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Intensifying Maize-Based Cropping Systems in the Sierra de Santa Marta, Veracruz

Daniel Buckles and Olaf Erenstein

NRG

Natural Resources Group

Paper 96-07

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Contents

Abstract

This paper focuses on intensifying maize-based cropping systems in the Sierra de Santa Marta Region of Veracruz, Mexico. Following a description of the study area, the paper examines the historical forces that have shaped regional maize-based cropping systems, current maize production practices, and major productivity and sustainability constraints. Potential solutions to these constraints, some of which have been successfully tested in the area, are described and possible productivity and sustainability impacts are appraised in qualitative terms. The appraisal provides the basis for a quantitative analysis of the farm-level costs and benefits associated with the adoption of the alternative practices. A farmer-based approach to extension is described and implementation costs are estimated.

Acknowledgments

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Acronyms

B/C ratio	Benefit-cost ratio
CBA	Cost-benefit analysis
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo
GEF	Global Environment Facility
INI	Instituto Nacional Indigenista
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias
LUI	Land use intensity
NGO	Non-Governmental Organization
PRINCE	Program for Measuring Incremental Cost for the Environment
PSSM	Proyecto Sierra de Santa Marta, A.C.
SAGAR	Secretaría de Agricultura, Ganadería y Desarrollo Rural
SARH	Secretaría de Agricultura y Recursos Hidráulicos (now SAGAR)
SEDAP	Secretaría de Desarrollo Agropecuario y Pesquero, Gobierno del Estado, Veracruz
SEDESOL	Secretaría de Desarrollo Social

Intensifying Maize-Based Cropping Systems in the Sierra de Santa Marta, Veracruz

Daniel Buckles and Olaf Erenstein

Introduction

Farmers in the Sierra de Santa Marta, an indigenous region of southern Veracruz, Mexico, have met their subsistence needs for generations by cultivating the lower slopes and adjacent hillsides of the Sierra using relatively land-extensive cropping practices. While these practices were viable and relatively sustainable in the past, they are no longer so due to the depletion of forested lands and increasing land-use pressures in areas already opened for agriculture. Intensification has lead to soil erosion and declines in soil fertility, with a parallel decline in agricultural productivity and forest cover. Technical options exist, however, that can potentially intensify the current system in a sustainable and equitable manner. Cover crops, soil conservation practices, and moderate amounts of external inputs can increase the efficient use of existing resources while maintaining or improving the resource base. This paper provides a detailed review of this option for intensifying maize-based cropping systems in the Sierra de Santa Marta, with special emphasis on the farm-level costs and benefits. Means of facilitating farmer access to and adaptation of these practices are also considered.

The paper is part of a broader collaborative study initiated by the Program for Measuring Incremental Cost for the Environment (PRINCE), a research program of the Global Environmental Facility (GEF) that is developing a set of practical tools for estimating the incremental cost[1] of actions that protect the global environment (PRINCE 1994). The study is an attempt to estimate the incremental cost of biodiversity conservation in the Sierra de Santa Marta area and is being undertaken by PRINCE, the Proyecto Sierra de Santa Marta A.C. (PSSM), and CIMMYT. This paper focuses on maize-based cropping systems in the Sierra de Santa Marta; it is intended to complement studies of other sectors in the area (GEF/PSSM/CIMMYT, forthcoming).

Following a description of the study area, the paper examines the historical forces that have shaped maize-based cropping systems in the Sierra de Santa Marta, current maize production practices, and major productivity and sustainability constraints. Potential solutions to these constraints, some of which have been successfully tested in the area, are described and possible productivity and sustainability impacts are appraised in qualitative terms. The appraisal provides the basis for an analysis of the farm-level costs and benefits associated with adoption of the alternative practices. A farmer-based approach to extension is described and implementation costs are estimated, followed by a summary of the study's main conclusions.

1 "Incremental cost" refers to the additional economic burden that developing countries have to bear when they take actions that benefit the global environment and that go beyond national development goals (PRINCE 1994).

The Study Area

The Sierra de Santa Marta is a remote mountain range in southern Veracruz located on the gulf coast between 18° 15′N and 18° 30′N latitude (Figure 1). It encompasses some 1,200 km^2 rising steeply from sea level at the Gulf of Mexico to more than 1,700 meters at its highest peak. Three municipalities—Pajapan, Soteapan, and Mecayapan—make up the northeastern and southern slopes of the range, while portions of two other municipalities—Catemaco and Hueyapan de Ocampo—comprise much of the western slope.

The Sierra is part of the Olmec heartland, a region where Mesoamerica's mother culture developed between 1200 and 400 B.C. (García de León 1976, p. 280). The population is mainly indigenous Nahua and Popoluca speakers that have inhabited the area since pre-Hispanic times. Mestizo communities of more recent origin are located at various points throughout the Sierra, although mainly on the northern slope where ranching activities dominate. The Sierra population amounts to approximately 40,000 people in 91 communities, most of which are *ejidos*. Agriculture, cattle ranching, coffee production, fishing, and the extraction of forest resources are the main economic activities of the population, but incomes are inadequate. Some 80% of the population lives in extreme poverty with incomes of less than US$ 1,200 annually (Arias 1991). The Sierra is one of the poorest regions in Veracruz and among the poorest in the nation.

To the south and east of the Sierra de Santa Marta lie the cities of Coatzacoalcos, Minatitlán, and Jáltipan—which have a total population of over one million. These cities comprise Mexico's most important petro-chemical complex. To the southwest lies the bustling cattle-ranching and commercial city of Acayucan. A major center for the regional cattle industry, the city exerts an important influence on developments in the Sierra. To the west lies the Tuxtlas region, which is important to the state economy as a center of tobacco production, ranching, and commercial maize.

