PN-ABB-301

MEMORANDUM

Date [illegible] Jan 1989

TO: PPC/CDIE/DI, Tina Wilson/Acquisitions - 209 SA-18

FROM: S&T/AGR/RNR, Lloyd R. Frederick

SUBJECT: Reprints of Articles with Partial Support of A.I.D. Contracts/Grants

Attached is one copy of the following article with the supporting contract/grant number:

Yost, Russell and Dale Evans. 1988. Green Manure and Legume Covers in the Tropics. Univ. of Hawaii HITAHR Research Series 055. 44 p.

Contract/Grant Number: AID/DSAN-G-0100

Project: 931-0129

Attachments: a/s

cc: T.Gill
D. Bathrick

PN-ABB-301

630 US ISSN 0197-9310

September 1988

GREEN MANURE AND LEGUME COVERS IN THE TROPICS

Russell Yost
Dale Evans

Research Series 055

HITAHR · College of Tropical Agriculture and Human Resources · University of Hawaii

Library of Congress Cataloging-in-Publication Data

Yost, Russell S. (Russell Shelley), 1945–
Green manure and legume covers in the tropics.

(Research series, ISSN 0197-9310 ;)
"Prepared in fulfillment of United States Agency for International Development, contract no. AID/211-d (DSAN-G-0100)"
"April 1986."
Bibliography: p.
Includes index.
1. Green manure crops—Tropics. 2. Legumes—Tropics. 3. Cover crops—Tropics. I. Evans, D. O. (Dale Ordway), 1943– . II. Title. III. Series: Research series (Hawaii Institute of Tropical Agriculture and Human Resources) ; .
S661.Y67 1986 631.8'74'0913 86-14888

THE AUTHORS

Russell Yost is an associate professor, Department of Agronomy and Soil Science, Hawaii Institute of Tropical Agriculture and Human Resources, University of Hawaii.

Dale Evans is a research associate in the Department of Horticulture.

Prepared in fulfillment of
United States Agency for International Development
Contract No. AID/211-d (DSAN-G-0100)

CONTENTS

	Page
Abstract	1
Introduction	2
Green manuring for Annual Food Crops	4
Green manuring of Flooded Rice with *Sesbania* Species	4
Intercropped Green Manures	4
Border-planted Green Leaf Manures	4
Rice Yield Responses to Green Manuring	5
Legume Species for Green Manure and Cover Crops	10
Grain Legumes as Cover Crops and Green Manures	11
Cajanus Cajan	11
Psophocarpus tetragonolobus	11
Vigna aconitifolia	12
Vigna unguiculata	12
Trailing Legumes as Cover Crops	12
Pueraria phaseoloides	13
Calopogonium mucunoides	14
Centrosema pubescens	14
Low-growing Legumes as "Living Mulch" Covers	15
Desmodium ovalifolium	15
Aeschynomene falcata	15
Perennial Legumes as GLM Crops	15
Leguminous Shrubs	15
Herbaceous Annual Legumes as GM Crops	16
Crotalaria juncea	16
Sesbania bispinosa	17
Trailing Annual Legumes as GMs	18
Use of Legume Covers with Root Crops	18
Use of Legume Covers and Green Manures with Plantation and Perennial Crops	20
Legumes and their Rhizobia	25
Types of Rhizobia	25
Legume Groups	27
Source of Inoculant	27
Economic Aspects of Green Manuring	27
Recommendation	27
Literature Cited	28
Appendix A: Questionnaire Results	33
Appendix B: Green Manure Simulations	41
Appendix C: Questionnaire Respondents	44

Tables

Page

1. Cassava root yields when grown with several green manure legumes at two sites 20
2. Observed rates of nitrogen fixation in tropical creeping legumes 21
3. Residual effects of various soil covers on soil physical conditions 22
4. Influence of legume and grass covers on nutrient status in a Paleudult soil four years after clearing 24
5. Influence of legume and grass covers on nutrient status in a 1-m soil profile four years after clearing 24
6. Green manures and legume covers and their associated rhizobia 26

A-1. Advantages and disadvantages of green manure/cover crops in local farming systems 35

A-2. Views on the use of green manure/cover crops in local farming systems 36

B-1. Simulation results considering green manure equivalent to fertilizer N in increasing rice yield 43

Figures

1. Rice yield response to *Sesbania rispinosa* green manure in combination with inorganic N fertilizer, vs. response to fertilizer N alone 6
2. Rice yield following *Sesbania rispinosa* green manure grown for different durations before incorporation, vs. rice receiving fertilizer N after fallow 7
3. Effect on rice yield of various time intervals between the incorporation of *Sesbania rispinosa* green manure into the soil and the transplanting of rice 8
4. Rice yield responses to fertilizer N applications with or without preceding *Sesbania rispinosa* or *Crotolaria juncea* green manure crop, vs. green manuring alone 9
5. Rice yields with fertilizer N alone, green manures alone, and green manures plus 60 kg/ha fertilizer N 10
6. Influence of covers on nitrogen maintenance or depletion in soil 23

GREEN MANURE AND LEGUME COVERS IN THE TROPICS

Russell Yost and Dale Evans

ABSTRACT

Growing leguminous plants for multiple uses has lately received renewed interest. Costs of fossil-based nitrogen fertilizer, after being unrealistically low for decades, have increased. Supplying nitrogen through biological fixation is attractive, but systems that accomplish this are needed in both temperate and tropical farming systems. Biological fixation as a source of nitrogen is natural for leguminous crops, yet the consumers of most nitrogen fertilizer are the major food cereals. One way these can obtain biological nitrogen is through the judicious use of green manures and legume covers.

This report provides an overview of literature describing various legumes and the cropping systems in which they are used in the humid tropics. Systems described include rice and green manures, plantation crops and legume covers, root crops and green manures, and some upland crops and green manures. A survey of current use of green manures and legume covers was conducted in 1981 as a preliminary part of the study.

Alternative sources of nitrogen are both more attractive for use in complex tropical farming systems and more in demand because of the scarcity of other nitrogen sources and of nitrogen fertilizer in many tropical countries. It seems apparent that biological nitrogen should be viewed as a complement to fertilizer nitrogen. The appropriate mix of the two is hard to assess because of inadequate or expensive techniques for measuring the amounts of nitrogen contributed by the green manure or legume cover. We emphasize the need to assess the advisability of legume use in particular situations from a farming systems research and development perspective because of the biologic, economic, and social complexity of tropical farming systems.

As a result of the study, we emphasize that knowledge gaps or research needs exist as follows:

1. Techniques to measure nitrogen contributed by the green manure or legume cover are inadequate.

2. Viable seeds for legume germplasm evaluation are hard to get.

3. There is not enough information on the characteristics of various candidate green manures and legume covers and on their climate and soil requirements. Such data could be used in screening candidate legumes.

Keywords: Legume covers, nitrogen fixation, green manures, biological nitrogen fixation.

INTRODUCTION

Growing plants for soil improvement dates from the earliest intensification of agriculture. The reason growing certain plants before others is beneficial became clearer when the distinction between legume and nonlegume was recognized. The often-cited result of growing such crops was to "build up," "restore," or "rejuvenate" soil after using it for an exhaustive cereal crop. The reactions, influences, and restorative factors caused by including legumes in cereal rotations are seldom quantified, much less understood or managed.

Much of the attraction of using legumes in rotations rests on its intuitive appeal. Rigorous measures of the legume benefit are rare. The controversy over "organic farming" methods and approaches feeds on the lack of definitive measurement, understanding, and management of critical factors when the use of legumes and other organic materials in agriculture is emphasized. Such studies as there are suggest several cropping or farming systems in which growth of legumes can be beneficial. We will describe some of these systems for tropical agriculture, with emphasis on the humid tropics, and attempt to determine factors in their success that can be extrapolated to other areas, lands, or farming systems.

A general difficulty encountered in the green manure (GM) literature has been that the frame of reference for comparing responses was usually whether yields could be increased by growing the legume. With today's high population and pressure for food production, high yields are mandatory in most cropping systems. The need now is to maintain or increase production while replacing a significant portion of the nitrogen (N) fertilizer requirement by GMs, either in the traditional systems or in new ones.

The use of legumes in farming systems often has multiple effects. For example, legumes in pastures contribute significantly to animal nutrition because of superior feed quality, contribute to associated grasses in N stress conditions, and aid in providing effective soil cover, protecting it from rainfall and preventing soil loss in runoff caused by low infiltration rates. One of the challenges in using legumes is to find crops or improve varieties and management so as to obtain a primary product such as grain, forage, or fiber and still leave a significant N residue for the following crop.

"Green manuring" generally refers to the growth and plowing under of green plants before maturation or harvest of seed. After harvest, such operations are considered crop residue management. These residues differ considerably from GMs in that they are no longer succulent and usually have wide carbon/nitrogen ratios. Young, succulent plants turned under before maturity decompose rapidly and release nutrients, mainly N, which are generally readily available to associated crops. The total quantity of absorbed N in the plants is greatest with older, less-easily-decomposed materials, while the young, highly degradable materials usually contain little total N on a hectare basis, although percentage composition may be high.

These properties are similar to those often discussed in forage analyses where feed quality and quantity are inversely related: large quantities of forage can be produced if one relaxes digestibility standards and permits longer plant growth; alternatively, a small amount of high-quality forage is provided by young plants. Although green manuring has often been practiced with legumes and nonlegumes alike, the tendency is to use legumes because of their symbiotic N benefit. Green manuring as discussed in this summary will largely refer to the use of legumes.

"Green leaf manuring" has traditionally referred to green manuring with plant material not grown in place. Plant material is cut and carried to the site of incorporation or surface application. This variation of green manuring has been popular in semi-intensive land use areas. In such areas, materials from woody perennial species have been used, e.g., *Gliricidia sepium, Leucaena leucocephala, Acacia auriculaeformis, Sesbania grandiflora, Tephrosia* spp., and others (NAS 1980). Regrowth from such plants growing on plot borders is quite succulent, and production may be comparatively high for the area planted. In other situations, material from annual herbaceous species has been carried and applied, e.g., *Pueraria phaseoloides, Crotalaria* spp., *Mucuna* spp., *Sesbania* spp., etc. This method probably cannot provide enough plant material for large mechanized fields but has been effectively used for small fields. A variation of this approach is "alley cropping," in which crops are grown between rows of perennial legumes (Agboola 1982; IITA 1979; Kang et al. 1981). Regrowth from the legumes is periodically cut and applied to the crop grown between the legume rows, which are several meters apart at the most.

Although systems such as alley cropping have appeal, especially in labor-intensive systems, their applicability to large-scale agriculture has not been demonstrated. There is great potential to grow plants specifically for the intensive production of N for use either *in situ* or in neighboring areas. A practical question that limits the usefulness of these systems concerns labor required to transport and apply bulky leaf material as green leaf manure (GLM). Creative alternatives are needed to develop these methods further.

The term "legume effect" has sometimes been used to indicate a benefit derived from having grown a legume on a field before growing a following crop. This effect is obtained from the below-ground portion of the legume after the tops have been harvested for GLM, fodder, or other purposes. The nature of this benefit is more obscure than the benefit from application of plant tops as GLM. The partitioning of N between tops and roots probably influences the extent to which this benefit is due to N. Seldom-documented aspects of residual legume benefit include the improvement of soil physical properties by root growth and the stimulation of microbial populations in the legume rhizosphere. Documentation of improvement in soil physical conditions as a result of having grown GM legumes is meager and often inconclusive.

Complications of quantifying such effects are great, and diagnosing situations in which significant improvement in crop growth or productivity would result from improved physical properties is difficult. Perhaps just as remote is the possibility of diagnosing situations in which microbial activity is suboptimal. The difficulties are great in measuring benefits to microbial and physical alterations in soil brought about by the growth of legumes.

The "associated crop," in relation to GMs or legume covers, is the crop to be benefited by the legume. The associated crop is usually either a cereal grown after the legume in a relay or rotational system, a crop to which the green leaf material is applied in an alley cropping system, or a crop that grows simultaneously with the legume as an intercrop. The nature of the associated crop is particularly important in a green manuring system, because management decisions must give the associated crop priority over the legume whenever conflicting requirements occur. Seasonal growing conditions for the legume will be determined by first providing optimal conditions for the associated crop. Examples include growth of the legume in drier or cooler portions of the crop year (ICRISAT 1980; Kamprath et al. 1958), growing the legume on marginal land and carrying the GLM to the associated crop growing on deeper, richer land, and growing the legume on field borders. The secondary priority usually considered involves the extents of stress tolerances of these crops so that, given the potential growing period and its constraints, the appropriate legume species and management can be used. Just as pasture legumes to complement grasses for acidic, low-P soils must be tolerant of these conditions, GM and cover-crop legumes must be chosen on the basis of their ability to tolerate the local soil and climatic situations.

GREEN MANURING FOR ANNUAL FOOD CROPS

Green Manuring of Flooded Rice with *Sesbania* Species.

Green manuring has been practiced widely in Asia. Fields are often small and management intensive, and animal manures, night soil, agricultural byproducts, composts, and GMs are often used as soil amendments and nitrogen sources. Many Asian cropping systems are based on rice cultivation, and because of the ability of *Sesbania* species to grow in heavy soils, withstand waterlogging and flooding, and tolerate soil salinity, they are often the preferred GM crop in these systems. The species most often used in India is *S. bispinosa*. The name *S. cannabina* is often given for the annual sesbania used in the People's Republic of China. These two species are taxonomically distinguishable (Gillett 1963), but are very similar in general appearance and growth habit, and confusion is possible. Occasionally, the perennial *S. sesban* has been mentioned as a GM crop. There is no authoritative Asian taxonomy for *Sesbania*, and the confusion over identification is so evident that one suspects the accuracy of nomenclature in many of the agricultural reports.

Within the body of literature on green manuring in the tropics (Evans et al. 1983), two practices can be distinguished, as we have defined above: green manuring in rotation with the crop to be benefited, where the GM crop—generally a fast-growing annual—is grown and plowed under in the same field; and green leaf manuring, where green matter is cut and brought from elsewhere to the field for burial. GLM may be any green matter cut or lopped from waysides and uncropped areas, may be partitioned from the yields of nearby GM crops, or may be from plants grown for the purpose. The perennials *S. sesban* and *S. grandiflora* and the annual *S. speciosa* are often planted on field borders and paddy bunds to be used as GLM.

Intercropped Green Manures. Techniques of interplanting and intercalating *S. cannabina* for green manuring have been developed in southern China for rice cropping systems (FAO 1977). The sesbania is raised in nurseries and is transplanted to the rice field in rows 2–3 m apart when the spring rice crop is in grain-filling stage. Several weeks after transplanting the legumes, the spring rice is harvested. After an additional two weeks' growth, the sesbania is incorporated into the soil along with 50–60 kg/ha ammonium sulfate before transplanting the next rice crop. According to these farmers, the use of green manuring with mineral fertilizers increases yields while reducing the fertilizer N requirement of the rice crop.

Similar practices were reportedly taken up in North Viet Nam during the 1965–1970 period, as described by several authors in Volume 27 (1971) of the English-language publication *Vietnamese Studies*. Although *Sesbania* was thought to be easier to grow than *Azolla* spp., the traditional GM, its cultivation as an intercrop was thought to compete with rice (the timing and management were unspecified), and the presence of woody taproots was said to make plowing difficult.

Border-planted Green Leaf Manures. In parts of South and Southeast Asia, farmers use field borders to grow crops to provide GLM. These borders may be paths or roadways between fields, bunds to contain water within flooded fields, banks of ponds, terracing walls or contour berms between different land levels, or combinations of these. Border planting for GLM is one element of the integration of trees and shrubs with annual row crops now collectively called agroforestry. In agroforestry, shrubs and trees planted in lines are used for windbreak or privacy, as living fences, as fodder and fuelwood sources, or for soil stabilization on hillsides. GLM border plantings may also serve auxiliary purposes and are characterized by intense management and intimate integration with the cropping cycle. Such plantings eliminate the need to haul bulky, fresh GLM long distances to the fields and are suited to small field sizes. Competition in the root zone and for light may reduce the yields of crop plants adjacent to these plantings. Such effects may be minimal and may be partially offset by factors such as N transfer in the root zone, leaf litter fall, and microclimate adjustments. As field areas become smaller, border-planted GLM yields on an area basis become larger, and opportunities for competitive effects increase. No study of equivalence ratios for border-planted systems is available. *Sesbania* species are particularly well adapted to border plantings in rice and other lowland irrigated cropping systems because of their tolerance of waterlogging. Their tolerance to salinity may also be an advantage in delta areas and where soils of bunds concentrate salts by evaporation. *Sesbania grandiflora* is frequently planted in borders of more permanent fields. Smaller bunds or waterway banks serving as subdivisions between fields are not appropriate for perennial species, as such subdivisions may be removed and restructured during cropping cycles. In parts of Indonesia, however, *S. grandiflora* is managed on bunds as an annual, sown during development of one crop, allowed to put on growth during periods when competition effects are not critical, and pulled out of the ground during field preparations for the crop to be sown during the next rainy cycle (D. Ivory, personal communication). This species has rapid initial growth and is well suited to such use. *Sesbania speciosa* has been extensively used for border planting in India, particularly in Tamil Nadu (formerly Madras State).

