



Restoring the Soil

**A Guide for Using Green Manure/Cover Crops to Improve
the Food Security of Smallholder Farmers**

Roland Bunch



Praise for *Restoring the Soil*

Hundreds of thousands of small farmers in many countries are using, experimenting with, and sharing green manure/cover crops, thereby reducing fertilizer use while improving the sustainability of crop production systems. Restoring the soil by using these technologies to feed food-insecure people will have a tremendous impact on improving global food security. Roland Bunch brilliantly shows how green manure/cover crops can best be used to achieve these objectives.

—*Elmer Lopez Rodriguez*
Secretary of Agrarian Affairs
Government of Guatemala

Roland Bunch's book on cover crops and green manures could not have come at a better time. Decades of experimentation and experience by farmers, technicians and scientists are presented clearly and practically, making this work an essential contribution not just for world food security but for the food sovereignty of the 2 billion smallholders who produce the bulk of the world's food.

—*Dr. Eric Holt-Gimenez*
Executive Director
Food First/Institute for Food and Development Policy

Roland Bunch's book distills for us decades of rich field experience in countries all around the world, where millions of farmers have given practical meaning to the concept of synergy. Farmers are doing this by growing a great number of crops in intelligent and profitable association with a huge variety of green-manure/cover-crop plants. These marvelous plants enrich the soil at the same time that they enhance crop yields, conserve soil moisture, and save farmers' labor. Thanks to Bunch's keen observations, systematic analysis and critical thinking, this agroecologically-based strategy is now accessible to anyone who will read, digest and apply what is in this book. It fills a huge gap in our published knowledge about how to make the most of our land, labor and water for meeting our food needs in sustainable ways.

—*Dr. Norman Uphoff*
Professor of Government and International Agriculture
Cornell University

A timely and extremely valuable book from one of the world's leading experts on green manures/cover crops. Clearly written, it is both practical and analytical, and richly illustrated with photographs from a great number of agroecosystems worldwide. Highly recommended.

—*Dr. Jules Pretty*
Author of Regenerating Agriculture
University of Essex

This is the book we have been waiting for. *Restoring the Soil* distils and condenses a lifetime of learning and a wealth of experience. It is a wonderful source of knowledge and advice about a vital and neglected area of huge potential, a treasure trove for small farmers around the world and those who work with them. Only Roland Bunch with his lifetime of learning and his unique worldwide experience could have written this. *Restoring the Soil* should have a major impact, widening farmers' choices and enhancing their sustainable production. It is practical, accessible and wide-ranging across an astonishing variety of green manures/cover crops. Let me hope that it will be widely available in several languages, and widely used.

—*Dr. Robert Chambers*
Institute of Development Studies
University of Sussex

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the Food Security of Smallholder Farmers**

Roland Bunch

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Preface

As world population numbers tick ever higher, ensuring that food production keeps pace is one of the biggest challenges facing humanity. Large-scale agriculture will provide part of the solution, but smallholder farmers (farmers in developing countries who often have limited land and capital, are poorly linked to markets and are vulnerable to risks) will also play a vital role in feeding the next generations.

Millions of smallholder farmers around the world, however, are facing a serious soil fertility crisis, and many of these families also suffer from food insecurity. Soil infertility and erosion losses in many regions of the world are standing in the way of increased food production and improved livelihoods for many smallholder farmers. Maintaining, and in many cases recovering soil fertility, has become a major challenge facing agricultural professionals and farmers.

Green manure/cover crops are proving to be an effective, locally appropriate and low-external-input solution to this crisis. This strategy for improving livelihoods of some of the world's most food-insecure people needs to be shared with agriculture development workers and smallholder farmers around the world.

With this objective in mind, the Canadian Foodgrains Bank (CFGFB) contracted agroecologist Roland Bunch to write this book. Roland has years of international field experience with green manure/cover crops and is widely recognized as one of the world's experts on this subject. He also has gained international respect for his passion to help smallholder farmers through a people-centered agriculture revolution, summarized in his popular book *Two Ears of Corn: A Guide to People-Centered Agriculture Improvement*.

This new book, *Restoring the Soil*, synthesizes Roland's extensive field-based research gathered from thousands of smallholder farmers he has visited around the world who incorporated green manure/cover crops into their farming systems. This book presents the information in a user-friendly format intended to help agricultural development workers and farmers decide what systems may be most appropriate for the geographical area they work in.

The CFGFB network of members and partners is committed to building capacity around the use of green manure/cover crops in agriculture development projects. We are convinced that green manure/cover crops are among the best solutions to sustainably increase production while improving soil fertility for smallholder farmers. It is our sincere desire that this book will assist not only the CFGFB network, but also a wider network of organizations and smallholder farmers in designing sustainable cropping systems.

*Jim Cornelius, Executive Director
Canadian Foodgrains Bank*

Acknowledgements

This book could never have been written if it were not for a handful of people who had the foresight to realize, 30 years ago, that sometime soon, the world demand for energy would outstrip the supply, and energy prices would increase dramatically. Furthermore, they knew that a major increase in energy prices would inevitably increase the price of chemical fertilizer, which would, in turn, mean that over a billion people around the world who were dependent on chemical fertilizer would have no known, economically feasible way of maintaining their soil's fertility. These people's predictions could not have been more accurate: energy prices have increased five-fold over the last decade, real fertilizer prices have doubled in less than five years, world food prices have soared and millions of smallholder farmers are watching their soils become rather similar to infertile bricks.

But due to the foresight of this handful of people, we now have a large selection of effective, very inexpensive alternatives to chemical fertilizer. Thousands of people have worked on green manure/cover crops over the last 30 years, but the pioneers and leaders in this effort are fairly well-known:

- Ana Primavesi has been the pioneer and theoretical leader of the entire Brazilian zero tillage and green manure/cover crop movement. Her classic book, *The Ecological Management of the Soil*, still has no rival worthy of the name.
- Claudio Monegat probably did more than anyone else to further the early experimentation with green manure/cover crops in Brazil. He later wrote his own classic, *Green Manuring in Southern Brazil*.
- Valdemar Hercilio (Salgado) de Freitas and Aldemir Calegari have headed up the state agricultural organizations for the Brazilian states of Santa Catarina and Parana, where most of the early green manure/cover crop work was done in Brazil and where over a million farmers now regularly use green manure/cover crops.
- Rolf Derpsch worked with the movement in Brazil for many years, and then spread it to much of Paraguay.
- Steve Gliessman and Roberto Garcia did pioneering work with jackbeans on the Yucatan Peninsula in Mexico.
- In 1983, within a year or two of the time the Brazilians initiated their work on green manure/cover crops, those of us in World Neighbors/Honduras began experimenting with half a dozen green manure/cover crop species.
- Milton Flores became the director in 1989 of the International Green Manure/Cover Crop Clearinghouse (CIDICCO), which was founded by World Neighbors/Honduras. He ably ran CIDICCO for two decades, spreading information about green manure/cover crops to more than 75 countries around the world.

In addition to these pioneers, I would like to thank the members of the Green Manure/Cover Crop Taskforce organized by the Canadian Foodgrains Bank (CFGB)

who recognized the need to have this book written. Dr. Tom Post and Dr. Wondimu Kenea from World Renew (formerly Christian Reformed World Relief Committee) first captured the vision of this book. They also came up with the crucial idea of building the book around a decision tree, so that the often difficult and complicated task of choosing among scores of green manure/cover crop systems could be simplified for the common practitioner. Dawn Berkelaar from ECHO Inc. has done an incredible job of editing the book, simplifying technical language where it was needed, and making sure, against all odds, that all the numbers in the text actually do correspond to the numbers in our latest version of the decision tree. Dr. Tim Motis from ECHO assisted in editing and adding a valuable seed resources section. Additional help in editing was provided by Philip Bender, Carol Thiessen, Rachel Evans, Tiffany Hiebert, Emily Cain, and John Longhurst. Lastly, this book would definitely not exist if Alden Brault from CFCB had not initiated the idea and pushed this project forward to its completion.

Roland Bunch

How To Use This Book

This book is written primarily as a practical manual. It is meant to support agricultural workers and smallholder farmers around the world in maintaining and/or improving soil fertility and effective weed control through the use of green manure/cover crops (gm/ccs). If you are exploring whether you wish to work with green manure/cover crops, the definitions, history and practical field level advantages and disadvantages of this technology will aid you in making that decision. The answer to why one would not use chemical fertilizer and the basic considerations of soil improvement are practical and non-ideological. If you are already convinced of the importance of green manure/cover crops, these sections will refresh your commitment and certainly provide extra motivation.

The methodological considerations of extension methodology that should be considered are covered in the sections of *What About Farmer Participation*, *How to Achieve the Adoption of Green Manure/Cover Crops*, and *Collecting the Necessary Information*. If the decision is made to promote this technology, then the elements mentioned in *Collecting the Necessary Information* should be carefully followed as a guide. Errors in this stage can seriously affect the probability of achieving positive results in the application of successful systems in the future.

The decision tree is a thoughtfully designed step-by-step process. It is presented to help the reader decide which of the 91 systems presented in the book have a better chance of being helpful in his/her particular work environment. This environment is by and large defined by answering the questions mentioned in the *Collecting the Necessary Information* section. The decision tree uses parameters such as altitude, predominant crops and cropping systems, the slope of the land, rainfall patterns, whether animals graze in a controlled fashion or not, etc., to guide the reader's decision process.

The decision tree will logically guide you, step by step, to green manure/cover crops systems to be considered for situations you have in your work area. Each system is assigned a number (from S1 to S91) which is used throughout the manual to help you identify and to note the systems you might be interested in testing as you work through the tree. Explanations of the 91 systems are given in the *Green Manure/Cover Crop Systems* section.

Annex 2 (The Evidence) deals with a few issues related to the scientific basis or justification of the systems. It provides the field level practitioners, who are primarily interested in practical and real results, clear, practical evidence that these systems have a scientifically defensible basis.

*Phil Bender, Independent Agricultural Consultant
Santa Cruz, Bolivia*

Introduction

During the last 30 years, green manure/cover crops have become an important agricultural technology for the developing world. Books on tropical soil management written during the 1950s, 1960s or 1970s seldom mention green manures except, perhaps, to briefly suggest they were a failure. But then in the 1980s, green manures began making a regular appearance in the literature.¹ Since the 1990s and 2000s, most books on sustainable or ecological agriculture for the tropics (and even some books on conventional agriculture) have included significant sections on the subject.

Despite all this recent attention to the subject, far too many people who hear the term “green manure/cover crops” (gm/ccs) still picture fields completely covered by mucuna (*Mucuna* species) or jackbeans (*Canavalia ensiformis*). Agronomists frequently run experiments with three or four easily available gm/cc species, and if these species don't work, they conclude that gm/ccs are not appropriate for the area.

In fact, over a hundred green manure/cover crop (gm/cc) species are currently in use around the world, in hundreds of different gm/cc cropping systems. Gm/ccs are grown together with all the world's basic subsistence crops, as well as with vegetables, root crops and trees.

Faced with literally hundreds of different possibilities, even many well-informed workers in agricultural development feel it is almost impossible for them to be able to choose the best gm/cc system for the farmers in their area. In the past, a few documents were written to help development workers make the best decisions about this jungle of possibilities, but often these documents were written by people with little grassroots experience, or people who only had experience with gm/ccs in one region of the world.

Unfortunately, some 20 different factors must be taken into account in order to select the two or three gm/cc systems that have the greatest potential in a specific situation. These factors include local food preferences, current market conditions, dominant cropping systems, the major weeds in farmers' fields, as well as local economic needs, environmental conditions and land ownership patterns.

This book presents a decision tree designed to make this difficult task much simpler. The decision tree guides the reader through a series of simple questions in order to arrive at the gm/cc cropping systems that would have the highest probability of success in a particular situation.

In all but three or four cases, the gm/cc systems recommended are ones that over a hundred smallholder farmers have used for at least five years with no outside subsidies or encouragement. They are systems that have proven to be successful. I have observed nearly all of these gm/cc systems and have talked with the farmers who use them. To

¹One of the first times they were mentioned positively would be in Roland Bunch, *Two Ears of Corn, A Guide to People-Centered Agricultural Improvement* (Oklahoma City: World Neighbors, 1982), p. 124.

the best of my knowledge, only two of the gm/cc systems recommended in this book are no longer being used.

By and large, this book (except for the Annex) is written in such a way that anyone with a basic understanding of the English language will be able to understand its content. However, I have included a few technical agricultural terms that many readers of English may not understand. I could have avoided using these terms, but they are terms that anyone who works with gm/ccs will find useful. In each case, I have explained the word's meaning the first time it is used in the text, and have included it in the small glossary at the end of the book. A list of the different species mentioned in the book is also included at the back of the book.

1. The Definition Of Green Manure/Cover Crops

We need to distinguish the term “green manure/cover crops” (gm/ccs) from what agronomists have traditionally called “green manures.” The basic idea of traditional green manures is that they are plants grown in a field all by themselves (they are monocropped) and then plowed into the soil (as one does with “manure”) when they are in the flowering stage, while they are still “green”.

But most gm/ccs are managed in an entirely different way. First, rather than always being planted alone, gm/ccs are usually planted together with farmers’ traditional crops and at about the same time (intercropped), or they are planted among the traditional crops just before these crops are harvested (“relayed” into the traditional crops). Occasionally gm/cc species are even planted under tree crops. In these ways, farmers can fertilize their soil without dedicating any extra land to growing the fertilizer.

Second, gm/ccs are almost always cut down after they have produced seeds, rather than at flowering time. This is done because the farmers want to eat the seeds, sell them, or feed them to their animals. And, finally, they typically save at least some of the seeds to plant the next year.

Third, the gm/cc species are almost always cut down and left on top of the soil, rather than being plowed or dug into the soil. This saves the expense of plowing or digging them into the soil, and the organic matter on the surface protects the soil from the hot tropical sun.

While we are still using the basic “green manure” idea of using plants to fertilize the soil, most of how we manage the gm/cc species today has been changed by smallholder farmers as they developed better and better ways to use them.

Smallholder farmers also want the chosen species to do a lot more than just fertilize their soils. One of the most important benefits smallholder farmers want is for the gm/ccs to control weeds. In fact, most farmers in the tropics are considerably more interested in controlling weeds than they are in improving their soil fertility. That is why we have joined the concept of “cover crops” (whose job is to control weeds) with that of “green manures” (whose job is to fertilize the soil).

Because the idea of gm/ccs has changed so completely in the last 35 years, it is important that we define exactly what we mean by gm/ccs. The following definition, used in this book, is the most commonly used definition today: a “green manure/cover crop” is a species of plant, usually a legume, whether it is a tree, a bush, a vine, a crawling plant or an algae, which is planted by farmers to maintain or improve their soil fertility or control weeds, even when they have many other reasons for growing these plants.

The two main objections to this definition by some agronomists is that systems that use trees to fertilize the soil (what some people call “agro-forestry systems”) are

included in the definition, as are systems using legume crops that people eat (“grain legumes”). These systems are purposely included here as gm/cc systems for a number of reasons. First, there is no good reason for excluding legumes that happen to be trees or that produce food. Trees and grain legumes can also fertilize the soil and control weeds. Furthermore, they all work similarly in how they fertilize the soil. Lastly, there is not always a clear line between which plants are “trees,” which are “viny legumes,” and which are “grain legumes.”

As an example, lablab beans (*Lablab purpureus* or *Dolichos lablab*) are known in most of the world as annual viny legumes, but in some countries, such as Haiti, they are allowed to grow into trees with woody stems 30 centimetres in diameter. Furthermore, in many places, no one has any idea that they can be eaten, whereas in India and Kenya they are a valued edible bean that is packaged and sold in supermarkets. Thus, some people might call lablab beans an “agro-forestry species,” others a “food legume,” and still others a “viny legume.” Whatever they are, by our definition they will be included as a gm/cc.

2. A Brief History Of Green Manure/Cover Crops

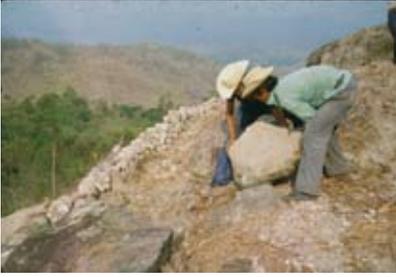
Green manures and cover crop systems have been used for at least 2,000 years. The Romans wrote papers advising people on how best to use green manures. In the richer countries of Europe and the United States, green manures were by far the most common method of maintaining soil fertility until the end of the Second World War. Some books from the 1930s include a tremendous amount of information about green manure systems in the tropics—information that today has been almost totally forgotten.²

Since 1945, the ability of organic matter to effectively fertilize the soil has often not been emphasized or even mentioned in crop production manuals or agriculture textbooks (Photos 1, 2, 3 and 4 show examples of the impact of organic matter in improving crop yields).

History shows beyond doubt that green manuring and gm/cc systems are capable of maintaining soil fertility for thousands of years. After all, they have done precisely that in virtually all the world's different soils, environments and farming systems (Photos 5 and 6).

In the tropics, the main method of maintaining soil fertility historically was by "fallowing." This process involved leaving agricultural land to grow into forests or grasslands for 10 to 15 years, until the soil had recuperated its natural fertility. Fallowing, like green manuring, maintained the fertility of the soils of whole continents for thousands of years. Since gm/ccs fertilize the soil in virtually the same way as fallows do, we can be quite confident (much more than we can be with chemical fertilizers) that gm/ccs are capable of keeping the soil fertile over the long term. Other methods are used in the tropics for maintaining soil fertility. Animal manure is, of course, an extremely good material for maintaining crop fertility, but only rarely do smallholder farmers have enough for more than about a tenth of their fields (Photo 7). Compost is probably the best of all soil amendments, but if we calculate the amount of labor it requires, we will almost always find that it is too expensive for basic grain crops among smallholder farmers, except in the case of rice (Photo 8). On the other hand, compost is usually far more useful than gm/ccs for farmers planting irrigated vegetables, since the cost of the compost is well-remunerated and the opportunity cost of the land used in planting gm/ccs is very high (Photos 9 and 10).

²See, for instance, Colombo, Charles, *Use of Leguminous Plants in Tropical Countries as Green Manure, as Cover and as Shade* (Rome: Printing Office of the Chamber of the Deputies, 1936).



1. Honduras. Farmers constructing rock walls to prevent more erosion and to make sure the organic matter they apply stays in the field.



2. Honduras. This photo was taken on the same field one year later, now with bean and maize crops. The maize is only fair, but the beans are growing very well.



3. Honduras. This field had been abandoned because it would not produce a decent crop of maize.



4. Honduras. One year later in the same field as #3. The maize crop at the top produced close to 4 MT/ha. The bean crop at the bottom produced better than the average bean crop in the United States that year. The treatment consisted only of soil conservation techniques (contour ditches with Napiergrass hedgerows) and organic matter.



5. Honduras. The contrast between the upper half of the field and the lower half consisted only of two years of mucuna that were intercropped with maize in the upper half of the field and then incorporated into the soil.



6. Honduras. In the same field as #5, it can easily be seen that the harvest in the upper half of the field will be at least four times the harvest in the control plot below. This increase is somewhat better than average. Usually, the harvest after two years of intercropping mucuna will only be about double that of a control plot.



7. Honduras. Animal manure is a valuable resource, and farmers should always be encouraged to use it if the transportation costs are not too high. Nevertheless, smallholder farmers almost never have enough easily-collected manure to maintain the fertility of their fields. All the manure of approximately 8 to 10 well-fed animals would be needed to maintain the fertility of one hectare of cropland.



9. Honduras. The only difference between the maize on the left and the row of foot-tall maize on the right is the turning into the soil of a very large amount of compost in the left-hand field. This farmer experiment in the early 1980's shows the potential of organic matter in improving soils. We were not aware of this experiment by Conrado Zavala of Guinope until the day this photo was taken. The amount of compost used was far more expensive in labor than the increased harvest, but the potential of organic matter was nevertheless demonstrated—and has been proven true in country after country. What this (and many later similar experiments in other climates and soils) taught us was that dramatic soil improvement was not a problem of soil chemistry (except where the soil is salty, is chemically polluted or has a manganese deficiency), but rather of economics: How can you get enough organic matter into the soil at a price that smallholder farmers can afford? After seeing this experiment, we began looking for cheaper ways of getting organic matter into the soil, an effort that quickly led us to gm/ccs as by far the cheapest technology for recuperating soils.



8. Guatemala. The transport of composting materials, management of the pile, transport to the field and spreading across the field involve so much labor that compost is also usually unprofitable if used on traditional basic grains (except rice) and root crops.



10. Ecuador. We do not yet have gm/cc systems for use with most low-lying vegetables. This photo shows an experiment in which a vicia is being intercropped with cabbages. Usually in irrigated vegetable fields, animal manure, compost or chemical fertilizer will be economically more advantageous than most gm/ccs because the opportunity cost of growing a gm/cc on such valuable land is very high.



11. Honduras. Gm/cc species should produce large amounts of biomass quickly. This photo shows the growth of mucuna on a small trellis only 45 days after planting

3. Existing Green Manure/Cover Cropping Systems Around The World

Advantages of Green Manure/Cover Cropping Systems

The proven advantages of gm/ccs are numerous:

1. Increased organic matter and soil nutrients (Photo 9). Gm/ccs are capable of adding as much as 50 metric tons/hectare (MT/ha) or more of organic matter (green weight) to the soil each year (Photo 11).³ This organic matter has various positive effects on the soil, such as recycling nutrients back into the soil, pumping nutrients up to the soil surface, and improving the soil's water-holding capacity. It can also increase the total amount of nutrients in the soil, improve its nutrient balance, increase the number of macro and microorganisms (very small animals in the soil, many of which also help a farmer's crops grow better), make soil softer and easier to plow, improve the acidity of soil (i.e.: buffer soil pH) and sequester carbon. Organic matter makes soil nutrients, including those supplied by chemical fertilizers, more accessible to crops, though this impact has been greatly underestimated. In the case of phosphorus, this is particularly important: in acidic soils, phosphorus may become four to five times more available to plants when surrounded by organic matter.



12. Honduras. When most of us think of nitrogen-fixing nodules, we think of tiny little spheres about one millimetre in diameter. This photo shows the nodules of just one mucuna plant grown under ideal conditions with no competition from other plants.

2. Nitrogen fixation. Legumes (plants that produce their seeds inside pods) are able to fix nitrogen (N) from the atmosphere into a plant-usable form that accumulates in plant tissues (Photo 12). Legumes can thereby add large quantities of nitrogen to farmers' soils. Most of the widely used legume gm/ccs are capable of producing more than 50 kg N/ha, while a few gm/cc species fix significantly more. *Mucuna* can fix 140 kg N/ha, the jackbean up to 240 kg N/ha and tarwi (*Lupinus mutabilis*), fava beans (*Vicia faba*) and *Sesbania rostrata* up to 400 kg N/ha.⁴

Even allowing for considerable losses of nitrogen to the air (volatilization), the 140 kg N/ha added by the gm/cc would cost at least US\$75/ha if purchased as a chemical fertilizer. This increase in both nitrogen

³Lathwell, Douglas J., "Legume Green Manures, Principles for Management Based on Recent Research" in *TropSoils Bulletin* No. 90-01 (Raleigh, North Carolina: Soil Management Collaborative Research Support Program, North Carolina State University, June 1990).

⁴National Association of Sciences (NAS) *Tropical Legumes, Resources for the Future* (Washington, D. C.: NAS, 1979) and Tisdale, Samuel L., et al., *Soil Fertility and Fertilizers*, Fifth edition (New York: MacMillan Publishing Co., 1993).



13. Honduras. Gm/ccs that can effectively control weeds, such as the mucuna in this photo, will be greatly appreciated by farmers.

(Photo 13). Especially in Africa, this often means that women's total workloads can be reduced by 20% or more.

In Africa, a particularly noxious weed is striga (*Striga hermonthica*). Striga can significantly reduce yields of maize, sorghum and millet, and is a major concern for farmers in areas with low soil fertility. The solution, however, is quite simple. Striga dies out if enough organic matter is added to the soil. Thus almost any gm/cc that produces a decent amount of biomass will gradually rid the fields of this weed.⁵ In areas where striga is a serious problem, this fact in itself will often convince farmers that they should use gm/ccs.

Imperata grass (*Imperata cylindrica*) is another serious weed that grows best in poor soils and therefore becomes less and less problematic as soils recuperate.

6. Reduction in the use of agrochemicals. If farmers are using chemical fertilizer, gm/ccs can usually reduce the amount used by 60% to 80% without lowering yields. Herbicide use is either reduced or eliminated, since many gm/cc species are able to smother weeds. Some species of gm/cc can be used in place of other chemicals. For example, mucuna and lablab beans kill nematodes, while sunnhemp (*Crotalaria ochroleuca*) can be used to control pests that eat stored grain.

7. Soil cover. The soil cover provided by many gm/ccs can be very important for soil conservation (Photo 13). In general, the value of soil cover (especially in the humid

and organic matter from gm/ccs can increase soil fertility tremendously. As a result, programs from India to Brazil and throughout Central America now speak not just of "soil conservation," but of "soil restoration" and "soil recuperation."

3. Zero transportation costs. Unlike most other materials that improve the soil, these additions of organic matter and nitrogen have no associated transportation costs. They are produced right in the field where they will be used, and are already well-distributed across the field.

4. Very low cost. Gm/ccs cost the farmer no money whatsoever once the farmer has purchased his or her first handful of seed.

