February 1998

Cover Crops *in* Hillside Agriculture

Farmer Innovation *with Mucuna*

Daniel Buckles, Bernard Triomphe, and Gustavo Sain

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Published jointly by the
International Development Research Centre
PO Box 8500, Ottawa, ON, Canada K1G 3H9
and the
International Maize and Wheat Improvement Center
Lisboa 27, Apartado Postal 6-641, 06600 Mexico DF, Mexico

Legal deposit: 1st quarter 1998
National Library of Canada
ISBN 0-88936-841-4

The catalogue of IDRC Books may be consulted online at
http://www.idrc.ca/index_e.html

This book may be consulted online at http://www.idrc.ca/books/focus.html

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"With the fertilizer bean, cowardly land becomes brave."
— Teodoro Reyes, La Danta, Honduras

PREFACE

Agriculture is essential to sustainable and equitable development in Central America. Many of the rural poor in this region earn their living on small farms, where basic grain production is a central component of their livelihoods. Land degradation, especially on hillsides, is a persistent problem — one that leads to impoverishment and stagnation of agricultural productivity.

Farmers are not passive in the face of adversity. No matter how poor, by necessity they are engaged in seeking solutions. This book examines an innovative solution developed by farmers — the use of velvetbean (*Mucuna* spp.) as a cover crop on the hillsides of northern Honduras. We comprehensively evaluate this practice and analyze the socioeconomic and agroecological conditions under which it developed. The purpose of this detailed study is to shed light on the opportunities and constraints presented by cover crops in the humid tropics and to examine the new strategies farmers have contributed to sustainable agriculture. To suggest that the technology provides a complete solution would be facile, but it is a creative and effective response to the social and political factors that pushed the farmers onto the steep slopes in the first place.

Many people contributed to the *Mucuna* story told in this book. Foremost among these are the farmers of northern Honduras, who shared their knowledge and ideas on how this legume can be used to sustain maize production in a difficult hillside environment. The book owes much to the farmers of San Francisco de Saco and La Danta, who graciously hosted us and many other visitors over the years. In these and other communities in northern Honduras, farmers gave us their information and time during the farm surveys and field trials and provided many insights into why the "fertilizer bean" has become so important to them. We feel honoured by their generosity, trust, and friendship and are particularly grateful to Don Jose María Ayala of San Francisco de Saco.

Many researchers and development workers in Honduras also contributed in various ways to the research reported in this book. Our key collaborators in the farm surveys were Ignacio Ponce, Jorge Salgado, and Gilmer Medina, all formerly of the Honduran Secretaría de Recursos Naturales (secretariat of natural resources). They were assisted by Marlon Arita, Helington Antuñez, Heber Bojorque, Armando Borjas, Ignacio Cortes, Roberto Escoto, Carmen Regina Garcia Hiza, Melesio Guillen, Gustavo López, Maria Gricel Navarro, Jose María Reina, Oscar Robles, Carlos Guillermo Rosales, Jesus Zelaya, L. Mejia, Hector Nolasco, and L. de Ramos. For support in the field trials and other aspects of the agronomic research undertaken in Honduras, we are grateful to Marco-Antonio Ponce, Luis Brizuela, Pedro Baca, Secarlos Padilla, Manuel López, Oscar Espinal, David Ashby, Carmen de Brooks, Leonel Castillo, Orly García, Angela Munguia, Rafael Meza, Oscar Robles, Guillermo Rosales, Pedro Baca, Maria Gricel Navarro, Christian Alix, and Denis Buteau.

The Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT, international maize and wheat improvement centre), based in Mexico, played a pivotal role in supporting this research. In 1982, Gustavo Sain and other researchers from CIMMYT and the Secretaría de Recursos Naturales noticed that farmers were using velvetbean to improve hillside land, so they asked Daniel Buckles to study the system when he arrived at the centre as a Visiting Research Fellow supported by The Rockefeller Foundation (1990–92). A grant from The Ford Foundation (1991–95) to the CIMMYT Economics Program for training, research, and policy analysis in natural resource management for Mexico and Central America helped support the field research and one of the principal researchers. The Centre de coopération internationale en recherche agronomique pour le développement (CIRAD, centre for international cooperation on agronomic research for development) and the Cornell International Institute for Food, Agriculture and Development sponsored the agronomic research undertaken by Bernard Triomphe while he was a PhD student at Cornell University. The International Development Research Centre (IDRC) supported the preparation of the manuscript as part of a broader strategy to stimulate research on cover crops and improved fallow systems in Latin America, Southeast Asia, and West Africa. IDRC has given support to specific projects in this field for a number of years.

Advice, technical assistance with various components of the research, and comments on the text were generously provided by Rob Tripp, Larry Harrington, Derek Byerlee, Hugo Perales, Hector Barreto, Sally Humphries, Milton Flores, Roland Bunch, Mauricio Bellon, Paul Heisey, Ken Mullen, Jose Crossa, Adrian Maître, Miguel Lopez-Pereira, Greg Edmeades, Stephen Sherwood, and Sean Neil, although remaining errors are our responsibility. Valuable assistance was provided by C. Charreau, D. Picard, F. Ganry, P. Siband, J. Pichot, and R. Oliver at CIRAD; and J. Mt Pleasant, D. Bouldin, C. Wien, S. Feldman, D. Picard, H. Van

Es, R. Schindelbeck, J. Duxbury, D. Lee, D. Thurston, Ken Schlather, Julie Lauren, Beverly McIntyre, Arturo Aguirre-Gomez, Alejandro Mateos, and Diego de Lozada at Cornell University. Special thanks go to Larry Harrington, Rob Tripp, and Derek Byerlee of CIMMYT and Ken Schlather of Cornell University for supporting our work over the years.

The editorial assistance of Debra Huron, Robert Buckles, Mike Listman, Kelly Cassaday, and Alma McNab enhanced the clarity of the text in various earlier versions and in this book. Bill Carman's careful supervision brought the book to completion. The authors also wish to thank their families for their support and patience during the field research and long hours of writing.

Daniel Buckles
Bernard Triomphe
Gustavo Sain

January 1998

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INTRODUCTION

Farmers in northern Honduras are at the forefront of a significant development in hillside agriculture. For more than 20 years, they have been quietly developing an aggressive vining legume called velvetbean and adapting it to the needs of maize production. These farmers developed the velvetbean–maize practice because they were excluded from the prime coastal land of northern Honduras, increasingly taken up by pineapple and African palm plantations and pastures owned by the elite classes and agroindustries. The farmers had to find a way to produce maize — their staple food — on poor and fragile hillside land.

The velvetbean–maize cropping practice they developed enhances productivity while conserving the resource base — a rare combination in hillside environments. Velvetbean seed (*Mucuna pruriens*) is initially introduced between the rows of maize, where it continues to grow profusely after the maize harvest. Once it has matured (some 8 months later), the velvetbean crop is slashed, and maize is planted once again in the mat of decomposing leaves and vines. Velvetbean residues are not burned or incorporated into the soil but left as mulch on the surface. Seed from the velvetbean crop eventually germinates on its own in the maize field, and the cycle is repeated. This cropping practice reduces labour costs by controlling weeds and increases maize yields by supplying nutrients when they are most needed. Productivity gains are realized without a concurrent decline in the resource base. In the words of Teodoro Reyes of La Danta, Atlántida, "with velvetbean, cowardly land becomes brave."

The maize–velvetbean combination represents a radical departure from the traditional techniques of slash-and-burn agriculture characteristic of the humid tropics. Slash-and-burn agricultural practices, with long fallow periods, used to be well adapted to the prevailing ecological and socioeconomic conditions. However, population growth and the conversion of forest land to pasture have increased pressure on land resources and induced more frequent cultivation. Without external inputs, intensive cropping using traditional slash-and-burn techniques leads to a decline in soil fertility and increases in weed invasion and soil erosion, which undermine the productivity and sustainability of shifting cultivation. By contrast, farmers in northern Honduras have been cropping maize–velvetbean continuously on the same plots for 20 years while maintaining or even markedly improving both yield and soil fertility.

Velvetbean seed, along with the knowledge of its potential uses, was introduced in northern Honduras through a complex process of innovation involving farmers, scientists, and transnational corporations on three continents (Buckles 1995). Originally from eastern India and southern China, velvetbean traveled to Africa, Brazil, the Caribbean, Central America, and the United States, circumnavigating the humid tropics over several centuries. Throughout the seed's history, farmers, acting in their own interest and with occasional scientific input, adapted the plant to their needs; in so doing, they provided the impetus for its spread. In northern Honduras, the adaptation and diffusion of velvetbean — or "the fertilizer bean," as it is known in the region — occurred spontaneously, from farmer to farmer, without the direct intervention of external groups. Currently, more than 10 000 farmers in northern Honduras and thousands more in Guatemala and southern Mexico use velvetbean to fertilize the soil, control weeds, and protect cropland from erosion.

Spontaneous adoption of a farmer-generated technology merits attention. Although science-based agricultural research is to be credited for huge successes in raising agricultural output, many scientists fail to realize that uneducated, small-scale farmers successfully experiment and innovate on their own initiative and achieve notable results. By definition, *farmers' modes of experimentation* are not equivalent to scientific inquiry, as they rely heavily on empirical, locally validated experience. Hence, they may not generate knowledge in a form easily accessible to outsiders or directly applicable in other regions. Nevertheless, many insights were gained in the past and many more may still be gained from assessing what farmers are doing to address key issues in crop or environmental management (Richards 1985; Sinclair et al. 1993). An important task for outside agencies therefore is to tap into this knowledge and strengthen the capacity of farmers to generate new ideas and agricultural practices to meet their own needs (Bunch 1982).

Interaction with Honduran farmers challenges researchers and development workers to redefine their role, as well as that of farmers, in the process of technology generation and diffusion. Farmers have been remarkably creative with velvetbean and other cover crops, not only developing and diffusing the system as practiced in places like northern Honduras, but also experimenting with numerous variations in crop associations, planting dates, densities, pruning, and weeding practices, as well as food and forage uses (Bunch 1990, 1995; Holt-Giménez 1993; Buckles and Arteaga 1993; Buckles and Barreto 1996; Flores 1997). Neither researchers nor development workers would dare claim that they are "leading" the research in this area or are in complete control of the processes of technology generation and diffusion. This local initiative has much to teach people who still doubt the potential role of farmers in the development, adaptation, and diffusion of improved technology.

The dilemma of hillside agriculture

The fact that this book focuses on a successful hillside cropping system does not mean its authors advocate farming hillsides. Hillside agriculture continues to challenge and frustrate farmers, scientists, development workers, and policymakers. Because of the intrinsic fragility of hillsides, some people believe that they should never be farmed. Soil on steep slopes is easily eroded after cultivation, which threatens the future productivity of the land and contributes to downstream costs, such as those arising from siltation and flooding. Broken topography and poor infrastructure constrain market production in hillside economies, leaving the population cash poor. In most cases, geographic isolation is accompanied by political and social marginalization. Hillside communities lack access to information on national and international developments and have very few opportunities to influence public policy or to demand the public services they deserve. Under such challenging conditions, hillside peoples have no other option but to continue farming to attempt to meet their food needs or move to urban areas.

The velvetbean system is no panacea. However, progress toward equitable and sustainable development depends on efficient hillside farming practices. Agriculture is impossible on hillside land if the soil resources are degraded or lost to erosion. A great many successful experiences with the long-term cultivation of hillside land have continued for centuries or even millennia (Siebert and Lassoie 1991). Terracing is a successful engineering approach, but it involves large initial investments and a concentrated labour force, often beyond the means of present-day hillside communities. Shifting cultivation is the most widespread and well known of the agroforestry systems used traditionally by farmers on hillside lands, but these systems are often in decline because of the long fallow periods they need to restore soil fertility. In some areas, indigenous strategies for intensification of shifting cultivation have emerged in response to this constraint (Buckles and Perales 1995; Cairns 1997).

Although they are not so well known, no-till slash-and-mulch systems, like the velvetbean–maize, have been developed in hillside environments to enhance productivity and sustainability. A practice of slashing natural or introduced vegetation and using it as a mulch for the following crop (typically without tilling the land) is used to grow beans on hillside land in Costa Rica; maize, in various parts of Mesoamerica; and rice, in the uplands of the Philippines (Thurston 1997). Of special interest are systems using legumes as the mulched species, as the N captured by the legume from the air and released through decomposition significantly boosts yields of nonlegume crops such as cereals (IRRI 1988; Lathwell 1990; Giller and Wilson 1991; Hargrove 1991; Sarrantonio 1991; Smyth et al. 1991). For cash-poor farmers who must cultivate cereals for food, using few external inputs such as commercial fertilizers and herbicides, these practices offer a low-cost and ecologically sound solution to key production constraints, including soil erosion, weed invasion, and loss of soil nutrients.

Despite their many qualities, legume-based slash-and-mulch systems are still very poorly documented in the scientific literature (Sanchez 1994). Before the research undertaken for this book, documentation of velvetbean use in northern Honduras was limited to general descriptive accounts (Flores 1987; Avila Nájera and López 1990). This book goes beyond description to a more rigorous understanding of the agroecological and socioeconomic conditions under which velvetbean use developed and the long-term impacts of its use on land productivity. The objectives of our analysis were to comprehensively evaluate the opportunities and constraints of the velvetbean system and to generally assess the factors influencing farmers' investments in resource-conserving practices.

The evaluation has practical implications insofar as it provides a solid basis for understanding the potential of similar systems for use in other areas. Careful documentation of the conditions enabling farmers' use of the system and the biological processes that make the system work should help detect constraints and orientate adaptive research. This is all the more important because the management of velvetbean–maize and the process of innovation it derived from are drawing attention from numerous organizations in Central America, Mexico, and elsewhere that currently research or promote the use of velvetbean cover crops. In most cases, these efforts do not rely on quantitative agronomic evidence about these practices or analyses of economic impacts and social constraints. Sometimes promotion is based on blind faith that velvetbean is a solution to the dilemma of hillside agriculture. New management options have been developed, but farmers' adoption and sustained use of velvetbean and other cover crops outside northern Honduras have not lived up to their initial promise (Arteaga et al. 1997; Flores 1997).

The analysis of the velvetbean system will also help in empirically and precisely examining the concept of sustainable agriculture. Quantitative and qualitative data on the agronomic and economic performance of the velvetbean system indicate that productivity has a nonnegative trend line over a period of 20 years, a reasonable measure of cropping-system sustainability. However, the conditions enabling farmers to adapt velvetbean to the hillside environment are open to the influence of forces from outside the boundaries of the cropping system. For example, the profitability of the velvetbean system is subject to the vagaries of maize prices on national and international markets. Also, the expansion of cattle ranching has induced changes in land-use patterns and land ownership that are incompatible with long-term use of the velvetbean system. The analysis of factors influencing adoption suggests that farmers' decisions regarding agricultural technology are more closely tied to the objectives of household food security and livelihood than to the objective of the sustainability of a single component of their farming system. Ultimately, these decisions are constrained by the limited capacity of smallholders to invest in sustainable development.

Key methodological choices

Our study focuses on the wet tropical hillsides of northern Honduras (Figure 1). It is an interdisciplinary study, applying the tools of agronomy, social anthropology, economics, and historical analysis to various collections of data and aspects of the complex processes of technological innovation and adoption in a specific setting. In an attempt to bring together various aspects of society and nature distinguishable in theory, but not isolated in reality, we examine issues ranging from the dynamics of nutrient cycling to the role that land tenure plays in fostering investment in resource-conserving practices.

Although our approach recognizes and depicts the complex web of socioeconomic and biophysical features of an agricultural system, the research was not designed from the beginning as an integrated body of analysis. It was undertaken over a 5-year period by three people, working relatively independently and employing concepts and methods from different disciplines and perspectives. Through dialogue and collaborative writing of this book, the anthropologist, the agronomist, and the economist found a great deal of common ground on the relative importance of the key arguments. In this sense, we moved toward an interdisciplinary understanding of the social nature of technology and the ecological foundations of cultural practices.

The research presented in this book began in 1990, following on earlier reports on velvetbean use in northern Honduras (SRN–CIMMYT 1983; Flores 1987; Avila Nájera and López 1990). Although the velvetbean system was well known in the region, no quantitative data on where and how intensively the practice was employed had been collected. In 1990, we conducted, through the Honduran Secretariá de Recursos Naturales (SRN, secretariat for natural resources) and the

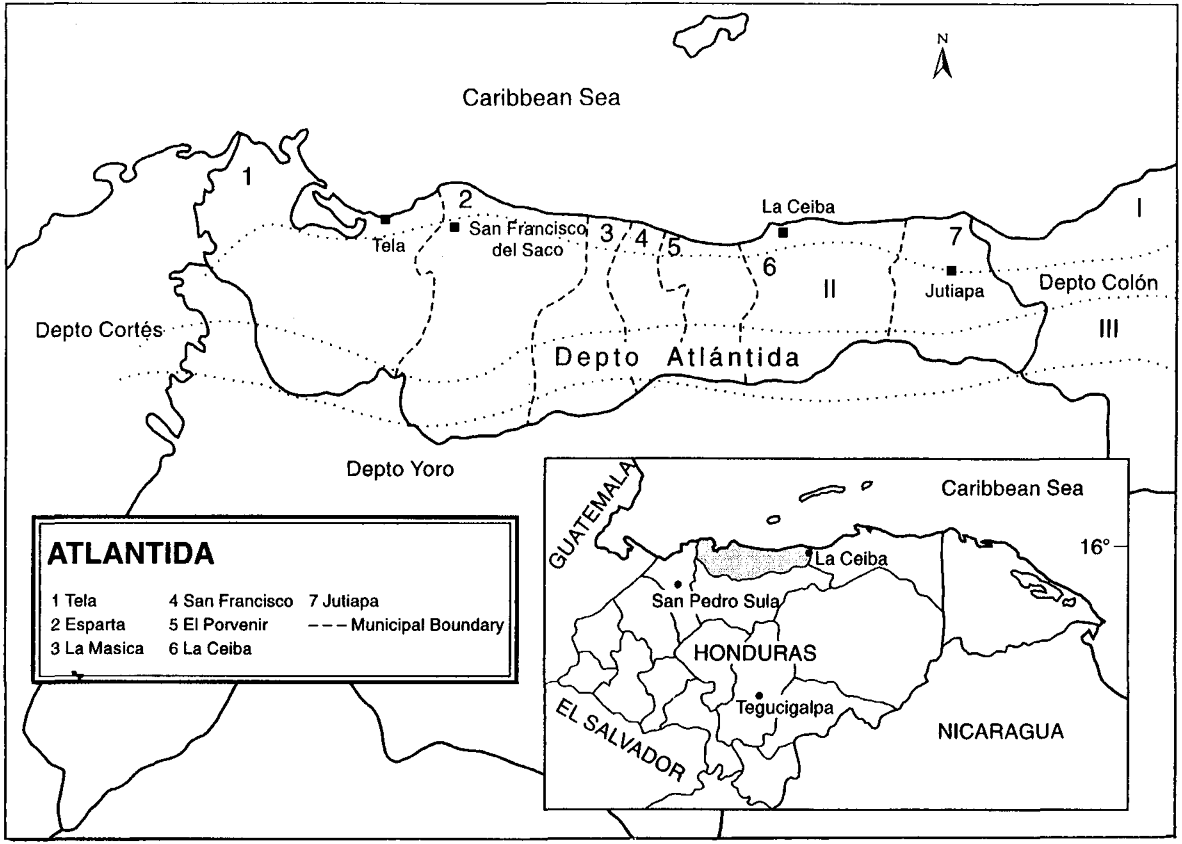

Figure 1. Northern Honduras. Note: I, coastal plain; II, hillside zone; III, mountain zone.

Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT, international maize and wheat improvement centre), a survey of 133 farmers in 25 communities between Tela and Jutiapa (Figure 1 and Appendix I). From these data, we created a representative picture of the geographic distribution and variation in the level of velvetbean use in northern Honduras (Buckles et al. 1991).

In 1992, we undertook a more detailed survey of 126 families in 16 hillside villages in two municipalities (Appendix I), again in collaboration with SRN and CIMMYT (Buckles et al. 1992). We chose a survey approach to facilitate quantitative analysis of the relationships among complex and apparently interrelated factors in farmers' decision-making. We knew from key informants and the previous survey that land tenure, farm size, and maize markets influenced farmers' adoption of velvetbean, but the relative weight of these factors and the interactions among them were unknown. Analysis of survey data dealing with a full range of farms' and farmers' characteristics helped us identify factors likely to influence farmers' adoption of farming practices in northern Honduras and elsewhere. Data from the 1992 farm survey are reported throughout the book.

We supplemented the farm-survey data with those of topical surveys and interviews conducted between 1990 and 1995 that dealt with labour inputs, the variability of input prices, and land markets. This information formed the basis for calculating the technical coefficients used in the economic analysis (Sain et al. 1994; Sain and Buckles 1997). The primary socioeconomic data were rounded out with archival research on historical uses of velvetbean, visits to areas in Guatemala where Honduran farmers had traced the origins of the practice, and interviews in 1994 and 1995 on major claims made by the authors (Buckles 1995; DB's field observations). We also reviewed official sources, such as census data, and the literature on agricultural development in Honduras, with a view to situating our case study in the broader development context.

Although the socioeconomic-research process was largely conventional, it was conducted with considerable emphasis on understanding farmers' perspectives in their own terms. All questionnaires were tested thoroughly and were adjusted to reflect the local idiom. Visual aids were used to collect information on the timing of field operations and to find out farmers' opinions of the potential advantages and disadvantages of the practices included in the survey (Appendix II). The results of this research later informed the agronomic work.

The agronomic research used novel methods and was first presented in partial completion of the requirements of a doctoral program (Triomphe 1996). The velvetbean system could be studied in its various dimensions nowhere but in the field because of the need to sample the diverse agroecological conditions of hillside environments. Furthermore, even basic information on the velvetbean system was unavailable, which would make it difficult to design relevant controlled experiments on station or even to formulate testable hypotheses. By studying the system *in situ*, we were able to identify a broad range of factors influencing agronomic performance and prioritize them for further, in-depth research (Sébillotte 1987).

On-farm research also offered us the only feasible opportunity to generate empirical evidence of long-term trends from continuous use of velvetbean. Because many farmers in northern Honduras had been using velvetbean continuously on the same fields for 10–15 years, we substituted a space-for-time, or chronosequence, approach for the classical but more costly long-term experiments (Pickett 1988; Johnston and Powlson 1994). We inferred trends over time from a systematic comparison of fields with different periods of velvetbean use. The opportunity to sample from a large number of farmers using the same technology in a consistent manner for 10 years or more is rarely encountered in long-term studies. The situation in northern Honduras was consequently very suitable for testing under farm conditions the opportunities and constraints of the chronosequence approach.

The risk of mixing up causal factors is great, however, when one is interpreting observations using a chronosequence approach. For example, it was impossible to be sure that the basis of comparison between fields was the same. Also, independent testing of the findings was not possible within the time frame and context of this study. The relatively large sampling scheme used for the study enhanced the validity of the conclusions obtained using a chronosequence approach.

Book outline

The book begins, in Chapter 1, by tracing the movement of velvetbean and the knowledge of its uses from Asia to northern Honduras and noting the conditions under which velvetbean practice has waxed and waned in various parts of the world. Basic botanical features of *Mucuna* spp. and their historical uses in the United States and elsewhere are described.

The main features of farming systems in northern Honduras are examined in Chapter 2. The favourable climate and fertile soils are discussed and linked to national patterns affecting maize production and prices. We examine the availability of hillside land and patterns of land distribution on the coastal plain (forcing farmers onto the hillsides) as other factors that have enabled farmers to use velvetbean. This chapter also examines the low productivity of shifting cultivation (which is the alternative maize-production system).

The book delves into the farm-level context in Chapter 3, with a view to developing a broader framework for the analysis of adoption.

Chapter 4 presents the adoption data from northern Honduras and describes the velvetbean-management practices in detail. Farmers' evaluations of the advantages and disadvantages of the velvetbean–maize system are also explained, and a general evaluation of the system is outlined.

The agroecological processes underlying the relatively high productivity of the velvetbean–maize system are assessed in Chapter 5, with a particular emphasis on understanding the nutrient-cycling effects and long-term trends in soil fertility. Field-level surveys and the chronosequence analysis of soils data form the basis of this analysis.

In Chapter 6, the profitability of the velvetbean–maize system is compared with that of other regional alternatives, and regional economic impacts of the system are assessed.

Factors influencing adoption of the velvetbean–maize system are discussed in Chapter 7, drawing attention to constraints associated with farmers' land and labour resources and broader economic factors, such as a regional shift in land use toward dual-purpose cattle raising.

The conclusion summarizes our main findings and discusses the conditions under which the velvetbean experience is relevant to small-scale farmers elsewhere in Mesoamerica. Although we did not set out to develop an integrated theoretical framework, it is our hope that the interdisciplinary analysis of the multiple facets of a precisely defined cropping system will contribute to broader debates on the theory and practice of sustainable agriculture.

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CHAPTER 1

VELVETBEAN: A NEW PLANT WITH A HISTORY

In recent years, cover crops have received considerable attention from scientists and development workers concerned about the productivity and sustainability of agricultural systems in the developing world. Velvetbean is prominent among the cover crops studied and promoted (Durón et al. 1989; Bunch 1990; Camas Gómez 1991; Quiroga Madrigal et al. 1991; Derpsch and Florentín 1992; Lobo Burle et al. 1992; SAA–Global 2000, Inc. 1992; Zea 1992; Buckles and Arteaga 1993; Chávez 1993; Versteeg and Koudokpon 1993; Arteaga et al. 1997; Calegari et al. 1997; Flores 1997). It is without doubt one of the most popular cover crops currently known for the tropics and a featured example of the potential contribution of cover crops to sustainable agricultural systems. What is not so well known is that velvetbean was heralded 75 years ago as "one of the most important crops of recent introduction" (Tracy and Coe 1918, p. 3). Velvetbean was cultivated extensively in the United States during the early part of this century and was included, at that time, in numerous research programs in Africa, Asia, and Latin America, with mixed success. It has also been grown successfully for more than 40 years by indigenous farmers in Mesoamerica. This chapter traces the history of velvetbean and the knowledge of its uses and identifies some of the environmental and socioeconomic conditions under which it has been used in various parts of the world. Understanding these conditions may help us to identify old constraints and new opportunities for using this not-so-new plant.

Origins and botanical features of velvetbean

Velvetbean, a vigorous annual climbing legume, originally came from southern China and eastern India, where it was at one time widely cultivated as a green vegetable crop (CSIR 1962; Burkill 1966; Duke 1981; Wilmot-Dear 1984). The genus *Mucuna* (Adans), belonging to the Fabaceae family, covers perhaps 100 species of annual and perennial legumes, including the annual velvetbean. The genus *Stizolobium* was used by Bort (1909) to distinguish velvetbean from perennial *Mucuna* spp., but this distinction was not maintained by Burkill (1966) or Bailey (1947).

Mucuna is self-pollinating; hence, natural out-crossing is rare (Duke 1981). The dozen or so cultivated *Mucuna* spp. found in the tropics probably represent a fragmentation from the Asian cultigen, and there are numerous crosses and hybrids (Piper and Tracy 1910; Bailey 1947; Burkill 1966; Bailey and Bailey 1976). The most commonly cited species include *M. deeringiana* Merrill, *M. utilis* Wallich (Bengal velvetbean), *M. pruriens* (L.) DC., *M. nivea*, *M. Hassjoo* (Yokohama velvetbean), *M. aterrima* Holland (Mauritius and Bourbon velvetbean), *M. capitata*, and *M. diabolica* (IIA 1936; Burkill 1966; Tanaka 1976; Duke 1981). However, the taxonomy of these species is confused, and some designations may be synonymous. For example, Burkill (1966) recorded *M. nivea* as being synonymous with *M. cochichinensis* and *M. lyonii* (Lyon velvetbean) (Awang et al. 1997).

The main differences among cultivated species are in the character of the pubescence on the pod, the seed colour, and the number of days to harvest of the pod. "Cowitch" and "cowhage" are the common English names of *Mucuna* types with abundant, long stinging hairs on the pod. Human contact results in an intensely itchy dermatitis, caused by *mucunain* (Infante et al. 1990). The nonstinging types, known by the common English name "velvetbean," have appressed, silky hairs. Cowitch may be the original type of the genus (Bailey 1947). Seed colours include shiny black, creamy white, gray, beige, and mottled. Life cycles range from 100 to 300 d to harvest of the pod (Tracy and Coe 1918; Bailey 1947). A nonvining variety, with low forage yields, is also reported under the name "bunch velvetbean" (Watson 1922; Duke 1981).

The velvetbean grown in northern Honduras is probably *M. pruriens*, which is the most widespread of the cultivated species. The mottled-seed type is the most common in northern Honduras, although shiny-black and creamy-white seeds are also present. Farmers note that the black-seeded velvetbean is slightly more precocious than the others, but all velvetbean types are harvested in bulk, irrespective of their type, and replanted together. All velvetbean fields observed in northern Honduras begin flowering in early to mid-October, regardless of the planting date. This suggests that the life cycle of the crop responds to shorter day lengths (photoperiodic). Flowering may also be stimulated by cooler night temperatures (21 °C) (Duke 1981). Velvetbean dies naturally after producing seed, about 45–60 d after flowering.

Most *Mucuna* spp. exhibit reasonable tolerance to a number of abiotic stresses, including drought, low soil fertility, and high soil acidity, although they are sensitive to frost and grow poorly in cold, wet soils (Duke 1981; Hairiah 1992; Lobo Burle et al. 1992). The genus thrives best under warm, moist conditions, below 1 500 m above sea level (asl), and in areas with plentiful rainfall. In such environments, velvetbean vines can grow to 10 m and the canopy may stand as high as 1 m above the soil surface. Velvetbean sheds significant quantities of leaves before reaching maturity, and these decay gradually in a litter layer below the actively growing velvetbean. Only a few roots tapping deep horizons can be found per square metre sampled, but surface roots are abundant (Tracy and Coe 1918; Hairiah 1992). Levels of aboveground biomass range from 5 to more than 12 t of dry matter (DM) ha^{-1}; below ground, more than 1 t of dried roots ha^{-1} may be produced (Duggar 1899; Ferris 1917; Camas Gómez 1991; Chávez 1993; see also Chapter 5). Pod production is variable, depending on the environmental conditions, but can easily reach more than 2 t ha^{-1}, especially if the velvetbean vines have the opportunity to climb trees, stalks, or other tutors. Like most legumes, velvetbean has the potential to fix atmospheric N through a symbiotic relationship with soil microorganisms. The N is converted by the rhizobia on the roots of the plant to an available form that is stored in the leaves, vines, and seeds — making the plant an efficient source of N.

Mucuna spp. have been reported to contain the toxic compounds L-Dopa and hallucinogenic tryptamines and antinutritional factors such as phenols and tannins (CSIR 1962; Ravindran and Ravindran 1988; Awang et al. 1997). Because of the high concentrations of L-Dopa (7%), velvetbean is a commercial source of this substance, used in the treatment of Parkinson's disease. However, L-Dopa can also produce a confused state of mind and intestinal disruptions in humans.

Despite its toxic properties, various species of *Mucuna* are grown as a minor food crop. Raw velvetbean seeds contain about 27% protein and are rich in minerals (especially K, Mg, Ca, and Fe; de la Vega et al. 1981; Duke 1981; Olaboro 1993). During the 18th and 19th centuries, *Mucuna* was grown widely as a green vegetable in the foothills and lower hills of the eastern Himalayas and in Mauritius (Watt 1883; Piper and Tracy 1910; CSIR 1962). Both the green pods and the mature beans were boiled and eaten. Burkill (1966) and Watt (1883) suggested that *Mucuna* was eventually replaced as a vegetable in Asia by more palatable legumes, although it is still used as a famine food and as specialty food in northeastern India (CSIR 1962; DB's field observations). In Guatemala and Mexico, *M. pruriens* has for at least several decades been roasted and ground to make a coffee substitute; the seed is widely known in the region as "Nescafé," in recognition of this use. The use of *Mucuna* spp. as minor food crops has also been reported in Ghana (Osei-Bonsu et al. 1995), Mozambique (Infante et al. 1990), and Nigeria (Ezueh 1977). However, an outbreak of acute psychosis in Mozambique was attributed to the inappropriate consumption of velvetbean: because of famine and drought, the water used to boil the seed was not discarded, as it normally is, and larger than normal quantities of this liquid were consumed (Infante et al. 1990).

The toxicity of unprocessed velvetbean may explain why the plant has few problems with insect pests (Scott 1910; IIA 1936; Duke 1981). Velvetbean is well known for its nematicidic 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). It also seems to possess a notable allelopathic activity, which may help it suppress competing plants (Gliessman et al. 1981). It can, however, harbour soil-borne pathogens, such as *Macrophomina phaseolina*, that are detrimental to maize and other food crops (Bell and Jeffers 1992; Berner et al. 1992).

Mucuna spp. have also been grown for some time as a fallow crop to improve soil fertility, a smother crop to control weeds, and a forage plant. Burkill (1966) noted that *Mucuna* was cultivated in Bali, Java, and Sumatra in the 17th century to recover worn-out ground — its first reported use as a cover crop. A survey on legume use in tropical countries, conducted by the International Institute of Agriculture (IIA) in the 1930s (IIA 1936), documented the use of *M. pruriens* in the Punjab of India to provide a cover crop and on the island of Madagascar to provide fodder for cattle and improve the soil for sugar cane, cassava, and lemon grass. The same species was reportedly used in Zanzibar to prevent the growth of *Imperata cylindrica* and to provide a green manure for maize, cassava, and sorghum. *Mucuna aterrima* was used as a green manure for maize and tobacco in Malawi and as a cover crop in Sierra Leone. *Mucuna deeringiana* was used as a cover crop on the citrus and banana estates in Jamaica and Puerto Rico as early as 1906.

In the 1920s, several experiment stations in Nigeria grew *Mucuna* spp. as an improved fallow and as a relay crop (with maize and cassava), with a view to intensifying small-scale, shifting-agricultural systems (IIA 1936); however, adoption of the practice was never reported. The authors of the IIA study argued that there was no pressing need for green manuring in West Africa, as forest land was abundant and traditional shifting-cultivation practices required less labour for clearing land than permanent cultivation did. In West Africa, during the 1920s, fallowing and slash-and-burn techniques effectively controlled weeds and provided optimum land preparation for planting. Under these conditions, farmers seemed unwilling to invest additional labour to establish green-manure cover crops. As noted below, however, changing circumstances may be opening up new opportunities for cover crops in this region.

Velvetbean in the United States

Velvetbean came into its own in the southern United States at the turn of the century, when it was used widely as an animal fodder and green manure. It was probably taken to the Caribbean by indentured workers from South Asia (Burkill 1966) and from there reached Florida in the 1870s, where it drew the interest of farmers and researchers (Bort 1909). One farmer, Mr Newheart of Ocoee, Florida, provided to O. Clute, of the Florida Agricultural Experiment Station, the seed of "a pea" in 1895, noting that "the abundance of foliage and vine, so completely covering the ground after the frost, suggested the idea of planting them in the orange grove as a manure, instead of buying commercial fertilizer" (Clute 1896, p. 342). By 1897, some 300 Florida orange growers were planting velvetbean in orchards to improve soil fertility (Miller 1902; Bort 1909).

The long frost-free season required to produce velvetbean seed (190 d) initially limited its use outside Florida and the southern half of the Gulf states (Duggar 1899; Piper and Tracy 1910; McClelland 1919). This limitation was partially overcome, however, when another farmer, Mr Clyde Chapman of Sumner, Georgia, collected beans from early-maturing plants of the Florida velvetbean. Seed from these plants was distributed after 1914 throughout the southern United States as the "Georgia velvetbean" (Coe 1918). Seed was produced from these varieties in about 100 d.

Use of early-maturing velvetbean as a soil-improving crop quickly extended to the northern limits of the cotton belt (Figure 2). From 9 293 ha in 1908 (Scott 1910), the area in velvetbean grew to more than 400 000 ha by 1915 and 2×10^6 ha by 1917 (Coe 1918). The Georgia and another early-maturing variety, the "Alabama velvetbean," accounted for some 80% of the velvetbean area in 1917 (Tracy and Coe 1918).

Velvetbean was typically intercropped between rows of maize to improve soil fertility in maize and cotton rotations in the southern states. According to many researchers, as a soil improver it had no equal (Miller 1902; Piper and Tracy 1910; Ferris 1917; Braunton 1918; Cauthen 1921; Pieters 1928). Its most important use, however, was to feed hogs and cattle (Ferris 1917; Templeton et al. 1917; Scott 1919; Lamaster and Jones 1923). When first introduced in the southern states, velvetbean was grown in maize and grazed by animals in the fall and winter, after removal of the maize. The remaining residue was then ploughed under, and a new crop cycle was initiated. As experience with velvetbean grew, more of the beans were picked after the crop was killed by a heavy frost, and the beans were either fed to animals on the farm or put on the market as beans in the

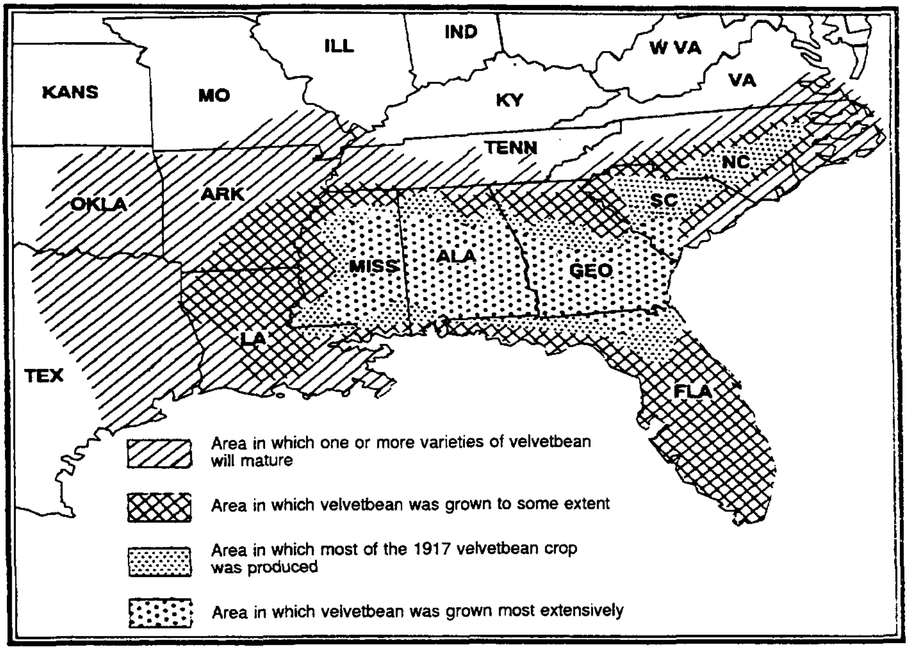

Figure 2. Distribution of velvetbean use in the United States, 1917.
Source: Tracy and Coe (1918).

hull (Ferris 1917; Templeton et al. 1917; Tracy and Coe 1918; Scott 1919; Lamaster and Jones 1923). Velvetbean pods were taken to mills and crushed or ground with the hull to provide feed for cattle, horses, and mules, largely replacing cottonseed meal as the protein component in animal feed used in the southern states (Ferris 1917; Willet 1918).

Velvetbean was very popular in the cotton belt of the United States because of its extreme vigour and its pod-producing capacity (Scott 1910, 1919). According to the early literature, velvetbean's growth greatly exceeded that of cowpeas — a common alternative green-manure crop — and it was never attacked by nematodes, a parasite that could be spread on cotton plantations by cowpea. When killed by frost, velvetbean leaves and vines would go down on the ground together, forming a close-knit mat that stayed in place until the whole crop was ploughed under. Bean yields (in the pod) of 2–3 t ha^{-1} were easily attained. The feed value of velvetbean produced on the farm for beef and milk production was comparable to that of purchased alternatives, such as cottonseed meal, but at less than 20% of the cost (Scott 1919; Cauthen 1921).

Although velvetbean was appreciated mainly for its role as a forage crop, its soil-improving effects were also well documented (Duggar 1899; Stubbs 1899; Miller 1902; Ferris 1917; McClelland 1919; Cauthen 1921). An estimated 155–200 kg N ha^{-1} was found in the leaves, pods, and roots of well-grown, sole-crop velvetbean, without mineral fertilization. When velvetbean was intercropped with maize at 30 d after maize planting, maize yields were reduced by up to 10%, but these losses were more than compensated for by subsequent crops (Ferris 1917; Tracy and Coe 1918). Maize-yield increases of 60–80% following velvetbean use were consistently reported in the early literature, prompting one researcher of that period (Duggar 1902, p. 176) to note that "velvetbeans are a cheaper source of nitrogen than is any nitrogenous material which may be bought as commercial fertilizer." Experiments conducted at various experiment stations with maize, sorghum, wheat, cotton, and oats showed that velvetbean was superior to cowpea or soybean for improving yield (Duggar 1899; Stubbs 1899; Miller 1902; Ferris 1917; Coe 1918; McClelland 1919). Even when velvetbean was grazed by cattle, soil fertility was maintained for succeeding crops (Scott 1910).

The invasion of the boll weevil and a decline in the cotton industry of the southern states boosted expansion of the area dedicated to velvetbean (McClelland 1919). Lands left relatively idle by the cotton crisis were brought back into production with velvetbean, which rapidly became one of the most important crops in the southern United States for feed and soil improvement. One researcher (Scott 1919, p. 216) noted that "the story of the velvet bean might be called an agricultural romance." Velvetbean was hailed by scientists and farmers alike as the saviour of southern agriculture because the large quantity of feed produced by the crop and its low cost stimulated the production of livestock (Ferris 1917; Coe 1918; Scott 1919). The net cash value of velvetbean produced as an intercrop in maize in 1917 was estimated by Scott (1919) at more than 20 million United States dollars (USD).

Velvetbean use declined somewhat at the beginning of the 1920s, but the crop continued to be important in the southern states until the mid-1940s, when the number of hectares in velvetbean dropped quickly (Figure 3). By 1965, velvetbean had disappeared from US agricultural statistics.

The decline of velvetbean in the southern United States was probably due to sharp drops in mineral fertilizer prices and to the increased popularity of soybean as a commercial crop. Both velvetbean and soybean could be intercropped with maize to improve soil fertility and could be grazed by cattle and pigs, and the seed of either one could be harvested for use in animal feed. Soybean, however, was a more versatile crop, garnering a much higher price as a grain crop.

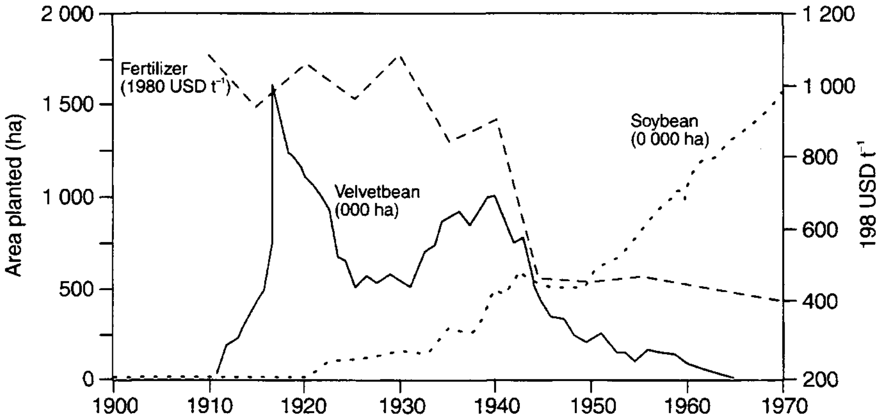

Figure 3. Velvetbean area, fertilizer use, and soybean area, United States, 1900–70 Source: USDA (1910–70); Hayami and Ruttan (1985, table c-2); Buckles (1995). Note: Current farm expenses for fertilizer divided by quantity of principal plant nutrients (N, P, and K).

According to United States Department of Agriculture (USDA) statistics, the production value of velvetbean grain in 1944 — the year the velvetbean area began to decline sharply — was 29 USD ha^{-1}, compared with 91 USD ha^{-1} for soybean. The soybean area in the United States began to increase sharply as the velvetbean area declined, reflecting the substitution of the one crop for the other. This shift in production was accompanied by a drop in the real price of commercial fertilizers during the mid-1940s, which further contributed to the decline of velvetbean and other soil-improving crops, such as cowpea, in the United States.

Velvetbean use in Mesoamerica

Enthusiasm for velvetbean in the United States stimulated diffusion of seed to many countries in the tropics for experimentation during the early part of this century. Initially, velvetbean seed was sold by seed companies in the United States under the name "banana field bean" (Duggar 1899; Bort 1909, p. 26) and was later distributed as velvetbean throughout the tropics by the USDA (Piper and Tracy 1910). Velvetbean and knowledge of its uses in Mesoamerica can be linked to management practices developed by farmers in the southern United States. The plant was probably introduced as a forage crop in Mesoamerica in the 1920s by the United Fruit Company, a banana producer with extensive tracts of land along the Atlantic coast of Central America. Elderly banana-plantation workers in Morales and Puerto Barrios, Guatemala, reported that velvetbean was grown in maize by plantation workers on company land and grazed by mules used to transport bananas from the plantations to the railway depots (Buckles 1995).