Rice Yield Responses to Green Manuring

Historically, GM and GLM practices have been justified by the additional yields they can provide. By modern standards, however, these yields and response increments have often been rather small. In southern India, Karunkar and Rajagopalan (1948) stated that GLM applications of 5 Mg/ha* fresh material (about 34 kg/ha N) maintained rice yields at 2.25 Mg/ha grain; supplementing the GLM with 34 kg/ha each of fertilizer N and phosphorus (P) resulted in general yield increases of 25 percent. Sahu (1965) reported average rice yields for Orissa, India, of 623 kg/ha, and stated that applications of 22.5 kg/ha inorganic N fertilizer could boost yields by 30 percent. In a survey of green manuring research in India, Panse et al. (1965) estimated an average rice grain yield response to GM or GLM amounting to 236 kg/ha, an increase of about 20 percent over average control yields of 1204 kg/ha. They suggested a plateau in rice yield response to incorporated green matter and concluded that application rates of 4.56 to 6.84 Mg/ha fresh material were sufficient. Assuming an application of 5 Mg/ha fresh material containing 20 percent dry matter, the N addition represented in the aboveground portion is probably 20–40 kg/ha. Such amounts of N, combined with the soil physical benefits obtained by incorporating plant material, were adequate to provide modest yield increases of the traditional rice varieties then in use.

Modern, high-yielding rice varieties also benefit from GLM applications. Chatterjee et al. (1979) in West Bengal applied a GLM mixture of *S. bispinosa* and *Ipomoea crassicaulis* at a rate of 10 Mg/ha dry matter (containing about 200 kg/ha N), flooded the field, and after four to five weeks transplanted the rice variety Jaya. Rice yield response was similar to the application of 40 kg/ha N as urea at transplanting. It appeared that at their site the N effect was of

---

* 1 Mg = 10^6 g = 1,000 kg = 1 metric ton

less importance in the wet season (summer), since other bulky organic manures added at similar dry matter but lower N rates produced similar effects. In the dry season, however, when increased solar radiation allowed greater yield expression, response to the high amounts of GLM-N was obtained. High-yielding varieties have elsewhere been shown to respond as well to addition of nonlegume biomass as to N-rich legume materials: Subramanyam and Dhar (1976) obtained yields of 5.8 Mg/ha grain with variety IR-8 by applying 50 Mg/ha fresh water hyacinth, plus phosphate.

Varietal differences may be involved, as the results of Sadanandan et al. (1973) suggest. Only one of two high-yielding varieties (HYVs) of rice responded to 5 Mg/ha *S. speciosa* GLM applied with or without NPK fertilizer.

Reddi et al. (1972) obtained a linear response of IR-20 rice to N regardless of source. Rao (1950) had obtained similar results to increasing GLM applications, using a variety called GEB-24, perhaps not a "modern" HYV. Ali and Morachan (1974) grew IR-8 and IR-20 on a fertile site and found similar response to GLM or equal amounts of N as ammonium sulfate: 5.33 Mg/ha grain with 25 Mg/ha fresh GLM applied 20 days before sowing, and 5.93 Mg/ha with the inorganic in a 2/3–1/3 split application. Dargan et al. (1975) also obtained a typical rice yield response to inorganic N, with a tendency for yield response to level off between 80 and 120 kg/ha N (Figure 1). Green manuring with *S. bispinosa* was equivalent to applying 80 kg/ha inorganic N.

On an acid soil (pH 4.8) in West Bengal, IR-8 rice grain yields were similar whether

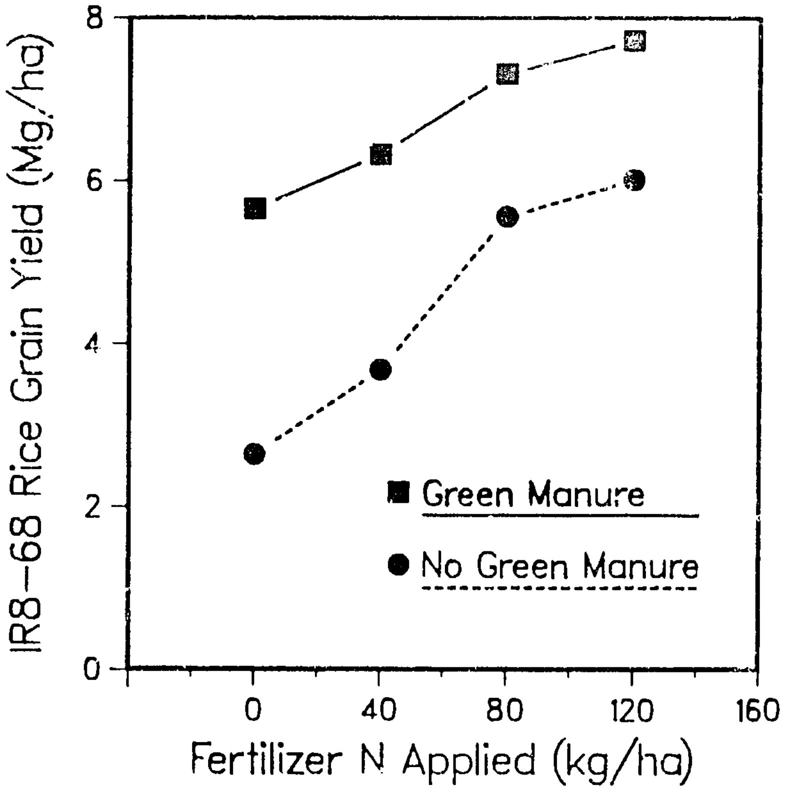

Figure 1. Rice yield response to *Sesbania bispinosa* green manure in combination with inorganic N fertilizer, vs. response to fertilizer N alone. (From Dargan et al. 1975.)

given NPK or a combination of GLM, basic slag, and K_2O: 3.92 and 4.03 Mg/ha grain respectively (Majumdar and Chakraborty 1977). These yields compared to control yields of 3.34, and 3.77 Mg/ha for basic slag plus K_2O without GLM. The following pulse crop yields were significantly increased on plots that had received GLM.

During the past few decades, introductions of HYVs have often increased cropping intensities, and the availability of inorganic N has made legume rotations or fallow periods less mandatory, resulting in unfavorable declines in soil fertility and physical properties. Gill (1978) characterized the HYV rice-wheat rotation in the Punjab as "exhaustive," citing among other evidences that zinc applications had become routinely necessary. He stated that where rice was grown continuously, soil physical conditions deteriorated. He recommended sowing *S. bispinosa* as a GM between the wheat harvest and rice transplanting. Similar declines have been noted in China (Smil 1984), where continuous rice cropping was blamed for formation of pans of "blue asbestos mud" impeding normal paddy drainage. Smil blamed increased cropping intensities and

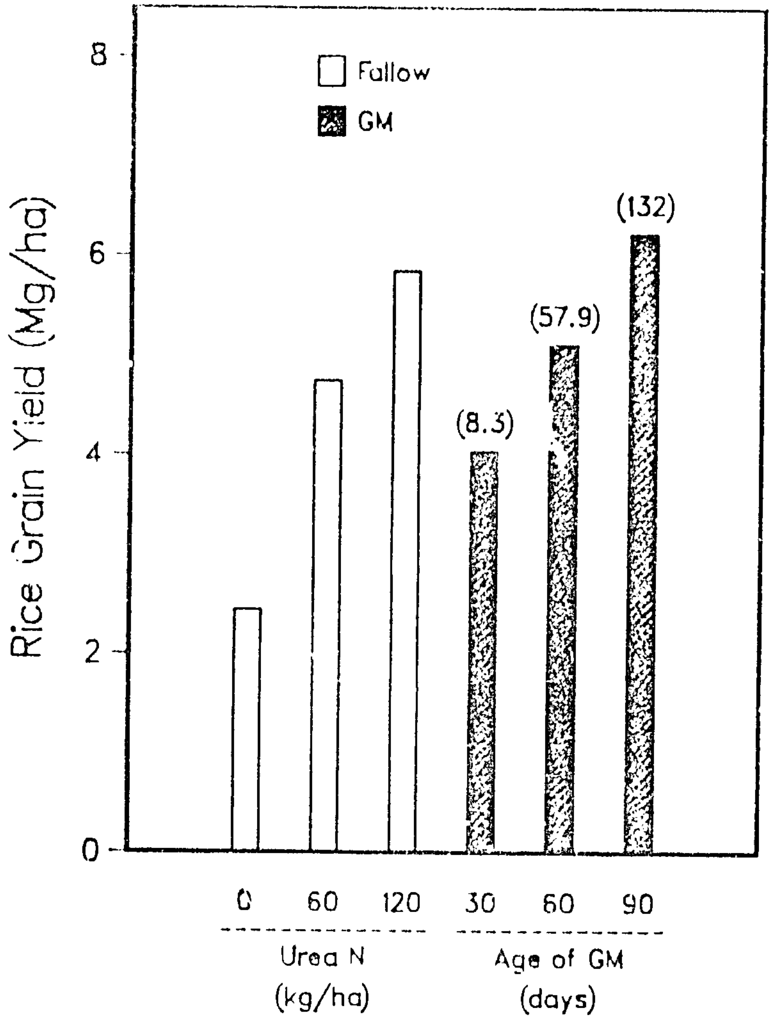

Figure 2. Rice yield following *Sesbania bispinosa* green manure grown for different durations before incorporation, vs. rice receiving fertilizer N after fallow. (From Khind et al. 1983.)

inorganic N fertilizer applications combined with decreases in green manuring, decreased incorporation of crop residues (straw being the most common rural fuel), and decreased sowing of legumes in general for widespread occurrences of potassium deficiencies, as well as of micronutrient deficiencies.

The sesbania species most often used as an *in-situ* GM for rice is *S. bispinosa*, because of its adaptation to lowland sites, heavy soils, salinity, and waterlogging. Much of the use of this crop sequence, both experimental and in farmers' practice, occurs—as we have seen—in India. Increases in rice yields have been obtained experimentally in Senegal, however, using *S. rostrata* (Rinaudo et al. 1983). When grown for 52 days in 1-m² cisterns under waterlogged conditions, this unusual species (which, under appropriate conditions, bears nodules on its stem) fixed an estimated 267 kg/ha N, based on the low (of the experimental deviation. When resulting legume biomass was chopped a incorporated into the surface 30 cm of s following rice yields (about 5.8 Mg/ha) w significantly superior to those obtained w either 60 kg/ha N as ammonium sulfate (Mg/ha) or the control (2.1 Mg/ha). Rice content was more than doubled over inorganic N treatment. The auth estimated that as a result of the C treatment, at least 178 kg/ha residual soi was present after harvest of the rice crop.

Timing is important in including GMs crop sequences. Singh et al. (1981) ha shown sharp increases in dry matter and production by GM legumes between the fi and seventh weeks of growth. Khind et (1983) found that upland rice yield in Punjab increased with the growth duration

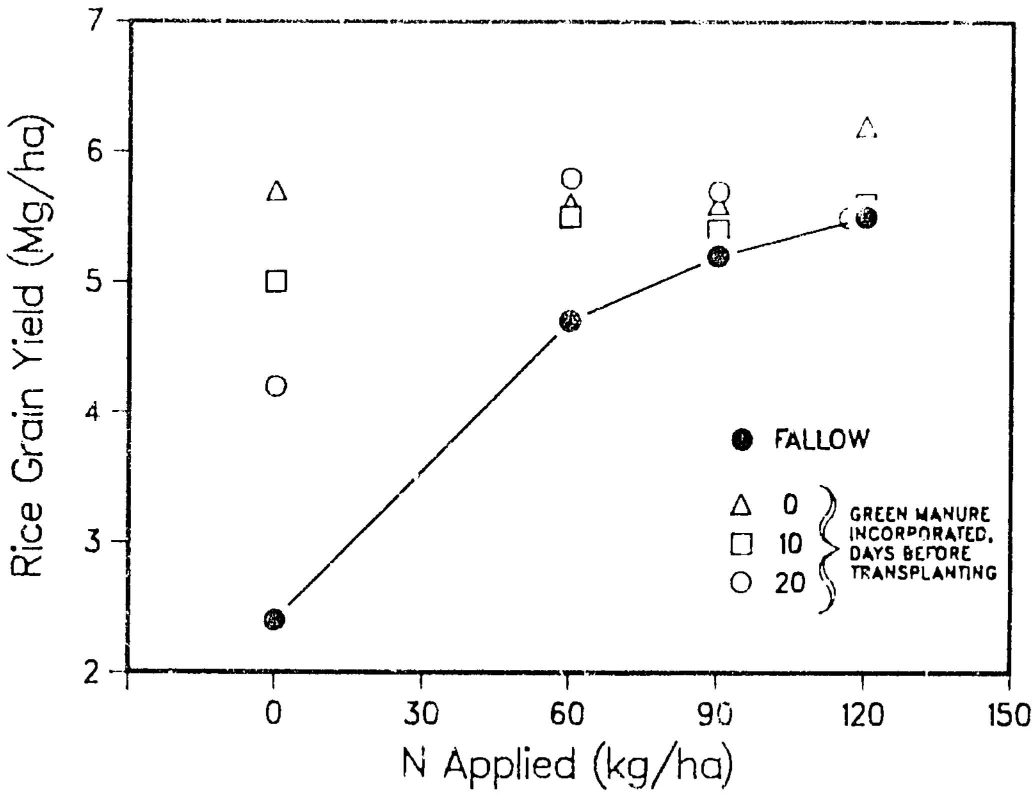

Figure 3. Effect on rice yield of various time intervals between the incorporation of *Sesban bispinosa* green manure into the soil and the transplanting of rice. (From Beri and Me 1979.)

the preceding *S. bispinosa* crop (Figure 2). Their results suggest that the effect of the 30-day GM crop involved more than the N contribution of the tops. Beri and Meelu (1979) showed that timing of transplanting the following rice crop has critical effects on N uptake after GM incorporation (Figure 3). The range of rice yield response was equivalent to 50–120 kg N/ha, depending on how soon after incorporation the rice was transplanted. The advantage of early transplanting was masked by applications of N in combination with the GM, especially at rates higher than 60 kg/ha.

Two other studies in India compared rice response to GMs with and without added inorganic N. Data of Bhardwaj et al. (1981) indicate a generally linear response to added N, regardless of its source (Figure 4); response from the green manuring was similar to that from 30 kg fertilizer N. Khind et al. (1982) found that GMs grown for two months were equivalent to 60–90 kg/ha inorganic N (Figure 5). Both experiments illustrated that GMs can supply at least half the N needed for moderate to high rice yields, and that a combination of GM with inorganic N can be highly beneficial to following crops. Green manuring in India has declined since the "coordinated research scheme" reported by Panse et al. (1965), or since the popularization of *S. speciosa* in Madras. A similar decline has been noted also in China during the past decade (Smil 1984). Increasing availability of fertilizer N and spread of short, high-yielding rice varieties have

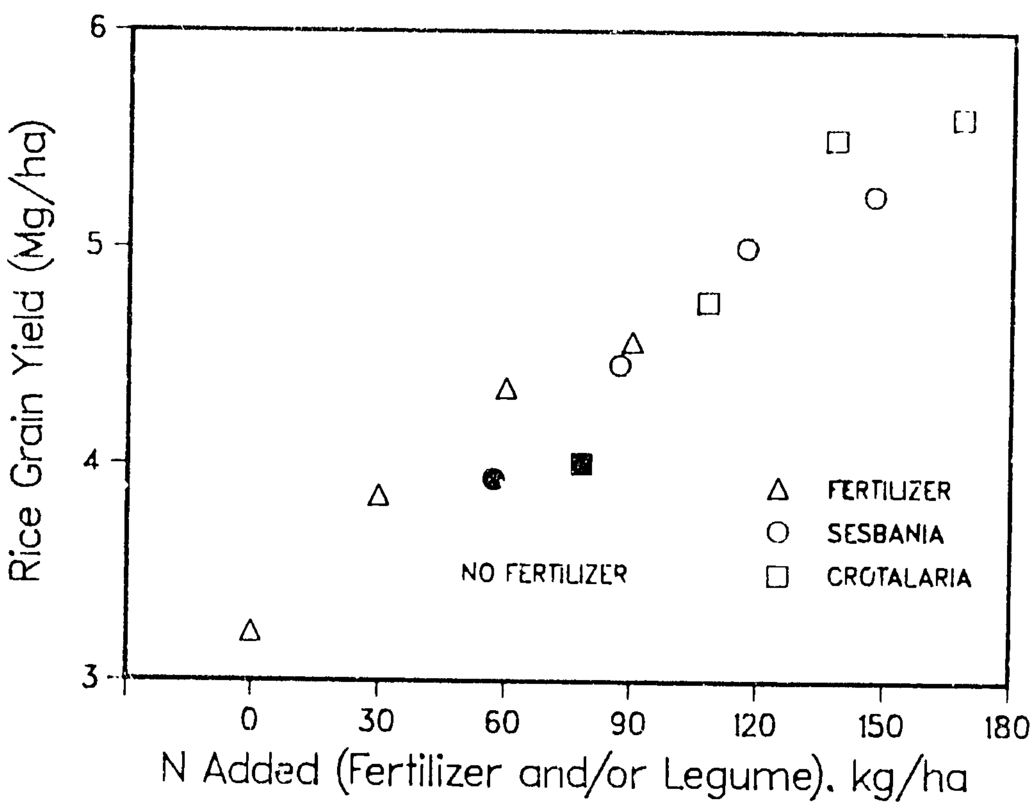

Figure 4. Rice yield responses to fertilizer N applications with or without preceding *Sesbania bispinosa* or *Crotolaria juncea* green manure crop, vs. green manuring alone. (From Bhardwaj et al. 1981.)

been partly responsible. Pressure on scarce resources has caused farmers to plant an edible pulse and use the nongrain portion for animal feed, rather than grow a crop to turn under. Green manuring—more often referred to in the literature as an art than a technology—has until recently fallen out of favor with agricultural scientists and officials. In developing countries, the local agricultural scientists have attempted to "catch up" with the more sophisticated production systems of the West (Jacoby 1974). This has often resulted in abandonment of traditional practices, and such appears to be the case with green manuring. Recent research on responses of HYVs to GM and GLM, discussed above, may be an indication of a turnabout in the attitudes of some researchers. As cropping systems are pushed into new areas of the tropics and the importance of management of organic matter is acknowledged, the use of legumes as crops that can build and stabilize soil fertility may be more seriously considered.