5. Weed control. Gm/ccs can also be an important factor in reducing the cost and the labor required for controlling weeds

⁵Dyck, E., et al., *Legumes in Every Farm, Strategies for Adoption of Soil-Improving Legumes by Smallholders in Kenya*, 1996.

tropics) has been greatly underestimated. High rainfall and substantial slopes on agricultural land create ideal conditions for erosion to occur. Rain drops hitting bare ground cause soil particles to be dislodged. These are transported downhill in water flow, and pick up more soil as momentum builds. But covered soil is less vulnerable to water erosion. One study showed that farmers cultivating maize and mucuna on hillsides with a 35% slope and more than 2,000 millimetres of annual rainfall in northern Honduras are actually increasing the productivity of their soil year by year, without using any other soil conservation practices. Their soils are totally protected from erosion because they are covered by mucuna 10 months of the year.⁶

8. Improved soil moisture. The soil cover, or mulch, that is provided by a gm/cc also greatly improves drought resistance. The gm/cc residues add organic matter to the soil, which increases infiltration of water into the soil and increases the water-holding capacity of the soil. In one experiment carried out during a drought in southern Honduras, maize fertilized with chemical fertilizer died one month into the drought, maize fertilized with animal manure died about two months later, and maize fertilized with jackbean still managed to produce a rather small harvest.

9. Zero tillage. The experience of hundreds of thousands of farmers in Brazil, Paraguay, Argentina and Honduras shows us that after two to four years of heavy applications of organic matter from gm/ccs (over 50 MT/ha, green weight), farmers can move to zero-till systems that retain very high levels of productivity. A tremendous amount of time and effort is saved when farmers no longer need to plow their soil. Using mucuna, zero tillage and no chemical fertilizer, smallholder farmers working on hillsides in northern Honduras have maintained yields of maize of over 2.5 MT/ha for over 30 years. They achieve maize yields of 4 MT/ha with very small additional applications of urea. Their cost of producing each sack of maize is about 30% less than that of the richer farmers nearby who use tractors, chemical fertilizers and herbicides, and have flat land.⁷

In Brazil, farmers who use gm/ccs combined with rotations and medium applications of chemical fertilizer regularly harvest 7 to 8 MT/ha of maize without having tilled the soil in over 10 years.⁸

10. Competitiveness with farmers using tractors. Gm/ccs are very effective in smothering weeds. They can also allow farmers to move to zero tillage. Since the primary method used in conventional agriculture for achieving both weed control and soil preparation is tillage, farmers who use tractors have traditionally had a huge advantage over smallholder farmers who cannot afford tractors. Now, by using gm/ccs, smallholder farmers using animal traction or hoes and sometimes even those working on

⁶Buckles, Daniel, et al., Cultivos de Cobertura en Agricultura de Laderas, *Innovación Campesina con Mucuna* (Ottawa: Centro Internacional para el Mejoramiento de Maíz y Trigo and Centro Internacional de Investigaciones para el Desarrollo, 1998).

⁷Flores, Milton and Nicolas Estrada, "Estudio de Caso, La Utilización de Frijol Abono (Mucuna spp.) Como Alternativa Viable para el Sostentamiento Productivo de Sistemas Agrícolas del Litoral Atlántico." Paper presented to the Center for Development Studies at the Free University of Amsterdam, 1992.

⁸Bunch, Roland, "El Trabajo de EPAGRI en el Estado de Santa Catarina, Brasil, Nuevas Posibilidades Importantes para Agricultores de Escasos Recursos." No date, unpublished.



14. Peru. This wasteland in highland Peru is being rehabilitated with tarwi. About 1/5th the amount of manure is needed to rehabilitate the land compared to only using manure. Basically, the manure just helps the tarwi reach maximum yield.



15. Honduras. The dramatic increase in soil organic matter and the addition of nitrogen make gm/ccs ideal for recuperating wastelands. Only in two cases (central Cambodia and Rwanda) have I ever seen lowland soil so degraded that jackbeans would not grow. In such cases, a light application of manure will usually allow the jackbean to grow, and the soil will be ready for cropping the following year.

12. The capture of additional nutrients. In places such as the Sahel in Africa, wind erosion is a major problem. Low-lying bushes that grow year-round, such as *Piliostigma reticulatum*, can capture large quantities of the soil that is blowing in the wind, adding important nutrients to farmers' fields.

hillsides can compete with much wealthier farmers. After all, eliminating these operations is more efficient than merely making them cheaper by using a tractor. In an age of falling trade barriers, this fact alone could justify the use of gm/ccs among the world's smallholder farmers.

11. Provision of additional benefits. In addition to improving the soil and controlling weeds, gm/ccs can provide many other benefits:

- high-protein human food;
- commercial products to be sold, thereby improving farmers' incomes;
- wasteland restoration—of both wastelands with extremely low fertility and those invaded by very bad weeds, such as imperata grass (Photos 14 and 15);
- shade for other crops;
- soil moisture conservation—either as green or dead mulches;
- high-quality fodder and bedding for cattle;
- prevention of plant diseases—from sun scorch on citrus fruits to root rots in vegetables;
- reduction of the incidence of pests, including nematodes in growing crops and various pests in stored grain;
- contour bunds;
- firewood.

Of course, when we use gm/ccs as fodder or fuel, we reduce the quantity of organic matter and nutrients that are added to the soil, thereby making them somewhat less valuable in improving the soil.

13. The ecological advantages of trees. When we use tree gm/ccs as dispersed shade, we also gain the ecological advantages provided by trees: soil and crops are protected from the tropical sun, soil moisture is conserved (because evaporation and transpiration rates are reduced), and desertification is curbed.

When we compare the above advantages to those of composting, we find that in the vast majority of cases, gm/ccs will be far more attractive to farmers than composting. Gm/ccs provide weed control, food, and many other products and advantages, with much lower transport and labor costs than compost (Photo 8). The exception would be those cases where farmers are growing very high-value crops and/or own a very limited amount of land (less than half a hectare, for instance), so that there is virtually no space where the gm/ccs can grow.

Each of the above advantages should be analyzed and weighed when choosing which gm/ccs to use and promote. Experience shows that farmers are rarely attracted primarily by the gm/ccs' ability to increase soil fertility. More commonly, farmers are most motivated by the gm/ccs' potential for human consumption (usually the highest priority of the above advantages) or their ability to control weeds. Therefore, gm/ccs should be promoted mostly by emphasizing these other advantages, not just the advantage of increasing soil fertility. For instance, sometimes we refer to a gm/cc as a "food crop" or a "green herbicide."

Disadvantages of Green Manure/Cover Crops

Despite all these advantages, gm/ccs are sometimes difficult to introduce to farmers. While working with the international development organization World Neighbors during the 1980s, I tried for eight years to introduce the use of mucuna to farmers in central Honduras, with very little success. This was because I didn't understand some of the important disadvantages of gm/ccs. If we fail to overcome these disadvantages, we will not be successful at introducing gm/ccs. In a few situations, these disadvantages will mean we should not try to introduce gm/ccs at all.

1. The opportunity cost of the land. Farmers normally will not plant something that only fertilizes their soil if the land could instead be planted with either food crops or cash crops. Unless the gm/ccs also produce food, the land used to grow gm/ccs must have no other valuable use (i.e.: it must have no "opportunity cost," meaning the "cost" represented by not taking advantage of an "opportunity" to do something else with the land). Traditional green manure systems from temperate countries require farmers to monocrop green manures on their land before planting their regular crop, thus taking otherwise useful land out of production for a few months in order to produce the green manure. These systems did not recognize the need to use land that had no other profitable use—which is probably why the introduction of green manures into the developing world before the 1970s was rarely successful.

2. The slow results. Soil improvement is a long-term process that may not be immediately noticeable to the farmer. Usually, significant improvement in productivity does not occur until after the first crop of gm/cc has been applied to the soil, which means that concrete, visible results are not apparent until well into the second cropping cycle. This slow appearance of results—improved soils—that are often difficult for people to believe, further complicates the adoption of gm/ccs. Once again, it is often preferable to promote gm/ccs for some reason other than soil fertility. If farmers are not aware of the value of organic matter in their soils, a heavy application of animal manure on a small plot of land the first year will help make farmers aware of the value of the organic matter the gm/ccs are producing in their fields (Photo 7). Simple demonstrations, such as showing how organic matter increases the water-holding capacity of soil, can also be used.

3. Dry season problems. Often gm/ccs must produce their organic matter at the end of the wet season, or must continue to grow during the dry season. Grazing animals, wild animals, termites, agricultural burning, bush fires or several other problems may destroy organic matter or growing plants before the farmer can use them the following rainy season. In very hot climates and on soils with no shade, the nitrogen and much of the organic matter will be burned off by the tropical sun. Thus, almost no benefit from the gm/cc will be available for the next crop.

4. Difficult growing conditions. Smallholder farmers in the tropics commonly cope with many challenging conditions, including extremely low or irregular rainfall, extremes in soil pH, severe drainage problems, or a combination of these. Such conditions will reduce the growth of gm/ccs, thereby reducing or destroying their impact. Through the years, we have learned how to overcome an increasing number of such problems. The solution is often to use gm/cc species that are particularly resistant to certain problems. For example, jackbean can withstand very poor soils and is often used for recuperating wastelands. However, these solutions are often achieved by using gm/cc species that produce less organic matter, don't fix as much nitrogen, don't have additional benefits, or don't fit as well into the local farming system.

5. Timing (also called “synchronization”). The nutrients provided by the gm/ccs, especially nitrogen, must be available to crops when they need them in order to raise productivity. Gm/ccs will boost farmers' productivity only if the gm/ccs' nutrients are available to the crops at the right time. In many gm/cc systems, the correct timing is either impossible or very difficult to achieve. Therefore, the efficiency of the systems is reduced.

Very often, this problem can be solved using natural foliar nutrient sprays at the appropriate time of year to supplement soil nutrients. Solutions of cattle urine or crushed mother of cacao (*Gliricidia sepium*) leaves are often used. Very small amounts of chemical fertilizer can have the same effect. These remedies can be very useful in supplying nutrients at exactly the time the crops are likely to run out of the nutrients supplied by gm/ccs.

Green Manure/Cover Crops Systems are Widespread

Gm/cc systems are surprisingly common around the world. This fact is understandable if we take into account all the advantages listed above. During the 1990s, the NGOs CIDICCO (International Center for Dissemination of Cover Crops) and COSECHA (Consultants for a Sustainable, Ecological and People-Centered Agriculture) in Central America each compiled a list of known gm/cc systems in about 45 countries. The lists were admittedly incomplete. One list included 96 gm/cc systems and the other 51 systems.⁹ Statistically, if we assume that the definitions of gm/cc systems in the two lists are identical and that each list was a random sampling of the world's existing systems, a simple mathematical extrapolation indicates that over 500 gm/cc systems probably exist around the developing world.



16. Indonesia. Our lunch at a roadside restaurant, which included three gm/cc species, in a country in which many agronomists had assured me no gm/ccs were being used.

Time and time again, in more than 30 developing countries, I have found that gm/cc systems are thriving where local agronomists were absolutely sure they did not exist. For instance, Indonesian agronomists assured me that because Indonesians do not eat beans, gm/cc systems would not exist in their country. However, on my first day out in the field in Indonesia, we ate lunch at a small roadside restaurant (Photo 16). The lunch included three legumes, all of which we later found farmers using as gm/ccs. None of these leguminous foods were actually cooked as beans, per se: the soybeans were served as

tofu, which was in the soup along with green cowpea pods, and the mungbeans had been made into some delicious sweet cakes. In the following four days, I observed six different gm/cc systems in just a very small area of southern Sumatra.

Characteristics of Known Green Manure/Cover Crop Systems

Of the known gm/cc systems that have been implemented by farmers around the world for at least five years without any subsidies, over 70% were basically developed by smallholder farmers themselves. This fact, perhaps more than anything else, shows how appropriate these systems can be for smallholder farmers, and how interested smallholder farmers are in finding and adopting alternatives to both fallowing and chemical fertilizers. (Data on adoption and abandonment of these systems would be a much better indicator of farmer interest, but such figures are not available in most cases.) It is also surprising that over 100 species of gm/ccs are used, with new ones being discovered all the time.

⁹Bunch, Roland and Milton Flores, Unpublished lists.



17. Haiti. Using expensive chemical fertilizers is not economically feasible for most smallholder farmers growing basic subsistence crops (except in the case of rice). Even when it is feasible, a normal application of unsubsidized chemical fertilizer will almost always cost the farmer over US\$100 for a half-hectare, a tremendous amount of money to take out of a farmer's pocket when similar yields can be produced with inexpensive green manure/cover crops.

This farmer will have to travel more than 6 hours from the road's end to apply this fertilizer to his fields. Most calculations as to the profitability of chemical fertilizer do not include the risk factor, high transportation costs and the cost of neutralizing the acidity caused by the fertilizer. When these costs are added, chemical fertilizer is almost never a profitable technology for basic grain or root-crop producers.

of the world's basic grains for smallholder farmers to produce. Farmers growing high-value vegetables and fruits can also make a profit using chemical fertilizer.

But for smallholder farmers in most of the world, especially those who produce maize, sorghum, millet, beans and root crops, using chemical fertilizer is no longer profitable. Many scientists still produce calculations that show fertilizers to be profitable. But if all the costs are taken into account, such as taking a bus to a local town; purchasing the fertilizer at a small-town retail price; returning on another bus (which will also charge for the transport of the fertilizer); applying the fertilizer; purchasing inputs to neutralize the acidification caused by the fertilizer (which can ruin an acidic soil if the acidity of the fertilizer is not neutralized periodically); paying interest on the money invested in the fertilizer (or the money's opportunity cost); and—most important of all—shouldering the risk of crop failure, the chemical fertilizer is usually unprofitable.

In semi-arid areas where droughts are common, farmers often adopt perennial gm/ccs. This type of gm/cc has much deeper roots than annuals, allowing them to withstand the frequent droughts. For example, in the African Sahel, farmers tend to use mother of cacao (*Gliricidia sepium*), *Faidherbia albida* and nyama (*Piliostigma reticulatum*) when they can, rather than gm/ccs that only last one year. Even lablab beans, if used in such climates, should usually be cut off at ground level and allowed to sprout again, rather than being planted from seeds again. This way the plants can take advantage of the root growth achieved during previous years.

Why Not Just Use Chemical Fertilizer?

Quite simply, chemical fertilizer has become unprofitable for most smallholder farmers who produce basic subsistence crops. The situation of each farmer is different, but in most cases the costs related to the use of chemical fertilizers would be greater than the benefit provided by the fertilizer (Photo 17). A few major exceptions to this rule exist; the most important includes those farmers who grow rice. The increasing demand for rice in Asia has resulted in a relatively high world price of rice, making it by far the most profitable

This is particularly true in drought-prone areas, where the risk of crop failure is high.

As a result, farmers in many parts of the developing world (except where chemical fertilizer is being subsidized) are already buying less and less chemical fertilizer or none at all.

But let's suppose that chemical fertilizer still could be used profitably. Most smallholder farmers in the world now possess less than a hectare of land per family. Even a light application of chemical fertilizer on that hectare of land will cost about US\$200. It is virtually impossible for a smallholder farmer to feed his or her family on what is left from the harvest of a hectare of basic grains, even when fertilized, if he or she has to sell enough of those grains to pay for the fertilizer. By contrast, gm/ccs, which can improve the soil's fertility just as well or better than chemical fertilizers, cost a fraction of what chemical fertilizers cost (or can be a free by-product of the production of high-protein grain legumes). Therefore, farmers can feed their families with high quality food on much smaller pieces of land. This is imperative if most of the world's smallholder farmers are to achieve anything approaching food security.

While it is true that highly efficient gm/cc systems do not exist for absolutely every farming situation, this manual shows that systems do exist for the vast majority of smallholder farmers around the world.

4. Improving Soils: The Basic Rules

Books on agriculture seldom mention how much organic matter we need on each hectare of soil to stop losing fertility or to actually improve the soil's fertility. This question has not been researched to any great extent; yet, it is of extreme importance in recovering, maintaining or improving soil fertility.

Long-term experience with a series of different species of gm/ccs around the world gives us a very approximate answer. Of the more than 100 gm/cc cropping systems I have observed, those that can keep soil fertility at about the same level over many years are those that supply somewhere around 20 to 25 MT/ha of leguminous organic matter (green weight) to the soil. These would include maize/runner bean systems at high altitudes and maize/lablab bean systems at lower elevations. Systems that supply 30 MT/ha or more of organic matter to the soil, such as the maize/mucuna (*Mucuna* spp.) system of northern Honduras, northern Guatemala and eastern Mexico, will gradually increase soil fertility over the long term, until a high level of productivity is reached.

In many cases, several soil fertility practices are being used in the same field at once: several different gm/ccs are grown, or gm/ccs are used along with manure. In these cases, the weight of the various kinds of organic matter can be added together. For many people, 20 to 25 MT/ha seems like a surprisingly large amount of organic matter. Those who have worked for years with compost will immediately realize that virtually no smallholder farmers are using enough compost to come anywhere near this amount of organic matter. Although a kilogram of compost may be a little more beneficial to the soil than a kilogram of leaves, most smallholder farmers observe little or no difference between the impact of a kilogram of compost as compared to a kilogram of gm/cc plant material. Thus, compost will almost never help a farmer maintain his or her soil fertility without the added contribution of gm/ccs (or chemical fertilizer).

A second very important factor in maintaining soil fertility without the use of chemical fertilizers is the heat in the tropical lowlands. Many experiments with gm/ccs have failed because the gm/ccs (such as mucuna) produced their organic matter primarily at the end of the wet season. The organic matter then lays on the ground for five to seven months of sweltering heat and often with high winds, until the next rainy season. During this time, the intense heat basically burns up all the nitrogen and much of the organic matter produced. By planting time at the beginning of the next wet season, the gm/cc's impact on soil fertility is almost all lost. (Animals grazing the gm/cc by roaming free during the dry season will, of course, cause the same loss of nitrogen and organic matter.) As a rule, the calculations of total organic matter applied to a piece of land in the lowland tropics should not include any organic matter that has lain on top of the soil throughout the dry season, without any shade.

The loss of both nitrogen and organic matter is one of the most difficult problems to overcome in using gm/ccs in the lowland tropics. Nevertheless, there are ways to do it.

First of all, legumes such as the jackbean (*Canavalia ensiformis*), lablab bean, tephrosia and most leguminous trees can grow through most or all of the dry season, thereby providing fresh organic matter close to the beginning of the rainy season. If animals are roaming wild, they will destroy the lablab beans. If they get extremely hungry, they may also eat the jackbeans. In this case, the tephrosia or leguminous trees may have to be used.

To overcome these challenges, a combination of two or three gm/ccs may provide the best results. For example, using trees and another type of low growing gm/cc could be a practical answer to this problem. By reducing the ambient temperature at least 10°C, dispersed trees can cool the fields enough so that the gm/ccs' organic matter will not be burned off, and the soil's fertility can be maintained. The temperature can be lowered even more if the trees are not pruned until the months right before the next rainy season, as is normally the case. Thus, dispersed shade can largely eliminate the problem of dry season burn-off of the gm/ccs' organic matter and nitrogen.

5. Choosing the Right Green Manure/Cover Crop System for a Specific Area

What about Farmer Participation?

Many people working in agricultural development strongly believe that farmers should participate in their own agricultural development. I would go one step further than that. I believe that farmers should become the protagonists, the architects or, as Paulo Freire wrote, the authors of their own development. In fact, if the smallholder farmers are not in charge of the process, at least after the first few years, I would question whether what is happening is really development.

The achievement of broad-based authentic farmer participation is not easy. Serious questions need to be answered about participation. Are we talking about participation of the powerful, or of everyone? And if a few of the powerful can manipulate a group, does participation exist, even if everyone is giving his or her “opinion”? Is true participation occurring if people are giving us the answers they think we want to hear, or the answers other development people have told them are the “right” answers? Is it participation if the men do all the talking, or women also talk but are afraid to contradict what the men have said? Can we assume that the farmers know all the technological possibilities in a given situation? If not, of how much value is their “participation”?

For 40 years, development organizations have been told they are not using farmer participation as much as they should, yet seldom have the above questions been asked. When they are asked seriously, they can have a tremendous impact on what we call participation.

These questions about participation should be in the back of people’s minds as they work with the decision tree in this book. Most questions in the decision tree should be discussed with the farmers, and most of the answers should be provided by the farmers, in an atmosphere of complete freedom, trust and confidence.

Furthermore, the gm/cc systems recommended by the decision tree are ones that have been tried and, at least for some farmers, have been successful over a period of several years. Still, they should not be considered the only possibilities that might be used in each situation. It is quite possible, that over time, smallholder farmers will find better gm/cc species or better ways of using them. I am sure that dozens of good gm/cc species are yet to be discovered, and perhaps hundreds of as-yet untried systems will also be discovered. The world is in serious need of more, and better, gm/cc systems. Farmers and programs should always be looking for more gm/cc species and more ways to use them, just as farmers are always looking for more crops to grow or better ways of growing them. This decision tree should not be allowed to reduce people’s creativity. We must allow creativity to blossom.

But programs should also not underestimate the difficulties involved in finding successful gm/cc systems. Hundreds of programs have tried, and many have failed. Some people will inevitably respond, “But why should we worry about finding solutions to the smallholder farmers’ problems? They already know everything they need to know. Don’t they have prodigious amounts of indigenous technical knowledge (ITK)?” Yes they definitely do. But if they know the best solutions to their problems, why haven’t they solved their problems already? Are we to believe that, knowing the most appropriate solutions, they have failed to implement them? I don’t believe this, in part because it would require us to believe the farmers are not very smart—and that is definitely not the case.

Farmers have spent hundreds of years learning about technologies and cropping systems they needed at different times. But during all those centuries, they were able to use fallowing, so there was little need to learn much about gm/ccs. Only in approximately the last 20 years has population growth restrained their ability to maintain their soil fertility through fallowing. Therefore, it has only been in the last 20 years that farmers have had a crucial need to learn about gm/ccs. Twenty years is not enough time for smallholder farmers to learn all elements of such a complex subject through their systems of informal experimentation.

Anyone who feels the smallholder farmers already know everything they need to know should look through the list of 91 gm/cc systems in this book. I think they will find that no smallholder farmers (except perhaps in Brazil) know about more than a handful of these systems, and yet many of these systems might be of use to them. There will be, in most cases, information here that the smallholder farmer themselves will admit they don’t know, and wish they had known before now.

So what should be our role as people who wish to promote true farmer-protagonist, farmer-led agricultural development? And how can a guide such as this support that role? Certainly we should be well-informed, we should listen carefully to the farmers, we should value their experience and we should be very slow to ever discount their knowledge and priorities. We also need to learn how technologies that smallholder farmers themselves have selected can best be adapted to local needs and most effectively communicated and/or promoted.

Then we need to train farmers in the relevant cropping systems mentioned below, while respecting the smallholder farmers’ priorities, their knowledge and their abilities. The training process needs to become more and more a dialogue in which both farmers and outsiders provide information and learn from each other. Eventually, by experimenting to obtain more knowledge on their own, by learning to train other farmers, and by having access to this decision tree in a language they can understand, the farmer leaders should take over the development process themselves. To learn more about these issues of agricultural extension processes, I would suggest my book, *Two Ears of Corn: A Guide to People-Centered Agricultural Improvement*.¹⁰

¹⁰Bunch, *op. cit.*

How to Achieve the Adoption of Green Manure/Cover Crop Systems

A great deal of discussion centers on the levels of adoption or abandonment of gm/cc systems around the world. In general, evidence indicates that many traditional gm/cc systems are gradually being abandoned as Green Revolution technology (for example, using chemical pesticides and genetically modified organisms) has spread, as traditional foods have become unfashionable, as chemical fertilizer has become more widely available, and as professional extension workers have criticized farmers for doing things that aren't recommended in university textbooks. This gradual process of abandonment has apparently affected such widespread systems as the maize/cowpea and maize/rice bean systems that once existed from Mexico through Nicaragua, and the scarlet runner bean/maize system that once stretched from the northern U.S. to Chile.

At the same time, some other gm/cc systems have spread widely and quickly right up to the present time. One of them is the maize/mucuna system that has spread spontaneously through Mexico, Guatemala, Belize and Honduras over the last 60 years. So the question persists: will gm/cc systems become sustainable, or will they, after much blood, sweat and tears, become just another footnote of history?

Quite frankly, a soil fertility crisis is approaching. It will affect the whole world, but the lowland, drought-prone areas of Africa will be the hardest hit. Population growth has drastically diminished the amount of land per family. Approximately 80% of small holder farmers in Africa have less than two hectares of land. Therefore, most people today have to farm every inch of what little land they have in order to survive; there is nothing left for fallowing. Thus, for the first time in history, most of Africa's lowland farmers can no longer fallow their soils. In addition to this unprecedented problem, farmers' animals have decreased in numbers (because grazing lands have also been swallowed up by cultivated farms), chemical fertilizers have increased dramatically in price because we have used up all the world's cheap fuels, and global warming is also taking its toll. Because of this "perfect storm" of factors, harvests in much of lowland, drought-prone Africa are dropping by 10 to 15% a year. Within the next five years, we could witness widespread hunger across much of Africa that will be among the worst in recent history, with the livelihoods and productive capacity of tens of millions of smallholder farmers severely damaged.

Most of the smallholder farmers of lowland Africa know something is terribly wrong. In hundreds of villages that I recently visited, the people are intensely worried. Their food supply is diminishing at a rapid rate, and they know of no way to solve the problem.

For years, a large majority of African farmers really weren't very interested in gm/ccs. But now, I can honestly say that I have never seen farmers as interested in gm/ccs as are the farmers today in most of the Sahel and lowland southern Africa. I think agencies working in the Sahel and the rest of lowland Africa will find that the farmers have much more interest in improving their soils than ever before.

The same problems—expensive fertilizer, smaller plots, little or no opportunity to fallow and decreasing soil fertility—are affecting smallholder farmers elsewhere, even though the crisis situation seems to be approaching more slowly. Thus many farmers in Latin America and Asia are also becoming increasingly interested in the benefits of gm/ccs.

It is highly unlikely that gm/ccs will ever become just a footnote in history. Nevertheless, if we are to make introduced gm/cc systems as sustainable and widely popular as possible, we need to discover what makes certain specific gm/cc systems so much more popular than others. What is the difference?