The use of velvetbean as a forage crop by the banana companies faded as mules were replaced by tractors during the 1930s, but the plant retained the name "mule bean," or *quenk mula*, among the Ketchi natives of Guatemala. The Ketchi, originally from the densely populated highland area of Verapaz, were employed on banana plantations in Guatemala and may have become familiar with velvetbean on these estates. Carter (1969) reported that the Ketchi migrating to the lowland valley of Polochic, in the department of Izabel, Guatemala, had been planting velvetbean in rotation with maize since their arrival in the 1950s. Commercial farmers, also settling in the valley during the 1950s, used velvetbean for a dual purpose: as a soil improver for maize and as a forage crop for cattle. According to elderly residents interviewed by DB, the crop was first introduced in the valley during the 1930s by a Jamaican banana-plantation owner financed by the United Fruit Company (see also Carter 1969).

The velvetbean-management strategy used by commercial farmers and Ketchi in the Polochic Valley differed from that used by US farmers. Whereas velvetbean was intercropped in summer maize in the United States, in Guatemala a rotation strategy with second-season maize was developed. As in northern Honduras, the mature velvetbean crop was slashed with a machete in November, and then maize was stick planted into the layer of decomposing velvetbean leaves and vines. After the maize harvest, the velvetbean crop reestablished itself through natural reseeding or was replanted by the farmer, thereby continuing the rotation indefinitely. These farmers also grew maize during the main wet season on a different field, using traditional techniques of slash-and-burn cultivation (Carter 1969).

The use of velvetbean by commercial farmers in the Polochic Valley declined sharply during the 1970s, when much of the land used for maize production was diverted to pasture for cattle (Buckles 1995). The increased area of pasture in turn reduced requirements for velvetbean as a forage crop. These changes occurred before commercial fertilizers became widely available in the valley. In fact, the few remaining large-scale maize producers in the valley continue to grow second-season maize in rotation with velvetbean, reportedly with better yields and higher net returns than those gained from maize-production practices based on commercial fertilizers (Chávez 1993; Buckles 1995). This account suggests that broad changes in land-use patterns may have more of an effect on the use of velvetbean in Mesoamerica than alternative maize-production techniques — an issue that emerges again in northern Honduras.

Velvetbean is still used by the Ketchi in the Polochic Valley, the northern coastal mountains near Livingstone, the Petén, and border areas in Belize. The crop has also been used since at least the 1950s by indigenous farmers in the Mexican states of Chiapas, Oaxaca, Tabasco, and Veracruz. The Mames of southwestern Chiapas (Tsuzuki, personal communication, 1993[1]) and the Nahua of Mecayapan in southern Veracruz (Buckles and Perales 1995) manage velvetbean on hillside land as a rotation crop, with winter maize, using practices similar to those of the Ketchi. The Popoluca of San Pedro Soteapan, also in southern Veracruz, broadcast velvetbean over maize fields they intend to fallow, giving rise to a practice they refer to as making a fallow field (*hacer acaual*). According to experienced farmers, maize yields on land improved using velvetbean for 2 years rival yields on land fallowed for 5 years with native trees and shrubs, a significant intensification of the traditional cropping cycle (Buckles and Perales 1995).

The Mixe and Chinantecos of southeastern Oaxaca have also used velvetbean for several decades in rotation with winter maize (Arévalo Ramírez and Jiménez Osornio 1988). However, the land type dedicated to the rotation differs from the hillside land used by the Ketchi, Nahua, and Popoluca. In southeastern Oaxaca, velvetbean is established on riverbanks subject to occasional flooding. This land is often very fertile because of the periodic deposition of new soil through floodwaters, but it is unsuitable for most wet-season crops because of the risk of flood damage. Furthermore, the riverbanks are heavily infested with weeds brought in with the sediment, and this increases the cost of cultivation. These features make riverbanks ideally suited, however, to the production of winter maize with velvetbean; the aggressive cover crop chokes out weeds, and when it is cut down, it forms a mulch that conserves the residual moisture from the wet season, which is needed to produce maize during the relatively dry period of the year (Narváez 1996.

The varied land types and traditional farming practices of the Chontales of Tabasco have given rise to yet another variation on the management of velvetbean with winter maize. These farmers use hummocks in the marshlands of their territory to grow winter maize in a velvetbean mulch, into which they also interplant squash (*Cucurbita pepo* L.) — an adaptation of the maize–bean–squash triad characteristic of indigenous intercropping systems in Mesoamerica (Miranda Medrano 1985; Granado Alvarez 1989). The diversified system controls soil pests that would otherwise significantly affect maize yields (Quiroga Madrigal et al. 1991).

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[1]A. Gonzalo Tsuzuki, agronomist, personal communication, 1993.

Figure 4. Areas in Mesoamerica with spontaneous adoption of velvetbean–maize rotations.

Velvetbean was introduced in northern Honduras during the early 1970s, possibly by two Guatemalan brothers who settled in Planes de Hicaque near Tela. A Honduran brother-in-law of theirs is credited with introducing the seed into San Francisco de Saco, also one of the earliest sites of velvetbean use in northern Honduras. It grew wild there, unnoticed, for a number of years. A few farmers in the community observed the plant's ability to control weeds and improve maize yields in fields where it dominated, thereby rediscovering the rotation practice of the Ketchi and others. In northern Honduras, a field of velvetbean became known as an *abonera*, or "fertilized field." The velvetbean seed became known as *frijol de abono*, "the fertilizer bean," in recognition of one of its main benefits.

No evidence has been found to explain how velvetbean was diffused among all these populations (Figure 4). Migration patterns and trade links among indigenous peoples in the region may have played a role. The Ketchi (early users of velvetbean) were displaced by political forces to areas throughout Guatemala and Belize and into southern Mexico, possibly taking velvetbean seed and knowledge of its uses with them. The person credited with introducing velvetbean to the Nahua of southern Veracruz migrated to the area from a Nahua enclave in Tabasco, where velvetbean is also used (Buckles and Perales 1995). Currently, velvetbean seed produced in the Guatemalan lowlands is marketed as a coffee substitute among indigenous people in the highlands who are linked culturally to the Mames of Chiapas. The use of velvetbean as a coffee substitute may also have stimulated diffusion of the seed, if not the cover-crop management practices as well.

Conclusions

The development and diffusion of velvetbean–maize associations are the result of experimentation by numerous farmers and scientists, spanning four centuries and taking place in at least eight countries. Farmers, agronomists, and transnational corporations are all linked in a fortuitous and complex chain of events that confound both conventional and farmer-first notions of technology generation and transfer. The development of velvetbean-management practices in the United States and Mesoamerica did not proceed in a linear fashion from agricultural research stations to farmers' fields. Nor did these practices simply arise from unadulterated local knowledge and innovation; rather, velvetbean seed and knowledge of its uses were diffused because numerous groups' "borrowed" and adapted foreign species and practices. This experience illustrates the dynamic and social nature of agricultural innovation: new ideas do not emerge from a vacuum, nor are they the purview of a privileged class of innovators.

The links to the past and across continents are strong. At the same time, current uses and adaptation of the crop show that farmers are sophisticated knowledge producers in their own right. Within a very short period, farmers in various places were able to assimilate, adapt, and integrate the use of velvetbean into cropping systems with distinctive land types and crop mixtures. The speed and inventiveness with which this was accomplished illustrate the close relationship between local knowledge and innovation. For the Popoluca of Veracruz, broadcasting velvetbean to make a fallow field was an extension of shifting-cultivation practices, used to restore soil fertility, eliminate weeds, and improve soil structure. The Chontales' management of maize, velvetbean, and squash arose from a traditional intercropping strategy. The use of velvetbean by the Mixe to control weeds on riverbanks derived from a well-developed understanding of local land types and plant biology. A practical understanding of the logic behind the way velvetbean works was a distinct advantage in the innovation process. Recognizing and strengthening this knowledge may provide new opportunities for building on older practices — an issue to which we return in the final chapter of this book.

CHAPTER 2
THE ENABLING ENVIRONMENT

Regional agroecology

Northern Honduras borders the Caribbean at about latitude 16°N and is divided into the departments of Atlántida, Colón, and Cortés (see Figure 1). The climate of northern Honduras is classified as humid tropical (Piñeda Portillo 1984; Zúñiga Andrade 1990). The sudden rise of the Nombre de Dios mountain range, from sea level to more than 2 400 m asl, interrupts moisture-laden prevailing winds from the Caribbean. This generates high annual rainfall in a bimodal distribution (Hargreaves 1980; Zúñiga Andrade 1990; van Wambeke 1992). Average annual precipitation throughout the region is at least 3 000 mm, with some rain during virtually every week of the year (Figure 5). The first rains usually begin in June, establishing the *primera*, or "first season." Rains are light at this time and subject to considerable variability from year to year, creating a production risk for farmers planting first-season crops. The heaviest and most consistent rainfall on the Atlantic coast coincides with the last trimester of the year (September–December), which initiates a second major cropping season, known as the *postrera*, or "second season." Daily rainfall of 100–200 mm is not uncommon during this period, producing monthly accumulations of 1 000 mm or more.

Rainfall is erratic during the later part of the second season. However, the soil profile usually contains 200–300 mm of stored water by the end of the heavy-rainfall period, making it possible for many crops and natural vegetation to resist a drought of 4–6 weeks with little negative consequence. By April, the rains diminish, ushering in a short, relatively dry period, known as *verano*, or "summer," that runs through to the end of May.

The average annual temperature at sea level is about 26°C, with an average year-round variation of only 10–12°C. Temperatures reach their peak in May, averaging 28°C, with average maximums of 30–32°C. The coolest month is January, which has an average temperature of 24°C and average minimums of 15–17°C. Evapotranspiration, as calculated by Hargreaves (1980), remains moderate during the rainy season (about 3 or 4 mm d^{-1}), increasing slightly during the

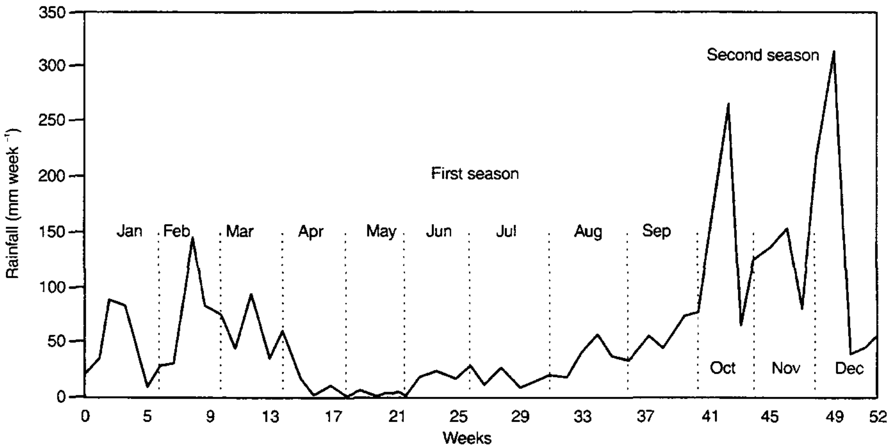

Figure 5. Average weekly rainfall, Finca Buena Vista, Atlántida, northern Honduras. Source: Finca Buena Vista Experiment Station, 1989–91.

dry season (to 5 mm d^{-1}). Winds are moderate most of the time, although occasional hurricanes and other tropical storms characteristic of the Caribbean can cause damage to crops, especially during the second season.

Climatic variations in northern Honduras occur up the altitudinal gradient of the Nombre de Dios mountain range and, to a lesser degree, along the coast. Increases in average annual rainfall at higher altitudes are due to precipitation from moisture-laden winds when temperatures decline. The eastern extreme of the region (Jutiapa) is a dry spot, with less rainfall (2 000 mm a^{-1}) as a result of the earlier onset of the dry period. Rainfall patterns also vary from community to community within the region (Figure 6).

Although the climatic conditions in northern Honduras are always wet, they vary periodically (Zúñiga Andrade 1990). Relatively wet periods occurred during the late 1970s and early 1980s, and relatively dry periods occurred during the mid-1970s, mid-1980s, and the early 1990s. In 1991, 1994, and 1995 the dry season lasted 4–5 months. These periodic variations in rainfall create uncertainty, but farmers estimate that fewer than 2 "bad years" occur out of every 10; many actually dispute the very idea that climatically bad years occur at all. Isolated rains fall irregularly here and there, even during the drier summers, sustaining most agricultural activities.

Northern Honduras is endowed with relatively rich, largely undegraded soils. Sedimentary materials from the ocean floor were pushed up during the Tertiary Period to form the Nombre de Dios mountain range, which runs parallel

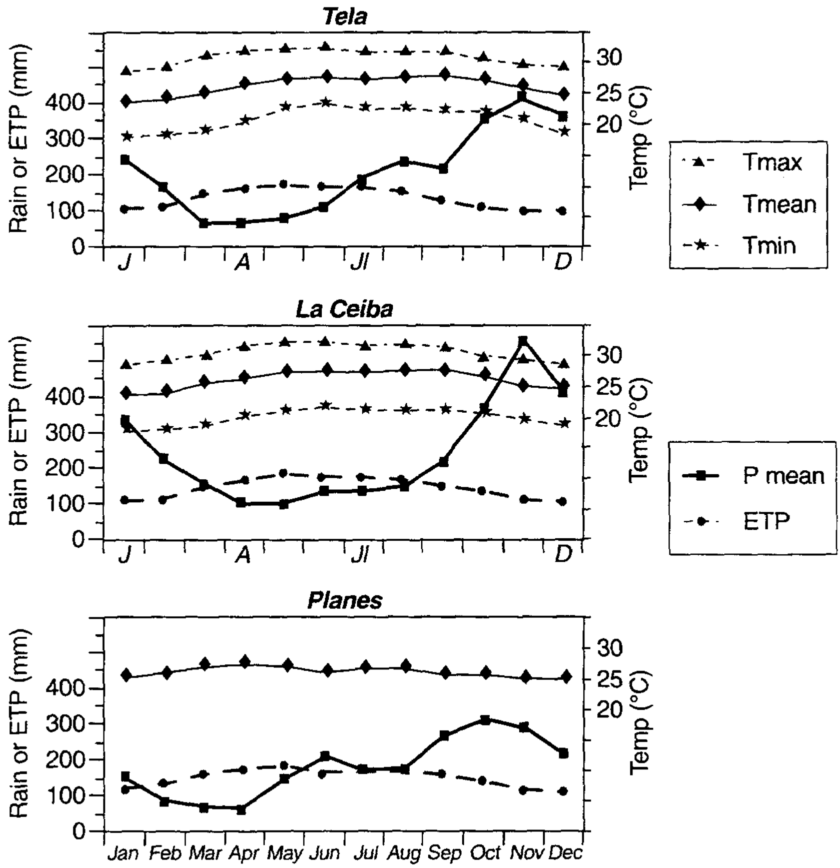

Figure 6. Average annual rainfall in three communities, northern Honduras. Source: Hargreaves (1980). Note: ETP, evapotranspiration; P, precipitation; T, temperature.

to the coastline and has peaks culminating at almost 2 500 m asl. This landform creates three contrasting natural regions: the mountain zone, the coastal plain, and an intermediate hillside zone (PDBL 1991).

The flat terrain and rolling hills of the coastal plain, a narrow strip along the coast that is less than 100 m asl, have the best agricultural land in the region. Slopes are typically less than 10% and never exceed 20% throughout the zone; topsoil depth is commonly more than 60 cm. The soils, derived from continental-shelf and recent marine deposits, are fertile Tropic Fluvaquents, with favourable properties for agriculture. Humid tropical forest was the primary vegetation type in this area — most of it was removed for ranching and agriculture before the 1940s (Yuncker 1939, cited in Ludeke 1987). Numerous rivers originating in the mountains dissect the plain; several of these rivers periodically flood coastal towns

Table 1. Typical ranges for selected soil properties at four sites in the hillsides of northern Honduras.

Property	Depth (cm)	San Francisco de Saco	Las Mangas	Rio Cuero	Piedras Amarillas
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
Ex. Ca and Mg (cmol[+] kg^{-1})	0–10	8–18	20–30	6–14	10–18
	30–60	10–22	20–30	3–8	7–17
Available P (Morgan) (ppm)	0–10	0–4	4–10	0–3	0–3
Sand (%)	0–10	40–55	30–50	40–60	NA
Clay (%)	0–10	15–30	20–35	15–25	NA
Clay (%)	30–60	20–40	25–40	20–30	NA
Typical soil depth (cm) [a]	—	>80	>80	60	60–80

Source: Triomphe (1996).
Note: Ex., exchangeable; NA, not available.
[a] No obstacle (physical or chemical) to root colonization down to this depth.

and cities during the peak rainy season, cutting them off temporarily from the rest of the country. The main land uses on the coastal plain are pastures for dual-purpose cattle production; banana, pineapple, and African palm plantations; and some rice production.

The hillside zone — below 600 m asl — is less suitable for agriculture than the coastal plain because of the very steep slopes, yet basic grain production is concentrated in this hillside zone. Soil types vary by elevation and specific location but include Ultic Hapludalfs, Typic Dystropepts, Typic Hapludults, Tropohumults, and Tropudults (Rosales and Sánchez 1990), derived mainly from hard metamorphic rock originating in the Paleozoic Era (Simons 1969). Most of these soils are relatively deep (typically 60–80 cm) and have mildly acidic pH (around 6.0) and good levels of exchangeable bases to a depth of 60 cm or more, usually from 10 to more than 20 cmol(+) kg^{-1} (Table 1). With soil properties like these the hillside zone would be favourable for agriculture were it not for the steepness and susceptibility to erosion of the landscape.

In the hillsides, topography is mixed but largely dominated by irregular, rolling landforms with slopes typically ranging between 20 and 100% (PDBL 1991). For example, the slopes of three-quarters of the buffer zone surrounding the Pico Bonito National Park (an area typical of the hillsides of the region) exceed 30%, and those of one-quarter of the area exceed 75% (Rodríguez Torres

1992). Many of these slopes are very unstable, which commonly results in localized landslides during periods of intensive rainfall. Very humid subtropical forests characterize the primary vegetation of the hillside zone, much of which has been displaced by crops, natural pastures, and secondary forest. The high risk of erosion, created by steep slopes and high rainfall, is the most important limitation on hillside agriculture in northern Honduras (Mikhailova 1995).

The mountain zone is generally unsuitable for agriculture, as it has very steep slopes and undeveloped, thin soils (PDBL 1991, 1994; Labelle et al. 1990). Hard igneous rock thrust to the surface during the Tertiary Period has evolved into Ultisols, the top horizon of which is typically less than 40 cm thick. Slopes through much of this zone exceed 50% (some exceed 100%), creating a very high risk of erosion after the forest cover is cleared. Very humid subtropical montane forest is the primary vegetation type at 800–1 800 m asl, and cloud forest predominates at higher elevations (PDBL 1991). Both forest types in the mountain zone are under increasing pressure from loggers, ranchers, and farmers using shifting cultivation who are migrating into the region.

Cultivated and natural pastures account for 50% of the farm area in Atlántida (Table 2). Permanent crops, such as African palm and pineapple on plantations, account for a much smaller percentage of the total farm area, but the land they are grown on includes some of the best agricultural land on the coastal plain. Maize, beans, and rice are the most important annual crops, and these are concentrated mainly in the hillside zone. Broadleaf forests, concentrated mainly

Table 2. Land uses, department of Atlántida, Honduras, 1993.

	Area (%)	Area (ha)
Total department area	—	425 120
Total farm area	—	162 494
Annual crops	11	17 812
Permanent crops	15	23 915
Cultivated pastures	33	54 363
Natural pastures	17	27 111
Fallow land	17	27 855
Forests on farm	5	8 543
Other uses on farm	2	2 895

Source: SECPLAN (1994).

on the high hills and mountain slopes of the Nombre de Dios range, still cover perhaps as much as 60% of the department area. However, the rate of destruction of broadleaf forests in Honduras is estimated at 46 000 ha $year^{-1}$, a rate of deforestation that will soon claim all significant remnants of this important forest type (Silviagro 1994; Kaimowitz 1996; Sunderlain and Rodríguez 1996).

In sum, the hillsides of northern Honduras have at least two of the major ingredients of potentially successful small-scale agriculture, namely, relatively good soils and a favourable climate. The rainfall pattern allows the completion of two rain-fed cropping cycles annually and the cultivation of a variety of perennials, such as cocoa, coffee, African palm, citrus, and a large range of fruit trees (PDBL 1991). Also, it is usually possible to keep the pastures green and growing year-round. The risk of total crop failure due to lack of rainfall is small, even during the second season, which is in sharp contrast to the situation in much drier regions of Honduras.

The seasonality of maize prices

The distribution of rainfall in the northern coastal area of Honduras is significantly different from that in the rest of the country (Figure 7). The convergence of southern and eastern winds from the intertropical zone generates and maintains a rainy period from mid-May to mid-October in most of the country, but the rainy period has less intensity and begins later on the northern coast. Cold winds and polar air

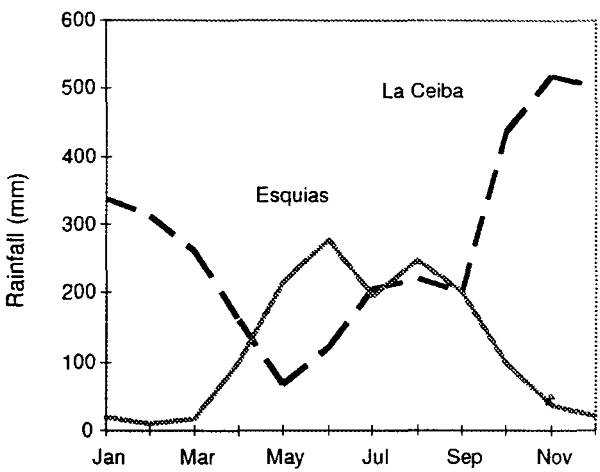

Figure 7. Average monthly rainfall, La Ceiba, Atlántida, and Esquias, Comayagua, 1980–89. Source: Zúñiga Andrade (1990). Note: The rainfall pattern in Esquias is common to central Honduras.

masses originating in the northern part of the hemisphere increase rainfall on the northern coast from October until January while producing a sharp drop in precipitation on the Pacific coast and southern and interior parts of the country. Clear skies and hot, dry weather follow throughout most of the country as the meteorological influence of the northern hemisphere declines, but rainfall on the northern coast is prolonged because of occasional tropical storms and hurricanes. Thus, the interior and southern regions experience long dry periods, whereas some rain falls throughout most of the year in northern Honduras.

Regional climatic differences have important implications for national agricultural production. The northern coast is one of only three regions in Honduras where the pattern of monthly rainfall allows farmers to have two cropping seasons in the year. In most of the rest of the country, maize production is limited to the first season.

The dominance of first-season maize production produces strong seasonal fluctuations in national and regional maize prices. Some 80% of the total annual maize production at the national level is produced in the first season, resulting in a trough for maize prices during the 3 months of harvest (October–December). By January, the national supply of maize decreases, so maize prices start to rise; the prices continue rising until the beginning of the harvest of the second season (March–April). Prices drop again as the supply of second-season maize flows into the market, but as the total volume is relatively low, maize prices stay above the annual average. In June, prices start to rise again and the seasonal price cycle starts over again (Figure 8). The amplitude of the price fluctuation between the second-season (+5%) and first-season harvests (−15%) is high, providing farmers

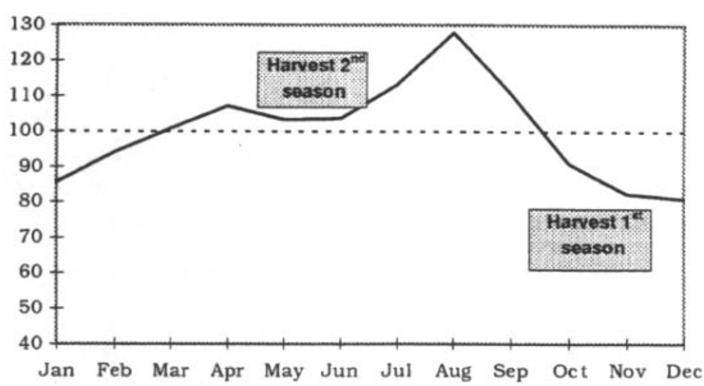

Figure 8. Seasonal pattern of maize prices at wholesale level, 1970–91, Honduras. Source: Sain et al. (1994).

with a strong incentive to plant second-season maize. (An additional advantage of the second over the first season is that the harvest occurs during a dry period, when the maize cob is relatively free of diseases.)

Before 1980, cultivation of second-season maize in northern Honduras was not widespread because first-season maize met regional demand and because farmers were relatively isolated from the national maize market. Improvements in transportation networks facilitated a shift in production patterns, but the second-season crop overtook the first as a proportion of total maize area and production only when use of the *abonera* system became widespread. The connection between diffusion of the *abonera* system and regional increases in second-season maize production is examined further in Chapter 6.

The availability of hillside land

Extreme inequalities in the distribution of agricultural land is a central and persistent feature of the Honduran countryside (Galvez et al. 1990; Rubén 1991; Pino et al. 1992; Stonich 1992; Walker 1993). The new agroexport industries of the 1950s and 1960s (cattle, cotton, shrimp) were accompanied by the concentration of land ownership in the fertile valleys and coastal plains of Honduras and a decline in rural employment (del Cid 1976; White 1977; Posas 1980; Howard-Borjas 1989; Ponce Cambar 1990; Thorpe 1991; Stonich 1992). Slow urban-based industrial growth was unable to absorb the displaced population, and people migrated to the agricultural frontier, urban slums, and other countries (Brockett 1990; DeWalt et al. 1993).

The availability of land in northern Honduras drew displaced populations, helping to reduce social unrest relative to that in other countries in Central America, where striking inequalities in land distribution also exist. As a result of migration, the population of northern Honduras grew at an annual rate of 4.2% between 1970 and 1990 (the nation as a whole had a 3.4% annual growth rate during this same period). During this period, population density in northern Honduras increased from 35 km^{-2} to 57 km^{-2}. The department of Atlántida currently has a population of about 243 000, and many of these people came from elsewhere.

Tolupan peoples (an indigenous population) originally lived along the coast and in the mountains of northern Honduras, but they are currently limited to a few communities in the neighbouring department of Yoro (Spahni 1982). Moskito natives live farther east, in the department of Gracias a Dios. A small *Garifuna* population (a people of escaped slaves) inhabits fishing villages along the coast.

New migrants to northern Honduras found few opportunities on the fertile coastal plain. The Honduran government made extensive land concessions during the early part of this century to the United Fruit Company and predecessors of the Standard Fruit Company; in exchange, the companies were to construct railways in the region (Ellis 1983). The companies established large banana plantations and extracted immense quantities of precious wood but completed only one of the several railway lines they were supposed to construct. In subsequent years, parts of these holdings were sold to Honduran nationals and military families turned ranchers and plantation owners (Euraque 1993). The land reforms of the 1970s created a number of peasant collectives from unused and remote coastal lands held by the transnationals, but the reforms did not significantly alter the regional agrarian structure (Rubén and Fúmez 1993).

The demand for labour in both plantation agriculture and cattle ranching was and remains low, limiting the opportunities for employment of landless workers. The transnationals had drastically reduced their labour force through mechanization after a major strike in 1954 (Ellis 1983), and land-extensive ranching practices common in the area employed few workers. In recent years, development of a regional capacity to process milk and milk products for national and international markets has spurred rural employment (Humphries, in press), but this has been insignificant relative to the large number of new arrivals.

Urban growth has been very rapid, resulting in a high concentration of urbanites (60% urban population for the department of Atlántida; 45%, for the nation — World Bank 1993). Urban growth is due primarily to the importance of La Ceiba, the third largest city in Honduras. La Ceiba figures highly in the agricultural history of Honduras but has been eclipsed in recent decades by the industrial centre of San Pedro Sula and the Port of Cortés, both in the neighbouring department of Cortés. Industrial development in La Ceiba has been limited, despite the establishment of a free-trade zone within the city limits, where some textile factories have opened. Shantytowns have sprung up around the city, serving as a temporary staging ground for migrant families in search of land or employment.

The concentration of land ownership on the coastal plain and low levels of employment generated by regional land uses and industrial activity have forced most new arrivals in northern Honduras to settle on the hillsides and upper slopes of Nombre de Dios. Until the late 1960s, the sloping lands of the region were virtually unoccupied and claims could be made simply by clearing the forest cover and registering the claim with municipal authorities. Most forested land in Honduras is state property, subject to usufruct (*dominio útil*), or squatters' rights. Although squatters' rights are less flexible than titled forms of property, the landless

Table 3. Farmers' reasons for leaving their place of origin, northern Honduras, 1992.

Reason	Households (%)	Households (*n*)
No access to land	45	47
Land degraded	24	25
Parents migrated	14	14
Personal conflicts	9	9
War with El Salvador	8	8

Source: Authors' survey, 1992.

can transform their labour into property rights on state land by clearing it for cultivation. Some 80% of all landowners in Honduras rely on squatters' rights to the lands they occupy and use (SEDA 1993).

The hillsides of northern Honduras were settled mainly during the 1970s and early 1980s and now have a fairly stable population, living in about 110 small towns and hamlets between Tela and Jutiapa (see Figure 1). Farmer-survey data indicate that more than three-quarters of the hillside families migrated to the region from other parts of the country. Most, however, reported that they had been living in the same hillside village for more than 15 years. By contrast, the upper slopes of Nombre de Dios, generally unsuitable for agriculture, continue to be an active frontier. Almost half the families interviewed by Humphries (in press), in three mountain villages had arrived there within the previous 5 years.

Farmers' reasons for leaving their home communities are overwhelmingly related to land degradation and to a lack of access to land (Table 3). Almost half the farmers interviewed in 1992 reported leaving their home communities because they had no land of their own or not enough, and one-quarter cited the declining quality of their land as the reason for migrating. Humphries (in press) also found that land degradation — perceived by farmers in terms of declining yields and increasing aridity — was a frequently cited reason for migration. In her study, as well as in our own, the Honduran war with El Salvador in 1969 was cited by some farmers as the reason they fled the western border communities.

Although the settlement of the hillsides is relatively recent, the distribution of land is already moderately concentrated (Table 4). Farm-survey data indicate that only 17% of the landowners had farms larger than 20 ha, but these landowners possessed 58% of the land in the hillside zone. Most were ranchers (see Chapter 3). By contrast, 46% of the landowners held only 10% of the total land,

Table 4. Distribution of land in the hillside zone and in the department of Atlántida, Honduras, 1992 and 1993.

Size of land holding (ha)	Survey of hillsides, 1992		National agricultural census, department of Atlántida, 1993	
	% of landowners	Land owned (%)	% of landowners	Land owned (%)
0.1–2.0	17.5	1.3	41.0	2.7
2.1–5.0	28.9	8.6	20.4	5.0
5.1–10.0	17.5	10.4	11.8	6.5
10.1–20.0	18.6	22.2	10.1	11.0
>20.0	17.5	57.6	16.7	74.8

Source: Authors' survey, 1992; SECPLAN (1994).

in holdings of less than 5 ha. Agricultural-census data from the department of Atlántida (SECPLAN 1994) reveal an even higher degree of land concentration for the region as a whole: almost three-quarters of the land is owned by some 17% of the landholders, in holdings of 20 ha or more. This reflects a higher degree of land concentration in the prime lowland area than in the hillside zone.

The concentration of land ownership is an important but not absolute limitation on access to hillside land for farming. Some 21% of the farm families interviewed in the hillside zone owned no farmland but were engaged in farming. These households used the land of others in exchange for cash, labour, or a share of the harvest. Humphries (in press) argued that early settlers on the hillsides claimed larger properties than they initially needed, with a view to making some of this land available to family members. This has given rise to a form of extended-family land ownership that is based on relations of interdependency between the older landowners, who need support in their old age, and their younger, landless sons and sons-in-law, who stand to inherit their land.

A more formal land-rental market is also well developed in northern Honduras, a market partly created by pasture-management practices. Medium- and large-scale landowners rent out fallow land to small-scale and landless farmers, who clear the land for annual crops. After a few cycles, this land is transformed by the farmers or the landowners into pastures for grazing cattle, a process documented throughout Central America (DeWalt and DeWalt 1984; Leonard 1987; Brockett 1990; Stonich 1992; Kaimowitz 1995).

However, in northern Honduras, the conversion of farmland into pastures is not permanent. The maintenance of permanent pastures, given the extremely high rainfall, extensive grazing, and seasonal overgrazing that are typical of the hillside zone, is very costly, prompting many ranchers to allow their pastures to gradually revert to fallow land. This fallow land is once again loaned out to farmers, who reestablish the pastures for the ranchers. Thus, through land-rental markets, movement of land is fairly constant from fallow, to crops, to pasture, and back to fallow again. The land-rich people benefit from the low costs of pasture establishment that these arrangements provide, and the land-poor people gain access to some farmland. Three-quarters of all households surveyed in 1992 rented some of the land they worked — typically 1 ha or so for maize and other annual crops. (Few households reported that they were renting pastures at the time of the survey, although informal interviews indicated that the practice was common among large-scale ranchers. As a result, the importance to ranchers of land-rental markets as a means of gaining access to pastures is probably greatly underestimated. This weakness in the survey data also biases estimates of ranchers' total farm size. We maintain, however, that more complete data would make no change in the general patterns identified.)

In sum, the availability of hillside land has allowed farm households displaced from other regions to settle and establish farms of their own, an option closed to them on the coastal plain. The availability of hillside land through ownership or land-rental markets enables farmers to use relatively extensive cropping patterns, such as shifting cultivation.

Shifting cultivation in northern Honduras

Maize, beans, and upland rice are the most important annual crops grown on the hillsides of northern Honduras, accounting for 92% of the cropped area (Table 5). Maize can be grown during either the first or the second season, and beans can be grown three times a year (February, June, and October). Upland rice, because of its moisture requirements, can only be grown during the first season. Cassava,

Table 5. Crops as a proportion of total cropped area in the hillside zone by cropping season, 1991/92.

Crop	% of cropped area, first season	% of cropped area, second season	% of cropped area, total
Maize	64	85	74
Beans	17	4	11
Rice	13	—	7
Other [a]	6	11	8

Source: Authors' survey, 1992.

[a] Cassava, chilies, and tomatoes (first season) and plantains and tree crops (second season).

plantain, cacao, coffee, and various citrus-fruit trees are also grown by most hillside farmers in small quantities, typically on the house compound. A few farmers produce quantities of chilies or tomatoes.

Traditionally, maize and other annual crops are grown using the shifting-cultivation techniques characteristic of the humid tropics (Weischet and Caviedes 1993). Trees and other fallow vegetation are slashed and burned to prepare the land for a short period of cultivation with annual crops (one to three cycles), followed by an extended period of fallow (anywhere from 5 to 20 years). The machete, axe, hoe, and dibble stick are the main farm implements.

Cropping patterns typically begin with first-season maize. Farmers prepare the land between March and May, depending on the amount and type of land being cleared. They slash low fallow vegetation by hand, using machetes, but need an axe to cut larger trees. After the vegetation is thoroughly dried, the farmers burn it in place, which not only clears the field for planting, but also allows the ash that remains to fertilize the soil. Burning is also supposed to reduce the risk of pests, such as rats, and maize diseases. The soil is exposed, however, to the erosive effects of rain, at least until the crop develops a protective canopy.

Farmers on hillside land in northern Honduras do not till the land before planting maize or other crops. Most farmers surveyed in 1992 limited land preparations for first-season maize to clearing and burning operations, although a quarter of the farmers also applied a contact herbicide (2-4D or paraquat) to their field to control weeds before planting.

Planting time for all first-season crops depends on the onset of the first rains, which are usually well established by early June. The farmers use dibble sticks to punch holes in the ground, then place three to five maize seeds into the holes, at densities ranging from 30 000 to 44 000 seeds ha^{-1}. As discussed in Chapter 5, plant density at harvest is much lower. More than two-thirds of the farmers surveyed used local maize varieties (Olotillo, Tusa Morada); the rest reported using open-pollinated varieties released through the national agricultural-research system. The farmers do not renew seed from improved varieties on a regular basis, with the result that the improved varieties are subject to introgression by local cultivars. To date, hybrid maize is practically unknown in hillside maize production (Sain and Matute Ortíz 1992).

Maize is weeded twice, with the first control usually done manually at about 30–35 d after sowing and the second control done with herbicides at about 40–45 d after sowing. Paraquat and 2-4D are the most commonly used herbicides, and these are applied with back-sprayers. Although herbicides are common, most farmers (71% surveyed) use no fertilizer with first-season maize. When fertilizer is applied, rates of application are very low (20–50 kg N ha^{-1}). The cost of commercial fertilizer and the high production risk associated with the first season are the most commonly reported reasons for not using this input.

According to the farmers' practice, the first-season maize plants are bent over (*doblado*) at a point under the ear after they reach physiological maturity, to facilitate the ears' drying in the field before harvest and to protect the plants from damage from birds. The ears are picked after they have dried. Because of the high incidence of ear rot, first-season yields on the hillsides of northern Honduras are generally low, 1.2 t ha^{-1}, compared with the national average, 1.5 t ha^{-1}.

Although maize cultivation in most of Honduras is restricted to the main rainy season, climatic conditions in northern Honduras allow a second maize cycle during the second season. Maize-cultivation practices differ in several key respects between the first and second seasons. Farmers do not burn the field before planting second-season maize but leave the slashed crop residues and weeds from the previous cycle on the field. The slash does not significantly interfere with planting, and it helps conserve soil moisture during the relatively dry period from February to April. Land preparations are usually initiated in November, and most fields are planted by December or early January.

About 44% of the farmers surveyed applied small amounts of fertilizer-N to second-season maize. Using fertilizer is less risky in this season than in the first season and is potentially more profitable. However, very few farmers apply fertilizer in *abonera* plots, as the farmers believe it is unnecessary — an issue discussed further in the following chapter.

Second-season maize reaches physiological maturity between March and June. The doubling operation is not needed during the second season, as the ears dry if they are left upright under the winter sun. Because it is a relatively dry period, yield losses from ear rot during the second season are minimal. Weed pressure is also less severe, as a result of lower overall rainfall. In most years, however, enough rain falls during the second season to complement stored water and avoid drought stress. As a result of these favourable conditions, maize yields of 1.5–2.0 t ha^{-1} are common, and labour costs are considerably lower.

Second-season maize is more successful than first-season maize, primarily because of the lower incidence of ear rot (known to Honduran farmers as *maiz muerto*, or "dead maize"), caused by *Stenocarpella maydis*, *S. macrospora*, and *Fusarium moniloforme*. These fungal diseases are transmitted from crop residues and other sources of the inoculant to plants weakened by poor nutrition, insect damage, and abiotic stresses. Maize plants are also vulnerable to the rapid spread of *Stenocarpella* spp. through rainfall splash during the flowering and grain-fill stages. Conditions favourable to the spread of ear rot are greatest during the first season, as the maize plant passes through the vulnerable stages at the height of the rainy season. In contrast, second-season maize reaches physiological maturity during the relatively dry period between April and May. Second-season yield losses caused by ear rot are virtually nonexistent.

Maize is usually planted as a sole crop, although it may be followed in relay by beans. In the hillside zone, beans can be planted three times a year (February, May, and October). Humphries (in press) noted that farmers tend to choose May for the principal bean cycle because of higher yields, a tendency confirmed by our survey data. Bush beans are the most common varieties, typically planted as sole stands or relayed into maize. As in many other parts of Central America, bush varieties have displaced the climbing beans characteristic of traditional maize-based farming systems.

Beans are usually cultivated on very steep hillsides to facilitate rapid drainage, especially during the first season. The risk of web blight — a common bean disease in Central America, caused by excessive moisture — is reduced in this manner, as well as through burning all crop and weed residues during land preparations. The risk of soil erosion, however, is greatly increased, a problem Humphries (in press) considers the most important threat to sustainable bean production in the region. Bean yields range from about 800 to 1 000 kg ha^{-1}, which are reasonable returns, considering the level of technology (Matute Ortíz 1992).

Because of moisture requirements, upland rice is limited to the first season and is usually planted on flatter lands with good moisture-holding capacity. Land recently cleared from fallow is also preferred for rice, to ensure higher levels of soil fertility. Very small fields are planted, however, partly because of limitations on access to appropriate sites but also because of competition for labour; rice cultivation in the hillside zone competes for labour with first-season maize and beans during both planting and harvest (Humphries, in press). Rice in the hillside zone is a low-yielding, subsistence crop; on the coastal plain, however, large cooperatives and private producers cultivate rice on a large scale.

As in all fallow-based systems, the key to sustainable shifting cultivation in northern Honduras is the ratio of cropping periods to fallow periods. Continuous cultivation of the same piece of land leads to a rapid decline in yields and a simultaneous increase in weeds, the general reasons for field shifting (Nye and Greenland 1960; Weischet and Caviedes 1993). Farmers in northern Honduras report that after only two or three cycles of cropping, maize yields decline to less than 800 kg ha^{-1} and the time dedicated to weeding a particular field doubles. The yield decline appears to be the most important reason for abandoning a field, a finding consistent with studies in other regions with similar land-use patterns (Stuart 1978; Chevalier and Buckles 1995). Although increased weeding costs are relevant, they are considered manageable if yields reach acceptable levels.

Without external inputs, lengthy fallow periods are needed to restore agricultural potential depleted by cultivation. Farmers in northern Honduras distinguish two important stages of fallowing, only one of which is considered suitable for cultivation. A field abandoned to natural regrowth is called a *guatal* for the first 3 years. During this stage, the vegetation consists of grasses (*zacates*) and tree species (*monte*) in roughly equal proportions. A *guatal* is relatively easy to clear, but little nourishment (*abono*) is produced by burning the vegetation. Furthermore, "bad weeds" (*mala hierba*) abound and grow quickly in the cleared field, increasing the weeding costs. Cultivation of *guatales* is therefore avoided.

After about 5 years, if left uncultivated, a *guatal* will become a *guamil*, a fallow composed mostly of woody tree species. Clearing a *guamil* is more time consuming because of the abundance of trees, but the field is "well rested" (*descansado*) and consequently better suited to cultivation. The ash from a *guamil* will fertilize crops for a cycle or two, and initially the field will be relatively free of grassy weeds. A *guamil* cannot, however, sustain production for more than four cycles.

Growing population density and improved infrastructure have led to a relatively intensive form of shifting cultivation characterized by the management of a series of fallow fields that never revert to forest. Humphries (in press) found that in established mountain communities, farmers typically rotate fallow fields, rather than clearing new lands from mature forest, because the labour costs for the latter are prohibitive and forest land presents no particular advantages over *guamiles*. Stuart (1978) found a similar pattern among the Nahua of southern Veracruz, even where land pressures were moderate. Farmers manage fallow fields as "future maize fields," to which they will return. This form of shifting cultivation, referred to by Morgan (1969) as a rotational bush-fallow system, is not necessarily a voracious consumer of mature rain forest. Throughout the remainder of this book, the term bush-fallow system will be used to refer to the shifting-cultivation practices of northern Honduras.

Although cropping periods of three to four cycles and fallow periods of 5–10 years are preferable, cropping patterns in northern Honduras vary considerably around this norm. The survey data indicate that cropping periods, including those for maize and other annuals, such as beans, ranged from as little as one cycle to as many as seven cycles; average was about three. Cropping periods of only one cycle were common. Fallow periods before clearing land for cultivation ranged from 1 to 15 years. The average was 4.2 years, slightly below the minimum period needed to establish a *guamil* (5 years). Although these measures were highly variable, they suggest that bush-fallow rotations in northern Honduras are on average as intensive as they can be within the parameters of shifting cultivation. Further intensification is likely to result in yield declines and possibly land degradation.

In sum, shifting cultivation in northern Honduras is characterized by relatively low yields of maize, beans, rice, and other annual crops. The potential for further intensification through more frequent cropping is very limited, and such intensification would likely undermine the sustainability of the system. Even with current cropping patterns, the risk of soil erosion, which is very high because of the heavy rainfall and steep slopes, threatens future land productivity.

Conclusions

The conditions under which the *abonera* system developed and diffused in northern Honduras are quite favourable. High rainfall in a bimodal distribution supports a long growing season, during which a least two crops can develop sequentially. Farmers can grow a velvetbean crop during the first season, followed by an economic crop (such as maize) during the second season, without risk of competition for critical water resources. The velvetbean crop establishes rapidly in the relatively fertile soils and produces large amounts of biomass.