LEGUME SPECIES FOR GREEN MANURE AND COVER CROPS

Diverse types of legumes are used as cover and GM crops in the tropics. One com-

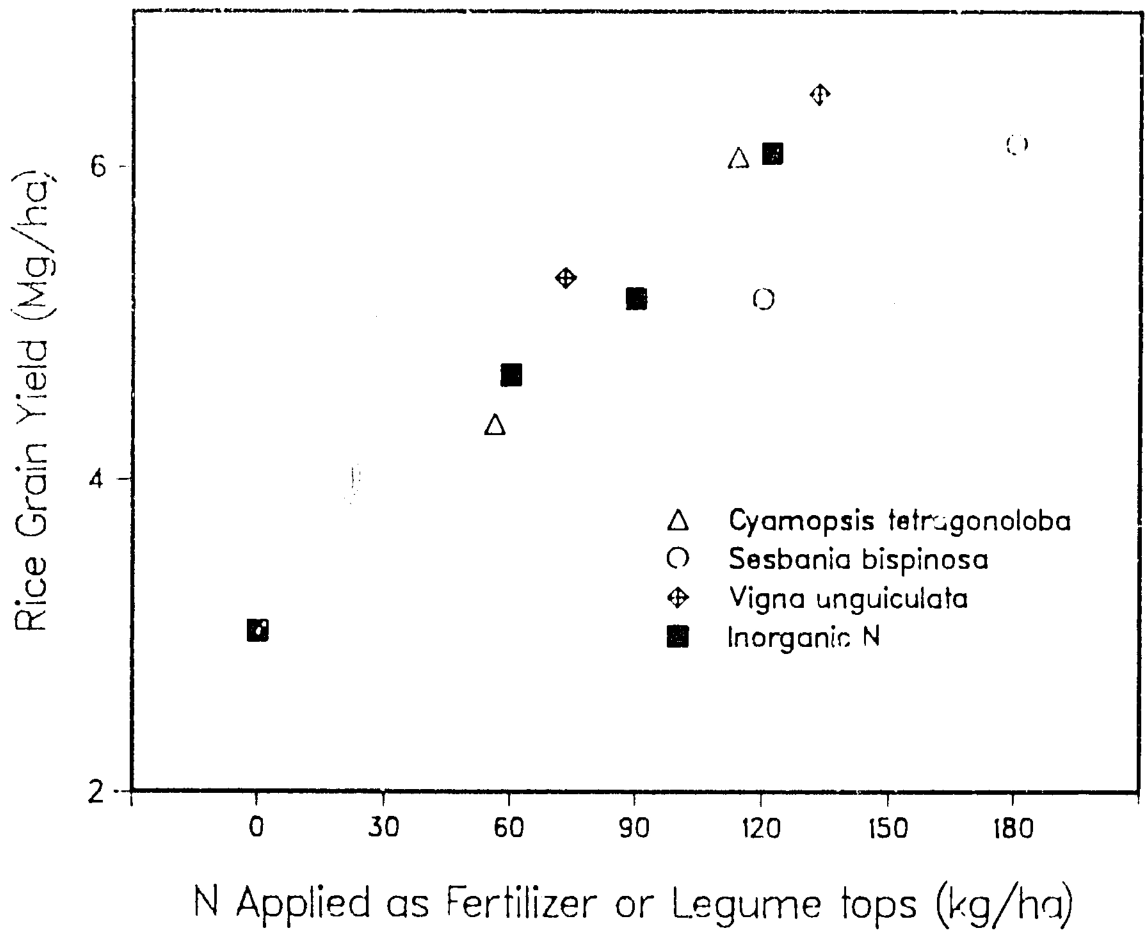

Figure 5. Rice yields with fertilizer N alone, green manures alone, and green manures plus 60 kg/ha fertilizer N. (From Khind et al. 1982.)

pilation of information covering many of these species is that of Duke (1981). Our abstracted bibliography on tropical GM and cover crops (Evans et al. 1983) is indexed so that the articles and publications included can be searched by species. Brief descriptions of the uses and qualities of some of these legumes follow.

Grain Legumes as Cover Crops and Green Manures

Historically, many grain, or pulse, legumes have been used as short-term cover crops or as GMs. These species generally have large seeds containing stored nutrients for rapid establishment and can soon begin to host a vigorous and extensive N-fixing symbiosis with the appropriate *Rhizobium* and suitable soil conditions. Because their seeds are articles of commerce, propagation material is readily available. These species, however, are seldom used now for GM. In the United States, *Glycine max* has evolved from a "soilage" crop to a major commercial grain legume crop. Economic and nutritional demands throughout the world weigh heavily against any possible benefits of plowing these crops down in their flowering stage for GM.

In tropical countries, grain legumes can and should continue to play a role in cropping patterns. Their function as soil cover during periods of erosion hazard can be of critical importance in maintaining soil productivity. Although the net N contribution of grain legumes as intercrops or in rotations is still a matter of debate and investigation (e.g., Eaglesham et al. 1982), it is advisable in most situations to include them in cropping patterns. Some species used as GM and cover crops in tropical regions are *Cajanus cajan*, *Macrotyloma uniflorum*, *Dolichos biflorus*, *Phaseolus calcaratus*, *Psophocarpus tetragonolobus*, *Vigna aconitifolia*, *V. marina*, *V. mungo*, *V. radiata*, and *V. unguiculata*.

Cajanus cajan. "Pigeon pea" is a short-lived, perennial, woody shrub with a deeply penetrating taproot. It is adapted to the semiarid and moderately humid tropics and subtropics, with an optimum annual rainfall between 600 mm and 1000 mm. Cultivars vary greatly in growth form, flowering habit, seed type, tolerance of conditions such as waterlogging or frost, and response to management. *Cajanus cajan* requires adequate soil moisture during its two-to three-month establishment period but thereafter is quite tolerant of dry periods.

In Africa, *Cajanus* has been successfully used for fallows of three to four years' duration (Watson and Goldsworthy 1964). In Ghana, following maize yields were benefited, but grass fallows had similar effects (Ghana Dept. Agr. 1958; Singh 1961). Worn-out maize and pineapple lands in Hawaii were at one time "rested" under *Cajanus*, which was then incorporated as a GM. One grower reported incorporating a four-year-old stand, plowing 0.2 ha/day with a disc plow and four large mules; the crop decomposed within three months (Krauss 1911).

Yields of *Cajanus* are often quite high. It was the highest-yielding legume shrub when intercropped and lopped as GLM for no-till maize and cassava; maize yields were benefited (IITA 1980). As a summer crop in Brazil, 13.2 Mg/ha dry matter were obtained when the crop was harvested at flowering (Campo et al. 1979). In Florida, *Cajanus*, sown at 67 kg/ha, produced 146 kg/ha N in 6 Mg/ha dry matter in six months on sandy soils in citrus areas, and 244 kg/ha N on a poorly drained site. Yields were poor where nematode infestation was severe (Anderson 1980).

Psophocarpus tetragonolobus. "Winged bean" is a twining species grown as a vegetable, pulse, and tuber crop. Its stover has been used experimentally as GM for maize in Puerto Rico. After harvesting the legume grain, 30 kg/ha N incorporated as stover increased maize grain yield to 3.1 Mg/ha, vs. 2.3 Mg/ha for maize following maize on an Oxisol, but a similar practice had no such effect on an Ultisol (Lugo-Lopez et al. 1981). We found very slow growth of a cultivar from Papua New Guinea on a manganiferous Oxisol in Hawaii, even when limed to pH 7 (Yost et al. 1981). Bourke (1975) rated *Psophocarpus* fair as a ground cover and poor as a competitor with weeds in lowland Papua New Guinea. Despite these observations, there may be potential for selected varieties of this species as a cover and N-accumulator in areas where it is well adapted. This species usually requires trellising for vigorous growth.

Vigna aconitifolia. "Mat bean" or "moth bean" is a hot-weather crop for semiarid areas that is grown in India as a pulse and GM and has been grown in China, Africa, and the southern United States (Duke 1981). Compared with other pulse legumes in one trial in India, it grew quite rapidly, achieving 80-90 percent canopy cover in 30 days (Verma 1968). This species and *Macrotyloma uniflorum* (horsegram) are sown in India as catch crops to utilize residual moisture after the main season crop. As such, these crops may protect the soil from the rains after the dry season. The entire plant is generally harvested for grain and fodder, however, and the crop is seldom turned under in India.

Vigna unguiculata. "Cowpea" has been widely used as a GM, especially cultivars with spreading habit and luxuriant growth (Duke 1981). It was at one time used extensively as GM in northern Queensland, Australia (QAJ 1938); it has also been used in the southern United States, Nigeria, Rhodesia, the Philippines, and elsewhere. It was judged an outstanding short-term creeping cover in Papua New Guinea (Bourke 1975). Comparing legumes for cover quality in India, Gupta et al. (1966) found it provided a good canopy, and Bhattawar and Rao (1969) found it better than rice, maize, or *Cajanus* for reducing soil loss from 2 percent slopes. With its wide variation in cultivars and phenotypes, cowpea is especially promising as a multipurpose legume in cropping systems.

Trailing Legumes as Cover Crops

Several trailing species often considered as tropical forage legumes can serve as cover crops, with or without the integration of grazing animals in the farming system. These legumes are prostrate or semiprostrate and often have a creeping or twining growth habit. Information on these species is available in compendia of tropical forages, e.g., Bogdan (1977) or Skerman (1977). The species include *Pueraria phaseoloides*, *Centrosema pubescens*, *Calopogonium mucunoides*, *C. caeruleum*, *Lablab purpureus*, *Mucuna cochinchinensis*, *Mucuna* spp., *Canavalia ensiformis*, *Desmodium* spp., *Vigna aconitifolia*, *V. hosei*, *Macroptilium autropurpureum*, *M. lathyroides*, *Neonotonia wightii*, *Clitoria ternatea*, and *Psophocarpus tetragonolobus*, which was discussed earlier as a grain legume. Of these, the first three have been widely used as covers in plantation crops, often sown in mixtures. *Calopogonium caeruleum* has come into prominence recently because of its shade tolerance. *Mucuna* spp., *Canavalia*, and *Lablab* have been more often used for green manuring. The remaining species, while suitable for particular locations and circumstances, have seen only limited use as cover crops.

Trailing legume cover crops are suited to plantation cropping systems with wide interrows. They have been used with such perennial crops as rubber, oil palm, coconut, coffee, sisal, and citrus. They require weed control during establishment, but once established compete strongly with weeds and may themselves require control to be kept from climbing on the associated crops. Despite occasional drawbacks such as harboring snakes or making collection of coconuts difficult, these legumes are recognized to provide significant benefits to the systems in which they are used.

Mixtures of *Pueraria*, *Centrosema pubescens*, and *Calopogonium mucunoides* have become the standard practice for covers in rubber and oil palm in Malaysia and elsewhere (Broughton 1976; Mendham 1971). *Calopogonium mucunoides* is usually faster to establish than *Pueraria* but less persistent. *Centrosema* helps to extend the life of the cover as the interrows become shaded and to maintain cover during droughty periods.

In Malaysia, *Mucuna cochinchinensis* and *Calopogonium caeruleum* have recently been added to the suite of "standard" covers for rubber. *Mucuna cochinchinensis* has come into favor as a short-term element of mixtures because it establishes cover rapidly on acid soils and has an extensive root system that enables it to overcome soil variability on newly cleared sites. This annual species dies out within five to eight months, and although it may regenerate self-sown, its main function is to reduce weed competition during establishment of its companion legumes. When *C. caeruleum* was sown with *M. cochinchinensis* under rubber (with or without *Pueraria*), the latter was shaded out in the fourth year. *Calopogonium caeruleum* persisted and provided a leaf litter turnover of about 1 Mg/ha (25 kg/ha N) between the 48th and 60th months (RRIM 1980). Compared with the traditional cover species for rubber, *C. caeruleum* is said to have greater vigor, less susceptibility to insect damage, greater drought tolerance, and two to three times greater N benefit to the soil (Pushparajah 1982).

Stands of trailing legumes are occasionally intersown with leguminous shrubs. In oil palm interrows, mixtures of trailing species with *Tephrosia* spp., *Flemingia congesta*, and *Crotalaria anagyroides* did not differ greatly from conventional (*Pueraria-Calopogonium*) covers in benefiting the palms (Broughton 1976). Wycherley (1963) discussed such "richer" mixtures, pointing out that allowing the trailing species to climb promotes seeding and that diversity of species offers resilience under pest attack. *Flemingia congesta* was cited as particularly useful, providing large amounts of mulch and tolerating shade, but it established cover slowly unless combined with trailing legumes. Different patterns of root exploitation of soil horizons may be another advantage of mixing legumes of diverse growth forms.

Pueraria phaseoloides. "Puero" or "tropical kudzu" is a vigorous, pioneer, twining plant adapted to hot, humid, low-altitude tropical environments where water is not limiting. It needs 1200–1500 mm rainfall per annum to persist, is not very drought tolerant, but will stand periods of waterlogging and brief periods of flooding. It is said to prefer heavy soils and to tolerate soil acidity but not soil salinity. *Pueraria* does not seed well in certain localities. It is a short day plant. Seeding may be affected by variations in humidity at time of flowering (FAO 1961) and is enhanced if the plants are allowed to climb. Hand harvesting is necessary because of uneven seed maturation. Seed is hardcoated and requires scarification for prompt, uniform germination. It may be inoculated with cowpea *Rhizobium*. *Pueraria* is often propagated from rooted cuttings.

Pueraria is slow to establish but once established will compete vigorously with weeds. Time to full cover has varied from three to four months broadcast at 5 kg/ha in burned-over forest land (SIPL, no date) to one to one-and-a-half years under coconut palms (Salgado 1936); six to nine months may be a reasonable average. It is often mixed with faster-growing species to achieve more rapid cover.

Once well established, this vigorous cover requires management to restrain its growth; cutting rings around palms is a common estate practice, and judicious applications of glyphosate are also used. In Tanzania, marginal rainfall for this species (as little as 800 mm/year) was thought to reduce its aggressiveness when grown with sisal

(Hopkinson 1971). In lowland Papua New Guinea with 2760 mm rainfall evenly distributed during the year, *Pueraria* was outstanding among trailing legumes tried (Bourke 1975).

Researchers have found that stands of *Pueraria* can fix large amounts of N, as much as 650 kg/ha (Jaiyebo and Moore 1963; Mathew et al. 1975; Schofield 1945; Watson et al. 1964a). For this reason and because of its slow establishment, *Pueraria* has been favored for long-term fallow plantings, particularly in Africa (Kannegeiter 1967, 1969; Lal et al. 1979; Moore and Jaiyebo 1963). The necessity for weed control during establishment has been reduced in Nigeria by relay planting amid maize given 2.5 kg/ha a.i. Primextra preemergence herbicide. Intersowing within one to two weeks of maize planting did not affect maize yield, and the legume attained full cover within three months of maize harvest (IITA 1980). Alachlor at up to 3.5 l/ha commercial product applied preemergence helped to control weeds, but 4.9 l/ha adversely affected *Pueraria* germination (Wong 1971).