The sudden rise of the Sierra de Santa Marta from sea level to over 1,700 meters creates a wide range of climatic conditions. The moisture-laden trade winds from the Gulf of Mexico are transformed into over 4,000 mm of rain on the northern slope, but as little as 1,200 mm fall on the

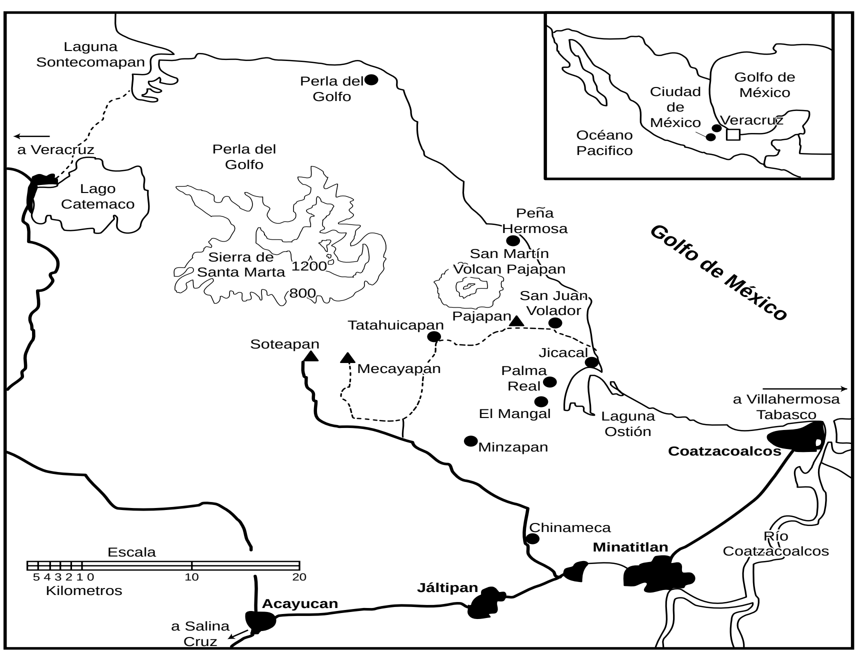

Figure 1. Sierra de Santa Marta study area in southern Veracruz, Mexico.

southwestern slope due to a rain shadow effect. Still, rainfall is generally abundant throughout the region and distributed in a bimodal pattern which allows for a growing season of more than 270 days. The altitudinal gradient modifies the temperature regime, and the soils, although generally of volcanic origin, are now quite diverse due to both climatic factors and varied land uses. The flora and fauna are also extremely diverse: some 3,000 plant species and 1,149 animal species have been documented, a number of which are unique to the region (Ramírez 1991). More than 450 bird species, almost 40% of the known bird species in Mexico, frequent the forests of the Sierra de Santa Marta and neighboring Tuxtlas range (Schaldach, Escalante, and Winker forthcoming). These unique features have prompted various formal declarations aimed at conservation, including the creation in 1980 of a Special Biosphere Reserve. Little action has been taken, however, to conserve the remaining 20,000 or so ha of forested land in the region (Paré et. al., forthcoming; GEF/PSSM/CIMMYT, forthcoming; Chevalier and Buckles 1995).

Three main agro-ecological zones can be identified.

- *Forest zone:* This refers to mountain peaks and craters (between 1,200 to 1,700 meters) where most of the remaining 20,000 ha of forest resources are concentrated. This zone is generally uninhabited, although frequently used by people from the upland zone.

- *Upland zone:* This refers the higher slopes (between 800 and 1,200 meters), and comprises communities bordering directly on the forest. Inhabitants make frequent use of forest resources and continue to open the forest margin.

- *Lowland zone:* This refers to the lower slopes and sloping land from sea level to about 800 meters, comprising the largest portion of the population and oldest communities in the region. Historically, the population of this zone has had considerable impact on regional forests; at present that impact has been reduced.

The analyses presented in this paper are based on these zones.[2]

The *forest zone* is covered with various kinds of montane forest of considerable biological importance (Ramírez 1991; Ramírez 1984; Andrle 1964). In this zone, average annual temperatures are 18° C or less, and rain falls in excess of 4,000 mm per year, providing the cool, wet conditions needed for development of these forest types. The mountain peaks and craters are frequently shrouded in clouds, adding through condensation as much water to the regional hydrology as falls in rain (Ramírez 1991). This water is gradually released to lower areas throughout the year, supplying the major bodies of water in the region, including the coastal lagoons Sontecomapan and Ostión, Lake Catemaco (Mexico's third largest), and numerous rivers feeding both the Coatzacoalcos and Papaloapan watersheds. Some 80% of Coatzacoalcos' potable water, 20% of the water consumed by Minatitlán, and virtually all of the drinking water of Acayucan is drawn from two springs on the southern slope of the Sierra, serving more than two million people. The agricultural potential of this zone is very limited, mainly because slopes exceed 60%, although the soils are relatively fertile Andosols.