Most of the programs and organizations that have been successful in introducing sustainable gm/cc systems have used the following guidelines:¹¹

1. The land occupied by non-food-producing gm/ccs must have no opportunity cost.

This means that if the gm/cc does not produce food, it must occupy land that cannot be used for producing either a cash crop or a subsistence crop during the time the gm/cc is using it. This sounds like a very difficult, if not impossible, rule to follow, but we are finding more and more places and times that gm/ccs can be used:

a) If the gm/cc does produce a valued food, it can be grown in any way that fits into the system like any other equally valuable food crop.

b) If the gm/cc does not produce food, it can be grown intercropped together with another food or market crop. For instance, jackbeans are intercropped with maize or cassava, or perennial peanut (*Arachis pintoï*) is intercropped with coffee. Intercropping is currently the most popular way of growing gm/ccs.

c) The gm/cc can be grown on wasteland or during the first year or two of a fallow as an improved fallow. For instance, farmers in Vietnam broadcast tephrosia (*Tephrosia candida*) seeds into their first year fallow. That way, instead of fallowing the land for five years, as they normally do, the soil will be fertile enough to farm again in just one or two years. In this case, since the soil is very poor when the fallow starts and the gm/cc is planted, farmers must use gm/cc species that can grow well in very poor soils. These include gm/cc species such as jackbeans, tephrosia, or certain very hardy trees.

d) The gm/cc can be grown mostly during the dry season. This can be done in three ways. First, the gm/cc can be relayed (intercropped with another crop that has already been growing for some time) into traditional crops. Examples of this are the maize/cowpea and maize/lablab bean systems in Thailand, which are S70 and S71 in the decision tree. The second way is to plant the gm/cc after the harvest of normal crops, such as in S78, the system in Vietnam in which rice bean is planted after the rice. The third way is to intercrop the gm/cc with the normal crop and

¹¹Bunch, Roland, "El Uso de Abonos Verdes por Agricultores Campesinos, Lo Que Hemos Aprendido Hasta la Fecha". *Reporte Técnico* No. 3, Segunda Edición, Tegucigalpa, Honduras: Centro Internacional de Investigación y Divulgación de Cultivos de Cobertura (CIDICCO), 1995.

then leave it growing through the dry season after the traditional crop is harvested. An example of this method is S7, the maize/sweet clover system in Mexico.

e) The gm/cc can be grown under fruit or forest trees or almost any perennial crops. In this case, we choose particularly shade-resistant gm/ccs, like jackbeans or *Centrosema pubescens*.

f) Occasionally we can use other ways of growing gm/ccs without affecting the main crop. These include growing gm/ccs during periods of frost (lupines, such as tarwi, often do well), in soils that are too acidic for our crops (mucuna or buckwheat), or during very short periods of time (as in the case of *Sesbania rostrata*).

2. Gm/ccs must not cost money. This rule implies that farmers must be able to produce their own gm/cc seed year after year, and that the gm/ccs must have no disease or insect problems that are serious enough to significantly diminish their growth. Insect attacks that do not affect the growth of the plants are fine; they merely help process the organic matter. If an insect or disease problem does significantly reduce a gm/cc's growth, we must usually discard that species and start using another one. The Brazilians, for instance, quit using lablab beans some 20 years ago because it was too heavily attacked by insects. This rule also means we cannot use inoculants (commercial products that increase the fixation of nitrogen).

3. Gm/ccs must not increase labor costs very much. This rule means that, except where animal traction or tractors are being used, gm/ccs will have to be left on the soil surface. It also means that the intercropping of gm/ccs is particularly advantageous, because the weed control the gm/cc provides when it is intercropped can often save more labor than the labor needed for planting and cutting down the gm/cc.

The labor problem is also the main reason why farmers appreciate zero till systems. Farmers will often decide to plant gm/ccs primarily because of the hope that they will never again have to plow or hoe their fields. Since farmers must maintain high levels of organic matter in the soil in order to be able to use a zero till system indefinitely, this desire to eliminate the plow or the hoe is a motivating factor for the long-term use of gm/ccs.

4. Gm/ccs must fit into the existing farming systems. Gm/ccs will be seen as much less important than food or cash crops, at least for the first few years. Thus farmers and extension workers have to adjust the gm/cc to fit into the already-existing cropping system, rather than adjust the farming system to fit some way of growing a gm/cc.

5. The gm/cc should provide at least one important benefit in addition to improving the soil. In a worldwide study of gm/cc systems that were taught to farmers through programs, almost all of the gm/cc systems that persisted after the development organization had left the area were those systems that produced important benefits above and beyond soil improvement. Thus, whenever possible, we should promote gm/cc

species that can be eaten, fed to animals, or provide some other benefit for which a strong felt need exists among the farmers.

In general, good gm/cc species should establish themselves easily and grow rapidly under local conditions; be able to cover weeds quickly; and be able to fix plenty of nitrogen. They also should be resistant to insects, diseases, grazing animals, bush fires, droughts, or any other problem they may have to face within the cropping system. As well, they should produce enough seed for future plantings. If the gm/ccs are to be used for intercropping, they should withstand shade and fit in with the growing cycle of the main crops.

Note that virtually all of the gm/cc systems recommended in this book fall within the above rules that favour easy adoption by farmers.

Gm/ccs have also become very useful for large-scale farmers who cultivate as much as 100,000 ha of land in Brazil. However, among smallholder farmers, gm/ccs tend to be most useful for those who have between 0.25 ha to 10 ha of land. Farmers who have more than 10 ha can still use fallows to maintain the fertility of their soils. It is fairly difficult, though definitely possible, for gm/ccs to compete with fallowing, because gm/ccs require more labor. For farmers who have less than 0.25 ha, the use of the land is usually so intense that there are virtually no times or places when the farmers aren't using the land. Thus, there is much less opportunity to use gm/ccs. In these cases, it is often better for farmers to make compost or buy organic or chemical fertilizer. Farmers who dedicate their land to year-round paddy rice production also may not have any good way to use gm/ccs.

Collecting the Necessary Information

The first step in choosing one or more gm/cc system(s) for a particular area is to get to know the area well. Some information is absolutely essential before you can choose the best systems for a given area. This includes:

1. Do the farmers have any preferences as to how they want to solve the soil fertility problem, and if so, what are they? Have they tried some techniques already? What were the results? Why?
2. At what elevation above sea level is the area? Zero to 800 metres (m) above sea level, 800 to 1,500 m, 1,500 to 3,000 m or above 3,000 m?
3. What leguminous grains or leaves do people already know and eat?
4. For what leguminous plants is there a good market?
5. When asked what their major agricultural problems are, do farmers (men and women) see soil fertility as one of the top two or three? Take care not to bias this question by former comments, by how the question is asked, or even by such

things as the organizational name or logo on the vehicles in which one arrives in the village.

6. Are yields of people's subsistence crops generally increasing or decreasing each year? By how much?
7. Have people already attempted to use natural means of improving soil fertility? What were these methods? Did any of them involve plants that fertilize the soil (that is, gm/ccs)? What do the farmers feel about using plants to fertilize the soil? Have they ever seen an example where this was done successfully? If so, what species did they see being used? Do people use animal manure? How much per hectare? Do they use compost, and if so, how much per hectare?
8. What are the dominant agricultural crops? Are other plants intercropped with these dominant crops? If so, what percentage of the land dedicated to these crops is intercropped? Do farmers use a crop rotation? What is the rotation, including the management and the seasons for each crop?
9. What percentage of farmers in the area still fallow land? For how many years at a time? Do farmers plant or harvest anything together with the natural vegetation on their fallowed land?
10. Do grazing animals exist in the area? Are they set free during the agricultural off-season(s)? Are there any limits on the areas where they roam?
11. What is the average rainfall? During which months does it rain the most?
12. What is the dominant land tenure system in the area? Do farmers own the land they farm, or can they be sure that they will be able to continue farming the land they have improved? What is the average size of the plot(s) belonging to each household? How many households have larger holdings, and how much land do they have?
13. Do women possess land? Do they have any use rights to land owned by others? Are these use rights long-term? How do women's priorities for the agricultural system differ from those of the men? (e.g. Do women want to plant different crops than men?)
14. What agricultural activities are carried out by women? What rights do they have related to crop or animal selection and use?
15. Have other agricultural programs worked in the area previously? What practices did they recommend, and what were the sustainable results of those efforts? What does the farm family feel about these efforts? Are other organizations working in the area presently? If so, do they work with gm/ccs, and what are their priorities among the various possible gm/cc systems?

These questions should be open-ended, to the extent possible. Farmers should be allowed to digress, bring up issues they want to mention, ask questions and express their opinions. As development agency personnel come closer to selecting a particular gm/cc technology to try, they need to consult farmers regarding how they feel about it.

In addition to these interviews, make careful observations. Often it is important to verify information by observation, since interviews alone can lead to wrong or incomplete information. Observe things like average yields, the prevalence of intercropping, and men's and women's roles in agriculture. Other factors that can and should be observed include the following:

1. Is nitrogen a major limiting factor in the soil? (If the leaves of maize or sorghum all turn yellow, nitrogen is almost surely the limiting factor.)
2. Do different fields vary widely in soil fertility? Why?
3. Are there large areas of fallowed land? Wasteland? Forest? How old are the trees in most of the fallowed land?
4. Is the agriculture quite intensive? For instance, are the crops well weeded? Is every scrap of land in use? Are technologies appropriate to intensive systems being used, such as terracing, contour ditches or barriers, diguettes, zai holes, etc.?
5. What kinds of erosion are problematic? Is the land mostly hilly or steep?
6. Is there a great variation in how the farmers of the area are using their land?
7. Is most of the organic matter in the fields consumed by animals? Is it burned?
8. Are farmers applying large amounts of animal manure, compost and/or sweepings from their compounds to their soil? Are they using chemical fertilizers? To which crops are these fertilizers applied? In what amounts?

6. Using The Decision Tree

How to Use the Decision Tree

The following decision tree should not be seen as a straitjacket. It should be used to get new ideas, but not to restrict what you can do. The options given may be expanded on. Other species can be tried. That said, the gm/cc systems listed in this decision tree are definitely worth a try. Nearly all of them are proven systems that hundreds of farmers have used for years, usually in the absence of any outside program. In many cases, thousands of farmers have used them for centuries.

Green Manure/Cover Crop Systems Included in the Decision Tree

The gm/cc systems included in this decision tree are almost all systems that either I or Gabino Lopez, a Guatemalan colleague, have observed during our more than 25 years of observing gm/cc systems around the world. Thus we know the systems, have a feel for the situations in which they have prospered, and have been able to interview farmers using these systems. The list includes systems that are used in about 25 developing countries. Obviously, there must be many systems that we have not observed in these countries, and additional systems most likely exist in approximately another 60 developing countries.

This list includes only gm/cc systems that use legumes. It does not include non-leguminous gm/ccs such as the oats, forage turnip (*Raphanus sativa*) and sunflowers often used in South America, the fonio used in West Africa or the three-year cassava used in Vietnam. It also does not include the vast majority of gm/cc systems based on tree species in agro-forestry systems, which are also extremely common around the developing world.¹² In most cases, the number of farmers mentioned is only a rough estimate, since it has often been 10 to 20 years since Gabino or I visited these systems.

The gm/cc systems are distinguished from each other by the species of gm/cc that is used, by the cash or subsistence crop, or by the date of planting or management of each system. When essentially the same gm/cc system is used in more than one country or continent, I will describe the system only once and list the other places it is practiced. In many cases, especially when gm/ccs are used in rotations or to recuperate wastelands, they are associated with any of a number of traditional crops. In these cases, each gm/cc species is counted as one system.

Characteristics of the Green Manure/Cover Crop Systems Recommended

As mentioned, the gm/cc systems included in this decision tree are those that have proven themselves most successful among smallholder farmers, according to two criteria. The first is that their use has spread fairly widely. A particularly dramatic case would be that of S1, the maize/mucuna system in Mexico and Central America,

¹²Cairns, Malcolm, ed., *Voices from the Forest, Integrating Indigenous Knowledge into Sustainable Upland Farming* (Washington, D.C.: Resources for the Future, 2007).

which has spread almost continuously from north of Veracruz in Mexico, through Guatemala and parts of Belize, to half way across the northern coast of Honduras, in less than 60 years.

The second criterion is that adoption of the system has lasted a long time, as exemplified by the case of S13, the maize/runner bean (*Phaseolus coccineus*) system. This system has lasted from long before Columbus arrived in the Americas to the present day. At one time, this system was utilized in both temperate and highland tropical regions from New York State in the U.S. (where it is known as the Seneca bean), through Mexico (*ayocote*), Guatemala (*piloy*) and Honduras (*chinapopo*) to Colombia (*frijol cacha*), Ecuador, Peru and Bolivia.

I have not included a few long-term, widely used systems that fall into one of two categories. First are some of those systems that use thorny gm/cc species. Anyone who has seen Dogon farmers in Mali trying to bury troublesome spines in their field, or seen a child's foot that was badly infected because it had been punctured by a thorn from a local bush, will understand why I have not included these.

The second group of gm/cc species not included here is that of plants, such as the kudzu (*Pueraria spp.*) or perennial soybeans (*Glycine wightii*) that have become, in one environment or another, serious invasive species. Invasive species are species introduced to a non-native environment, where they act like weeds or otherwise negatively affect the local ecosystem. These plants might sometimes serve as very good gm/ccs, but the danger that they will spread and negatively affect tens of thousands of smallholder farmers is just not worth the risk.

In both of these cases (the thorny and the invasive species), we usually have other species that can serve just as well, or nearly so. The comparative advantage that the former species might provide is not worth the risk of their becoming a problem. Other systems included in the list of gm/cc systems are not recommended by the decision tree. These systems can add to your knowledge of the potential variety of gm/cc systems, but I consider them to be a distant second- or third-best system for any particular situation. They are mentioned so you can read about and consider them, and even visit them if they happen to exist near where you work, but they are not—to my way of thinking—the best possible solution to any particular situation.

In places where soils are so poor that most of the gm/cc species listed below will not grow well, we have to start by using a gm/cc species that is more resistant to poor soils, such as the jackbean (*Canavalia ensiformis*) or tephrosia (*Tephrosia spp.*). After one to three years, these species will have improved the soil enough so that less hardy species can take the place of these hardier “pioneer” species. The original gm/cc species will not have many secondary advantages (almost all of the hardest species cannot be eaten because they have serious anti-nutritional factors), but within a few years, farmers will be able to switch to species that do have additional advantages.

Another faster, but more expensive, way of improving very poor soils is to use a moderate amount of animal manure the first year or two, in order to allow the ideal

gm/cc to develop adequately. After one or two years, the gm/cc will have improved the soil to the point that there is no more need to use manure.

Elevations listed for the gm/cc species in the decision tree should be taken as a general guide, not as hard and fast rules. The best elevations will vary somewhat according to the variety of the gm/cc species being used, the quality of the soil (with better soils, they will grow well in a wider range of altitudes), and the distance from the equator (the further from the equator, the lower the elevation at which they will grow best). Still, we should remember that gm/ccs are only valuable if they grow rather vigorously, and altitude above sea level has a tremendous impact on the growth of most gm/cc species. A gm/cc may grow outside of the range of elevations mentioned, but grow so slowly that it would be better to use a different gm/cc species that grows more vigorously under the given conditions. Other local management considerations can also affect what species is grown at a given altitude. The lablab bean, for instance, is only recommended in this decision tree between the altitudes of 0 to 1,500 m. Nevertheless, near Jesus de Otoro, Honduras, hundreds of farmers working at 1,800 m in elevation are growing lablab beans as a gm/cc despite their less-than-vigorous growth at that altitude because the farmers are very interested in the high quality dry-season fodder produced by the plant.

Some agronomists looking at this decision tree will be bothered by the lack of attention to different soil types. Our experience around the world has been that soil type rarely has a tremendous impact on the growth of gm/cc species, except when soils are waterlogged or have extremely high or low pHs. When pHs are extremely low, jackbeans (or even *Desmodium ovalifolium*) may have to be used until the increase in organic matter buffers the pH up to a more hospitable level of acidity.

Tree species are apparently more susceptible to pH levels. For example, mother of cacao (*Gliricidia sepium*) grows better in acid soils and leucaena (*Leucaena leucocephala* and *L. diversifolia*) grows better in neutral to alkaline soils.

A Note about Scientific Names

The idea of establishing scientific names for each species of plant in the world was to have only one name for each species. Yet over time, scientists have changed the names of many gm/cc species, in some cases over and over again, which to some extent defeats the purpose of having scientific names. Lablab beans have, at different times, been called *Dolichos lablab*, *Lablab purpureus*, *Dolichos purpureus* and *Lablab niger*. Mucuna has been called *Stizolobium pruriens*, *Stizolobium aterrium*, *Stizolobium niveum*, *Stizolobium deeringiana*, *Mucuna deeringiana*, *Mucuna pruriens* and *Mucuna utilis*. Some of these names are used only for one color of mucuna seed (that is, one particular species of mucuna), but many of them have been used to refer to all the different types of mucuna in general.

In this book, we use the scientific name that from our experience is most commonly used around the world today.

7. Decision Tree

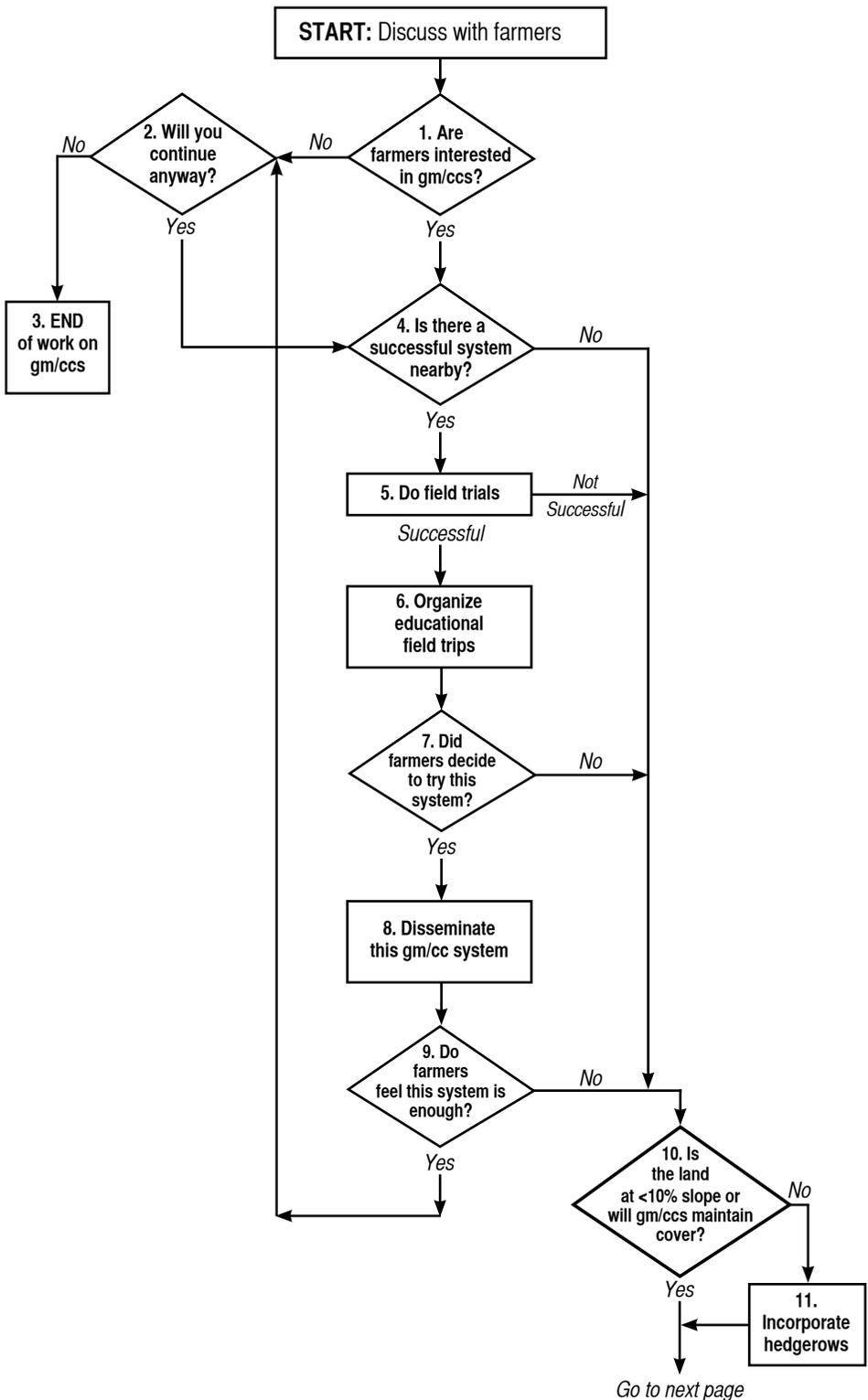
Introduction

The decision tree presented in this section is relatively simple to use. Start with #1 on the diagram and answer the questions in each box to help identify the most appropriate gm/cc system for a given location.

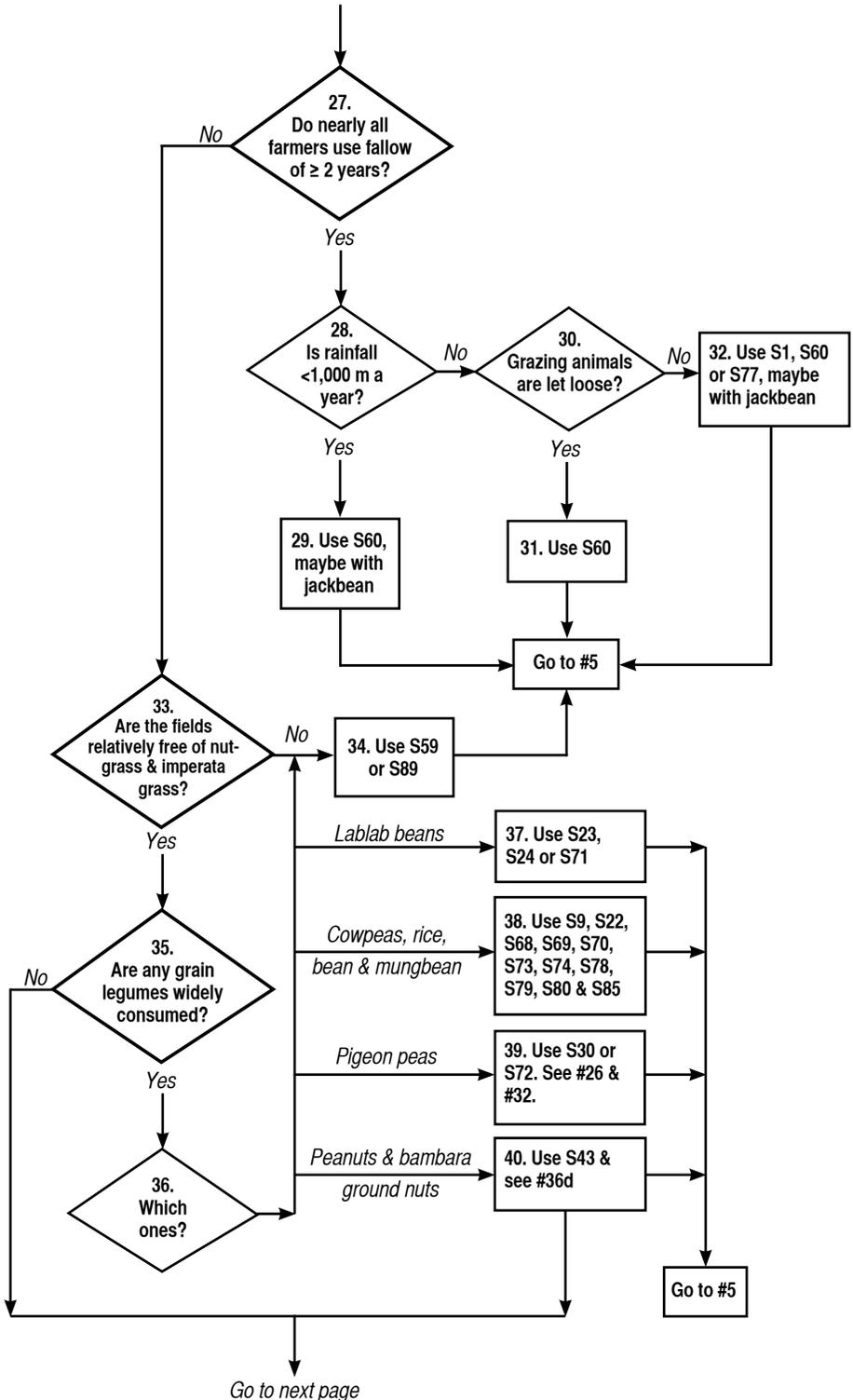
Note that there are two types of numbering system used in the decision tree. The first numbering system simply numbers each box in the decision tree. Additional information on each of these boxes is provided in the section immediately following the decision tree named “Decision Tree Guide.”