Calopogonium mucunoides. "Calopo," a vigorous pioneer legume, is adapted to humid tropical areas to 2000 m altitude with at least 1200 mm evenly distributed rainfall. This perennial achieves cover within three to six months, and much sooner on newly cleared lands where fertility is high. It is less tolerant of drought, shade, or waterlogging than *Pueraria* and does not tend to persist as long when sown in mixtures under maturing rubber. It is said to be more susceptible to pests than the other "standard" legumes for rubber; however, its inclusion in mixtures has been considered cheap insurance against failure of *Pueraria* (Wycherley 1963).

Calopo is a profusely seeding perennial that spreads by rooting at the nodes of its trailing stems. Its seeding habit allows it to behave like an annual, regenerating after dying out during dry periods. Low palatability to animals permits its persistance under grazing. Because of its rapid initial growth and ability to spread and regenerate, calopo is especially useful for weed and erosion control on newly cleared lands and for soil stabilization and gully control in ravines and other rough, erosion-susceptible lands (Bunting and Milsum 1928; Pandey 1966). Calopo produces a dense mat of foliage 30–60 cm deep, which, if killed by drought or frost, provides a thick mulch.

Seeds are hardcoated and must be scarified or soaked for even germination. Calopo is nodulated by the ubiquitous cowpea *Rhizobium*, so, although desirable, inoculation is not absolutely necessary in most cases. Calopo may be seeded by drill or broadcast directly into ashes after a burn. It has tolerated up to 4.9 l/ha commercial alachlor applied preemergence (Wong 1971). Calopo may also be oversown into natural grassland under wet conditions. When included in grazed situations, plants should be well established and beginning to grow erect before being grazed. Care should be taken to prevent severe defoliation, as recovery is slow. Vegetative propagation is possible, but cuttings are succulent and susceptible to drying.

Centrosema pubescens. "Centro" is adapted to humid or moderately humid tropical or subtropical lowlands under 1000 m altitude receiving at least 1200 mm annual rainfall. It is less tolerant of hot conditions than *Pueraria* or *Calopogonium mucunoides* but more tolerant of drought. When sown in mixtures with these under maturing rubber, it is generally the last to die out from shading. It is less tolerant of poor drainage than *Pueraria*.

Centro is generally slower than calopo to establish cover when sown alone, requiring four to eight months. Weed control helps during its initial, slow-growing phase, but during later establishment stages its twining habit allows effective competition with weeds. Centro does not tolerate close grazing.

Seed maturation is differential, favoring hand harvesting aided by growing on fences or trellises, although mechanical harvesting systems have been devised in Australia (Skerman 1977). Seeds are hardcoated and must be scarified or soaked. Inoculation is necessary in most cases because of Centro's specific *Rhizobium* strain requirement.

Low-growing Legumes as "Living Mulch" Covers

A recent variation of the concept of permanent covers is the use of low-growing, creeping legumes as a living mulch in annual cropping patterns. Legumes appropriate as ground cover for tea plantations are candidates for this type of use, and some "new" species have been under consideration at the International Institute for Tropical Agriculture (IITA) in Nigeria. Legume species in this group include *Arachis prostrata*, *Desmodium ovalifolium*, *D. triflorum*, *Indigofera spicata*, *Aeschynomene falcata*, and *Psophocarpus palustris*.

IITA has been working with *D. triflorum*, *I. spicata*, *Arachis prostrata* and *P. palustris* as live mulch for no-till maize. The last two species were effective in controlling weeds, but the first two were not (IITA 1979). *Indigofera spicata* has been used in tea plantations (Holland 1928) and was found effective in controlling soil loss on sloping lands (Holland and Joachim 1933). It is toxic and is not appropriate for grazing.

Desmodium ovalifolium. *Desmodium ovalifolium* and *D. heterocarpon* have been evaluated as components of grass-legume pastures in Australia (Grof 1982) and may be appropriate as a live mulch cover.

Aeschynomene falcata. "Joint vetch" (*A. falcata*, cv. Bargoo) is a prostrate, nonstoloniferous perennial plant tolerant of poor soil fertility. When tested in Australia, this species persisted at all 50 experimental sites, usually spreading from the sown plots (Wilson et al. 1982).

Perennial Legumes as GLM Crops

The branches of many different shrubs and tree species are lopped for GLM. This use is often haphazard and exploits the fertility of woodlands, roadsides, and rough lands in the vicinity of cropped areas. It may also involve harvesting of vegetation deliberately planted along bunds and field borders, irrigation ditches, roadways, and household compounds. Species chosen for such plantings often fulfill multiple purposes, alternatively providing (1) cut-and-carry fodder and sometimes food, (2) physical barriers for windbreak, shade, privacy, and confinement or exclusion, (3) wood for fuel or construction, and (4) seed for replanting or for sowing as *in-situ* GM crops in certain cases. This kind of multi-use planting of trees and shrubs is done almost universally, but it is only in southern and southeastern Asia that appreciable green leaf manuring has been reported. Even where once widespread, as in southern India, this practice has probably declined significantly, and in recent years formerly extensively hedgerowed "bocage" landscapes have not been maintained or replanted. Species chosen for these purposes are commonly legumes, the principal ones in Asia being *Gliricidia sepium*, *Sesbania grandiflora*, *S. speciosa*, *Leucaena leucocephala*, *Tephrosia* spp., and *Erythrina lithosperma*. Other perennials that may be of value in providing GLM while being grown for other purposes are listed in NAS (1980, 1983).

Leguminous Shrubs

This category of erect plants contains a range of species selected for particular use as GM, GLM, or cover. Many of these have become known principally because of their use for these purposes.

An example is *Sesbania speciosa*, which was introduced to southern India via Sri Lanka from Africa during this century and was extensively used as a GM and GLM for rice in the former Madras State area during the 1950s. Its popularity resulted from its good growth on heavy rice-growing soils and enthusiastic promotion by local agricultural agencies. This species, somewhat less herbaceous than *S. bispinosa* and taking about four months (twice as long) to produce a heavy yield, was used for *in-situ* GM but was especially promoted for border planting on bunds and field borders. It was often grown in nurseries and transplanted to these borders, there producing as much as 4-5 Mg/ha of fresh GLM, with some plants being left for seed production. Use of this plant has declined in southern India since that period of popularization, although it is still to be found as a GM crop.

Erect herbaceous or shrubby legumes have been used on a limited scale as covers, with varying results. *Flemingia congesta* has been regarded favorably as a cover. *Mimosa invisa* has, on occasion, been used as a cover because of its vigorous growth. This shrubby legume, however, is considered a noxious weed in many areas. Its thorniness has contributed to its being considered a serious weed. Stands killed by seasonal droughts have posed fire hazards in some regions. The related *M. pigra* is a serious weed in Thailand, spreading in waterways and actually encouraged in regrowth or regenerative vigor by traditional eradication methods of slashing or burning (IPPC 1980).

Shrubby *Crotalaria* species have been used in the southern United States as covers in extensive, annual cropping systems. *Crotalaria spectabilis, C. pallida, C. striata, C. mucronata* and others have been sown after summer maize to improve the soil and provide wildlife shelter; these covers were generally plowed down in the next spring. In some cases, they were grown as summer crops in alternate years with maize, resulting in cumulative maize yields greater than if twice as many maize crops had been grown in the same period without legumes (McKee 1946).

Recent, intensive investigation of the genus *Stylosanthes*, (e.g., Burt et al. 1983) has resulted in consideration of this plant as a cover for certain cropping situations. Its adaptability to acid, infertile soils with low phosphate availability, and the diversity of species types made available through Australian pasture research efforts, have made it likely that this genus will see increased use as an element of cropping patterns, especially if problems with disease susceptibility can be overcome. Its habit of forming a persistent crown helps it hold soil in place and resist grazing pressure.

Herbaceous Annual Legumes as GM Crops

Although species previously discussed under other categories may be occasionally incorporated into the soil, a group of species can be distinguished that are particularly suited as *in-situ* GM crops. These are fast-growing herbaceous or shrubby plants, usually annuals, that rapidly produce large quantities of relatively succulent biomass. Included here is a group of species often called "summer legumes" in temperate regions: *Vicia* spp. (*V. benghalensis, V. ervilia, V. faba, V. sativa, V. villosa*); *Melilotus* spp. (*M. alba, M. indica*); *Cyamopsis tetragonoloba; Crotalaria* spp. (*C. spectabilis, C. pallida*); *Trifolium alexandrinum*; and *Sesbania exaltata*. These are suited to Mediterranean climates, and some, such as *Cyamopsis*, to semiarid areas. We will restrict discussion to species more commonly used in tropical environments.

The erect species are principally *Crotalaria juncea* and *Sesbania bispinosa*, with some use of other *Crotalaria* and *Sesbania* species, and *Aeschynomene* spp. Trailing legumes occasionally used for GM are *Mucuna* spp., *Lablab purpureus*, and *Canavalia* spp.

Crotalaria juncea. "Sunn hemp" is the species most widely used as *in-situ* GM for upland crops in the tropics. It is an annual shrub with erect growth habit, 1–3 m high. It grows best at elevations below 300 m; growth may be slowed by cool seasons, and above 600 m, planting should be during summer months. *Crotalaria juncea* is adapted to lighter, well drained soils, although good growth is obtained on heavy soils during drier periods. Poorly drained soils are the major limitation, although constant wet weather is detrimental to growth on any soil type. Moderate soil salinity and alkalinity are tolerated. Soil acidity below pH 5 appears to reduce growth on manganiferous Oxisols (Yost et al. 1981).

Crotalaria juncea grows rapidly in height and can be used as an intercrop amid such crops as maize and sugarcane. Plants branch at about 75 cm above the ground when not crowded, but branching is higher and sparser when grown in the high populations favored for GM or fiber production. Seedlings are tender and susceptible to mechanical damage. This may restrict its use as a relay intercrop where field operations would occur at this stage. Plants remain succulent until six to eight weeks from sowing, at which time flowering begins and stems begin to lignify. Proper timing of plowdown is critical, with the bud or early flowering stage preferred. In high rainfall areas, early incorporation opportunities are preferable to risking overmaturation as a result of wet soils precluding field operations. In dry regions, irrigation may be necessary to bring soil moisture to a favorable level for timely incorporation (Rotar and Joy 1983). One incorporation method is mowing, then disking and plowing before the material dries. Alternatively, the standing crop may be plowed after laying down the crop by "planking" or light disking in the direction to be plowed.

Seed production is a problem in the subtropics, where daylengths short enough for flowering occur during cool winter months unfavorable to growth. For example, in the United States, seed is obtained in commercial quantity only in southern Texas (McKee 1946). In tropical areas, flowering may begin at six weeks, with maturity reached at four months or more. The seed pods, which do not readily dehisce in the field, may be combine-harvested when mature and dry. Hand harvesting and threshing may be done without difficulty. Seed yields of over 2.25 Mg/ha have been recorded with the accession HA-6 selected at the USDA Plant Materials Center on Molokai, Hawaii (Rotar and Joy 1983). Scarifying seeds before sowing is unnecessary for some varieties. *Crotalaria juncea* has been found nontoxic to livestock, unlike most other *Crotalaria* species, which are toxic. Palatability may be a limitation, and multiple use of the crop as a fodder source requires further investigation. *Crotalaria juncea* is nodulated by cowpea *Rhizobium*, and although in many cases inoculation is unnecessary, it generally improves N-fixation potential. Sowing rates may vary from 25 to 90 kg/ha; within this range, broadcast rates are higher than for drilling. Higher populations favor prolonged stem succulence. High sowing rates are recommended when the crop is to be grown only for short periods (four to five weeks). When incorporation is planned for the six-to-eight-week stage, seed rates of 35–40 kg/ha broadcast or 30–35 kg/ha drilled are adequate. For seed production, lower rates are sown.

Sesbania bispinosa. An annual species, *S. bispinosa* is adapted to warm lowland tropical and subtropical areas. In India, it is commonly called "dhaincha" and often called by its former name, *S. aculeata*. It is closely related to and resembles *S. cannabina* and *S. sericea*. These three species grow 1–4 m high, preferring moderate to abundant rainfall but tolerating drought once established. They can be used in semiarid areas, starting with seasonal rains and maturing during dry periods.

Sesbania bispinosa tolerates heavy soils and soil waterlogging, flooding, alkalinity, and salinity and has been used extensively as a nitrogen source in lowland rice-based systems. It has been used as GM for reclaiming salt-affected soils in India, often in conjunction with gypsum applications. In the People's Republic of China, *S. cannabina* rows are intercropped in flooded fields and lopped for GLM, the leaves and young branches being pushed into the soil during weeding and thinning operations (FAO 1977). In Viet Nam, hills of plants are established amid the main rice crop during its maturation phase. If there is adequate water for a second rice crop, the legume is green-manured; if not, it is left to stand and is harvested for fuelwood (Nao 1979).

Sesbania bispinosa seeds profusely and has the potential to become a weed if not properly managed. It is recommended that plants be harvested for seed when about two-thirds of the seed has begun to turn from green or purple to brown. Seed is hardcoated to varying extents, and scarification is recommended to obtain complete germination. Specific *Rhizobium* inoculant is necessary in most situations unless effectively nodulated crops have been grown previously. In India it is sown as a summer crop with the onset of monsoon rains. Sowing rates range from 20 to 90 kg/ha.

Trailing Annual Legumes as GMs

Trailing annual legumes used as GMs include *Mucuna* spp., *Lablab purpureus*, and *Canavalia* spp. These legumes are large-seeded and have the advantage of establishing cover rapidly. Most varieties are trailing types, but form is often variable, and erect bush types are also known. Because of their twining habit, their use as intercrops (as with maize) requires careful management. They may produce heavy mats of intertwining vegetation, and their incorporation into the soil as fresh material may present some difficulty, so they are sometimes not incorporated but killed or allowed to senesce and left as mulch. Since they will spread and cover large areas, rows for planting may be spaced widely. Killing the crop is accomplished more easily by hand by walking along the rows and cutting the main stems, as compared to the labor of cutting broadcast crops by hand.

Lablab purpureus, formerly called *Dolichos lablab*, has been used mainly in Central and South America and is often grown for GM as an intercrop with maize in maize-bean Phaseolus rotations. This versatile species has been used as a cover crop in orchards and in coffee and coconut plantations, and as a fodder crop. The beans are edible, and some varieties are edible as vegetable bean as well as dry bean. Von Schaaffhausen (1963) reviewed the uses of this species.

Canavalia species (*C. ensiformis*, "jack bean"; *C. gladiata*, "swordbean"), like *Lablab purpureus*, are used more in the Americas than elsewhere. The swordbean, however, is widely grown as a vegetable in South and East Asia. As toxic substances are associated with *Canavalia* beans, careful selection of varieties and special cooking methods are recommended (Duke 1981).

Species of *Mucuna* ("velvetbean") are variable in habit and are grown throughout the world. *Mucuna* has been used extensively as a cover and GM in southern Africa (Haylett 1961) and in the southern United States (Piper and Morse 1938). Beans of certain varieties are occasionally eaten as tempeh in Sumatra. Local farmers report occasional disorientation or dizziness, however, after eating this bean.

USE OF LEGUME COVERS WITH ROOT CROPS

Few published reports exist about the use of legume covers or GMs with tropical root crops. Research seems largely confined to sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), and occasionally Irish potato (*Solanum tuberosum*). Many of the legumes already mentioned have been used in rotations with potato, although measurements of benefit are few.

Sweet potato has been green-manured at various times. Stokes et al. (1936) compared the effects of growing four legumes and a nonlegume in rotation with sweet potato on a highly weathered soil (Paleudult, Norfolk series). Maximum yields occurred following *Crotalaria striata* (100 percent), while yields after velvet bean (*Mucuna* sp.) were 69 percent, after beggarweed (*Desmodium* sp.) 60 percent, and after cowpea 72 percent; yield after the nonlegume cover was 53 percent of maximum. In other rotations, corn was preceded by various legumes, and the same legumes provided greatest yield increase. This study was significant because it was one of the few studies where the soil taxonomy was given. These soils are characteristically acid and have many analogues throughout the humid tropics. Lugo-Lopez et al. (1954) suggested that velvet bean was a more appropriate GM legume than *Crotalaria* for sweet potato in acid soils of Puerto Rico. Our own work (Yost et al. 1985) seems to support the conclusions of this study.

Studies of the use of legumes as intercrops or in rotation with cassava are particularly important because of the frequent use of cassava in low-input or subsistence agriculture. One of the few studies of legumes with cassava was performed by Nitis and Sumatra (1976) in Indonesia. Yields of cassava tubers were 117 percent of control (no fertilizer or legume) when it was intercropped with *Stylosanthes guyanensis*, while they were 121 percent when 74 kg/ha N as urea was added. The results suggested that the intercropped stylo provided some N to the cassava. In other experiments, Nitis and Sumatra (1976) grew cassava and stylo under coconut. In this comparison, undersowing cassava with stylo reduced cassava root dry matter yield 14 percent where no P or K fertilizer was added. Where P, K, and micronutrient fertilizers were added, however, there was no yield reduction. Stylo growth under cassava was reduced by 23 percent compared with stylo grown without cassava. These results also suggested considerable competition and that at least part of the competition was for nutrients.