The *upland zone* of the Sierra is characterized by various kinds of subtropical rain forest as well as oak and pine forests, particularly on the southern slope. Maize and coffee production are the most

[2] For more details on the zones and the agroecological features of sub-zones, see Ramírez et al. 1995 and Paré et al. 1993.

important agricultural land uses in most of this zone, although in a few Mestizo communities located on the northern slope of the upland zone pastures are dominant. Rainfall in this zone is high, ranging from 2,000 to 3,000 mm over most of the zone, but strong winds limit agricultural potential. *Nortes* peaking at over 100 km/hr strike the region from September through March, lodging maize fields and deflowering fruit trees and bean crops. Hot, dry winds known as *suradas* can also devastate crops between February and May. These strong winds confine most forms of agricultural production to the main rainy season (*temporal*) from June through September. The soils of the upland zone, composed mainly of Andosols, are slightly acid (pH 6.0) and extremely poor in phosphorous (0.6 ppm, Bray) (Tasistro 1994). Levels of organic matter (4.0%) are very high, in keeping with the relatively extensive land use patterns still present in this zone (Tasistro 1994). However, slopes of 30-60% in agricultural areas make these soils very susceptible to erosion.

The *lowland zone* was once covered with tropical rain forest, virtually all of which has given way to pastures, crops, and secondary vegetation. The relative importance of ranching and crops varies considerably within the zone. In general, however, the northern, southern, and eastern slopes of the lowland zone are dominated by pastures; annual cropping is the main land use on the western slope. Rainfall varies considerably, although it is generally distributed bimodally. Two growing seasons are usually possible, a main season (*temporal*) from June through September and a minor season (*tapachole*) from October through March. A short dry season that interrupts all agricultural activity occurs later as hot air masses (*suradas*) sweep in from the south from March through May. These dry winds pose considerable risks to crops like maize that are planted during the minor season (see below). The soils of the lowland zone are mainly Luvisols and Vertisols. They exhibit a moderately acid condition (pH 5.5-6.0) and are low in P (0.5-1.5 ppm, Bray) as well as other base nutrients (K, Ca, Mg) (Tasistro 1994). In general, the cation exchange capacity of the subsoil in both the upland and lowland zones is very low, a condition that reduces the capacity of the soil to retain nutrients and increases the vulnerability of crops to the effects of soil erosion and drought (Tasistro 1994).

Most communities in the Sierra are *ejidos*, comprising a specific territory and an association of producers (*ejidatarios*) with rights to use the collectively owned land. All but seven *ejidos* in the Sierra have been formally subdivided into individual parcels of an equal size distributed among *ejido* members.[3] *Ejidos* vary considerably in total size and membership as well as in the amount of land available to individual *ejidatarios*. The largest *ejido* (Pajapan[4]) comprises almost 14,000 ha and has over 900 members. Most *ejidos* are much smaller, however, with membership of 100 *ejidatarios* or fewer. Individual parcels range from as small as 4 hectares in some *ejidos* to as large as 25 hectares in others. All *ejidos* retain some lands, typically forests, for communal use.

3 Non-parceled *ejidos* include San Fernando, Ocotal Grande, Ocotal Chico and El Tulín in the municipality of Soteapan; Santa Rosa Loma Larga in the municipality of Hueyapan de Ocampo; Plan Agrario in the municipality of Mecayapan; and El Pescador in the municipality of Pajapan. In these *ejidos*, access to specific parcels of land is regulated by customary land use rights.

4 Technically, Pajapan, the capital of the municipality of the same name, is an agrarian community (*comunidad agraria*), not an *ejido*. Agrarian communities have a particular form of land tenure reserved for indigenous populations that chose to exercise traditional claims to land rather than request state land grants in the form of *ejidos*. While formally different land tenure systems, agrarian communities and *ejidos* typically function in much the same way.

Recent revisions to Mexico's constitution (Article 27) allow *ejidatarios* to legally rent, lease, or sell individual *ejido* land rights, with permission from the general assembly of *ejidatarios*. This reform has increased pressure to subdivide the few remaining collectively held *ejidos*, creating considerable uncertainty and conflict in a number of communities. The process of parceling has also constrained the adoption of land-conserving technologies such as living fences, which require secure land tenure (see below).

Other forms of land tenure within the Sierra include associations of independent producers *(colonias),* which are mainly concentrated on the northern slopes of the Sierra. These land holdings are considerably larger, 50 ha per *colono* in the case of Perla del Golfo. Very small extensions of private titled property (*pequeña propiedad*) are located on the western slope, and large blocks of state lands are located in the forest zone. These later lands form the core of the Special Biosphere Reserve.

Each *ejido* has a town site, an area specifically designated for habitation. In general, such town sites are also used by residents known as *avecindados*, usually family members of *ejidatarios* with no land-use rights of their own. These families may gain access to farmland held by family members in exchange for labor, a share of the harvest, or cash. In non-parceled *ejidos,* residents may also gain access to vacant land over which they acquire squatters' rights over time. In many communities, however, access to land is highly unequal. While data on the distribution of land for the Sierra as a whole are limited, evidence from specific communities highlights problems of land access found throughout the region. For example, Pajapan is a lowland zone community of approximate 9,000 people, 40% of whom are landless (Chevalier and Buckles 1995). In many of the upland zone communities, the number of landless *avecindados* is greater than the number of *ejidatarios*.

While the distribution of agricultural land is skewed, even landless households engage in some agricultural production, usually maize, for subsistence purposes. More than 95% of the households in the upland zone grow some maize (Rice, Godinez, and Erenstein, forthcoming). In the lowland zone, occupational opportunities are more diverse, making it possible for some families to meet their maize requirements through cash purchases. Nevertheless, even in this zone, an estimated 80% of the households grow some maize for subsistence purposes (Chevalier and Buckles 1995). It is important to note, however, that the degree of self-sufficiency in maize in both zones is highly variable; in Pajapan, for example, most households purchase maize for household consumption during at least four months of the year. The loss of self-sufficiency in maize production throughout the region is due in part to the decline of the traditional *milpa* system, as discussed below.