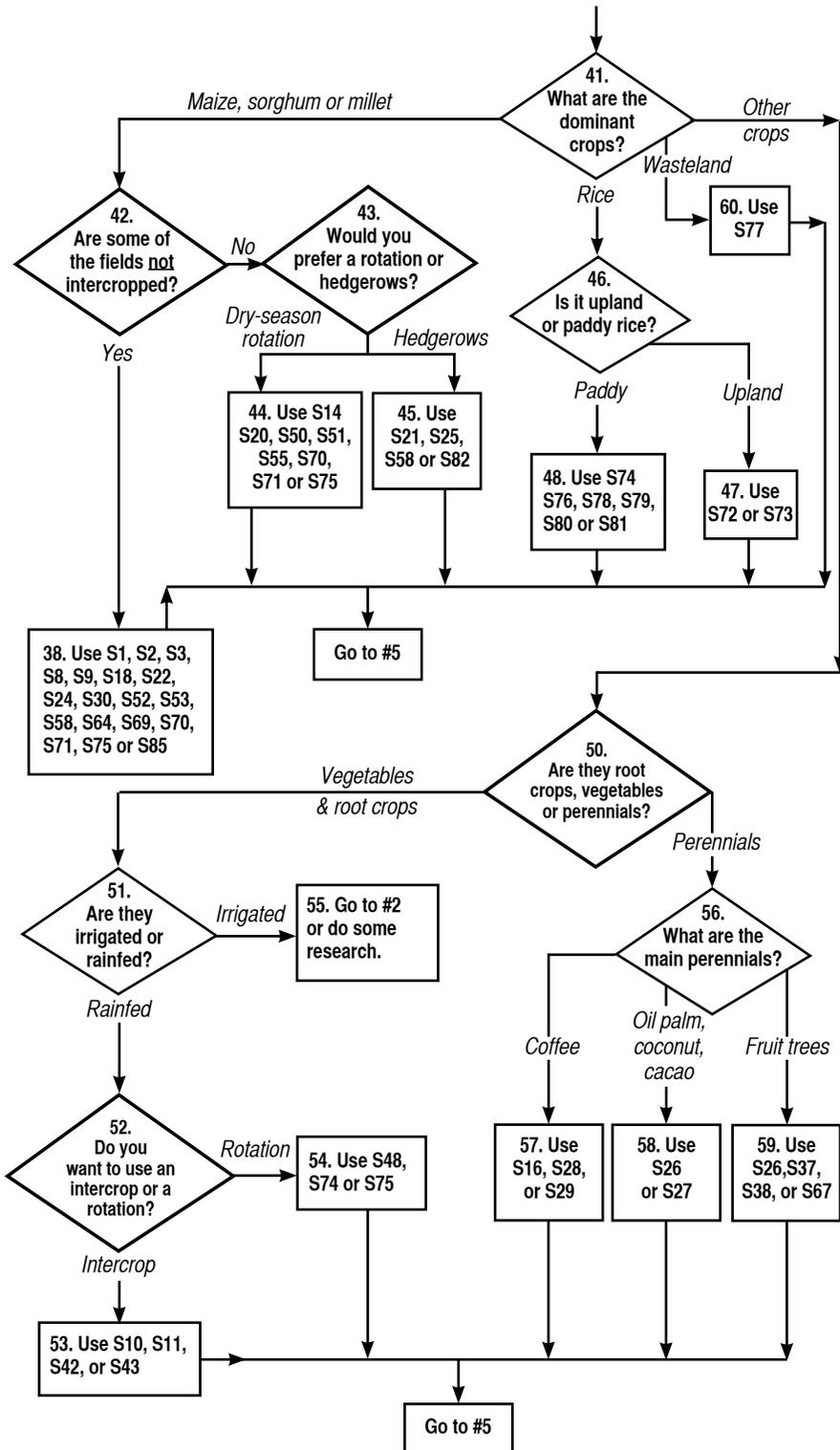
The second numbering system in the decision tree identifies each of the recommended gm/cc systems one arrives at after working through the decision tree. Each number in this second numbering system begins with an “S.” Immediately following the “Decision Tree Guide” is the section with detailed explanations about the 91 recommended gm/cc systems, titled “Green Manure/Cover Cropping Systems.”

The most important characteristics of each of the more important gm/cc species in each system will be included when that species is first mentioned in the decision tree. A list of where each species description appears is provided in Annex 3: List of Recommended Green Manure/Cover Crop Species.



Go to next page





Decision Tree Guide

Each of the points below refers to a numbered box in the decision tree. Each point provides additional information on the decision tree boxes and will assist in selecting options as one moves through the decision tree.

1. **Farmers' priorities.** If farmers do not include soil fertility or the need for fertilizers as one of their two or three most important problems, and don't seem to show much interest in working on soil fertility, go to #2. If they do identify soil infertility as a major problem and show a strong interest in trying to solve the problem, go to #4.
2. **The importance of gm/ccs.** Seriously consider the possibility of not working in soil fertility. If the decision is not to work in soil fertility, go to #3. If you still believe strongly that soil fertility is a major problem in the area and success in tackling it is still definitely possible, go to #4.
3. **The end.** This is the end of the program's work in gm/ccs. Maybe something will change (for instance, people's soils become poorer, so they will have more motivation to improve them) that will make gm/ccs more attractive or easier to manage in the future, but for now, gm/ccs will not be part of the program's agenda.
4. **A successful system nearby?** Is there a successful gm/cc system near the project location or in an area of roughly similar farming systems and ecological environment? Or do the farmers know of such a system, and are they interested in it? Are more smallholder farmers adopting this gm/cc system, or are they gradually abandoning it? Are they adopting it in the absence of any artificial subsidies or any program that is promoting it? If the answer is yes to most of these questions, go to #5. If there is no such system, go to #10.

If there is such a system, but you cannot answer yes to the questions, interview the farmers that are using it, being careful not to just take their answers at face value. Analyze the system's economics and its pros and cons, both according to the farmers and according to your own analysis. If the system does not seem to provide more benefits than costs, go to #10. If it does, go to #5.

5. **Field trials.** Organize at least three or four trials of the technologies in question. Preferably, trials can be done on the land of the best farmer leaders, or of those farmers who will do the best job of managing the experiments and whose farms, if possible, are accessible. If there is not a strong relationship with the farmers, or the farmers may not properly manage the experiments, conduct a trial on a small plot of rented or borrowed land.

Keep very close records of the costs and benefits as compared to traditional systems, being especially careful to include all labor costs. Far too often those of us

who work in agricultural development recommend certain technologies without knowing at all whether their costs are actually covered by their benefits. If the experiments fail, go to #10. If they are successful, go to #6.

The germination of all seeds that are bought should be tested by placing 50 to 100 seeds between about 30 pages of a moistened newspaper. The newspapers should be kept moist throughout the test period. One to two weeks later, the germination rate of the seeds will be obvious. Note that with some of the more drought-resistant seeds, such as mucuna, some of the seeds will not germinate until up to a month's time.

6. **Educational field trips.** Organize educational field trips so that influential farmers of both sexes can see the results of the gm/cc experiments. If possible, it is important that farmers take note of two things in particular. One is that gm/ccs may well also be food crops. The second is that after the gm/cc crop residues have been applied to the soil, traditional crops grow healthier and are more productive. Two educational field trips will probably be needed to observe both of these features of the system. Go to #7.
7. **Farmer interest.** If the farmers still do not seem interested, find out why. If their objections are justified, go to #10. If they seem excited about the new possibility, or want to learn more about what was done in the experiments, go to #8.
8. **Extension work.** Start promoting the system in the area, by getting farmers to test the system on a small scale on a plot anywhere from 10 m x 10 m to 25 m x 25 m. To do this, use a participatory extension methodology, whereby farmers first experiment with the new technology on a small scale (known as participatory technology development) and then teach each other the technology once they have successfully tried it out (known as farmer-to-farmer extension). See my book, *Two Ears of Corn: A Guide to People-Centered Agricultural Improvement*, where I refer to "villager extensionists."

It is very important to get as much feedback as possible on these experiments done by farmers. Have frequent conversations with these farmers. If problems occur, try to trouble shoot very quickly. In addition to listening closely, watch closely whether farmers who have tried the technology use it on larger and larger plots of land, whether those not in the program adopt it (both of these are good indications), or whether those who tried it abandon it (a bad indication). Go to #9.

9. **Do the farmers want to learn about more gm/ccs?** If the farmers understand the potential of gm/cc systems yet feel that, with this first system working well they already are using enough gm/cc systems, go to #2. If they would like to learn about more gm/cc systems, go to #10.
10. **Hillsides.** If the land most farmers in the area are using is at a 10% slope or less,

or the gm/cc systems they would most likely apply will keep the soil covered during almost all of the annual rainy season or seasons, go to #12. If the soil is at less than a 35% slope and will be well-covered during the rainy season, go to #12. If neither of these conditions applies, go to #11.

- 11. Contour hedgerows.** To prevent or reduce water erosion, many farmers around the world are using contour hedgerows. This is a subject that could fill a book. I will mention just a few points that are very important and controversial among some practitioners. First of all, ground cover is far more important than physical barriers in preventing water erosion, whether the barriers are contour hedgerows, rock walls, ditches, or whatever. If the gm/cc covers the ground well and the rains are not too plentiful, farmers may not need hedgerows at all, even when the land is at a 40% slope. The ranges mentioned in #10 are applicable to most situations.

Second, trees are not as effective as grass at holding the terrace face that may gradually build up (to as much as 75 cm), so probably the best over-all species for hedgerows is Napier grass (*Pennisetum purpureum*), which is sometimes called elephant grass. This species has a double function, as it holds the eroded soil very well and provides a large amount of fodder for animals. If possible, use the varieties of napier grass that do not have small hairs on the leaves, as they are much more palatable for animals and do not spread into farmers' fields nearly as quickly. If grazing animals roam free during the dry season, the farmer who owns the hedgerows will receive no benefit from the napier grass as a good source of fodder. A better choice in that case would be vetiver grass (*Chrysopogon zizanioides*). If the slope is less than 20% (so the terrace face will never get too high), the fields are at less than 1,000 m in elevation and the animals are under control, sugarcane is usually much more popular—but it will fall over if the terrace face grows more than 25 centimetres (cm) in height.

If farmers really want to plant non-grass crops in their hedgerows, such as pine-apples or fruit trees, a good option is to plant the grass and then space the other crops along the grass barrier. This would also apply to trees planted to create dispersed shade. If farmers want to plant other grasses, such as lemon grass or a shorter-stature grass among vegetables, they can use these instead of napier grass, at least on parts of their land.

Hedgerows should not be planted at less than 12 m apart, because farmers will usually reject any shorter spacing. The rows can be as far as 20 m apart on less inclined slopes. If the hedgerows are too far apart to catch all the soil, do not move them closer together than 12 m; instead, find a way to cover the soil better with a gm/cc. Hedgerows should be laid out by the farmers using A-frame levels.

Hedgerows can be planted after the gm/ccs or at the same time, except where erosion is excessive. In the latter case, the gm/ccs will not provide any increase in crop yields until the hedgerows are developed enough to prevent the gm/ccs' organic matter from being washed down the hill. Go to #12.

12. Altitude above sea level. At what range of altitudes do you work?

- a) If mostly below 1,500 m above sea level, go to #22.
- b) If mostly between 1,500 m and 3,000 m above sea level, go to #17.
- c) If mostly above 3,000 m above sea level, go to #13.

13. Above 3,000 m. What is the main crop in the area? If it is maize, go to #14. If it is potatoes, go to #15. If it is fruit trees, go to #16.

18. Mexico. In the Americas, fava beans are only produced at high altitudes, but are produced at low elevations in the Sudan and other parts of the Arab world. In either case, they make a very valuable and tasty gm/cc for intercropping with maize, sorghum or millet. In fact, since the plants are erect and therefore will not pull down the sorghum or millet, they might be one of the best intercrops for these grains. However, I know of no one who has ever tried such a system.



19. Honduras. Scarlet runner beans have tremendous potential for use in highland maize systems. Sometimes tephrosia will also have to be grown in the same field, to keep the weight of the runner bean's biomass from pulling down the maize stalks.

14. Maize. Fava beans (also called “broad beans”) and runner beans (sometimes called “scarlet runner beans” because many varieties have bright orange-red flowers) can usually be intercropped with maize at these altitudes (Photos 18 and 19). Both produce widely consumed and tasty edible beans. Fava beans can be eaten both green and dry. The runner bean generally produces more organic matter, and increases soil fertility more, than do the fava beans.

Farmers from central Honduras have intercropped runner beans with their maize for 20 years without using chemical fertilizer and without seeing any decrease in their soil's productivity. Runner beans often don't grow well the first year in a given field (presumably because of a lack of appropriate rhizobium), but should grow very well after the first year. They also have a tuber that sprouts each year for up to ten years after the first planting, thereby eliminating the cost of reseeding them, but farmers say it is better to replant them every fifth year.

See information on the systems using both fava beans and runner beans in S6, S12 and S13. If you choose one of these, go to #5.

Another possibility is sweet clover (*Melilotus albus*), used in areas where people also raise cattle. Sweet clover is a very hardy perennial that will fertilize the soil efficiently, and also provide fodder for cattle during the entire dry season. It is so

hardy that the biggest worry for years with respect to this species was that it was difficult to eliminate. One method to remove this species from a field is by pruning it down to the soil surface at the beginning of the dry season. If you select this system (described in S7), proceed to #5.

15. **Potatoes.** Tarwi (*Lupinus mutabilis*) can be used at these altitudes (Photo 14). Tarwi is used in a number of ways to fertilize white potatoes in the Andean countries. Tarwi produces a traditional, still widely-consumed edible bean, although it must be washed and cooked before consumed. Tarwi is an erect plant that reaches about 1.5 m in height. It is also one of the best legumes in the world in terms of fixing nitrogen and produces up to 400 kg N/ha. Choose between systems S32, S33, S34 and S35, and then go to #5.
16. **Fruit trees.** See information on tarwi in #19. See S40 and then go to #5.
17. **Area's main crop?** What is the main crop in the area? If maize, go to #18. If white potatoes, go to #19. If fruit trees, go to #20. If it is various other annual crops, go to #21.
18. **Gm/ccs for medium-altitude maize.** Both fava beans (*Vicia faba*) (Photo 18) and runner beans (*Phaseolus coccineus*) are commonly intercropped with maize. (See descriptions of these in #14.) If the farmers prefer fava beans, use S6 and go to #5. If they would prefer runner beans, use S13 and go to #5.
19. **Potatoes.** Tarwi (see #15) can be planted with potatoes in a variety of ways. If farmers prefer to use tarwi in a rotation with potatoes, choose S32. If they prefer to grow it along the borders of their potato fields, use S33. If they choose to intercrop it among their potatoes, use S34. In each case, return to #5.

If farmers would prefer to grow fava beans (described in #14) with their potatoes, see S35, and go to #5.
20. **Fruit trees.** Select S40, and then go to #5.
21. **Other crops.** Consider S40 and S63. If you decide in favor of either, go to #5.
22. **Below 800 m?** If the region is between 800 m and 1,500 m in elevation, or in a temperate zone, go to #27. If within the tropics and below 800 m in elevation, consider using dispersed shade along with the low-stature gm/ccs. Go to #23.
23. **Dispersed shade.** Dispersed shade refers to a light tree cover (about 15% to 20% shade) that is maintained over a field in the lowland tropics. In these areas, the mid-day heat is so intense that all unshaded crops stop growing for two or three hours in the middle of the day. A light shade will create a favorable micro-environment that can increase crop yields by about 40%. Scientific experiments have shown that 15% shade will also increase the growing period of crops by at

least a week or two. This happens because with the reduced temperature under the trees, both the rate of evaporation and the rate of transpiration are reduced. Therefore, the soil dries out slower allowing crops to grow longer. Soil nitrogen also burns off more slowly. These differences often mean that farmers can, for instance, grow maize instead of sorghum.

The benefit to crops from shade trees provides a win-win situation. In addition to improving crop yields, the trees can produce fruit, timber, firewood, natural pesticides, and/or soil fertility. All these advantages come with the simple cost of planting the trees, protecting them for one or two years from animals (including termites), and pruning them once a year (or twice a year if there are two rainy seasons). Even the pruning offers a benefit to families, because the firewood produced in this way usually requires less labor than cutting and carrying firewood from distant forests.

Most dispersed shade systems consist of trees planted 8 to 12 m apart in each direction, creating a population of about 64 to 150 trees/ha. If only bushes are used (for example, to supply shade to low-growing vegetables), the spacing might be only 1.5 to 2.5 m between the bushes. Gm/ccs used in this way include pigeon peas (*Cajanus cajan*) and tephrosia (either *Tephrosia vogelii* or *T. candida*).

Dispersed tree systems will also provide significant protection against the effects of global warming. As the weather gets hotter, the trees can be pruned a little less, thereby creating the same favorable temperatures for the crops below them. Go to #24.

- 24. Native trees or exotic species?** Several rapid growing non-native tree species can improve crop yields, simplify management and provide multiple benefits for farmers. These are mother of cacao (*Gliricidia sepium*), leucaena (*Leucaena leucocephala* or *L. diversifolia*) and pigeon pea (*Cajanus cajan*). Mother of cacao grows three to four times faster under Sahelian conditions than does *Faidherbia albida*, one of the best native Sahelian species for use as dispersed trees. The mother of cacao has edible flowers, no thorns and bark that is a natural pesticide. If exotic tree species are desired, go to #26.

However, native species are usually more resistant to local pests and diseases, ecologically more desirable, and better known by the local farmers. Sometimes fields already contain trees of these species, or still harbor root systems that grow every year but are often cut off at ground level by farmers. Advantages of local trees include the fact that they do not need to be propagated, and their already well-developed root systems will provide good growth and drought resistance from the beginning. The system of allowing tree roots to grow into trees in farmers' fields is now widely called "Farmer Managed Natural Regeneration," or FMNR. It has been successfully used to dramatically increase the number of trees in major parts of Niger and Mali.

Native trees and exotic trees can both be used to provide dispersed shade. A combination will provide a wider variety of trees and increase biodiversity, and will therefore be a more sustainable option. If the farmers select native tree species, go to #25.

- 25. Dispersed shade with native species.** The species you decide to use will probably depend on what is locally available. If a lot of trees already exist in the fields, you can pick and choose among those species, selecting leguminous trees without spines, if possible. Though it does have the problem of thorns, *Faidherbia albida* (previously *Acacia albida*) is easily the most desirable in very drought prone areas like the northern Sahel because it drops its leaves during the rainy season and therefore does not need to be pruned. (Other trees will need some pruning immediately before the rainy season to reduce crop shading.) Furthermore, because it is dormant during the rainy season, it does not compete with nearby crops for water. Therefore, despite its thorns, *F. albida* is preferred by farmers in northern Sahel. Nevertheless, as one moves from the drier areas to higher rainfall regions, the advantages of the *F. albida* will diminish in importance, and the problems of its thorns and relatively slow growth will make it less desirable than some other species.

Trees like the shea butter trees that produce an income are also a desirable option.

Those wanting to use native species in dispersed shade systems in very dry areas (such as the northern Sahel) should consider using the Farmer Managed Natural Regeneration (FMNR) system. In this system, instead of establishing nurseries and planting trees (a process that in these extremely difficult environments fails more often than it succeeds), farmers are encouraged to quit cutting or burning, and to protect the trees that grow naturally each year from stumps or underground roots in their fields. In many of these environments, well over 50 such stumps or roots per ha already exist. Trees grown this way almost always survive, and often grow much faster than trees grown from seeds because the new trees do not have to grow a new root system. On the other hand, farmers have to resign themselves to having trees of various species growing in their fields in a random spacing. In Mali, many Dogon farmers prune these trees in order to maximize crop production under the trees, and some plant additional trees by feeding viable seeds of desired species to their cattle. FMNR has been used to successfully populate hundreds of thousands of hectares of cropland with trees in Mali, Burkina Faso and southern Niger.

- 26. Dispersed shade with exotic species.** First, remember that having many different species in your field (that is, having high biodiversity) is always good. If you can combine some native trees with the exotic trees, the system will be less risky and perhaps more sustainable—because if one tree species dies out, others can still be used. It should be noted that most native trees grow much more slowly than leucaena or mother of cacao.

Leucaena trees have been written about extensively. They are the miracle trees for neutral and alkaline soils. The leaves are extremely good for soil improvement (the impact on the soil of various tree species depends on a lot of poorly understood factors, only one of which is the amount of nitrogen in the leaves). The leaves can be eaten by animals, but leucaena leaves should make up no more than half of the animals' diet. The branches are good for firewood and the immature seeds are edible. The trees sprout vigorously after being trimmed or cut off, so that a forest of leucaena, like one of eucalyptus, never really disappears. *L. leucocephala* generally works better below 800 m of elevation and *L. diversifolia* grows better above that altitude.

For acid soils, mother of cacao replaces leucaena as the miracle tree. It also produces vast amounts of leaves that fertilize the soil. The leaves are edible by animals, though cattle will generally not consume it unless they are hungry. The branches are good for firewood, the bark can be used to kill rats and mice, the leaves are used to make insecticides and foliar fertilizers, and the flowers are edible for humans. The tree also grows vigorously after having been cut off, which makes it very easy to control the amount of shade under it.

Bushes, such as pigeon peas and tephrosia, can be planted every 1.5 to 2.5 m to provide dispersed shade for low-growing crops such as vegetables or beans.

Pigeon peas (*Cajanus cajan*) can be used for shade only when associated with crops like vegetables that grow low to the ground. The pigeon pea plant lives for about four years, usually producing its best harvests of edible peas in the second and third years. Sometimes it grows rather poorly the first year in a given field, probably because of a lack of rhizobia. Pigeon pea is usually 2 to 4 m tall with its height strongly influenced by the soil fertility level. If over-shading is a concern, the pigeon pea can be pruned each year to a minimum height of about 60 cm.

The pea is edible, tasty and highly nutritious. In fact, pigeon pea is the fourth most widely eaten grain in the entire world (after rice, wheat and maize). It is eaten in most of India, West Africa and the Caribbean. The grain can also serve as an excellent feed for animals. It should be cooked for fowl, but not for other animals.¹³

It is preferable to use pigeon peas where livestock grazing is controlled during the dry season. Tephrosia is best used in uncontrolled grazing systems since only goats will eat this species if it is planted quite near the homestead. See #29 for a more complete description of tephrosia.

Dispersed shade trees can often be combined with hedgerows planted with another gm/cc species. The hedgerows can be planted between the shade trees in every tree row or every other tree row. In the Sahel, for instance, nyama or tephrosia is grown in hedgerows under dispersed shade provided by mother of

¹³Kowal, Torsten Mark, Manual sobre el Manejo y Aprovechamiento del Frijol Gandul, 1994.

cacao or leucaena. This arrangement is potentially beneficial because dispersed trees are planted so far apart that they normally do not provide enough organic matter to maintain the soil's fertility.

If interested in a system designed for the northern to central Sahel, go to S58. If interested in finding a temporary dispersed shade for coffee, go to S16. In either case, try to organize an educational field trip to somewhere where such a system already exists (go to #6). If a dispersed shade tree system doesn't exist in the region, it is impractical to do field trials of this technology because these species take so long to mature. Thus it is best to plant some dispersed shade examples with interested farmers—not as experiments, but as eventual demonstrations, with the idea that the systems will be available as demonstrations for many years. Since dispersed shade trees also need low-growing gm/ccs to improve soil organic matter, go to #27.



20. Haiti. Jackbean seeds can often be found in the forests of Latin America or Africa. In Africa, village women will often know where to find them. The jackbean pods can be eaten when they are long and still thin, but the seeds should not be eaten, as they contain "Concanavalin A," which blocks calcium absorption by the body. In areas with a major lack of firewood, the pod can work quite well as an alternative to firewood.



21. Mexico. In this dry area of Mexico, most of the maize in this field died because of a lack of rain, while the jackbean shows no sign of moisture stress. Jackbean is the most drought-resistant of all the annual gm/cc species we know.

27. Fallows still exist? If a large majority of the farmers in the area still use a two-year or longer fallow, go to #28. If not, go to #33. In the case of improved fallows (#28 to #32), farmers who cannot fallow their land will not be able to use the technology. Avoid promoting improved fallowing systems where a large part of the farming population has limited access to land, as this may further reduce land accessibility and exacerbate inequalities.

28. Rainfall levels for improved fallows.

The simplest way of introducing a gm/cc in a region is by using it in an improved fallow. By focusing on what grows on the fallowed land, rather than change the farming system, soil fertility will be improved at a significantly faster rate than what farmers would achieve in five to ten years with a natural fallow. These systems of improved fallows are normally very popular, if kept as simple as possible. If the rainfall is less than 1,000 mm per year, go to #29. If it is more than 1,000 mm per year, go to #30.

29. Improved fallows in lowland, drought-prone areas. Probably the best approach here is to test the following three varieties/species to determine and compare which



22. Honduras. Tephrosia is most widely used as a temporary shade for coffee, but has tremendous potential as a smallholder gm/cc crop where uncontrolled grazing is practiced. Being poisonous, animals will not bother it.

grow well and effectively control weeds given the local conditions of altitude and weed pressure. The three varieties/species are bushy-type jackbean, climbing jackbean or swordbean and tephrosia (either *Tephrosia vogelii* or *T. candida*). A week or two before the beginning of the first rainy season in the fallow period, broadcast the seed of both varieties of jackbean and the tephrosia. The jackbean seed (Photo 20) should be sown at a rate of about three seeds per square metre and the tephrosia about one to two seeds per square metre.

The jackbean (*Canavalia ensiformis* - white seed) and its close relative, the swordbean (*Canavalia gladiatus* - red seed), are by far the most drought resistant gm/cc species used, even when just a week or two old (Photo 21). They are also the most resistant to poor soils, and grow well in moderate shade. The jackbean can fix up to 240 kg N/ha each year, so where nitrogen is

the limiting factor, soil fertility will increase rapidly in one year. Furthermore, like the tephrosia, jackbean can grow through much or all of the dry season, greatly reducing the nitrogen loss problem.

Both species of tephrosia are woody-stemmed bushes that will reach three or four metres in height under good growing conditions. The tephrosias are very drought-resistant, but usually don't grow well below 300 to 400 m of elevation. Because they are poisonous, animals will not eat them except under conditions of serious drought (Photo 22).¹⁴ Tephrosia plants will die after about four years, but the soil is generally fertile before then. African farmers who use either of the tephrosias as an improved fallow usually cut it down and kill it after only one or two years, because the soil is ready for cropping by that time. Weed control is usually very good if it is sown thickly, as mentioned above. Tephrosia can be used to make an insecticide. If tephrosia is the best fit, see S60, then go to #5.

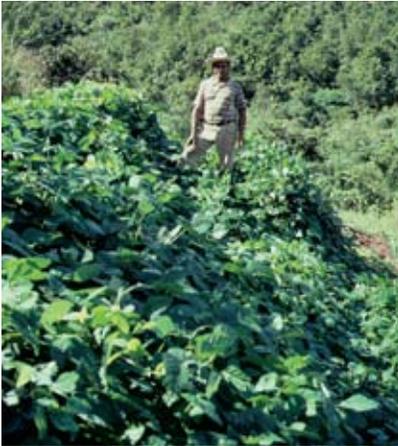
30. Are animals let loose during the off season? Are the domestic animals (cattle, sheep or goats) let loose when crops are not in the fields? If so, go to #31. If not, or if there are no grazing animals in the villages, go to #32.