Studies by Centro Internacional de Agricultura Tropical (CIAT 1975) have shown competition between GM legumes and cassava when intercropped (Table 1). The length of the cassava growing period was not specified but may be important in intercropping studies with cassava. It is likely that the greater benefit would accrue if the legume was cut back, matured, died back, or was harvested well before cassava is harvested. This should permit recuperation and exploitation by the cassava of the legume residues. Our observations (Yost, unpublished research data) indicate that with long growth (over 12 months), cassava appears to more than make up for the earlier competition if available N is released as a result of dieback of the legume. Timing of cassava harvest relative to the legume dieback is thus probably important so as to take advantage of the legume N contribution. Also to be considered are the residual effects of having grown the stylo. Our observations of growing cassava after a cassava-stylo intercrop suggest a moderate amount of N (50 kg N/ha) can be contributed to the crops following the cassava-stylo intercrop even after early legume dieback in the intercrop (Yost and S. A. El-Swaify, unpublished data).

Competition was also noted between the legume and root crop in a study by Swaminathan and Singh (1960). Four cropping patterns were compared over a four-year period. Potato was grown after fallow or after the legumes *Crotalaria juncea*, *Cyamopsis tetragonoloba*, and *Sesbania bispinosa*, which were (1) grown *in situ* and buried, (2) grown but the tops taken elsewhere, or (3) grown elsewhere and only the tops of the legumes applied and incorporated as GLM. Greatest yields occurred where the legume tops were applied as GLM. The authors noted that when rainfall was greater the green-manured potato yielded about as much as the crop with GLM. Where GMs were grown on the site and then removed before the potato crop, yields were usually the lowest of the four patterns. Results suggested

Table 1. Cassava root yields when grown with several green manure legumes at two sites.[1]

Legume	-----Quilichao----- Legume Grain Yield	Cassava Yield	----Carimagua---- Legume Grain Yield	Cassava Yield
	kg/ha	Mg/ha	kg/ha	Mg/ha
None	0	38	0	18
Beans	104	37	262	17
Peanuts	609	36	—	--
Soybeans	21	31	—	—
Kudzu	2.1*	30	7.1*	2
Stylosanthes	4.7*	25	3.6*	20
Cowpea	338	23	595	11
Rice	—	—	5.44	15
Desmodium ovalifolium	—	—	14**	15
Indigofera	—	—	20**	9

[1]Source: CIAT (1978). Sites are in Colombia.
*Mg/ha dry weight; no grain estimate.
**Mg/ha fresh weight.

that the legumes were competing with potato for nutrients and water. The GLM, on the other hand, was produced elsewhere, and as it did not compete for water and nutrients, its nutritional benefit was evident in greater potato yield.

USE OF LEGUME COVERS AND GREEN MANURES WITH PLANTATION AND PERENNIAL CROPS

The use of legume covers in plantation crops is much more widely accepted than is the use of legumes in green-manuring annual crops and, in fact, is standard plantation practice for rubber and oil palm (Pushparajah and Hua! 1979). In contrast to the additional labor required by the use of legumes in annual cropping systems, legume covers provide a labor-saving method of controlling weeds and rainfall-induced soil erosion in perennial crops where weed control, erosion control, and uniform understory growth are major concerns. By planting either one or a group of legume species, a relatively uniform cover is provided throughout the initial years of the plantation. Such uniformity greatly facilitates management and control of the plantation crop. Vigorous legumes that quickly dominate the understory and suppress weeds play a highly useful role (Teoh et al. 1979). In addition to such management considerations, legume covers provide rather large amounts of N, which otherwise must be provided by N fertilizer (Table 2). Cover legumes in plantation systems reportedly

Table 2. Observed rates of nitrogen fixation in tropical creeping legumes.[1]

Legume	Habitat	Nitrogen Excess[2]	References
Glycine javanica	cover crop	200	Jones (1942) Henzell and Norris (1962)
Centrosema pubescens	pot	235	Watson (1957)
C. pubescens mixed with *Cynodon plectostachyus*	pasture	280	Moore (1962)
Pueraria phaseoloides	cover crop	650	Jaiyebo and Moore (1963)
Calopogonium mucunoides plus *Centrosema pubescens* and *P. phaseoloides*	cover crop	170	Watson (1963)
C. pubescens with *Panicum maximum*	pasture	100	Bruce (1965)
Desmodium uncinatum	pasture	125	Henzell et al. (1966)
Phaseolus atropurpureus or *Stylosanthes humilis*	pasture	20–290	Henzell (1968)
P. atropurpureus	pasture	44–81	Vallis (1972)

[1]Source: Broughton (1977).
[2]Estimated N fixed, kg/ha.

contribute the equivalent of about 1000 kg/ha N as urea (Pushparajah 1982; Broughton 1977) for the duration of rubber tree and oil palm plantings.

Legume covers contribute to the improvement of physical properties of soils, according to studies on rubber plantations in Malaysia. Soong and Yap (1976) reported that the influences of legume covers were primarily thought to occur via changes in soil surface (0–15 cm) content of organic matter. These workers found increased aggregation of finer soil particles, increased average size of soil aggregates, increased total porosity, and increased permeability of soil for water as measured by permeability of soil cores. Comparisons from three of Soong and Yap's experiments are shown in Table 3. The authors also suggested that soil impedance to root extension would be less on soils with lower bulk densities. Regression analyses indicated that soil organic carbon was the primary factor in improvement of the various measures of soil physical properties, with soil texture accounting for some effects. These workers suggested that while grasses could provide soil physical improvements, the influence of the added N from legumes gave legume covers a distinct superiority to grass covers in the plantations. Legume covers have a role in either maintaining or improving soil physical conditions, which may otherwise deteriorate with clean cultivation.

Table 3. Residual effects of various soil covers on soil physical conditions.[1]

Soil[2]	Cover	O.C.[3]	Agg.	MWD	BD	Perm.	Porosity
		%	%	mm	g/cc	cm/h	%
Munchong series (Tropeptic Haplorthox)	grass[4]	1.35	91.1	2.67	1.11	29.0	27.7
	legume	1.34	93.9	3.77	1.04	110.7	31.0
	natural	1.53	90.0	3.22	1.00	45.2	28.2
Malacca series	grass[5]	1.26	86.0	3.28	1.13	43.1	16.4
	legume	1.39	88.2	2.93	1.19	62.0	19.0
Rengam series (Typic Paleudult)	grass[6]	1.43	73.8	3.39	1.13	13.2	12.3
	clean	1.09	66.2	0.95	1.21	8.4	16.4
	legume	1.39	69.4	1.98	1.13	12.4	12.3
	natural	1.28	72.4	2.20	1.16	2.0	11.5
$LSD_{.05}$		—	3.6	0.24	0.08	7.0	—

[1] Source: Soong and Yap (1976).
[2] Munchong: sandy clay loam. Malacca: sandy clay loam. Rengam: sandy clay.
[3] O.C. = organic carbon (Walkley-Black); Agg. = % of soil aggregated; MWD = mean weight diameter; BD = bulk density; Perm. = permeability of soil cover to water; Porosity = air-filled porosity.
[4] Planted to rubber in 1957, but legume cover plants had died by 1964, and by 1972 the plots had been overrun with *Nephrolepsis* and grasses. Legume covers at all sites were *Pueraria phaseoloides*, *Centrosema pubescens*, and *Calopogonium mucunoides*; grasses were *Axonopus compressus* and *Paspalum conjugatum*.
[5] Legumes died off by 1964 and were overrun with grass.
[6] Legumes were beginning to thin by 1964, and grass was invading.

The significance of the early presence of legume covers in the rubber ecosystem may be greater than that suggested by simple measures of N content of legume tops or even of the total N fixed by the legume. The rubber ecosystem is efficient in nutrient recycling, suggesting that early N input may accumulate in the organic and inorganic N pools of the system.

The effect of the larger N pool may last for much longer in a highly efficient recycling system as opposed to one in which such buildup of N pools would be lost from the system. During the plantation establishment, legume and grass covers recycle nutrients that would otherwise be lost by leaching, runoff, and erosion before the tree roots are extensive. Watson et al. (1964b) studied soil profile content of nitrate, ammonium, calcium, magnesium, and potassium as influenced by four covers: bare soil, legumes, grass, and natural cover. Legume covers consisted of a mixture of *Pueraria phaseoloides*, *Calopogonium mucunoides*, and *Centrosema pubescens*. The soil, Rengam series, was a Typic Paleudult with soil pH 4.7, probably a sandy clay loam. Measurements began after clearing and continued for

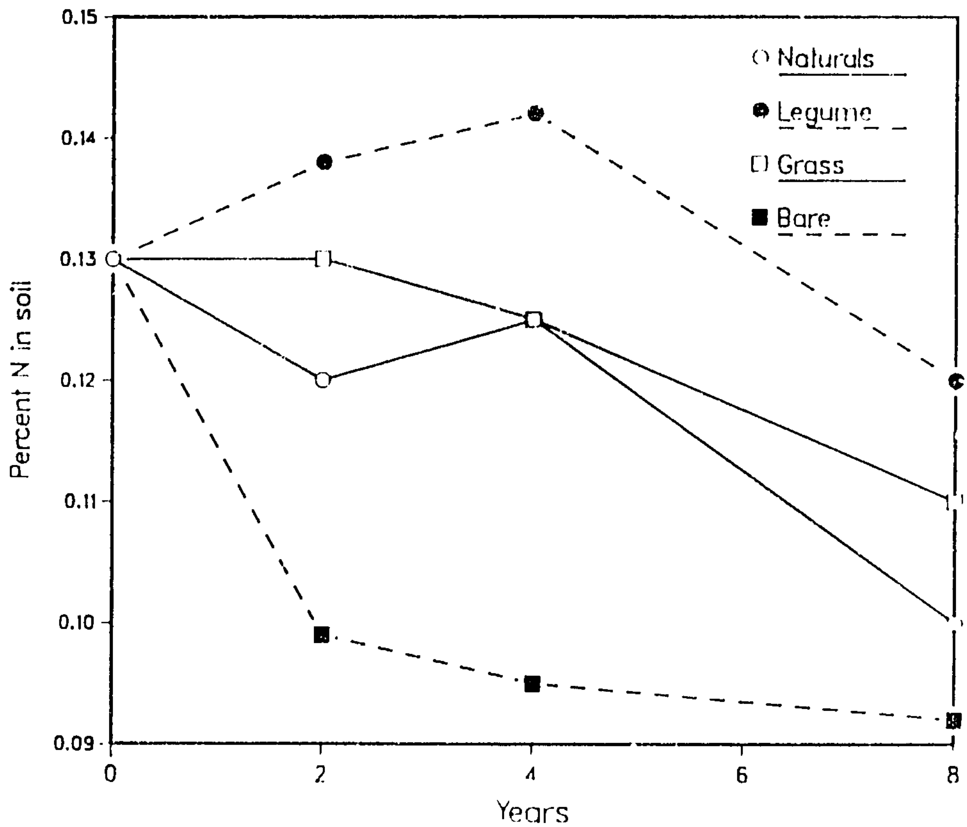

Figure 6. Influence of covers on nitrogen maintenance or depletion in soil. (From Watson et al. 1964b.)

four years. Nitrogen contents varied with cover and nitrogen ionic species. Total soil N was greater under legumes than under grasses, which in turn yielded greater N content than did bare soil (Figure 6). Ammonium-N content was greater under legumes than under grass, whose content was greater than bare soil's. Nitrate-N was present in much greater quantities in bare soil than under the various covers. Nitrate level in bare soil peaked during the following wet season. After the fourth year, nitrate content at about 1 meter depth was 40 mg/kg nitrate-N in bare soil, compared with 3–4 mg/kg in soil with covers.

The decrease in total N and the sharp increase in nitrate-N in bare plots suggests rapid mineralization to N forms susceptible to leaching. The high level of nitrate at 1 meter depth in bare plots further supports this suggestion. Together, these data suggest organic N was more rapidly mineralized and leached into and through the subsoil of the bare plots than in plots with legume covers Agamuthu and Broughton (1981) estimated that as much as 100 kg/ha/year N was leached from bare soil under oil palms and that these losses were reduced by about 60 percent when a legume cover was maintained.

The contents and distributions of calcium, magnesium, and potassium also varied with cover, with the greatest difference occurring between treatments with bare soil and those with plant covers (Table 4). Contents of Ca, Mg, and K in the surface horizon were higher in the soil with covers than in the bare soil. At about 1 meter, nutrient content was greater in the bare soil than in soil with covers, suggesting that K and probably Mg were leached from the topsoil and through the subsoil. These static measurements probably underestimate leaching loss. Nevertheless, these results and some approximations suggest covers play a significant role in reducing nutrient loss in exposed soil of humid tropical rainforests (Tables 4, 5).

systems contain low-activity clays that do not have the necessary charge to retain the cations and have virtually no ability to retain nonadsorbed anions such as nitrate unless they are so weathered that there is positive charge.

These results support the suggestion of Broughton (1977) that the beneficial effects of legume covers can continue long after they

Table 4. Influence of legume and grass covers on nutrient status in a Paleudult soil four years after clearing.[1]

Depth (cm)	Bare	Grass	Legume	$LSD_{.05}$	Bare	Grass	Legume	$LSD_{.05}$
	Ca				Mg			
	meq/100							
0-15	0.18	0.56	0.32	0.25	0.04	0.19	0.15	0.12
15-30	0.07	0.14	0.12	0.10	0.04	0.06	0.06	0.06
	K				Total N			
	meq/100 g				%			
0-15	0.04	0.10	0.11	0.05	0.10	0.12	0.14	0.02
15-30	0.04	0.05	0.05	0.02	0.06	0.07	0.07	0.02

[1] Source: Watson et al. (1964b).

Table 5. Influence of legumes and grass covers on nutrient status in a 1-m soil profile four years after clearing.[1]

Nutrient	Cover		
	Bare	Grass	Legume
	kg/ha		
Ca	140	260	200
Mg	33	52	47
K	99	117	124
NO_3-N	180	5	10

[1]Source: Watson et al. (1964b).

Legume cover provides one of the few mechanisms to retain nutrients mineralized from organic pools of rainforest ecosystems after clearing. Many of the soils under such

have been shaded out. This may occur if the legume covers prevent nutrient loss by leaching or runoff after clearing and before full development of the rubber tree canopy. Nutrients thus retained, together with the symbiotically fixed N, accumulate in the organic nutrient pools.

Cover legumes in Malaysian and other Southeast Asian conditions usually must be tolerant of soil acidity and low nutrient availability. Because rubber and oil palm grow well in the highly weathered soils of the humid tropics, legumes for use in such systems must grow well in such situations. For such perennial crops, legumes that grow slowly or initially have low germination may be of use. For example, a rotation of legumes has been devised in plantation systems. The legumes used include species with rapid initial growth (e.g., *Mucuna* and

Calopogonium), species that are slow starting but capable of sustained growth (such as *Centrosema* and *Stylosanthes*), and other species with shade tolerance (such as *Calopogonium caeruleum*) that provide N to the plantation longer than those that are shade sensitive.

Another successful use of legumes in plantation crops is in conjunction with managing cattle under coconuts (Plucknett 1979). Given the large area of coconut in the tropics, the potential benefit of improved management of legume covers for multiple purposes under coconut is considerable. Cattle, legume pasture, and the coconut plantation form a mutually complementary cropping system in which a great deal of symbiosis occurs. Generally, cover crops in coconut plantations should be (1) somewhat tolerant of shade, (2) capable of being grazed to within 8 to 10 cm of the soil surface to facilitate nut collection, 3) capable of enduring trampling by grazing animals, (4) perennial, and (5) palatable for grazing animals.

The legumes should not have nutrient requirements in great excess of those of coconut, and they should not compete heavily for nutrients and water. This may require mowing or grazing, particularly during early growth of the coconut, when the cover crops may compete too well and reduce coconut yield. After this initial period, soil moisture content may be greater in plantations with cover plants because of increased infiltration rate and less runoff (Silva 1951). Creeping or prostrate legumes are probably best for control of soil loss and of weeds. *Pueraria*, *Centrosema*, and *Calopogonium* are among the most successful species under coconuts. Unfortunately, comparison of long-term yield benefits or the amount by which N fertilization can be reduced when coconuts are cover-cropped is not known. It is likely that many plantations are not fertilized. In such cases, additions of N by the cover legume are probably quite significant.

LEGUMES AND THEIR RHIZOBIA

Rhizobia are soil bacteria characterized by their unique ability to infect root hairs of legumes and induce effective nitrogen-fixing nodules on the roots. In the family Leguminosae, most of the species examined in the subfamilies Papilionoideae and Mimosoideae are known to nodulate, but very few species in the subfamily Caesalpinoideae do. Rhizobia commonly occur in soils but often fail to produce effective nodulation either because too few are present or because those present only work effectively with a particular legume. Rhizobia associated with a particular legume are sometimes absent in the soil and need to be introduced together with the intended legume. An extreme example is the pasture legume *Lotononis bainesii*, which requires a highly specific *Rhizobium* only found in the cooler parts of eastern and southern Africa. Successful introduction of *Lotononis* into a new area requires also introducing its associated *Rhizobium*.