Elsewhere in Honduras, the less favourable climatic conditions not only constrain annual rotations such as the *abonera* system but also create seasonal fluctuations in maize supply and prices. Second-season maize grown in northern Honduras can realize a much higher price as a result of this seasonality, thereby enhancing the profitability of the *abonera* system.

The availability of hillside land, either through direct land ownership or through inexpensive land-rental markets, enables farmers to use relatively extensive land-use systems, such as bush fallows and velvetbean fallows. Farmers in northern Honduras generally have access to land needed for economic crops during the first season, when the velvetbean crop is growing.

Finally, the *abonera* system developed in Honduras when agricultural productivity was low and possibly declining. Although shifting cultivation on hillside land is often an effective use of labour, it generates fairly low outputs per unit of land; furthermore, numerous risks of erosion are presented by the open cultivation.

Declining soil fertility and weed invasion are common problems arising from the intensification of bush-fallow systems, a scenario undoubtedly facing hillside producers in northern Honduras. The *abonera* system, with its relatively high yield potential and complete and dense ground cover, was a very attractive alternative for producing maize — the staple food crop — on hillside land. Hillside farmers were quick to notice and appropriate this innovation.

CHAPTER 3
LAND, LABOUR, AND LIVELIHOODS

The multiple occupations of farming families

The availability of land in northern Honduras drew families to the hillsides and initially allowed settlers to establish farms. The fact remains, however, that most households cannot devote all of their productive time to farming. About 69% of all hillside households surveyed were relying partly on the off-farm earnings of at least one family member. Almost half of those in the male labour force were working part or full time as day workers, petty traders, loggers, journeyworkers, or seasonal construction workers.

Day workers are employed by other farm households to assist in land preparation and in planting, weeding, and harvesting annual crops. Ranchers employ day workers to establish and manage pastures. Other forms of wage employment reported by hillside farm households include seasonal highway maintenance, work in small factories, and public-sector jobs (mainly as primary-school teachers).

Members of hillside farm households also engage in various forms of self-employment. Petty trading (fruit, bread) and craft work (mainly baskets) provide limited cash earnings to meet the household subsistence needs of some families. Others extract logs from the high forests of the Nombre de Dios and dress them by hand for sale as timber. Logging is profitable but has various problems, such as the insecurity of tree tenure and inconsistent regulations (PDBL 1991; Rodríguez Torres 1992; Humphries, in press). For these reasons and because of the sheer physical strain of the work, logging is usually a complementary activity of relatively young people engaged in agriculture.

Land ownership enables people to live independently of off-farm employment and to diversify their farm enterprises. Some households cultivate commercial crops, such as chilies, cacao, and coffee. Others specialize in livestock production, including cattle and pigs. Table 6 shows the size of the herds in the hillside zone and their distribution among households. About one-quarter of the farm families surveyed in the hillside zone owned cattle, with herds ranging from a few to 125 head. Most of these ranches produce milk for local cheese manufacturers or for sale to a regional milk-processing facility that has collection centres

Table 6. Ranches in the hillside zone, northern Honduras, 1992.

Size of herd	Households	
(n) [a]	(%)	(n)
0	72	91
1–5	16	20
6–10	6	7
>10	6	8

Source: Authors' survey, 1992.
[a] Number of cattle.

at various points in the department. About one-quarter of these ranches — typically the more isolated ones — raise beef cattle for sale in regional markets. Many hillside farmers hope to establish ranches, as cattle ranching is less risky and more profitable than other regional agricultural enterprises. Humphries (in press) calculated that a rancher with only three milk-producing cows can realize profits as high as those of the average producer of basic grains, but with considerably less effort and risk. The relative profitability of basic grains and cattle production is discussed briefly in Chapter 6.

Pigs are a poor household's form of livestock production. Although raising pigs is mainly a means to accumulating savings, pig production can be used to convert excess grain and the by-products of cheese-making (whey) into cash, thereby providing a stepping-stone into cattle ranching. Some 37% of the surveyed population owned pigs, although usually they owned no more than three or four. Slightly more than half the households surveyed owned one or two horses, which they use to transport grain from the field to the home. In a few cases, farmers rented out their horses or their own services as muleteers.

Land and livestock also provide the basis for investment in small businesses. Cattle brokers with trucks buy cattle in the hillside communities and resell them to slaughterhouses in the regional urban centres. These merchants may also use their vehicles to transport milk produced by other ranchers to regional collection centres. Among ranchers a popular way to invest is to establish small stores stocked with dry goods (machetes, rope) and food items (rice, salt, canned milk).

The classification of livelihood strategies

The diverse and multiple occupations of farm households are both conditioned and enabled by the distribution of land and other resources. To explore this complex relationship and identify the livelihood strategies that households adopt, we developed a hierarchical classification of households.

The methods for the analysis are described in Buckles and Sain (1995). We examined the relationships among the variables and cases (households) in the survey data, using multivariate analysis. A hierarchical classification of cases was used in successive iterations of a computer program (TWINSPAN) to obtain a hierarchical classification of variables according to their case preference. The two classifications were then used together to obtain an ordered two-way table (case by variable) to express the hierarchical relationships as succinctly as possible. This contrasts with most standard clustering techniques that classify only cases (or variables) and that depend on single measures of similarity or dissimilarity (van Groenewoud 1992).

A hierarchical classification offers a more comprehensive picture of strategic relationships between resources and households than analyses based on individual profiles only (head of household, for example) or key variables such as farm size (cf. CEPAL 1982; Galvez et al. 1990). The method simultaneously combines various criteria that researchers normally consider separately in the classification of farming populations, such as land ownership, occupational profiles, and land uses.

The classification applies to households rather than to individuals, in keeping with the domestic character of rural livelihood. Farm families pool their resources and combine activities in ways that differ from those of specialized enterprises or wage-based households. This is not to say, however, that farm households are a single unit of production or that the intrahousehold distribution of resources and gender division of labour have little impact on the power and well-being of individual members of households. The agricultural land farmed by Honduran households is typically owned by men, although women also work in the fields. Some 20% of the farm households surveyed indicated that female members of the household engaged in agricultural labour, typically during weeding operations and at harvest time. Women also accounted for a full 50% of the time spent in self-employment by households, typically as small-scale traders. However, the survey instrument failed to capture the level of detail needed to examine the gender roles and differences as an element in the classification. Furthermore, the data-collection process was not conducive to the documentation of gender-based differences in priorities and relative contributions to overall livelihood strategies. This bias against the study of the economic contribution of women to farm livelihoods remains an important weakness typical of farm surveys (Poats 1991; Thomas-Slayter et al. 1993).

Table 7. Household groups in the hillside zone, northern Honduras, 1992.

Classification	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers
Households (%)	15.1	15.1	23.8	22.2	23.8
Households (*n*)	19	19	30	28	30

Source: Authors' survey, 1992.

Comparisons among livelihood strategies

The classification of livelihood strategies resulted in the identification of five relatively homogeneous household groups: ranchers, diversified farmers, medium-scale farmers, small-scale farmers, and subsistence workers (Table 7). These groups represent major divisions with respect to the distribution of land, labour and capital resources, land uses, and occupational profiles.

Differences in farm size and land use among the groups are presented in Table 8. Ranchers control more land, both in production and in fallow, than other groups. They have roughly half of their total farm area in pasture but also control substantial cropland, reflecting a strategy among ranchers of mixed farming, rather than specialization in cattle ranching. The dual strategy of diversified farmers engaged in some crop and livestock production is also brought to light by data showing the distribution of their land resources among crops, fallow, and pastures. By contrast, medium- and small-scale farmers dedicate as much land to crops as diversified farmers but manage no pastures. Their focus on crops, fallows, and permanent tree crops distinguishes them from the subsistence workers, who have highly specialized land uses and the smallest farms.

Table 8. Average land holdings and land uses of household groups, northern Honduras, 1992.

	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	*P*
Farm size (ha)	32.0	12.3	7.7	5.1	2.0	**
Cropland (ha)	7.3	3.5	2.8	3.2	1.8	**
Fallow land (ha)	8.5	4.2	4.3	1.7	0	**
Pasture (ha)	15.1	4.5	0.5	0	0.2	**
Permanent tree crops (ha)	1.1	0.1	0.1	0.2	0	NS

Source: Authors' survey, 1992.
** Significant at $P \leq 0.01$ (*F* test); NS, not significant.

Table 9. Proportion of farmed areas owned and rented by household group, northern Honduras, 1992.

	Farm property rights (%)					
	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	*P*
Owned	96.3	94.0	83.2	58.2	10.8	**
Rented	3.7	6.0	16.8	41.8	89.2	**

Source: Authors' survey, 1992.
** Significant at $P \leq 0.01$ (F test).

The close relationship between farm size and land rights is illustrated by Table 9, which shows the proportion of farmed area owned and rented by farmers in each household group. Farmers with larger farms (ranchers and diversified and medium-scale farmers) are much less dependent on land-rental markets for access to land. By contrast, subsistence workers depend almost entirely on rented land. Land-rental markets also play a significant role in the farming systems of small-scale farmers. These observations underline the importance of land-rental markets to large sectors of the hillside population and point to relations of interdependency and exchange between the landed and the landless farmers. Hillside ranchers, as well as urban-based landowners, play the role of land brokers to land-poor households. This system allows ranchers to invest their capital in fallow land to establish pastures at little or no direct cost while providing landless workers with access to farmland.

Although the land-rental market gives the land poor an opportunity to rent some farmland, it does not fundamentally alter their potential to increase or diversify their crops (Table 10). The survey indicated that subsistence workers tend to specialize in maize production, on average cultivating 1.3 ha of maize in either season. Only half of the households in this group cultivate beans, and less than one-third cultivate rice, typically on very small fields. In keeping with the limited land resources of this group, other annual crops and commercial-scale tree crops are rarely grown.

Small- and medium-scale farmers have more substantial farms. Households in both groups typically cultivate maize — on average, 1.5–2.0 ha each season — as well as small fields of beans. Rice is cultivated by fewer than one-third of the households in these groups. A sizable proportion of small-scale farmers tend tree crops, an uncommon strategy for diversification among medium-scale farmers (Table 10). Medium-scale farmers more typically diversify by renting out pastures or using them for grazing by their own animals.

Table 10. Proportion of households cultivating various crops and average cropped area (excluding 0 values), for each household group, northern Honduras, 1991/92.

	Proportion of households (%) [a]					
	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	*P*
First-season maize	100.0	100.0	93.3	96.4	90.0	**
	(3.8)	(1.7)	(1.6)	(1.5)	(1.3)	
Second-season maize	94.7	94.7	86.7	96.4	90.0	**
	(3.8)	(2.4)	(1.8)	(2.0)	(1.3)	
Beans	73.7	89.5	70.0	75.0	50.0	NS
	(0.7)	(0.6)	(0.6)	(0.8)	(0.4)	
Rice	89.5	47.4	30.0	28.6	30.0	*
	(1.0)	(0.4)	(0.4)	(0.8)	(0.5)	
Other crops	42.1	21.1	33.3	25.0	0.0	NS
	(0.6)	(0.3)	(0.5)	(0.2)	(0.0)	
Tree crops	57.9	26.3	6.7	42.9	3.3	NS
	(1.9)	(0.4)	(0.7)	(0.6)	(0.2)	

Source: Authors' survey, 1992.
[a] Values in parentheses are the average values of the cropped area in hectares.
*, ** Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively (*F* test); NS, not significant.

The crop profiles of farmers who diversify reflects the tendency of households in this group to engage in a wide range of farm-based activities. Most of these farmers produce beans, and nearly half grow rice as well. The proportion of households in this group producing additional annual crops does not differ significantly from that of other groups. The average maize area for this group is somewhat greater, however, surpassing 2 ha for the second-season crop.

Ranchers constitute the group with the most diversified crop-production strategies. Their average maize area is quite large, 3.8 ha in both seasons, but the area they crop in beans is the same as that of farmers in other groups. Rice is a difficult crop for hillside environments, requiring relatively good land and careful weeding, but it is grown by almost 90% of ranchers; other annual crops (mainly chilies) and tree crops are also much more common among ranchers than among other farmers. This crop-production profile reflects the capacity of ranchers to muster the land, labour, and financial resources needed to cultivate a wide range of crops. It also underlines the mixed-farm nature of livelihood strategies among households of this group; these ranchers never abandon agriculture altogether but continue to rely on a range of activities and land uses for their livelihood. This finding does not conform to the narrowly defined logic of enterprise development that implies that larger farms specialize and smaller farms maintain diversified production strategies. One possible explanation for this is that the management and supervision costs of diversified strategies remain small for even larger farms in northern Honduras.

The ability of ranchers and diversified farmers to respond to production constraints is also greater than that of farmers in other household groups. Whereas two-thirds of the ranchers and almost three-quarters of the diversified farmers applied fertilizer to their maize, only one-quarter of the medium-scale farmers and one-third of the small-scale farmers did. Slightly more than half the subsistence workers used fertilizer on maize, possibly reflecting the fact that they have more access to cash than do farmers who depend on farming alone. Reliance on fertilizers as a source of nutrients may also be an appropriate strategy for farmers with less control or knowledge of the fertility status of the land they crop, a situation to be expected among renters.

Only 10% of the surveyed population — mostly ranchers — received credit for maize production in 1992. Widespread cash and credit constraints among poorer households have probably influenced their decisions to use the *abonera* system as a way to manage soil fertility — an issue discussed in subsequent chapters.

Data on the percentage of households within each group that sold half or more of the 1991–1992 harvest of various crops (Table 11) shed light on the relative importance of various market transactions to each group. Most hillside farmers (71%) sell little or none of their first-season maize, but diversified farmers are more likely than those in other groups to put their harvest on the market. This tendency reflects the greater dependence of diversified farmers on income from crop production, compared with ranchers.

Table 11. Proportion of households that sold half or more of their harvest, northern Honduras, 1991/92.

	Proportion of households (%)					
	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	P
First-season maize	26.3	42.1	20.0	21.4	33.3	NS
Second-season maize	73.7	57.9	50.0	32.1	40.0	*
Beans	21.1	31.6	30.0	21.4	3.3	*
Rice	52.6	15.8	10.0	10.7	20.0	***
Other crops	31.6	5.3	13.3	10.7	0	**

Source: Authors' survey, 1992.
*, **, *** Significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively (Chi-square test); NS, not significant.

Farmers and ranchers in all groups more commonly sold second-season maize on the market, in response to the much higher maize prices during this season. Sales of second-season maize are very common among ranchers, which is in keeping with the much larger maize area cropped by members of this group. Diversified and medium-scale farmers also tend more than small-scale farmers and subsistence workers to sell second-season maize. As noted above, the maize area for these households also tends to be greater during the second season, a seasonal strategy that is uncommon among small-scale farmers and subsistence workers.

The proportion of households selling half or more of their bean harvest is low for all groups. Although beans are a key subsistence crop, small amounts of beans sold by numerous farmers located throughout the region account for almost half of the beans consumed in La Ceiba, the country's third largest city (Matute Ortíz 1992).

Sales vary among groups much more for rice than for beans. Ranchers are clearly the most important rice producers, in terms both of average area cultivated and the tendency to market the harvest. These ranchers also market sizable proportions of other crops, such as chilies, fruit, coffee, and cacao. Overall, however, the level of home consumption of annual crops is high among all groups, including ranchers and diversified farmers, in keeping with the subsistence orientation of most agricultural activities in the region.

We found no significant differences in family size or age of the head of the household to point to the role of the family-development cycle in the rise of livelihood strategies (Table 12). Although the availability of family labour was undoubtedly important to individual households, it has no group profile. However, the capacity of households to employ nonfamily labourers does vary from group to group. Data on the use of nonfamily labour by household group highlight the

Table 12. Family-labour resources and labour hired by household group, northern Honduras, 1992, second season.

	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	*P*
Average family size (*n*)	6.2	6.3	6.3	7.1	6.2	NS
Average age of male head of household (years)	43.6	46.8	43.5	44.3	38.1	NS
Average use of hired labour (d)	27.8	12.5	7.9	0	3.7	**

Source: Authors' survey, 1992.
** Significant at $P \leq 0.01$ (*F* test); NS = not significant.

Table 13. Livestock ownership by household group, northern Honduras, 1992.

	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	*P*
Average number of cattle (*n*)	19.2	3.2	0.2	0	0	**
Average number of pigs (*n*)	2.1	4.2	0.7	1.8	0.1	**

Source: Authors' survey, 1992.
** Significant at $P \leq 0.01$ (F test).

advantaged position of ranchers and, to a lesser degree, diversified farmers. Ranchers hired workers for an average of 28 person–day to assist in clearing, planting, and weeding second-season maize. Data on wage-labour use for other crops and seasons were not collected.

The distribution of livestock ownership among groups is also extremely skewed (Table 13). All households in the rancher group owned cattle, with average herds of some 19 animals. Diversified farmers had many fewer head of cattle but a larger number of pigs, reflecting a strategy of using pig production to gradually accumulate capital in livestock. Complementarities between very small scale dairy and pig production may also account for the development of this strategy (Humphries, personal communication, 1996[2]). Ranchers earn their income through the direct sale of milk, but diversified farmers, with smaller herds, must transform milk into cheese for profit. Whey, a by-product of cheese-making, can be used to fatten pigs, thereby increasing the profitability of this activity as well.

Independent and small-scale farmers may own a pig or two as a way to accumulate savings. By contrast, subsistence workers cannot support livestock, which is evidence of the structural limitations on their livelihood strategy.

The classification of livelihood strategies can be extended to an analysis of multiple occupations among hillside families. As noted previously, about 69% of the households surveyed depend to some degree on the off-farm employment of a family member. Specific forms of off-farm employment are more common, however, among some groups than among others (Table 14). Day work on the farms and ranches of other households is primarily the domain of small-scale farmers and subsistence workers, who have little land of their own on which to employ family labour. These two groups, representing 46% of the households surveyed, account for 93% of the time dedicated to day work. Small-scale farmers

[2]S. Humphries, University of Guelph, personal communication, 1996.

Table 14. Proportion of households engaged in various occupations by household group, northern Honduras, 1992.

	Proportion of households (%)					
Occupation	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	*P*
Day work	5.3	10.5	20.0	89.3	80.0	**
Off-farm wage work	0.0	31.6	3.3	0.0	20.0	**
Self-employment	0.0	10.5	13.3	17.9	10.0	NS
Logging	0.0	0.0	43.3	3.6	0.0	**
Small businesses	15.8	0.0	6.7	3.6	3.3	NS

Source: Authors' survey, 1992.
** Significant at $P \leq 0.01$ (Chi-square test); NS, not significant.

and subsistence wage workers averaged 16 and 26 weeks year^{-1} per household, respectively, as day workers. These averages highlight the greater commitment of subsistence workers to day work, compared with more independent small-scale farmers. Day work is physically demanding yet very poorly paid; most day workers earn about 1.25 USD d^{-1} slashing brush to clear fields for cultivation or planting, weeding, and harvesting.

Only 10% of the households surveyed engaged in nonfarm wage employment, divided into two types. Members of diversified farm households who were employed off the farm had relatively stable and better paying jobs as school teachers, workers in small factories, and skilled journeyworkers. These workers were all literate, which made it possible for them to find better jobs and, through employment, accumulate land and livestock. By contrast, subsistence workers employed in the nonfarm sector typically worked seasonally or temporarily in highway construction. They had a much lower level of literacy; only one-third of the wage workers in this group could read. Family labour cannot be productively employed on the limited farms managed by subsistence workers, nor can their labour skills fetch wages above the subsistence level.

Logging was important to only 11% of the households surveyed; virtually all of those who did this work were classified as independent farmers. All but one of these households belonged to a logging cooperative that provided them with access to community forests and assistance in marketing finished lumber. Although logging is physically demanding and constrained by uncertain access to suitable forest resources and the risk of having finished lumber confiscated by government officials (Humphries, in press), the financial rewards of logging can be considerable, as mahogany and Spanish cedar fetch a good price on regional markets. Logging families reported dedicating a combined household average of

30 weeks year^{-1} to extracting precious woods, generating an estimated 1 000–2 000 USD per family, depending on the type and quality of wood cut. This estimate is based on the average number of weeks per year of logging activities reported by the entire household (30 weeks) and on Humphries' (in press) calculations of individual logging income (143–285 USD month^{-1}). Logging typically takes place during the dry winter season and may involve the concentrated effort of several family members.

Self-employment in the hillside zone is important to 11% of the households surveyed; family members are engaged in petty trading (fruit, bread), craft work (mainly baskets), or managing small food stands from their homes. Small-scale self-employment has no particular group orientation. A small proportion of households in all groups except the ranchers reported the employment of some family members (mainly women) in petty trade, crafts, or food preparation. By contrast, the small businesses were established mostly by ranchers reinvesting income in small stores or in trucks for brokering animals and milk — an opportunity closed to other household groups.

Conclusions

The analysis reveals a high degree of social differentiation in hillside areas of northern Honduras and the development of distinct strategies for maintaining households. These livelihood strategies reflect the structural limitations on the opportunities and land-management practices of land-poor households and reflect as well the opportunities available to the land rich. Strategies differ in ways that strongly influence land-use patterns, employment of family labour, and other features of hillside agricultural systems.

Ranchers represent 15% of the households surveyed. They own cattle and pigs, pastures, and fallow land. Their crop production is typically diversified, and they cultivate larger than average areas of maize, beans, and rice. Many of the ranchers are able to sell at least half of their harvest of annual crops on the market. Their financial resources allow them to establish small businesses, such as stores or livestock brokerages, and to avoid low-paying off-farm employment.

Diversified farmers — also representing some 15% of the surveyed households — have on average fewer cattle than ranchers but more pigs, a less land-intensive form of livestock production. Nevertheless, diversified farmers own enough land to grow a wide variety of annual crops. They also control some pasture and fallow land. Diversified farmers have no need to rely on day work for their livelihood, but they may engage in relatively stable and better paying forms of off-farm employment, such as factory work and teaching. The money earned by family labour in off-farm employment seems to provide these households with additional opportunities to accumulate land and livestock, an association that points to the role that improvements in wages and rural employment opportunities might play in local development.

Medium-scale farmers represent almost 24% of the households surveyed. They own land, including sizable fallow areas, on which they grow small quantities of maize, rice, and beans. They may have some land under permanent tree crops. Their land and other resources are too limited, however, for livestock production. Their farming activities allow them to avoid low-paying day work, but most opt to complement farming with logging. Their memberships in logging cooperatives facilitate this activity.

Small-scale farmers, representing some 22% of the surveyed households, own some cropland but have very little of it under pasture or in fallow. Access to land through rental markets is very important to members of this group. Crop production by small-scale farmers is usually limited to maize and beans, typically for subsistence, and livestock production is beyond their means. Small-scale farmers are forced by their limited capital in land to employ family labour in day work and some forms of self-employment (crafts and petty trade) to even make ends meet. This dependence on off-farm employment among small-scale farmers suggests that they have little labour within the household to invest in new land-management practices.

Subsistence workers constitute a large group, accounting for almost 24% of the households surveyed. Members of their households frequently engage in low-paying off-farm employment as day workers, which is their primary source of income. Crop production among subsistence workers is focused exclusively on maize, the main subsistence crop in the region. As with small-scale farmers, subsistence workers do not have enough land to permit crop diversification or livestock production. These households are highly dependent on rental markets for cropland.

The picture of household strategies that emerges from the analysis enables us to holistically appreciate the context in which farmers make decisions regarding technology. The remainder of this book examines in detail the experience of Honduran farmers with velvetbean and the factors influencing adoption of the *abonera* system.

CHAPTER 4

THE *ABONERA* SYSTEM

Measures of adoption

By the early 1990s, almost two-thirds of the hillside farmers in northern Honduras were using the *abonera* system, according to the 1992 farm-survey data (Table 15). About 19% of the farmers interviewed reported past but not current use, and 16.7% indicated that they had never used the *abonera* system. Figure 9 shows cumulative levels of adoption on the north coast of Honduras between 1972 and 1992, based on farmers' recall of the first year of velvetbean use. These reports were adjusted to exclude farmers too young (<20 years) to be heads of households and those who lived outside the region when they first started using the technology. This adjustment is particularly important, as many farmers currently living in northern Honduras migrated there from other parts of the country, where they may have first learned about the *abonera* system.

Figure 9 indicates that the technology spread slowly in the first 10 years following its introduction in the region but that the spread increased explosively in the subsequent 10 years. Adoption of the *abonera* system increased at a rate of about 5% annually, peaking in the early 1990s. This level of adoption is similar to that estimated from a 1990 survey in the same region (61%, reported in Buckles et al. 1991). The use of velvetbean has leveled off in recent years, as a result of land constraints — an issue discussed in detail in Chapter 7.

The proportion of farmers' maize fields in the *abonera* system, a measure of adoption intensity, is very high. About 78% of farmers (surveyed in 1992) with

Table 15. Adoption of the *abonera* system by hillside farmers, northern Honduras, 1992.

Adoption	Households (%)	Households (*n*)
Current use	64.3	81
Past use	19.0	24
Never used	16.7	21

Source: Authors' survey, 1992.

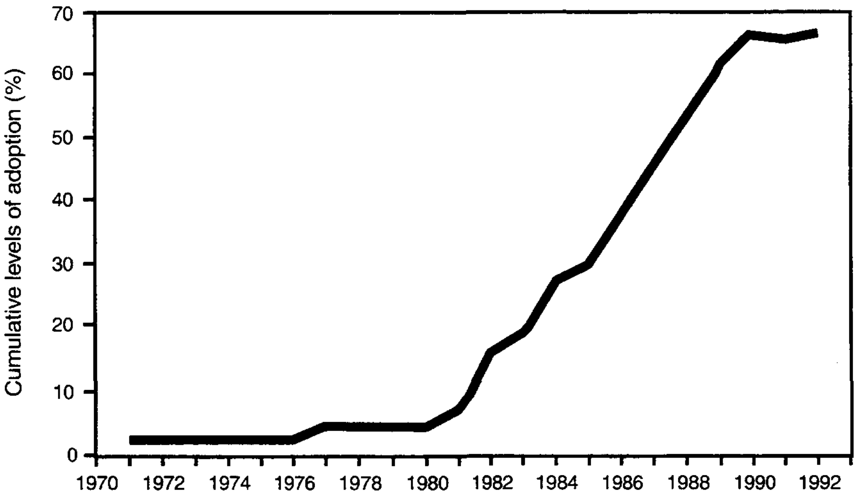

Figure 9. Adoption of the *abonera* system, northern Honduras.
Source: Buckles et al. (1992).

velvetbean fields cultivate more than half of their second-season maize in this association, and about 55% cultivate all of their second-season maize in this manner. For this latter group of farmers, the *abonera* system has virtually displaced traditional forms of second-season maize production. It is worthwhile noting, however, that a significant proportion of farmers using velvetbean also plant some maize in the traditional manner — an issue examined further in Chapters 6 and 7.

Farmers appear to convert to the *abonera* system remarkably quickly. Furthermore, they do not seem to pass through a period of small-scale experimentation with the technology, as is normally expected with new practices. Data shown in Table 16 indicate that new users plant about as much of their winter maize with velvetbean as farmers with many more years of experience.

Table 16. Intensity of *abonera* adoption by years of use (adopters only), northern Honduras, 1992.

Years of use	% of winter maize planted with velvetbean	Adopters surveyed (*n*)
1–4	75.0	25
5–10	84.1	51
>10	74.0	9

Source: Authors' survey, 1992.

Adoption of the *abonera* system has been relatively uniform throughout the hillsides of northern Honduras, from Tela to Jutiapa. According to surveys conducted in 1990 (Buckles et al. 1991) and 1992 (Buckles et al. 1992), adoption rates in all municipalities in the department of Atlántida were similar except in Tela, where the rate was slightly higher. Interviews in the region suggest that a few communities in Tela — notably, San Francisco de Saco and Planes de Hicaque — were among the first in the department to extensively adopt the technology.

Diffusion of the *abonera* system occurred without the intervention of formal extension services or incentive programs. Virtually all of the farmers surveyed in the region indicated that they learned of the technology from family members or other farmers, either in the same community or in one nearby. Many farmers said that they asked for velvetbean seed from other farmers after seeing maize crops grown in velvetbean. Soon after, they established their own velvetbean fields. In the early 1980s, researchers took note of this development, but only recently have government and nongovernmental organizations begun to support diffusion of the technology in the region. Spontaneous farmer-to-farmer diffusion of the *abonera* system has been both effective and rapid.

Although the adoption of the *abonera* system is very high, not all farmers who have planted maize in velvetbean continue to do so. About 19% of the farmers interviewed in 1992 reported past but not current use. The main reason given by farmers for discontinuing use of the *abonera* system was that the velvetbean field belonged to someone else (Table 17). All farmers reporting this reason had no land when they stopped using velvetbean, and all but one were still landless. The reasons given by farmers who owned land reflect their concerns about the opportunity costs of land or accidental losses of the velvetbean crop. These findings point to the role of land tenure and farm size in the adoption decision — issues examined further in subsequent chapters.

Table 17. Reasons for discontinuing use of the *abonera* system, northern Honduras, 1992.

Reason	Households discontinuing use (*n*)
The velvetbean field was rented	13
The velvetbean field competes with other land uses (pastures, other annual crops)	6
The velvetbean field was destroyed by fire	3

Source: Authors' survey, 1992.
Note: Two other households did not provide reasons.

The adoption rates, the intensity of velvetbean use, and the spatial distribution of adopters clearly indicate that the *abonera* system is widespread in the region. The 1992 survey revealed, for example, that about 83% of the sampled households were current or past users of the *abonera* system. Given that this sample reasonably reflects the 13 000 or so households in the hillside villages between Tela and Jutiapa (see Appendix I), we can assume that more than 10 000 of those households had some direct experience with this technology.

Abonera management

In managing their *aboneras*, the farmers take advantage of the long growing season in northern Honduras (>270 d) by establishing velvetbean as a sole crop during the main rainy season (first season) and then planting maize on the same field during the minor rainy season (second season). (The climatic features of northern Honduras were discussed in Chapter 2.) The mature velvetbean stand is slashed in December with machetes, and the second-season maize is planted in the layer of decomposing leaves and vines. The field is not burned, and the legume is not incorporated in the soil. Eventually, during the maize cycle, the velvetbean reseeds itself spontaneously from pods that have matured in the mulch. The pods burst open when they are dry, ejecting seeds over the field fairly evenly. The velvetbean aggressively takes control of the maize field around harvest time (April to June), using the maize stalks as tutors. From then until the next slashing, in December, no other field operations are performed, which leaves the field under a short-term velvetbean fallow. Figure 10 shows the agricultural calendar for the velvetbean system and the main management phases.

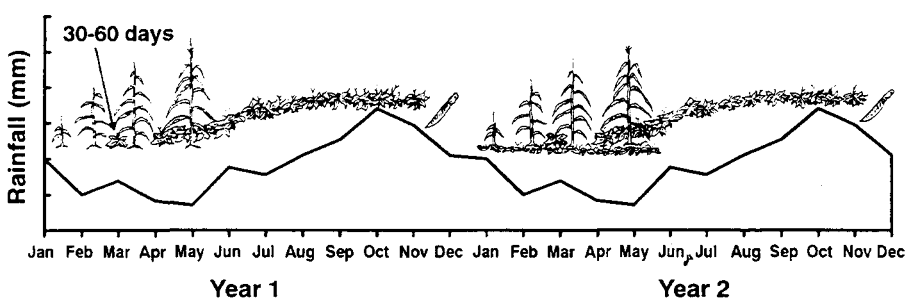

Figure 10. Management phases of the *abonera* system (indefinite rotation) and rainfall pattern, northern Honduras.

Initial establishment

Most farmers introduce velvetbean into a field 40–60 d after the maize planting in the second season, or winter-maize cycle. The farmers use dibble sticks to punch holes 1–2 m apart between the rows of maize and then place two or three velvetbean seeds in each hole. Labour costs of initially establishing the velvetbean field are minimal, typically about 12 USD ha^{-1}. The seed usually comprises a mixture of types, and the quantity used ranges from 10 to 15 kg ha^{-1}. As the farmers have no velvetbean-seed market, they use seed collected from established velvetbean fields.

Initial establishment of velvetbean is occasionally accomplished by broadcasting velvetbean seed in the maize field, apparently to save labour. However, the dibbling method is considered more effective because it promotes even establishment. A few farmers reported that they established velvetbean directly after clearing a fallow field.

Annual reestablishment

After initial establishment, the *abonera* may require replanting, the following year, in spots where the velvetbean failed to densely populate the field the first time. Once the velvetbean is established, however, the farmers typically rely on natural reseeding to maintain the stand. Natural reseeding will occur unless the farmer slashes the crop before enough viable pods have been produced.

The resilience of a velvetbean field is remarkable. Farmers in San Francisco de Saco have relied on natural reseeding for more than 15 years without ever replanting their *abonera* crops from new seed. Even after the marked failure of the velvetbean cycle in the winter of 1993/94 and the extremely unfavourable conditions for seed germination that followed, the seed produced by the sparse velvetbean stands that reached maturity the next year was so plentiful that most farmers had no need to replant their stands.

Although it is rarely necessary, some farmers toss velvetbean pods into their fields at slashing time to ensure uniform stands. Others replant velvetbean later in the season in spots where it failed to reestablish itself. The seed used for replanting is usually harvested from plants growing on trees or rocks, where seed production is more favourable than under the dense canopy of a pure velvetbean stand.

Reliance on the natural reseeding of the velvetbean field allows farmers to maintain the crop permanently in their fields at no direct cost. Thus, although farmers receive no direct economic benefits from the velvetbean seed, they have no need to make a direct investment in maintenance of the crop. The practice does, however, have some less favourable management implications. Velvetbean plants germinating in the maize field may grow so vigorously early in the season that farmers have to thin the emerging plants, or "prune" them, to delay their dominance until after the maize is harvested. However, this can be accomplished during normal weeding operations, adding little to total labour costs, and is not always necessary.

The long-term vigour of the velvetbean stand may also be negatively affected by reliance on natural reseeding. When farmers fail to complement natural reseeding with deliberate replanting, patches devoid of velvetbean plants may be colonized by aggressive weeds, such as *Rottboellia cochinchinensis*. This has occurred in some areas, and the weed has become a significant pest (Sharma and Zelaya 1986; Munguia 1992).

Slashing

Slashing the velvetbean crop when it reaches maturity and is starting to die naturally is the main activity required for *abonera* management. A wide range of slashing dates are used within a given community or even within a given field, but all farmers are careful to slash velvetbean only after it has produced enough viable pods. Once this is assured, the timing is influenced by how late farmers think they can wait to plant winter maize without running too great a risk of exposing it to drought later in the season. Factors related to family or hired labour also influence the farmer's choice of slashing date.

Slashing involves liberally cutting the pliant velvetbean cover with a machete and using a wooden hook to pull velvetbean vines up from the ground or rocks. Farmers make no attempt to cut velvetbean finely because this would increase the time devoted to this labour and could destroy the velvetbean pods, which are needed for natural reseeding. However, some farmers insist that the slashed velvetbean material must be evenly spread on the surface of the field to ensure adequate soil cover and uniform maize growth. Slashing velvetbean requires far less labour than slashing a conventional woody fallow — about 10 d ha^{-1} for an *abonera* versus about 18 d ha^{-1} for a field that has been fallow for 4 or 5 years. Velvetbean slashing incurs significantly lower labour costs than traditional techniques for land preparation — an issue addressed further in subsequent chapters.

In years favouring the proliferation of rats (a cyclical pest, apparently not restricted to velvetbean fields), teams of three to five people may be formed to slash the *abonera* in such a way that rats are gradually corralled. Scores of rats can be easily killed with machetes as they attempt to escape the watchful farmers.

Efficient rat control during slashing can significantly reduce the loss of maize seed and seedlings later on, and farmers claim it is entertaining.

Maize planting

Most farmers prefer to plant maize as soon as possible after they have slashed the velvetbean, thereby avoiding some of the competition from growing weeds. In practice, the interval ranges from a few days to a few weeks, depending mainly on the farmers' ability to mobilize labour. Many farmers do the slashing and planting in tandem: they spend a day or two slashing one area and then plant it before going on to slash and plant the next area.

Planting is done 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 is to plant three or four seeds per hole in rows 80–100 cm apart, with an interrow spacing of 50–80 cm. To protect the seed from a variety of insect predators (particularly ants), the farmers treat it with an array of home recipes or strong pesticides, such as malathion. Sometimes farmers use pregerminated seed to hasten emergence and provide young maize seedlings with a competitive edge against weeds. As with first-season maize, local genotypes (*Olotillo*, *Tuza morada*, *Raque*) reproduced on the farm are preferred.

Weeding

Weeding is key to the fate of both maize and velvetbean. The practice keeps weeds from diverting nutrients and light from the growing maize crop, and it creates a window relatively free of competition from weeds for successful natural reseeding of velvetbean.

Weeding strategies in *aboneras* are similar to those used in bush-fallow systems. One exception is that farmers using chemical control in *aboneras* apply 2-4D very cautiously — or not at all — as it can easily kill the emerging velvetbean. Manual weed control in velvetbean plots requires significantly less labour than in nonvelvetbean plots (up to 50% less, according to farmers' estimates), even with the advent of the noxious weed *Rottboellia*. Velvetbean gradually eliminates most weed species (especially broadleaves) through allelopathy or by preventing them from germinating or by outcompeting those that do emerge (Gliessman et al. 1981). According to farmers, weeds that manage to survive in a velvetbean system are rooted much more superficially than weeds in bush-fallow systems, owing to the presence of the velvetbean-mulch layer; furthermore, the topsoil is looser (see Chapter 5) and wetter, making it easier to pull out weeds manually.

As noted previously, velvetbean itself can behave like a weed if it competes too soon with maize plants. However, this occurs infrequently and is never generalized in a given field; moreover, the labour involved in controlling velvetbean is minimal (less than 1–2 person–day ha^{-1}).

Fertilization

By and large, farmers apply no commercial fertilizer to maize crops planted in the *abonera* system. Many feel that the velvetbean mulch provides enough nutrients to satisfy the nutritional requirements of maize. Farmers describe with delight the "bluing" of maize planted in established *abonera* plots, taking it as proof of good plant health, a status generally confirmed by foliar analysis (see Chapter 5).

In the San Francisco de Saco *aboneras*, however, almost half the farmers apply small doses of urea (25–50 kg ha^{-1}) to their maize fields 40–60 d after planting. These farmers do not necessarily apply it every year or to their entire field. Furthermore, it seems to be applied preferentially in young velvetbean fields. Effects of this fertilization on maize yields remain unclear (see Chapter 5).

Maize harvest

Depending on planting date and elevation, second-season maize reaches physiological maturity between mid-April and early June. Most farmers harvest their crop almost immediately after it matures, to capture the best possible price on the local market. If they wait until the summer rains come, it is difficult to obtain a dry and disease-free grain suitable for either sale or long-term storage.

Although it is uncommon, some farmers bend the second-season maize plants to avoid lodging, to facilitate the harvest (ear-insertion height on local cultivars is frequently more than 2 m), and to protect the maize from birds. After the maize plants are bent, the velvetbean grows a lot more quickly because it is exposed to more light. This luxurious velvetbean growth can make the maize harvest more tedious, however, as one has to literally fight the velvetbean to get at the maize ears.

Maize is the only harvested output in the *abonera* system (stover is left entirely in place) and is both the staple in farmers' diets and a major source of income. Consequently, a good maize crop is the main criterion the farmers use to judge the performance of the velvetbean association, a criterion more important to farmers than the sustainability of the system.

Maize yields and yield components in the *abonera* system will be discussed in detail in Chapter 5. For the moment, suffice it to say that in all documented cases, yields from maize without velvetbean were consistently about half those obtained from maize planted after a velvetbean fallow. In the high-yield sites (San Francisco de Saco and Las Mangas; see Figure 1), we found that most yields were in the range of 2.5–4.5 t ha^{-1}, a satisfactory level, considering that the maize cultivars were mostly unimproved, plant densities remained relatively low, and external inputs were applied sparingly (no external inputs were applied at all in Las Mangas). At both sites, the best yields measured were close to 6 t ha^{-1}, indicating the high yield potential of the system. In Piedras Amarillas and Rio Cuero, actual yields and yield potential (as indicated by the best yields) were lower on average, consistent with lower intrinsic soil fertility (Rio Cuero) or lower rainfall (Piedras Amarillas) and also suboptimum management (low plant densities, late planting dates).

Beyond harvest: the velvetbean fallow

After the maize harvest, the *abonera* is abandoned to the velvetbean crop and remaining weeds for a full 6 months, until it is time to slash again. A few weeks after the harvest, the velvetbean has usually managed to pull down all standing maize stalks and achieve full canopy closure. Velvetbean fields are not grazed or used for any other purpose during this period. Indeed, velvetbean is grown for the sole purpose of protecting the soil and enhancing soil fertility for the benefit of the maize crop. Even farmers with livestock use no velvetbean as a forage, although it has documented value as a feed stuff. Inadequate access to information on this use may be the reason for this lost opportunity — an issue addressed in the concluding remarks on further potential uses of the *abonera* system.

Miscellaneous

Many farmers at San Francisco de Saco and Las Mangas use *Gliricidia sepium* as a live fence around their velvetbean fields and pastures. The main reasons cited for the choice of this leguminous tree were its very fast growth and its capacity to provide posts for fencing in pastures. The trees are usually pruned at the beginning of the maize cycle, and the prunings are left in place, adding biomass and nutrients to the velvetbean mulch at the fields' edges.

Management variability and its causes

Management varies, in a number of ways, from farmer to farmer, from field to field, and from year to year. The timing of velvetbean slashing and maize planting varies, as do the choice and timing of weed-control operations. Such variations can be attributed to local environmental conditions, such as actual timing of velvetbean maturity, intensity of rainfall at the time of slashing, or weed pressure.

Table 18. Main management practices in the *abonera* system, northern Honduras, 1992.

Practice [a]	Early–late dates	Criteria [b]	Input used	Observations
Slashing	Mid-Nov–late Jan	Pod maturity–drought avoidance	Machete	—
Maize planting	Late Nov–early Feb	Slashing	Dibble stick, local seed	—
Weed control	5–60 DAP	Weed growth, labour availability	Machete, hoe, or herbicide	1 or 2 controls
(Velvetbean reseeding)	Mid-Feb–mid-Mar	(Deficiency in natural reseeding)	Seed from previous cycle	Rarely done
(Fertilization)	40–60 DAP	(Cash availability, perceived need)	Urea (25–60 kg N ha^{-1})	Not used at all in some villages
Harvest	Mid-Apr–mid-Jun	Household needs, market prices	—	—

Source: Authors' survey, 1992.
Note: DAP, days after planting the maize.
[a] Parentheses denote practices not done by the majority of farmers.
[b] Parentheses denote criteria that are not a concern of the majority of farmers.

Constraints at the household level may also influence management practices — if there's no cash available, the farmer is unlikely to hire wage labour or purchase herbicides, for example. Overall, farmers' practices throughout the entire region closely follow a unique model of crop management, or technical itinerary (Cerf and Sébillotte 1988); this suggests a common origin for the practices and also indicates that regional environmental conditions significantly influence management strategies. Variations in management among fields, sites, and years represent tactical adjustments to fluctuating agroecological or intra-household factors and conditions, rather than inherently distinct management strategies (Table 18).

Main benefits of the *abonera* system

In subsequent chapters, we attempt to quantify and rank the actual contribution of specific features of the *abonera* system to its agronomic and economic success. From a qualitative viewpoint, however, many of the characteristics of the system can be examined in terms of the major practical benefits of the system, summarized as follows:

- The *abonera* system requires very little investment in labour. The costs of velvetbean establishment are minimal; maintenance costs are nil; and land-preparation costs are lower than for the traditional woody fallow.

- The *abonera* system allows farmers to take full advantage of the best growing season for maize — the second season. This season is characterized by sufficient but lighter rains; an abundance of soil water, stored from the previous rainy season; healthier maize; better harvest conditions; and better market prices.

- The vegetation (both velvetbean and maize residues) is never burned. The mulch promotes conditions favourable to biological activity in the layer below. When decomposed, the mulch provides significant quantities of N and other nutrients to the succeeding maize crop. The mulch protects the soil year-round from direct exposure to rainfall (and consequently limits the potential for soil erosion) and also helps to conserve water in the soil profile, which in dry years may provide a buffer against drought stress in the maize crop.

- The mulch and the velvetbean fallow help control weeds.

- Maize yields in fields with velvetbean are twice those in fields without it. Furthermore, yields start increasing the first year after the velvetbean is introduced, in contrast to the much longer period needed to realize benefits from other practices with low external inputs.

- The *abonera* system allows continuous cultivation of the same field year after year, without the need to extend fallow periods.

By and large, these benefits are due to the intrinsic properties of slash-and-mulch cropping systems (Bunch 1994; Thurston 1996). The first two benefits, however, are specific to the environment of northern Honduras or to the ecology of the velvetbean plant and hence may not be generalizable to other mulch systems or to other regions — an issue discussed further in subsequent chapters.