31. Improved fallows where the animals are loose. Here the best species are the two tephrosia species and the jackbean. As with the tephrosias, the jackbean may be attacked by animals if they are very hungry, but this rarely occurs in areas with

¹⁴ See, for instance, Cherry, Stefan, "Tephrosia fallow management in Cameroon," in *ECHO Development Notes*, Issue #65, 1999.

more than 1,000 mm per year. These systems would be the same as those in #29. Go to #29.

- 32. Improved fallows where the animals are kept away from the fields.** In these areas, improved fallows can use any one of several species. Try mucuna (*Mucuna spp.*) (Photos 15 and 23) and pigeon pea (*Cajanus cajan*), along with the jackbean and tephrosia.



23. Honduras. This mucuna was planted in another part of the same field as shown in photo 15. The mucuna has only been growing for 45 days, in spite of the poor condition of the soil. For extremely poor soil, jackbeans will grow better than mucuna.



24. Honduras. The mucuna we use as a gm/cc must not be confused with the itchy type of mucuna, which has a cover of small hairs on the pod (the variety to the right). This itchy kind should never be used in farmers' fields. Some farmers traditionally use the itchy kind (e.g., in central Ghana). These farmers should be told that the non-itchy kind is just as "strong," meaning it fertilizes their fields just as well.

This may be the ideal situation for mucuna, a gm/cc species that has, in the past, been tried in many situations that were not ideal for it. If there is enough rain mucuna will grow most of the year, or will reseed naturally in January (July in the southern hemisphere). The use of mucuna usually results in a very good, high-nitrogen level improved fallow that is also very efficient at eliminating most weeds. The farmer obtains a virtually weed-free, fertile soil in 12 months (Photo 13). The mucuna seed can be broadcast either when there is no vegetation because the field has just been plowed or the vegetation cut, or when there is naturally very little vegetation, such as just before the rains start (although the field must have been dug or plowed sometime within the last year or so). In either case, the mucuna seed should be planted when under normal climatic conditions there will be significant rainfall for at least the following three or four months. The use of mucuna can restore the soil in six months to a year. (See, for instance, S1 and S77. The mucuna need not be a perennial mucuna, like that used in Vietnam.)

Mucuna is the best-known of all the gm/cc species (Photo 24). It is also probably the most widely used gm/cc species in the world, since it is extensively grown in the Americas, Asia and Africa. This may seem strange, given that it produces no easily edible bean or widely useful by-product. The beans can be eaten, and are high in protein, but only after some major



25. Honduras. *Mucuna* can also be consumed, once it has been treated to rid the bean of its L-Dopa (which is a medicine used for treating Parkinson's disease). Gm/ccs like cowpeas, rice beans, mungbeans and lablab beans for low altitudes, and fava beans, scarlet runner beans and tarwi for higher altitudes, can be consumed without the need to take any such precautions.

processing to get rid of the L-Dopa they contain (Photo 25). On the other hand, for people with Parkinson's disease, L-Dopa is the drug of choice, so a cup or two of coffee each morning, made with well-roasted *mucuna* seeds, can provide some relief for those Parkinson's patients too poor to buy pills. If mixed half and half with normal coffee, the slightly different taste of the *mucuna* coffee is not noticeable.

Very likely, *mucuna*'s popularity is due to its ability to control weeds. It is by far the best gm/cc species for this purpose. The fact that farmers have given it so much use and prominence is a major indication of

farmers' priorities: reducing labor demands is very high on their list and manual weed control demands a lot of labor.

Most *mucunas* are superior weed killers because they crawl and climb aggressively. (Photo 13—only the perennial *mucuna* is a bushy type, but it has not been popular with farmers because it often fails to produce seed and it does not control weeds as well.) Generally, we prefer not to use *mucuna* as an intercrop for this very reason—it is too difficult to keep it from smothering the crop(s) with which it is associated. At first, program personnel and farmers who see *mucuna* growing over everything in sight might fear it will become a pest, crawling over and suffocating everything. (I have seen it grow up to the top of a 20 m tall pine tree.) But it is very easy to get rid of. If *mucuna* is cut below the first branches before it has produced viable seed, it will disappear from a field.

Mucuna's aggressiveness and ability to place its next leaf precisely where it will prevent weeds from getting any sunlight at all are probably what make it such a superior "green herbicide." Some people also attribute *mucuna*'s weed control attributes partly to allelopathic substances in its leaves that may deter the growth of weeds. Furthermore, the 140 kg of N that is fixed per hectare and high levels of organic matter production (in some cases as high as 75 MT of organic matter (green weight) per hectare each year) make it a wonderful fertilizer (Photo 12). It also decomposes quickly, like most legumes containing a high percentage of nitrogen. When the leaves are incorporated into a moist, lowland tropical soil, they will disappear within two to three weeks.

Rapid decomposition is usually not desired, because a lot of the nitrogen will be washed out of the soil (and into the groundwater) as a result. That is one reason to leave the plant material on top of the soil, or bury it together with the rest of the organic matter from the fallow. If the *mucuna* is planted with crops, we leave

it on top of the soil (together with the residues of crops such as maize or millet), so the decomposition process will take place more slowly. Leaving the mucuna vegetation on the surface is far preferable in nearly all instances especially since this practice also saves labor. A fair amount of nitrogen will be lost into the air (it will “volatilize”), but this is normally not a major worry. Smallholder farmers rarely need more than 100 kg N/ha each year.

In the case of any of the maize/mucuna systems, if farmers also raise pigs, they can experiment with using the mucuna to feed them. Mix one part of maize flour with one part of ground mucuna seeds, then lightly cook the dough to make a very cheap (and therefore profitable) feed for pigs that is just as nutritious as commercial feeds. See S8.

In rare cases, mucuna is not effective. For example, in Kalimantan Island in Indonesia, the local weeds will outgrow the mucuna. But this is rare. Another situation is in areas where there are lots of wild animals, such as deer (Kalimantan) or wild grazing animals (near the Sierra de Las Minas in Guatemala) which can eat enough of the mucuna to kill it.

ICRAF, the World Agroforestry Center, recommends planting trees as improved fallows. This requires a good deal more labor than just broadcasting mucuna or jackbeans, and it may be several years before you see the desired impact on fertility or weed control. Nevertheless, if the area’s natural fallows are quite long and firewood can be sold at a good price, this would be an option worth considering. *Gliricidia* and *leucaena* would be among the best species.

Pigeon pea was mentioned as another appropriate species for improved fallows where animals are kept away from the fields. A description of pigeon peas can be found in #26.

Once you have tried and chosen any one or several of these fallow systems, go to #5.

33. **Noxious weeds?** Is your area relatively free of nut-grass (*Cyperus rotundus*) and imperata grass (*Imperata cylindrica*)? If so, go to #35. If not, go to #34.
34. **There are serious weed problems.** Use S59 or S89, and then go to #5.
35. **Do farmers grow grain legumes?** Are any grain legumes widely consumed? If so, go to #36. If not, go to #41.
36. **Local grain legumes.** What grain legumes are locally known and consumed, or have a good price in local markets, with major demand?
 - a) Lablab beans. Go to #37.
 - b) Cowpeas (*Vigna unguiculata*), rice beans (*V. umbellata*) or mungbeans (*V. radiata*). Go to #38.

c) Pigeon peas. Go to #39.

d) Peanuts (also called groundnuts) or bambara groundnuts (*Voandazeia subterranean*). Go to #40.



26. Honduras. Lablab seeds can be black, red, brown, cream-colored, and speckled, but the hylum is always a bright white. The black seeds may be better tasting, at least according to some cultural preferences.

37. Lablab beans. Lablab beans are widely consumed in northern Peru (as green peas), Kenya (as a dry bean, called “black beans”), India (as a pulse, called “horsepeas”), Bangladesh (called “hyacinth beans”), Cambodia and Vietnam (as dry beans) and the Philippines (as green pods, for which they have a tender variety), just to name the places I have personally encountered them being eaten. They contain no anti-nutritional factors, and therefore require no special processing before being eaten (Photo 26).

Lablab beans are especially valuable in areas of moderate to poor rainfall. Once they have grown for five or six months, they are extremely drought-resistant and are capable of growing and producing grain for four to six additional months with almost no rain at all. This means they can provide fresh beans up to six months after the harvest of all the other field beans has ended—a very important consideration for the nutritional well-being of smallholder farmers. However, lablab beans are not nearly as drought-resistant if they have rain for only three months, so they normally will not do well in areas with two rainy seasons that last only three months each.

Lablab beans can also be cut off at ground level after their first year of production. They will then sprout again. Particularly in drought-prone climates, this practice can help the lablab bean get a fast start the next year in order to acquire drought tolerance earlier in its growth period.

The main problem with lablab beans is that they do not grow well in poor soils that have not been inoculated with rhizobia. In relatively poor soils or in a field in which they have not been planted before, it is almost always necessary to fertilize them with either chemical or organic fertilizers for the first year or two. After those first two years, they will grow very well with no additional fertilizer.

Lablab beans are capable of producing over 60 MT/ha of organic matter (green weight), which means that if grazing animals are not consuming a large part of the organic matter, the lablab beans will maintain or gradually increase the soil fertility of maize fields for many years.

Lablab beans produce better when they can climb, so they are frequently planted as an intercrop in maize fields, where they can climb up the maize stalks. They

grow somewhat slowly during their first few months, so they never become a problem for the maize. When intercropped with maize, they should be planted about three seeds per square metre. If weed control is particularly important, four seeds could be tried, though the early slow growth of lablab beans makes them less able to control weeds than, for example, mucuna. Lablab beans should not be intercropped with sorghum or millet. Since the stems of these crops are not very strong, the lablab beans will cause the sorghum and millet to fall over.

Animals very much like lablab beans. Cattle will prefer them to virtually any other fodder. Since the plant as a whole contains about 23% protein, it is a very valuable animal feed. Where cattle are allowed to graze freely during the dry season, small plots of lablab beans will be grazed down to the ground, unless they are protected from the animals. This greatly reduces the value of the lablab bean, since it does not produce much seed before the dry season starts when most of the organic matter needed for soil fertility has not yet been produced. Lablab beans are therefore largely useless when planted where there are free-ranging cattle, sheep or goats.



27. Honduras. These lablab plants, intercropped with maize, will stay green and produce seeds all through a 6-month dry season, thereby providing highly nutritional, vitamin-rich fodder for cattle right through the time when animals have the least fodder to eat.

On the other hand, for farmers who can ensure that the lablab beans are consumed by their own animals, lablab beans can be a wonderful feed. Cattlemen in Honduras grow lablab beans with their maize during the wet season. After the maize is harvested, they let their cattle feed on the lablab plants and maize stalks during the entire 6-month dry season. This way, their animals continue to gain weight even during the long dry season (Photo 27).

Probably the best way to manage free-ranging cattle is to have farmers grow the lablab beans for several years, either in

fenced areas or areas where cattle and other animals have no access. Once farmers realize the value of the lablab bean for human consumption and also for dry season grazing and fertilizing the soil, they will often make village-level decisions to limit the grazing areas of the cattle or to control grazing completely. This process is facilitated when the cattle-owners have lablab beans in their own fields, and therefore will have plenty of dry season fodder.

Use S23, S24, or S71, and then go to #5.

38. Cowpeas, rice beans and mungbeans. Cowpeas, rice beans and mungbeans all belong in the genus *Vigna*. They grow in similar ways, except that certain varieties of cowpeas and rice beans crawl or climb, while others are bushy. The bushy-type *Vignas* can be intercropped with maize, sorghum or millet, but the climbing vari-

eties should not be intercropped with sorghum or millet, because the sorghum and millet stalks will not support the weight of the intercropped beans.

Vigna species fix much more nitrogen than do the common beans (*Phaseolus vulgaris*). They can fix approximately 80 kg N/ha as opposed to about 30 kg N/ha for *Phaseolus* beans, so just switching from *Phaseolus* beans to a *Vigna* species as an intercrop can make a major difference in the maintenance of soil fertility (assuming all the nitrogen is not being burned off during the dry season).

In general, among the *Vignas*, cowpeas and rice beans are more drought-resistant, while mungbeans require more soil moisture. For the driest situations, especially at the end of the wet season when soil moisture can be expected to gradually decrease, short-cycle (60- to 70-day) cowpeas are probably the best option.

In places like the Sahel, the introduction of short-cycle cowpeas can improve soil fertility, because the crops with which they are intercropped usually last at least a month longer. This fact means that the cowpea residues—at least that part of them that is not carried off to sell or store for forage—will die and be incorporated into the soil by termites before the millet or sorghum is harvested. In this way, the organic matter is protected from the heat and from other farmers' grazing animals, which are not allowed to roam free until the millet or sorghum is harvested.

If you are working with cowpeas, select S22, S68, S70, S73, S74 or S80, and then go to #5. If you are working with rice beans, select S9, S69 or S78 and then go to #5. If working with mungbeans, select S79 or S85, and then go to #5. Hedgerows can also be used with these systems, and are advisable especially under 800 m in elevation. See #45.

- 39. Pigeon peas.** Pigeon peas can be used as a gm/cc in many different ways.
- Pigeon peas can be a very good temporary, dispersed shade (up to four years) for vegetables or other low-stature crops. They allow flexibility in complicated and changing farming systems because they can be taken out or replanted at any time. They also provide a high-protein food and fertilize the soil very well. See #26.
 - Pigeon peas can be used as an improved fallow. See #26.
 - If you want to try a system in which pigeon peas are intercropped with maize, go to S30 and then go to #5. For upland rice, go to S72 and then #5. Pigeon peas can also be grown together with many other crops, often benefiting them because of the shade while producing additional food and organic matter for the soil.
- 40. Peanuts and bambara groundnuts.** Peanuts and bambara groundnuts are often planted together with maize, sorghum, millet and even cassava. They are usually planted at the same time as the basic grains with which they are being intercropped. Both species can also be intercropped with cassava (see S43, and then #5, if you and the farmers wish).
- I did not describe these systems below. They do not fertilize the soil well because

the nitrogen and organic matter are burned off or eaten by animals, so farmers rarely use them for the purpose of fertilizing the soil. This means they are not gm/cc systems by our definition. Nevertheless, these crops can be used to fertilize the soil somewhat, especially where dispersed shade is used, dry seasons are short or animals are absent.

If either of these species is used, dispersed shade and perhaps other gm/ccs should also be used in order to achieve a noticeable improvement in soil fertility. If you are working below 800 m in elevation, go to #24. Additional ways of fertilizing the soil should also be used. Go to #41.

- 41. Major crop.** What is the major subsistence crop in the local farming system?
- If the main subsistence crops are maize, sorghum or millet, go to #42.
 - If the main subsistence crop is rice, go to #46.
 - If the main subsistence crops are vegetables, a root crop or a perennial, go to #50.
 - If a lot of the area's land has no crops because it has been turned into wasteland, go to #60.
- 42. Maize, sorghum and/or millet are the main crops.** Are many of the maize, sorghum or millet fields free of intercropped species? If not, go to #43. If so, go to #49.
- 43. All fields are intercropped.** First of all, it is important to make sure this is actually the case. Observation of the fields will be more reliable than asking people. In many areas of the world, people feel they should intercrop all their fields, and therefore claim they do. If a significant portion of fields are not intercropped, see #49 also. Where all the fields are, in fact, intercropped, the best approach is usually to plant the gm/ccs in a hedgerow or (if the rains permit) use them in a dry-season rotation. Both these systems are usually a little less popular than most other gm/cc systems, but they have been successful and sustainable in many areas. If farmers prefer a dry season rotation, go to #44. If they prefer hedgerows, go to #45.
- 44. Dry season rotations.** Grain legumes can often be relayed into maize, sorghum or millet crops (if the intercrops are harvested before the maize), or planted after the main crops at the beginning of the dry season (Photo 28). The limiting factors here will be the length of the wet season, how much moisture is retained in the soil and whether or not at least some rain falls during the "dry" season. Dry season rotations are usually used in areas where the total annual rainfall is well over 1,000 mm, although S20, the maize/wild sunflower (*Tithonia diversifolia*) system, is used in a droughty area that receives an average of much less than 1,000 mm. For dry season rotations that are used with maize and its intercrops, you could choose S14, S20, S69, S70, S71 or S75, and then go to #5.

S50 and S51 can also be used in the same sort of situation, even though they are



28. Thailand. Lablab beans, cowpeas and rice beans are each grown during the dry season in maize fields in northern Thailand. The practice was originally developed by the farmers mostly to keep down the weeds and maintain soil moisture, but these gm/ccs now are also being consumed and sold in the local market.

not dry-season rotations. These systems violate the gm/cc rule of not spending money or effort on transportation, but thousands of farmers use this system in Burkina Faso. These systems do usually require a lot less labor than collecting and taking animal manure out to the fields from the homestead.

45. Hedgerows. These are not usually very popular among farmers because they occupy land that farmers' crops could be using and because they often require pruning during the wet season, when the demand for labor is highest. This is why "alley cropping" was almost universally

rejected by farmers.

Several things can be done to make hedgerows less objectionable. First, farmers should be consulted about the distance between hedgerows. If they choose (as they likely will) a distance such as 25 m between hedgerows, we should agree even though the impact on soil fertility will be minimal due to this large distance. In time, when they see the impact of the hedgerows on soil fertility, they may want to add a hedgerow between each of the two they already have, making the distance 12 m instead of 25 m. Perhaps a better practice would be to add a second row of bushes to the already existing hedgerows.

Second, if dispersed trees are planted in the hedgerows, the hedgerows will be less objectionable, because they will be occupying the area of maximum shade, where crop growth may be somewhat poor anyway if the pruning is not done heavily enough. Furthermore, the hedgerows will be seen as part of a total system with benefits of moisture retention and crop shade in addition to soil fertility.

Third, if on hillsides the hedgerows can double as contour hedgerows to prevent erosion, they will be more acceptable. This is the case on several islands in Indonesia, where the alley cropping hedgerows have met with considerable acceptance.

Fourth, some hedgerow species, such as nyama (*Piliostigma reticulatum*), can be pruned to ground level, which gives the field crops a head start. Nyama is a native bush in much of the Sahel, from Senegal to Kenya. It is a perennial whose leaves do an extremely good job of fertilizing the soil. It is very resistant to animals (although some protection may be required the first year) and maintains its leaves until June, when the rains come. A field that is no longer fertile can be plowed and nyama seedlings planted, either from a nursery or using seedlings that volunteer near where the bushes already exist. The seeding rate will depend on the number of seedlings available, but they could be planted one seedling

each metre in hedgerows 8 to 12 m apart. Soil improvement using nyama will be a slower process than with jackbeans, because the nyama grows much more slowly. However, this technology could be used in areas where it is so dry that the animals are eating the jackbean. There is also a tremendous advantage in having a permanent gm/cc, rather than one that has to be planted every few years, like the jackbean. When nyama is planted in maize, sorghum or millet fields, it does not need to be pruned at all during the wet season, which is a major advantage over alley cropping systems.

For examples of other hedgerow technologies, consider S21, S25, S58 or S82, and then go to #5. Recently, mother of cacao hedgerows have been gaining popularity in Haiti, Indonesia and the Philippines. However, they had not been used long enough when I saw them to justify being included in the list of successful gm/ccs below.

- 46. Gm/ccs for rice.** The search for gm/cc systems that work well with rice, whether upland rice or paddy rice, has been a frustrating endeavor. Rice is such a short-stature crop that it is difficult to find anything that can be intercropped with it. Besides, very few legumes can survive for long in standing water. Luckily, there is not too much pressure to find gm/ccs for rice. For one thing, the System of Rice Intensification (SRI) is raising rice yields dramatically around the world without gm/ccs, and many rice farmers are busy learning about and refining their use of SRI. [For information about SRI, see <http://sri.ciifad.cornell.edu/index.html>]. Secondly, rice has such a good international price that farmers can easily use chemical fertilizer, gather organic matter from other fields or apply compost without losing money. Both these factors reduce the urgency of finding gm/ccs for rice. Even so, there are a limited number of options for using gm/ccs with rice.

If the dominant system is upland rice, go to #47. If it is paddy rice, go to #48.

- 47. Upland rice.** In northern Laos, pigeon peas and a crawling variety of cowpea (also found in certain areas of Africa, including parts of the Sahel) are intercropped in some upland rice fields. Choose S72 or S73, then go to #5.
- 48. Paddy rice.** If development workers and the farmers are interested in using a traditional green manure system, see S76 and then #5. If a system with a rotated or relayed gm/cc sounds more interesting, see S74, S78, S79 and S80. Afterwards, go to #5. If people are interested in using azolla, an algae that grows in paddy water and fixes nitrogen, go to S81.
- 49. Many of the fields are not intercropped.** By and large, maize fields that have no other crops growing in them can be intercropped with any one of a large number of leguminous gm/ccs. In high-rainfall areas, mucuna can be intercropped with maize. Plant it at least 30 to 40 days after the maize, and allow the mucuna to grow until the next crop of maize is planted. The mucuna may need to be pruned

at least once, depending on the height and days-to-harvest of the maize. Be careful to plant the mucuna late enough that it will not cover the maize (see S1 and S2). If the soil is too infertile for mucuna to grow well, jackbeans can be grown instead. Jackbeans will fix even more nitrogen (up to 240 kg per hectare), but will usually not provide the same degree of weed control. The jackbean can be grown alone or associated with maize, sorghum, millet or cassava. When planted together with other crops, the bushy type of jackbean should be used rather than the climbing type. (For more information on jackbean, see #29. For information on mucuna, see #32.)

If farmers are interested in one of the edible legumes and if conditions allow them to grow well, lablab beans, cowpeas, rice beans or mungbeans are good options.

Short-cycle legumes, like 60-day cowpeas, are often best for this use. For areas with less than 1,000 mm of rain, select S3, S9, S22, S53, S58 or S64 and then go to #5. For wetter areas, select S1, S8, S18, S30, S53 or S85 and then go to #5. In wetter areas where grazing animals are not a problem, relay systems in which the legume grows well into the dry season can also be used. Select S24, S69, S70, S71 or S75, and then go to #5. When shorter-cycle legumes are planted together with maize, a relay crop might be used in the same field after the first legume is harvested but the maize is still growing.

For millet and sorghum, any of these systems may be used, as long as the legume does not climb. In the drier areas of the Sahel, *Piliostigma reticulatum*, which is a native bush, can also be used with millet or sorghum (decide whether to try S52, and then go to #5).

50. **Gm/ccs for vegetables, root crops or perennials.** If people need gm/ccs in vegetables or root crops, go to #51. If the people need gm/ccs in perennials, go to #56.
51. **Gm/ccs for vegetables or root crops.** If these crops are irrigated, go to #55. If they are rain fed, go to #52.
52. **Rainfed vegetables or root crops.** Would the farmers prefer to intercrop the gm/ccs with their vegetables or use them in a rotation? The latter process is far more widely used and easier to manage. If they prefer intercropping, go to #53. If they prefer a rotation, go to #54.
53. **Rainfed vegetables or root crops with gm/cc intercrops.** If the vegetables are of short stature, like carrots or radishes, we don't have any proven systems except for dispersed shade from trees or pigeon peas. Research on this issue is needed and could prove to be very important. If the vegetables are of medium stature, such as tomatoes, chilis or eggplants, use S10 and S11, then go to #5. If the vegetables are on bushes that are fairly large (like cassava, for example), use S42 or S43, and then go to #5.

- 54. Vegetables or root crops with rain-fed rotations.** Choose S48, S74 or S75, and then go to #5. In this case, depending on the nature of the crops in the rotation, many other possibilities of gm/cc species could also be tried.
- 55. Irrigated vegetables.** Our present level of knowledge doesn't provide us with any effective options for gm/ccs to use with irrigated vegetables. In fact, the possibilities for gm/ccs in these circumstances will always be rather limited, for a number of reasons. In irrigated vegetable systems, the crops are usually of short stature, the system is in constant change and is highly variable, the land is extremely valuable (making the opportunity cost of growing gm/ccs high), and the value of the crops is also usually relatively high. Every one of these factors works against finding advantageous gm/ccs for this situation. In most cases, growing irrigated vegetables is quite profitable, so the use of chemical fertilizers, compost, animal manure or some other purchased fertilizer will not only be feasible, but will prove even more advantageous than gm/ccs. Therefore, the best approach here is either to go to #2, or try to do some original research into gm/cc use under these circumstances.
- 56. Perennials.** Where perennials are being grown as a main crop, it is normally more efficient (though not always possible) to use gm/cc crops that are also perennials. Using perennial gm/ccs avoids the labor of replanting every year. More importantly, it normally allows a much better control of weeds across the entire field or orchard once the perennial gm/cc has become established. Thus, the advantages of a perennial gm/cc include improved soil fertility, reduced weeding and reduced maintenance costs after the second year.

What is the main perennial being grown? If it is coffee, go to #57. If it is coconuts, oil palm or cacao, go to #58. If it is fruit trees, go to #59.

- 57. Gm/ccs for coffee.** Most of the systems recommended currently for growing coffee use shade. Leguminous tree gm/ccs are recommended for this role. But the trees used for permanent shade in coffee fields tend to grow rather slowly, leaving the young coffee trees unprotected for the first four or five years of their growth. In Guatemala, using *Tephrosia vogelii* as a temporary shade for coffee has become very popular among both smallholder farmers and plantation owners. Check out S16; if you choose to use it, go to #5. See also #29 for more information on tephrosia.

Many smallholder farmers are interested in intensifying their coffee fields and guarding against those years when the coffee price crashes. Some have found that using diversified fruit trees as shade can improve both their incomes and their diets. In Guatemala, such farmers will prune their fruit trees fairly heavily in years when the coffee price is high in order to reduce the shade to 50%, which is ideal for maximum coffee production. When the coffee price is low, they let their fruit trees grow without any pruning. This increases their fruit production while reducing their unprofitable coffee production.