Maize-based Cropping Systems in the Sierra de Santa Marta: The Current Baseline

This section examines the historical factors that have affected the maize-based cropping systems in the Sierra de Santa Marta and provides an outline of the current maize production practices. The major problems currently affecting maize producers in the region are summarized; these are problems that will likely prevail in the near future and may worsen if no action is taken.

The decline of the traditional *milpa* system

Using slash-and-burn techniques, the indigenous population of the Sierra de Santa Marta has been growing maize for more than 4,000 years (Stuart 1978; Foster 1942; García de León 1976). It is the main crop in a diversified cropping system known as a milpa. In this system, forest land is cleared, cultivated with a wide range of crops for a few years, and abandoned to natural regrowth. A new milpa is then established on forested land, where the cycle is repeated.

Land management in the traditional *milpa* system of the Sierra de Santa Marta was circular: farmers "rested" a field when the land became "tired" and returned to it when agricultural potential had been restored under secondary vegetation. Farmers managed secondary vegetation as a future *milpa*; they noted subtle changes in soil characteristics, weed populations, and plant species—all of which were indicators of soil fertility. Secondary vegetation, known as an *acaual*, was preferred over mature forest because it required much less time to clear and was equally productive (Stuart 1978). *Milpas* were surrounded by *acauales* at various stages of regrowth and by areas of mature forest from which natural vegetative succession could occur. Thus, the traditional *milpa* system of the Sierra de Santa Marta was a forest-linked system based on the shifting of fields and the constant regeneration of forest species.

Fallow successions were complemented by a multiple cropping strategy. The traditional *milpa* of the Sierra de Santa Marta was a field of maize widely planted in rows and interseeded with 10 to 20 other crops at various times of the year (Foster 1942; Stuart 1978; Perales 1992). Most *milpas* contained climbing beans, squash, sweet potatoes, pigeon peas, sesame, yam bean, dasheen, cherry tomatoes, chiles, and other plants intercropped or volunteering among the maize plants. In addition, sugar cane, plantains, cassava, pineapple, and papaya were planted in a section or along the border of the *milpa*. While most crops other than maize were grown in very small quantities, they were important to family nutrition and presented a number of ecological advantages (Stuart 1978) .

The key to *milpa* cultivation in the Sierra de Santa Marta as elsewhere is the length of the cropping and fallow periods. Continuous cultivation of tropical soils leads to a decline in yields and an increase in weeds, the general reasons for field shifting (Weischet and Caviedes 1993). The time required to fully restore the agricultural potential exhausted by cultivation varies greatly from one area to another depending upon rainfall, plant species composition in the secondary vegetation, soil type, the period of cultivation, and farming techniques. Scientists generally hold, however, that fallow periods must exceed cropping periods if long-term soil impoverishment is to be avoided (Sánchez and Cochrane 1980; Weischet and Caviedes 1993).

In most of the lowland zone of the Sierra, two-year cropping periods (3-4 cycles) were traditionally followed by approximately eight years of fallow (Chevalier and Buckles 1995; Perales 1992). Farmers report that after rested lands are continuously cropped for 3-4 cycles, yields decline to less than 800 kg/ha and weeding time doubles. Fallowing for eight years was enough to eradicate grassy weeds and regain the agricultural potential of the land. Stuart (1978) reports that along the northern coast of the Sierra where rainfall is higher, cropping periods of 3-5 cycles were traditionally followed by a fallow period of equal duration, with no apparent negative effects on system sustainability. As Stuart reports, "No informants reported having used longer fallow periods in the past, nor do they consider fallows longer than five years to be in any way superior to present fallowing periods" (1978, p. 315). On the drier eastern slope of the Sierra (e.g., in Soteapan), traditional fallow periods were somewhat longer, perhaps as much as 10 years on average (Perales 1992).

Soil erosion caused by traditional *milpa* practices was probably quite acute on steep slopes due to the exposure of the soil after crop residues are burned. Lands with minor slopes may not have suffered significantly from soil erosion, in part because even after burning, fields were littered with large trunks which would break the force of rain runoff. Stuart (1978, p. 311) notes that the land cultivated along the northern coast of the Sierra using traditional techniques did not suffer from soil erosion or exhibit other evidence of land degradation.

Under conditions of low population density and limited alternative land uses, the traditional *milpa* system satisfied the subsistence needs of regional farmers and produced small amounts of surplus production for sale at regional markets (mainly beans and pigs fattened with surplus maize). Agriculture co-existed with the forest, and land degradation was probably limited. These conditions no longer hold, however. Beginning in the 1960s, a land-hungry cattle industry on the rise displaced farmers from traditional farming areas and converted secondary vegetation and forest into pasture. According to census data from the Secretary of Agriculture and Water Resources (SARH), the area under pasture in the three main municipalities of the Sierra (Pajapan, Mecayapan, and Soteapan) increased from 19% in 1950 to 49% in 1988, while agricultural land uses remained stagnant or declined. Meanwhile, the area under forest decreased dramatically: some 75% of the original forest was lost in 20 years (Table 1).

The conversion of secondary vegetation and forest into pasture was accompanied by a process of land concentration. Regional and local ranchers displaced farmers from the best lands in the lowland zone through the manipulation of communal land-tenure systems, coercion, land purchases, and various other forms of economic and political power. In one large community (Pajapan), some 2% of the population (ranchers) controlled more than half of the community land (Chevalier and Buckles 1995). Landless farmers were forced into the forest margin where new communities were established in more remote areas of the lowland zone and in the upland zone, thereby extending the agricultural frontier. More frequently, however, farmers were pushed out of agriculture altogether into marginal urban employment in the industrial centers of Coatzacoalcos and Minatitlán. The municipality of Pajapan experienced a net population loss during periods of rapid growth in the cattle industry due to out-migration by displaced farmers (Chevalier and Buckles 1995).