Farmers' perceptions of the *abonera* system

Honduran farmers who plant second-season maize in *aboneras* readily identify the reasons why. Interviews with farmers reveal a sophisticated understanding of the effects of the *abonera* system on maize production and the advantages of the system over alternative cropping patterns, such as bush-fallow rotations and continuous cropping with external inputs. Farmers report that soil fertility is maintained

Table 19. Adopters' evaluation of the advantages of the *abonera* system, northern Honduras, 1992.

Criteria	Ranking (%)	
	First selection	Second selection
1 "Fertilizer" effect of the velvetbean litter	39	20
2 Ease of land preparations	23	28
3 Moisture conservation	22	25
4 Weed control	8	24
5 Erosion control	8	3
Improved land productivity (1, 3, 5)	69	48
Improved labour productivity (2, 4)	31	52

Source: Authors' survey, 1992.

by the *basura*, or "litter," left by the velvetbean crop, thereby permitting annual cropping without reductions in maize yields. They also note that the aggressive legume chokes out weeds and thus facilitates land preparation before planting of second-season maize and reduces weed populations. According to farmers, the thick mulch left from the slashed velvetbean crop suppresses weeds in the maize field and conserves soil moisture during the relatively dry period of the year. Farmers say the dead mulch and the green velvetbean crop protect the soil from erosion year-round. Some farmers also say that damage to maize from stem borers (*Gallina ciega*) is reduced because the insects would rather eat velvetbean mulch than healthy maize plants. These perceptions go a long way to explaining the rapid rate of adoption of the *abonera* system in northern Honduras and the high levels of overall adoption.

During the farm survey, farmers were asked to rank five (commonly reported) reasons for using the *abonera* system: fertilizer" effect of the decaying velvetbean litter; ease of land preparations (slashing); weed control in the subsequent maize crop; moisture conservation provided by the velvetbean mulch; and erosion control (Table 19). Illustrations of these reasons (see Appendix II) were laid out before the farmers, and after a discussion of each, the farmers were asked to select, sequentially, the first and second most important reasons for establishing an *abonera*.

As noted in the description of the survey methods (Appendix I), women were not interviewed separately from men, and no female-headed households were sampled. Consequently, we do not know whether gender differences affected the farmer's perceptions of advantages and disadvantages of the *abonera* system.

Study of this issue is relevant because women bear some responsibility for weeding the maize field.

Although all the farmers surveyed were asked these questions, only the responses of farmers using *aboneras* at the time of the interview are reported. Numerous nonadopters also had clear opinions regarding the technology — an indication of widespread awareness of the *abonera* system — but their responses were in no way different from those of the users of the technology. When asked directly why they were not using the *abonera* system, these respondents overwhelmingly pointed to the lack of land of their own — an issue mentioned above and discussed further in Chapter 7.

For the majority of adopters (39%), the most important reason for planting maize in an *abonera* was the fertilizer effect of the decaying velvetbean litter. Ease of land preparations and moisture conservation were also rated first by a large proportion of the adopters. Weed control was selected as the second most important reason by a quarter of the adopters, but very few farmers cited it as the most important reason. Erosion control (a characteristic important to researchers) was selected by only a few farmers as an important reason for using the technology — an issue discussed further below.

The farmers' reasons for adopting the *abonera* system can be grouped into two categories (see Table 19): criteria related primarily to land productivity (fertilizer effect, moisture conservation, erosion control) and criteria related primarily to labour productivity (ease of land preparations and weed control. Considered in this manner, more than two-thirds of the farmers selected positive impacts on land productivity as their first reason for using the technology, whereas the remainder placed first priority on the *abonera* system's impacts on labour productivity. However, important interactions occurred between these two sets of criteria. Analysis of adopters' first and second selections indicates that the majority (68%) chose combinations of land- and labour-productivity criteria. A quarter of the farmers surveyed selected mainly land-productivity criteria in giving their main reasons for using the technology, whereas 7% selected only labour-productivity criteria. This pattern suggests that land-productivity criteria are the most important reasons for farmers' using the *abonera* system but that the *abonera* system's potential to respond simultaneously to land and labour constraints on productivity is highly valued. This pattern also suggests that labour is an important consideration in the decision-making of farmers.

The wide range of reasons farmers gave for adopting the technology and the various combinations of priorities suggest that their reasons for using *aboneras*

Table 20. The relation between adopters' main criteria for using the *abonera* system and their farm resources, northern Honduras, 1992.

Main criteria	Average land owned (ha)	Average fallow area (ha)	Average yield of wet-season maize (kg ha^{-1})	Family labour per farmed area
Land productivity [a]	8.0	5.1	698	1.1
Labour productivity [a]	18.5	16.1	986	0.8
t test	0.012	0.004	0.031	0.225

Source: Authors' survey, 1992.
[a] See Table 19.

are related to particular constraints on their own system resources. Analysis of the relationship between farmers' first selection and farm resources indicates that farmers who cited principally land-productivity criteria in their adoption of the *abonera* system had on average fewer land resources (land owned and fallow land) and had land of poorer productive value (lower wet-season maize yields) than farmers whose first concern was labour productivity (Table 20). Farmers selecting ease of land preparations or weed control as their first reason for using the technology had on average fewer family-labour resources per unit of farmed area than those who selected land-productivity issues first, but these differences were not statistically significant.

Although the adopters' assessments of the *abonera* system were highly favourable, discussions also revealed potential problems with the technology. Farmers noted that the *abonera* system can increase the risk of damage to maize by rodents. (This perception was widespread, but the researchers found little evidence of greater rodent damage to maize in *aboneras* than in fields cleared from bush fallow.) The farmers argued that rodents prefer to build their nests in *aboneras*, as they are more protected from predators by the abundant velvetbean mulch. Farmers also noted that the rats in the *aboneras* cause a proliferation of snakes, a hazard for the people who slash the velvetbean in the field.

Adopters throughout the region also expressed concern about the risk of localized landslides in fields planted with velvetbean. They argued that velvetbean smothers all other vegetation and loosens the soil, thereby increasing the risk of landslides during the height of the rainy season. A more in-depth discussion of this issue is provided in Chapter 5, but it is important to bear in mind at this stage that landslides also occur on land under pasture and even in native forests, mainly because of the instability of soils on steep slopes and the extremely high rainfall in the region.

Table 21. Adopters' evaluation of the potential disadvantages of the *abonera* system, northern Honduras, 1992.

	Proportion of respondents (%)	
	First selection	Second selection
Pests	46	12
Landslides	28	11
Loss of opportunity to plant first-season maize	11	15
No problems of importance	15	62

Source: Authors' survey, 1992.

Another disadvantage of the *abonera* system noted by adopters was that first-season maize cannot be planted in a field dedicated to the system. The opportunity cost of land planted to velvetbean is a constraint already mentioned, and it is analyzed further in Chapter 7.

Illustrations of the three main disadvantages of the *abonera* system (see Appendix II) noted during informal discussions with farmers were also presented to the adopters during the farm survey. These included the risk of pests (rats and snakes) and landslides and the loss of opportunity to plant first-season maize. The farmers were asked to indicate which, if any, of these potential disadvantages of the *abonera* system were of concern to them.

Table 21 shows that the greatest concern of adopters was the risk of rat infestations (selected by 45%), followed in importance by the risk of landslides. A few farmers mentioned the loss of opportunity to plant maize during the first season as a problem with the *abonera* system. The remainder of the responses were that there were no problems of importance.

Although farmers perceive specific problems with the *abonera* system, no relationship could be found between these perceptions and reported pest problems, slope of fields, or farm size. This does not mean, however, that the concerns are vacuous or without impact on farmers' behaviour. Some farmers reported that they occasionally burn their velvetbean crops to reduce the risk of rat damage to maize, and others claimed to avoid certain field conditions they considered too risky for *aboneras*. But almost unanimously, farmers consider these constraints very minor compared with the benefits of the *abonera* system.

Farmers' perceptions of the relative merits of the *abonera* system, traditional fallows, and commercial fertilizers were also explored during the farm survey through direct comparisons. Farmers were asked to indicate whether they preferred an *abonera* over an established bush fallow (4 years or more) and the reasons for their preference. The same comparison was made for an *abonera* and a field cultivated using commercial fertilizers. Again, only the responses of adopters are reported.

The adopters indicated overwhelmingly that they preferred an *abonera* over a field under bush fallow. The reasons for this preference were consistent with the characteristics of the *abonera* system noted above. Farmers reported that an *abonera* is as fertile as a field recently cleared from bush fallow. They also indicated that the mulch created by the *abonera* system is more substantial than that left by a maize field managed in a traditional bush-fallow rotation and consequently conserves soil moisture more effectively. Finally, farmers indicated that an *abonera* is easier to clear than a field managed under the bush-fallow system. Together, these responses indicate that farmers perceived the *abonera* system as a land-management strategy similar but superior to the bush-fallow alternative.

Some 70% of the adopters stated a clear preference for the *abonera* system over a maize-production system relying solely on commercial fertilizers to maintain soil fertility. A quarter of the farmers stated that the two cropping systems were equally appealing, but the remainder preferred commercial fertilizers over the *abonera* system. Most farmers stating a preference for the *abonera* system gave as their reason the high cost of commercial fertilizers, noting as well that yields were similar under both systems. They also preferred the benefits provided directly by the *abonera* but not by commercial fertilizers, such as ease of land preparations, weed control, and moisture conservation. These results suggest that the *abonera* system is perceived by farmers as a lower-cost substitute for commercial fertilizer, with additional management benefits.

Conclusions

The *abonera* system appears to be very close to an ideal cropping practice for hillside farming. Its main features include slashing of the velvetbean stand at physiological maturity, no burning of crop or field residues, dibble-sticking of maize in the velvetbean mulch, reliance on the natural reseeding of velvetbean for its reestablishment, and an untouched velvetbean fallow extending over 6 months during the main rainy season. The *abonera* system combines some of the most desirable traits of a no-tillage cropping system with low external inputs, from both a scientist's perspective (resource conservation, nutrient recycling, good productivity; see Sanchez 1994) and the farmers' standpoint (low investment, short-term benefits, compatibility with existing knowledge base; see Bunch 1993; Buckles and Perales 1995).

CHAPTER 5

THE AGROECOLOGY OF THE *ABONERA* SYSTEM

The *abonera* system is similar to an improved, short-term fallow. After the maize crop is harvested, the field is abandoned to the spontaneous growth of velvetbean vegetation. The function of the velvetbean fallow is to help maintain and build up soil productivity for the benefit of the following maize crop. No direct economic benefits are realized from the fallow vegetation *per se*.

The thick mulch layer that velvetbean leaves on the soil year-round is a distinctive feature. In this respect, the *abonera* system is more like natural ecosystems, such as tropical forests with litter layers, than rotational fallow cropping systems (see Budelman 1988). One of the main effects of the velvetbean-mulch layer is improved mineral nutrition in the maize crop. The mulch layer also has favourable cumulative effects on soil fertility and reduces soil erosion, making the *abonera* system a viable, productive long-term option for continuous cultivation of hillsides.

In this chapter, two central aspects of the *abonera* system are examined to show how the system works and how it is related to the climate, soil, and other aspects of the surrounding environment. First, this chapter provides baseline information about annual nutrient cycling in the *abonera* system, with a strong emphasis on N dynamics. The main aspects considered here include quantification of organic inputs, pace and timing of N accumulation in the legume, mulch decomposition, and the related accumulation of inorganic nitrogen (N_i) in the soil profile. Uptake of N by the maize crop is also examined. The evidence for this analysis comes mainly from measurements of velvetbean biomass made in farmers' fields at slashing time and from monitoring N_i in the soil profile throughout the maize cycle in a subsample of these fields (see details in Appendix III).

N dynamics has been studied in numerous 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; Smyth et al. 1991; Kang and Mulongoy 1992; Haggar and Beer 1993). What is much less common, however, is empirical evidence from developing countries on the long-run effects of cropping systems, and this is due to the high costs of maintaining experiments

(Pieri 1989; Swift et al. 1991; Sanchez 1994; Steiner 1995). This chapter analyzes the agroecological sustainability of the *abonera* system by comparing farmers' fields managed continuously under the *abonera* system for periods of 1–15 years. We analyze soil samples collected in chronosequences of the velvetbean–maize rotation in four villages in northern Honduras. The set of properties examined includes levels of soil organic matter (SOM) in the upper soil profile, soil acidity and exchangeable bases, P content, infiltration, bulk density, and macroporosity (see details in Appendix III).

A chronosequence approach allows inferences to be made about the evolution over time of a system. To obtain the data for this, a comparative survey is conducted at a given point in time on a set of fields that are supposed to represent successive historical states of the system. The use of this space-for-time substitution scheme is a common practice in ecology studies (Pickett 1988) and in soil-genesis studies. It is much less common, however, in cropping-system studies (Staley et al. 1988; Feller et al. 1991; Kleinman 1995), probably because the proper conditions for the use of such schemes are rare. This approach also entails many assumptions that make the analysis more vulnerable to failure. Nevertheless, it was the only alternative at hand that does not require at least a decade of observations before an experimental database is available for the formulation of recommendations. We believed, moreover, that a chronosequence scheme was particularly pertinent in northern Honduras, where numerous contiguous fields are managed in similar ways for various periods.

Nitrogen cycling

This section analyzes annual trends in aboveground velvetbean biomass and N dynamics and their relations to the availability of N_i in the soil profile during the maize cycle. We analyze management options for meeting the N requirements of maize by determining the effects of limited additions of fertilizer-N or fertilizer-P on maize production.

Main components of the aboveground biomass

Aboveground biomass in the velvetbean–maize rotation includes several key components, whose nutrient content or relative contributions to total biomass vary with the phases of the rotation (Figure 11). As a first simplification, the aboveground biomass can be divided into "live" and "dead" fractions. The live fraction comprises either growing velvetbean (from June to December) or growing maize and its accompanying weeds (between December and May). The biomass content of

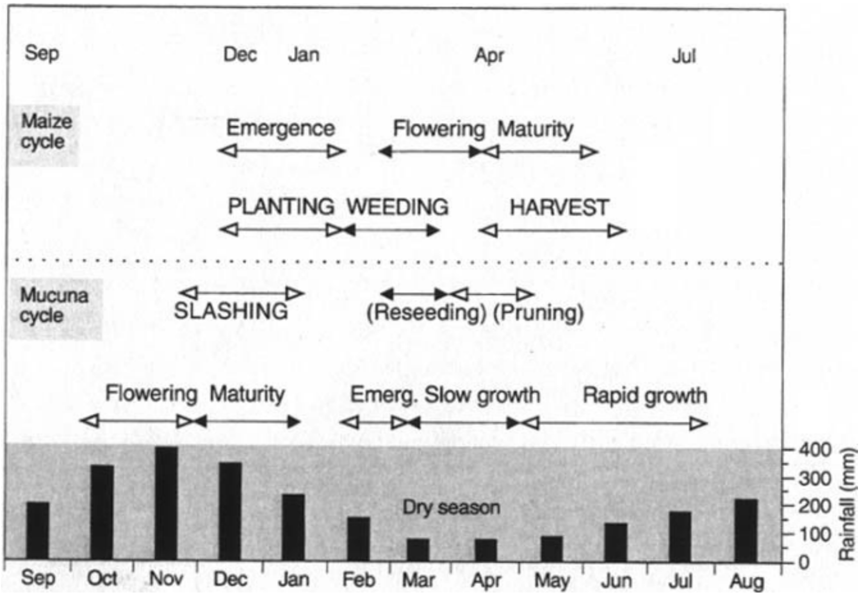

Figure 11. Main phases of the *abonera* system. Note: Arrows indicate periods during which most farmers do a given practice.

this fraction varies widely during the year, reflecting the various phases of the velvetbean–maize rotation. In all cases, however, no biomass other than maize ears is ever removed from the velvetbean fields: maize stover is left in place, and velvetbean is never grazed or harvested as forage or grain.

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

Velvetbean biomass and nutrient content at slashing

Slashing of the live velvetbean crop constitutes the pivotal moment in the velvetbean rotation. We will now turn our attention to two fundamental aspects of slashing, namely, the quantity of biomass present at that time and its composition.

Total biomass content

For the four villages sampled in December 1993 (Las Mangas, Piedras Amarillas, Rio Cuero, and San Francisco de Saco), the average levels of total aboveground biomass fell within a relatively narrow range of 10.7–12.4 t ha^{-1}, on a DM basis (Table 22), although differences among sites were statistically significant. Similarly, the year-to-year variability within a site was moderate (Table 23), although biomass was significantly lower in December 1992 than in the two following cycles. The largest differences occurred among fields within the same year and site. For example, in San Francisco de Saco in 1992, the individual-field minimum was 6.1 t ha^{-1}, whereas the maximum exceeded 15 t ha^{-1} (Table 23). The within-field variability was low on average (not statistically significant), although in a few cases differences of several tonnes per hectare were found between sampling plots within a single field.

The overall stability of the biomass production (coefficient of variation of less than 15%) probably stems from a combination of factors. First, total biomass includes a strong semipermanent litter component, which is only partly influenced by seasonal fluctuations in climate and plant growth. Also, the length of the velvetbean cycle (8 months minimum) probably allows the velvetbean–weed stand to compensate over the growing season for any stress that would temporarily reduce growth. To go beyond total biomass and grasp its actual composition, we subdivided the live fraction into three subfractions — green material (velvetbean leaves and fine stems), velvetbean pods, and velvetbean vines (partly lignified stems) — reflecting the morphological and functional differences of this fraction's components.

On the one hand, the proportions of the various subfractions were relatively stable among sites (Table 22): 10–15% for green material and 14–22% for vines. (Interestingly, as Table 23 shows, live weeds were almost always nonexistent at slashing time — weeds present at the end of the maize cycle get incorporated in the mulch–litter layer.) On the other hand, pod production was quite variable among sites (Table 22): pods constituted as little as 6% of the total biomass and as much as 24% (the range was wider for comparisons among fields). This variability also occurred across years (Table 23). The litter (dead) fraction constituted on average close to 60% of the total dry weight, or 5–9 t ha^{-1} (Table 22). Thus, the annual December slashing added only 4–6 t ha^{-1} of fresh DM to the preexisting litter, itself an undetermined mix of recent and old litter. (Roots add probably another 1–2 t of fresh DM to this total [Lathwell 1990; Hairiah 1992].)

Table 22. Aboveground biomass in velvetbean fields at four sites at slashing time, northern Honduras, December 1993.

		t DM ha^{-1}			% of total biomass			
	(*n*)	Total biomass	Minimum	Maximum	Green [a]	Pods [b]	Vines [c]	Litter [d]
San Francisco de Saco	32	12.4±2.15*a*	7.0	16.3	11±5	6±4	14±4	69±6
Las Mangas	29	11.0±1.4*b*	8.8	13.9	10±5	24±6	22±4	45±8
Rio Cuero	21	10.7±1.6*b*	8.6	14.5	15±6	7±5	18±5	60±8
Piedras Amarillas	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

Note: Each cell represents the average for the site, followed by its standard deviation. DM, dry matter.
[a] Leafy material and tender vines.
[b] Including immature seeds.
[c] Old stems, partly lignified and possibly about to start rotting.
[d] Dead material, including freshly shed leaves.
a,b Means followed by the same letter within a column do not differ significantly according to Tukey's test at the 10% family rate.

Table 23. Interannual variability in aboveground biomass in velvetbean fields at slashing time, San Francisco de Saco, northern Honduras, 1992–94.

	(*n*) [a]	Total biomass [b] (t DM ha^{-1})	Minimum (t DM ha^{-1})	Maximum (t DM ha^{-1})	Litter (% of total biomass)	Pods (% of total biomass)	Live weeds (t DM ha^{-1})	Total N (kg ha^{-1})
1992	44	10.8±2.3*b*	6.1	15.9	61	NA	(0.0) [c]	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)	NA
Average	98	11.7±2.5	6.1	17.0	64	10	—	284±75

Note: DM, dry matter; NA, not available.
[a] Number of plots sampled.
[b] Average ± standard deviation.
[c] *Parentheses indicate that only a few plots had weeds or that quantities per plot were not significant.*
a,b Means followed by the same letter within a column do not differ significantly according to Tukey's test at the 10% family rate.

Table 24. Selected characteristics of the aboveground biomass in velvetbean fields at four sites at slashing time, northern Honduras, December 1993.

Property		Green [a]	Pods [b]	Vines [c]	Litter [d]
N (%)	Average	2.88	3.03	1.94	2.61
	Minimum	1.83	2.43	1.54	1.86
	Maximum	3.70	3.59	2.49	3.26
C–N ratio	Average	15.50	14.90	23.40	17.70
$\delta^{13}C$ [e]	Average	−26.80	−25.20	−26.20	−24.80

[a] Leafy material and tender vines.
[b] Includes immature seeds.
[c] Old stems, partly lignified and possibly about to start rotting.
[d] Dead material, including freshly shed leaves.
[e] $\delta^{13}C$ = the ratio of ^{13}C to ^{12}C atoms, expressed in delta units.

Characteristics of the biomass fractions

Across sites, the levels of N and the C–N ratios were fairly consistent among the various components of the biomass (Table 24). The pods had the highest level of N (about 3% on average); the vines had the lowest (less than 2%), which translates into a C–N ratio of greater than 23. The litter fraction had relatively high but variable levels of N within site: about 2.65%, on average, with consequently low C–N ratios of 16–18. The litter had a $\delta^{13}C$ value close to −26 (δ^{13} is a measure of the relative abundance of ^{13}C in the plant tissues [Mariotti 1991]). The N and $\delta^{13}C$ values indicate that the litter fraction at slashing received a greater contribution from the velvetbean, a C3 plant, than from maize stover (a C4 plant with a $\delta^{13}C$ value of close to −13) or from C4 grass weeds (*R. cochinchinensis* in the case of San Francisco de Saco), which predominate in numerous velvetbean fields across northern Honduras. By contrast, when velvetbean did not reestablish itself properly during the 1994 summer cycle, the biomass at the next slashing had a much higher proportion of weeds, yielding a lower N content (less than 2%) and lower $\delta^{13}C$ values for the litter fraction (−15 to −20).

Nitrogen content

Table 25 shows total N content in the aboveground biomass averaged across all four sites. As was the case for total biomass, total N content was similar across sites and reached almost 300 kg ha^{-1} on average. Again, the major source of variability was among fields: at San Francisco de Saco, for example, content dropped to as little as 100 kg ha^{-1} in one field and, conversely, reached almost 500 kg ha^{-1} in another. As N content was fairly similar across all sites, total N mainly depended on biomass levels, rather than on the N content of the various fractions.

Table 25. Nitrogen in aboveground biomass in velvetbean fields at four sites at slashing time, northern Honduras, December 1993.

	N (kg ha^{-1})					Litter
	Green [a]	Pods [b]	Vines [c]	Litter [d]	Total	(% of total N)
Mean [e]	40±20	42±30	39±11	174±59	295±58	58±13
Minimum	2	1	11	68	164	26
Maximum	95	140	74	322	504	81

[a] Leafy material and tender vines.
[b] Includes immature seeds.
[c] Old stems, partly lignified and about to start rotting.
[d] Dead material, including freshly shed leaves.
[e] Each cell represents the average across sites (n = 101), followed by its standard deviation.

Consequently, almost 60% of the N present at slashing was found in the litter, rather than in the live subfractions. The pod subfraction accounted for a low percentage of total N on average, but not at Las Mangas, where it accounted for almost 25% of the total N, in keeping with the high proportion of pod biomass at this site. Because velvetbean seeds will eventually germinate, most of this pod N is not expected to be available for subsequent recycling via decomposition.

Nutrient content

Although N is the nutrient of primary interest in this discussion, the accumulation of other key nutrients in the velvetbean biomass was quite significant (Table 26). Considerable variability occurred across sites, but the velvetbean "complex" accumulated large quantities of Ca (140 kg ha^{-1} on average, 70% of it in the litter) and K (100 kg ha^{-1}, 82% in the live subfractions). Even P (15–20 kg ha^{-1}, 45% in the litter) was found at levels adequate for the requirements of a moderately high yielding maize crop.

Seasonal behaviour of the velvetbean cover

We now examine in more detail how a velvetbean crop accumulates DM and nutrients in the first place, before releasing both on decomposition.

Biomass accumulation during the rainy season

The two main phases of the velvetbean cycle are the vegetative, from February and March (velvetbean reseeding) to early October, and the reproductive, from October to December, at which time velvetbean starts to die naturally, even without slashing. The vegetative phase spans the dry season and the first half of the

Table 26. Nutrients (other than N) in the aboveground biomass of velvetbean at four sites at slashing time, northern Honduras, December 1993.

Nutrient	Average [a]	Minimum	Maximum
Total P (kg ha^{-1})	20±7	14	28
% of total P in litter	45±14	31	58
Total K (kg ha^{-1})	100±24	82	114
% of total K in litter	18±9	11	27
Total Ca (kg ha^{-1})	140±37	111	159
% of total Ca in litter	70±10	62	78
Total Mg (kg ha^{-1})	26±7	22	32
% of total Mg in litter	56±12	45	67

[a] Each cell represents the average over all fields sampled at four sites, followed by its standard deviation. Sample sizes were 32, 29, 21, and 19 for San Francisco de Saco, Las Mangas, Rio Cuero, and Piedras Amarillas, respectively.

rainy season, whereas the reproductive phase takes place during the peak of the rainy season.

After it reseeds itself, between February and March, the velvetbean grows relatively slowly because of the shade provided by a fully developed maize crop. Also, it has to withstand either farmers' pruning operations in wet years (see Chapter 4) or extremely dry and hot conditions if the winter cycle is drier than usual. Weeds left uncontrolled by farmers may also compete heavily with the young velvetbean plants for light, nutrients, and water. Usually not until after maize harvest and the return of rains (by end of May to early June) do conditions become favourable for rapid velvetbean growth, leading to full canopy closure within a few weeks. By mid-summer, a typical field has a relatively uniform, dense velvetbean stand. By then, maize stover has been pulled down and incorporated in the litter by aggressively growing velvetbean vines, which had been using the stalks as support. Weeds have usually been reduced to a marginal presence by that time, as velvetbean gradually outcompetes most of the weeds present at the end of the maize cycle. Velvetbean starts flowering in early to mid-October, apparently in response to shorter days (it is still unclear how strictly photoperiodic velvetbean is). At this point, a typical velvetbean field in northern Honduras has accumulated about 10 t DM ha^{-1}, with close to 40% of the DM in the live velvetbean fraction and slightly more than 60% in the litter layer (see Table 23).

But biomass accumulation does not stop at flowering. During the 1993 cycle, total biomass increased from 10 t ha^{-1} in mid-October (early flowering) to

Table 27. Accumulation and apparent decomposition of DM and N in the aboveground biomass in velvetbean fields, San Francisco de Saco, northern Honduras, October 1993 to May 1994.

	Accumulation			Decomposition		
	Oct	Nov	Dec	Dec	Mar	May
Total biomass (t DM ha^{-1})	10.1±1.4	12.0±2.2	14.2±1.2	12.6±1.8	8.6±2.2	10.6±2.2
Total N (kg ha^{-1})	289±54	334±62	367±51	316±63	198±50	235±67

Note: Actual dates were 15 October 1993, 15 November 1993, early March 1994, late May 1994, and variable in December 1993 and 1994 as a function of actual timing of slashing by each farmer. DM, dry matter.

12 t ha^{-1} a month later and to 14 t ha^{-1} after another 3–4 weeks (Table 27). DM accumulation seemed to affect the litter layer more than the live fraction. Between mid-October and mid-November, the biomass contained in the live fraction remained roughly stable, around 3.5 t ha^{-1}, or less than 30% of the total biomass, only to increase by about 1 t ha^{-1} by slashing time in mid-December, probably as a result of accumulation of DM in the pods themselves. On the other hand, litter biomass increased sharply (from 6.4 t ha^{-1} in mid-October to 8.7 t ha^{-1} in mid-November and to almost 10 t ha^{-1} at slashing; data not shown), which may indicate that although velvetbean does not die massively until it is slashed, it starts decaying before or soon after flowering, by shedding leaves and stopping maintenance of its extensive vine network.

As expected, the overall accumulation of N by the velvetbean 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 to 367 kg ha^{-1} by slashing time (Table 27), giving an overall rate of N accumulation of about 1.3 kg ha^{-1} d^{-1}. Again, the situation differed markedly for each fraction: whereas the live fraction apparently accumulated no net N during the 2-month period, the litter fraction gained 89 kg ha^{-1}. This gain, together with a decrease in the C–N ratio, is consistent with the net transfer of biomass from the live fraction to the litter fraction via leaf-shedding, hypothesized earlier. This has important implications for nutrient release and recycling, which start significantly before velvetbean slashing and follow closely the addition of this fresh, N-rich material to the litter layer, where abundant rainfall favours its rapid decomposition. Further evidence that this is the case is found in the N_i levels in the soil profile (see below).

Mulch decomposition during the dry season

After farmers have slashed the velvetbean stand, decomposition is the major process affecting the litter layer. Data presented in Table 27 show decomposition trends between December 1993 and May 1994, a drier than normal period for the region. The table shows apparent, rather than actual, rates of decomposition because periodic samplings of unconfined material made it impossible to separate out the decomposition of the litter *per se* from litter renewal via the addition of fresh weed biomass during weed-control operations.

Litter biomass appeared to drop markedly at first, from 12.6 t ha^{-1} at slashing to 8.6 t ha^{-1} in early March, corresponding to a loss of about 45 kg ha^{-1} d^{-1}. From March to the end of May, however, the total biomass present in the litter layer seemed to increase, reaching 10.6 t ha^{-1}. Although it may be an artifact stemming from approximate sampling procedures, this increase may also reflect the impact of weed-control practices during the February–March period. That slashing the weeds or drying them out with paraquat (see Chapter 2) actually contributes new biomass to the litter layer is an interpretation supported by an analysis of *in situ* labeling, provided by the $\delta^{13}C$ values (Balesdent et al. 1988).

According to these calculations, the original velvetbean litter decomposed relatively quickly from December to early March, losing 43% by weight during this period, and much more slowly afterwards, losing only an additional 6% (Table 28). Weeds controlled by farmers contributed significant quantities of new litter during the same period: by the end of May, the weeds seemed to represent almost 40% of the litter found (4 t ha^{-1} out of a total litter of 10.6 t ha^{-1}). This table does not include the biomass of live weeds, which can range anywhere between 0.5 and 4 t DM ha^{-1}. The situation in terms of N was similar to the one for biomass: total N (for the entire litter) dropped sharply between December and March, from 316 kg ha^{-1} to 198 kg ha^{-1}, and increased again to 235 kg ha^{-1} by late May, paralleling the apparent biomass increase (see Table 27). Using the same sort of calculations on natural abundance mentioned previously, we estimated the quantities of N remaining in the original velvetbean fraction (Table 28). N content dropped from 316 kg ha^{-1} to 176 kg ha^{-1} in early March, to 171 kg ha^{-1} in late May. About 140 kg ha^{-1} of N seemed to have been released by the litter on average in the first 80 d following slashing; and less than 5 kg ha^{-1}, in the following 80 d (however, the variability associated with both estimates was huge).

It is probable that these crude figures, obtained in a very dry cycle, represent lower than average estimates of the N released during a typical (that is, fairly wet) winter cycle, especially after March when there are usually at least a few significant rains. However, the behaviour of the velvetbean cover during two phases (fast then slow release) seems consistent with observations of the decomposition of green manures elsewhere (Bouldin 1988).

Table 28. Estimated litter and N left in velvetbean fields at various times after slashing, San Francisco de Saco, northern Honduras, December 1993 to May 1994.

	Sampling date [a]		
	Early Dec 1993	Early Mar 1994	Late May 1994
$\delta^{13}C$ litter [b]	−25.7±2.0	−24.2±2.3	−22.6±2.0
Original litter left (t ha^{-1}) [c]	12.6±1.8	7.2±2.2	6.6±2.6
Weed in litter (t ha^{-1})	(None)	1.4±1.4	4.0±2.3
Original N left (kg ha^{-1}) [c]	316±63	176±52	171±66
N released (kg ha^{-1})	—	140±94	(5±76)

[a] Actual sampling date varies by field; values in parentheses are approximations.
[b] Weighted average (by biomass) of ^{13}C for the various fractions constituting the litter.
[c] Original refers to litter or N already present at slashing; see text for assumptions made. Each figure represents the mean of 18 plots.

Nitrogen dynamics in the soil–maize system

The main objective of this section is to gain some understanding of the relation between N supplied by the decaying litter–SOM and the N demand and uptake from the maize crop (in terms of quantities and synchronization). This issue is critical to overall system productivity, as the N released by the velvetbean is of little direct value to the maize crop unless its availability is in synchrony with the demand for it from the maize.

Temporal patterns of inorganic nitrogen

Figure 12 shows the general temporal patterns exhibited by N_i (sum of NO_3-N and NH_4-N [kg ha^{-1}] over the entire 0- to 60-cm soil profile) over the 1992/93 and 1993/94 maize cycles for a number of neighbouring, well-established velvetbean fields (each with 5–14 years of continuous use of the velvetbean–maize rotation). Several features are apparent from the figure:

- All fields displayed a relatively homogeneous behaviour in when N_i was highest and in how fast its level changed. The similarity of pattern within and between years illustrates both the homogeneity of management across fields and the strong influence of environmental factors and conditions (other than the soil) in shaping N mineralization processes.
- Each year, N_i reached a marked peak at about 30 d after slashing, followed by a rapid decrease over the next 3 or 4 weeks. The maximum

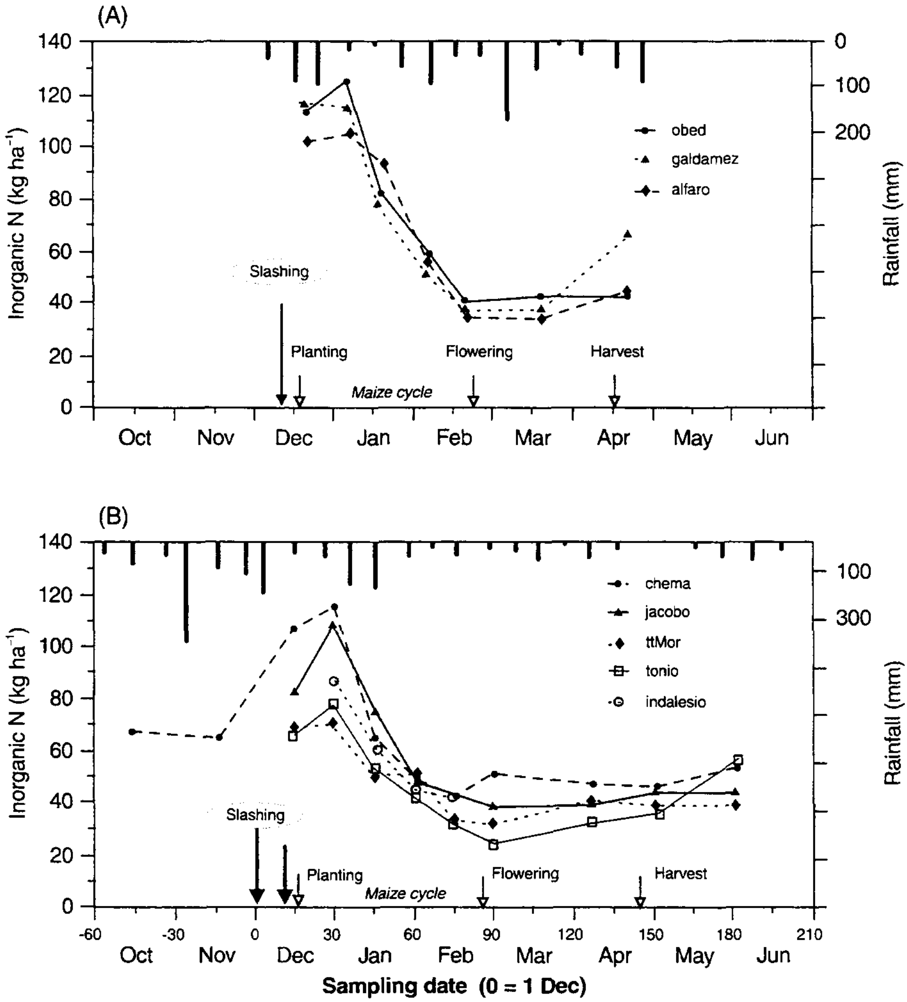

Figure 12. Seasonal dynamics of inorganic nitrogen in the 0- to 60-cm soil profile of well-established *Mucuna* fields, San Francisco de Saco, northern Honduras: (A) 1992/93 cycle; (B) 1993/94 cycle. Note: Each point represents the average of three replications.

observed levels of N_i were close to 100 kg ha^{-1} for both years (the maximum observed was 115 kg ha^{-1}; the minimum, 70 kg ha^{-1}). They never dropped below 30–50 kg ha^{-1} N_i, even during the period of maximum maize uptake.

- As maize is planted, immediately after slashing, a satisfactory synchronization can be obtained between N released by the decaying velvetbean mulch and that taken up by the maize crop. The sharp decrease observed in the levels of available N_i between days 30 and 80 (1992/93) or 90 (1993/94) — during which 60–80 kg ha^{-1} of N_i disappeared — coincided with periods of intense crop uptake (see below). In addition to maize, weeds are also likely to have benefited from the high levels of available N_i, especially in the first few weeks after slashing, when maize grows slowly.

- A sizable pool of N_i (40 kg ha^{-1} or more) was available in the profile even when maize was not growing. This is especially evident from the 1993/94 data, which cover a longer time span (from October to June). In particular, the relatively high levels of N_i (around 60–70 kg ha^{-1}) found in the profile in October–November (that is, well before slashing) may indicate that active decomposition is taking place in the litter layer–SOM complex during the heaviest rains, when velvetbean is still growing. This trend is consistent with the increase in litter biomass caused by leaf-shedding, mentioned earlier.

Distribution of inorganic nitrogen by horizon

As the season progressed (that is, as maize went from emergence to flowering), the profile was gradually depleted of its N_i at all depths. Toward the end of the maize cycle, availability of N_i tended to increase again, especially in the top horizon, which became the main contributor to total N_i. Even in 1993/94, a dry year, its share reached around 50% of the total N found in the profile.

The dynamics affecting the first horizon over time and the observed difference between the upper and lower horizons probably reflect the influence of maize–weed uptake, as roots preferentially deplete the N_i of the superficial horizons. In terms of concentrations, the order showed a strong gradient — horizon 1 > horizon 2 > horizon 3 — a situation typical of a no-tillage system with a litter layer. The decreases in concentrations over time in the various horizons may be due to decreasing availability of substrate and moisture, which are both key factors in the decomposition process.

Nitrogen released by the decomposing litter

The decomposing litter alone appeared to release about 100 kg ha^{-1} in the first 80 d after slashing (this value differs from the one reported in Table 28 because it was calculated only for the fields monitored for N_i). How much of this N found its way into the soil solution remains a matter of speculation, as the N 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 entering the soil profile (Schlather 1997).

Nitrogen released by the mineralization of soil organic nitrogen

An estimate of the N mineralized from SOM during the maize cycle can be derived by estimating mineralization rates for the organic N stored in the soil profile. This was a humid, tropical climate and, on average, the moisture content of the various horizons remained favourable to mineralization from December until at least early March; therefore, mineralization rates in the 0- to 10-cm horizon may have reached 1–1.5% of the N present for this 3-month period (based on a 4–6% annual rate). If the estimated contributions of the different horizons are added together, N mineralized in the 0- to 60-cm profile from the pool of soil organic N alone could have contributed about 50–75 kg N_i ha^{-1} between early December and early March, thus adding significantly (as much as 50%) to the levels of N released by the decaying litter.

Nitrogen budgets

By summing figures for the main sources or sinks of N over the maize cycle, one can calculate approximate N budgets at various stages in the maize cycle (Table 29). The terms taken into consideration in this analysis include the following:

- The aboveground litter, with dynamics discussed earlier;
- The maize crop, with the assumption that the N-uptake curve over time was of the form $a/(1 + b \exp -ct)$, where a, b, and c are fitting constants and t is time (Hunt 1982);
- Weeds, which constitute another important but variable factor, both in N uptake (especially when weed control is deficient) and in N recycling (in effect, because of the way weeds are controlled [slashed manually or desiccated with paraquat], most of the N the weeds take up can be expected to be recycled later during the growing season [Lambert and Arnason 1989]); and
- The N_i found in the 0- to 60-cm soil profile (its level reflects the mineralization of both the litter and the soil organic N).

Table 29. Estimated N budgets at several stages in the maize cycle, San Francisco de Saco, northern Honduras, winter 1993/94.

	N (kg ha^{-1})					
Stage	Litter [a]	Maize [b]	Weed [c]	Soil N_i [d]	Total N	N unaccounted for [e]
Field A						
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
Field B						
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
Field C						
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
Field D						
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

Note: Each value represents the mean of three replications. DAP, days after planting.

[a] Total N found in aboveground biomass (live fraction + dead fraction), which is measured.

[b] Total N in aboveground maize biomass, estimated using a logit function, except for harvest, which is measured.

[c] Total N in weed biomass, estimated, except for harvest, which is measured.

[d] Inorganic N as measured in 0- to 60-cm soil profile.

[e] Calculated as total N_s − total $N_{slashing}$, where *s* is the given stage in the maize cycle.

The N unaccounted for (obtained as the difference between the total N at a given stage and the 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). Overall, these budgets appear to offer reasonable approximations, as the N unaccounted for represents relatively small amounts (a small percentage of the total N at slashing, with maximum deviations of 10–20%). In other words, the various components taken into consideration in calculating these budgets (litter, crop, weeds, and N_i in the profile) seem to represent the most important ones, with little room for losses via leaching or other forms of N immobilization.

Nitrogen leaching

In an N-rich environment subject to abundant rainfall, leaching is the probable fate of N released by the decomposing litter–soil, and the calculations obtained above for N budgets are compatible with leaching's playing a role. Following an approach developed by Jones (1975), we estimated apparent leaching rates by calculating for each field the average depth of the N_i for the various sampling dates and regressing this against the cumulative amount of rainfall. The results of these calculations showed that in both cycles (1992/93 and 1993/94), no downward movement of N_i was apparent.

This indirect evidence, combined with indications from the N budgets and from N_i monitoring, indicates that leaching is probably not a significant source of N loss in the velvetbean system, at least not during the maize cycle. But it may be a result of the gradual release of N from the decomposing litter and the temporary trapping of N in weeds, which may play a significant role in protecting N against leaching early in the maize growing season. This is when rains are still frequent and heavy and the maize crop is still unable to take up much N. Further evidence is required, however, to assess leaching losses more fully.

Nitrogen 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 SOM itself. No data are 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 the substrate produced by slashing. In all likelihood, the turnover of this N is relatively fast (Duxbury et al. 1989) and hence the net release of some of it is possible, even within the maize cycle, still in time for subsequent plant uptake.

Evidence of the long-term role of SOM as a sink is given by the generally positive trend observed for soil organic N values in the 0- to 10-cm horizon (see below): from about 0.2% in check fields where no velvetbean has ever been grown to more than 0.3% for old velvetbean fields. The gradual increase observed over the years corresponds to an overall storage of about 50–80 kg N ha^{-1} year^{-1}, on average. How much of this yearly storage occurs during the maize cycle remains unclear.

Recycling of nitrogen versus N_2 fixation

It is usually assumed that much of the N in legume–cereal rotations comes from biological fixation. We made no direct measurements of this during the study, but the data gathered on N cycling allow us to make some indirect estimates.

Disregarding losses via leaching and volatilization and assuming stable levels of the microbial pools of N across years, we considered two mechanisms by which annual N cycles are kept open: nutrient removal via harvest (grain only) and long-term storage in SOM (at least until the system reaches near equilibrium).

Each term representing about 50–80 kg ha^{-1} year^{-1}, a total of 100–160 kg N ha^{-1} year^{-1}, must be obtained from an external source to make up for the loss or storage. Some N may enter via rainfall or nonsymbiotic fixation (perhaps, 20–30 kg ha^{-1} year^{-1} [Wetselaar and Ganry 1982]), but most probably the bulk of it is provided through symbiotic N_2 fixation by the velvetbean crop itself. Until direct, *in situ* measurements are made, it appears reasonable to conclude that a velvetbean crop may fix anywhere between 70 and 130 kg N ha^{-1} per cycle.

Conversely, as much as 200–300 kg N ha^{-1}, or about two-thirds of the total N, is simply recycled through the system every year. The velvetbean crop (and to a much lesser extent, the weeds) appears to be a primary candidate for scavenging any available N, 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 the conditions highly favourable for mineralization and litter decomposition found during this wet period. In addition, one may expect velvetbean to rely as much as possible on the ample supply of N_i in the environment, rather than incurring the high energy costs of fixing all the N it needs (Giller and Wilson 1991).