However, if fruit trees are used for shade, something must be done to provide soil fertility. Farmers who want to improve their coffee fields' fertility can use perennial peanuts (*Arachis pintoii*) as a low-lying gm/cc, if they can get the cuttings. Perennial peanuts are a little difficult to get established, but once they are established, they provide a cover less than 20 cm thick that will completely control weeds and fix nitrogen for as long as it is in the ground. Choose S28 and go to #5.

If farmers cannot obtain perennial peanut cuttings, they will usually settle for jackbeans as an intercrop with their coffee. See S29, then go to #5. Also see the description of jackbeans in #29.

- 58. Coconuts, oil palms or cacao.** Select S26 (or S29 if perennial peanut cuttings are not available) and go to #5.
- 59. Gm/ccs for fruit trees.** I have seen jackbeans, mucuna, perennial peanuts and *Centrosema pubescens* used as gm/ccs for fruit trees. I believe the perennial peanut is easily the best of these systems. See S26 then go to #5. *Centrosema* works well as a perennial, but forms a mat of about 30-40 cm in depth; this means fruit that drops is often lost. As well, the *Centrosema* might become a cover for snakes. If extension workers and the farmers favor this system, go to S67 and then to #5. Jackbeans can be used, but have to be replanted every year or two. Go to S38, and then #5. Mucuna would have to be replanted every year in most climates, and would also have to be trimmed regularly around the trees. I consider mucuna as advantageous only where farmers have a serious problem with sun scorch (as they do in Paraguay, where farmers are very happy with mucuna). In this case, use S37 and then go to #5.
- 60. Much of the land is wasteland.** See S77, which can be used with the normal annual mucuna, or the perennial species. In most situations, however, it would be better to plow the soil and broadcast jackbean seeds on it, at a rate of approximately 4 seeds/m². If the soil is so infertile that even jackbeans will not grow on it (an extremely rare phenomenon), you might use a little animal manure to get the jackbean started.

8. Green Manure/Cover Crop Systems



29. Honduras. The maize/mucuna-1 system covers thousands of hectares in Mexico, Guatemala and Honduras. It is still spreading in some areas of each country, but is losing ground in others. The factors deciding spread or contraction include the abandonment of maize as a crop, the spontaneous spread to new farmers who just didn't know about it, and the competition for maize land from cattle ranchers and oil palm producers.

Latin American Green Manure/Cover Crop Systems

Mexico

S1. Maize/mucuna-1. The primary maize/mucuna (*Mucuna spp.*, also called velvet-bean) system extends along the east coast of Mexico, from about halfway between the U.S. border and the city of Veracruz to Tabasco State, just west of the Yucatan Peninsula (Photo 29). The mucuna dies in December, maize is planted in January, and the mucuna reseeds itself naturally in January and grows until the following December. A major advantage with this

system is that very little weeding, if any, is necessary. The system results in slightly improved harvests over a period of at least 40 years, with maize grown every year and with no use of chemical fertilizers (Photo 30). The system apparently either spread originally from Guatemala, or was independently developed by Mexican farmers when the seed was introduced into Mexico from the southeastern U.S. during the early to middle 20th century. An estimated 10,000 to 15,000 farmers use this system in Mexico alone, and it is still expanding in Tabasco State and north of Veracruz.

The same system has spread into Guatemala along the Polochic River Valley of the Department of Alta Verapaz. During the last 30 years, it has spread into many areas of the Department of El Peten. Nevertheless, its use along the Polochic River has been reduced, largely because much of the land there has been bought up to grow sugarcane for making biofuels. The system apparently was initiated about 60 years ago when the mucuna was first brought to Guatemala by the United Fruit Company to feed the company's mules. Over 5,000 farmers likely use this system in Guatemala.

The maize/mucuna-1 system has also spread from the Guatemalan border north into patches of southern Belize and east to the mountains of north-central Honduras, where it was once used by an estimated 10,000 Honduran farmers. In this area, however, the system is losing ground rapidly because maize farmers are being replaced by large cattle ranchers who now prefer to use the hillsides to graze their cattle because Hurricane Mitch killed many of the animals they previously grazed on the coastal flatlands.

It should be mentioned that rainfall basically has to be year-round for this maize-mucuna-1 system to work.



30. Honduras. This photo is not of a handful of compost, though it may seem like it is. This is the soil of a typical field in the maize/mucuna-1 system, after planting maize every year for 40 years. Without the mucuna in this poor tropical soil, a farmer can grow maize for three to four years, and then will have to fallow it for ten to twelve years. By using mucuna (which can be seen in the background of the photo), farmers can plant maize every single year with no loss in productivity. Instead, production gradually increases, up to a point of diminishing returns at which maize yields are about 35% less than those produced on the lower-elevation flatlands using hybrids, irrigation, plows, etc.. However, even though the productivity is lower, the total cost per ton produced is about 30% lower than in the conventional system, because the expenses are so much lower. Thus, the maize/mucuna system provides a much larger profit while operating on less valuable land and increasing the productivity of that land from year to year.

paraguayensis are intercropped with maize. Thousands of farmers in both Mexico and Brazil use this traditional system. For this system, use only the bushy-type jackbean, not the climbing type.

S4. Maize/lima bean. Lima beans (*Phaseolus lunatus*), locally called “ibes,” are intercropped with maize on the Yucatan Peninsula. The beans produced are, of course, eaten. The lima beans are planted either together with the maize or up to a month afterwards. Tens of thousands of farmers are using this traditional system. A similar system is used in western Guatemala (where the lima bean is called “piligua”) and southern Honduras (where it is called “chilipuca”).

S2. Maize/mucuna-2. This system is used west and south of the maize/mucuna-1 system, where there is less rainfall and a dry season occurs from December through April. It is used on irrigated land, with the mucuna intercropped among the maize 30 to 40 days after the maize is planted. The earlier planting increases the danger of the mucuna choking out the maize, but the later dates reduce the organic matter that the mucuna will eventually produce. Often one pruning is needed to keep the mucuna from covering the maize, although this will depend on the height of the maize, how many months the maize requires to mature, etc.. Different planting patterns are used; one is to plant three seeds per hill of maize, but only in every other row. The planting seasons depend on the supply of irrigation water. This system seems to only be used by a few hundred farmers in Mexico, and a few others in Costa Rica. This system is probably an adaptation of maize/mucuna-1 developed by farmers themselves for use in lower-rainfall areas.

S3. Maize/jackbean. Jackbean (*Canavalia ensiformis*) is intercropped with maize in a number of areas of northern Yucatan and the state of Oaxaca. The jackbean is planted at the same time as the maize, with two or three seeds per square metre, or sometimes four if the weeds are particularly problematic. Sword beans (*Canavalia gladiatus*) can be used in place of the jackbean. In Brazil, both jackbean and *C.*

S5. Maize/vetch. Vetch (*Vicia toluca*) is widely intercropped with maize in the State of Michoacan, both to fertilize the soil and to feed animals during the dry season. Probably well over 10,000 farmers use this traditional system. The vetch is planted at the same time as the maize. After the maize harvest, most of the vetch is cut and carried to the homestead to be stored and fed to animals during the dry season.

S6. Maize/fava beans. Fava beans are intercropped with maize by hundreds of thousands of farmers on the central plateau of Mexico, both for soil fertility maintenance and food (Photo 18). Usually two or three seeds are dropped in each hill of maize. The same system is used in the higher areas of the Guatemalan highlands (thousands of farmers) and in Lao Chai Province of Vietnam (by only a few hundred farmers, to my knowledge). This traditional system maintains maize yields for at least twenty to thirty years.

S7. Maize/sweet clover. In this system, which I believe exists in only two or three villages in northern Oaxaca State near the town of Tlaxiaco, the sweet clover (*Melilotus albus*) is planted together with the maize. The sweet clover is a perennial and grows to about two m in height after the maize is harvested. After the harvest, the maize stalks and sweet clover are grazed to ground level, if necessary, during the dry season. When the rains start again, what is left of the sweet clover is cut down to ground level and the maize is planted again. In this way, the sweet clover maintains the soil's fertility for decades and feeds the animals during the dry season. This system should only be used where farmers value raising cattle, because it is fairly permanent. The sweet clover can only be killed by cutting or grazing it to ground level at the beginning of the dry season. Probably around 50 farmers use this system, which was introduced in the mid-20th century.

S8. Maize/mucuna-3. The difference between this system and S1 or S2 is that farmers are using the mucuna seeds to feed pigs, which is a very lucrative business.¹⁵ As a result, the farmers are not concerned if the mucuna reduces their maize harvests a little. In the southern Yucatan Peninsula town of Xpujil, farmers intercrop mucuna with maize, and then feed the mucuna seeds (cooked and mixed half and half with maize meal) to their pigs. Introduced in the 1990s, the system never included more than a hundred farmers, to my knowledge.

S9. Maize/rice bean-1. Rice bean (*Vigna umbellata*) is intercropped with maize, largely to be eaten. Both crops are planted at the same time, with rice bean seeds planted at about three seeds per square metre. This practice was once (and perhaps is still) practiced by thousands of farmers on the Isthmus of Tehuantepec. It was also common at one time on Guatemala's south coast and in much of El Salvador (where it was used by hundreds of thousands of farmers). A similar maize/rice bean system is also practiced in Vietnam.

People like the taste of the rice bean, but Mesoamerican women complain that the tiny bean is hard to thresh and clean. Anyone promoting this system in Latin America

¹⁵CIDICCO, et al., *Experiencias Sobre Cultivos de Cobertura y Abonos Verdes* (Tegucigalpa, Honduras: CIDICCO, 1997), pp. 112-15.

should therefore also teach the community to winnow the grain as Asians do their rice and other small grains.

S10. Tomatoes/jackbeans. Jackbeans are intercropped in the rows between tomato plants. They are usually planted at the same time as the tomatoes. When they begin to shade the tomatoes, they are pruned back to a height of about 30 to 40 cm, which forces them to sprout more branches and grow laterally rather than vertically. At most one hundred farmers use this practice that was developed in Yucatan during the 1980s.

S11. Chili peppers/jackbeans. Jackbeans are managed in chili pepper fields in Yucatan the same way as in the tomato fields in S10.

Guatemala

S12. Maize/runner bean-1. In the Department of San Marcos, scarlet runner beans are intercropped very sparsely with maize. The runner beans produce a good deal of organic matter. Since they are climbers, they can cause the maize to fall over toward the end of the growing season. Therefore, farmers tend to plant it quite sparsely, using as few as one or two seeds in each 3 m x 3 m sector. The runner bean is planted at the same time as the maize. At least 3,000 to 5,000 farmers use this traditional system.

This “problem” of the production of a massive amount of organic matter by the runner bean could be a tremendous advantage in terms of soil fertility and productivity. I suspect that if the runner bean and maize could be supported by a third, fast-growing, woody-stemmed plant (perhaps tephrosia?), the system could become one of the most profitable and sustainable highland maize-growing systems anywhere. This possibility needs to be researched.

S13. Maize/runner bean-2. In the central highlands a variety of runner bean is intercropped much more densely with maize (up to one seed for every 2 square metres) (Photo 19). Maize yields have been maintained for up to 20 years in many places with this system. Before the Europeans arrived, similar systems were apparently used in virtually all the temperate or highland areas from New York State in the United States, south to Mexico, Guatemala, Honduras, Colombia, Ecuador, Peru, Bolivia and northern Chile. Hundreds of thousands of farmers, stretching from Mexico to Bolivia, use this system today.

S14. Maize/mucuna-4. Mucuna is rotated with maize in the Cerro San Gil region, Department of Izabal (Photo 31). The maize is planted when the rains start in May or June, and mucuna is relay-cropped into the maize 30 to 40 days before the maize is harvested (Photo 32). Maize following mucuna, without chemical fertilizer, has produced up to 7.4 MT/ha on Brazilian experimental stations.¹⁶ This is evidence of the potential yields that can be achieved by rotating or relaying mucuna with maize. This system is also used in Nicaragua and Brazil. In Paraguay some farmers wait to plant

¹⁶Lathwell, *op. cit.*



31. Honduras. Mucuna in a maize field after the maize harvest. Most farmers in Honduras who intercrop a gm/cc with their maize no longer use mucuna because there is too much danger that it will smother the maize. Farmers prefer to use the less aggressive jackbean, or something that is more useful, such as lablab beans.



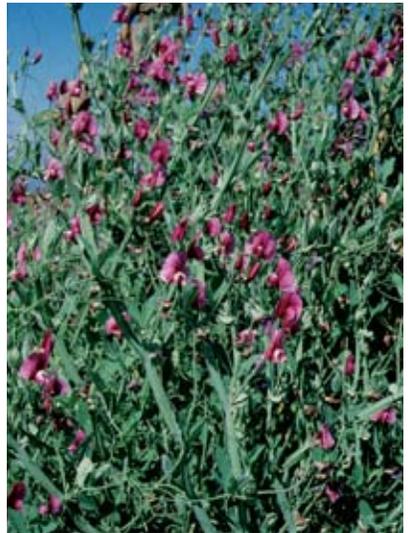
32. Honduras. The maize/mucuna-4 system as used in Honduras



35. Honduras. In this field of second-season maize, the maize is tall enough to have needed a second weeding. Nevertheless, because the owner of this field is using the maize/mucuna-6 system, the field was not weeded. This is one very clear example, among many, of the fact that the oft-stated belief that eco-agricultural practices always require additional work is not correct.



33. Guatemala. For centuries, choreque was intercropped with maize. This photo, taken at the end of the dry season, shows that only the choreque and a few trees and bushes have remained green.



34. Guatemala. We failed to spread choreque to other areas of Central America because it has a very narrow ecological niche. The climate must be cold, but the plant will not withstand frosts. Furthermore, the runner bean and sweet clover can do what the choreque does, with a number of important additional advantages.

the mucuna until 40 to 60 days before the maize harvest. In this way, the mucuna will keep growing through much of the dry season, rather than dying in December, as it usually does. While thousands of farmers in Paraguay and Brazil use some version of this system, only a few hundred farmers in Guatemala and about 2,000 farmers in Nicaragua do.

S15. Maize/choreque. Many farmers in the west of the Department of Chimaltenango traditionally used to intercrop choreque (*Lathyrus nigrivalvis*) with their maize (Photo 33). They then fed their animals on the choreque throughout the six-month dry season. The system has died out largely because the area where it was practiced has gone heavily into vegetable production, and few people have cattle any more (Photo 34). Forty years ago, slightly over 2,000 farmers used this traditional system.¹⁷ This system and one other in this section are the only ones close to dying out.

S16. Coffee/tephrosia. *Tephrosia vogelii* has become popular in the last 35 years among large-scale coffee producers on Guatemala's south coast as a temporary shade for coffee during plantation establishment. Farmers plant the tephrosia at the same time as the coffee, and it shades the coffee for three to four years before the tephrosia dies out. By that time, the slower-growing permanent shade trees are providing adequate shade. Adopters probably number in the thousands.

Honduras

S17. Maize/mucuna-5. Some farmers have tried to intensify the maize/mucuna-1 system by growing two crops of maize a year. This complicates management of the mucuna, but pays off in increased over-all yields per hectare. The maize is planted in both January and May. The mucuna has mostly died out in December, but drops seeds that will sprout in January/February. However, in April the farmers must cut down all the mucuna or eliminate it with an herbicide. As far as we know, only a few hundred farmers use this recently developed system.

S18. Maize/mucuna-6. Around the town of Omoa on Honduras' northwest coast, farmers have developed another mucuna system. They plant maize in May/June intercropped with mucuna. After the harvest, they cut down the mucuna to form a dense mulch and injection plant the second crop of maize through the mulch in September, without planting mucuna. The mucuna mulch allows them to grow the second maize crop without ever having to weed it. Probably not more than 200 or 300 farmers use this now traditional system (Photo 35).

S19. Maize/mucuna-7. In this surprising system near La Entrada in the Department of Santa Barbara, the mucuna is grown just as in S1, and then is burned just before the next crop of maize is planted. Perhaps a few thousand farmers use this system.

¹⁷CIDICCO, *op. cit.*, pp. 57-61.



36. Honduras. Wild sunflower is a phosphorus accumulator, so it can be especially important as a green manure in areas where phosphorus is the limiting factor in crop production.



37. Honduras. Cowpeas were traditionally intercropped with maize in much of El Salvador and the Pacific coasts of Guatemala, Honduras and Nicaragua. Now, because of the buying up of land by large-scale farmers and the active promotion of monocropping by government extension services, the practice is used by perhaps only 10% of the farmers it once served.

number in northern Nicaragua continue to use the same system, as do thousands of farmers on the south coast of Guatemala, where cowpeas are called “frijol rienda” or “frijol de tierra.” In Panama, tens of thousands of farmers use virtually the same traditional system.

S23. Maize/lablab bean-1. Farmers in the village of Pacayas, near Guinope, intercrop lablab beans (*Dolichos lablab*) with their maize, planting both of them at the same time in May/June when the rains start, at a rate of two to four seeds per square metre (Photo 27). In this case, farmers are motivated in large part because the organic matter from the lablab controls the nematodes that previously did tremendous damage to the irrigated garlic produced during the dry season (December to April). Probably about 50 farmers use this system, which was recently developed by farmers. A similar traditional system of lablab intercropped with maize is used in northern Peru (notably between Cajamarca and San Ignacio), where the lablab beans are eaten as green peas. In this case, tens of thousands of farmers use the system.

S20. Maize/wild sunflower-1. Farmers around Sabana Grande in central Honduras sometimes broadcast wild sunflower (*Tithonia diversifolia*) seeds into their fields after the maize harvest in November/December (Photo 36). It grows throughout the dry season, and provides a good source of fertility for the following year's crops. Probably a hundred farmers, at most, use this recently developed system.

S21. Maize/wild sunflower-2. Farmers in western Honduras sometimes plant the wild sunflower as a contour hedgerow, cutting and spreading the branches across the field before planting each year in order to fertilize the field. Again, this is another system recently developed by innovative farmers. It is probably only used by a hundred farmers or so.

S22. Maize/cowpea-1. Cowpea (*Vigna unguiculata*) varieties, locally known as “alacin” and “pochote,” are intercropped with maize in much of southern Honduras (Photo 37). They are usually planted at the same time and within the maize row to facilitate weeding. Probably somewhere between 5,000 and 10,000 farmers use this traditional system. Several thousand farmers in El Salvador and an equal

S24. Maize/lablab bean-2. During the last 20 years, large-scale lowland cattle ranchers in southern Honduras have begun intercropping lablab beans with their maize, so that the cattle will have a plentiful, green, very palatable and high-protein fodder throughout the 6-month dry season. The number of ranchers using this system is well over 100, and is increasing.

S25. Maize/tephrosia. Tephrosia is sometimes planted in hedgerows and then cut and scattered across the fields to fertilize crops right before farmers plant their maize. I have no idea how many people do this, but probably not many.

S26. Oil palm/perennial peanut. The perennial peanut or forage peanut (*Arachis pintoï*) is planted under new oil palm trees (when they are about 50 cm tall) in large plantations, mostly to prevent weeds from ever growing in the fields, but also to supply nitrogen to the oil palms. It takes about a year to eighteen months to establish the perennial peanut, but once it has covered the ground, virtually no weeding ever needs to be done again. Several thousand large-scale farmers use this system in Honduras and Costa Rica. Occasionally the perennial peanut is used the same way to produce palm hearts (“pejibaye”) in Costa Rica.¹⁸

S27. Oil palm/desmodium. Desmodium (*Desmodium ovalifolium*) is used as a cover crop in oil palm plantations by perhaps a few hundred farmers.¹⁹ Desmodium is also being used this way in Belize in situations where the soil pH is below 5.0.

Costa Rica

S28. Coffee/perennial peanut. The perennial peanut is used in coffee fields, much as it is used in Honduras for oil palms. Somewhere between five hundred and several thousand farmers use this system that I believe was developed during the 1970s to 1980s.²⁰

S29. Coffee/jackbean. Jackbeans are also used among coffee plants, both to fix nitrogen and control weeds. I believe the number of farmers presently doing this is well into the hundreds.²¹

Panama

S30. Maize/pigeon pea. Pigeon pea (*Cajanus cajan*) is widely consumed in Panama, and is also widely intercropped with maize as a gm/cc species and food crop. Approximately one seed of pigeon pea should be used for every two square metres, planted at the same time as the maize. Tens of thousands of farmers use this traditional system, both here and in Brazil. Farmers near the town of Machakos in Kenya also plant pigeon peas in their maize, but the number of pigeon pea plants per unit of land varies widely, often in the same field. The number of farmers doing this runs into the thousands.

¹⁸*Ibid.*, pp. 87-90, 94-98.

¹⁹Flores, Milton, “La Utilización de Leguminosas de Cobertura en Plantaciones Perennes.” n.d.

²⁰CIDICCO, op. cit., pp. 91-93.

²¹CIDICCO, op. cit., pp. 99-104.

S31. All crops/mucuna. Mucuna is used to restore land that has been taken over by “pajablanca,” a tall grass of the genus *Saccharum*, closely related to sugarcane. Pajablanca was imported into Panama to stabilize the steep banks along the canal. It has since become a very noxious weed. Mucuna is being used to control it, in ways similar to that used to control imperata grass (see S59). Probably a few hundred farmers are using this system, which farmers first developed about 15 years ago.

Peru

S32. Potatoes/tarwi-1. Tarwi is described in #19. In the Andes, it is traditionally grown in rotation with potatoes, both to fertilize the potatoes and to provide a high-protein bean. The tarwi is planted during the rainy season one year, potatoes the next year, and often a small grain the third year, before returning to tarwi. Potato yields often triple under this system. Used in Peru, Ecuador and Bolivia, this traditional technology has hundreds of thousands of practitioners.²²

S33. Potatoes/tarwi-2. Tarwi is often also grown around the edges of potato fields, for the same two purposes. Tens of thousands of farmers also use this traditional practice in both Peru and Ecuador.

S34. Potatoes/tarwi-3. In Peru some farmers intercrop the tarwi with their potatoes. The latest information I have is that a few hundred farmers continue to use this practice.

S35. Potatoes/fava beans. Fava beans are planted in a rotation with potatoes, much as the tarwi is in S32. Again, this is a traditional system used by tens to hundreds of thousands of farmers.

S36. Potatoes/peas. Common peas (*Pisum sativa*) are used just like the tarwi in S32. This system is used by hundreds of thousands of farmers.

Paraguay

S37. Citrus trees/mucuna. A handful of farmers use mucuna as a gm/cc for citrus (Photo 38). Though this requires more work than using a perennial, they have found the mucuna very useful because they let it climb over the tree to cover it right before harvest, thereby preventing sun scorch on the fruit. Mucuna is also used as a cover crop for citrus trees near Veracruz, Mexico. In this case no problem of sun scorch exists, so a perennial cover crop would probably be preferable.

S38. Citrus/jackbean. Jackbean is a more conventional gm/cc for citrus. It requires less work because it can grow and maintain the cover for several years. When a bushy-type is used, it does not climb up into the trees. Perhaps several hundred farmers in Paraguay use this system, and even fewer in Honduras.

²²Beingolea Ochoa, Victor Julio, “Inventario de Sistemas de AVCC de Pequeños Productores en los Tropicos,” 1997. Unpublished.



38. Paraguay. Gm/ccs are often used among fruit trees (in this case, a citrus grove), more because of the weed control they achieve than because of the improvement in soil fertility.



39. Brazil. Lupines are grown in Brazil as a perennial cover crop for fruit trees. They are used primarily in areas where frosts can be a problem, because they are highly resistant to frost.



40. Paraguay. Because of the jackbeans growing between the rows of this cassava field, the field has required only one weeding, rather than the three to four weedings a crop of cassava normally requires.

S39. Citrus/lupine. In Paraguay and Brazil, some lupine species (i.e.: *Lupinus albus*) are used as a gm/cc for citrus (Photo 39). The number of farmers who used this practice previously numbered in the thousands. Anthracnose has now decimated the lupine crop in Brazil, in part because of not rotating gm/ccs (personal communication with Rolf Derpsch).

S40. Various other tree crops/lupine. Lupines were also used with other tree crops to improve soil fertility.

S41. Maize/mucuna-8. Mucuna is used to prepare land for tobacco. One crop of mucuna, often intercropped with maize, is used to rehabilitate worn-out land to permit farmers to then grow tobacco, which requires fairly fertile land. Sometimes farmers can also shift to zero tillage after only one year of mucuna.²³ Thousands of farmers use this technology.

S42. Cassava/jackbean. In a traditional system, jackbean is intercropped with cassava (Photo 40). Both are planted at the same time. The jackbean provides nitrogen to the cassava crop, but farmers appreciate even more not having to weed their cassava again after the first weeding. The jackbean is planted between the rows of cassava. Tens of thousands of farmers use this traditional practice. Several small groups of farmers in Honduras have taken up the same practice.

S43. Cassava/peanuts. Peanuts (*Arachis hypogaea*) are also quite commonly intercropped with cassava to help with soil fertility and to provide a second cash crop. Probably tens of thousands of farmers use this traditional technique.

²³Ministerio de Agricultura y Ganadería de Paraguay/GTZ, "Extracto de los Sistemas de Producción del Proyecto de Desarrollo Rural de San Pedro Norte," n.d.

Brazil

EPAGRI, the agricultural development arm of the state government of Santa Catarina in Brazil, has introduced well over a hundred gm/cc systems, using over 70 gm/cc species, in the state. Many of these systems, and some others, have also been introduced into huge areas of Parana, Rio Grande do Sul and other Brazilian states, to a sum total of well over a million farmers. I have personally observed the handful of systems listed below, but they are only the tip of a very large iceberg.



41. Brazil. Brazilian farmers use gm/ccs, among other things, to be able to increase the organic matter in their soils as rapidly as possible, so they can begin using zero tillage within a year or two. Therefore, gm/ccs like this crotalaria, that was intercropped with maize, are very popular, because they commonly produce a total biomass of well over 80 t/ha (green weight).