Types of Rhizobia

Two types of rhizobia (slow growing and fast growing) are recognized according to their growth rates and growth reaction observable on yeast mannitol agar (YMA) medium containing bromthymol blue indicator at pH 6.8.

Slow-growing (7–10 days to form visible colonies on YMA) cowpea rhizobia produce an alkaline reaction on this medium. These bacteria nodulate most of the tropical legumes so far examined. The majority of slow-growing rhizobia are promiscuous or unspecialized because of their wide host range or cross-inoculation abilities.

Fast-growing (2–3 days to form visible colonies on YMA) rhizobia show an acid growth reaction on the agar medium. These rhizobia are relatively more specialized or specific in their legume host requirements for effective nodulation and N fixation.

Table 6. Green manures and legume covers and their associated rhizobia.

Legume Species	Type of *Rhizobium* and Nodulation Group
Acacia auriculaeformis	Slow-growing, cowpea-type promiscuous *Rhizobium*
Aeschynomene falcata	
Arachis prostrata	
Cajanus cajan	
Calopogonium caeruleum	
C. mucunoides	
Canavalia gladiata	
Centrosema pubescens	
Clitoria ternatea	
Crotalaria anagyroides	
C. juncea	
C. pallida	
C. spectabilis	
Cyamopsis tetragonoloba	
Desmodium ovalifolium	
D. triflorum	
Dolichos biflorus	
Erythrina lithosperma	
Flemingia congesta	
Glycine javanica	
Indigofera spicata	
Macroptilium atropurpureum	
M. lathyroides	
Macrotyloma uniflorum	
Mucuna cochinchinensis	
Neonotonia wightii	
Phaseolus calcaratus	
Psophocarpus palustris	
P. tetragonolobus	
Pueraria phaseoloides	
Stylosanthes spp.	
Tephrosia spp.	
Vigna spp.	
Gliricidia sepium	Fast-growing, specific nodulation group *Rhizobium*
Leucaena leucocephala	
Melilotus spp.	
Mimosa pigra	
Sesbania bispinosa	
S. grandiflora	
S. macrocarpa	
S. rostrata	
Trifolium alexandrinum	
Vicia spp.	

Legume Groups

Tropical legumes can be divided into three broad groups according to their *Rhizobium* requirements (Table 6). The first group consists of legumes that nodulate and fix nitrogen with a wide range of rhizobial strains. The majority of tropical species, especially those nodulated by the slow-growing rhizobia, are in this category.

The second group consists of legumes that require specific strains of *Rhizobium* for effective nodulation and N fixation. Examples in this group are *Leucaena*, *Gliricidia*, *Sesbania*, and several other legumes that do not fall in the category of GMs and legume covers listed in Table 6.

In the third group are legumes that vary in specificity and fall between the two extremes. Examples of species with variable specificity are *Centrosema*, *Stylosanthes*, *Desmodium*, and a few others not listed in the GM or legume cover group.

Source of Inoculant

It is important to know the *Rhizobium* requirements of legumes so that the correct inoculant can be used for seed inoculation. The University of Hawaii NifTAL Project will provide, on request, research quantities of high-quality peat-based *Rhizobium* inoculants for any of the legumes listed in Table 6.

ECONOMIC ASPECTS OF GREEN MANURING

The economic considerations of green manuring are even less well understood or researched than are the agronomic aspects. In a 1980, 33-nation survey (Appendix A), the reasons most often cited for nonacceptance of proposed green manuring practice were economic. Most agronomists responded to the query, "What factors most hindered farmer acceptance of green manuring?" by citing farmer unwillingness to plant crops that gave no direct benefit. This objection was repeated in numerous countries and does not represent only a few societies. Duncan (1975), in a description of economic considerations of organic materials, lists four major disadvantages of green manuring:

1. GM may use stored water that might otherwise be used for the food crop.

2. Considerable energy, human or animal, is required in green manuring; labor cost can be considerable.

3. Opportunity cost of the land may be high unless the land would otherwise be fallow. Usually land is scarce, and thus the opportunity cost is relatively high.

4. Timing of the GM incorporation is, under certain circumstances, critical to the N's becoming mineralized to coincide with the plant absorption curve; this requires a high degree of crop management skill.

Value-cost ratios usually must be on the order of 2:1 to 4:1 before adoption can be expected (Ruthenberg 1971). The disparity between the recommended use of GM and its acceptance is probably symptomatic of systems that appear sound on experiment stations and thus seem attractive from research or academic points of view, yet are only occasionally practiced by the farmers.

RECOMMENDATION

In our view, green manuring practice needs to be tested on farmers' fields using farming systems research techniques (Shaner et al. 1982). These techniques can be described as being farmer-based, problem-solving, comprehensive, interdisciplinary, iterative and dynamic, and responsible to society. The farming systems research and development approach includes five basic activities:

1. Target and research area selection.
2. Problem identification and development of a research base.
3. Planning on-farm research.
4. On-farm research and analysis.
5. Extension of results.

These techniques require much greater participation of the farmer in the research process than do typical research programs. This helps improve the acceptability of the proposed system. The potential of green manuring in its present or altered form can best be evaluated or developed under such an approach, which actively includes the farmer in developing cropping alternatives that incorporate the growing of legumes for the nitrogen they provide.

LITERATURE CITED

Agamuthu, P., and W. J. Broughton. 1981. Nitrogen cycling in a legume-oil palm ecosystem in Malaysia. *In* R. Wetselaar, J. R. Simpson, and T. Rosswell (eds.), Nitrogen cycling in South-East Asian wet monsoonal ecosystems. Australian Acad. of Sci., 1981:101–108.

Agboola, A. 1982. Organic manuring and green manuring in tropical agricultural production systems. *In* Non-symbiotic nitrogen fixation and organic matter in the tropics. Symposia papers, 12th Intl. Soil Sci. Congr., New Delhi. 1:198–222.

Ali, A. M., and Y. B. Morachan. 1974. Effect of irrigation levels and forms of manures on rice varieties IR8 and IR20. Madras Agr. J. 61(8):268–272.

Anderson, C. A. 1980. Legume covercrop trials in citrus groves. Soil & Crop Sci. Soc. Florida Proc. 39:80–82.

Battawar, H. B., and T. P. Rao. 1969. Effectiveness of crop-cover for reducing runoff and soil loss. J. Soil & Water Conserv. India 17(3–4):39–50.

Beri, V., and O. P. Meelu. 1979. Effect of time of burying of dhaincha (*Sesbania aculeata*) on nitrogen economy in paddy. Intl. Rice Res. Newsltr. 4:22.

Bhardwaj, S. P., S. N. Prasad, and G. Singh. 1981. Economizing nitrogen by green manures in rice-wheat rotation. Indian J. Agr. Sci. 51(2):86–90.

Bogdan, A. V. 1977. Tropical pastures and fodder plants. New York: Longmans.

Bourke, R. M. 1975. Evaluation of leguminous cover crops at Keravat, New Britain. Papua New Guinea Agr. J. 26(1):1–9.

Broughton, W. J. 1976. Effect of various covers on the performance of *Elaeis guineensis* (Jacq.) on different soils. *In* D. A. Earp and W. Newall, (eds.), International oil palm developments: Proc. Intl. Oil Palm Conf., 1976, Kuala Lumpur. Pp. 501–525.

________. 1977. Effect of various covers on soil fertility under *Hevea brasiliensis* Muell. Arg. and on growth of the tree. Agroecosystems 3:147

Bruce, R. C. 1965. Effect of *Centrosema pubescens* Benth. on soil fertility in the humid tropics. Queensland J. Agric. Anim. Sci., 22:221–226.

Bunting, B., and J. N. Milsum. 1928. Cover crops and green manures. Malayan Agr. J. 16(7):256–280.

Burt, R. L., D. G. Cameron, and D. F. Cameron. 1983. *Stylosanthes*. *In* R. L. Burt, P. P. Rotar, J. L. Walker, and M. W. Silvey (eds.), The role of *Centrosema*, *Desmodium*, and *Stylosanthes* in improving tropical pastures. Westview Trop. Agr. Ser. (6). Boulder, Colo.: Westview Press.

Campo, R. J., D. S. Cordeiro, G. J. Sfredo, C. M. Borkert, and J. B. Palhano. 1979. Algumas leguminosas de verao indicadas para adubacao verde (in Portuguese). Empresa Brasileira de Pesquisa Agropecuaria, Centro Nacional de Pesquisa de Soja, Tech. Commun. 1. Mimeo.

CIAT. 1975. Annual Report 1974, Centro International de Agricultura Tropical, Cali, Colombia.

CIAT. 1978. Annual Report 1977, Centro International de Agricultura Tropical, Cali, Colombia. P. 36.

Chatterjee, B. N., K. I. Singh, A. Pal, and S. Maiti. 1979. Organic manures as substitutes for chemical fertilizers for high-yielding rice varieties. Indian J. Agr. Sci. 49(3):188–192.

Dargan, K. S., R. K. Chillar, and K. K. R. Bhardwaj. 1975. Green manuring for more paddy in alkali soils. Indian Farming 25:13–14.

Duke, J. A. 1981. Handbook of legumes of world economic importance. New York: Plenum Press.

Duncan, A. 1975. Economic aspects of the use of organic materials as fertilizers. *In* Organic materials as fertilizers. Food & Agr. Org. of the UN, Rome. Soils Bull. 27, pp. 353–378.

Eaglesham, A. R. J., A. Ayanaba, V. Ranga Rao, and D. L. Eshew. 1982. Mineral N effects on cowpea and soybean crops in a Nigerian soil. Plant & Soil 68:183–192.

Evans, D. O., R. S. Yost, and G. W. Lundeen. 1983. A selected and annotated bibliography of tropical green manures and legume covers. Hawaii Inst. Trop. Agr. & Human Resources, Univ. of Hawaii. Res. Ext. Ser. 028.

FAO. 1961. Agricultural and horticultural seeds. Food & Agr. Org. of the UN, Rome.

FAO. 1977. China: Recycling of organic wastes in agriculture. Food & Agr. Org. of the UN, Rome. Soils Bull. 40.

Ghana Department of Agriculture. 1958. Report for 1955–1956: Agronomic Research.

Gill, K. S. 1978. Strategy for getting more production from rice-wheat rotation. Progressive Farming 15(2):5–7.

Gillett, J. B. 1963. *Sesbania* in Africa. Kew Bull. 17:91–159.

Grof, B. 1982. Performance of *Desmodium ovalifolium* in legume-grass associations. Trop. Agr. 59(1):33–37.

Gupta, R. N., M. L. Khanna, O. P. Agarwal, and M. C. Amoria. 1966. Comparative value of different legumes in soil and water conservation. J. Soil & Water Conserv. India 14(3–4):55–62.

Haan, C. T. 1977. Statistics in hydrology. Iowa State Univ. Press.

Haylett, D. G. 1961. Green manuring and soil fertility. S. African J. Agr. Sci. 4(3):363–378.

Henzell, E. F. 1968. Sources of nitrogen for Queensland pastures. Trop. Grasslands 2:1–17.

Henzell, E. F., and D. O. Norris. 1962. Process by which nitrogen is added to the soil/plant system. *In* A review of nitrogen in the tropics with particular reference to pastures. A symposium. Commonw. Bur. Past. Field Crops. Hurley. Berkshire. Bull. 46:1–18.

Henzell, E. F., I.F. Fergus, and A.E. Martin. 1966. Accumulation of soil nitrogen and carbon under a *Desmodium uncinatum* pasture. Australian J. Exp. Agr. Anim. Husb., 6:157–160.

Holland, T. H. 1928. Experience in the use of creeping crops in tea cultivation, with special reference to *Indigofera endecaphylla*. Trop. Agrst. (Ceylon) 70(5):312–318.

Holland, T. H., and A. W. R. Joachim. 1933. A soil erosion experiment. Trop. Agrst. (Ceylon) 80:199–207.

Hopkinson, D. 1971. Leguminous cover crops for maintaining soil fertility in sisal in Tanzania, 2: Effects on moisture status of soil and sisal. Exp. Agr. 7(4):337–343.

ICRISAT. 1980. Annual Report. Intl. Ctr. for Res. in the Semi-Arid Tropics., Pantacheru, India.

IITA. 1979. Annual Report 1978. Intl. Inst. Trop. Agr., Ibadan, Nigeria.

IITA. 1980. Annual Report 1979. Intl. Inst. Trop. Agr., Ibadan, Nigeria.

IPPC. 1980. Spreading weed menaces North Thai agriculture. Intl. Plant Protection Ctr. Infoltr. 43 (Jan.–Feb.).

Jackson, I. J. 1977. Climate, water, and agriculture in the tropics. London: Longmans.

Jacoby, E. H. 1974. Structural changes in Third World agriculture as a result of neo-capitalistic developments. The Developing Economies 12(3):201–213.

Jaiyebo, E. O., and A. W. Moore. 1963. Soil nitrogen accretion under different covers in a tropical rain-forest environment. Nature 197(4864):317–318.

Jones, G. H. G. 1942. The effect of leguminous cover crop in building up soil fertility. East Afr. Agr. J. 8:48–52.

Kamprath, E. J., W. V. Chandler, and B. A. Krantz. 1958. Winter corn crops: Their effects on corn yields and soil properties. North Carolina Agr. Exp. Sta., Tech.

Bull. 129.

Kang, B. T., G. F. Wilson, and L. Sipkens. 1981. Alley cropping maize (*Zea mays*) L. and Leucaena (*Leucaena leucocephala*) Lam. in southern Nigeria. Plant & Soil 63:165–179.

Kannegieter, A. 1967. Zero cultivation and other methods of reclaiming pueraria-fallowed land for foodcrop cultivation in the forest zone of Ghana. Trop. Agrst. (Ceylon) 123:51–73.

________. 1969. The combination of a short-term pueraria fallow, zero cultivation and fertilizer application: Its effects on a following maize crop. Trop. Agrst. (Ceylon) 125:77–89.

Karunkar, P. D. and T. Rajagopalan. 1948. Manuring of rice. Trop. Agrst (Ceylon) 104:211–214.

Khind, C. S., O. P. Meelu, and V. Beri. 1982. Efficiency of green manure substituted for applied nitrogen in rice. Intl. Rice Res. Newsltr. 7(2):20.

________. 1983. Age of dhaincha, green matter, and nitrogen economy in rice. Intl. Rice Res. Newsltr. 8(2):17–18.

Krauss, F. G. 1911. Leguminous crops for Hawaii. Hawaii Agr. Exp. Sta. Bull. 23.

Lal, R., G. F. Wilson, and B. N. Okigbo. 1979. Changes in properties of an alfisol produced by various crop covers. Soil Sci. 127 (6):377–382.

Lugo-Lopez, M. A., J. A. Bonnett, E. Hernandez-Medina, P. Landreau, Jr., and G. Samuels, 1954. Soil organic matter levels and crop yields in Puerto Rico. Soil Sci. Soc. Proc. 18:489–493.

Lugo-Lopez, M. A., R. Perez-Escolar, and R. del Valle. 1981. Winged beans as a potential food and green manure crop under conditions in Puerto Rico. J. Agr. Univ. Puerto Rico 65(1):75–78.

Majumdar, S. K., and T. Chakraborty. 1977. Effect of basic slag and organic matter over NPK manuring on the yield of IR-8 rice in laterite soil. Indian Agrst. 21(2): 159–162.

Mathew, M., M. V. Pushpadas, and M. Abdul Kalam. 1975. Effect of phosphorus, potassium and magnesium on nitrogen fixation and dry matter production by *Pueraria phaseoloides*. Paper from scientific symposium, Sept. 26–28, 1974, Cochin, India. London: Intl. Rubber Res. & Dev. Board. Vol. 1, Sess. B(23).

McIntosh, J. L., and S. Effendi. 1979. Soil fertility implications of cropping patterns and practices for cassava. *In* E. Weber, B. Nestel, and M. Campbell (eds.), Intercropping with cassava: Proc. Intl. Workshop 1978. Trivan-drum, India. Ottawa: Intl. Dev. Res. Ctr.

McKee, R. 1946. *Crotalaria* culture and utilization. USDA Farmers' Bull. 1980.

Mendham, N. J. 1971. Legume cover-crops for oil palms in West New Britain. Papua New Guinea Agr. J. 22(4):250–256.

Moore, A. W. 1962. The influence of a legume on soil fertility under a grazed tropical pasture. Empire J. Exp. Agr. 30:239–248.

Moore, A. W., and E. O. Jaiyebo. 1963. The influence of cover on nitrate and nitrifiable nitrogen content of the soil in a tropical rain forest environment. Empire J. Exp. Agr. 31(123):189–198.

Nao, T. V. 1979. Sesbania species in two agro-forestry systems. UNU/CMU workshop on agro-forestry for rural communities, November 1979, Chiang Mai, Thailand. Mimeo.