Maize response to nitrogen

In this section, we examine whether the "natural" supply of N from the velvetbean biomass meets the N requirements of a maize crop and how sensitive this is to the levels of N present in the soil–plant system. The two main N inputs for a growing maize crop in the velvetbean system are the N provided by the decomposing velvetbean-biomass fractions constituting the litter, on one hand, and the soil organic N, on the other — both of which release N gradually upon mineralization. Fertilizer-N can constitute a third source for those farmers willing and able to invest in such a costly input (as a matter of fact, on a regional basis, 40% of farmers do; see Chapters 2 and 3).

Fertilizer can at best add flexibility to the management of the velvetbean system, as velvetbean can almost instantaneously increase N availability for plant uptake over that spontaneously released by the soil–litter organic complex. It may thus contribute to higher yields, for which ample N is needed at critical stages in crop growth, irrespective of its source (organic or chemical). Nevertheless, adding even more N may constitute a wasteful use of precious cash and labour, as well as an undesirable contribution to N leaching in the environment, given the large quantities of N present in the velvetbean system.

Maize response to the nitrogen accumulated by velvetbean at slashing

Data on the response of maize to N accumulated by velvetbean at slashing comprise N content of the litter at slashing, maize-ear-leaf N content at silking, and maize yields. Clearly, factors other than N supply influence the relationships among these variables. However, a number of trends are apparent (Figure 13).

First, highly significant differences ($P < 0.001$) between sites appeared in maize-ear-leaf concentrations. Similarly, highly significant differences ($P < 0.001$) were found between years at the same site. In 1993, maize appeared to have achieved a better nutritional status vis-à-vis N (average % N = 2.81) than in 1994 (average % N = 2.41), although the levels of potential N supply, measured by N content of the biomass, were similar for both years. A weak tendency for yields to increase in response to corresponding increases in maize-ear-leaf concentrations was evident.

Using an interpretative approach based on envelope curves (Siband and Wey 1994), we inferred that N supply might possibly have been limiting if less than 70 kg ha^{-1} was present in the live fraction (which translates into levels of total biomass at slashing of less than 8 t ha^{-1}). Above this threshold, maize appeared to have no clear response to N content, as maize yields seemed to reach a plateau around 5–5.5 t ha^{-1}. Most of the velvetbean fields had N levels of more than 70 kg ha^{-1}, the threshold mentioned earlier, but also had yields much below the alleged plateau (2–3 t ha^{-1}, compared with 5 t ha^{-1}). This may indicate the likelihood of limiting factors other than potential N supply. Overall, the lack of a clear trend in Figure 13 indicates that potential N supply did not limit maize yields.

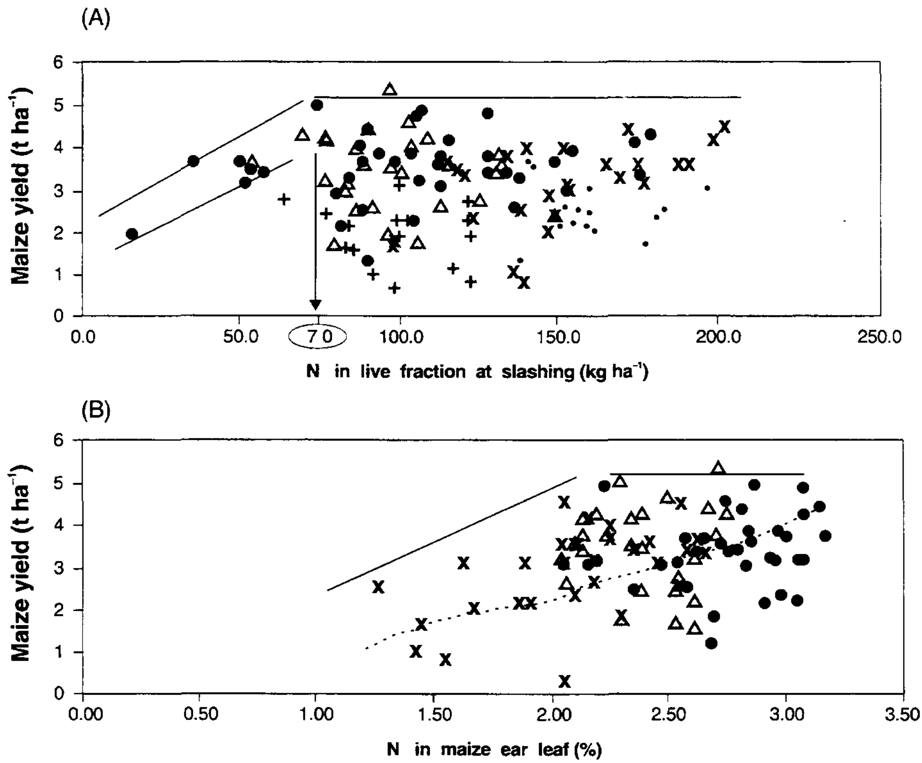

Figure 13. Relationship between maize yields and N content of (A) the biomass and (B) the maize ear leaf, northern Honduras, 1992/93 and 1993/94 cycles. Note: Each point represents the average of three (in 1993/94) or four (in 1992/93) replications. Slashing refers to the approximate date for manual cutting of the *Mucuna*, which is left to decompose on the soil surface. Planting, flowering, and harvest refer to approximate dates for the maize cycle. ●, San Francisco de Saco, 1993; ▵, San Francisco de Saco, 1994; **X**, Las Mangas, 1994; •, Piedras Amarillas, 1994; + Rio Cuero, 1994.

Maize response to adding nitrogen fertilizer

How maize in the velvetbean system responded to a single dose of urea-N applied at the rate of 50 kg ha^{-1} is the focus of this section. The fertilizer was applied, not as a replacement for the N from the decomposing velvetbean litter, but as a complement to this organic source. Whereas the previous results came exclusively from survey data, the fertilizer analysis was carried out by establishing a total of 14 simple, replicated on-farm experiments.

Variability of the response to nitrogen fertilizer

Variability in response among and also within fields (from one replication to another) was important (Table 30). In practical terms, it reflects the fact that certain fields showed no response to N (or a very weak one), whereas others responded sharply (yield increases of about 1 t ha^{-1} were obtained in a few cases). Three of the 10 fields analyzed in 1993/94 showed a statistically significant response to N, whereas 7 showed no significant response when taken individually.

The average response by site (across fields) to N was markedly different between years. In 1992/93 (a relatively wet winter cycle), maize showed no significant response to N, and average yields showed no increase with the application of fertilizer-N ($P = 0.21$).

In 1993/94, however (a rather dry cycle), overall response to N was highly significant ($P < 0.01$), with an average yield increase over the case of no fertilizer reaching about 0.6 t ha^{-1}. Interestingly, similar behaviour was observed for maize nutritional status vis-à-vis N: visual symptoms of N deficiencies, almost absent in 1993, were widespread in 1994, and ear-leaf N concentrations at silking were significantly lower in 1994 than in 1993 (see Figure 13) and were also significantly affected by the application of fertilizer (2.31% without N versus 2.50% with N in 1993/94; $P < 0.0001$).

The fact that fertilizer is advantageous in a relatively dry year may appear contrary to conventional wisdom. But it is hardly surprising if one considers that drier conditions slow down decomposition of the surface mulch without affecting the water availability in the soil profile too drastically. In effect, the rainfall pattern and the fairly deep soils characteristic of the hillsides of northern Honduras allow a winter maize crop to start growing with a soil profile holding up to 300 mm of stored water, which serves as a buffer against potentially extended dry spells. Moreover, a mulched profile can efficiently conserve this stored water (Steiner 1994).

Possible causes of the differential response to nitrogen

The marked variability detected in maize response to N (which was confirmed further in a series of 15 fertilizer-N trials conducted in San Francisco de Saco and Rio Cuero in the 1994/95 cycle [Barreto, personal communication, 1996[3]]) raises the question of why a given velvetbean field or block responds to fertilizer-N. We

[3]H.J. Barreto, agronomist, Centro Internacional de Agricultura Topical, personal communication, 1996.

Table 30. Yield response of a maize crop to the application of fertilizer in well-established velvetbean fields, San Francisco de Saco, northern Honduras, 1992/93 and 1993/94.

	Yield increase (t ha^{-1})											
	1992/93 cycle				1993/94 cycle							
Treatment	Field A [a]	Field B [b]	Field C [c]	Site mean [d]	Field D [b]	Field E [b]	Field F [b]	Field G [a]	Field H [e,f]	Field I [e,f]	Field J [e,f]	Site mean [d]
No fertilizer	3.67	4.31	3.35	3.80±0.72	4.06	3.94	3.43	4.15	3.34	4.93	4.13	3.98±0.60
+N	0.03 NS	0.02 NS	0.02	0.02±0.56	0.89*	0.40**	0.76**	0.50 NS	0.58 NS	0.45 NS	0.70 NS	0.61±0.59
+P	0.25 NS	0.07 NS	−0.03	0.09±0.90	0.25 NS	0.24*	0.30 NS	0.42 NS	—	—	—	0.22±0.66
+N+P	0.34 NS	0.17 NS	1.26	0.45±0.64	0.85 NS	0.99 NS	0.77 NS	0.79 NS	0.53	0.72	1.56	0.87±0.71

Note: Response to fertilizer expressed as yield increase over that of the treatment without fertilizer.
[a] See text.
[b] Mean of three repetitions.
[c] One repetition only.
[d] Mean ± standard deviation.
[e] Mean of two repetitions.
[f] +P omitted in these fields.
*,** Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively; NS, not significant.

Table 31. Selected variables associated with three classes of maize-yield increases measured in individual experimental blocks with application of 50 kg urea-N ha^{-1}, northern Honduras, 1992/93 and 1993/94.

Variable	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 (t ha^{-1}) [a]	−0.18±0.34	0.43±0.11	0.90±0.14
Yield without N (t ha^{-1}) [b]	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
Total N at slashing (kg ha^{-1}) [c]	309±57.0	268±34.0	297±35.0
Green N at slashing (kg ha^{-1}) [d]	38±17.0	31±18.0	40±23.0
Litter N at slashing (kg ha^{-1}) [e]	183±68.0	161±39.0	190±48.0

Note: Each value represents the average for the class followed by its standard deviation. Number of samples: 11, 17, and 8 for classes 1, 2, and 3, respectively.
[a] Calculated for each block as average yield with N – average yield without N.
[b] Average yield of the block for treatments in which no N was applied.
[c] Total N in aboveground biomass at slashing.
[d] N in green fraction (leaves + tender stems).
[e] N in dead fraction.

conducted a qualitative assessment of this issue by analyzing the values taken for a series of possible factors in maize response to N, using three incremental classes of response to N obtained at the repetition level: nil, weak, and strong (Table 31).

This analysis yielded some statistically significant differences ($P \leq 0.01$) between repetitions belonging to class 0 (nil response), on the one hand, and repetitions belonging to classes 1 and 2 (weak and strong responses, respectively), on the other hand. In particular, repetitions from class 0 presented the highest maize yield levels, highest maize N status, and highest soil organic N levels. Whereas the N content of the velvetbean production was equivalent among classes, the repetitions that showed no response to fertilizer-N had been on average cropped for more time in the velvetbean system than the ones responding markedly to N (10 years for the former versus 7 years for the latter), indicating that response to N is more likely in younger velvetbean fields than in older ones. All other variables, whether reflecting environmental conditions (such as rainfall received) or management (such as timing of weed control), presented similar levels for all classes.

Farmers' practical knowledge about nutrient dynamics and soil fertility

Evidence from the N_i 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 N_i entering the profile, which in effect brought about an almost ideal synchronization of the crop uptake and N environment. Considerations other than nutrient availability constrain the choice of a slashing–planting date. Slashing has to be delayed until viable seeds are produced (see Chapter 4). However, the interval during which it is desirable to slash also depends on the need to avoid possible drought or weed competition. Given these constraints, farmers seem content to cleverly pattern management to the ecology of velvetbean without trying to modify its basic parameters.

Many farmers don't use fertilizer-N when growing maize in rotation with velvetbean, although generally it is locally available and they know about its use. When asked about their rationale for not using fertilizer-N, many stated very clearly that a major reason (even before considering costs) for not applying urea to their maize in rotation with velvetbean was that their fields didn't need it. In effect, they consider velvetbean a green manure produced *in situ*, replacing external fertilizer. As noted previously, it is no coincidence that the local name for velvetbean is the fertilizer bean (*frijol de abono*). Conversely, farmers readily recognize that maize planted without velvetbean responds markedly to fertilizer-N applications.

In sum, although farmers in northern Honduras have never formally experimented with velvetbean decomposition patterns and fertilization, many of these farmers have for the most part already assimilated the bulk of the practical knowledge about its use in their management practices. We turn now to the analysis of long-term trends, using a chronosequence approach at four sites distributed in northern Honduras.

Long-term changes in soil properties

Overall changes in content of soil organic matter in the 0- to 10-cm horizon

Figure 14 shows changes in C and N contents of the 0- to 10-cm horizon for one village only, San Francisco de Saco. As expected, the variability for a given age group is high, but the trends exhibited by C and N contents are sufficiently consistent to be statistically highly 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 was even stronger, from 0.21% to 0.28%, a 30% increase (2.5% yearly).

On a regional basis, the tendencies observed in San Francisco de Saco were not entirely confirmed at other sites. At Las Mangas, no changes in C or N contents appear to have occurred, but at Rio Cuero, the changes seem quite dramatic, even after only 7 years in the velvetbean rotation (Figure 15). Also, the

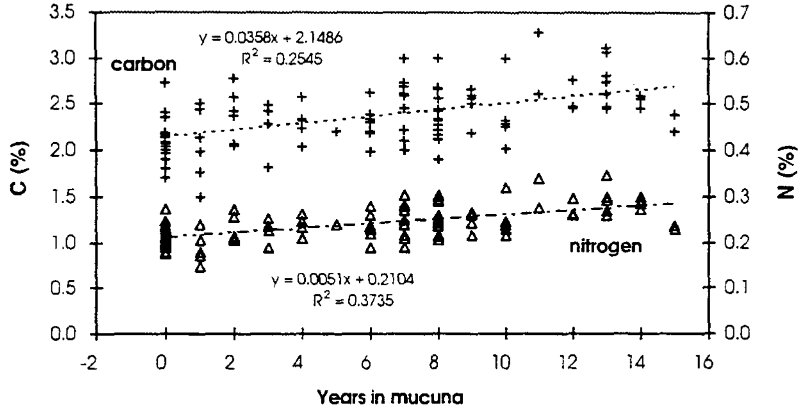

Figure 14. Relative changes in total C and N contents of the 0- to 10-cm horizon in the velvetbean system, San Francisco de Saco, northern Honduras. Note: Each point represents one observation plot; dotted lines represent least-standard regressions.

levels of C or N found in the check plots vary significantly across sites, undoubtedly reflecting differences in edaphoclimatic conditions and perhaps in agricultural history at the village level (the fact that San Francisco de Saco exhibited the lowest levels of both elements appears consistent with both its lower elevation and its being the oldest human settlement of the sites studied). In no cases did the older velvetbean plots have less C or N than the check plots. Stated conservatively, then, the velvetbean rotation appeared to allow at least the conservation of the initial stocks of C and N, despite continuous annual cultivation.

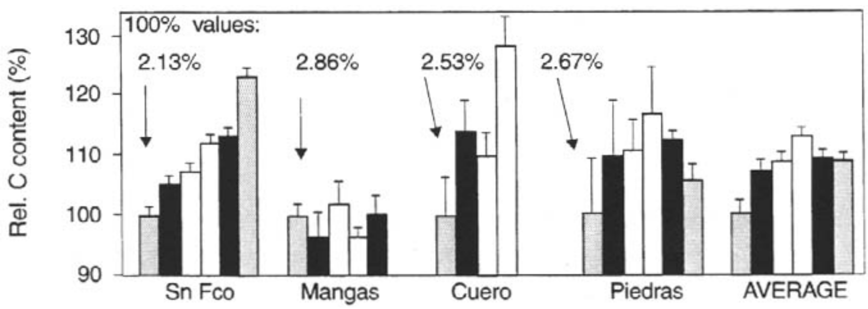

Figure 15. Relative changes in C content in the 0- to 10-cm horizon in the velvetbean system at four sites, northern Honduras. Note: Each bar represents the average for a given age class and site, topped by its standard error. Sn Fco, San Francisco de Saco; Mangas, Las Mangas; Cuero, Rio Cuero; Piedras, Piedras Amarillas.

Distribution of soil organic matter in the upper soil profile

Soil samples were collected in 2.5-cm increments in the upper 15 cm of the soil profile to verify whether the accumulation of C was mainly affecting the top centimetres of the soil profile, as expected in any no-tillage cropping system (Follett and Peterson 1988; Barreto 1989; Dalal et al. 1991). Figure 16 shows that changes in C content were significant in the first 5 cm of the soil profile, especially in the 0- to 2.5-cm layer, in which the relative increase was about 50% over a decade (from 3% to 4.5%). For the 2.5- to 5-cm layer, over the same period, the increase was 40%, with a peak value of 2.8%. Conversely, no apparent increases were detected for layers between 7.5 and 15 cm: all plots had a uniform C content, regardless of their age.

Furthermore, the regression approach to the analysis of these two horizons yielded in both cases a quadratic term that was statistically significant. This may indicate that a leveling off of the C accumulation is taking place after about 9–10 years of rotation.

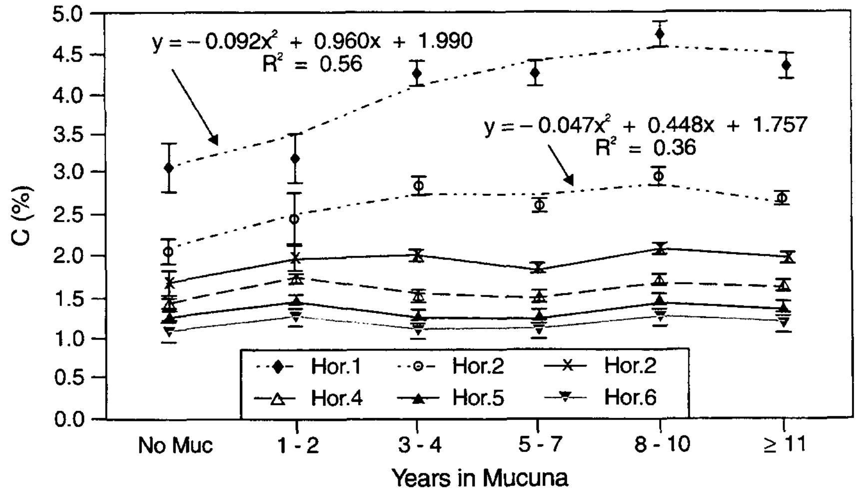

Figure 16. Changes in the distribution of organic C by 2.5-cm increments in the first 15 cm of soil profile under the influence of the velvetbean–maize rotation, San Francisco de Saco, northern Honduras. Note: Vertical bars represent standard errors. Horizon 1, 0–2.5 cm; horizon 2, 2.5–5 cm; horizon 3, 5–7.5 cm; horizon 4, 7.5–10 cm; horizon 5, 10–12.5 cm; horizon 6, 12.5–15 cm.

Changes in chemical properties

A sensible hypothesis for long-term evolution of the soil profile is that acidification is likely to take place in a wet tropical environment such as that of northern Honduras, as potential imbalances between an ample supply of N from the velvetbean biomass and moderate uptake by the maize crop might rapidly induce significant leaching of N, along with its accompanying cations (Bouldin 1989; Cahn et al. 1993). However, soil-test results for both pH and exchangeable Ca and Al did not present any evidence to support this hypothesis (Figure 17). In San Francisco de Saco, after 15 years of continuous use of the velvetbean rotation, pH appeared to have remained fairly constant, around 6.0, throughout the entire soil profile (up to 60 cm), with perhaps even a slight (not significant) tendency to increase over time. Likewise, levels of exchangeable Ca and Mg (Table 32) appeared to have increased over time at all depths at three out of four sites, to reach levels close to

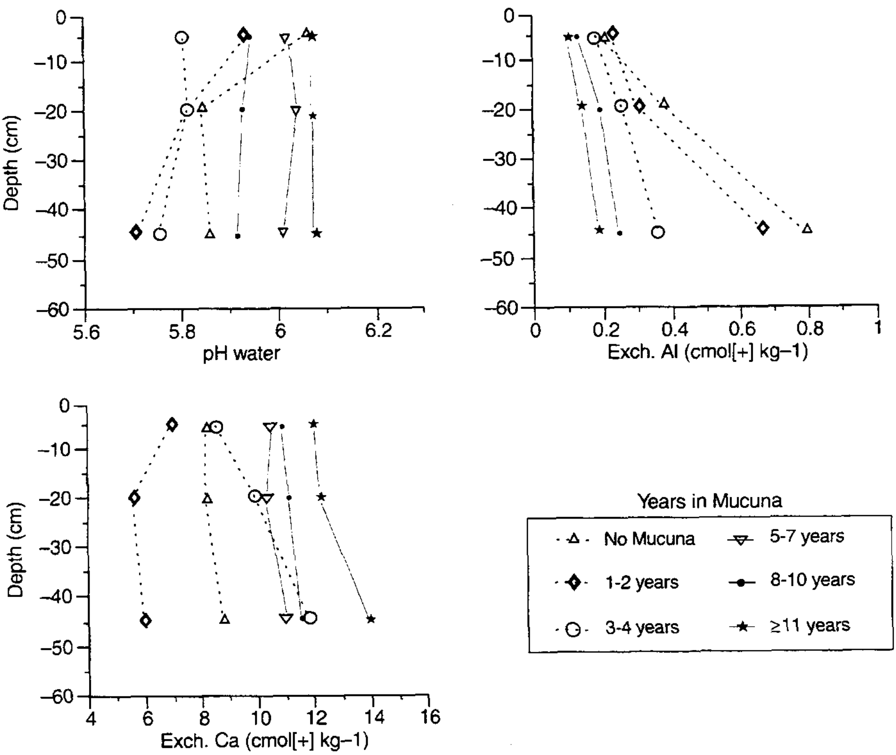

Figure 17. Changes in pH and Al and Ca contents over time in the velvetbean–maize rotation, San Francisco de Saco, northern Honduras. Note: Each point represents the age-class average for each horizon.

Table 32. Changes in exchangeable-Ca content in the 0- to 10-cm horizon at four sites, northern Honduras.

	Exchangeable Ca (cmol[+] kg^{-1})					
		Years with *Mucuna*				
Site	No *Mucuna*	1–2	3–4	5–7	8–10	>11
San Francisco de Saco	8.7	6.9	8.8	10.7	11.1	12.0
Las Mangas	18.6	20.6	19.4	18.9	20.9	(23.9) [a]
Rio Cuero	6.9	8.7	7.5	8.4	—	—
Piedras Amarillas	9.8	13.6	11.8	10.2	8.5	7.6

[a] One sample only from Las Mangas for this age class; parentheses indicate that the value is an approximation.

15 cmol(+) kg^{-1}. At these levels of pH and exchangeable bases, one expects to find no free Al ions, a condition confirmed by the soil-test results. Similar but less clear results were obtained at other sites.

The increase in exchangeable bases has also been observed in other mulched systems (Lal 1989; Hulugalle et al. 1990); it may be attributed to the large yearly additions of Ca and Mg via the velvetbean biomass — reaching more than 150 kg ha^{-1} $year^{-1}$ in the case of Ca, or the equivalent of more than 0.6 cmol(+) kg^{-1} of Ca if applied to the 0- to 10-cm horizon. How and from what source the velvetbean crop mobilizes this Ca remain a matter of speculation. In sum, the absence of soil acidification is consistent with the previous observation that although the availability of potentially leachable N_i was high during the maize cycle, there was little evidence of actual N_i leaching.

Phosphorus

Together with N, P is a very common limiting factor in crop production throughout the tropics. In systems that include a legume to supply N, a shortage of P frequently becomes a major obstacle to sustained yields (Schlather 1997). Hence, maintaining an adequate supply of available P over time is a critical concern in the velvetbean system.

Across sites, a sizable variability occurs in both trends detected and quantities of available P. Overall, however, a conservative view is that P availability seems to remain fairly stable in the velvetbean system despite yearly exports (via harvest) amounting to about 15–20 kg ha^{-1} $year^{-1}$, an observation well in accord with the velvetbean system's lack of response to fertilizer-P (see Table 30). As is the case for all other nutrients, decomposition of the velvetbean biomass is undoubtedly a major source of available P: yearly additions of P via the aboveground biomass reach about 15–20 kg ha^{-1}.

Changes in physical properties

We analyzed historical trends for one site only (San Francisco de Saco) and for a limited subsample of the fields analyzed for chemical properties or SOM. As might be expected for soil physical properties measured on few plots and at a microscale, within- and between-field variability was fairly high. This contributes to the uncertainty of the analysis (see Horowitz 1995).

Erosion

Soil erosion was not actually measured in this study. Given the overwhelming importance of soil erosion in hillside farming, however, some general, qualitative comments are in order.

The characteristic signs of erosion at the field scale were virtually absent, even in the oldest velvetbean fields (with more than 15 years of continuous cultivation). Gullies or rills were seldom observed, except in very localized areas, where rill erosion seemed more a result of marginal management errors than of anything else. Also, the upper horizon presented none of the enrichment in coarse material typical of areas with significant surface runoff (Foster et al. 1985). The chemical analyses demonstrated that no depletion of nutrients was occurring over time and that the upper profile was actively accumulating organic matter, as well as being comparatively richer in nutrients than the underlying horizons. These observations suggest that little erosion was occurring.

On a larger scale, small creeks collecting water at the bottoms of the slopes in the velvetbean rotation were very clear, even during or after intense rains, whereas high sediment loads could be observed at the bottoms of neighbouring, unmulched slopes.

Other evidence is more difficult to interpret. As discussed in Chapter 4, as many as 40% of farmers surveyed reported that the velvetbean system might induce localized landslides in areas with very steep slopes (more than 60–70% slope). Our discussions 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 (several hundred millimetres in a few days: see Figure 5).

A possible explanation for these landslides includes a combination of the heavy weight of the wet velvetbean biomass; a loosening of the upper soil profile, as a result of the shallow rooting habits of the velvetbean plant; and a state of supersaturation of the soil resulting from increased infiltration (see below), inducing a lower shear strength and higher overburden weight (Van Es, personal communication, 1995[4]). Some farmers also indicated that landslides might be explained by a 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 velvetbean. Furthermore, if left unpruned, velvetbean is quite able to eradicate the few trees left in place by farmers.

None of these possible explanations is completely convincing. The landscape in the mountains of northern Honduras is geologically very young, not fully stabilized. Hence, mass redistribution continues to take place spontaneously in many areas, and landscapes with abrupt slopes are most likely to be affected by this gravity-driven redistribution process (whether such landscapes should be cultivated on a large scale is definitely a relevant question). Also, one can argue that if hundreds of millimetres of water pour on any landform in a few hours or days, something dramatic is likely to happen; the actual role of the velvetbean cover in causing a landslide is probably much less significant than that of the sheer masses of water rushing their way downhill. This may explain why landslides, when they take place, affect lands under all kinds of use, from virgin forest to pastures, to fields without velvetbean, and have no obvious preference for any one category of land use. When 400–700 mm of rain fell in a 15-h period (31 October 1993), it caused countless landslides in the hillsides.

The issue seemed important enough to be addressed in a general survey of the velvetbean system conducted in the summer of 1994. Farmers were specifically asked about the occurrence of landslides before and after introducing the velvetbean rotation in their fields. Out of 34 fields that had suffered landslides (from a total of 44 fields included in the survey), 21 (62%) had had similar problems before velvetbean was ever introduced. Furthermore, only one-third of the farmers attributed the landslides to velvetbean use. Their perceptions varied strongly from village to village: in Piedras Amarillas, where landslides are common, farmers blamed velvetbean for making things worse, whereas in San Francisco de Saco, where landslides are rare, most experienced velvetbean users vehemently opposed this view.

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[4]H.M. Van Es, Cornell University, personal communication, 1995.

In sum, it is fair to say that globally, the velvetbean system is extremely efficient in preventing erosion, as it creates and maintains year-round a thick mulch that protects the entire soil surface from the direct impact of rain. The evidence with regard to the landslide issue remains inconclusive, and further assessment is needed.

Bulk density and macroporosity

Bulk density and macroporosity tell us a lot about the health of a soil profile, as they are indicators (not necessarily unambiguous or direct) of important synthetic properties such as soil structure and, to a lesser degree, root and faunal activities.

BULK DENSITY — Average bulk-density values at the field level tended to decrease in the soil profile (Table 33). In horizon 1, bulk density dropped sharply from an initial 1.36 Mg m^{-3} to about 1.20 Mg m^{-3} in old velvetbean fields (the regression of bulk density on years in velvetbean was highly significant, with $P < 0.01$). For the lower horizons, the drop was smaller: from 1.41 Mg m^{-3} to about 1.33 Mg m^{-3} in horizon 2 (not significant) and from 1.45 Mg m^{-3} to 1.37 Mg m^{-3} in horizon 3 ($P < 0.04$).

These trends are consistent with what one expects the velvetbean roots (most of which are very shallow) to achieve without tillage, as well as with the increase in SOM. Interestingly, they also reflect the increased looseness or softness of the upper profile, induced by velvetbean use, that many farmers reported in qualitative terms.

Table 33. Changes in bulk density of the 0- to 10-, 10- to 20-cm, and 40- to 50- cm horizons in the *Mucuna*–maize rotation, San Francisco de Saco, northern Honduras.

Years with *Mucuna*	Bulk density (Mg m^{-3}) 0–10 cm	10–20 cm	40–50 cm
No *Mucuna*	1.36±0.145	1.41±0.065	NA
1–2	1.32±0.066	1.32±0.072	1.45±0.022
4–7	1.20±0.075	1.32±0.124	1.40±0.067
8–11	1.28±0.083	1.37±0.066	1.42±0.076
>12	1.20±0.091	1.33±0.064	1.37±0.070

Note: Each value represents the average for a given age class and depth, followed by its standard deviation. NA, not available.

MACROPOROSITY — As indicated by the bulk-density figures, total porosity increased over time, especially in the 0- to 10-cm horizon. We hypothesized that, regardless of what happened to the total porosity, shifts in the distribution of pores of different sizes may occur as a result of velvetbean use. We examined this hypothesis by quantifying the porosity associated with the biggest pore-size classes (pores ranging in diameter from 15 to more than 395 μm).

In the 0- to 10-cm horizon, we found that immediately following the introduction of velvetbean rotation, the porosity associated with both pores larger than 15 μm and those larger than 133 μm increased (from less than 8% of the soil volume to about 10% and from about 3% to about 5%, respectively). The porosity remained virtually stable in subsequent years (Figure 18). For the 10- to 20-cm horizon, porosity was essentially identical for all fields and was quite high in all but one case.

The clear increase in porosity detected for the largest pore sizes may be a slight exaggeration because of unavoidable imperfections in the construction of the chronosequence. What is most striking, however, is that the velvetbean rotation appears to allow the soil to maintain an extensive array of large pores, without any tendency for degradation of this favourable pore architecture.

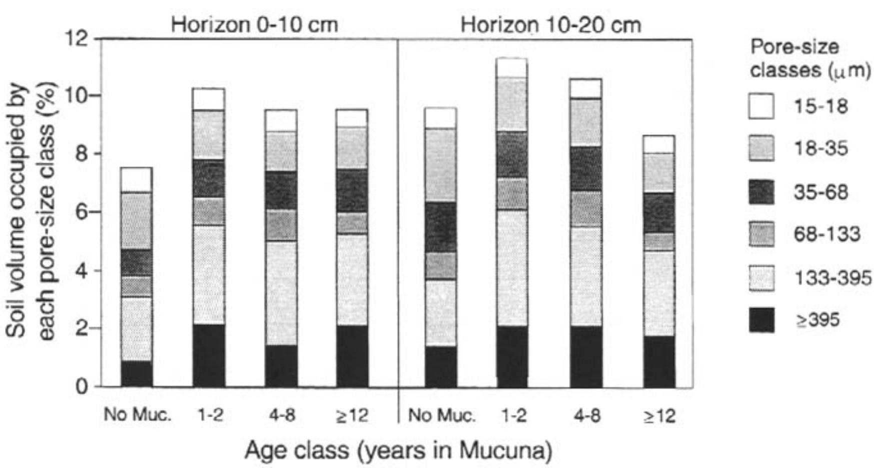

Figure 18. Changes in macroporosity (pores of >15 μm diameter) in the 0- to 10-cm and 10- to 20-cm horizons under the influence of the velvetbean–maize rotation, San Francisco de Saco, northern Honduras.

Infiltration

The steady-state infiltration rate — a parameter directly related to an intrinsic profile property (Hillel 1982) — increased markedly with time under the influence of the velvetbean–maize rotation, although variability within and between fields was quite high (Figure 19).

Using a multiple-regression approach to accommodate the effect of a number of variables under the specific conditions of the infiltration measurements, we found that, on average, steady-state infiltration rates increased by 2–3 mm h^{-1} for each year of the velvetbean rotation. Over 15 years, this led to an increase of more than 30 mm h^{-1}, roughly double the initial rates measured in no- or young-velvetbean situations. Conversely, runoff rates (observed under a simulated rainfall intensity of 100 mm h^{-1}) decreased by about 2 mm h^{-1} $year^{-1}$ on average, from 72 mm h^{-1} in no-velvetbean fields to a low of 26 mm h^{-1} in old velvetbean fields.

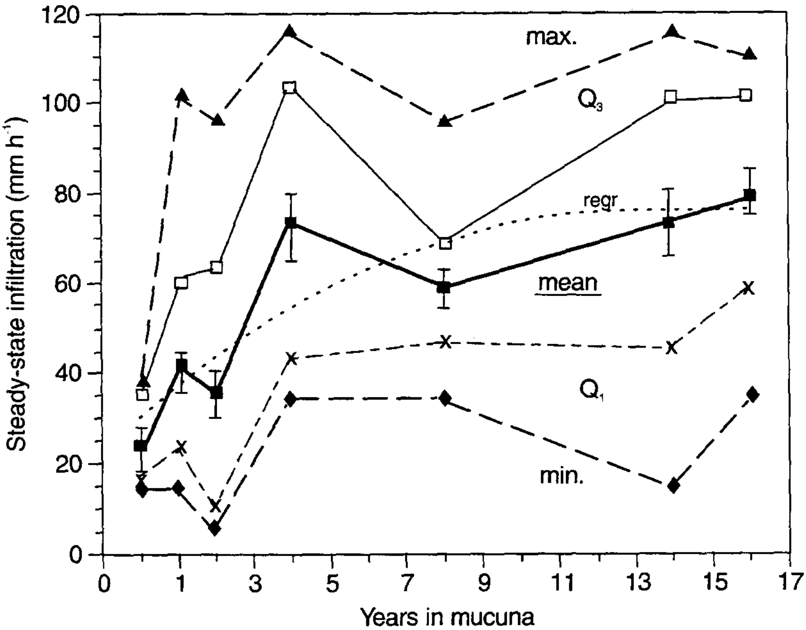

Figure 19. Changes in steady-state infiltration rates under the influence of the velvetbean–maize rotation, San Francisco de Saco, northern Honduras. Note: SSI = $-0.2738a^2 + 7.097a = 29.77$ ($R^2 = 0.757$), where SSI is steady-state infiltration; and *a* is age (years in *Mucuna*).

Water balance in the velvetbean system

Profile recharge and water-holding capacity are affected by higher infiltration rates and porosity and make more water available to the maize crop, supporting such pivotal biological activities as decomposition and mineralization. This may be particularly important during winter cycles with a marked dry season and may be even more so in drier environments than in northern Honduras, with water balance becoming a critical parameter in crop production.

One should be careful not to underestimate the consequences of decreased runoff rates and intact porosity for erosion. As runoff is reduced, the erosive action of rainfall is also drastically decreased. Because the velvetbean system provides a year-round, full cover for the soil surface, it prevents even occasional high levels of runoff from translating directly into high erosion or soil-structure degradation (such as surface sealing [Bielders and Baveye 1995]). The runoff flows on top of or in the mulch layer, rather than over a bare surface.

Long-term changes in crop productivity

Does maintenance or build-up of soil fertility (as reported earlier for a number of components of global soil fertility) translate into increased crop (maize or velvetbean) productivity? We addressed this by looking at trends in maize yields with the velvetbean rotation. To assess the validity of our analytical findings, we also asked farmers to evaluate the long-term changes in the soil fertility of their fields.

Changes in average maize yields and yield components

Table 34 shows the trends for average maize yields at each site for different age classes. Four main conclusions can be drawn from these data:

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

- Maize yields with velvetbean were almost double those obtained for crops without velvetbean (Rio Cuero was an exception, with an increase of only 40%, but the study at this site included only one check plot).

- Once the velvetbean rotation is well established (more than 3 years), yields seemed to remain fairly constant. In fact, there was no apparent

Table 34. Changes in average maize yields as a function of the duration of the *Mucuna* rotation, northern Honduras, 1992/93 and 1993/94 winter cycles.

	No *Mucuna*	Years with *Mucuna*				
		1–2	3–4	5–7	8–10	≥11
				1992/93 cycle		
San Francisco de Saco						
Sample size (*n*)	4	7	4	14	21	15
Yield (t ha^{-1})	1.9*b*	2.2*b*	3.7*a*	3.0*ab*	3.5*a*	3.6*a*
Las Mangas						
Sample size (*n*)	2	5	9	11	1	0
Yield (t ha^{-1})	2.5*b*	4.2*a*	4.2*a*	4.9*a*	(4.4)	—
				1993/94 cycle		
San Francisco de Saco						
Sample size (*n*)	10	2	5	3	10	10
Yield (t ha^{-1})	2.0*b*	3.3*ab*	3.7*a*	2.7*ab*	3.6*a*	3.4*a*
Las Mangas						
Sample size (*n*)	4	3	6	12	4	4
Yield (t ha^{-1})	1.4*b*	1.8*ab*	3.1*a*	3.2*a*	3.9*a*	3.1*a*
Rio Cuero						
Sample size (*n*)	1	6	6	6	0	0
Yield (t ha^{-1})	(1.4)	2.2 NS	2.0 NS	1.7 NS	—	—
Piedras Amarillas						
Sample size (*n*)	0	0	6	2	2	6
Yield (t ha^{-1})	—	—	2.2*b*	1.6*b*	2.8*ab*	3.0*a*

Note: Parentheses indicate that the value is an approximation.
a,b Means followed by the same letter within a row are not different according to Tukey's test at the 10% family rate; NS, not significant.

tendency for yields to decline. Maize yields have a tendency to be more stable in the older velvetbean fields: the standard deviation across sites dropped from 1.5 t ha^{-1} in younger velvetbean fields in 1992/93 to 0.73 t ha^{-1} in fields with velvetbean for 8 or more years; and from 1.0 t ha^{-1} to 0.7 t ha^{-1} in 1993/94.

- Maize-yield components, such as the number of ears per plant and number of kernels per ear, provide an additional basis for analyzing the effects of soil fertility on crop productivity, as they are good indicators of favourable growing conditions before flowering (Fleury et al. 1982;

Navarro Garza 1984; Fleury 1991). In our case, these components demonstrated a significant improvement with velvetbean in the 1992/93 cycle (the situation was not as clear-cut in the 1993/94 cycle).

The role of another yield component, plant density, is more complex, as it partly depends on management decisions. A drop in plant density seems to explain the apparent drop in yield in fields with velvetbean for 5–7 years (1992/93 and 1993/94 cycles), as well as the old velvetbean fields' failure to outyield the medium-term ones in 1992/93. Plant densities were lower in check plots than in fields planted to velvetbean, probably as a consequence of farmers' deliberate adaptation to an increase they perceived in soil fertility with the use of velvetbean.

Years in velvetbean and plant stand were significant predictors of yield levels in a multiple-regression approach for all sites and years, with the exception of Rio Cuero (Table 34). Using the slope of the equations obtained in the various cases, we concluded that, on average, every additional year in velvetbean results in an extra 50–170 kg ha^{-1} of maize, whereas every additional 5 000 plants harvested results in an increase of 250–500 kg ha^{-1} in maize.

Especially noteworthy from a qualitative viewpoint is perhaps the greater stability apparently provided by the velvetbean rotation in the face of adverse climatic conditions. There is less risk of low yields with the velvetbean rotation than with other cropping systems, as shown graphically in Figure 20. (The cumulative distribution function [CDF] for maize yield under different seasons and cropping systems is discussed in Appendix IV.) Figure 20 shows that the probability of achieving a yield level less than or equal to 1 000 kg ha^{-1} is about 70% in the first

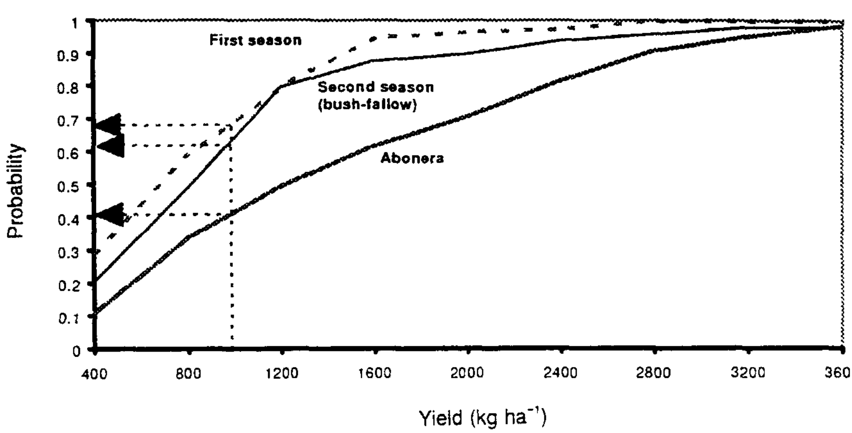

Figure 20. Cumulative distribution function for maize yield under different seasons and cropping systems, northern Honduras.

season in the bush-fallow system; about 62% in the second season in the bush-fallow system; and only 40% in the *abonera* system (a second-season maize cycle). The distribution for second-season maize in an *abonera* system lies everywhere to the right of the other two distributions (Sain and Buckles 1997). The lower risk of losses in second-season maize production for farmers who use the *abonera* system significantly influences their evaluation of the benefits of this system (see Chapters 4 and 7).

Field observations also point to the same trend. During the drier than usual 1993/94 cycle, many maize fields suffered from drought stress. In some villages, yields from fields without velvetbean dropped to very low levels (less than 1 t ha^{-1} or even complete crop failure), whereas nearby fields planted to velvetbean around the same time were faring reasonably well (2 t ha^{-1} or more). This implies improved access to water for maize in velvetbean fields, which can be ascribed to a combination of reduced evaporation and better infiltration, as indicated earlier.

Farmers' evaluations of long-term changes

Farmers using the velvetbean rotation were asked to compare yields they could reasonably hope to get before using velvetbean with those after it was firmly established in their fields. In the most extreme cases, farmers reported that velvetbean helped to triple their yields or even to reclaim fields they considered too poor to produce a maize crop. By contrast, 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 also interesting to note that an overwhelming majority of farmers (43 out of 46) thought that the soil quality of their fields had improved with the introduction of velvetbean (soil was judged "better" or "much better" by equal proportions of the farmers). Many of the farmers claimed to deliberately use higher plant densities in velvetbean fields because they felt that the velvetbean made the soil more productive. No farmers reported degradation resulting from velvetbean use. In collective interviews conducted at the village level, farmers were explicitly asked to consider any negative behaviour or characteristic affecting velvetbean fields with the passage of time, but they could identify none. Not even the risk of landslides seemed to increase in older fields. Another solid indication of the improved quality is the higher sale prices and rents fetched by land in velvetbean than fetched by average farm land; the difference can be as much 70% (Buckles et al. 1992; Humphries, in press).

Altogether, velvetbean farmers were extremely satisfied with the agronomic results of velvetbean use. A final proof is that none of the farmers seemed to have ever abandoned a velvetbean field for agronomic reasons.

The *Rottboellia* puzzle

One long-term negative trend in productivity was reported by farmers in San Francisco de Saco, Atlántida. Beginning in the middle to late 1980s, an obnoxious weed, *R. cochinchinensis*, began invading *Mucuna* fields. In this section, we give a brief explanation of why this happened and examine its impacts on the *abonera* system.

Rottboellia may have been introduced to northern Honduras with food aid (mainly rice) brought in after the devastating typhoon Fifi. The weed spread rapidly to the communities lying very close to the main road along the coast, including San Francisco de Saco (Munguia 1992). *Rottboellia* found an ideal environment in the *abonera*. Most other weeds, especially broadleaf weeds, are eradicated by the *Mucuna* crop. But nutrients, light, and water were readily available after the slashing of the *Mucuna* field and before full establishment of the maize crop. Farmers' reliance on natural reseeding of *Mucuna* also allows gaps to form in the *Mucuna* stand, which are quickly invaded by *Rottboellia*. Elimination of the weed after it is firmly established is extremely difficult because its reproductive cycle is very rapid and it produces massive amounts of seed with great longevity (Bridgemohan et al. 1991). These factors favoured the rapid establishment of *Rottboellia* in *abonera* fields in some communities.