S44 to S46. Maize/crotalaria. At least three species of the genus *Crotalaria* are used as intercrops with maize in Santa Catarina State (Photo 41). The crotalarias are generally planted at the same time as the maize. In Brazil, all of these systems including those using other intercrops such as forage turnips, jackbeans and oats (the latter not included here because they are not leguminous) are designed not so much to provide nutrients to the soil as to produce large quantities of organic matter. Farmers use the systems so they can increase their soil organic matter content enough to move to zero tillage as quickly as possible. Over 25 million ha of land in Brazil and Argentina are now in zero tillage.²⁴

S47. Fruit/mucuna. *Mucuna* is used as a cover crop under various species of fruit trees in Acre State. Perennial peanut would probably be a better choice of cover crop, to reduce the labor of cutting the *mucuna* out of the trees and of reseeding the *mucuna* each year.

S48. Onions/mucuna. *Mucuna* is used in a rotation for onion production in Santa Catarina. Hundreds of farmers use this system introduced by EPAGRI.

S49. Various crops/common peas. For a number of different crops, peas are grown as a winter rotation crop in Santa Catarina, both as a gm/cc and as a cash crop. Hundreds, if not thousands, of farmers use this traditional system.

²⁴Brown, Lester R., *World on the Edge, How to Prevent Environmental and Economic Collapse* (New York: Earth Policy Institute, 2011), pp. 143-44.

African Green Manure/Cover Crop Systems

Burkina Faso

S50 and S51. Millet and sorghum/nyama-1. Nyama (*Piliostigma reticulatum*) is a perennial bush native to the Sahel (see #45 for information on nyama). In this system, nyama leaves are carried from the bush to fertilize millet and sorghum in northeastern Burkina Faso. We know that at least hundreds of farmers use this traditional system.

S52. Millet/nyama-2. Nyama is allowed to volunteer in farmers' fields. Just before the rains come, it is pruned down at ground level and the leaves are spread across the field to fertilize it. This traditional practice is used by thousands of farmers in both Burkina Faso and Mali.

Ghana

S53. Maize/mucuna-9. This system is a simple rainy season intercrop of mucuna in maize. The mucuna is intercropped late enough in the maize's growing season so the maize is not overcome by the mucuna. In one area, the people were actually using the variety of mucuna that provokes severe itching, meaning they couldn't go near their fields for two months. They switched to the non-itchy mucuna immediately after learning about it. Thousands of farmers use this traditional system. In addition, thousands—if not tens of thousands—use the same system in Benin and Oaxaca State in Mexico.

S54. Maize/nyama. At the end of the fallow period, when the fields are to be burned, the nyama bushes are cut and covered with dirt, so that less nitrogen will be burned off. Actually, this system was used traditionally for all local crops, but is disappearing as fallowing itself is disappearing in the Sahel. Quite likely almost no one is using this traditional system today.

S55. Maize/calopogonium. Calopogonium (*Calopogonium mucunoides*) is used in rotation with maize in parts of Ghana and neighboring countries. There are probably thousands of adopters. This system started being used after calopogonium was introduced into the country. To the dismay of many farmers, calopogonium has become a noxious weed. This system is not recommended for use anywhere else.

S56. Maize/leucaena. In another interesting system, *Leucaena leucocephala* is intercropped (three seeds per square metre) in maize and allowed to grow the whole rainy season. After the maize harvest, the field is burned lightly to kill the leucaena without burning away all the nitrogen. This is done in Benin (where the practice originated and where it is apparently widely practiced) and southern Ghana, where perhaps a few hundred farmers use it.

Mali

S57. Millet/*Faidherbia albida*. Farmers in Mali, Burkina Faso and Niger purposely leave existing *Faidherbia albida* (previously *Acacia albida*) trees in their fields. These trees, different from all the other Sahelian trees, drop their leaves during the rainy season, therefore supplying a very beneficial 15 to 25% shade to the crops under them. This shade allows crops to keep on growing all day, instead of closing down during the excessive mid-day heat, thereby increasing productivity by up to 40%. The lower soil surface temperature achieved by the shade also dramatically reduces evaporation and transpiration rates. As a result, soil moisture losses are reduced and the annual growing season is extended by a week or two. Farmers who practice this traditional system probably number in the hundreds of thousands.

S58. Millet/nyama-3. This is the only system in the decision tree that has never been practiced by any farmers exactly as described. But I believe it would be an ideal system for the African Sahel. I venture this bit of hubris for two reasons. First, the system I am suggesting is basically a combination of two already-existing systems (S52 and S57). A fast-growing exotic tree and organized on a grid to make animal traction plowing easier will reduce the labor requirement of the traditional systems.

Second, the Sahel suffers from a lack of good gm/cc systems. This has happened in part because of a widespread but mistaken belief that they will not work under semi-arid conditions. It also has happened in part because the environment in the Sahel is definitely somewhat hostile to all living things, especially gm/cc species, with their high nitrogen, and therefore high protein content.

Yet even in the northern Sahel, two gm/cc systems are presently working very well. Farmer managed natural regeneration (FMNR) has populated some 5 million hectares of Niger with trees, as well as another half million hectares in northern Mali. Since a large number of these trees are leguminous, the soil in this system has gained both an increase in organic matter and an increase in nitrogen. Millet yields have increased significantly. Another system, developed by the Dogon around the town of Koro, involves leaving naturally occurring trees in the fields and protecting certain other desired species of trees (such as *Faidherbia albida*) that sprout naturally in their fields. These trees are all pruned in the shape of a funnel, which prevents the area under the tree from getting too much shade, yet shades all the field at some time during the day as the sun moves across the sky. Under this dispersed shade, the Dogon farmers practice a rotation that includes such gm/ccs as peanuts, Bambara groundnuts and fonio. Just as with FMNR, yields have increased as the organic matter content of the soil has also increased. The last time I visited this area, the Dogon farmers using this system were collecting the largest harvest they had had in years, while everyone around them for many miles was complaining that the drought had destroyed their crops.

For the southern Sahel (from about 13°N latitude towards the south), the gm/cc system that I would like to see tried more widely consists of dispersed shade provided by mother of cacao (*Gliricidia sepium*) and, if farmers wish, *Faidherbia albida* trees,

spaced anywhere from 8 m to 12 m square. Parallel rows of nyama would run under every row or every other row of trees (i.e. every 12 to 24 m across the field). In drier northern areas, where the nyama grows rather slowly, tephrosia (*Tephrosia vogelii* or *T. candida*) could be planted along with the nyama to provide plenty of organic matter until the nyama is large enough to do so.

With sufficient rainfall, the mother of cacao trees will produce well within five to seven years, and the nyama would produce sometime before that. Within seven years, this system would produce enough gm/cc organic matter to maintain soil fertility. By including the already traditional cowpeas, peanuts and Bambara groundnuts (whose nitrogen would be better-maintained because of the dispersed shade), I am sure the system would be capable of increasing soil fertility in the Sahel, without using any chemical fertilizer.



42. Benin. Two plots on a research station show the relative growth of speargrass with and without mucuna. (This is the only photo of green manures used in this book that was not taken on the field of a farmer who had already adopted the use of green manures.)

sufficiently to smother it. The imperata grass will die after being shaded four or five months. Often the last 5% of the imperata grass must be eliminated by hand. The last I knew, 14,000 farmers were using this system, which was largely introduced by IITA (International Institute of Tropical Agriculture) in Nigeria.²⁵ Sometimes tithonia (*Tithonia diversifolia*) is used in a similar manner to control imperata grass. Leucaena and mother of cacao can also be used, but these take three or four years to shade out the weed.

Cameroon

S60. Tephrosia fallow. *Tephrosia vogelii* is used as an improved fallow near the town of Bamenda. A year or two after the tephrosia is planted, it is cut down and cropping begins again. The fertilizing effect of this one-year improved fallow equals the impact of between two and four years under a natural fallow (Photo 43). One farmer started doing this in the late 1990s; eight years later the practice had spread spontaneously

Benin

S59. All crops/mucuna. Mucuna is used in Benin to control imperata grass (*Imperata cylindrica*, generally called speargrass in West Africa). Imperata grass is one of the world's most noxious weeds (Photo 42). With mucuna, imperata-dominated wastelands are returned to cultivation. The specific techniques vary somewhat, depending on the level of infestation of imperata grass. Usually the imperata grass must be burned. Mucuna is then planted. The imperata grass may need to be cut once more to let the mucuna develop

²⁵Okon, Paul B. and Uche C. Amalu, "Rehabilitation of Degraded Tropical Farms Using Weed to Fight Weed," n.d. Unpublished.



43. **Cameroon.** An improved fallow using tephrosia near Bamenda, Cameroon.

to over one thousand neighboring farms, without the support of any outside institution.²⁶ A very similar system is used in parts of Vietnam by thousands of farmers.

Ethiopia

S61. Teff/grasspea. Grasspea (*Lathyrus sativa*) is planted in a rotation with teff and other crops. Traditional grasspea varieties should not be eaten, although ICARDA (the International Center for

Agricultural Research in the Dry Areas) has now developed low-toxin varieties that are safe for human consumption. Tens of thousands of farmers practice this traditional system.

Rwanda

S62. Other crops/buckwheat. Buckwheat (*Fagopyrum esculentum*) is rotated with a number of other crops throughout much of Rwanda. Tens of thousands of farmers use this traditional system.

Uganda

S63. Various crops/common peas. In southwestern Uganda, common peas are grown with various highland crops to maintain fertility, either in a rotation or as contour hedgerows on steep hillsides. Thousands of farmers use this traditional system.

Tanzania

S64. Maize/sunnhemp. Sunnhemp (*Crotalaria ochroleuca*) is intercropped with maize, both to fertilize the soil and to provide a very good pesticide to control insects during grain storage. The sunnhemp is broadcast at a rate of about 30 kg/ha of seed, mixing one part sunnhemp seed with two parts sand to get a fairly even distribution of the seed. The sunnhemp is planted at the same time as the maize. Tens of thousands of farmers use this introduced system.²⁷

²⁶Anagho, Richard, "Green Manure for Improved Fallows in the Northwest Province of Cameroon." Paper delivered at a Follow-Up Seminar Workshop "Eco-Farming in Africa," on November 10, 2000.

²⁷Kullaya, I. K., et al., "Towards Improving Soil Productivity by Sunnhemp (*Crotalaria ochroleuca*) in the Highlands of Kilimanjaro in Northern Tanzania," in *Norwegian Journal of Agricultural Sciences*, No. 21, pp. 99-106.

Asian Green Manure/Cover Crop Systems

Bangladesh

S65. Various crops/lablab bean. Land-hungry Bengalis often plant a few seeds of lablab beans (known there as “hyacinth beans”) right next to their houses, so the bean will grow up and cover the roof of the house. The seeds are eaten as a pulse, and the greenery is spread across their fields as fertilizer. Probably hundreds of thousands of Bengalis use this traditional system.

Thailand

S66. Citrus/mimosa. Spineless *Mimosa* species are grown near the town of Chiang Mai as a cover crop under citrus trees. Probably only 50 to 100 people use this introduced system.

S67. Citrus/centrosema. *Centrosema pubescens* is grown under citrus trees near Chiang Mai as a perennial gm/cc, as well as for animal fodder. Perhaps a hundred farmers use this system.

S68. Citrus/cowpeas. Cowpeas are also grown as a cover crop under citrus. Very few farmers are as yet using this introduced system.

S69. Maize/rice bean-2. Rice bean is relayed into maize fields a month or two before the maize is harvested. Then the rice bean continues to grow throughout much of the dry season. The rice bean is grown partly to fertilize the soil, partly to produce the rice beans as a cash crop, and partly to keep the soil covered during the dry season for better weed suppression and protection of the soil. The system also reduces the loss of soil nitrogen and, in many cases, allows farmers to use zero tillage (reducing costs once again).²⁸ Two or three hundred farmers use this system that was recently developed by farmers.

S70. Maize/cowpea-2. The cowpea is relayed into maize, as is done with the rice bean in S69. Most of the same farmers who use S69 also use this one, just alternating between one legume and another in different years.

S71. Maize/lablab bean-3. The lablab bean is relayed into maize, just as it is done with rice bean in S69 (Photo 28). Two or three hundred farmers use this system.

Laos

S72. Upland rice/pigeon pea. Pigeon pea (*Cajanus cajan*) is planted at the same time as upland (non-irrigated) rice, at a rate of about one seed every 1.5 to 2 m in each direction. Thousands of farmers use this traditional practice in northern Laos.

²⁸Prinz, Klaus and Somchai Ongprasert, “Relay Cropping as an Improved Fallow in Northern Thailand”, Unpublished.

S73. Upland rice/cowpea. A variety of creeping cowpea found only rarely in Asia (I have seen it only in northern Laos), and also in some places in the Sahel, is planted quite sparsely among the rice. Some farmers mix cowpea seeds with rice seed at a rate of only about one part of cowpea seed to 200 parts of rice seed before broadcasting the mixture. Thousands of farmers use this practice.

Cambodia

S74. Various crops/cowpea. In southern Cambodia, cowpea is relayed into or planted after rice or vegetables, to grow during the dry season, much like in S70. Perhaps several thousand people use this traditional system.

S75. Various crops/jackbean. The jackbean is used in a manner similar to that of the cowpea in S69. Probably hundreds of farmers use this traditional system.

S76. Rice/sesbania. In a traditional green manure system, *Sesbania rostrata* is grown at the beginning of the rainy season in rice paddies to fertilize them for the subsequent rice crop. The sesbania is incorporated into the soil after it has grown just a month or so. Then rice is planted, as is done in traditional “green manure” systems from temperate climates. This practice is used sporadically in many parts of Southeast Asia and Sri Lanka. Tens of thousands of farmers use it.

Vietnam

S77. Many crops/mucuna. In northern Vietnam, a perennial mucuna species is sometimes used to recuperate wastelands. It is planted at the beginning of the rainy season on a piece of wasteland, and then allowed to grow until the land is judged fertile and largely weed-free. Thousands of farmers use this traditional system.

S78. Rice/rice bean. Rice bean is frequently grown immediately after the paddy rice harvest, during seasons when the rainfall is insufficient for rice. In fact, farmers in Vietnam say rice bean has that name because it is grown after rice. However, in most of the world, farmers think it is called “rice bean” because of the shape and very small size of the grain. Hundreds of thousands of farmers (perhaps millions) use this traditional system in northern Vietnam.

S79. Rice/mungbean. Mungbean (*Vigna radiata*, known in Vietnam as “green bean” and in India as “green gram”) is planted after rice, just as in S78. Many thousands of farmers use this traditional system. A similar system was also used traditionally in much of Indonesia.

S80. Rice/cowpea. Cowpeas are used in the same way as the rice bean in S78 (Photo 44). Tens of thousands of farmers use this traditional system in northern Vietnam. A similar system was traditional in Indonesia, but largely died out when the national government began subsidizing chemical fertilizers. Once the subsidies were ended, the gm/cc system was revived in some areas, such as in southern Sumatra.



44. Indonesia. Cowpeas and other edible gm/cc species often grow well on paddy fields during seasons when there is not enough water in the rivers to irrigate paddy rice.

S81. Rice/azolla. Azolla is an algae that grows in rice paddy water and fixes up to 30 kg of nitrogen per hectare. It can be spread from paddy to paddy to fertilize the rice virtually for free.

S82. Various crops/tephrosia. *Tephrosia vogelii* is planted as a contour barrier in mountainous areas to recuperate wastelands. This is done in various provinces of northern Vietnam, especially Son La and Thai Nguyen Provinces. Hundreds or thousands of farmers use this introduced system.

S83. Various crops/yam bean. Yam bean (*Pachyrhizus erosus*) is used in southern Vietnam, both as a gm/cc in rotation with other crops, and as a home-made insecticide. This traditional system is practiced widely by an unknown number of farmers.

S84. Various crops/soybeans. Throughout Vietnam, soybeans (*Glycine max*) are rotated with other crops to improve soil fertility and to produce a valued food. Hundreds of thousands (if not millions) of farmers use this traditional system.

S85. Maize/mungbeans. Mungbeans are intercropped in maize fields in northern Vietnam. Both crops are planted at the same time. Thousands of farmers use this traditional system.

S86. Several crops/jackbean. The jackbean is occasionally grown on wastelands in Yen Bai Province to recuperate the areas for the cultivation of many other crops. Jackbean seeds are broadcast on the land a week or so before the beginning of the rainy season, at about two or three seeds/square metre. Where weeds are particularly aggressive, you may need to cut the weeds back once, in order to allow the jackbean to grow vigorously. In such cases, planting the seeds (placing them about two cm under the soil surface) might also solve the problem, because planted seeds will germinate about two weeks sooner than if they are broadcast. The number of farmers who use this traditional technology is probably well into the thousands.

S87. Several crops/Indigophera spp. Indigophera trees are used like the jackbean in S86, except the tree is usually used where farmers expect to spend several years recuperating the wasteland. Again, the number of farmers who use this traditional technology is probably in the thousands.

S88. Cassava/rice bean. Bushy-type varieties of rice bean are intercropped with cassava. When the rice bean starts to compete with the cassava, the rice bean plants are pruned down to between 1 and 1.5 m in height, forcing the plant to grow laterally rather than vertically. Hundreds, if not thousands, of farmers use this traditional system.

S89. Nutgrass control with mucuna. Nut-grass (*Cyperus rotundus*), one of the world's most noxious weeds, is almost impossible to eliminate from a heavily infested field. However, farmers in parts of Vietnam and Honduras know that nutgrass can be eliminated by planting mucuna densely in an infested field and allowing the mucuna to shade it for six months.

The Philippines

S90. Several crops/Stylosanthes. *Stylosanthes* spp. are used in rotation with several local crops on Leyte Island. Hundreds of farmers were using this introduced system when I was there.

S91. Vegetables/lablab beans. Many Filipinos plant lablab beans to climb up the fences of their home gardens. They do this primarily because they have a soft-podded lablab variety; they eat the pod like a snowpea. They also plant lablab to fertilize the soil in their gardens. Tens of thousands of households on several of the islands use this traditional system.

Annex 1: Glossary of Agricultural Terms

Agrochemicals: Chemicals that are used in agriculture. These include chemical fertilizers and chemical-based pesticides, such as insecticides, fungicides and herbicides

Annuals: Plants that die within one year or less of germinating

Biodiversity: Refers to an environment containing a wide variety of different species living together

Dispersed shade: A condition of reduced sunlight in a field, produced by evenly spaced trees that produce fairly light shadows

Exotic plant: A plant that is not native to a given region

Fallow: The practice of temporarily not planting a field for several years, usually for the purpose of allowing natural vegetation to grow back and return the land to its natural state of fertility

Global warming: The gradual over-all increase of the world's temperature that is being caused at least in part by people's use of fossil fuels, by the destruction of the world's forests and other natural environments and by the decreasing amount of organic matter in agricultural soils

Grain legumes: Leguminous plants (plants with seeds that grow inside an elongated pod) whose seeds are eaten by humans

Green manure/cover crop, or gm/cc: A species of plant, usually a legume, whether it is a tree, a bush, a vine, a crawling plant or an algae, which is planted by farmers to maintain or improve their soil fertility or to control weeds. Farmers may also have many other reasons for growing these plants

Hedgerow: A line of plants grown across a field to protect it from erosion or to provide some other agricultural or environmental benefit

Inoculant: Microorganisms (extremely small microscopic plants or animals) used to increase the production of nitrogen on the roots or stems of certain legumes

Intercrop: A crop grown simultaneously amongst another crop or crops, planted within a month or two of the latter

Invasive species: Plants that have gradually propagated themselves in areas where they were not planted or did not previously exist, and are damaging other human production activities or the environment

Legume: A plant with seeds that grow inside an elongated pod. These plants are particularly important in agriculture since, through a natural process, they take nitrogen out of the air and make it available to other plants

Monocrop: A crop that is grown alone in a field at a given time

Nitrogen: A crop nutrient that is probably the greatest limiting factor to soil productivity around the world. It is becoming a more and more expensive part of chemical fertilizer because of the increasing price of energy around the world

Opportunity cost: The money or time you lose (that is, the “cost”) by choosing one option that eliminates the possibility (the “opportunity”) of taking advantage of another option

Organic matter: Anything that, in its previous form, was part of a living organism, such as parts of dead plants, bodies of dead animals, urine and manure

Perennial: A plant whose natural lifetime is two years or more

pH: A measure of acidity or alkalinity. A soils’ pH will affect almost all plants’ growth, especially if the soil is either extremely acidic or extremely alkaline

Relay crop: A crop that is planted in a field where another crop is growing within a month or two of the initial crop’s being harvested

Rhizobium: A microorganism that often grows on the roots of legumes and fixes nitrogen. It takes nitrogen out of the air and puts it in the soil in a form that plants can access

Rotation: A cropping system in which one crop is followed by another, or several others, in a systematic way. The crop sequence usually being designed to maintain soil fertility and reduce insect pests and diseases

Synchronization: The timing of the application of nutrients to the soil so they will provide the amount and kind of nutrients a crop will need at any given stage of its growth

Annex 2: The Evidence

Introduction

Some readers will feel that many statements in this book have been made with insufficient back-up. For a book of this length, the number of footnotes is meagre, and virtually none of them refer to a peer-reviewed article.

The fact of the matter is that most of the English-speaking scientific community has been very slow to do research on green manure/cover crops. The scientists who have done a fair amount of research on these crops are mostly Latin American, especially Brazilian. Their work on the subject is magnificent, but, of course, they write the results of their research in Portuguese and Spanish, sometimes in journals that few English speakers would have access to, even if he or she is able to read Spanish or Portuguese.

For those who do read Spanish and/or Portuguese, I would heartily recommend the following three books, more or less in descending order of priority:

Monegat, Claudino, *Plantas de Cobertura del Suelo: Características y Manejo en Pequeñas Propiedades* (Tegucigalpa, Honduras: CIDICCO, 1997). In Spanish and Portuguese. The original in Portuguese was printed in Chapeco, Santa Catarina, Brazil, and copyrighted in 1991. The Spanish edition is probably most easily obtained from CIDICCO in Honduras.

Calegari, Ademir, et al., *Aduacao Verde no Sul do Brasil* (Rio de Janeiro, Assessoria e Servicos a Projetoem Agricultura Alternativa, 1993). In Portuguese only. AS-PTA in Rio de Janeiro would probably be the best source.

Binder, Ulrike, *Manual de Leguminosas de Nicaragua, Volume I* (Esteli, Nicaragua: PASOLAC and the Escuela de Agricultura y Ganaderia de Esteli, 1997). In Spanish only.

Research notwithstanding, the vast majority of what we know today about gm/ccs has resulted from experimentation by smallholder farmers. Some of these experiments were done through a process of action research, or “participatory technology development” (PTD). Others were merely informal, trial-and-error experiments that smallholder farmers have done for millennia in their fields. These practical processes are admittedly not as carefully quantitative as scientific experiments, and often there are problems of experimental design. However, they have been done under smallholder farmers’ conditions. They reflect smallholder farmers’ priorities and they have been conducted within the economic, social and climatic limitations under which smallholder farmers must work. Each kind of experimentation, whether it be scientific, participatory or totally informal, has its advantages and disadvantages.

For example, smallholder farmers never do 15 replications of exactly the same experiment on one small piece of land. But if a technology is to the liking of the farmers, we may have hundreds of replications of very similar experiments, spread across dozens of soil types, topographies and different (though fairly similar) management styles. Mathematically speaking, these trials will give us a much better approximation than will a scientific experiment of what will happen when other smallholder farmers replicate that technology on their own farms. This better predictability from farmers' experiments occurs because a scientific experiment will normally include dozens of replications on fairly uniform micro-plots, carried out on one soil type (which usually has a bizarre history of cultivation under past experiments), on flat land (hillside experimental stations are virtually nonexistent) and under only one standardized, and often very expensive, form of management. Each of these conditions makes the scientific experiment less representative of the farmers' conditions than do the farmers' experiments.

Despite the informal nature of their experimentation, the varied trials smallholder farmers do can be analyzed mathematically to find out to what precise level of confidence we can generalize their results across a wider population of farmers.

I have not done any such analysis. I have visited the fields of thousands of farmers and seen the results. This book is a summary of what I have learned. The vast majority of this book's content is based on those observations of individual fields and on conversations I have had with the owners, plus conversations with dozens of the owners' neighbors and collaborators. It also includes observations of tens of thousands of other fields from moving vehicles.

For agricultural extension purposes, most agricultural research in the world is done with the purpose of trying to predict what technologies farmers will find beneficial, and will therefore adopt. When it comes to gm/ccs, we do not need to predict what systems farmers will adopt in the future. We already know what technologies they have adopted in the past. The only predictions needed are whether or not other farmers working in similar conditions will act in the same way. This prediction is best tested by showing other farmers the results of the technology, and then watching what they do or don't do with it.

If we believe that farmers are, by and large, economically rational (given their own priorities), we don't need to be guessing about whether the gm/cc technologies in this book will be beneficial to smallholder farmers under the conditions in which they are being used. The very fact of widespread farmer use, given the assumption of farmer rationality, leads us to conclude that these technologies are, in fact, benefiting the farmers.

Still, some readers may have questions about issues that are more in the realm of the theory of soil fertility rather than farmer adoption of technology. I will refer to a few of those questions and issues here.

The Amount of Organic Matter Required to Maintain or Improve Soil Fertility

First, I have purposely not given a recommendation for the exact quantity of organic matter that will maintain or improve soil fertility. The exact amount of organic matter needed will depend on a series of factors that vary from one village to another: the characteristics of the leaves, compost or manure being used; the density of nutrients in that organic matter; the amount of moisture it contains (when we are using green weight as a measurement); the quality of the soil, the specific factors in the soil that limit productivity; the amount of erosion; the climate; etc. Any exact figure of an optimum level of organic matter required would vary depending on the particular situation, taking each of these factors into account.

