRON	2	4	1/15/94	3.14	45.3	0.80	300	85.9	1085	28.6
94	mg	anastacio	1	5	12/22/93	4.03	35.6	0.97	368	115.7	1273	31.4
94	mg	anastacio	2	5	12/22/93	3.59	41.9	0.89	303	94.1	1134	31.0
94	mg	anastacio	3	5	12/22/93	2.45	37.4	0.83	275	75.8	846	27.7
94	mg	Hernandez	1	6	12/22/93	4.05	52.1	0.89	301	86.2	1407	28.7
94	mg	Hernandez	2	6	12/22/93	4.26	35.6	0.96	370	115.1	1364	31.1
94	mg	Hernandez	3	6	12/22/93	1.60	45.8	0.59	184	45.6	511	24.6
94	mg	ANTONIO RUIZ	1	6	12/15/93	3.79	38.9	0.86	335	118.5	1116	35.3
94	mg	CRISTINO CASTRON	1	6	12/27/93	2.29	37.5	0.87	273	70.4	851	25.8
94	mg	CRISTINO CASTRON	2	6	12/27/93	2.29	34.1	0.92	252	72.7	867	25.9
94	mg	Albarenga	1	7	12/22/93	3.83	44.7	0.88	311	95.8	1184	31.5
94	mg	Albarenga	2	7	12/22/93	3.47	36.4	0.92	290	103.0	967	35.5
94	mg	Albarenga	3	7	12/22/93	3.38	36.7	0.83	319	114.7	1157	[illegible]
94	mg	ADOLFO CONTRERAS	1	8	12/20/93	3.67	32.3	0.95	361	122.1	1171	33.1
94	mg	ADOLFO CONTRERAS	2	8	12/20/93	3.67	27.1	0.99	416	137.6	1118	33.1
94	mg	ABRAHAM CONTRERAS	1	8	01/01/94	4.54	42.8	0.87	444	126.1	1658	28.4
94	mg	ABRAHAM CONTRERAS	2	8	01/01/94	3.62	41.4	0.85	365	116.3	1347	31.9
94	mg	FRANCISCO PAREDES	1	11	12/15/93	2.85	31.7	0.87	434	105.2	1197	23.7
94	mg	FRANCISCO PAREDES	2	11	12/15/93	3.40	33.2	0.92	421	109.5	1292	26.0
94	mg	JOSE RIVERA	1	11	12/29/93	3.21	33.8	0.83	442	118.4	1231	26.9
94	mg	JOSE RIVERA	2	11	12/29/93	3.11	39.2	0.62	366	103.5	1178	28.3
94	cu	Cheque del Cid. c	1	0	01 10 94	1.40	26.5	0.66	264	79.4	463	30.2
94	cu	Manuel Varela 6a	1	1	01 10/94	1.83	26.4	0.69	252	77.8	598	30.9
94	cu	Ismael del Cid	2	1		1.65	22.8	0.97	277	76.9	610	27.8
94	cu	Manuel Varela 1a	1	2	01 10 94	3.09	29.2	0.88	401	125.1	1127	31.2
94	cu	Manuel Varela 1a	2	2	01 10 94	2.36	23.7	0.82	407	126.0	775	31.0
94	cu	Miguel Carballo 1	1	2		1.65	33.0	0.61	285	72.3	757	25.4
94	cu	Miguel Carballo 1	2	2		2.52	32.8	0.91	317	93.9	947	29.6
94	cu	Manuel Varela 2a.	1	3	01 10 94	1.83	23.9	0.76	315	103.8	570	32.9
94	cu	Manuel Varela 2a.	2	3	01 10 94	2.72	26.0	0.83	363	120.2	831	33.1
94	cu	Manuel Varela 3a	1	4	01/10 94	2.63	22.6	0.96	413	126.6	897	30.7
94	cu	Manuel Varela 3a	2	4	01 10/94	3.52	35.0	0.88	336	115.2	1032	34.3
94	cu	Luis Carballo	1	4		0.88	28.3	0.56	235	65.6	373	28.0
94	cu	Luis Carballo	2	4		0.61	29.7	0.58	164	47.2	282	28.9
94	cu	Miguel Carballo 4	1	5	01 01 94	1.68	28.1	0.78	214	64.1	715	29.9
94	cu	Miguel Carballo 4	2	5	01 01 94	2.47	30.0	0.88	303	93.5	796	30.5
94	cu	Manuel Varela 5a	1	6	01 10 94	2.39	25.7	0.85	326	109.3	710	33.5
94	cu	Manuel Varela 5a	2	6	01 10/94	2.11	28.4	0.98	259	78.1	723	30.2
94	cu	Rosendo del Cid	1	7	01/07 94	0.65	23.8	0.62	212	47.9	314	22.6
94	cu	Rosendo del Cid	2	7	01/07 94	1.13	21.8	0.75	238	68.4	301	28.8
94	pi	RAFAEL CASTELLANO	1	3		1.88	32.6	0.77	329	79.0	761	24.6
94	pi	RAFAEL CASTELLANO	2	3		2.65	27.7	0.87	362	112.8	876	31.2
94	pi	RODOLFO GUTIERREZ	1	3		2.14	26.3	0.93	270	88.0	657	32.6
94	pi	RODOLFO GUTIERREZ	2	3		2.52	33.8	0.82	342	97.5	948	28.5
94	pi	ELADIO CASTEL. *	1	4	2/15/94	2.07	26.3	0.87	263	92.2	604	35.0
94	pi	ELADIO CASTEL. *	2	4	2/15/94	2.25	27.8	0.59	322	91.5	796	28.2
94	pi	LUIS ALF. CAST.	1	6		1.30	35.5	0.75	266	53.0	712	19.9
94	pi	LUIS ALF. CAST.	2	6		1.07	28.3	0.96	288	73.2	778	25.5
94	pi	INGLOBERTO BORJAS	1	8		2.59	34.4	0.80	344	115.2	949	33.4
94	pi	INGLOBERTO BORJAS	2	8		3.07	27.6	0.73	413	153.1	830	37.0
94	pi	MAGDALENO RIVERA	1	11		2.53	27.7	0.99	342	100.7	855	29.5
94	pi	MAGDALENO RIVERA	2	11		2.71	26.3	0.93	323	112.5	788	34.8
94	pi	RODOLFO GUTIERREZ	1	13		2.42	31.3	0.82	377	99.6	969	26.4
94	pi	RODOLFO GUTIERREZ	2	13		3.07	24.4	1.02	466	124.9	1152	26.8
94	pi	MAGDALENO RIVERA	1	13		3.65	36.2	0.99	428	113.3	1386	26.5
94	pi	MAGDALENO RIVERA	2	13		3.71	33.6	0.89	383	122.2	1151	32.0

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