Farmers in San Francisco de Saco indicated that the cost of weed control increases markedly in fields invaded by *Rottboellia*, and maize yields decrease by as much as 0.5 t ha^{-1} on average. Efforts to prevent its spread and eradicate it if it is firmly established seem so futile that farmers in this community have come to accept *Rottboellia* as unavoidable in the *abonera* system. The farmers argued that the added cost and inconvenience are a small price to pay for what is otherwise a very productive and beneficial maize-production system. Our own research on the role of weeds in nutrient recycling suggests that fast-growing *Rottboellia* may capture nutrients early in the season that would otherwise be lost. These nutrients would be released later when the weed is cut — a process documented for other weed species in cropping systems (Lambert and Arnason 1989). The puzzle is whether *Rottboellia* will be a significant threat to long-term crop productivity.

Synthesis: how does the velvetbean system work?

Perhaps it is worth restating that the challenge of continuous cultivation without long-term fallowing (especially on hillsides) is the rapid decline of soil fertility from erosion or nutrient mining. As soil fertility declines and noxious weeds start competing strongly with crops, crop yields drop, farming becomes both very tedious and unprofitable, and fields are abandoned. This is the point of reference needed to judge the achievements of the velvetbean system.

The most important conclusion from our analysis is that the velvetbean system shows us a working example of how to sustainably exploit the properties and dynamics of a natural ecosystem for the benefit of commercial maize production (Gliessman et al. 1981). At the heart of the velvetbean system lies the velvetbean crop: the crop acts alternately as a major collector (when growing) or supplier (when decomposing) of nutrients, so its natural seasonal dynamics dictate the major features of the velvetbean system.

The multilayered structure of the velvetbean system explains its overall dynamics. At any given time, at least two distinct layers (or compartments) are functioning in concert. One layer is the growing, live biomass (in effect, a crop–weed mixture). It actively accumulates nutrients under the driving force of photosynthesis. Depending on the phase of the cycle, the crop is either in velvetbean or in maize and its associated weeds. Whereas the function of maize in the system is relatively straightforward, the function of the growing velvetbean 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.

The other layer of the system is a semipermanent dead-litter layer, which, together with the first few centimetres of soil, serves as a major provider of nutrients for the growing biomass. The litter is from the natural or farmer-induced decay of velvetbean, maize, or weed biomass. Its continuous presence and multiform activity throughout the year make it a prime regulator of nutrient fluxes, acting both as a substrate for decomposition and as an almost ideal habitat for decomposing flora and fauna that thrive in a microenvironment, as well as protecting that environment from brutal variations in temperature and moisture. Alone or in association with the live biomass, velvetbean fulfils several other key functions, such as weed and erosion control (the latter, by cushioning the impact of water drops and favouring infiltration).

The litter layer is maintained by two opposite processes: litter formation and litter decomposition. Part of litter formation is farmers' management of maize, weeds, and velvetbean, which codetermines, with environmental conditions regulating plant growth, the levels of addition to the litter, as well as its timing.

Each of the three main components added to the litter also has distinct initial properties vis-à-vis decomposition. For example, velvetbean typically has a high N content, low C–N ratio, and very leafy, easily decomposable material, but the opposite is true of maize stover. Although the processes of litter decomposition may fluctuate markedly in response to periodic additions of fresh material, they 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 decompose.

Nutrient cycles

With the *abonera* system, farmers derive substantial nutritional benefits for their maize crop. They let the velvetbean accumulate *in situ* the biomass and nutrients needed for the succeeding second-season maize cycle. These nutrients are gradually released through the decomposition of the velvetbean mulch, which is created by slashing and deliberately maintained by the farmers' decision not to burn it. The velvetbean's N_2-fixing and recycling abilities prevent significant nutrient losses to the environment and practically eliminate the need for costly and impractical (on a hillside) use of external fertilizer, without compromising yield levels.

Symbiotic fixation of N_2, estimated at 80–150 kg N ha^{-1} $year^{-1}$, is crucial in balancing the N budget. This newly fixed N helps counterbalance both the export of N via the maize harvest (typically in the range of 50–80 kg ha^{-1} $year^{-1}$) and the storage of N in the SOM, which may reach 50 kg ha^{-1} $year^{-1}$, at least in the first 10 years of the rotation (in the years after this, the soil seems to achieve a certain equilibrium). It remains unclear whether fixation is actually more important in the initial years following velvetbean introduction and then drops to maintenance levels after a significant pool of recyclable N is established.

The velvetbean system appears to recycle large quantities of nutrients throughout the year via the velvetbean and the weeds. For a dry cycle like 1993/94, more than 200 kg N ha^{-1} was recycled. This magnitude is comparable to that of a number of natural forestry or agroforestry ecosystems (Vitousek and Sanford 1986).

As in natural ecosystems, the losses of N in the *abonera* system unrelated to crop exports (that is, leaching, volatilization) seem relatively limited (at least under the conditions where our data were gathered). However, losses from leaching may be higher in very wet winter cycles, when decomposition is probably fairly active. We also cannot rule out the possibility of significant losses through volatilization after slashing.

Long-term trends in soil fertility

Continuous use of the velvetbean system has a number of cumulative effects on the soil profile. Here again, the net impact is a balance between the results of processes that tend to deplete the stocks of nutrients (such as repeated exports via crop harvest) and decrease the soil fertility and the results of processes that tend to replenish the stocks (such as N_2 fixation) and increase the soil fertility.

SOM accumulates at or very near the soil surface as a result of the humification of the litter. Water infiltration increases markedly, as does total porosity. Despite a theoretical possibility that N imbalances lead to soil acidification, measurements indicated that soil pH remained stable, although exchangeable bases tended to increase throughout the soil profile. At the same time, most other nutrients remained at stable levels, at least in their available forms, despite yearly exports. These observations confirm that the velvetbean system is a relatively efficient nutrient-cycling system, as was mentioned earlier. Although soil biological life was not measured, it appeared to prosper, as indicated by the proliferation of earthworms, insects, and fungi at the litter–soil interface. The quasi absence of serious pests or soil-borne pathogens also points to a healthy functioning of the soil profile.

Finally, although erosion was not measured directly in this study, it was visibly only a marginal occurrence in most velvetbean fields because of the permanent protective cover provided by the velvetbean biomass (live or dead), day after day, year after year. Velvetbean use may, however, contribute to localized landslides at certain sites with excessive rainfall and slope. But no clear strategy against these occurrences seems possible, as even native forest is not immune to landslides.

In short, the long-term indicators we were able to examine gave positive or at least satisfactory results. Perhaps the clearest indication of success, from a user's perspective, was that maize yields in old velvetbean fields were actually as high as or even higher than in new ones and, on average, about double those from check plots not planted to velvetbean.

Conclusions

A maize crop benefits in many ways from the environment and general dynamics of a well-established *abonera* system. First, the system seems fairly stable, allowing respectable yield levels (usually 2–4 t ha^{-1}) every year. In particular, the system appears to prevent or at least greatly diminish drought stress because the mulch layer helps conserve water in the soil profile (Steiner 1994). With enough water around, nutrients (N, P, K, Ca, Mg, etc.) are made readily available, in good synchronization with major crop uptake. In addition, the *abonera* system creates a relatively trouble-free environment for maize because most weeds (with the notable exception of *R. cochinchinensis*) have a hard time flourishing in this system, either because velvetbean physically prevents them from germinating and emerging or from surviving very long during the velvetbean cycle or because a shallow rooting of weeds in the litter layer–soil interface makes them easier to control.

The *abonera* system has, however, a number of minor constraints. One is the tight coupling of maize planting with slashing. Until alternatives are found (for example, the introduction of velvetbean or maize germplasm of different maturity classes), the planting date will be chosen with a very limited window (in practice, it is restricted to a 6-week period starting in early December). Also, whether maize can be planted at any other time of year without negating most of the advantages of the velvetbean system is unclear. Another problem is the tough competition that the quickly reestablishing velvetbean gives to the growing maize crop in certain years, obliging farmers to prune the velvetbean. Finally, the year-to-year variability in the rate at which nutrients are made available via decomposition is difficult to predict (up to now at least), which may be seen as a constraint, especially if farmers make the achievement of high maize yields more and more a part of their agenda.

In sum, the analysis in this chapter suggests that the continuous annual rotation of velvetbean and maize can be sustained for at least 15 years at a reasonably high level of productivity (about 2–4 t ha^{-1} $year^{-1}$, with its current form of management), without any apparent decline in the natural resource base. Clearly, conserving or even improving the resource base does not in itself guarantee the global sustainability of a cropping system — an issue discussed at various points throughout the rest of this book. But the *abonera* system at least offers farmers the option of cultivating the same plot continuously if they wish to. If they decide to shift the land to another use, fields that have been in the velvetbean system for several years have none of the restrictive characteristics of degraded agricultural soils (low fertility, high weed or pest pressure, compaction, etc.). These fields are probably in an ideal condition to guarantee success with any other crop-, pasture-, or tree-based system.

The *abonera* system not only is an elegant way to provide and recycle nutrients or build up soil fertility, which has been the focus of this chapter, but also offers a host of other benefits, including weed control, reduced labour, and lower production risk. Clearly, the success of the *abonera* system varies among farmers and locations. For example, not all velvetbean fields accumulate quite enough biomass and nutrients to satisfy all maize nutritional requirements. Similarly, management decisions (from the choice of timing of slashing–planting to that of planting densities, as well as the timeliness of weed control) affect the production potential of the fields. This said, the fact remains that the performance of the *abonera* system would undoubtedly be much less satisfactory if not for its nutritional or soil-fertility benefits. These benefits, and their impacts on maize yields, also form the core of the economic analysis of the *abonera* system, to which we now turn.

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CHAPTER 6

THE ECONOMICS OF THE *ABONERA* SYSTEM

Probabilistic cost–benefit analysis

Cost–benefit analysis (CBA) can be used to compare two technological alternatives, such as the bush-fallow and *abonera* systems. The different flows of benefits and costs from year to year are compared to determine the relative profitability of each system. In the analysis, the annual net benefits (NB) per unit of land in year t generated by the bush-fallow system (NB_{b_t}) and those of the *abonera* (NB_{a_t}) are defined as the difference between annual gross benefits (GB) and annual costs:

$$NB_{b_t} = p_m \times Y_b - C_b \quad [1]$$

$$NB_{a_t} = p_m \times Y_a - C_a \quad [2]$$

where Y_b and Y_a are the annual maize yields from the bush-fallow and *abonera* alternatives; p_m is the price of maize; and C_b and C_a are the annual production costs of these alternatives.

To assess the profitability of the *abonera* system relative to that of the bush-fallow system, CBA calls for the calculation of the net present value (NPV) of the incremental flow of net benefits generated by the alternatives compared (Steiner 1980). The NPV of the incremental flow of net benefits is given by the following:

$$NPV_i = \sum_{t=0}^{T} \frac{1}{(1+r)^t} [p_m \times (Y_{a_t} - Y_{b_t}) - (C_{a_t} - C_{b_t})] \quad [3]$$

where r is the rate of discount; and T is the time horizon considered in the analysis. The *abonera* system will be relatively more profitable to the farmer if NPV is greater than zero. Equation [3] shows that the relative profitability of the *abonera* system depends on two factors: the discounted value of the flow of the annual yield differences and annual cost differences.

Traditionally, CBA uses average or modal values of the variables in calculations of NPV. The data needed for the analysis are limited, making it a fairly easy technique to use (Pagiola 1994). It is, however, a deterministic approach — that is, no measurement of variability is attached to the resulting net benefits.

To illustrate, consider the calculation of gross benefits for a practice in a given year. Assume that the average maize price received (p_m) is 0.09 USD kg^{-1} and that the average maize yield (Y_{avg}) is 2 000 kg ha^{-1}. The gross benefits would be as follows:

$$GB_{avg} = (0.09 \text{ USD kg}^{-1}) \times (2\,000 \text{ kg ha}^{-1}) = 180 \text{ USD ha}^{-1}$$

One can enhance this statement by performing a sensitivity analysis, considering worst- and best-case scenarios, as well as the modal case. Although sensitivity analysis is more revealing, it still fails to indicate the likelihood that a farmer will realize high, low, or average gross benefits.

Probabilistic CBA attempts to overcome this limitation by not only considering the range of values of the variables but also attaching to these values a measure of the likelihood of their occurrence (Anderson and Dillon 1992). Alternatives are compared through their impact on the variability of NPV, thereby giving a measure of the impact of alternatives on the levels of uncertainty or risk faced by farmers. Some or all of the parameters in this analysis must be treated as random variables to enable one to calculate from these a CDF. Such functions in turn make it possible to associate probabilities of occurrence with the range of the variable.

Maize yield is a good example of a random variable. Yields obtained by farmers under rainfed conditions are subject to many unpredictable events, which result in variability from year to year and from farmer to farmer. If this yield variability is assumed to follow a normal distribution, then maize yield (Y) will have a normal CDF. This is represented as $Y \sim N(\mu,\sigma^2)$, where the mean is μ; and the variability around the mean (variance) is σ^2.

Unlike a deterministic CBA, which produces a single value, the probabilistic approach produces the CDF of NPV of economic returns for the alternatives. Comparison of these measures makes it possible to assess the impacts of the alternatives not only on average economic returns but also on the risk the farmer faces. This information allows us to make a more comprehensive assessment of economic profitability, one that recognizes that farmers are interested not only in increasing average net benefits but also in reducing production risk (Anderson and Dillon 1992).

Table 35. Characteristics of the variables used in the simulation model to calculate the net present value of net benefits.

Variable	Characteristics
Maize yields under different systems	Random
Input and output prices	Random
Technology (technical coefficients)	Nonrandom
Time horizon and rate of discount	Nonrandom

Our analysis takes a probabilistic approach to examine the relative profitability of the *abonera* and bush-fallow systems. We specify the maize-production technology, along with the CDF of all random variables and the values of the nonrandom variables included in the calculation of NPV, as outlined in equation [3] above. In this analysis, we treat maize yields and prices as random variables and represent them by their CDF. For simplicity, technology is considered nonrandom and represented by a set of constant technical coefficients. The time horizon of the analysis and the discount rate — two other variables in the analysis — are also considered nonrandom (Table 35). Model specifications — including maize-production technology, maize yields, and farm prices — are given in Appendix IV. The data used in the analysis are from the farm survey, supplemented, when appropriate, with data on farm inputs and outputs collected during intensive, focused interviews with regional farmers.

The calculations are carried out through Monte Carlo simulation. Simulation analysis was performed using @Risk software by Palisade Corporation. The model ran 2000 iterations before reaching convergence. Convergence of the simulation is evaluated by the amount of change in three statistics: the average percentage change in the percentile values; the mean value; and the standard deviation. When the percentage change in these statistics is less than an established threshold, this means value convergence is achieved. In this study the threshold value was set at 1.5%. The method involves estimating the CDF of NPV by simulating a process of sampling the probability distribution of the random variables in the analysis. Following the example above, the CDF of gross benefits is obtained by sampling the probability distribution of the yield variable and multiplying it by a sampled value from the probability distribution of the price variable. This process is repeated very many times to obtain a robust estimate of the CDF of gross benefits.

The analysis is based on several other assumptions that need to be identified. It assumes that cropland is readily available (it is an extra or marginal unit) and that it is allocated to maize (it is the preferred land use). As indicated in

Chapter 2, cropland is available in northern Honduras at relatively low cost, and annual crops other than maize are grown in very small quantities. Within these parameters, the options available to the farmer are to cultivate maize in either the bush-fallow system or the *abonera* system. Thus, we ignored the cost of land and the opportunity costs, focusing instead on returns per units of land, labour, and other factors of production.

In building up the budgets of the alternative systems, we took only short-run impacts into account. Financial on-farm prices were used in the calculations, and all long-run benefits (soil conservation) were ignored.

Field-level analysis

Returns per unit of land

The period of comparison between the two alternatives used in the simulation is 6 years, an average cycle in the current bush-fallow system. The analysis assumes that first- and second-season maize are produced in the bush-fallow system for up to 2 consecutive years, followed by a fallow period of about 4 years. The entire 6-year cycle results in an annual land-use intensity (LUI) of 33%. In contrast, farmers crop an *abonera* field once a year in a continuous rotation with velvet-bean. With the period of comparison being the 6-year cycle employed in the bush-fallow system, the LUI of the *abonera* system is 50%.

Although the main reason for the superior return per unit of land in the *abonera* system can be seen immediately from this comparison, the particular paths of costs and benefits over time for the two systems are quite distinct. The costs of establishing an *abonera* system (mainly labour cost and the opportunity costs of the land) are paid in the first 2 years, whereas the benefits from the investment are realized only in the third year and afterward. This start-up or investment period must be evaluated in economic terms with a view to farmers' planning horizons and the degree to which the farmers discount the future benefits of the *abonera* system. The annual budgets over the 6-year period in the analysis are presented in Appendix IV.

Table 36 shows the flow of annual net benefits from the two systems and the incremental flow of benefits, evaluated at the mean values of the random variables (maize yields and prices). The last four rows of the table show for both systems the NPV of the annual flow of net benefits and the incremental flow, calculated at different discount rates. Returns per unit of land in the *abonera* system are higher than those derived from the bush-fallow system, even at discount rates as high as 100%.

Table 36. Annual flow of average net returns per unit of land in the *abonera* and bush-fallow systems.

	Average net return (USD ha^{-1})		
	Abonera	Bush fallow	Incremental flow
Year			
1	97.85	119.92	-22.08
2	89.30	135.54	-46.24
3	192.79	0.00	192.79
4	192.79	0.00	192.79
5	192.79	0.00	192.79
6	192.79	137.87	54.92
NPV (10%)	734.60	328.75	405.84
NPV (30%)	487.80	261.32	226.48
NPV (100%)	232.87	192.00	40.87
NPV (150%)	183.66	175.55	8.11

Note: NPV, net present value; USD, United States dollars. Values in parentheses are discount rates used in the calculation of NPV.

The analysis can be enhanced by using a probabilistic approach to consider the impact of the *abonera* system on yield risk. Table 37 presents the probability distribution of the NPV of the incremental flow of net benefits of the *abonera* and the bush-fallow systems. It shows the probability that the NPV of the incremental flow of net benefits is greater than zero (that is, the probability that the *abonera* will be more profitable than the bush-fallow system). These parameters were estimated for different discount rates (with the planning horizon fixed at 6 years) and for different planning horizons (with the discount rate fixed at 30%).

The results of the probabilistic analysis indicate that when the farmer's planning horizon spans the 6 years of the bush-fallow cycle, the *abonera* system has more than an 80% probability of producing a NPV of net benefits that is larger than that of the bush-fallow system. Even with discount rates as high as 100%, this probability is still very high (more than 60%). By contrast, when the planning horizon is 2 years, the probability of realizing an advantage from an *abonera* system is only 13%.

This comparison indicates that the planning horizon is a much more significant constraint on farmers' decision-making than the discount rate. For farmers constrained to a short planning period, the *abonera* system is not a feasible option.

Table 37. Selected parameters of the distribution of NPV of the flow of incremental net benefits per unit of land for different discount rates and planning horizons.

Discount rate (%)	Mean (USD ha^{-1})	SD (USD ha^{-1})	*P* (NPV > 0) (%)	Planning horizon (years)	Mean (USD ha^{-1})	SD (USD ha^{-1})	*P* (NPV > 0) (%)
10	409	515	83	1	−22	8	0
30	229	300	82	2	−58	62	13
50	137	195	79	3	57	118	70
70	85	137	75	4	146	193	82
90	53	103	70	5	213	253	86
110	32	80	66	6	229	300	82

Note: NPV, net present value; SD, standard deviation; USD, United States dollars.

Table 38. Calendar of activities and labour requirements per unit of land for maize production under different seasons and systems.

Activity	Labour requirement (person–day ha^{-1})											
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
								First season				
Slash and burn						20						
Sowing							5					
First weeding								12.5				
Second weeding									2.5			
Doubling maize										5		
Harvesting maize												20
		Second season										
Slash (bush fallow)	12											
Slash (*abonera*)	10											
Sowing (bush fallow)		5										
Sowing (*abonera*)		5										
First weeding (bush fallow)			11									
First weeding (*abonera*)			9									
Second weeding (bush fallow)				2.5								
Second weeding (*abonera*)				2.5								
Sowing *Mucuna*												
Harvesting (bush fallow)					17							
Harvesting (*abonera*)					18							

If, however, the planning period is 3 or more years, then the *abonera* system is very likely to provide higher net benefits than the bush-fallow system, regardless of the degree to which future benefits are discounted.

Returns per unit of labour

Farm households consider not only returns per unit of land when evaluating the economic consequences of alternative investments but also net returns per unit of family labour, which may be just as important as returns per unit of land, especially in a place like northern Honduras, where land is relatively abundant.

Table 38 presents a monthly calendar of common activities in first- and second-season maize production and the labour requirements per unit of land for each activity. The data indicate that first-season maize requires a total of

65 person–day ha^{-1}. Second-season maize in the bush-fallow system requires 47.5 person–day ha^{-1}; in the *abonera* system, 44.5 person–day ha^{-1}. The *abonera* system requires on average 4 fewer person–day ha^{-1} for clearing the field and weeding but an additional 1 person–day ha^{-1} for harvesting the higher yielding maize crop.

The economic implications of the labour-saving effects of the *abonera* system can be seen in Table 39. The table presents the annual flow of family labour used in the bush-fallow and *abonera* systems (person–day ha^{-1}), as well as the flow of annual net benefits for each system in terms of returns per person–day per hectare of land. (Farm-survey data show that half of the farmers interviewed hired off-farm labour, mainly for land preparation and planting. The simulation analysis assumes that these activities are accomplished by 50% hired labour and 50% family labour, with the remaining activities performed using exclusively family labour.) The last column of the table presents the incremental flow of annual net returns per unit of labour, values clearly superior to those of the bush-fallow system.

The flow of net returns per unit of labour is more immediate than that per unit of land. The return per unit of labour in the *abonera* system is lower than in the bush-fallow system during the first year, but the assessment changes completely in the second year, when labour costs drop. Even before yield benefits at the end of the second year are added, the *abonera* system provides higher net returns per unit of labour. The short-term positive impact on returns per unit of labour in the *abonera* system may have triggered adoption of the practice in northern Honduras, which is a perspective consistent with farmers' own evaluations of the system (see Chapter 4).

Table 39. Annual requirements of family labour and summary results of the simulation of the net present value of net returns per unit of family labour.

	Person–day ha^{-1}		Annual net returns (USD person–day^{-1} ha^{-1})		
Year	*Abonera*	Bush fallow	*Abonera*	Bush fallow	Incremental flow
1	54.5	49.5	3.75	4.38	–0.63
2	19.0	45.5	6.65	4.93	1.72
3	19.0	0	12.10	0.00	12.10
4	19.0	0	12.10	0.00	12.10
5	19.0	0	12.10	0.00	12.10
6	19.0	27.0	12.10	7.06	5.04
Total	149.5	122.0	—	—	—

Note: USD, United States dollars.

Comparison of labour requirements for both systems also reveals that although the *abonera* system requires less labour per unit of land than the bush-fallow system, more labour is employed over a 6-year period. The intensification of land use in the *abonera* system implies an increase of 23% in total family labour employed in maize production on that land (27.5 person–day ha^{-1} more, over 6 years). Thus, the *abonera* system has a dual impact on labour use. On the one hand, the annual labour costs per unit of land are reduced, but on the other hand, the total demand for labour over a 6-year cycle is increased. These economic effects are discussed below in the farm-level analysis and in the discussion of the regional impacts of the *abonera* system.

Sensitivity analysis

The CBA of the net returns per units of land and labour demonstrates that the *abonera* system is currently more profitable than the bush-fallow system, at least in northern Honduras. This economic advantage is subject, however, to changes in the main factors influencing relative profitability. Future use of the *abonera* system in northern Honduras or diffusion of the technology into other regions requires that these factors remain about the same.

Table 40 shows the main factors in the differences between the flow of net benefits in the *abonera* and that in the bush-fallow systems under different discount rates. The data reveal the sensitivity of the CBA to changes in these factors. For example, at the lower discount rates, the maize yield realized in the *abonera* system is clearly the most important factor. The positive correlation coefficient of this variable is very strong.

The importance of seasonal differences in maize prices is also indicated by the opposite signs of the correlation coefficients of these variables. This relationship suggests that as long as seasonal price differences continue, the *abonera* will be more profitable than the bush-fallow system. Because the price difference is a

Table 40. Sensitivity analysis of the simulation analysis of the net present value of the incremental flow of net benefits per unit of land.

	Ranked correlation for different discount rates					
Variable	10%	30%	50%	70%	90%	110%
Yield of second-season maize in *abonera*	0.91	0.89	0.87	0.84	0.86	0.84
Yield of first-season maize	—	—	—	—	−0.36	−0.42
Second-season maize price	0.35	0.34	0.33	−0.32	0.25	0.24
First-season maize price	−0.14	−0.18	−0.26	0.32	−0.11	−0.13

result of a seasonal scarcity in maize relative to a stable demand, policies affecting maize imports are likely to have a marked effect on the relative profitability of the *abonera* system. The current rising trend in international maize prices suggests that, at least for the time being, seasonal differences in maize prices are likely to continue.

In sum, the *abonera* system is economically more productive at the field level — when a single unit of land is considered (at the margin) over the 6-year cycle of the bush-fallow system. These returns per unit of land are realized, however, only if the farmer's planning horizon is greater than 2 years, which implies that adopting the *abonera* system is subject to factors conditioning farmers' planning horizons. Returns per unit of labour are somewhat more immediate (halfway through the second year). Although annual labour costs are reduced in the *abonera* system, the intensification of land use increases the overall demand for labour, an important economic impact in a country where opportunities to invest family labour are limited. The relative profitability of the *abonera* system is sensitive, however, to changes in the yield of maize in the two systems and in the seasonality of maize prices — factors examined further in subsequent chapters.

Farm-level analysis

The economic implications of the *abonera* system cannot be assessed at the field level alone. Adoption of the *abonera* system implies a series of land and labour allocations affecting the whole farm. These are assessed by farmers with a view to their broader livelihood objectives and alternative sources of income and land uses. In this section, we examine the economic implications of alternative land and labour allocations at the farm level and the income-generating potential of the *abonera* system relative to that of other major forms of land use.

Cropping patterns

Before the *abonera* system was introduced, most regional farmers planted maize for several seasons in the same field, followed by an extended bush-fallow period. Currently, farmers have more options when allocating land, indicated schematically in Figure 21. Farmers can decide to continue to grow first- and second-season maize in the bush-fallow system without establishing a velvetbean field (scenario A in the figure). Alternatively, farmers can decide to allocate a field to the *abonera* system while continuing the conventional double-cropping pattern in a bush-fallow field (scenario B). Finally, farmers can decide to employ two distinct and exclusive cropping patterns, with a single crop of first-season maize

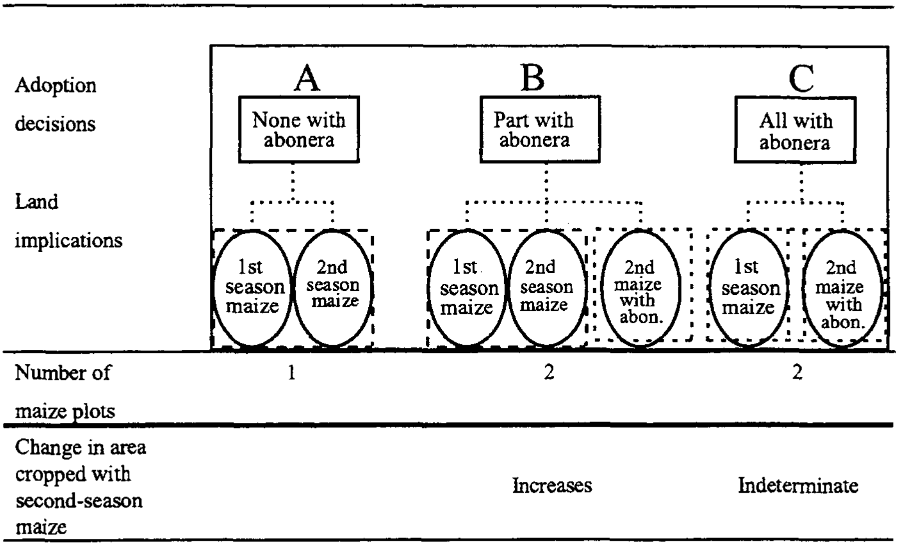

Figure 21. Adoption and land-allocation decisions, northern Honduras.

grown in an annual bush-fallow pattern and a second-season maize crop grown in an *abonera* system (scenario C).

The three scenarios have distinct implications for the number of maize plots cultivated per household and the land area dedicated to maize over a 6-year period, the cycle of the bush-fallow system (Table 41). In Table 41, a *plot* means a physical parcel of land, whereas a *land unit* refers to the use of the plot over time. The farmer employing only the bush-fallow system (scenario A) cultivates a plot of land for 2 years and then shifts to a new plot for 4 years. Two similar-sized plots are left in fallow at any given time, for a total of three plots. Over the 6-year period, a total of 12 units of land are cropped.

Farmers adding an *abonera* field to their system (scenarios B and C) require four plots, three to maintain the bush-fallow rotation and a fourth for the *abonera*. This represents an increase of 33% in the number of plots cultivated. In scenario B, the total area cropped with maize resulting from the addition of an *abonera* increases by 158%, assuming that farmers make full use for maize of each land unit opened for cultivation. In scenario C, the total area cropped with maize also increases (58%). Furthermore, farmers gain greater flexibility in the use of the plots dedicated to the bush-fallow system, as they can either grow a different crop in the second season (for example, beans) or simply leave the plot in fallow. In both scenarios, the addition of one plot under the *abonera* system to the maize-production system represents a significant increase in LUI.

Table 41. Land-use intensification over a 6-year period, as a result of adopting the *abonera* system (hypothetical).

	Second-season maize adoption decisions		
Land use over 6 years	Without *abonera* (scenario A)	Part with *abonera* (scenario B)	All with *abonera* (scenario C)
Number of plots used (*n*)	3	4	4
Increase relative to nonadopters (%)		33	33
First-season maize land units (*n*)	6	7	7
Size of each land unit (ha)	1	1	1
Total area in maize (ha)	6	7	7
Increase relative to nonadopters (%)		17	17
Second-season maize land units (*n*)	6	12	6
Size of each land unit (ha)	1	2	2
Total area in maize (ha)	6	24	12
Increase relative to nonadopters (%)		300	100
Total maize land units cropped (*n*)	12	19	13
Increase relative to nonadopters (%)		58	8
Total maize area cropped (ha)	12	31	19
Increase relative to nonadopters (%)		158	58

Note: Land unit = 1 ha. Figure 21 illustrates scenarios A, B, and C.

Farm-survey data show that farm management in northern Honduras is divided almost equally among these three hypothetical scenarios. A third of the farmers surveyed continue to manage all of their maize in the bush-fallow system. Another third use both cropping systems simultaneously within the same farm and within the same season. For these farmers, adoption of the *abonera* system does not replace the bush-fallow system but adds to it. Finally, a third of the farmers surveyed grow all of their second-season maize in *abonera* fields and all of their first-season maize in fields cleared from bush fallow. First-season fields are either left fallow during the second season or planted to other annual crops, such as beans and yucca. Farmers who adopt the *abonera* system (scenarios B and C in Figure 21) typically plant two plots of maize in the second season, whereas farmers without *aboneras* (scenario A) crop only one plot. The total amount of maize is also greater among farmers using the *abonera* system, especially during the second season. Adopters plant an average of 1.91 ha of maize in the second season, whereas nonadopters plant only 1.24 ha ($P \leq 0.05$; Table 42). These comparisons were made for landowners only, as they have more flexibility than tenants in the adoption decision (see Chapter 7).

Table 42. Average area cropped in maize and number of plots by landowner farmers, northern Honduras, 1991.

	Second season		First season	
	Farmers with *abonera*	Farmers without *abonera*	Farmers with *abonera*	Farmers without *abonera*
Average area (ha)	1.91	1.24	1.63	1.18
SD	1.35	0.97	1.60	0.98
Difference	0.67*		0.45	
Number of plots	2	1	1	1

Note: SD, standard deviation.
* Significant at $P \leq 0.05$ (*t* test).

Labour use

The introduction of the *abonera* system to northern Honduras modified not only farm-level land allocations but also the allocation of labour resources. Table 43 shows the monthly labour demands for maize production at the farm level, estimated for the three groups of farmers outlined above: nonadopters (scenario A), farmers who use both systems to grow second-season maize (scenario B), and farmers who grow all second-season maize in the *abonera* system (scenario C). To calculate the labour requirements, we assume that nonadopters grow 1 ha of first- and second-season maize. In the case of partial adoption (scenario B), farmers grow 1 ha of first-season maize, 1 ha of second-season maize in the *abonera* system, and 1 ha in bush fallow. In the case of total adoption (scenario C), farmers grow 1 ha of first-season maize and 2 ha of second-season maize in the *abonera* system. Labour requirements are then calculated by multiplying the per unit of land requirements by the area cropped to maize in the first and second seasons.

The data indicate that annual labour requirements increased by 39 and 37% for partial and full adoption of the *abonera* system, respectively. This increment results because the area cropped to maize in the second season is larger than the area cropped to maize in the bush-fallow system. This increase in the area cropped implies additional labour requirements, which must be filled either by family labour or by hired off-farm labour. (Note that the difference between the labour requirements of scenario B and those of scenario C is minimal.)

In sum, the *abonera* system plays a dual role with respect to labour use. First, it has a labour-saving effect per unit of land (field level), a benefit for farmers pressured by seasonal labour shortages within the household. This saving allows farmers to increase the area cropped to maize in the second season with a

Table 43. Monthly labour requirements at the farm level for maize under different cropping systems

	Labour requirements (person–day) by second-season adoption decision		
	Without *abonera* (scenario A)	Part in *abonera* (scenario B)	All in *abonera* (scenario C)
May	20.0	20.0	20.0
Jun	5.0	5.0	5.0
Jul	12.5	12.5	12.5
Aug	2.5	2.5	2.5
Sep	5.0	5.0	5.0
Oct	0	0	0
Nov	20.0	20.0	20.0
Dec	12.0	22.0	20.0
Jan	5.0	10.0	10.0
Feb	11.0	20.0	18.0
Mar	2.5	5.0	5.0
Apr	17.0	35.0	36.0
Total	112.5	157.0	154.0

Note: Figure 21 illustrates scenarios A, B, and C.

less than proportional increase in labour use. At the farm level, adopting the *abonera* system leads to an increase in the total labour used. This benefits households with limited opportunities to invest their labour in productive activities and increases the demand for labour at a regional level — an issue discussed further, below.

Regional impacts

The analyses indicate that the *abonera* system has a farm-level impact on the area allocated to second-season maize, on annual net benefits accruing to farmers, and on aggregate labour demand. Extensive adoption of the *abonera* system implies that these farm-level effects can be expected to lead to a regional increase in the total area and magnitude of second-season maize production.

Table 44 shows that the contribution of second-season maize to total maize production in northern Honduras grew at a rate of 1.4% a year between 1975/76 and 1994/95, a rate higher than that of the first-season maize. To illustrate more clearly the underlying trend, Figure 22 also shows (with a solid line) the moving

Table 44. Area, production, and yield of maize grown in first and second seasons, northern Honduras, 1975/76 to 1994/95.

	Area			Production		
Cropping year	First season (ha)	Second season (ha)	Second-season share (%)	First season (t)	Second season (t)	Second-season share (%)
1975/76	12 644	7 053	35.8	26 588	14 159	34.7
1976/77	13 672	8 570	38.5	25 299	18 711	42.5
1977/78	14 722	10 088	40.7	24 010	23 262	49.2
1978/79	18 008	10 404	36.6	31 408	15 593	33.2
1979/80	11 708	8 161	41.1	9 868	9 468	49.0
1980/81	25 855	13 831	34.9	41 232	23 071	35.9
1981/82	26 167	20 631	44.1	53 446	30 493	36.3
1982/83	15 812	14 966	48.6	19 695	21 529	52.2
1983/84	20 615	9 646	31.9	36 843	20 892	36.2
1984/85	30 687	6 588	17.7	56 019	13 231	19.1
1985/86	9 921	13 271	57.2	27 205	26 876	49.7
1986/87	9 483	13 271	58.3	19 156	26 876	58.4
1987/88	20 629	15 879	43.5	47 377	28 970	37.9
1988/89	21 078	11 670	35.6	34 327	22 516	39.6
1989/90	12 329	12 159	49.7	21 143	23 427	52.6
1990/91	11 641	16 233	58.2	25 245	29 659	54.0
1991/92	14 035	12 810	47.7	22 403	21 837	49.4
1992/93	18 459	13 699	42.6	45 280	26 471	36.9
1993/94	17 899	12 019	40.2	28 445	15 651	35.5
1994/95	13 188	12 040	47.7	19 582	19 232	49.5

Source: Secretaria de Recursos Naturales (1984, 1991, 1994, 1995).

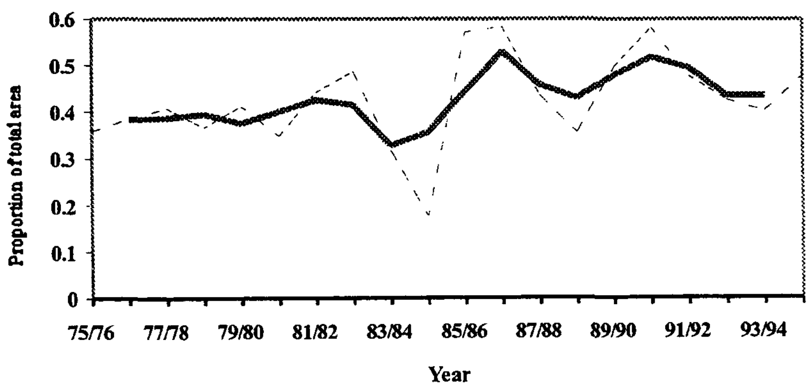

Figure 22. Area cropped in maize in the second season as a proportion of the total maize area, northern Honduras, 1976–94.

average of 3 years. During most of the 1970s and early 1980s, the area allocated to second-season maize represented less than 40% of the total area planted in maize in the region. In the middle 1980s, the second-season share began to increase, and by the end of the decade it had become the most important season.

The connection between the adoption of the *abonera* system and the contribution of second-season maize to total maize production in northern Honduras is difficult to establish because of the possible influence of exogenous factors. Unfortunately, data on the variables of interest disaggregated by cropping season are unavailable at the department level. These would have allowed us to compare areas with and without extensive adoption of the *abonera* system. The available data can, however, be used to test the association between the growth in the importance of second-season maize and the expansion of the *abonera* system, which is an indirect measure of regional impacts.

To test this association, we regressed the series on the relative share of the area cropped in second-season maize (A_t) on the percentage of farmers who adopted the *abonera* system (A_{a_t}) and on the ratio of second- to first-season maize prices, lagged 1 year ($p_{m_{t-1}}$).

To estimate the pattern of adoption over time, we fitted a logistic function to the farm-survey data from the department of Atlántida. The logistic equation has the following form:

$$Y = K/(1 + e^{-a-bt}) \qquad [4]$$

where K is the adoption ceiling; t is time (in years); and a and b are unknown parameters to be estimated (CIMMYT Economics Program 1993).

A K of 70% was assumed. This value is reasonable, given that land ownership seems to be an important factor influencing the adoption of the *abonera* system (see Chapter 7) and that about 75% of farmers in the region are landowners. We estimated the equation by ordinary least squares, transforming the equation using the value of K defined at 70%:

$$Y_t^* = -6.63 + 0.437t \qquad [5]$$
$$(-17.8^{**}), (18.7^{**}); R^2 = 0.98; n = 15$$

where Y_t^* is the transformed variable, ln $(Yt/K - Yt)$, that allows linearization of the equation; values in parentheses are t statistics; and ** indicates that the associated coefficient is significant ($P \leq 0.01$). Figure 23 shows the observed and estimated adoption pattern.

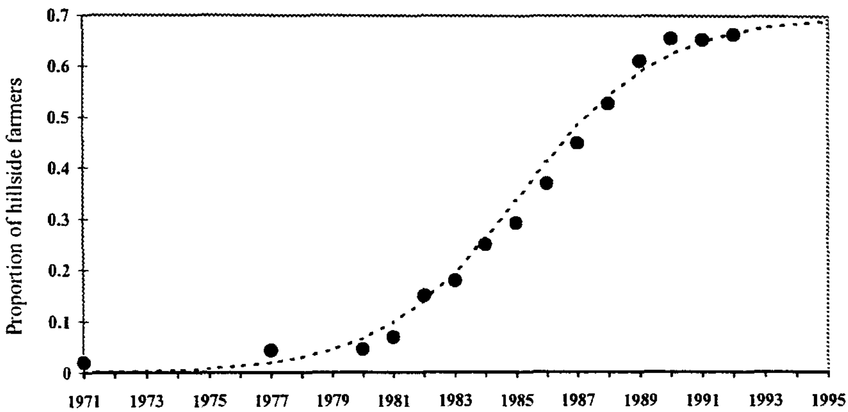

Figure 23. Observed and estimated patterns of diffusion of the *abonera* system, northern Honduras.

Analysis of the association between the two series yielded the following result:

$$A_t = 0.33 + 0.18A_{a_t} + 0.03p_{m_{t-1}} \qquad [6]$$
$$(3.6^{**}),\ (0.60);\ R^2 = 0.52;\ n = 15;\ \text{Durbin-Watson} = 1.56$$

where values in parentheses indicate t values; and ** indicates that the coefficient is significant ($P \leq 0.01$). The value of the Durbin-Watson test indicates the absence of autocorrelation in the estimated equation.

The impact of the expansion of the *abonera* system on the relative importance of the second season to maize supply is reflected in the highly significant coefficient of the adoption variable. An increase of 10% in the number of farmers who adopted the *abonera* system in the study area resulted in an increase of almost 2% in the relative importance of the second season to maize supply at the regional level.

Although the action of other factors affecting land allocation between seasons cannot be ruled out, no other technological innovations with the potential to produce the observed shift in the interseason land allocation were introduced during this period. A comparative analysis of maize-production technology from 1982/83 to 1992/93 showed that no significant changes occurred in that time, other than the introduction of the *abonera* system (Sain and Matute Ortíz 1992). Although the analysis is indirect, it suggests that the development and diffusion of the *abonera* system stimulated second-season maize production, a development that in turn may have raised farmer incomes and demand for labour at the regional level.

Land-rental markets

The development of the *abonera* system also seems to have had an impact on regional land-rental markets. The ability of the *abonera* system to increase the second-season maize productivity of land is well known to farmers and is reflected in their willingness to pay more rent for land planted to velvetbean.

Abonera rental markets were studied in the context of broader trends in markets for land in the hillsides of northern Honduras. The analysis determined that the selling or buying price of agricultural land is influenced by its ability to produce long-run economic rents and by other factors, such as the degree of urbanization and accessibility (distance to roads), and some macroeconomic variables, such as the inflation rate. By contrast, the rental market for agricultural land depends mainly on specific short-run land productivity. A farmer wishing to rent a plot for a single year or a single cropping season will pay close attention to factors related to land fertility, rather than to other types of factors.

Table 45 shows that land-rental prices in northern Honduras vary according to the type of vegetation dominant on the land. The rental price of 30.00 USD ha^{-1} for an established *abonera* (3 years or more) represents a significant increase (67%) relative to the rental price for land that has been in fallow or is under pasture. The absolute difference of 12.00 USD ha^{-1} represents the gain that farmers perceive in sowing maize in a plot of land under the *abonera* system if we assume access to perfect market information and no transaction costs. This value is lower, however, than the estimated difference between the average net benefits from sowing maize in an established *abonera* and those from the bush-fallow system (first and second season). The discrepancy may be attributed partially to profits accrued to the tenant and partially to land-rental market distortions. Among the most important would be farmers' lack of information about the real gain in the land's productivity, the impact of alternative land uses, and changes in agricultural policies. For example, massive land buying by international enterprises to produce pineapple has been an important distorting factor in the land market in the area. Furthermore, maize pricing and credit policies have discouraged maize production, promoting a shift to alternative uses of land. The economic reasons for this change in land use are discussed briefly below.

Table 45. Land-rental prices by vegetation type, northern Honduras, 1991.

	Rental prices by vegetation type (USD ha^{-1})				
	Abonera				
	<3 years (*n* = 23)	>3 years (*n* = 23)	*Guatal* (*n* = 23)	*Guamil* (*n* = 22)	Pasture (*n* = 10)
Mean	29.10	30.20	18.10	19.40	16.70
Median	27.00	27.00	16.20	16.20	14.80
Mode	27.00	27.00	13.50	13.50	17.00
SD	7.10	7.00	9.30	9.00	8.40
Minimum	10.80	16.20	5.40	5.40	5.40
Maximum	43.10	43.10	43.10	43.10	27.00

Note: SD, standard deviation; USD, United States dollars. *Guatal* is a field left unused, for natural regrowth, for a period of 3 or fewer years. *Guamil* is a field left unused, for natural regrowth, for a period of about 5 or more years.