Expansion of the cattle industry displaced forests, but it also forced farmers to cultivate those areas open to agriculture more intensively, with grave implications for agricultural resources and system performance.

Table 1. Deforestation in the Sierra de Santa Marta

Year	Forest (ha)	Cumulative forest loss (%)
1967	81,170	0
1976	55,190	32
1986	21,170	74
1990	20,000	76

Source: Ramírez (1992).

In the lowland zone, fallows of only two years are now common, while in the upland zone fallow periods have been reduced to four years or less. While the relatively longer fallows in the upland zone probably result in higher levels of soil fertility, in both zones the current maize cropping system lacks many of the adaptive features of the traditional *milpa*, as discussed below.

The current maize cropping system

Maize is still the most important crop grown in the Sierra, and while other food crops may play a minor role in the cropping system, the requirements of maize set the tone for all agricultural activities (Figure 2). In the lowland zone, climatic conditions facilitate two maize seasons per year, the *temporal* or summer season and the *tapachole* or winter season. In the upland zone, summer maize is the only significant season due to the low productivity of the winter cycle (see below). Otherwise, maize cropping practices are similar for both zones.

Planted in June and harvested between November and January, the *temporal* maize crop is the main one of the year. Land preparations begin during the winter season when fallow vegetation (*acaual)* is cut down by hand with a machete and burned in the field once it has thoroughly dried. The soil is typically not tilled. Mechanized or animal traction is used by fewer than 5% of the farming population in the lowland zone and not at all in the upland zone, where steeply sloping fields prohibit this form of land preparation.

Once the field is cleared, a dibble stick is used to punch a hole in the ground into which maize seeds are placed. Since moisture is critical to

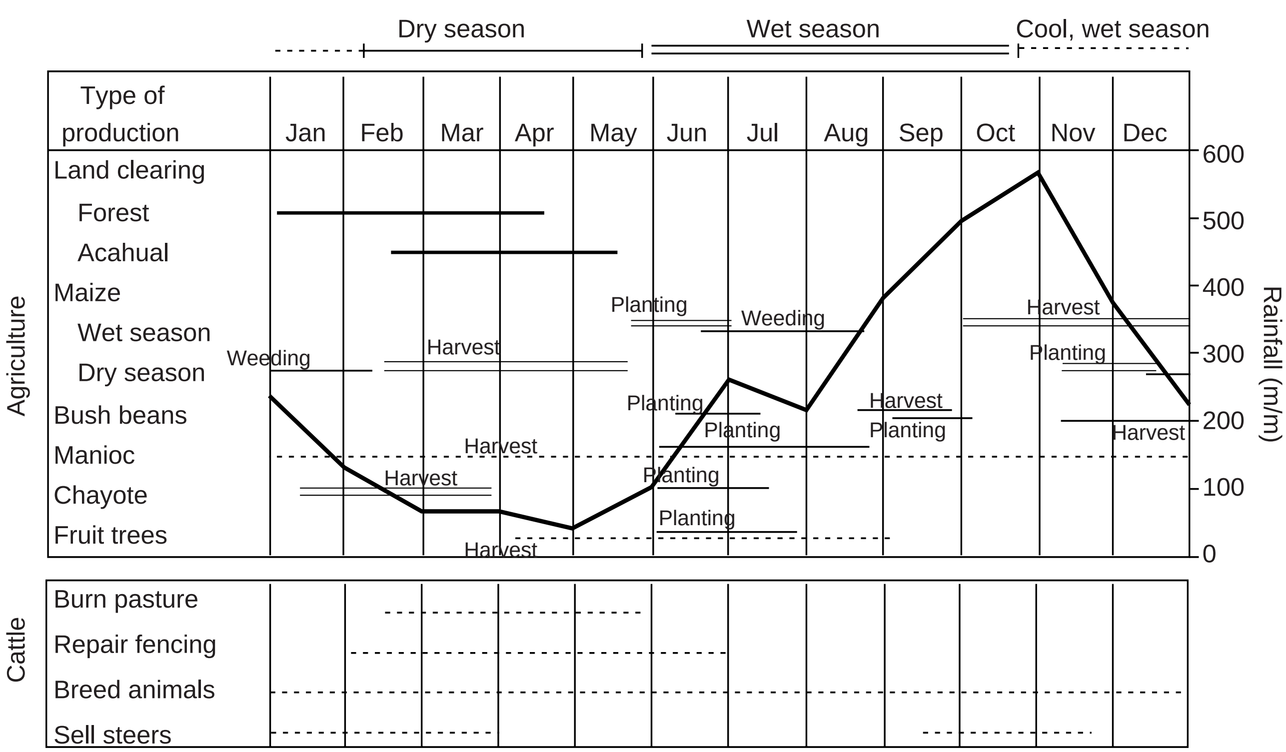

Figure 2. Production calendar for Pajapan area, Sierra de Santa Marta, Veracruz.
(Key: Solid horizontal lines indicate regular activity; broken horizontal lines irregular activity)

the germination of maize seed, most farmers plant their maize when they feel certain that the summer rains have begun in earnest, typically by early June. While premature planting can result in crop failure due to poor germination, planting too late increases the risk of damage to the crop caused by strong winds (*nortes)* late in the season.