Where did I get the approximate figure of 20 to 25 MT/ha, green weight, of leguminous leaves (that is, above and beyond the normal crop residues)? It comes basically from having made an analysis of the impact of dozens of different gm/cc systems that I have observed around the world. I will present here a much-simplified version of that analysis:

Name and number of system:	Approximate amount of organic matter produced:	Does it usually maintain system or improve soil fertility?*
Systems that tend to increase soil fertility:		
Maize/mucuna-1 (S1)	70 t/ha	Improves
Maize/sweet clover (S7)	40+ t/ha	Roughly maintains, but also feeds grazing animals
Maize/runner bean-2 (S13)	60 t/ha	Improves
Maize/lablab bean-1 (S23)	60 t/ha	Improves
Systems that more or less maintain soil fertility:		
Maize/fava beans (S6)	25 t/ha (depending on the density of the legume)	Maintains
Millet/native dispersed shade/short-cycle cowpeas	20 t/ha	Roughly maintains
Tephrosia fallow (S60)	60+ t/ha, once every 3 - 4 years	Maintains
Systems that fail to maintain soil fertility (not including those where burn-off is a factor):		
Maize/wild sunflower-2 (S21)	15 t/ha (depends on spacing of hedgerows)	Fertility decreases
Maize/tephrosia (S25)	10 t/ha	Fertility decreases
Potatoes/tarwi (S33)	5-10 t/ha (depends on the size of the field)	Fertility decreases
Various crops/common peas (S63)	5-15 t/ha	Fertility decreases

*Note: Those systems that "improve" the soil do so only up until a certain point of diminishing returns, at which they, too, only maintain a specific level of soil fertility.

Though the data for some of these systems is very approximate, I think that these and other gm/cc systems provide fairly strong evidence supporting the 20 to 25 t/ha figure given. Furthermore, I have never seen a case where a gm/cc flagrantly violated this rule, regardless of the species of gm/cc or management of it.

The source of our knowledge on the impact of dispersed shade?

Among smallholder farmers, the use of dispersed shade is traditional and surprisingly widespread. Professionals, however, have only recently begun paying any attention to the technology.

Probably the best study ever made of the traditional use of dispersed shade was done by Malcolm Cairns, who worked in Southeast Asia with the International Center for Research in Agroforestry. He found dozens of such systems spread from northeastern India to Indonesia. I have seen traditional systems in a dozen countries of Latin America (most notably in Mexico, El Salvador, Guatemala, Honduras, Nicaragua and Brazil). I am told that the most notable case in West Africa, the millet/*Faidherbia albida* system (S57), is used from Senegal to Niger, although I have only personally seen it in three of those countries.

Scientific research on dispersed shade was conducted for a number of years by Dr. Ian Cherret and Ing. Luis Martinez in Honduras for the United Nations Food and Agriculture Organization (FAO). Much of the theoretical and quantitative information I presented in earlier chapters came from conversations held with Ian and Luis and their team during the years I lived in Honduras.

The effect of organic matter on phosphorus availability

Virtually all farmers, including those in the United States, know that phosphorus availability is greatly enhanced if the phosphorus is not actually in contact with the soil. This is why chemical fertilizers are commonly “banded” into the rows of crops rather than broadcast or spread more evenly across the soil.

In tropical soils where extremes of pH are much more common, the tying up of phosphorus in contact with the soil is even more important. Most literature agrees that very acidic soils (with a pH of less than about 5.0) will have virtually no phosphorus that is available to the plants, even though reasonable levels of phosphorus are present in the soil.

What is happening in developing world soils that have more moderate pHs? First, let’s admit that we don’t really know for sure. We do know that the amount of total phosphorus in a soil that is actually available to crops can range from 0.5% to 2.0%, and that much of this variation depends on the level of organic matter in the soil. Though an increase in availability from 0.5% to 1% of the total soil phosphorus doesn’t sound like much, it represents a 100% increase in the phosphorus available to crops. My observations of soil phosphorus levels in the developing world lead me to believe that

this level of increase is quite common when we use gm/ccs.

The one case I have followed most closely is the maize/mucuna system in northern Honduras (S1). It is a very interesting case, and quite well documented (see, for instance, Bernard Trombley's Cornell University doctoral dissertation). In this case, thousands of farmers working on poor tropical soils with a parent material low in phosphorus have been planting maize and mucuna on the same fields every year for 40 to 45 years. Most of these farmers have never applied chemical phosphorus to the soil. Yet, after 40 or more years of harvesting maize at rates of 1.5 to 2.5 t/ha, they still are having no problem with phosphorus availability in the soils. In fact, Bernard found no yield response to adding phosphorus to these soils.

In most of my travels across more than 45 developing countries, I have observed gm/cc systems in use. Yields have doubled or tripled in case after case. Yet I have never observed a serious phosphorus deficiency, even where farmers have applied no phosphorus for decades. The northern Honduras phenomenon is not an exception. It is well within the normal range of cases.

So what is happening? How can farmers take significant levels of phosphorus every year out of a soil that was never particularly rich in it anyway, and do so without running out of phosphorus?

One answer, of course, is that the incredible amounts of organic matter added to the soil have increased the available phosphorus by 100%, or maybe even several hundred percent. That would explain a good part of the mystery, but not all of it.

I think the problem may well lie with one inherent assumption that undergirds everything that has been written above: the assumption that these farmers' fields are closed systems. Most agronomists don't even realize they are constantly making this assumption. Up until now in our discussion, we have been assuming that the only phosphorus that could possibly exist in each farmer's field is the phosphorus that was there 40 years ago, when they began using mucuna.

But this assumption is wrong. It is, in fact, very wrong. I once visited a scientific research station in the Brazilian Amazon near the city of Belen. Farmers there were cutting down virgin forest, largely because of the weed pressure on all land that had been farmed for more than a few years. Scientists found that birds and bats deposited an average of 10,000 viable weed seeds on each hectare of new farm land per year. How much phosphorus would be deposited in the guano along with those seeds? We don't know, but the amount would be significant, especially given that a large majority of bird species are carnivorous and eat insects rather than seeds. In addition to those depositions, phosphorus would be spread from forest to farm and from farm to farm by microorganisms, insects, earthworms, wild animals, domestic animals, etc.

This transfer of nutrients does not only happen near the edges of virgin forests. Across the Sahel, far larger transfers of phosphorus occur over larger areas because of the

seasonal winds called the “harmattan.” Thousands of tons of topsoil are carried across the southern perimeter of the Sahara desert. To understand how much soil is moved, you only need to look at the windward side of many homes on the windward side of Sahelian villages. The build-up of topsoil against those walls is frequently over a metre high, and occasionally reaches the eaves of the house. In much of the Sahel, every low-lying bush that has leaves year-round (including the nyama) has around 40 cm of soil built up around its base. This represents a major transfer of nutrients from one field to another, and a major influx of phosphorus to fields in which farmers are using nyama or other bushes to fertilize their soil.

With these dynamics as background, let’s return to the original question of the effect of organic matter on the availability of phosphorus. Our present methods of soil analysis do not give us a very good answer. Some scientists who have looked at phosphorus levels in organic systems have admitted they cannot explain where all the phosphorus is coming from (Cheryl Palm is one of them).

CGIAR (Consultative Group on International Agricultural Research) system scientists have been telling us for over a decade that Africa is heading for a major crisis of soil phosphorus deficiency. They have not been clear about exactly when the problem would hit, but certainly sometime within the 25 years following the start of their predictions. They normally give two major reasons for decreasing levels of available phosphorus. One is the gradually decreasing levels of available phosphorus they have found in the soil analyses they’ve done. The second is a calculation based on crop yields, from which they have calculated the annual loss to the soil of various nutrients.

But there is reason to believe that somehow more phosphorus is available to plants than scientific studies would indicate. The CGIAR calculation based on crop yields may be based on a major misunderstanding of the dynamics of smallholder agriculture in Africa. In the United States, calculating nutrient losses on the basis of crop yields can be quite accurate because American farmers consume virtually nothing of what they harvest, and even what they do consume goes into flush toilets and far away from their farms. However, the vast majority of African smallholder farmers produce only enough food for 6 to 10 months of consumption. That is, most African villages are net importers of food, and therefore net importers of phosphorus. Their food waste all goes either onto the soil surface or into hand-dug latrines that go nowhere near as deep as some of the roots of nearby bushes and trees. So quite likely, the total amount of phosphorus recycled into people’s fields is even greater than the amount that is taken out at harvest time.

That leaves soil analyses of available phosphorus as the main credible piece of evidence for the predicted African soil phosphorus crisis. Remember, scientists point to gradually decreasing levels of available phosphorus in soil analyses. But do decreased levels of available phosphorus correlate well with decreased levels of the total phosphorus in the soil?

Soil analyses, by and large, do not give us a very accurate assessment of the phosphorus

content of a soil. First, they do not measure the phosphorus that is tied up chemically and therefore is unavailable to plants. Secondly, they do not measure the phosphorus that exists in organic forms, whether that be in decomposing plant material or in soil fauna and flora. Furthermore, these inaccuracies may be quite large, leaving out a large majority of the total phosphorus present in the soil.

During a study I did in Africa in late 2009 for the Christian Reformed World Relief Committee, I traveled through significant areas of Malawi, Zambia, Kenya, Uganda, Niger and Mali, interviewing farmers wherever I visited. When doing such studies, I observe all the agricultural practices and conditions that I can as I travel along the highways and dirt roads in order to triangulate that information with what I see in smallholder farmers' fields and hear from the farmers. I saw tremendous evidence that yields were diminishing, primarily because of nutrient deficiency. But nitrogen was clearly most deficient in at least 95% (probably closer to 98%) of the tens of thousands of fields that I observed. Nitrogen deficiency is due to a lack of organic matter in the soil. All over Africa, farmers are mining the nitrogen out of their soils. Wherever one goes, one can observe the yellowish, stunted maize and millet fields that indicate a nitrogen deficiency. On the other hand, the purple leaves and stems associated with phosphorus deficiency were visible on less than 5%, and probably closer to 2%, of the fields.

Something is obviously wrong with the CGIAR's prediction of a major phosphorus-based crisis within the next decade or so. But why such a striking lack of phosphorus deficiency symptoms? Deficiency symptoms in most grasses like maize and millet tend to indicate only the single element that is most limiting. That is, if a nitrogen deficiency is more limiting to the plant's growth than a phosphorus deficiency, you will see only the symptoms of nitrogen deficiency on the leaves or stems of the plants. So my observation of fields around Africa did not indicate that there was no phosphorus deficiency. Rather, it indicated that in a widespread, consistent pattern, the soil's phosphorus deficiency (if present) was masked by a worse nitrogen deficiency.

This consistent masking of whatever phosphorus deficiency there was—across a whole continent—leads me to believe there must be some relationship between the available amounts of the two nutrients, causing the phosphorus deficiency to be consistently less limiting than the nitrogen one.

If the original amount of phosphorus in the soil and subsoil minus the amount taken out by African farmers over the years were the main factor in determining the amount of available phosphorus, there would be no relationship between that quantity of phosphorus and the quantity of nitrogen in the soil. There would, therefore, tend to be many fields in Africa with the purplish signs of phosphorus deficiency. However, if the amount of organic matter in the soil were the main determinant of how much phosphorus was available to plants, then a very clear relationship would exist. In the absence of chemical fertilizer, the amount of nitrogen in a soil correlates quite closely with the amount of organic matter, which in turn would correlate quite closely with the amount of available phosphorus in the soil.

To check out this theory, I asked about a dozen owners of the few fields with significant phosphorus deficiency symptoms whether they had used any chemical fertilizer in the last year. In every single case (except one where worms had obviously done major damage to the maize's roots), the farmers reported applying urea, and only urea, to those fields. Application of urea would mean that nitrogen was plentiful. Therefore, in the absence of a complete formula of fertilizer that also contained phosphorus, phosphorus would become the limiting factor for the crops.

Thus, I propose that there is major evidence that a lack of organic matter is the main reason African soils are deficient in available phosphorus, and that most evidence of rapidly decreasing phosphorus availability is due not to a lack of over-all phosphorus, but to a lack of organic matter to make those reserves of phosphorus available to farmers' crops. As we increase the amount of organic matter in the soils, as we can do with gm/ccs, the amount of available phosphorus is also going to increase substantially, as has happened in northern Honduras.

The logical conclusion would seem to be that the organic matter supplied by gm/ccs significantly raises the availability of phosphorus in the soil, making additional applications of chemical phosphorus unnecessary, at least in the short to medium term. Of course, nothing can come from nothing. Where will all that phosphorus, that is slowly becoming available, come from over the long run? If my thesis about the net inflow of phosphorus into most African smallholders' fields is correct, and maintains itself, the whole theory that total phosphorus is diminishing is mistaken, and Africa's smallholder farmers may never have to worry about the so-called phosphorus deficit. If my thesis is wrong, or if it is correct and African smallholder farmers increase their productivity to the point of being net exporters of phosphorus, African farmers will need to start buying replacement phosphorus for their fields—but probably not until some 20 to 40 years from now, given the supplies of phosphorus from the harmattan, birds, bats, termites, etc.. By that time, hopefully, they will have advanced enough, and their harvests, or world food prices, will be high enough, that they will be able to afford it.

Annex 3: List of Recommended Green Manure/Cover Crop Species

Note: A number immediately following the common name of the species indicates the box of the decision tree in which there is a general description of this species.

Common name	Scientific name	Gm/cc Systems	Countries where systems used
Azolla	<i>Azolla pinnata</i>	S81	Vietnam
Bambara groundnut	<i>Voandzeia subterranean</i>	S58	Mali
Black bean (see lablab bean)			
Broadbean (see fava bean)			
Buckwheat	<i>Fagopyrum esculentum</i>	S62	Rwanda
Calopogonium	<i>Calopogonium mucunoides</i>	S55	Ghana
Centrosema	<i>Centrosema pubescens</i>	S67	Thailand
Choreque	<i>Lathyrus nigrivalvis</i>	S15	Guatemala
Common pea	<i>Pisum sativa</i>	S36 S49 S63	Peru Brazil Uganda
Cowpea (#38)	<i>Vigna unguiculata</i>	S22 S58 S68 S70 S73 S74 S80	Honduras, Guatemala, El Salvador, Nicaragua, Panama Mali Thailand Thailand Laos Cambodia Vietnam, Indonesia
Crotalaria	<i>Crotalaria spp.</i>	S44 to 46	Brazil
Desmodium	<i>Desmodium ovalifolium</i>	S27	Honduras, Belize
Faidherbia (#25)	<i>Faidherbia albida</i> , formerly <i>Acacia albida</i>	S57 S58	Mali, Burkina Faso, Niger
Fava bean	<i>Vicia faba</i>	S6 S35	Mexico, Guatemala, Vietnam Peru
Forage peanut (see perennial peanut)			
Grasspea	<i>Lathyrus sativa</i>	S61	Ethiopia
Green bean (see mungbean)			
Green gram (see mungbean)			

Groundnut (see peanut)			
Horsepea (see lablab bean)			
Hyacinth bean (see lablab bean)			
Indigophera	<i>Indigophera spp.</i>	S87	Vietnam
Jackbean (#29)	<i>Canavalia ensiformis</i>	S3 S10 S11 S29 S38 S42 S75 S86	Mexico, Brazil Mexico Mexico Costa Rica Paraguay, Honduras Paraguay, Honduras Cambodia Vietnam, Nicaragua
Lablab bean (#37)	<i>Dolichos lablab</i>	S23 S24 S65 S71 S91	Honduras, Peru Honduras Bangladesh Thailand Philippines
Leucaena (#26)	<i>Leucaena leucocephala</i> and <i>L. diversifolia</i>	S56	Ghana
Lima bean	<i>Phaseolus lunatus</i>	S4	Mexico, Guatemala, Honduras
Lupines	<i>Lupinus albus</i> , <i>L. luteus</i> and <i>L. angustifolius</i>	S39 and S40	Paraguay and Brazil
Mimosa (see spineless mimosa)			
Mother of cacao (#26)	<i>Gliricidia sepium</i>	S58	Mali
Mucuna (#32)	<i>Mucuna spp.</i>	S1 S2 S8 S14 S17 S18 S19 S31 S37 S41 S47 S48 S53 S59 S77 S89	Mexico, Guatemala, Belize, Honduras Mexico, Costa Rica Mexico Guatemala, Nicaragua, Brazil, Paraguay Honduras Honduras Honduras Panama Paraguay, Mexico Paraguay Brazil Brazil Ghana, Benin, Mexico Benin Vietnam Vietnam
Mungbean	<i>Vigna radiata</i>	S79 S85	Vietnam, Indonesia Vietnam
Nyama (#45)	<i>Piliostigma reticulatum</i>	S49 S50 S51 S52 S54 S58	Burkina Faso Burkina Faso Burkina Faso Burkina Faso, Mali Ghana Mali

Pea (see common pea)			
Peanut	<i>Arachis hypogea</i>	S43 S58	Paraguay Mali
Perennial peanut	<i>Arachis pintoii</i>	S26 S28	Honduras, Costa Rica Costa Rica
Pigeon pea (#26)	<i>Cajanus cajan</i>	S30 S72	Panama, Brazil, Kenya Laos
Quickstick (see mother of cacao)			
Rice bean	<i>Vigna umbellata</i>	S9 S69 S78 S88	Mexico, Guatemala, El Salvador, Vietnam Thailand Vietnam Vietnam
Runner bean (#14)	<i>Phaseolus coccineus</i>	S12 S13	Guatemala Guatemala, United States, Mexico, Honduras, Colombia, Ecuador, Peru, Bolivia, Chile
Scarlet runner bean (see runner bean)			
Sesbania	<i>Sesbania rostrata</i>	S76	Cambodia, Sri Lanka, etc.
Soybean	<i>Glycine max</i>	S84	Vietnam
Spineless mimosa	<i>Mimosa spp.</i>	S66	Thailand
Stylo	<i>Stylosanthes spp.</i>	S90	Philippines
Swordbean	<i>Canavalia gladiatus</i>	S3	Mexico
Sunnhemp	<i>Crotalaria ochroleuca</i>	S64	Tanzania
Sweet clover (#14)	<i>Mellilotus albus</i>	S7	Mexico
Tarwi (#15)	<i>Lupinus mutabilis</i>	S32 S33 S34	Peru, Ecuador, Bolivia Peru, Ecuador Peru, Bolivia
Tephrosia (#29)	<i>Tephrosia vogelii</i> and <i>T. candida</i>	S16 S25 S58 S60 S82	Guatemala Honduras Mali Cameroon Vietnam
Tithonia (see wild sunflower)			
Velvetbean (see mucuna)			
Vetch	<i>Vicia toluca</i>	S5	Mexico
Wild sunflower	<i>Tithonia diversifolia</i>	S20 S21	Honduras Honduras
Yam bean	<i>Pachyrhizus erosus</i>	S83	Vietnam

Annex 4: Seed Sources for Green Manure/Cover Crops

In many cases, seeds can be found in-country; look for seeds in village markets, NGOs with agriculture-related projects, and research institutions (e.g., agricultural colleges and universities). If seeds of a particular crop or variety cannot be found in the country or region where you are working, it is possible to order seeds from other countries.

When transferring seeds across borders, you will likely need the following documents: 1) a seed import permit from the country that the seeds will be shipped to; 2) a phytosanitary certificate from the country of origin (often the shipper/seed supplier can supply this) stating that the seeds are free of pests and diseases. Check with the Ministry of Agriculture in the country you work in to find out details regarding documents needed and how to obtain them. Typically, one would begin by obtaining the import permit, as this document could contain specific seed treatments required for entry of particular crops. One would then send the import permit to the seed supplier in the country of origin. Based on requirements outlined in the import permit, the seed supplier can carry out any specific seed treatments, list those in the phytosanitary certificate, and include both documents (originals may be required) in the box of seeds to be shipped. Request that shipments be sent via a reputable carrier such as DHL. Be aware that extra costs can be incurred if it becomes necessary to hire a separate courier to clear seeds through customs once they arrive in your country.

Below are a number of seed suppliers that carry seeds of gm/ccs:

Abundant Life Seed Foundation

PO Box 279

Cottage Grove, OR 97424-0010 USA

www.abundantlifeseeds.com

Tel: (541) 767-9606

Fax: (866) 514-7333

Source of clover and hairy vetch

B & T World Seeds

Paguignan

34210 Aigues-Vives

France

www.b-and-t-world-seeds.com

Tel: 00 33 (0)4 68 91 29 63

Fax: 00 33 (0)4 68 91 30 39

Numerous species and varieties in stock; allow up to 8 weeks for seeds not in stock.

Baker Creek Heirloom Seeds

2278 Baker Creek Road
 Mansfield, MO 65704 USA
 www.rareseeds.com
 Tel: (417) 924-8917
 Fax: (417) 924-8887
 Email: seeds@rareseeds.com
Source for a number of cowpea varieties

Banana Tree

715 Northampton St.
 Easton, PA 18042 USA
 www.banana-tree.com
 Tel: (610) 253-9589
 Fax: (610) 253-4864
 Email: faban@banana-tree.com
Source for jackbean

CIAT**International Center for Tropical Agriculture**

Km 17, Recta Cali-Palmira
 Apartado Aéreo 6713
 Cali, Colombia
 Tel: +57 2 4450000
 Fax: +57 2 4450073
 E-mail: ciat@cgiar.org
 www.ciat.cgiar.org
 URL for regional office contact info:
 www.ciat.cgiar.org/AboutUs/Paginas/contact_us.aspx

CIDICCO**International Center for Information on Cover Crops**

Apdo. Postal 4443,
 Tegucigalpa, Honduras
 Tel: +504 239 5851 +504 232 385
 www.cidicco.hn

A CGIAR (Consultative Group on International Research) research institution with an extensive collection bean and forage lines. URL for information on how to request seeds: <http://isa.ciat.cgiar.org/urg/inforequestmaterial.do>

ECHO Seed Bank

17391 Durrance Road
 North Fort Myers, FL 33917
 Email: echo@echonet.org
 www.ECHOcommunity.org

Trial packets of a number of gm/cc crops are available to ECHO's network of international development workers. See the website for information on how to join ECHO's network and request seeds.

Inland & Foreign Trading Co., LTD

Block 1090, #04-04/05

Lower Delta Road

Tiong Bahru Industrial Estate

Singapore 169201

www.iftco.com.sg

Tel: (65) 2722 711

Fax: (65) 2716 118

Email : iftco@pacific.net.sg

See legumes under "Legume Cover Crop" and "Pasture Seed" categories. Source of bulk quantities (50 kg).

Shivalik Seeds Corporation

05, Panditwari, P.O. Prem Nagar

Dehradun, 248007, Uttaranchal

India

www.shivalikseeds.com

TeleFax: +91 135 773348

Source for a number of annual gm/ccs

Setropa B.V.

Troelstralaan 4

Postbox 203

1400 AE Bussum

Holland

www.setropa.nl

Tel: +31 (0)35 5258754

Fax: +31 (0)35 5265424

Email: setropa@setropa.nl

Source of a number of gm/ccs

Wolf and Wolf Seeds

Rua Paulo Padovan, 81

Ribeirão Preto-SP

Brasil

Email: online form

www.wolfseeds.com

Source of gm/ccs in bulk amounts

Heritage Seeds Pty. Ltd

7-9 McDonalds Lane

PO Box 4020

Mulgrave, Victoria 3170

Australia

www.heritageseeds.com.au

Tel: 03 9501 7000

Fax: 03 9561 9333

Email: heritage@heritageseeds.com.au

Source for several tropical and temperate legumes

If you are aware of other sources of seeds, please communicate that to the moderator of the Green Manure/Cover Crops discussion group on www.ECHOcommunity.org. We hope to be able to add sources to the above list over time.

Annex 5: Additional Resources on Green Manure/ Cover Crops

Books

Centro Internacional de Divulgacion sobre los Cultivos de Cobertura (CIDICCO), et al., *Experiencias sobre Abonos Verdes y Cultivos de Cobertura* (Tegucigalpa, Honduras: CIDICCO, 1998).

Eilittä, M., J. Mureithi, and R. Derpsch. *Green Manure/Cover Crop Systems of Smallholder Farmers: Experiences from Tropical and Subtropical Regions* (Dordrecht, The Netherlands: Kluwer Academic Publishers, 2004).

Florentin, M.A., M. Penalva, A. Calegari and R. Derpsch. *Green Manure/Cover Crops and Crop Rotation in Conservation Agriculture on Small Farms* (Rome: Food and Agriculture Organization 2011).

International Development Research Centre (Editors: D. Buckles, A. Eteka, O. Osiname, M. Galiba, and N. Galiano). *Cover Crops in West Africa/Plantes de couverture en Afrique de l'Ouest* (Sasakawa Global, 1999).

Kay, D.E. *Food Legumes* (Tropical Products Institute, 1979).

Monegat, C. *Plantas de Cobertura del Suelo: Características y Manejo en Pequeñas Propiedades* (Tegucigalpa, Honduras: CIDICCO, 1997).

National Research Council. *Tropical Legumes: Resources for the Future* (National Academy Press, Washington, D.C., 1979)

Rinaudo, T. *Farmer Managed Natural Regeneration: Exceptional Impact of a Novel Approach to Reforestation in Sub-Saharan Africa* (Technical Note #65, Educational Concerns for Hunger Organization 2012)

Website: https://echocommunity.site-ym.com/?page=tech_notes

Virtual Community

ECHO Community:

https://echocommunity.site-ym.com/group/green_manure_crops



Roland Bunch has worked in agricultural development for more than 42 years in more than 50 nations of Latin America, Africa and Asia. He has done consultancies with the Ford Foundation, Cornell University, CARE and the top non-governmental organizations from Canada, Great Britain, the Netherlands, Germany and Switzerland, as well as the governments of Guatemala, Honduras, Swaziland and Vietnam. In 1982, he published the book, *Two Ears of Corn, A Guide to People-Centered Agricultural Improvement*, which has since been published in ten languages and is an all-time bestseller

in the field of agricultural development. *Two Ears of Corn* pioneered the ideas of development programs' organizing smallholder farmers to teach each other and organize experiments, both of which have now become major movements around the world under the names of "farmer-to-farmer extension" and "participatory technology development."

Starting in 1983, Roland began investigating the use of plants that are particularly good at fertilizing the soil, which are now called "green manure/cover crops." Together with an independent group of agronomists in southern Brazil, he has spearheaded the effort that has successfully put this technology on the agenda of development organizations around the world.

Roland has been nominated for the Global 500 Award, the End the Hunger Prize of the President of the United States, and the World Food Prize.



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