Comparative profitability of maize production

Although the *abonera* system is clearly economically superior to the bush-fallow system, it is not the only option available to regional farmers. Despite its merits, the short velvetbean fallow used in the *abonera* system still limits maize production to one harvest per year, whereas two crops are feasible if the farmer uses external inputs, such as chemical fertilizers, and mechanized weed control. Furthermore, the *abonera* system does not lend itself to the periodic cultivation of other annual crops — such as beans, rice, and chilies — or sequential rotations with pasture for grazing cattle.

Comparison of the costs and benefits of these alternative uses of available land, labour, and capital would provide a more complete picture of the economic implications of the *abonera* system and the reasons why hillside farmers continue to maintain some land under the bush-fallow system. Unfortunately, a systematic discussion of this is beyond the scope of this study, partly because of the complexity and amount of data needed to shed light on these issues. An indication of the most important comparisons can be gleaned from the few other regional studies so far undertaken to consider this topic, together with some qualitative data of our own.

Flores (1993) compared the *abonera* system with a mechanized fertilizer-based system for producing maize; both systems were located on flatlands of the coastal plain. He estimated that mechanized and fertilized maize production gave farmers 18% higher net profits per hectare of land but considerably lower returns per unit of capital invested (30% lower than in the *abonera* system). Public credit played an important role in maintaining the high-external-input system, a service not generally available to farmers in the hillside areas. Flores also noted that 52% of the total cash expenditures in the *abonera* system were returned to local farmers in the form of wages for work, but some 72% of the financial costs in the mechanized system were for inputs and services from outside the community. Thus, although the high-external-input system is more profitable from the farmers' perspective, it can also be considered less beneficial to the local economy. Rubén et al. (1997) used a production-function approach in a comparative study of the *abonera* system and a high-external-input system and found that the relative productivity of the *abonera* system is extremely vulnerable to the vagaries of maize prices — a finding consistent with our analysis in Chapter 7 of factors influencing adoption.

Humphries (in press) estimated that summer-bean production brings an annual net return of 300 USD ha^{-1}, whereas winter beans gave an even higher return (about 400 USD ha^{-1}). Returns on the production of Tabasco chilies for regional industrial markets were considerably higher, about 2 000 USD ha^{-1}, according to her estimates. These returns are vastly superior to the 100 USD ha^{-1} return she estimated for maize grown in an *abonera* system, although they are comparable to our own estimates. She noted, however, that the risk of bean-crop failure is much higher than that for maize and that the loss of soil in bean production (especially summer beans) is extremely high. Tabasco-chili production also entails high risks and requires the frequent application of pesticides to ensure a healthy crop. The economic implications of these risks and the costs of long-term degradation of soil resources cannot be quantified from the available data.

The profitability of annual crops cannot be compared with that of cattle production solely on the basis of returns per unit of land because of the fundamental differences in the land-management practices of the two activities. Taking a whole-farm approach, however, Humphries (in press) estimated that a farmer with three milk-producing cows could realize yearly profits as high as those obtained by a typical hillside producer of maize and beans. (The typical farmer used in the calculation grows 3 ha of maize [2 ha in an *abonera* system and 1 ha in a bush-fallow system] and 1 ha of beans over the two bean cycles.) Interviews we conducted with several ranchers near San Francisco de Saco, Atlántida, suggest that a herd of 10 milking cows can easily generate total earnings of about 2 700 USD, a sizable income compared with that from maize farming or wage work. (A herd of 10 milking cows, each producing 5 L d^{-1} for 200 d $year^{-1}$, could be expected to generate total earnings of 2 700 USD, assuming a milk price of 0.25 USD L^{-1}.) In both studies, ranchers emphasized that dairy production is much less risky and requires considerably less physical effort than the very difficult and uncertain task of maize farming. These advantages are all the more compelling in light of increasing regional demand for milk and milk products, such as cheese.

Conclusions

Field- and farm-level analyses of the *abonera* system indicate that it is significantly more profitable than the bush-fallow system. Land-use intensity is greater in the *abonera* system (50% LUI, compared with 33% in the bush-fallow system), and net returns per units of land and labour are considerably higher. These net benefits are realized, however, after a 2-year period, during which farmers invest labour in velvetbean establishment and forego the benefits of maize production on that parcel of land for the first rainy season following establishment. After the *abonera* system is established, the probability of higher net returns per units of land and labour is very high (60–80%).

The probabilistic CBA suggests that factors affecting farmers' planning horizons (such as the security of access to land) are more likely to influence their adoption of the *abonera* system than factors affecting farmers' sensitivity to discounting future benefits (such as vulnerability to shortfalls in household supply of maize). One implication is that small-scale farmers cannot be assumed to simply reject practices with investment strategies based on discounted future benefits. At least in this case, with a modest planning horizon (more than 2 years), farmers with virtually any tendency to discount future benefits are justified in investing in the *abonera* system.

The profitability of the *abonera* system is sensitive to changes in the relative yield of maize in the two alternative systems, as well as in the seasonality of maize prices. However, these factors will be subject to no change in the near future. Yields in the bush-fallow system are likely to remain what they are, as a result of constraints on the use of chemical fertilizer in the region (absence of credit and high costs of transportation to remote fields) and the soil losses to be expected from intensification of the bush-fallow systems on hillsides. Rising trends in international maize prices are likely to suppress maize imports, thereby also enhancing the seasonality of maize prices and the relative profitability of the *abonera* system.

Higher returns per units of land and labour in the *abonera* system seem to make it the economically logical way to grow maize. However, farmers' decision-making is influenced by food-security concerns. They are unwilling to forego first-season maize production altogether and consequently always maintain some land under the bush-fallow system. Some farmers (two-thirds of the farmers surveyed) combine the *abonera* system with the less profitable bush-fallow system, whereas the rest stick to the bush-fallow system for all their maize production.

The economic implications of the cropping patterns available to farmers are twofold. Farmers incorporating the *abonera* system in their farms can easily increase the total land dedicated to second-season maize, with a less than proportional increase in labour costs. This effect, combined with an increase in LUI under the *abonera* system, results in an overall increase in labour use at the farm level — an important economic impact in a country where scarce opportunities exist for profitably investing family labour.

With these factors impacting at the regional level, the *abonera* system has probably increased the relative contribution of second-season maize to total maize production and to overall levels of maize production for the region as a whole. The potential of the *abonera* system to generate higher profits has also stimulated the development of a land-rental market for *aboneras*, which rent for higher prices than other types of land.

CHAPTER 7

FACTORS INFLUENCING ADOPTION OF THE *ABONERA* SYSTEM

Hypotheses regarding adoption

The 1992 farm-survey data indicate that some two-thirds of hillside farmers in northern Honduras use the *abonera* system to grow second-season maize (see Chapter 4). Although this level of adoption is significant, it also implies that one-third of the hillside farmers do not.

Differences between the two groups can be analyzed in light of the features of the *abonera* system that create costs and benefits. The probability of adoption is likely to be reduced by features that increase the farm-level costs of the *abonera* system, whereas features that increase the benefits can be expected to increase the probability of adoption. This analysis assumes with conventional economics that farmers' decision-making is based mainly on their objective of maximizing utility at the whole-farm level (Anderson et al. 1977). However, in contrast to adoption studies emphasizing the individual characteristics of farmers at one point in time, our analysis examines the role of broader market effects and ongoing changes in land-use patterns and land-tenure modalities in the technology-adoption process. We recognize that one decision criterion may be important to some farmers but not to others and that interactions between factors may influence farmers' behaviour in unforeseen ways.

Below, we describe seven hypotheses regarding features of the *abonera* system likely to influence adoption, and in the next section we use survey data to test these hypotheses.

- *Hypothesis 1* — Landowners are more likely than tenants to adopt the *abonera* system. Farmers adopting the *abonera* system require a planning horizon of 2 years to realize economic returns on investment. As noted in previous chapters, velvetbean relayed in second-season maize provides no direct economic benefits until the following second season. Because of this delay, security of access to the fields' improvements can be expected to influence the farmers' ability to benefit from adopting the *abonera* system and consequently their willingness to invest in it. Land ownership provides a measure of secure access to land, and a land-tenure arrangement is also likely to increase the probability of adoption. By contrast, land-rental arrangements in northern Honduras are insecure. Land is typically rented for one season at a time, with no assurance of access to the same field in subsequent seasons. Tenants considering using the *abonera* system consequently face the risk of losing their investment. This may reduce the probability of adopting of the technology.

- *Hypothesis 2* — Land-rich farmers are more likely than land-constrained farmers to adopt the *abonera* system. Land dedicated to the *abonera* system cannot be used to grow first-season maize or other annual crops important to hillside farmers in northern Honduras. Virtually all hillside farmers grow maize during both seasons, and many of the farmers cultivate beans, rice, and other crops as well. The decision to establish an *abonera* on land owned by the farm household consequently imposes an opportunity cost equal to the value of the alternative crops that could have been produced on the same land. The opportunity cost of the *abonera* system can be expected to decline as the amount of land resources available to farmers increases. Farmers with more land can allocate some of it to the *abonera* system while still producing alternative crops on their other lands. Thus, the opportunity cost associated with the *abonera* system is lower for land-rich farmers.

- *Hypothesis 3* — Ranching activities can be expected to influence farmers' adoption of the *abonera* system. Land dedicated to the *abonera* system competes not only with annual crops but also with more profitable ranching activities. The demand for pasture has increased dramatically in recent decades as cattle ranching expands throughout the region, applying pressure on the land area available for crop production. This broad change in land-use patterns can be expected to influence farmers' adoption of the *abonera* system for two reasons: given the strong regional demand for pastures, the opportunity cost of establishing an *abonera* instead of pasture is even higher than the opportunity cost of not planting annual crops; and the *abonera* system conflicts with pasture-management practices common on the hillsides of northern

Honduras. As noted in Chapter 3, pastures are often managed in long, sequential rotations with bush fallow and annual crops, a flexible and discontinuous land-use strategy incompatible with the relatively permanent *aboneras*. Land managed in a sequential rotation can be brought into pasture or used for various annual crops with greater ease than land managed as an established *abonera*. For these reasons, the costs of adopting the *abonera* system are higher for farmers engaged in cattle and pasture production.

- *Hypothesis 4* — Hillside farmers with steeper maize fields are more likely than farmers with flatter maize fields to adopt the *abonera* system. The analysis of the agroecological characteristics of the *abonera* system, presented in Chapter 5, indicates that the *abonera* system decreases the yield risk during the drier second season because the velvetbean mulch helps conserve soil moisture. This suggests that the benefit of water conservation is greater on steeper land, where soil depth and moisture-holding capacity are inherently inferior, than on relatively flat land.

- *Hypothesis 5* — Constraints on the availability of labour can be expected to influence farmers' decisions to adopt the *abonera* system. The *abonera* system is a labour-saving technology. As noted in Chapters 4 and 6, the system, by reducing land-preparation and weeding costs, provides higher returns per unit of labour during the second season. The benefits of improved labour productivity may be particularly relevant to households with labour constraints.

- *Hypothesis 6* — The decreased need for chemical fertilizers (mainly N) in the *abonera* system may influence the adoption behaviour of farmers with limited access to commercial sources of N. Typically, farmers use little or no commercial fertilizer on second-season maize planted in an *abonera* plot. The adoption of the *abonera* system offers farmers an opportunity to reduce the costs of intensive land-use strategies.

- *Hypothesis 7* — Market-oriented farmers are more likely than subsistence farmers to adopt the *abonera* system. The profitability of the *abonera* system is also subject to the seasonal changes in maize prices in northern Honduras. Maize prices increase during the second season and drop dramatically when first-season maize is harvested (see Chapter 2). Under the *abonera* system, maize can be harvested when maize prices are highest. Market-oriented farmers may consequently give greater weight to this additional benefit than subsistence farmers might.

The costs of acquiring velvetbean seed and knowledge of its uses may have been high during the early stages of diffusion of the *abonera* system in northern Honduras; factors influencing this transaction cost, such as farmer characteristics (place of origin, age, education, etc.), may also have been relevant 20 years ago. Today, however, knowledge of the technology is very widespread, and the seed is readily available throughout the region; thus, the costs to farmers of gaining access to the information and seed needed to adopt the technology are undoubtedly very low and have little importance in explaining northern Honduran farmers' adoption of the *abonera* system. Versions of the adoption model that included farmer characteristics and other statistical tests of their relationship to adoption failed to reveal any significant associations. Consequently, farmer characteristics and other proxies for transaction cost are not included in our adoption model (presented below), although transaction costs may be relevant in areas where the use of the technology is fairly recent. Thus, in some areas, transaction cost could be considered in a general model for examining factors influencing adoption of the *abonera* system.

Empirical analysis

The factors influencing adoption of the *abonera* system, outlined above, are complex and interconnected. To examine the combined effects of these factors on the adoption decision, we used logit analysis of data from the farm survey of 126 maize producers.[5] The variables in the analysis, described in Table 46, follow the hypotheses formulated above. A binary variable for the adoption decision (CHOICE) was defined as 1 if the farmer grew at least some second-season maize under the *abonera* system during the 1991/92 winter cycle; 0, if the farmer did not. Results of the regression, presented in Table 47, indicate that the combined effects of the independent variables significantly explain adoption behaviour. Sensitivity analysis, presented at the end of this section, helps to rank the importance of each factor.

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[5]The assistance of Kenneth Mullen and Paul Heisey in the use of logit techniques is gratefully acknowledged. Errors in interpretation are, however, the sole responsibility of the authors.

Table 46. Variables in the logistic regression.

Variable	Value	% with a value of 1	Mean ± SD
CHOICE	1 if used on some maize fields; 0 if not	64.3	
LAND TENURE	1 if own land; 0 if not	71.4	
CROPLAND	Cropland owned, including fallow and cultivated land but not pasture (ha)		5.6±8.2
RENT1ST	Area rented during first season (ha)		0.7±1.2
RENT2ND	Area rented during second season (ha)		0.5±0.9
PASTURE	Pasture area owned (ha)		3.1±8.2
LSLOPE	Logarithm of % slope of main maize field		3.8±0.7
LABOUR	Sum of adult family labour (*n* = men + women)		2.5±1.2
FERT1ST	1 if farmer uses fertilizers during first season; 0 if not	28.6	
SALES2ND	1 if farmer sold half or more of second season harvest in 1990; 0 if not	48.4	

Note: Sample size, 126; SD, standard deviation.

Table 47. Effect of farm-household characteristics on the probability of adoption of the *abonera* system, northern Honduras.

	Parameter estimates	
Variable	Logit estimated coefficient	Significance level
LAND TENURE	1.112 80	0.084 55
CROPLAND	0.120 82	0.028 22
RENT1ST	0.854 30	0.017 27
RENT2ND	−0.661 98	0.079 99
PASTURE	−0.113 69	0.017 90
LSLOPE	0.853 26	0.023 61
LABOUR	0.180 42	0.406 89
FERT1ST	−0.374 39	0.478 80
SALES2ND	1.512 50	0.002 04

Note: Sample size, 126; R^2 = 82.12; $P \leq 0.05$; percentage correctly predicted, 80.2%

Land, labour, and markets

To examine the impact of land ownership on the adoption decision, we used a binary variable distinguishing between landowners and tenant farmers. As expected, the results of the regression indicate that landowners are more likely to adopt the technology than tenant farmers (hypothesis 1; $P \leq 0.01$). This tendency may reflect the greater potential for landowners to capture the benefits of investment in the *abonera* system, compared with farmers who depend on rented land. We initially analyzed the effect of land opportunity costs on the adoption of the *abonera* system through its relationship to a variable for total farm size (including both owned and rented land), on the assumption that the opportunity costs of land dedicated to the *abonera* system would decline with farm size (hypothesis 2). The results of the regression were not significant, however; farm size had no apparent effect on adoption behaviour.

The logit regression was run again with variables distinguishing between the amount of owned and rented cropland and pasture, as opposed to an aggregate variable for farm size. We hypothesized that the opportunity costs of the *abonera* system may be subject to the amount of land available to farmers through either ownership or rental markets. Well-developed and low-cost land-rental markets in northern Honduras may make it less costly for very small landowners to adopt the *abonera* system on their own land while renting land for other crops. The effect of land-rental markets on land opportunity costs and subsequent adoption decisions should be most apparent during the first season, when land planted to velvetbean is not available for alternative crops. We created variables for land rented during the first season and land rented during the second season to analyze this effect.

Results of the logit regression showed that land ownership and land-rental markets affect adoption in tandem. A variable for the amount of fallow and cultivated land owned by the household (CROPLAND) has a positive effect on the probability of adoption ($P \leq 0.05$). In addition, land area rented during the first season (RENT1ST), when the opportunity costs of the *abonera* system are greatest, also has a positive and significant effect on adoption ($P \leq 0.05$). The land area rented during the second season (RENT2ND), when the *abonera* system presents no opportunity costs, has a negative effect on the probability of adoption ($P \leq 0.1$). These results suggest that the relative availability of land resources, either through ownership or rental markets, reduces the opportunity costs of the *abonera* system and consequently enhances the probability of adoption. The seasonal effects of land-rental markets on land opportunity costs are also apparent.

The effect of ranching activities on adoption of the *abonera* system (hypothesis 3) can be analyzed through its relationship to pasture production. A variable for the amount of pasture owned by a household (PASTURE) has a negative effect on adoption of the *abonera* ($P \leq 0.05$). (A variable for the ownership of cattle was also tested in the logit model. By itself, it showed a significantly negative impact on the adoption decision, but the PASTURE variable was used instead because it more directly reflects the potential conflict between pasture-management practices and the *abonera* system.) This result supports the hypothesis that competition between pasture-management practices and the *abonera* system increases the costs of adoption for farmers engaged in ranching or pasture-production activities. Given the increasing importance of cattle ranching in the region, the apparent incompatibility of these two land uses may become a significant limiting factor in adoption of the *abonera* system — an issue discussed further, below.

A variable for the percentage slope of the largest maize field cultivated by each farm household (LSLOPE) was included in the analysis to assess the impact of land type on the costs and benefits of the adoption decision. A nonlinear form was used for the percentage slope because farmers' concerns about landslides on very steep slopes planted in an *abonera* system can be expected to reduce the probability of adoption at the upper end of the distribution (see farmers' perceptions of the risks of the *abonera* system on very steep slopes, in Chapter 4). A positive effect on adoption was found ($P \leq 0.05$). As hypothesized (hypothesis 4), farmers with steeper maize fields are more likely to adopt the *abonera* system, possibly because the potential benefits of the technology (risk reduction) are greater under these field conditions.

The impact of household labour constraints on the adoption decision was analyzed through its relationship to the availability of family labour (LABOUR), calculated as the sum of adult family labour (n = men + women). We hypothesized (hypothesis 5) that the labour-saving benefits of the *abonera* system would be greatest for families with smaller labour resources available for on-farm work. However, the effect of this variable on the adoption decision was not significant, and the sign of the coefficient for the variable was contrary to that expected. One possible explanation for this outcome is that labour-constrained and labour-abundant households may actually benefit equally from adoption of the *abonera* system, either because labour costs per unit of land are reduced or because labour resources are freed for investment in other activities. More fundamentally, however, the variable may simply not be sensitive enough to capture the effect of relatively small variations in the availability of labour resources within the sample population; the standard deviation for this variable is narrow.

The effect of constraints on access to commercial fertilizer was, according to hypothesis 6, an important factor affecting adoption of the *abonera* system. On methodological grounds, however, the effect was indeterminable on the basis of actual fertilizer use during the second season, as the *abonera* system is perceived by farmers as a low-cost substitute for commercial fertilizers on second-season maize. As noted previously, farmers do not generally apply fertilizer to maize planted in an *abonera* system as they believe it is unnecessary for achieving reasonably high maize yields. Hence, fertilizer use during the second season would veil an endogenous relationship with adoption, the dependent variable.

This problem of endogeneity does not hold, however, for farmers' use of commercial fertilizer on first-season maize. The application of commercial fertilizers to first-season maize has increased markedly during the last decade and is now widely considered a beneficial but expensive input for first-season maize. Thus, the use of commercial fertilizer on first-season maize (FERT1ST) can be considered a proxy for constraints on access to this input. When introduced into the logit regression, however, the variable is not significant, although the sign of the coefficient for the variable is negative, as expected. Consequently, no conclusion regarding this factor can be reached from this analysis.

The effect of market orientation on the adoption of the *abonera* system (hypothesis 7) can by analyzed through its relationship to farmers' actual maize sales during the second season. The *abonera* system is ideally suited to the production of maize during the second season, a cycle when maize prices are at their highest. For market-oriented farmers, the potential benefits of adoption can be expected to be greatest during this period. To test this effect, we included in the model a variable (SALES2ND) measuring the proportion of the previous year's second-season maize harvest sold on the market (we used a value of 1 if the farmer sold half or more of the harvest; 0, if not). The sign of the coefficient for this variable is positive, as expected, and significant at $P \leq 0.01$, suggesting that the market orientation of farmers does influence the adoption decision. This finding supports arguments made earlier that policy changes affecting the seasonality of maize markets could have impacts on adoption of the *abonera* system.

In sum, four types of factors have significant effects on farmers' adoption of the *abonera* system: security of access to land (hypothesis 1); influences on the opportunity costs of land, such as farm size, land-rental markets, and the management of pastures (hypotheses 2 and 3); land characteristics (hypothesis 4); and the market orientation of maize producers (hypothesis 7). Constraints on access to commercial fertilizers (hypothesis 5) and the impacts of labour resources (hypothesis 6) were inconclusive. Overall, the factors included in the model enable it to correctly predict 80.2% of the sampled observations, a compelling result for analyses of this nature (see Table 47).

Table 48. Probabilities of adoption of the *abonera* system by the typical farmer and by the typical farmer when the value of one variable is changed, northern Honduras.

	Probability of adoption
Typical farmer: sells less than half of second-season maize crop, owns land, and does not fertilize first-season maize	0.64
Typical farmer but sells more than half of second-season maize crop	0.89
Typical farmer but doesn't own land	0.37
Typical farmer but fertilizes first-season maize	0.55

Sensitivity analysis

The qualitative and quantitative factors examined above do not all have the same level of impact on the adoption decision. The relative importance of the qualitative factors can be seen by examining the changes in probabilities that would result from changes in the values of these variables. To rank these factors, we defined a "typical farmer" by the most frequent values of the qualitative variables included in the model. Thus, a typical farmer is one who owns land (71.4%), does not apply fertilizer during the first season (71.4%), and sells less than half of the second-season maize harvest (51.6%).

Table 48 shows the probability of adoption for this typical farmer and the effect of changing the values of the qualitative variables. Results are consistent with expectations. The probability of adoption for a typical farmer evaluated at the sampling mean of the quantitative variables is 64%, a measure virtually equal to the actual level of adoption indicated by the survey data. By contrast, farmers who are typical in all respects except that they sell more than half of their second-season maize crop have a much higher probability of adoption (an increase of 40% over that of the typical farmer). The probability of adoption among farmers with a typical profile but without land ownership decreases by 42%, a clear indication of the influence of this factor on the adoption decision. Finally, the probability of adoption among typical farmers decreases by 14% if they also fertilize first-season maize.

A different approach is needed to measure the sensitivity of quantitative variables to changes in their values. The relative importance of the quantitative factors in the adoption decision can be seen by examining variable elasticities, defined as the percentage change in probabilities that would result from a percentage change in the value of these variables. These values are calculated for a typical farmer as described above, as well as for a typical farmer more oriented to the market. Table 49 shows the results for both types of farmer.

Table 49. Elasticities of the probability of adoption of the *abonera* system by a typical farmer, northern Honduras.

Variable	Variable elasticities (% change in probability of adoption relative to a 10% increase in the variable)	
	Typical farmer	Market-oriented typical farmer
CROPLAND	2.45	0.75
RENT1ST	3.09	0.95
RENT2ND	-1.20	-0.37
PASTURE	-1.27	-0.39
LSLOPE	3.09	0.95

For a typical farmer, the opportunity cost of land, as measured by the variables CROPLAND and RENT1ST, has a sizable impact on the adoption decision. For example, an increase of 10% in the average amount of cropland owned increases the probability of adoption by almost 2.45%. Similarly, an increase of 10% in the area rented during the first season increases the probability of adoption by 3%. By contrast, the impact of the quantitative variables is much less among the market-oriented farmers, indicative of the high probabilities of adoption already found among farmers with this profile.

Adoption and livelihood strategies

The logit analysis of factors influencing adoption helps explain the pattern of adoption found among household groups identified in Chapter 3 (Table 50). The data show that subsistence workers are least likely to adopt the *abonera*. This may be due to their dependence on small parcels of rented land for maize production. The high rate of adoption among medium-scale farmers may be due to their being relatively free of land constraints and fully engaged in commercial maize production. Small-scale farmers are somewhere in between these two situations; they are land constrained but have some land of their own where an *abonera* can be established.

Diversified farmers have only an average level of adoption, despite being relatively well endowed with secure land resources. This may be due to the competing demands on the land held by members of this group. Diversified farmers are struggling to become ranchers rather than farmers and may tend to emphasize pasture production over other land uses. The opportunity costs of the *abonera* system may consequently be higher for this group. Established ranchers, by contrast,

Table 50. Adoption of the *abonera* system by household group, northern Honduras.

	Proportion of households (%)					
	Ranchers	Diversified farmers	Medium-scale farmers	Small-scale farmers	Subsistence workers	All household groups
With abonera	84.2	68.4	76.7	64.3	36.7	64.3
Without abonera	15.8	31.6	23.3	35.7	63.3	35.7

Source: Authors' survey, 1992.

can afford to dedicate a few hectares of land to the *abonera* system without significantly affecting their ability to acquire pasture for their cattle. Among this group, adoption of the *abonera* system is high.

Discussion and conclusions

The analyses presented above indicate that land tenure, land distribution, competing land uses, and relative prices of outputs (maize) significantly influence farmers' adoption of the *abonera* system. These findings have implications for policymakers and researchers concerned with developing hillside agriculture.

First, it seems clear that security of access to land is a fundamental condition for investment in productivity-enhancing, resource-conserving technologies in hillside environments. This general conclusion should be qualified, however, in light of several distinctive features of the land-tenure system in northern Honduras. As noted in Chapter 2, individual land ownership can take two forms in northern Honduras: titled property (*dominio pleno*) and squatters' rights (*dominio útil*). Titled property is fully recognized by the state, which conveys the right of use and unimpeded transfer of land. Squatters' rights also convey the right to use and transfer land, so long as annual municipal land taxes have been duly paid and the buyer assumes the obligation to continue paying these taxes. These rights are less flexible, however, than titled property because banks and other lending institutions do not recognize squatters' rights as guarantees against farm loans. This represents an unimportant limitation for most farmers, however, as farm credit is extremely limited throughout the region anyway.

Survey data from 1990, distinguishing between titled property and squatters' rights, indicates that squatters and titled owners are equally disposed to adopt the *abonera* system; adoption rates for these two types of landowners are statistically the same (Buckles et al. 1991). This finding suggests that although land ownership is an important consideration in the adoption decision, the form of land tenure may not be. A legal tradition that recognizes the rights of squatters to use public lands seems to convey with it the level of security of access needed by farmers to invest in the *abonera* system. This experience contradicts the common assumption that formal land titles are the only form of land tenure consistent with the long-term planning horizon needed to support the adoption of technologies with long-term benefits. An implication of this finding is that policies reinforcing the rights of squatters might be just as effective in providing security of access to land and facilitating use of conservation technology as formal titling programs.

Second, the lack of land ownership is not an absolute limitation on farmers' use of the *abonera* system. A third of the tenant farmers surveyed reported that at least some of their maize was planted in an established *abonera* rented from someone else. This is possible because *abonera* land-rental markets have developed throughout the region in recent years, as farmers with more land than they can cultivate themselves divert some of it to *aboneras* for rent or for use by family members. For landowners, an *abonera* is an improvement in the land that can be captured in higher rental rates; as noted in Chapter 6, farmers are willing to pay a premium of 60–70% for rights to cultivate maize on land with an established *abonera*, a clear indication of the potential the farmers perceive in the field. Thus, although land ownership is important, the development of *abonera* land-rental markets has facilitated the use of this technology by landless farmers as well.

The adoption decisions made under the two circumstances are nevertheless distinct. For landowners, a decision to adopt the *abonera* system is relatively secure and enduring; they can expect to realize tangible benefits from the investment over an indefinite period of time. By contrast, tenant farmers decide whether to rent an established *abonera*, with the expectation that the field will be immediately more productive than lower-cost alternatives. Their decision is subject to the availability of established *aboneras* in uncertain land-rental markets, and their use of the system is potentially discontinuous (their use of the *abonera* system may be interrupted, as was noted in Chapter 4).

Land-rental markets are important in providing access to *aboneras* not only to tenants but also to small-scale landowners. The logit analysis demonstrates that differences in the amount of land resources available to farmers, either through ownership or land-rental markets, modify the opportunity costs of the *abonera* system and consequently the probability of adoption. In tandem, land ownership and first-season land-rental markets seem to have a significant impact on the probability of farmers' adopting of the *abonera* system. An explanation for this result is

Table 51. Adoption of the *abonera* system by landowner group, northern Honduras.

	Proportion of households (%)					
	Land owned					All landowner groups
	>10 ha	5-10 ha	2-5 ha	1-2 ha	Landless	
With abonera	86.1	70.8	76.0	55.6	33.3	64.3
Without abonera	13.9	29.2	24.0	44.4	66.7	35.7

Source: Authors' survey, 1992.

that farmers with larger farms are more likely to adopt the technology; farmers with smaller farms of their own are likely to adopt it if they can rent the land for the first-season crops that the *aboneras* displace. Data for landowner groups are presented in Table 51; these data show high adoption rates, even among farmers with very little land of their own. These farmers adopt the *abonera* on their own land and rent land for other crops.

Land constraints on farmers' adoption of the *abonera* system are currently eased by a well-developed and low-cost land-rental market. This situation is subject, however, to changing land-use patterns affecting northern Honduras. Pasture production, stimulated by new markets for milk products, is expanding rapidly throughout the hillside area. As noted in Chapter 6, milk and cheese production is more profitable than annual crops and entails fewer risks. For farmers with enough resources to become ranchers, the shift from crops to pasture can improve their livelihoods. The people most likely to be in this situation are the diversified farmers, who work with numerous competing demands on their land resources.

For many people in hillside households, the purchase of cattle of their own is beyond their means, leaving them the more limited option of renting out land for pastures or selling some land to finance the acquisition of cattle. Qualitative evidence (Humphries, in press; DB's field observations) suggests that larger-scale ranchers residing in coastal communities not included in this study are acquiring the more accessible and better-quality land in the hillsides for seasonal grazing of herds, displacing small-scale producers to more marginal lands. These developments increase pressure on land-rental markets, reducing the availability of land for first-season crops and consequently making it increasingly difficult for small-scale operators to dedicate land to the *abonera* system. In the Conclusion, we discuss this threat to the stability of the *abonera* system and the opportunities to enhance its productivity without undermining its ecological merits.

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CONCLUSION

Main features of the *abonera* system

The *abonera* system is a multipurpose innovation that responds simultaneously to several constraints on its productivity. The fast-growing velvetbean accumulates nutrients through recycling and N fixation and suppresses weeds while shielding the soil from direct exposure to heavy rains in the major rainy season. Once the velvetbean is slashed, the thick mulch layer continues to suppress weeds during the maize cropping cycle and protects the soil from erosion. The mulch layer also conserves soil moisture, thereby greatly reducing the risk of drought stress during the relatively dry period during which the maize grows. The velvetbean system provides these multiple benefits at little direct cost, as the velvetbean stand reseeds itself spontaneously.

In the *abonera* system, at least some vegetation is always actively growing — be it velvetbean, maize, or weeds — and some recently formed litter is decomposing. Periods of net accumulation of biomass and N (when velvetbean is growing) alternate with periods of net mineralization (after velvetbean has been slashed). At its peak, before slashing, the *Mucuna* vegetation constitutes on average more than 10 t aboveground biomass ha^{-1} on a DM basis and contains on average more than 300 kg N ha^{-1}, 100 kg K ha^{-1}, and 20 kg P ha^{-1}. The nutritional requirements of maize are met by the nutrient supply derived through decomposition of the velvetbean mulch, resulting in average maize yields of 2–4 t ha^{-1} (in comparison, the bush-fallow system has yields of less than 2 t ha^{-1}).

The fate of the N in the velvetbean biomass at slashing can be described as follows. A maize crop yielding 4 t ha^{-1} accumulates around 100 kg N ha^{-1} in its aboveground biomass, most of which is exported via maize harvest. Weeds take up about 50 kg N ha^{-1} before they are controlled, and even more than this after farmers stop controlling them. A fraction of the N, perhaps as much as 50–80 kg ha^{-1} on average, appears to be stored in the newly formed SOM every year. Biological N fixation by the velvetbean supplies about 100 kg new N ha^{-1} $year^{-1}$. No evidence suggests that losses of N by either leaching or volatilization are playing an important role in the *abonera* system. Thus, most of the N in the *abonera* system (200 kg ha^{-1}) is simply recycled by velvetbean, weeds, maize, and the soil–litter biota; about 100 kg is exported via maize harvest.

Long-term trends in soil fertility and soil structure also seem to be very favourable in the *abonera* system. Despite continuous annual cropping, SOM in the upper-soil profile increases or remains stable for as long as 15 years. Water infiltration and total porosity also increase markedly. Nutrient cycling seems to be relatively efficient, maintaining nutrients at stable levels in a form available to growing plants. The risk of soil acidification from N imbalances does not seem to be significant; soil pH remains stable; and exchangeable bases tend to increase throughout the soil profile. Earthworms, insects, and fungi at the litter–soil interface abound in an *abonera*, and serious pests or soil-borne pathogens are largely absent, a clear indication of soil health. Finally, maize yields in old velvetbean fields are as high as or higher than those in young ones and on average about double those obtained in check plots not planted to *Mucuna*.

The only agronomic concern of note is the risk of invasion by aggressive annual grasses. *Rottboellia cochinchinensis* is likely to prosper in the *abonera* system unless farmers invest in periodic replanting of velvetbean to prevent the appearance of significant gaps in the velvetbean stand.

The active cycling of nutrients and the high soil fertility in the *abonera* system make it possible to intensify land and labour use. Although only three maize crops can be harvested during a typical 6-year bush-fallow cycle, continuous annual cropping of maize is achieved in the *abonera* system without degrading the resource base. Labour costs are 17% lower on average because of the weed-control effects of the *Mucuna* crop and mulch.

Probabilistic analysis of returns per units of land and labour shows that over a 6-year period, the *abonera* system has a 60–80% probability of producing net benefits higher than those of the bush-fallow system. Even when the flow of benefits of the *abonera* system is heavily discounted (100% discount rate), the probability of net returns to land and labour over the 6-year period is still very high (more than 40%).

However, the timing of net benefits is not ideal. Farmers must invest in an *abonera* system a full year before realizing the first labour savings and almost 2 years before realizing yield benefits. This delay is relevant to farmers with a highly constrained planning horizon, such as tenants and farmers who have no access to other lands for first-season maize and other crops important to subsistence (cassava, beans, etc.). Direct short-term costs (seed and labour) are nevertheless minor, mainly a one-time investment to establish a *Mucuna* field.

The second-season maize harvest in the *abonera* system enhances profitability. Maize prices are highest at this time because of the seasonality of national maize production. The timing of the harvest also reduces the risk of ear rot that enacts a heavy toll on first-season maize. The proportion of total maize area and output in the second season has increased notably in northern Honduras, a shift in production stimulated by the *abonera* system.

Extrapolation from the *abonera* system in northern Honduras

The agroecological and socioeconomic conditions under which the *abonera* system developed in northern Honduras are quite specific. Understanding these conditions can shed light on the constraints and opportunities farmers in other regions are likely to face.

From a biophysical point of view, the *abonera* system seems best suited to areas with high total annual rainfall in a bimodal distribution. The climate of northern Honduras is very wet, with more than 3 000 mm of precipitation and an annual growing season in excess of 270 d. Under these climatic conditions, farmers can dedicate the first season to production of the velvetbean crop and the second season to a high-yielding, relatively disease-free maize crop. Both seasons have enough rain to support the maximum development of crop biomass.

The climatic conditions of northern Honduras are found elsewhere in Central America. The humid zone, characterized by more than 270 d $year^{-1}$ with rainfall in excess of evapotranspiration (Figure 24), extends all along the Caribbean coast of Belize, Costa Rica, Honduras, Nicaragua, and Panama and into the interior of Guatemala (El Peten) (Chapman and Barreto 1994). As noted earlier, spontaneous adoption of *Mucuna*–maize systems very similar to the one in place in northern Honduras has occurred in the northern portion of this climatic niche and in parts of southern Mexico.

Less favourable climatic conditions found elsewhere in Central America not only constrain annual rotations, such as the *abonera* system, but also create seasonal fluctuations in maize supply and prices. The seasonal premium on maize is subject, however, to national policies affecting maize imports. In recent years, structural-adjustment programs in Central America have applied downward pressure on maize prices and in some areas greatly reduced the seasonality of prices, which reduces one of the advantages of the *abonera* system.

The extensive humid area in Central America is not traditionally the location of agricultural development or of most of the population of the region. The *abonera* system has thrived more in underpopulated areas where farmers have had

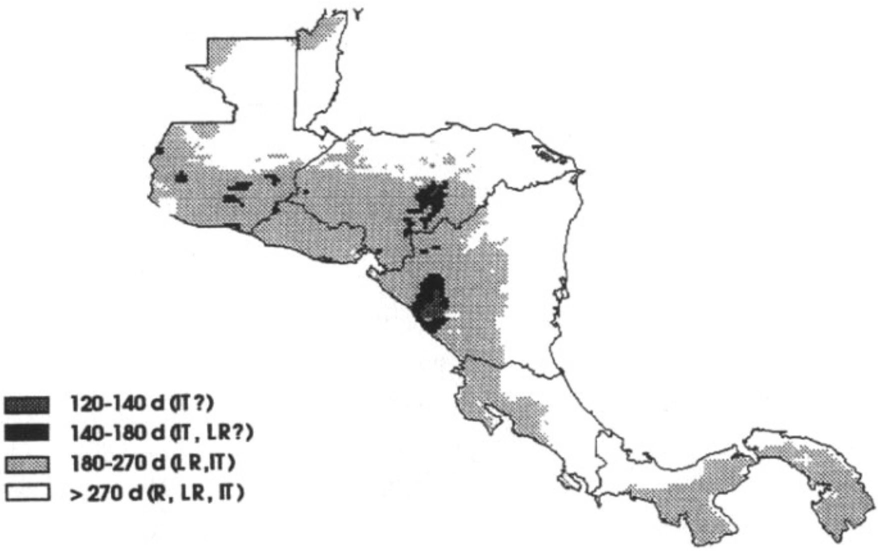

Figure 24. Growing season (days with precipitation exceeding evapotranspiration) and possibilities for legumes as a cover crop, Central America. Source: Adapted from Chapman and Barreto (1994). Note: IT, intercropping: LR, legumes in relay; R, rotation.

relatively easy access to land. Farmers in northern Honduras can allocate some land to the *abonera* system while still producing alternative crops on other lands. The analysis shows, however, that farm size is not an absolute limitation on adoption. Even farmers with very small land holdings (<2 ha) have adopted the *abonera* system on their own land while renting land for the production of first-season maize and other subsistence crops. This can often be done at low cost, as land-rich ranchers are interested in converting fallow land into pasture: through land-rental markets, land moves relatively constantly from fallow to crops to pasture and back to fallow again. The land-rich farmers benefit through these arrangements from the low costs of establishing pasture, and the land-poor farmers gain access to some farmland, thereby modifying local constraints on the availability of land.

A rental market for velvetbean fields allows even the landless to use the velvetbean technology. Farmers with more land than they can cultivate themselves divert some of it to *Mucuna* fields for rent or for use by family members. For landowners, an *abonera* improves land so that it can capture higher rents; farmers are willing to pay a premium of 60–70% for rights to cultivate maize on land planted to *Mucuna*. Thus, *abonera* land-rental markets facilitate landless farmers' use of the velvetbean technology.

In short, the role of land constraints on adoption of land-extensive systems such as the *abonera* system should be understood in the broader system of access to land, including various forms of land ownership and land-rental markets. The system affecting access to land, rather than individual farm size or land-tenure arrangements, is likely to be a determining factor in farmers' adoption of the velvetbean technology elsewhere.

How much of the success of the *abonera* system is due to labour-saving effects and how much the potential labour productivity will affect adoption elsewhere are unclear. Returns per unit of labour are significantly higher in the *abonera* system than in bush-fallow systems, but in our study labour constraints *per se* had no effect on adoption. All farmers, whether labour constrained or not, recognized and valued the labour advantages of the *abonera* system, especially savings in labour needed for land preparations and weed control. Farmers' accounts of early use of the *abonera* system in northern Honduras also suggest that these labour benefits initially attracted farmers to the velvetbean technology.

Weed invasion is a common problem, arising from the intensification of bush-fallow systems; *R. cochinchinensis* is spreading in northern Honduras and seems to have found a favourable environment in the *abonera* system. By contrast, evidence from Benin and Ghana indicates that *Mucuna* can control *Imperata cylindrica* — a noxious weed dramatically affecting crop productivity throughout the subhumid tropics of West Africa (Versteeg and Koudokpon 1990, 1993). The intensity of *Imperata* invasion is so great in the region that even land-constrained farmers are adopting *Mucuna* rotations to control it (Vissoh et al. 1997). This recent experience suggests that cover-crop systems such as the *abonera* system can play a role in places where labour productivity is low and declining.

Finally, relative prices of external inputs, particularly chemical fertilizers, are likely to have an influence on the feasibility of the *abonera* system elsewhere. The potential to substitute for chemical inputs the nutrients produced *in situ* by the velvetbean crop is a distinct advantage. Farmers in the *abonera* system can avoid the high costs of purchasing, transporting, and applying chemical fertilizers to remote maize fields on the hillsides of northern Honduras while maintaining good crop yields. As significant reductions in chemical-fertilizer costs in Honduras and elsewhere in Central America seem unlikely in the foreseeable future, this advantage will hold in most regional settings where smallholder agriculture dominates.

By contrast, evidence from Southeast Asia suggests that the cost of chemical fertilizers, which is low and declining relative to the price of grain (rice), has undermined the traditional use of green manures and cover crops and continues to create barriers to adoption of these practices (IRRI 1988; Fujisaka 1993). As noted in Chapter 1, sharply falling fertilizer prices in the southern United States during the 1940s contributed to the rapid decline in *Mucuna* use, as did price increases for competing crops (soybeans). These experiences indicate that market forces affecting the relative prices of external inputs (fertilizer) and crop outputs (maize) will play a key role in the rise or decline of *Mucuna*–maize associations.

Lessons for technology development

A number of lessons can be derived from farmers' experience in northern Honduras that are more broadly applicable to the development of sustainable agricultural technology in hillside environments. First, the production and maintenance of residues *in situ* have considerable potential to improve bush-fallow systems. The agronomic benefits of mulch (erosion and weed control, improved water balance, nutrient supply, shelter for biological life, alleviation of soil constraints) are not specific to northern Honduras or to the *abonera* system but are well documented elsewhere. Similar effects 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), and mulches composed of crop residues (Larson et al. 1972; Fukuoka 1978; Alberts and Neibling 1994; Schlather and Duxbury 1994; Schomberg et al. 1994).

Second, high-yielding cropping systems can be devised by taking full advantage of the spontaneous ecological processes at work in a given environment, in sharp contrast to technologies that greatly modify the crop environment with external inputs. Farmers wait until velvetbean dies naturally before slashing it and rely on spontaneous reseeding for *Mucuna* reestablishment. They also rely on the environmentally controlled decomposition of the velvetbean mulch to meet the nutritional requirements of maize. In short, the *abonera* system seems to mimic the functioning of a natural ecosystem, except that a crop is planted and harvested every year.

Third, farmers' having considerable control over the technological agenda leads to successful technologies. The usual constraints linked to the need for external capital, training, or complex information all but disappear in the case of the *abonera* system, as it relies heavily on farmers' local resources, past experiences, and empirical knowledge. Furthermore, farmers' direct experience of bush-fallow systems and knowledge of local ecosystems may have enhanced innovation with *Mucuna*. Farmers in northern Honduras understand the logic underlying the *abonera* system and appreciate its overall purpose and coherence. A process of technological innovation that builds on such understanding is more likely than otherwise to result in feasible and adoptable technologies.