Maize in the Sierra de Santa Marta is typically planted in rows one meter apart. Hills within rows are also a meter apart, with three to four seeds in each hill, resulting in a density of approximately 30,000 to 40,000 plants per hectare. Perales (1992) reports that farmers have replaced very tall traditional maize varieties with shorter varieties derived from the same landraces (Tuxpeno and Olotillo) to reduce the incidence of lodging caused by strong winds. Traditionally, farmers grew white, yellow, black, and red maize types. Now white maize has largely replaced other maize types in the lowland zone. Both white and yellow maize are still grown in the upland zone. Very small areas of black and red maize (Perales 1992; Blanco 1995) are still grown in both zones. Current local maize varieties require approximately 100 days to attain physiological maturity in the lowland zone and, due to lower temperatures, slightly more in the upland zone (120 days). The genetic potential of local maize varieties is generally high, although additional yield gains can be made using modern varieties under farmer conditions (Blanco, Buckles, and Perales 1994).

Being very susceptible to weed competition, maize requires relatively clear cultivation, especially during the early stages of plant development. Maize is typically weeded twice during the summer season, in early July and in August. According to a recent survey, an estimated 92% of the regional farming population currently use some herbicides to control weeds (Buckles 1995). The contact herbicide Paraquat is the most common, sprayed directly on the weeds between rows of maize; it is applied with a back-pack sprayer.[5] The main reason why farmers have turned increasingly to herbicides is that manual weeding with a machete or hoe is the most time-consuming of farming operations.

Fertilizer use in the Sierra de Santa Marta is very recent and subject to periodic fluctuations in cost and availability. Two-thirds of the farmers who reported using commercial fertilizer in 1994 began using the input less than four years earlier, typically as a result of agricultural credit programs introduced by the National Indigenous Institute (INI) and the national social program SEDESOL (Buckles 1995). Perhaps as many as 50% of the farmers in the region were using small amounts of fertilizer on their maize in the early 1990s, but by 1995 this had dropped to less than 20% due to suspension of the credit programs, increases in the price of fertilizer, and uncertainties in maize markets created by the most recent Mexican economic crisis.

Depending upon the time of planting, the first tender ears of maize can be harvested beginning in late August. Maize plants are doubled below the main ear after reaching physiological maturity and left in the field to dry thoroughly. The maize cobs are harvested piecemeal throughout the winter, even as late as March. The harvest is carried manually or by horse from the field to the home. Maize is stored on the cob, in the kitchen loft (*tapanco*), or in stacks on the house floor. Summer maize

[5] Paraquat is a highly toxic herbicide, and has caused numerous cases of toxic shock among farmers in the Sierra de Santa Marta. It is preferred by farmers over other herbicides available in the region due to its lower price.

yields currently average around 1.2 t/ha in the lowland zone and about 1 t/ha in the upland zone (Chevalier and Buckles 1995; Perales 1992; Rice, Godinez, and Erenstein, forthcoming). The relatively higher average yields in the lowland zone, despite shorter fallow periods, are due to the higher incidence of fertilizer use.

In the upland zone, the summer season *temporal* is the only significant maize season. In the lowland zone, however, periodic rainfall from November to February makes it possible to grow winter maize (*tapachole)*, provided that certain modifications are made to the cropping system. Winter maize is usually planted in November between the rows of doubled summer maize, a task eased by the presence of the earlier maize rows. Weed and crop residues from the summer season are not burned prior to planting winter maize but rather are left on the field as mulch to conserve soil moisture. Because of the relatively dry winter conditions, maize plants do not need to be doubled prior to harvest and only one weeding is required; these advantages reduce labor costs as compared to costs in the summer season. Nevertheless, the risk of crop failure due to drought stress during the later part of the season is high, and maize crops can be flattened by strong winds during the early part of the season. Birds are more problematic during this season as well. As a result of these constraints, the most important of which is drought stress, winter yields are lower than summer yields, averaging only 500 kg/ha throughout the lowland zone.

Although traditionally maize yields were also complemented by the harvest of other food crops in the *milpa,* most current fields consist primarily of maize and do not yield significant intercrops. The use of herbicides has made it more difficult to manage intercrops and volunteer food plants, and the practice has thus declined. Climbing beans traditionally interseeded in maize have been replaced by small areas of bush beans grown as sole crops in a separate part of the field. Other food crops such as plantains, cassava, and fruit trees are also absent from many farmers' fields (Perales 1992; Chevalier and Buckles 1995).

The total land area dedicated to maize production per household and the frequency of winter maize production have also been modified by increasing land pressures. Traditionally, farmers in the Sierra de Santa Marta made summer *milpas* of approximately two hectares and winter *milpas* of a hectare or so (Blom and La Farge 1926; Foster 1942; Beaz-Jorge 1973; Stuart 1978). Currently, the total maize area is smaller, and not all farmers cultivate winter maize. In the lowland zone, farmers cultivate on average only 1.3 hectares of summer maize and 0.6 hectares of winter maize (Chevalier and Buckles 1995; Perales 1992; Buckles and Arteaga 1994). Not all farmers in the lowland zone can grow winter maize due to constraints on the availability of suitable land. In the upland zone, farmers currently cultivate on average two hectares of maize, predominantly in the summer season (Rice, Godinez, and Erenstein, forthcoming). As noted above, growing winter maize in the upland zone is a high-risk activity due to strong winds and erratic rainfall.

Major constraints on maize productivity

Two main categories of problems constrain the productivity of the current maize-based cropping system in the Sierra de Santa Marta: problems associated with the degradation of fallow land and problems resulting from inadequate adjustments by farmers to new circumstances (Figure 3).