NAS. 1980. Firewood crops: Shrub and tree species for energy production. Nat. Acad. Sci., Washington, D.C.

NAS. 1983. Firewood crops, Vol. 2. Nat. Acad. Sci., Washington, D.C.

Nitis, I. M., and I. G. N. Sumatra. 1976. The effect of fertilizers on the growth and yield of cassava undersown with stylo sown at Penebel, Bali. Fakultas Kedokteren Hewan and Peternakan. Univ. Udayana Bull. 48.

Pandey, S. N. 1966. *Calopogonium orthocarpum* in conservation farming. J. Soil & Water Conserv. India 14(3-4):51–54.

Panse, V. G., T. P. Abraham, and C. R. Leelavathi. 1965. Green manuring of crops: Review of experimental results in India. Indian Council Agr. Res. Tech. Bull. 2.

Piper, C. V., and W. J. Morse. 1938. The velvet bean. USDA Farmers' Bull. 1276.

Plucknett, D. L. 1979. Managing cattle under coconuts. Westview Trop.Agr. Ser. (2). Boulder, Colo.: Westview Press.

Pushparajah, E. 1982. Legume cover crops as a source of nitrogen in plantation crops in the tropics. Symposia papers. 12th Intl. Soil Sci. Congr. New Delhi. 1:189–197.

Pushparajah, E., and T. K. Huat. 1979. Legumes in the economy of rubber cultivation. *In* W. J. Broughton, C. K. John, J. C. Rajarao, and B. Lim (eds.), Soil microbiology and plant nutrition. Proc. symposium, 1976, Kuala Lumpur. Univ. Malaysia Press, Kuala Lumpur. Pp. 413–434.

QAJ. 1938. Poona pea as a green manure crop. Queensland Agr. J. 50(2):238–241.

Rao, C. H. 1950. Manurial experiments on rice, 3: Applications of green manures in combination with phosphates. Madras Agr. J. 37(4):150–156.

Reddi, S. N., G. P. Rao, Y. Y. Rao, and G. H. S. Reddi. 1972. Note on the effect of green leaf manuring with and without fertilizers on the growth and yield of IR20 rice. Indian J. Agr. Res. 6(1):67–69.

Rinaudo, G., B. Dreyfus, and Y. Dommergues. 1983. *Sesbania rostrata* green manure and the nitrogen content of rice crop and soil. Soil Biol. & Biochem. 15(1):111–113.

Rotar, P. P., and R. J. Joy. 1983. 'Tropic Sun' sunn hemp, *Crotalaria juncea* L., Hawaii Inst. Trop. Agr. & Human. Resources. Res. Ext. Ser. 036.

RRIM. 1980. Annual Report 1979. Rubber Res. Inst. Malaysia, Kuala Lumpur. Pp. 114–119.

Ruthenberg, H. 1971. The economics of introducing fertiliser. Proc. 7th colloquium, Intl. Potash Inst., Bern.

Sadanandan, A. K., A. N. Sivappah, and M. Guruswamy. 1973. Response of C0-25 and ADT-27 rice to nitrogen, phosphorus, potash, and green manure. Agr. Res. J. of Kerala 11(2):130–134.

Sahu, B. N. 1965. Management of lateritic soils of Orissa for increased production—a review. Indian J. Agron. 10:29–42.

Salgado, M. L. M. 1936. Questionnaire on cover crops and green manures (in relation to coconut cultivation). Trop. Agrst. (Ceylon) 87(4):202–209.

Schofield, J. L. 1945. A comparison of soil nitrate nitrogen values under bare fallow and after ploughing in various perennial tropical legumes and cow-peas. Queensland J. Agr. Sci. 2:170–189.

Shaner, W. W., P. F. Philipp, and W. R. Schmehl. 1982. Farming systems research and development. Boulder, Colo.: Westview Press.

Silva, M. A. T. 1951. Cover crops under coconuts. Ceylon Coconut Q. 2:17–22.

SIPL. No date. Oil palms: Use of pueraria covers for weed control. Solomon Islands Plantations Ltd., Honiara. Mimeo.

Singh, K. 1961. Value of bush, grass or legume fallow in Ghana. J. Sci. Food & Agr. 12(2):160–168.

Singh, N. T., R. Singh, and A. C. Vig. 1981. Yield and water expense of cowpea, clusterbean, and sesbania as summer green manures in semi-arid regions of Punjab. Indian J. Agr. Sci. 51(6):417–421.

Skerman, P. J. 1977. Tropical forage legumes. Plant Prod. & Prot. Ser. 2. Food & Agr. Org. of the UN, Rome.

Smil, V. 1984. Environmental degradation in China. Armonk, N.Y.: M. E. Sharp, Inc.

Soong, N. K., and W. C. Yap. 1976. Effect of cover management on physical properties of rubber growing soils. J. Rubber Res. Inst. Malaysia. 24:145–159.

Stokes, W. E., R. M. Barnette, and J. B. Hester. 1936. Effects of summer cover crops on crop yields and on the soil: 1. Yields of corn and sweet potato following summer cover; 2. Influence of summer cover on nitrate and organic matter content of a poor grade of Norfolk soil. Univ. Florida Agr. Exp. Sta. Bull. 301.

Subramanyam, T. K., and N. R. Dhar. 1976. Use of water hyacinth (*Eichhornia crassipes*) in rice production. Intl. Rice Comm. Newsltr. 25(1/2):49.

Swaminathan, K., and M. Singh. 1960. Value of growing kharif legumes with or without phosphatic fertilizers in influencing yield of succeeding potato crop. Indian Potato J. 2(2):83–93.

Teoh, C. H., A. Abdullah, and W. M. Reid. 1979. Critical aspects of legume establishment and maintenance. Proc. Rubber Res. Inst. Malaysia Planters' Conf., pp 252–271.

Vallis, I. 1972. Soil nitrogen changes under continuously grazed legume-grass pastures in sub-tropical Queensland. Australian. J. Exp. Agr. Anim. Husb. 12:495–501.

Verma, T. R. 1968. Legumes in soil conservation. J. Soil & Water Conserv. India 16(1–2):65–68.

von Schaaffhausen. R. 1963. *Dolichos lablab* or hyacinth bean: Its uses for feed, food and soil improvement. Econ. Bot. 17(2):146–153.

Watson, G. A., 1957. Nitrogen fixation by *Centrosema pubescens*. J. Rubber Res. Inst. Malaysia. 15:168–174.

________. 1963. Cover plants and tree growth, Part 2. Leguminous creeping covers and manuring. Planters' Bull. Rubber Res. Inst. Malaysia. 68:172–176.

Watson, G. A., W. P. Wong, and R. Narayanan. 1964a. Effect of cover plants on soil nutrient status and on growth of *Hevea*, 3: A comparison of leguminous creepers with grasses and *Mikania cordata*. J. Rubber Res. Inst. Malaysia 18:80–95.

________. 1964b. Effects of cover plants on soil nutrient status and on growth of *Hevea*, 5: Loss of nitrate-nitrogen and of cations under bare soil conditions; a progress report on results from a small-scale trial. J. Rubber Res. Inst. Malaysia 18:161–174.

Watson, K. A., and P. R. Goldsworthy. 1964. Soil fertility and investigations in the middle belt of Nigeria. Empire J. Exp. Agr. 32(128):290–302.

Wilson, G. P. M., R. M. Jones, and B. G. Cook. 1982. Persistance of joint vetch (*Aeschynomene falcata*) in experimental sowings in the Australian subtropics. Trop. Grasslands 16(3):155–156.

Wong, Phui Weng. 1971. A selective preemergence weedicide for grass control in the establishment of legume cover crops. Planter 47(547):459–462.

Wycherley, P. R. 1963. The range of cover plants. Planters' Bull. Rubber Res. Inst. Malaysia 68:117–122.

Yost, R. S., D. O. Evans, N. A. Saidy, and R. L. Fox. 1981. Green manuring—renewed interest in an old concept. Dept. Agron. & Soil Sci., Univ. of Hawaii. Illus. Concepts in Trop. Agr. 25.

Yost, R. S., D. O. Evans, and N. A. Saidy. 1985. Tropical legumes for N production: Growth and N content in relation to soil pH. Trop. Agr. (Trinidad) 62:20–24.

APPENDIX A

Questionnaire Results

Questionnaires returned from 33 countries indicated that green manuring and cover-cropping in the tropics as a whole have received limited acceptance. In some plantation systems, such as rubber and oil palm, cover-cropping with legumes is common practice, has received more research attention, and is better understood than green manuring/cover-cropping (GM/CC) in annual farming systems. The questionnaire results indicated that green manuring is not highly correlated with cover-cropping. For example, green manuring appears to be far more common in Asia than in Africa, tropical America, or Oceania, where the practice is rare. Cover-cropping was more frequently practiced in Oceania and Africa than in tropical America. For incidence of both GM and cover-cropping, the response rating was 1.2 on a scale of 0–3, where 0 = not practiced at all, 1 = rarely practiced, 2 = moderately, and 3 = commonly practiced. The response rating was somewhat higher for cover-cropping (1.27) than for green manuring (1.15), probably because in Africa GM crops were rarely used (0.6) and cover crops were somewhat more frequent (1.4).

Economic Aspects

The causes of infrequent use of GMs or cover crops in annual cropping systems are hard to determine. A common response to our questionnaire was that economic factors were the main reasons for either not adopting green manuring and cover-cropping or discontinuing their use in countries with a green manuring tradition (India, Sri Lanka, Taiwan). In general, farmers, extension workers, and researchers have had trouble in translating or evaluating agronomic benefits into dollars and cents. These economic factors have often reflected the competition between GMs and food crops for land, rainfall, and labor. They may also have reflected competition between the farms and off-farm income sources. In some situations, the low price of N fertilizer also seems to have been important.

The majority of the cited advantages of green manuring were agronomic, whereas most disadvantages were economic. The use of GMs as a nitrogen source seems to require more management skill on the farmer's part and may add to the uncertainty of yield of the following crop because of either competition for inadequate rainfall or the harbouring of disease or pest organisms. These potential difficulties can be compounded by the uncertainty of having an adequate amount of N produced by the GM crop. Such uncertainty could be alleviated to some extent by planting areas of the farm to legumes for the sole purpose of producing nitrogen for GLM to supplement production by the *in-situ* GM crop. Greater N production and efficiency may result from innovations in techniques of GM crop management and incorporation methods. Hence, the inclusion of a GM crop in a farming system requires increased management skills and perhaps increased effort and some additional resources, compared with systems relying exclusively on N fertilizer.

A greater variety of legumes and planting combinations has been used in GM systems with annual crops than in plantation systems, so it has been harder to identify typical models of legumes and associated crops in annual cropping systems than in perennial systems. The inclusion of GM/CC in annual cropping systems tends to be location-specific and depends on times in which crops are not grown for one reason or another. Furthermore, GM crop species selection and management will vary with the availability of land, rainfall, and sunlight during periods in which a GM can be grown. This suggests a strong case for local adaptive research on systems that may have succeeded in regions of similar agroenvironments. Local consideration of the alternatives is important, because the complex local farming systems are best integrated by the farmers themselves.

The stated advantages of GM are numerous (Table A-1). The extent to which each of these advantages is agronomically or economically significant must be determined and economic effects assessed. This lack of assessment appears to be a major inadequacy in current knowledge and use of GM. If the benefit that accrues from planting GM is not known, the cost/benefit ratio cannot be determined. Legumes grown for GM may also serve, in certain instances, as fodder, grain and vegetable food, firewood, fiber, shade, and sometimes medicine. As suggested above, if these uses are sought as justification for committing a large portion of the farmer's resources, then each of their economic benefits must also be assessed.

Agronomic Aspects

The competition for rainfall that often occurs between the GM crop and the associated crop is a major determinant of where the GM practice is appropriate and which GM crop is likely to be most successful. Classifications of climate in the tropics that use rainfall criteria, such as that proposed by Jackson (1977), are useful in conjunction with compilations of the climate and soil requirements rainfall criteria. A list of climatic and soil requirements of major GM crops such as that suggested in Duke (1981) would assist in associating these legumes with the appropriate climatic regions. Such a grouping could be of use to scientists seeking to compare several alternative GM crops for use in local farming systems. Lack of information and low availability of seed and vegetative propagation materials were reported to hinder GM use in many areas. This suggests that extension personnel and agribusiness people need to establish plant materials centers.

Table A-1. Advantages and disadvantages of green manure/cover crops in local farming systems.

	TOTAL				AFRICA				THE AMERICAS				ASIA				OCEANIA			
	GM	CC	U*	T	GM	CC	U*	T	GM	CC	U*	T	GM	CC	U*	T	GM	CC	U*	T
ADVANTAGES																				
Soil physical benefits	6	6	16	28	1	2	4	7	0	0	4	4	5	3	6	14	0	1	2	3
Erosion control benefits	0	12	16	28	0	3	2	5	0	2	5	7	0	6	2	8	0	1	7	8
Nutrient benefits	10	2	15	27	1	2	3	6	0	0	6	6	7	0	4	11	2	0	2	4
Weed and pest control benefits	0	8	6	14	0	4	0	4	0	0	3	3	0	2	1	3	0	2	2	4
Soil nitrogen benefits	2	5	5	12	0	1	0	1	0	1	1	2	2	2	1	5	0	1	3	4
Organic matter benefits	4	2	4	10	0	2	1	3	0	0	2	2	3	0	0	3	1	0	1	2
Reclamation benefits	5	1	2	8	0	0	0	0	0	0	2	2	5	1	0	6	0	0	0	0
Other benefits	1	3	4	8	0	1	0	1	0	1	2	3	1	1	1	3	0	0	1	1
Yields improved	0	0	4	4	0	0	0	0	0	0	0	0	0	0	2	2	0	0	2	2
Economic benefits	3	0	1	4	0	0	0	0	0	0	0	0	3	0	0	3	0	0	1	1
Total advantages	31	39	73	143	2	15	10	27	0	4	25	29	26	15	17	58	3	5	21	29
DISADVANTAGES																				
Lack of materials	6	1	3	20	0	0	5	5	0	1	1	2	6	0	2	8	0	0	5	5
Competition for land	6	1	12	19	0	0	3	3	0	0	0	0	6	1	4	11	0	0	5	5
Use other techniques	4	0	12	16	2	0	1	3	0	0	1	1	2	0	5	7	0	0	5	5
Lack of money	3	0	12	15	0	0	5	5	1	0	2	3	2	0	1	3	0	0	4	4
No real benefits	2	1	10	13	0	1	2	3	0	0	3	3	2	0	3	5	0	0	2	2
Harm/problems	5	2	6	13	1	1	0	2	1	0	1	2	3	0	1	4	1	0	4	5
Lack of "documentation"	1	2	8	11	1	0	1	2	0	0	3	3	0	2	1	3	0	0	3	3
Climate/physical	5	1	4	10	2	0	1	3	1	0	2	3	2	1	0	3	0	0	1	1
Lack of land	2	1	4	7	1	0	0	1	0	0	1	1	1	1	2	4	0	0	1	1
Tradition/culture	1	0	6	7	1	0	2	3	0	0	2	2	0	0	2	2	0	0	0	0
Lack of time	2	1	1	4	1	0	0	1	1	1	0	2	0	0	0	0	0	0	1	1
Cost of labor	0	2	2	4	0	0	1	1	0	1	0	1	0	0	0	0	0	1	1	2
Total disadvantages	37	12	90	139	9	2	21	32	4	3	16	23	24	5	21	50	0	2	32	34
Total replies				49				12				11				15				11

*U = unspecified

Table A-2. Views on the use of green manure/cover crops in local farming systems.

COUNTRIES	USE OF GREEN MANURE: Commonly	Moderately	Rarely	Not at all	USE OF COVER CROPS: Commonly	Moderately	Rarely	Not at all	% FARMERS USING FERTILIZER NITROGEN	Purchase	Credit	Govt.	Non-govt.	MAJOR ADVANTAGES	MAJOR DISADVANTAGES
THE AMERICAS															
Belize			X				X		--	X		X		Improves soil fertility, improves soil structure.	Lack of planting material, lack of knowledge.
Brazil				X			X		60		X			Controls soil erosion.	Houses insects, no visible and direct return.
Brazil			X				X		--		X	X		Controls weeds and pests, maintains soil fertility.	Lack of tradition, lack of long-term experimental results on advantages.
Brazil		X					X		90		X	X		Improves physical and chemical conditions, improves water-retention of soil.	Loss of crop because of length of green manure crop growth, transportation and distribution on soil.
Costa Rica			X				X		10	X		X		Neutralizes aluminum toxicity, provides mulch to assist seed germination.	The small area of available land is used for food crops, lack of suitable cover crop for use in acid/toxic soils.
Ecuador			X				X		15-20					Prevents soil erosion, improves physical conditions.	Loss of crop, continual cropping in rice areas.
Guatemala			X				X		--		X	X		Controls erosion, low cst.	---------
Peru		X					X		100 20 5	X	X	X	X	Adds organic matter to soil.	Lack f water, time only to grow food crop.
Puerto Rico		X					X		100	X		X		Conditions soil, uses waste by products.	Costs of management, application, etc., lack of experience to apply it.
Venezuela		X					X		10	X		X		Renews pastures.	---------
West Indies				X		X			60	X			X	Provides fodder, conserves soil.	Nitrogen released too rapidly for use by crop, workers refuse to work in thick cover because of snakes.