Fourth, farmers are willing to use technologies with no immediate benefits if their short-term costs are low and their benefits are foreseeable. The direct costs of establishing an *abonera* (seed and labour) are low, and the first benefits are realized 1 or 2 years after establishment. Farmers can easily see that "something good is going on" in their fields, even by the end of the first year. Although various studies indicate that short-term benefits are especially important in motivating individuals and communities to adopt a new technology (Bunch 1982, 1993; Graf et al. 1991), low direct costs, combined with midterm benefits, may be sufficient conditions. This observation may be useful in research on agroforestry systems, many of which also lack immediate benefits.

Finally, agricultural innovations that respond simultaneously to several important constraints on system productivity have considerable potential for adoption. The *abonera* system is a multipurpose innovation, with a wide range of benefits, including improved soil fertility and conditions and reduced weed and pest populations. The combined and incremental effects of these benefits are substantial, although effects on a specific constraint (low soil fertility, for example) may not be equal to the potential impact of a more targeted input (such as chemical fertilizer). Much as agroforesters have come to recognize the need for multipurpose trees (Francis 1993), crop scientists may also need to pay more attention to multipurpose technologies in sustainable cropping systems. Such an approach contrasts with component technologies, such as the seed–fertilizer–irrigation complex of the Green Revolution (Byerlee and Hesse de Polanco 1986).

The quest for sustainability in hillside environments

The agronomic assessment of the sustainability of the *abonera* system is very favourable. The *abonera* system presents fewer risks of long-term land degradation from soil erosion or nutrient loss than other cropping systems in hillside environments. Complete soil protection against the erosive effects of heavy rains is provided by the *abonera* system, either by the living *Mucuna* crop or by the dead mulch left on the soil surface. Leaving aside the issue of landslides (Chapter 4), we found no evidence of soil erosion.

But the sustainability of the *abonera* system cannot be judged simply by its agronomic performance. Although the system is an efficient way to produce maize on the hillsides of northern Honduras, farmers' needs and aspirations exceed its current economic output. The *abonera* system has no built-in bias against income generation. The problem is that maize farming, even with relatively productive technology, cannot generate a significant cash income if only a few hectares are in production. Maize prices in Honduras are low as a result of policies that make up for shortfalls with imports and food aid from favoured areas such as the US grain belt. When all is said and done, maize farming falls short of providing households with resources above the bare minimum needed to survive. When questioned about aspirations for their children, the vast majority of farmers surveyed indicated that they do not want their sons and daughters to continue to be maize farmers. They see no future in it.

This desperate reality is reflected in the willingness of farmers to convert land from annual crops to pastures and plantation crops, if they can. As discussed in Chapter 2, rapid growth in regional demand for milk and beef products is driving the conversion of cropland to pastures. This is a potentially positive development for hillside farmers, as higher and less risky incomes can be realized from cattle ranching. Furthermore, well-managed pastures can be an ecologically sound land use in hillside environments, as they provide permanent ground cover. However, the capacity of most hillside farmers in northern Honduras to take advantage of these new opportunities and make use of appropriate technology is limited by poor access to capital, infrastructure, and technical assistance. Established and large-scale ranches can respond more quickly to new market opportunities, leaving the ranching newcomers struggling to make the transition. Qualitative evidence from the region suggests that large-scale ranchers residing in lowland communities are already acquiring the more accessible and better-quality land in the hillside zone (Humphries, in press; DB's field observations). Hillside pastures help them overcome seasonal constraints on grazing in the lowland areas (flooding), thereby increasing their dominance of the market for milk and ownership of land.

Further development of the cattle industry in northern Honduras is likely to have a significant impact on the cropping systems and livelihood strategies of hillside farmers. As noted in previous chapters, extensive pasture-management practices, common on the hillsides, rely on the sequential rotation of fallow land, crops, and pasture — a low-cost approach compatible with bush-fallow cropping patterns. When well-financed ranching operations establish permanent pastures on the best hillside land, this will reduce the availability of fallow land to poor farmers and increase the intensity of bush-fallow cropping systems. As these systems are already as intensive as they can be within the bounds of fallow-based agriculture, one can expect land degradation and a further decline in cropping-system productivity.

In the past, extensive pasture- and crop-management practices have supported active land-rental markets favourable to the land poor. The analysis of farm livelihood strategies in Chapter 3 indicates that many farmers rely on access to underutilized lands owned by ranchers and better-off households for growing maize and other subsistence crops important to household food security. Higher rents, following on reduced supply of fallow land, may threaten their already precarious access to land and undermine their livelihood strategies.

The impact of land conversion and concentration on the use of the *abonera* system is twofold. *Aboneras* may be converted directly to pastures by aspiring ranchers or sold by farmers seeking better livelihoods. Households with small herds of cattle (Chapter 7) appeared less likely than others to use the *abonera* system, as they relied more than large-scale ranchers on their own land resources for access to pasture. Sherwood (1997, p. 3), monitoring agricultural land use near Tela, Atlántida, in February 1997, noted that "entire mountainsides and much of the coastal lowlands once under maize–*Mucuna* cultivation are now converted to African palm production or pasture." He recounted the experience of a hillside farmer who converted much of his land to pasture and rented it to ranchers while maintaining some under the *abonera* system, only to sell all of it a few years later to an African palm-processing plant. He and his family moved in search of urban employment. Although further research is needed to confirm and explain these observations, they suggest that farmers' decisions regarding agricultural technology are strongly linked to livelihood objectives, not to the sustainability of a single component of their farming system.

Land conversion may also affect the use of the *abonera* system indirectly. Our analysis shows that the availability of land, through both ownership and land-rental markets, is an important factor influencing farmers' use of the velvetbean technology. Land-rich farmers adopt the *abonera* system, but so do land-poor farmers who establish *abonera* plots on their own fields while renting land from others for first-season maize and other crops. In these circumstances, the conversion of fallow land to permanent pasture has no direct affect on the *abonera* system but undermines the broader system of land use that allows farmers to keep land under velvetbean during the first season, when subsistence food crops must also be grown. For household food security, most hillside families rely on the production of some first-season maize in the bush-fallow system, a cropping cycle they will not forgo.

The dynamic and interdependent nature of factors affecting farmers' use of the *abonera* system underlines the delicate balance farm families must strike between food-security objectives and the desire for better livelihoods. Some farmers seem to be abandoning the *abonera* system because maintaining it would constrain the production of first-season maize and other crops they depend on for survival. Others seem to abandon the system because they see new opportunities to improve their livelihoods by switching, if they can, to other land uses. The search for sustainable agricultural practices clearly must reconcile these two legitimate concerns.

Exploring the limits of hillside agriculture

Farmers such as those on the north coast of Honduras have been far ahead of the scientific community in developing durable ways to farm difficult environments. The *abonera* system is one example. But rapid change in the farming systems and in broader economies calls for an acceleration in the pace of innovation and adaptation. The pressures on the land base mounting in northern Honduras represent an immediate and significant challenge to hillside agriculture and the families that depend on the fragile resource base.

Based on the results of this study, improvements in the *abonera* system seem feasible on several fronts, without causing a loss of the agronomic benefits it provides. Average maize yields could probably be doubled fairly easily if planting densities were increased from around 30 000 plants ha^{-1} at harvest to 40 000 or 50 000 plants ha^{-1}. This increase would probably also require that improved, shorter maize varieties be used — beyond 40 000 plants ha^{-1}, with the high fertility provided by the velvetbean system, severe lodging would affect present landraces.

The promotion of improved maize germplasm or hybrids in northern Honduras is a controversial issue. A shift in germplasm could imply a new dependency on commercial maize-seed suppliers and could result in the erosion of the genetic diversity conserved in the local landraces. Furthermore, smallholders in Mesoamerica have generally not benefited from advances in plant breeding because the improved germplasm also typically requires favourable growing conditions (available nutrients and water) rarely found on small farms without the application of chemical fertilizers, the chemical control of pests, and in some cases irrigation as well.

In the *abonera* system in northern Honduras, however, these constraints are partly lifted, as mineral nutrients and water are readily available and disease pressure on the maize crop is minimal during the second season. Evidence from various sources suggests, as well, that farmer-based plant breeding, seed selection, and seed distribution could go a long way toward enhancing the use of genetic diversity for the benefit of local populations (Sperling and Loevinsohn 1995; Witcombe et al. 1996).

The overall productivity of the *abonera* system could also be increased if farmers made direct economic use of the velvetbean crop. As noted in Chapter 1, velvetbean was grown extensively in the southern United States, initially as a forage crop for cattle and later for the seed, which was harvested and transformed into animal feed. Mules were also grazed on velvetbean fields in Guatemala by plantation owners. Farmers in northern Honduras have noted that cattle graze velvetbean fields, but this has always been considered a problem to be avoided because it interferes with the reestablishment of the velvetbean crop. With increasing demand for fodder, however, the use of *Mucuna* vegetation as forage could be explored. This research would also need to examine the potential negative impacts of grazing on management of the *abonera* system, soil cover, and soil compaction.

The collection and transformation of *Mucuna* seed into animal feed may have the greatest potential for increasing farm income and the lowest risk of undermining the agronomic benefits of the *abonera* system. As discussed in Chapter 1, *Mucuna* seed has been successfully integrated into animal diets, in combination with maize, especially for cattle. Experience with swine was less favourable in the United States, and recent research on the use of *Mucuna* feed for swine has been mixed (Flores et al. 1997). Further information is needed to assess the phytochemical and toxicological characteristics and processing potential of *Mucuna* because of the various toxic compounds in the seed (Awang et al. 1997). This research would also shed light on the potential of *Mucuna* seed for human consumption.

Perhaps the most important contribution of the *abonera* system to sustainable agriculture in northern Honduras is to the food security of hillside farm families and communities. Maize, a high-quality source of calories, is the key ingredient in rural diets. Our analysis shows that the *abonera* system can produce, in a small area and with relatively few risks, more than enough maize to meet the consumption needs of a typical household. Improvement in maize-storage technology is still needed, however, to control postharvest losses and ensure an adequate maize supply over the entire year.

Directed to food security instead of maize markets, second-season maize production with the *abonera* system could completely eliminate the need for first-season maize. This would free fallow lands for other purposes, including food crops or cash crops. Currently, the most prominent of these alternatives is the production of raw milk or value-added milk products, such as cheese. But the hillsides of northern Honduras are also suitable for perennial tree crops, such as achiote, cacao, coffee, and a wide range of tropical fruits in demand both in nearby urban centres and elsewhere. The region supported a timber industry at one time and could once again supply specialty markets with high-value tropical woods (see PDBL 1991). These kinds of activities might contribute to income generation more efficiently than even the most productive and intensive maize-cropping system.

Enhancing the income and profitability of small-scale production systems through cash-crop diversification has been a central thrust of numerous development projects throughout Central America, with mixed results (Tucker 1992; Stonich 1993). The lessons learned from these experiences suggest that cash-crop production entails considerable risk because of high start-up costs, significant price swings for outputs, and relatively high and stable input costs. Specialty crops are also extremely vulnerable to rapid market saturation resulting from more and more farmers switching over to the most-profitable crops. Furthermore, smallholders in fragile environments typically have no sustainable production technologies to use with these crops, which increases the risk of environmental degradation. Thus, although diversification strategies merit attention, the social costs created by indiscriminate intensification could be much greater than the gains from higher levels of agricultural output.

Our analysis of the *abonera* system suggests that the development of sustainable cropping systems in hillside environments cannot rest on their agronomic merits or even on their productivity. Agriculture in northern Honduras is extremely dynamic, stemming from processes of land concentration, shifting land uses, declining maize markets, and migration. The institutions and policies dictating access or entitlements to resources favour large-scale ranching and plantation operations on the coastal plain and increasingly on the hillsides as well. Very few public or private resources are available for technical and financial support of small-scale producers. These factors inform smallholders' perceptions of livelihood options and constrain their capacity to invest in resource-conserving technologies.

When closely examined, the concept of sustainability captures more of an attitude toward issues of economy and the environment than an actual set of practices or analytic framework. The analysis of problems and of the chains of causality remains fairly underdeveloped. Prescriptive attitudes, however, provide little guidance for the strategic decisions that governments, farmers, researchers, and development workers must make to manage land responsibly. Solutions to the dilemma of hillside agriculture in northern Honduras will have to address, in one way or another, some fundamental questions: Why have farmers migrated to fragile areas in the first place? Who designs and benefits from regional development policies? What social policies and investments are needed to attain the goals of sustainable development? Without the concerted efforts of the Honduran government and civil society to modify current patterns of development, it seems uncertain whether widespread use of the *abonera* system will continue.

APPENDIX I

FARM-SURVEY METHODS

With few exceptions, noted in the text, the farm-survey data reported in this book were drawn from a 1992 survey of households in the municipalities of Tela and Jutiapa, department of Atlántida. From a list of all hillside communities in these two municipalities, developed in consultation with the Secretaría de Recursos Naturales (secretariat of natural resources), 16 were selected at random, with the chance of selection being in proportion to the population of the community. A 1988 village-level health census provided the names of heads of households and data on family size for each of these villages; 130 households were then randomly selected for inclusion in the survey. An additional requirement for a household's being selected was that its members had to have planted maize during the 1992 winter cycle or the previous summer cycle. This requirement was in keeping with the survey's focus on maize-production practices but may also have been a source of bias against the selection of households engaged mainly in nonagricultural activities. With this exception, the sample, reduced later to 126 households with complete data, can be considered as providing a reasonable reflection of hillside households in northern Honduras. The 16 communities were Piedras Amarillas, La Danta, Los Olanchitos, Aguacate Línea, El Cantor, El Naranjo, Descombros, Las Delicias, El Paraíso, Pueblo Nuevo, and Santa Fe, in the municipality of Jutiapa; and San Francisco de Saco, Planes de Hicaque, Las Metalias, Los Laureles, and El Zapote, in the municipality of Tela. A 1990 survey of 133 farmers, also reported here, followed a similar sampling procedure. The 25 villages included in that survey were drawn randomly, with the chance of selection in proportion to the population of the village, from a list of hillside villages in all eight municipalities of the department of Atlántida.

The survey questionnaire was tested and revised; enumerators were trained during a 3-d workshop; and each questionnaire was reviewed by the coordinators of the survey at the end of each day. The survey was completed over 3 weeks, coded, and subsequently entered into a spreadsheet for analysis. Inconsistencies in the data were cross-checked until it was felt that the quality of the information was satisfactory. An initial report was produced from the data (Buckles et al. 1992).

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APPENDIX II
VISUAL AIDS

Figures 25A–E were used to discuss with farmers the advantages of the *abonera* system; Figures 25F–H, the disadvantages.

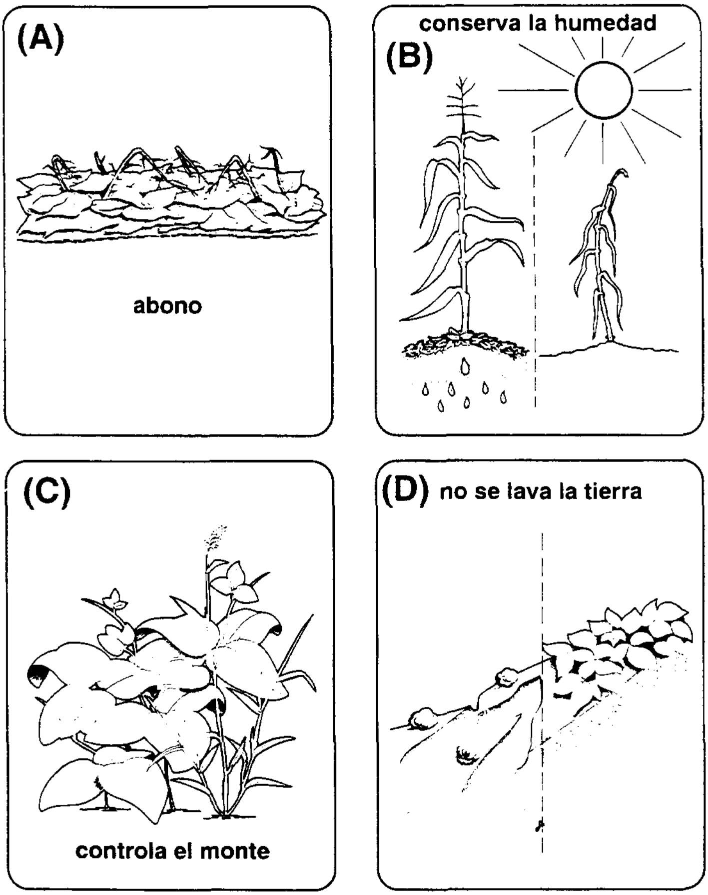

Figure 25. These illustrations convey the following messages: (A) fertilizes; (B) conserves soil moisture; (C) controls weeds; (D) prevents erosion *(continues)*

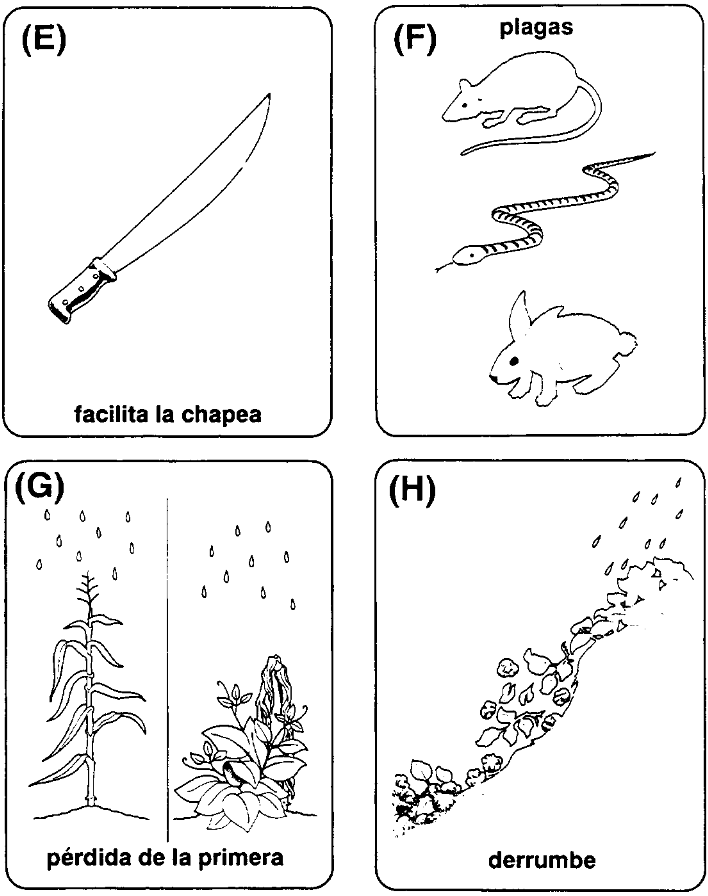

Figure 25. *Concluded.* (E) Slashes down easily; (F) harbours snakes and rodents; (G) involves the loss of first-season maize; (H) carries the risk of landslides.

APPENDIX III

MATERIALS AND METHODS USED TO COLLECT THE AGRONOMIC DATA

Chronosequence approach

Field selection

Independent chronosequences were constructed for each of four villages (San Francisco de Saco, Rio Cuero, Las Mangas, and Piedras Amarillas). To minimize variability not related to field history, care was taken to select neighbouring 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. Furthermore, it was decided not to work at the scale of whole fields (Milleville 1972; Moormann and Kang 1978) but to focus on small, uniform observation plots (10 m × 10 m) selected on linear-backslope topographical positions, thus avoiding variability associated with topographical position, as well as the typical within-field heterogeneity induced by farmer's management (Hall and Olson 1991; Milleville 1972, 1976). The representativeness of the chemical properties of backslope positions was nevertheless examined by comparing them with those measured for a number of footslopes and shoulder positions of four fields, which showed no systematic differences for any positions. Slope in the observation plots was kept as much as possible within the range of 25–70%, representing the most typical conditions under which farmers grow maize on the hillsides.

The range of field–plot ages explored by each chronosequence depended on the particular village: only at one site (San Francisco de Saco) did the chronosequence include fields as old as 15 years. Conversely, another site (Rio Cuero), the oldest field, had been no more than 7 years in the *Mucuna* rotation.

Reconstitution of field history

Dating of the individual fields making up the chronosequence was facilitated by the fact that the *abonera* system had been adopted fairly recently by the farmers of northern Honduras (see Chapter 1). Hence, although no written records had been kept of the farmers' adoption of the system, it was possible to use farmers' oral recollections about when they had introduced the *Mucuna* rotation in their fields. Despite the constraints of oral history, it has been recognized as a valid methodological approach for investigating contemporary events, especially if written evidence is scarce (Dunaway and Baum 1984).

Four villages with at least 5 years of use of the *abonera* system were selected along an east–west transect, representing a broad range of agroecological and socioeconomic conditions typical of the Atlantic littoral region. In each of the villages, individual interviews were conducted with farmers whose fields spanned the entire range of adoption dates detected during the collective interview. Check fields (no adoption of the *abonera* system but planted to a winter-cycle maize crop in a maize–fallow rotation) were included in each village to provide a basis for comparisons with the *Mucuna* fields. Cropping history was reconstituted, starting with the rotation fallowed before the adoption of the *abonera* system and going as far back as the last significant fallow period preceding adoption, whenever possible. Cropping history was carefully scrutinized for disqualifying events, those that 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). Also, particular care was taken to detect within-field heterogeneity in the history, leading the way to the independent sampling of several plots within the same field, whenever appropriate. At the end of the 2-year field study, a second historical survey, both collective and individual, was conducted in most of the fields of the four villages to cross-check the results of the initial surveys and to fill information gaps about various aspects of the *abonera* system, including changes in management that might have taken place with the increase of time spent in the rotation.

Agronomic surveys

Agronomic surveys focusing on the maize cycle were conducted during 2 consecutive years (year 1, winter 1992/93; year 2, winter 1993/94) in the four villages 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.

In three of the villages, 10–20 farmers' fields were selected; in San Francisco de Saco, 35. These fields were not selected randomly, as the major criterion for selection was time spent in the *Mucuna*–maize rotation (see above). Two small (10 m × 10 m) observation plots, systematically located on linear-backslope positions within each field (not the fields), represented the basic observation units on which all data analysis was made, unless otherwise specified.

The data-collection protocol common to all four villages included data on farmers' practices, *Mucuna* biomass (year 2 only for all sites except San Francisco de Saco), yield and yield components, and soil chemical properties. Farmers' practices (dates of main operations, quantities and type of inputs used, and rating of the success of the operation) were established at the field level by interviewing the field owners. In addition, a recapitulative survey of fields' cropping histories and 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.

Evaluation of *Mucuna*-biomass accumulation

In each village, the aboveground total biomass was determined by harvesting two to four quadrats (2.25 m^2 each) per observation plot just before the slashing (December of each year). Total biomass was separated into various fractions, easily recognizable by sight: green *Mucuna*, live-weed material, and litter (this being simply all dead organic matter, whatever its stage of decomposition). In December 1993 and 1994, further subcategories were made for pods and vines, respectively. It should be noted that easily recognizable pieces of maize stover (from the previous maize cycle) were systematically excluded from the sampling process, owing to an initial (unwarranted) assumption that only neoformation of litter during the *Mucuna* cycle was important for understanding cycling processes: this methodological flaw probably brings about an average underestimation of aboveground biomass of roughly 0.5–1 t dry matter ha^{-1}. This omission is rather insignificant in terms of N (about 1% or less of the total N).

Additionally, a periodic assessment of *Mucuna*-biomass accumulation and decomposition was conducted at San Francisco de Saco from October 1993 to May 1994 in a small number of plots.

Monitoring of inorganic-nitrogen dynamics during the maize cycle

Periodic monitoring of inorganic N in the soil profile was done in most check plots (without fertilizer application) of the fertilizer trials at San Francisco de Saco only. In 1992/93, sampling started in December and ended in April (7 sampling dates altogether), whereas in 1993/94, it started in October and ended in June, for a total of 11 sampling dates. Samples were taken from three depths — 0–10 cm (0–15 cm in 1992/93), 10–30 cm (15–30 in 1992/93), and 30–60 cm — and extracted with 2*M* Kcl. The extracts were analyzed colorimetrically for both NO_3 and NH_4 at Cornell University after the experiment.

Fertilizer farm trials

Simple, replicated farm experiments were set up to study the effect a single, moderate dose of urea-N (50 kg ha^{-1}) applied 40 d after planting in well-established *Mucuna* fields had on the yield compared with the yield obtained solely on the basis of nutrients provided by the decomposing *Mucuna* litter. The trials were conducted during two consecutive cycles and included a total of 14 fields, 11 of which were clustered close to each other at one site (San Francisco de Saco); the other 3 were at another site more than 160 km east of the first (Las Mangas, 1993/94 only). Data losses due to heavy wind damage were important the first year. In 1993/94, 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, losses caused by *Phyllophaga* spp.) made it necessary to use plant density as a covariable in the analysis of variance (Neter et al. 1985). Also, missing data (1992/93) and slight imbalances in design (1993/94) made it necessary to use type III sums of squares on SAS (Littel et al. 1991).

Soil-fertility measurements

Chemical properties and soil organic matter

Composite samples (12–15 subsamples) were taken from every observation plot at each of the four sites from three depths: 0–10, 10–30, and 30–60 cm. All these samples were analyzed for pH, P, Al, exchangeable bases and micronutrients, and exchangeable acids in the Cornell Nutrient Analysis Laboratory. Additionally, all 0- to 10-cm 1993 or 1994 samples and a subset of the 10- to 30-cm samples were analyzed for organic C, total N, and stable isotopes (^{13}C, ^{15}N) by a Europa Scientific Corporation Roboprep™ C–N analyzer coupled to a Tracermass™ mass spectrometer (Europa Scientific, Crewe, Cheshire, United Kingdom). Also, organic-C (Walkey and Black) distribution in the soil profile was determined on composite samples from 36 observation plots (17 fields) collected at 2.5 cm increments, up to 15-cm depth, at San Francisco de Saco.

Physical properties

Infiltration in seven fields, covering the entire chronosequence at San Francisco de Saco, was measured using portable rainfall simulators–infiltrometers calibrated to deliver a constant 100 mm h^{-1} on an area 25 cm × 25 cm (Ogden et al. 1997). Eight positions were selected in each field (four backslopes, four shoulders); for each position, infiltration was measured in a pair-wise fashion, with and without mulch.

Macroporosity was determined for the same fields and positions, using a sand-table methodology (Ball and Hunter 1988; Topp et al. 1993). The undisturbed cores used for this study (6.7 cm diameter × 7.5 cm height) were collected from two depths — 1–8.5 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 h at 110°C (Blake and Hartge 1986).

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APPENDIX IV

MODEL SPECIFICATIONS AND CROP BUDGETS FOR THE PROBABILISTIC COST–BENEFIT ANALYSIS

Maize-production technology

As noted in Chapter 3, maize-production technology in northern Honduras is relatively uniform. With the few exceptions noted below, there are no important differences between the maize-production technology used in the bush-fallow system and that used in the *abonera* system. Seasonal differences in maize-production technology are also minimal (Buckles et al. 1992).

The maize-production technology specified for the simulation model is described in Chapter 2 and summarized in Table 52. To avoid exaggerating costs in the bush-fallow system, we calculated annual budgets (Table 53) in the simulation with no fertilization, although the farm survey had indicated that a large proportion of farmers apply fertilizer-N to second-season maize in the bush-fallow system. This is in keeping with the customary practice in cost–benefit analysis of judging the current practice (in our case, the bush-fallow system) under the best

Table 52. Maize-production technology in the first and second cropping seasons, northern Honduras, 1992.

	Cropping season [a]	
	First	Second
Land preparation	Slash and burn (69)	Slash (94)
Type of seed	Local (72)	Local (65)
Plant density (number of seeds ha^{-1})	41 000	44 000
Weed control (number of controls)	2 (60)	2 (70)
Fertilizer application	No (71)	No (56)
Doubling maize before harvest	Yes	No
Harvest	Manual (100)	Manual (100)

Source: Buckles et al. (1992).
[a] Values in parentheses correspond to percentage of surveyed farmers.

Table 53. Crop budgets: annual budgets for growing maize under the *abonera* and the bush-fallow systems, using mean values of the random variables (maize yield and input–output prices).

	Costs and benefits by system (USD ha^{-1})	
	Abonera	Bush fallow
1st year (implantation)		
1st season		
Land preparation		
1. Cutting and burn	37.20	37.20
Planting maize		
2. Seed	1.81	1.81
3. Labour	9.30	9.30
Weed control		
4. 1st manual weeding	23.25	23.25
5. Gramoxone™ (2nd chemical)	7.12	7.12
6. Labour to apply herbicide	4.65	4.65
Total costs (excluding land and labour)	87.50	87.50
Cost of capital	4.17	4.17
Total costs (excluding land)	86.04	86.04
Maize yield	1 394.00	1 394.00
Maize field price	0.08	0.08
Gross benefits	117.10	117.10
Net benefits, 1st season	29.60	29.60
2nd season		
Land preparation		
1. Cut	22.32	22.32
Planting maize		
2. Seed	1.52	1.52
3. Labour	9.30	9.30
Weed control		
4. 1st manual weeding	20.46	20.46
5. Gramoxone™ (2nd chemical)	7.12	7.12
6. Labour to apply herbicide	4.65	4.65
Planting *Mucuna*		
7. *Mucuna* seed	3.31	—
8. Labour to plant *Mucuna*	9.11	—
Total costs (excluding land and labour)	77.98	65.37
Cost of capital	3.90	3.27
Total costs (excluding land)	81.88	68.64
Maize yield	1 413.00	1 413.00
Maize field price	0.11	0.11
Gross benefits	150.13	158.96
Net benefits, 2nd season	68.25	90.32
Total net benefits, 1st year	**97.85**	**119.92**

(continues)

Table 53. *Continued.*

	Costs and benefits by system (USD ha^{-1})	
	Abonera	Bush fallow
2nd year		
1st season		
Land preparation		
1. Cut and burn	—	22.32
Planting maize		
2. Seed	—	1.81
3. Labour	—	9.30
Weed control		
4. 1st manual weeding	—	23.25
5. Gramoxone™ (2nd chemical)	—	7.12
6. Labour to apply herbicide	—	4.65
Total costs (excluding land and labour)	0.00	68.45
Cost of capital	0.00	3.42
Total costs (excluding land)	0.00	71.87
Maize yield	—	1 394.00
Maize field price	—	0.08
Gross benefits	0.00	117.10
Net benefits, 1st season	0.00	45.22
2nd season		
Land preparation		
1. Cut	18.60	22.32
Planting maize		
2. Seed	1.52	1.52
3. Labour	9.30	9.30
Weed control		
4. 1st manual weeding	16.74	20.46
5. Gramoxone™ (2nd chemical)	7.12	7.12
6. Labour to apply herbicide	4.65	4.65
Total costs (excluding land and labour)	57.93	65.37
Cost of capital	2.90	3.27
Total costs (excluding land)	60.83	68.64
Maize yield	1 413.00	1 413.00
Maize field price	0.11	0.11
Gross benefits	150.13	158.96
Net benefits, 2nd season	89.30	90.32
Total net benefits, 2nd year	**89.30**	**135.54**

(continues)

Table 53. *Concluded.*

	Costs and benefits by system (USD ha^{-1})	
	Abonera	Bush fallow
3rd to 5th year		
2nd season		
Land preparation		
1. Cut	18.60	—
Planting maize		
2. Seed	1.52	—
3. Labour	9.30	—
Weed control		
4. 1st manual weeding	16.74	—
5. Gramoxone™ (2nd chemical)	7.12	—
6. Labour to apply herbicide	4.65	—
Total costs (excluding land and labour)	57.93	—
Cost of capital	2.90	—
Total costs (excluding land)	60.83	—
Maize yield	2 387.00	—
Maize field price	0.11	—
Gross benefits	253.62	—
Net benefits, 2nd season	192.79	0.00
Annual net benefits	**192.79**	**0.00**
6th year		
2nd season		
Land preparation		
1. Cut	18.60	—
Planting maize		
2. Seed	1.52	—
3. Labour	9.30	—
Weed control		
4. 1st manual weeding	16.74	—
5. Gramoxone™ (2nd chemical)	7.12	—
6. Labour to apply herbicide	4.65	—
Harvest wood	—	100.44
Total costs (excluding land and labour)	57.93	100.44
Cost of capital	2.90	5.02
Total costs (excluding land)	60.83	105.46
Maize yield	2 387.00	—
Maize field price	0.11	—
Wood yield	—	200.00
Wood price	—	1.22
Gross benefits	253.62	243.33
Net benefits, 2nd season	192.79	137.87
Annual net benefits	**192.79**	**137.87**

Note: USD, United States dollars.

Table 54. Technical coefficients for maize under different cropping systems and seasons, northern Honduras.

	Unit ha^{-1}
Labour for slashing, *guamil* (person–day)	20.0
Labour for slashing, *guatal* (person–day)	15.0
Labour for slashing, first season (person–day)	12.0
Labour for slashing, *abonera* (person–day)	10.0
Maize seed (kg)	14.5
Labour for sowing, maize (person–day)	5.0
Mucuna seed (kg)	14.0
Labour for sowing, *Mucuna* (person–day)	5.0
Gramoxone™ chemical weeding (L)	2.0
Labour for applying Gramoxone™ (person–day)	2.5
Labour for manual weeding, *abonera* (person–day)	9.0

Note: *Guatal* is a field left unused, for natural regrowth, for a period of 3 or fewer years. *Guamil* is a field left unused, for natural regrowth, for a period of about 5 or more years.

possible conditions. The costs associated with the management of the velvetbean crop after the first year are negligible and were consequently ignored in the simulation. The technical coefficients used in the simulation are presented in Table 54.

Maize yield

Maize yield in northern Honduras is very unpredictable because of rainfall variability from season to season and from year to year. Yield is consequently the main source of income uncertainty faced by maize farmers, an important consideration in the analysis of the economics of alternative cropping practices. In Chapter 5, the impact of the *abonera* system on maize yield relative to the bush-fallow system was examined in detail, highlighting the higher than average yields and the reduction in yield variability. This effect arises mainly from the control of drought stress in maize made possible by the contribution of the velvetbean mulch to the conservation of soil water.

To capture the variability of maize yield, we estimated the cumulative distribution function (CDF) for maize yield. Table 55 shows the summary statistics for first- and second-season maize yields reported by farmers for the 1991/92 agricultural year. These data, based on the farm survey, are the most complete and comprehensive source of yield information available from the region.

Table 55. Main statistics for maize-yield distribution under different seasons, northern Honduras, 1991/92.

	Maize yield for different seasons (kg ha^{-1})		
		Second	
	First	Without *abonera*	With *abonera*
Mean	851.00	1007.00	1498.00
SD	509.00	742.00	954.00
Coefficient of variation	0.60	0.74	0.64
Minimum	209.00	201.00	201.00
Maximum	2 667.00	3 978.00	4 546.00
Average 25% worst	313.00	363.00	486.00
n	104	47	63

Source: Buckles et al. (1992).
Note: SD, standard deviation.

Comparison of the farm-survey yield data with other yield measures taken in the region suggests that the estimated average yields from the 1992 survey may be considerably below normal. Table 56 shows that the values for mean maize yield from four other sources were consistently above that found in the farm survey. For example, the average yield for second-season maize grown in the abonera system estimated by the four additional sources was 2 645 kg ha^{-1}, which is well above that in the farm survey. This difference may be due to underreporting of yield by farmers (a common limitation in farm surveys), or the drought in the region in 1991, or both.

Despite this discrepancy between the 1992 farm survey and other data sources, the estimate of yield variability faced by farmers in the farm survey seems correct. The coefficient of variation (see Table 55) for second-season maize grown in an *abonera* (r^2 = 0.64) is much smaller than for second-season maize grown without the *abonera* system (r^2 = 0.74), a tendency consistent with similar comparisons made in other regions. Mausolff and Farber (1995) reported trials in central Honduras in which the coefficient of variation of maize yield was 0.47 with the *abonera* system; 0.67, without. As could be expected, the coefficient of variation for first-season maize (r^2 = 0.60) is smaller than for second-season maize under either system, possibly as a result of the much lower variability of rainfall during the first season. Although the farm survey gave an estimate of yield mean that was lower than normal, the data seem to provide a valid basis for estimating yield variability.

Table 56. Average maize yields by system and season according to different sources of information, northern Honduras, 1985–93.

	Maize yield (kg ha^{-1}) for different seasons								
				Second					
	First			Without *abonera*			With *abonera*		
Source	Mean	SD	Observations (*n*)	Mean	SD	Observations (*n*)	Mean	SD	Observations (*n*)
1985/86 verification trials [a]	1 662		8						
1989 informal survey [b]				1 472		11	2 622		23
1991 informal survey [c]	1 668		7				2 638		9
1992 informal survey [c]				1 413		7	2 340		8
1992 formal survey [d]	851	509	90	1 007	742	47	1 498	954	63
1992/93 field sampling [e]						6	2 835		46

Note: SD, standard deviation.
[a] On-farm research experiments, 1985/86.
[b] Licona (1987).
[c] Avila Nájera and López (1990).
[d] Buckles (1992).
[e] Triomphe (1996); field observations.

A two-step procedure for estimating CDF for the three different ways that maize can be grown in northern Honduras was used to compensate for the limitations in the available data. The procedure builds on the maize-yield variability provided by the farm-survey data and incorporates the additional information provided by the four other available data sources (see Table 56). In the first step, we used data from the farm survey to estimate a base CDF for each maize-cropping practice. In the second step, we used additional yield data from other sources to adjust the CDF estimated in the first step.

- *Step 1: Building the basic CDF* — A theoretical distribution was fitted to the data from the farm survey. Results showed that the probability distribution that best fit the data was the lognormal distribution function.[6] This function is defined by two parameters: the mean and the standard deviation. Table 57 shows the values of these parameters before any transformation.

- *Step 2: Incorporating additional information* — To correct for the apparent underestimate of yield levels in the farm survey, we scaled up the yield mean of the lognormal distributions identified in the previous step while preserving the variability around it. The mean yield was scaled up by a specified factor, and the standard deviation was adjusted to preserve the coefficient of variation. The new mean was estimated by calculating the average of the mean yield from all available sources of information.[7]

Table 57 shows the results of the transformation. According to the new parameter values, the mean yield of maize in an *abonera* system is almost double that obtained from second-season maize without the *abonera* system or that obtained in the first season. This is consistent with the common perception of yield

[6]The lognormal distribution is commonly used to represent random variables that are the product of a large number of other unknown variables. Like the normal distribution, it is characterized by two parameters — the mean and the standard deviation — but unlike the normal distribution, only positive numbers are allowed in its domain.

[7]We attempted several weighting procedures, using the number of observations as a base to build the weights, with no satisfactory results. The main reason for this lies in the uneven structure in the number of observations for each system from the different data sources. For example, the weight derived from the farm survey varies from 42% in the case of maize in an *abonera* system to a high of 94% in first-season maize.

Table 57. Transformed yield mean and standard deviation for maize grown in different seasons and cropping systems.

	Parameters (kg ha^{-1}) of the lognormal probability distribution (mean [SD])	
	Before transformation	After transformation
Yield, first-season maize	851 (509)	1 394 (834)
Yield, second-season maize without *abonera*	1 007 (742)	1 413 (1041)
Yield, second-season maize with *abonera*	1 498 (954)	2 387 (1520)

Note: SD, standard deviation.

differences noted by farmers, researchers, and extension agents familiar with the technology, as well as being consistent with findings of measured estimates (Avila Nájera and López 1990; Mausolff and Farber 1995).

The analysis assumes that the effects of the *abonera* system on maize yields start in the second year after velvetbean has been introduced and that yields remain constant over subsequent years. As noted in Chapter 4, in the first year (establishment), velvetbean is sown at maize flowering and consequently does not have any significant detrimental (or positive) impact on maize yields. Maize yields do seem to increase gradually over subsequent years, but for simplicity and with a view to judging the *abonera* system conservatively, we assumed a constant yield over the remainder of the 6-year cycle.

Farm prices

Prices the farmers received for their products and paid for their inputs and services are also subject to considerable variability arising from market forces of supply and demand and from economic policies used to modify the economic environment of farmers. Prices consequently constitute an important source of uncertainty for the farmers' household incomes.

To analyze the past performance of farm-level prices for maize and for the main production inputs, we first deflated nominal prices in lempiras by using the Consumer Price Index, with a base in 1985, and then converted to United States dollars, using the official exchange rate. As can be seen in Table 58 — showing the results of this transformation — real prices for maize and for the main inputs and services declined steadily during 1980–91, with sharp declines in 1990 and 1991. This long-term downward trend is the result of structural-adjustment programs in Honduras.

Table 58. Real prices of maize and main inputs and labour used in maize production, Atlantic coast of Honduras, 1980–91.

	Prices				
	Inputs and labour		Maize (USD kg^{-1}) [a]		
	Gramoxone™ (USD L^{-1})	Labour (USD d^{-1})	Annual	First season	Second season
1980	7.56	3.90	0.18	0.15	0.19
1981	10.27	3.67	0.16	0.13	0.16
1982	9.80	3.09	0.17	0.14	0.18
1983	8.61	2.93	0.17	0.14	0.17
1984	7.79	2.67	0.14	0.12	0.15
1985	7.13	2.50	0.16	0.14	0.17
1986	6.85	2.76	0.17	0.14	0.17
1987	6.19	2.62	0.17	0.14	0.17
1988	5.92	3.20	0.16	0.13	0.17
1989	7.33	1.99	0.16	0.13	0.17
1990	4.24	0.78	0.08	0.07	0.08
1991	4.06	0.52	0.14	0.12	0.15

Note USD, United States dollars.
[a] First- and second-season prices were calculated by weighting annual maize prices, using a seasonal index of −15 and +5%, respectively.

Another important characteristic of maize prices in Honduras is seasonal fluctuation, described in Chapter 2. Maize prices at the farm gate were calculated by adjusting the annual farm prices by the seasonal indexes: +5 and −15% for the second season and the first season, respectively. Field prices were estimated by weighting down the farm-gate price by harvest and transport costs. These amounted to 25% of the farm-gate price in the first season; 20%, in the second season with the *abonera* system; and 15%, in the second season without the *abonera* system. These differences reflect differences in the labour costs for doubling the maize in the first season and collecting the ears with *Mucuna* in the field.

Maize-seed prices for local varieties were estimated using opportunity costs; that is, second-season farm-gate prices were used as seed prices for planting first-season maize and vice versa.

We introduced price uncertainty into the simulation by assuming that prices follow a uniform CDF, with the maximum and minimum prices chosen from maximum and minimum values achieved during 1987–91. (The initial year chosen was 1985, as it can be considered the commencement of the structural-adjustment

Table 59. Probability distributions of the prices used in the simulation.

Variable	Probability distribution (parameters) [a]
Price of maize first season (USD kg^{-1})	Uniform (0.07, 0.14)
Price of maize second season (USD kg^{-1})	Uniform (0.08, 0.17)
Price of Gramoxone™ (USD L^{-1})	Uniform (4.06, 7.33)
Price of labour (wage) (USD person–day^{-1})	Uniform (0.52, 3.20)

Note: USD, United States dollars.
[a] For the uniform distribution, the parameters are the minimum and maximum values.

program in Honduras.) All prices in that range have the same probability of coming out in the simulation. This is consistent with the price-band scheme adopted by Honduras to stabilize internal prices for agricultural products. According to this scheme, the government establishes maximum and minimum prices (band limits) for the products of interest, based on the past variation in international prices. Supply and demand (trade) determine the internal price for the product within the band limits, but the government keeps prices within the band limits by regulating the import and export markets. Prices are linked to allow the simulation to draw the same price for the same season. Table 59 summarizes the probability distributions of the prices used in the simulation.

An output of the bush-fallow system that also needs to be priced for the simulation is the firewood produced during the fallow period. After 4 years of fallow, a significant amount of firewood can be collected and sold on the market, although access to firewood markets varies considerably within the region, depending on proximity to major urban centres. In this analysis, the level of production is assumed to be 200 *cargas* (a *carga* is a local unit of measurement, equivalent to about 50 pieces of firewood) over the 4-year fallow period. The average price for firewood in 1992 (based on an informal survey) was used as a nonrandom variable, as the lack of systematic data precluded an estimation of probability distribution for this variable. Finally, a discount rate of 10% per annum was assumed, in keeping with the average real rate of interest in Honduras during 1985–91.

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APPENDIX V

ACRONYMS AND ABBREVIATIONS

asl	above sea level
CBA	cost–benefit analysis
CDF	cumulative distribution function
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (international maize and wheat improvement centre)
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement (centre for international cooperation on agronomic research for development)
DM	dry matter
IDRC	International Development Research Centre
IIA	International Institute of Agriculture
LUI	land-use intensity
N_i	inorganic nitrogen
NPV	net present value
SOM	soil organic matter
SRN	Secretaría de Recursos Naturales [Honduras] (secretariat for natural resources)
USD	United States dollars
USDA	United States Department of Agriculture

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