Reduced fallow periods. Increasing land use intensity and corresponding reductions in fallow periods have resulted in incomplete regeneration of the fallow vegetation essential to the recovery of agricultural potential in shifting cultivation systems. Fallow periods of two years are now common in the lowland zone, and these fallows consist entirely of grass species rather than the woody tree species, shrubs, vines, and herbaceous plants characteristic of secondary forest. Slashing and burning such grassy fallows cannot support crop production without drawing heavily on the already limited soil resources. Soils subject to frequent cultivation are consequently depleted of fertility, resulting in poor crop yields and soil chemical imbalances as some nutrients are mined from the soil. Land degradation is probably not as severe in the upland zone due to the longer fallow periods. Shorter fallow periods and the consequent elimination of tree species during this period have also contributed to the build-up of grassy weeds in many farmers' fields. Stuart (1978) reports that weeds were not considered a major problem in the traditional *milpa* system. By contrast, weed control in maize currently represents the single most important cost of production throughout the lowland zone (see economic analysis below). Chemical weed control has increased in recent years, but farmers have not yet developed sufficient knowledge of safe management practices. Paraquat, the most commonly used herbicide in the Sierra, is a highly toxic chemical that in recent years has reportedly caused several deaths from toxic poisoning and numerous cases of toxic shock due to improper handling. The practice of washing back-pack sprayers in streams and rivers may also have affected aquatic life.

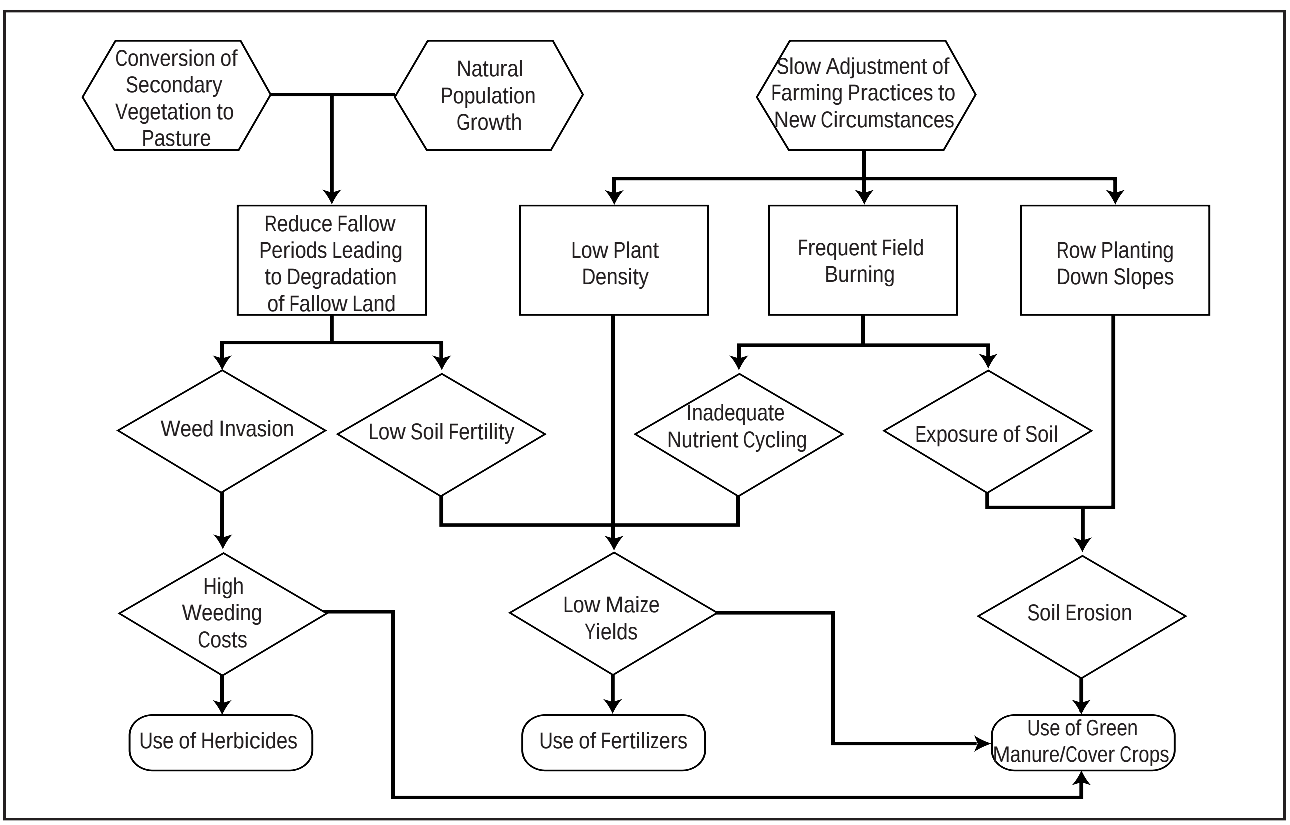

Figure 3. Hypotheses on maize problems and causes, Sierra de Santa Marta, Veracruz.
(Key: problems are indicated by rectangles; causes by hexagons; outcomes by diamonds; and adaptations to outcomes by ovals)

Frequent field burning. As noted above, slashed secondary vegetation and crop residues were burned in the traditional system to clear the field for planting, kill weed seeds, reduce the incidence of maize diseases (e.g., black spot, *chahuistle*) and pests such as rats, and convert vegetation into ash available for cultivated crops. While this strategy is well adapted to the management of mature fallows, it is much less effective in systems where fallow periods are too short for significant regrowth. Fallow fields throughout the Sierra are no longer composed of large trees, vines, and herbaceous growth but rather grasses and small shrubs that present few obstacles to planting. Burning these residues leaves the soil almost bare, which in turn increases the risk of soil erosion during the heavy rains early in the season. Furthermore, the use of fire to manage short fallows breaks the plant-to-plant recycling process characteristic of traditional shifting cultivation systems; only very little ash is left on the field to nourish maize plants after annual weed and crop residues are burned. Finally, the loss of soil organic matter may also reduce the moisture-holding capacity of the soil, with negative impacts on the potential of land to support winter maize production (not included in Figure 3). In short, under prevailing fallow practices, burning provides few benefits and imposes new costs on the cropping system.