Table A-2. Views on the use of green manure/cover crops in local farming systems. (Cont.)

COUNTRIES	USE OF GREEN MANURE: Commonly	Moderately	Rarely	Not at all	USE OF COVER CROPS: Commonly	Moderately	Rarely	Not at all	% FARMERS USING FERTILIZER NITROGEN	Purchase	Credit	Gov.	Non-gov.	MAJOR ADVANTAGES	MAJOR DISADVANTAGES
AFRICA															
Burundi						X			0					Maintains soil humidity, controls weeds.	Lack of plant material.
Cameroon				X		X			Few	X		X		Conserves soil and water, improves soil.	Pueraria tends to climb on crops, expensive to establish and maintain.
Ghana				X				X	<20			X		Adds nitrogen, controls erosion.	Lack of scientific information.
Ghana			X		X				--	X	X	X		Controls weeds, increases soil organic matter.	Farmer sees no need/benefit, uses maize stubs.
Kenya			X			X			50	X				Improves soil structure, fixes nitrogen.	Culture doesn't allow farmers to use food crops as green manure, materials expensive.
Madagascar				X				X	10	X		X			Establishment of crop difficult, traditional agriculture primitive.
Malawi			X				X		30	X	X	X	X	Increases soil nutrients, improves water-holding capacity.	Farmers don't see value of sacrificing crop to green manure or cover crop.
Mauritius				X			X		100	X	X		X		Use artificial fertilizers, restricted land use for food crop production.
Nigeria			X				X		20	X		X		Shortens fallow period, builds up soil fertility.	No economic returns, need special drills for seeding through dead sod as no-till.
Nigeria				X		X			10-15 70			X			Not enough rain for green manure, green manure decomposes too quickly.
Sudan			X				X		Low	X		X		Maintains high level of organic matter, controls soil erosion.	Difficult to clear new land, green manures and mulches encourage termites.
Swaziland			X				X		70	X	X		X	-----	Lack of rainfall, livestock wander on land.
Tanzania			X			X			<20	X		X		Increases infiltration of rain, reduces splash erosion.	Inadequate knowledge of practices, lack of machinery to turn down green manure.
Rep. of South Africa			X				X		100		X			Reduces use of expensive N fertilizers.	High cost of land, intensive production systems.

Table A-2. Views on the use of green manure/cover crops in local farming systems. (Cont.)

COUNTRIES	USE OF GREEN MANURE: Commonly	Moderately	Rarely	Not at all	USE OF COVER CROPS: Commonly	Moderately	Rarely	Not at all	% FARMERS USING FERTILIZER NITROGEN	Purchase	Credit	Govt.	Non-govt.	MAJOR ADVANTAGES	MAJOR DISADVANTAGES
OCEANIA															
Australia	X				X				<50					Controls erosion, controls weeds.	Price and availability of seed, low rainfall.
Guam				X			X		90		X			Adds nutrients, enhances soil structure.	Expensive to establish.
Indonesia				X			X		20			X		Maintains fertility, controls erosion.	Too much labor, lack of knowledge of benefits.
Indonesia			X				X		60 90	X				Covers soil, produces organic matter.	No planting material or seed, lack of time to grow it.
Indonesia									--	X				Improves crop production, added fertility.	Costs for establishment, lack of viable seed.
Indonesia		X					X		99					Increases yield, controls erosion.	Limits time for planting food crop, transportation cost.
Papua New Guinea			X			X			<1	X			X	Fixes N, controls pests.	Requires frequent cutting, competes with coffee crop.
Philippines		X				X			--		X		X	Reduces cost of inorganic fertilizers, prevents leaching of nutrients.	Provides breeding places for pests, competes with food crops for nutrients.
Philippines			X			X			90+	X	X		X	Economizes fertilizer use, controls erosion.	Farmers prefer instant income from crops, small landholdings.
Philippines			X			X			99		X		X	Provides animal feed, improves soil physical property.	Interferes in harvesting operations of coconuts, citrus; yield declined with cover cropping.
Solomon Islands			X			X			<5			X		Reduces labor for weed control and ground maintenance, reduces need for fertilizer N.	Use of *Rhizobium* limited, poor establishment techniques.
Taiwan	X					X			100	X	X			Adds organic matter to soil, conserves soil and water.	Time-consuming, less land and time.

Table A-2. Views on the use of green manure/cover crops in local farming systems. (Cont.)

COUNTRIES	USE OF GREEN MANURE: Commonly	Moderately	Rarely	Not at all	USE OF COVER CROPS: Commonly	Moderately	Rarely	Not at all	% FARMERS USING FERTILIZER NITROGEN	Purchase	Credit	Govt.	Non-govt.	MAJOR ADVANTAGES	MAJOR DISADVANTAGES
ASIA															
India--Tamil Nadu		X					X		90	X	X			Fixes atmospheric nitrogen, reclaims soil.	Multiple cropping gaining importance, use of other fertilizers.
India--Andhra Pradesh		X					X		80		X	X		Provides fodder, economizes fertilizer use on principal crops.	Green manure increases power or energy requirement in preparatory tillage, competes with more productive crops.
India--Karnataka		X					X		30-90		X	X	X	Upgrades saline and alkaline soils to some extent, improves soil structure.	Stray cattle menace, inadequate moisture due to vagaries of monsoons.
India			X				X		--					-----	Need for food and fodder crops because of rapid population increase.
India--Punjab		X					X		98.6	X	X	X	X	Reclaims salt = affected soils, added organic material, stimulates microorganism activity.	Possible increase of diseases, insects, nematodes, loss of kharif crop.
India--Kerala		X					X		70		X	X		Checks weed growth, conserves soil and moisture.	Lack of seeds in time for planting, acute shortage of land.
Nepal			X				X		25	X	X			Prevents soil erosion in hilly areas, adds nutrients to. soil.	Not enough land, need for food crops.
Pakistan			X				X		50-90		X		X	Improves soil tilth, more yield per acre.	Lack of water for decomposition, lack of tractors and tractor implements.

Table A-2. Views on the use of green manure/cover crops in local farming systems. (Cont.)

COUNTRIES	USE OF GREEN MANURE: Commonly	Moderately	Rarely	Not at All	USE OF COVER CROPS: Commonly	Moderately	Rarely	Not at all	% FARMERS USING FERTILIZER NITROGEN	Purchase	Credit	Govt.	Non-govt.	MAJOR ADVANTAGES	MAJOR DISADVANTAGES
ASIA (cont.)															
Pakistan			X					X	90	X	X	X		Alkaline soils become mellow and friable, adds N through fixation.	Difficult to adjust green manure in rotation, increased use of chemical fertilizers.
Sri Lanka		X					X		90	X	X	X	X	Improves soil physical conditions, prevents soil erosion.	Change in pattern of agriculture, slow destruction of green manure sources.
Sri Lanka		X			X				80			X		Renovates soil, conserves soil and moisture.	Lack of plant material.
Sri Lanka			X			X			90-100		X	X		Adds nutrients, improves soil structure.	Absence of tradition or promotion, easy availability of cheap fertilizers.
Thailand			X					X	20		X		X	Restores and maintains soil fertility.	Lack of knowledge, lack of cash.
Thailand			X			X			30	X	X	X	X	Conserves soil and moisture, controls weeds.	Extra cost in plowing, short growing season.

APPENDIX B

Green Manure Simulations

A simulation study was conducted with the objective of determining how the use of GMs in a rice cropping system is affected by the availability and use of N fertilizers. The simulation was developed to represent alternatives of using N fertilizers with or without a crop in addition to the rice or growing rice with a preceding GM crop. Crop response was determined by estimates of potential yield that would include consideration of genetic, general climatic, and other fixed constraints. Simulated yields were determined from functions of N application and simulated rainfall distributions (McIntosh and Effendi 1979).

Model Organization

The growing season of one year was subdivided into three four-month periods. Rainfall was generated for each period, using an autoregressive approach described in Haan (1977) (Equation 1).

$$x_{i+1} = u_x + r_x \cdot (x_i - u_x) + t_{i+1} \cdot s_x \cdot \sqrt{(1 - r_x^2)} \qquad (1)$$

where x_{i+1} = rainfall for the current period, x_i = rainfall for the previous period, u_x = average rainfall for the current period, r_x = serial correlation between successive periods, t_{i+1} = random number from a $N_{0,1}$ distribution, and s_x = standard deviation of rainfall. Mean monthly rainfall for each period is a flexible program input. Most of the simulations assumed 400 mm/month for Period 1, 300 mm/month for Period 2, and 100 mm/month for Period 3. Table B-1 shows the simulated values and the results. The equation provides random variates (monthly rainfall), which are $N(u_x, s_x^2)$, and successive months of rainfall are correlated (r_x) with each other. Rice is assumed to be the main end product. Only one option is considered that does not include rice. The alternative rotations include:

1. Produce rice with no N fertilizer and with GM crop.
2. Produce rice with N fertilizer and a pulse crop.
3. Produce rice with no N fertilizer and a pulse crop.
4. Produce only the pulse crop with fertilizers.

Each option is evaluated for each cropping period.

Several overall parameter changes are available for performing sensitivity analysis on the system. Tallies are also made of estimates of labor, capital, and fertilizer usage over an indicated period of simulation.

Results

The results of various runs are given in Table B-1 with the factors that were examined.

Influence of level of nitrogen fertilizer available for application (level of N) was varied from 0 to 150 kg N/ha. Response to these levels of N were calculated using the general form of equation (2) with parameters $A_0 = 1.0$, $A_1 = 0.05$, $A_2 = 0.05$, and a yield potential for rice of 7.5 Mg/ha. Yield was then a function of the amount of applied N, the N from GM, and that from the pulse crop. It was further assumed that yield was proportional to rainfall relative to 300 mm/month. At greater levels, yields would increase; at levels below 300 mm/month, yields would decrease.

Yield of rice was assumed to follow a response function of the form:

$$\text{Yield} = A_0 + A_1 \cdot (\text{applied N}) + A_2 \cdot (\text{green manure N} + \text{pulse crop N}) \qquad (2)$$

Yields of GM and pulse crop were considered to be primarily of the type:

$$\text{Yield} = B_0 P_1 - B_1 P_1 e^{B_2 \cdot \text{rain}} \qquad (3)$$

Where B_0 is the maximum yield of the cultivar, P_1 is the potential yield for the particular growing conditions, B_1 is the net response (difference between yield with no rain and the maximum yield B_0), and B_2 is the curvature coefficient, which represents how rapidly maximum yield is obtained with increasing rain. The amount of N produced by the GM crop was calculated assuming 2.25 percent N, while it was assumed the pulse crop contained 1 percent N in the tops. In initial runs, the efficiency of GM N was assumed to be equal to that of fertilizer N (1 Mg rice for each 50 kg N/ha; parameters A_1 equalled A_2 in Equation 2). The amount of GM also was a function of yield potential for the species and the rainfall. The amount of N produced was assumed to be a constant proportion of the dry matter yield. Values were assigned to rice and pulse crop to reflect the opportunity cost of growing the GM. In early stages of simulation, it was assumed that the pulse crop was worth 2 times the grain weight of the rice. This tends to reflect the value of short-term pulse crops that are often intercalated with the rice. This was subsequently modified to represent the result of growing a short-term pulse instead of the GM legume.

Simulation results indicated that when GM is considered half as effective as fertilizer N in increasing rice yield, $A_2 = 0.5 \cdot A_1$ in Equation 2. As soon as 20 or more kg N/ha became available for application to the rice, the GM crop was replaced by the pulse crop.

Maximum rice yield with GM was 2.06 Mg/ha. When GM was considered 0.75 as effective as urea N, then if 30 kg of urea N were available, it would be preferred over use of GM. In this case maximum rice yield was 2.7 Mg/ha without fertilizer N.

Table B-1. Simulation results considering GM equivalent to fertilizer N in increasing rice yield.[1]

Fertilizer N	Crop	Period		
(kg/ha N)		P1	P2	P3
		Rainfall (mm)		
		339	270	92
40	Rice Yield	3.3	3.2	0.9
	Legume N	65	64	48
	Pulse Crop	0.74	0.72	0.51
Best Option: Grow rice and GM during Period 1. Yield: 3.3 Mg/ha rice.				
50	Rice Yield	3.3	3.2	0.9
	Legume N	65	64	48
	Pulse Crop	0.74	0.72	0.51
Best Option: Grow rice with the 50 kg N/ha (no GM) and grow the pulse crop instead of GM. Yield: 3.2 Mg/ha rice and 0.74 Mg/ha pulse.				
60	Rice Yield	3.3	3.2	0.9
	Legume N	65	64	48
	Pulse Crop	0.74	0.72	0.51
Best Option: Grow rice with the 60 kg N/ha application and the pulse crop instead of GM. Yield: 3.5 Mg/ha rice plus 0.74 Mg/ha pulse.				

[1] $A_1 = A_2$ in Equation 2. All yields are Mg/ha.

APPENDIX C: Questionnaire Respondents

Name	Institute	Country
Prin. Agr. Officer	Min. of Natural Resources	Belize
Edson Lobato	EMBRAPA/CPAC -Brasilia	Brazil
Avilio Franco	EMBRAPA-KM47, Rio de Janeiro	Brazil
Antonio L. B. Salgado	Inst. Agron. de Campinas	Brazil
J. Kafurera	ISABU	Burundi
G. W. van Barneveld	IRA/FAO Soil Resource Project	Cameroon
Ralph Hervey	Tropical Science Center	Costa Rica
Angel Mesa Napoles	Direccion de Suelos y Fert.	Cuba
M. A. Adansi	Oil Palm Research Center	Ghana
Peter Kwakye	Soil Research Institute	Ghana
Jetren Demeterio	University of Guam	Guam
M. R. Rao	ICRISAT, Farming Systems	India
V. Rajagopalan	Tamil Nadu Agr. University	India
R. Dwarakinath	Bangalore Agr. University	India
Karter Singh Chela	Punjab Agr. University	India
Djoko Santoso	Centre for Soil Research	Indonesia
Jerry McIntosh	Agency for Agr. Res. & Dev.	Indonesia
Asparno Mardjuki, Jr.	Gajah Mada University	Indonesia
Ben W. Wanjala	National Agr. Res. Station	Kenya
H. K. Mwandemere	Min. of Agr. & Nat. Resource	Malawi
Sydney Moutia	Min. of Agr. & Nat. Resource	Mauritius
P. S. Rana	Agricultural Department	Nepal
Mr. Luis Kurika	Lowlands Agr. Exp. Station	Papua New Guinea
V. Balasubramanian	Ahmadu Bello Univ.	Nigeria
R. Lal	Int'l. Inst. Tropical Agr.	Nigeria
Taj Mohammed Chaudhry	Agr. Res. Inst., Tandojam-Sind	Pakistan
Mohammad Aslam Mian	University of Agriculture	Pakistan
Luis Kurika, Meli Lulo	Lowlands Agr. Exp. Station	Papua New Guinea
A. E. Charles	Dept. of Primary Industry	Papua New Guinea
Sven Villagarcia	Univ. Nacional Agraria	Peru
Bonifacio Felizardo	Univ. Philippines, Los Banos	Philippines
Eduvigis Pantastic	PCARR, Crops Res. Division	Philippines
Godofredo N. Alcasid	Ministry of Agriculture	Philippines
Oscar Muniz Torres	Univ. Puerto Rico, Mayaguez	Puerto Rico
J. W. Snyman	Inst. for Crops and Pastures	South Africa
Lidio M. Cairo	Univ. de Santo Domingo	Santo Domingo
Steven E. Watson	Lever Solomons Limited	Solomon Islands
J. Handewela	Agriculture Research Station	Sri Lanka
H. P. M. Gunasena	University of Sri Lanka	Sri Lanka
M. M. Musa	Gezira Research Station	Sudan
Dir. of Agr.	Ministry of Agriculture	Swaziland
I. Haque	Univ. College of Swaziland	Swaziland
Tzo-Chuan Juang	National Chung Hsing Univ.	Taiwan
Andrew Uriyo	Univ. of Dar Es Salaam	Tanzania
Trevor Gibson	Crop Replacement Project	Thailand
Boonyaruk Suebsiri	Dept. of Land Development	Thailand
Joseph Lindsay	University of West Indies	Trinidad
B. A. Krantz	University of California, Davis	U.S.A.
Eudomar Parra	Estacion Exp. el Guayabo	Venezuela

DISCLAIMER

Reference to a company or product name does not imply approval or recommendation by the College of Tropical Agriculture and Human Resources, University of Hawaii, or the United States Department of Agriculture, to the exclusion of others that may be suitable.