Row planting down slopes. Planting maize in rows up and down the slope facilitated the manual weeding with a hoe of steep hillsides in the traditional system. However, the practice also favors soil erosion, especially in the current situation where runoff is relatively unimpeded by the intercrops, tree trunks, and roots that littered traditional *milpa* sites. While no formal studies of soil erosion have been conducted, field observations suggest that both sheet and channel erosion have been severe; the causes include inappropriate planting arrangements, hand weeding in rows, and burning of crop residues (Tasistro 1994; Chevalier and Buckles 1995; Perales 1992; Gutiérrez 1995).

Low plant density. As noted above, maize plants were widely spaced in the traditional system to accommodate intercrops and very tall maize varieties. Low plant densities have been retained, however, despite the dramatic reduction in intercropping and a tendency for local varieties to be shorter. This practice limits the maize yield potential per unit of land and leaves the soil relatively unprotected from erosive rainfall. While low soil fertility and limited use of commercial fertilizers may partly explain farmer reluctance to increase plant densities, preliminary adaptive research suggests that such increases would improve maize productivity, at least in the more fertile soils (Blanco, Buckles, and Perales 1994).

The reduction of fallow periods resulting in low soil fertility and weed invasion is the most important problem currently constraining maize productivity in the Sierra de Santa Marta. Longer-term problems of sustainability in the *milpa* system include frequent field burning and row planting down sloping land—traditional practices which have become inappropriate under the current circumstances. Low plant density also constrains the productivity of the maize system. Other problems such as inefficient use of commercial fertilizers, reduced biological control of pests in monocropped maize, and inadequate post-harvest maize storage (not discussed) are also present in the region, although such problems are of lesser overall importance.

Alternative Strategies for Intensifying Maize-Based Cropping Systems

Effective responses to major constraints on maize productivity have been developed by regional farmers and adapted to more intensive conditions through participatory research by farmers and scientists, as reported below. The negative effects of reduced fallows on soil fertility and weed populations can be compensated for, in part, through the use of cover crops and moderate amounts of external inputs (fertilizer and herbicide). Further farmer adjustment to new farming conditions can be accelerated by improved farmer access to appropriate information regarding technological options and local adaptive research, extension, and incentive schemes. Soil conservation techniques involving the use of contoured hedgerows, contour planting of maize, and the conservation of crop residues are among the most promising means of reducing erosion in the current system and enhancing the sustainability of maize production. Adaptive research and extension focused on optimal maize planting densities and the improvement and management of local maize varieties may also help mitigate current problems and enhance the productivity and sustainability of the system. This section describes these technological options and assesses their productivity and sustainability impacts in qualitative terms. The subsequent section estimates the farm-level costs and benefits associated with the adoption of these alternative practices.

Cover crops

The advantages of using cover crops in tropical agriculture have been widely recognized and documented (Giller and Wilson 1991; Wade and Sánchez 1983). These crops, grown in association with food crops, can be efficient sources of N, improve soil physical and chemical properties, control pests and weeds, and reduce erosion. Cover crops can also supply food, feed, and fuel. Since the 1950s, a few farmers in the Sierra de Santa Marta have been using *Mucuna* spp. (aggressive, leafy legumes) in their maize fields to improve soil fertility and eradicate weeds (Buckles and Perales 1995). Farmers in San Pedro Soteapan, the cultural center of the Sierra Popoluca, have indicated that they encountered velvetbean growing wild in their fields and noted its ability to smother weeds and improve maize yields. They collected seed and broadcast it over a larger area, giving rise to a practice known as "making a fallow field" (*hacer acaual*). According to experienced farmers, weeds are eliminated by the aggressive velvetbean crop, and soil fertility is regained. In the neighboring *ejido* of Mecayapan, farmers plant velvetbean at the end of the dry season in winter maize fields and allow it to develop as a sole crop throughout the summer season. The abundant velvetbean growth, known locally as a *picapical*, is slashed in November, and winter maize is planted into the mat of decomposing leaves and vines, where it develops relatively free of competition from weeds.

On-farm research with velvetbean during the early 1990s resulted in the development of more intensive management strategies in summer and winter maize. These strategies have the potential to improve maize productivity and slow the decline of soil fertility (Buckles and Perales 1995). The research determined that farmers are willing to plant mucuna into summer maize 40-60 days after the maize with a view to improving soil fertility and controlling weeds. While no long-term data on the soil fertility implications of this practice have been collected for the Sierra de Santa Marta, evidence from similar locations suggests that fertilizer substitution rates in maize of 60-80 kg N/ha following a mucuna relay crop can be attained (Lobo Burle et al. 1992; Moscoso and Raun 1991). In addition, the effects of weed control are probably significant. Qualitative observations from the Sierra de Santa Marta suggest that weed populations are reduced by two thirds in fields managed with mucuna relay crops compared to current farmer management (Buckles and Perales 1995). These effects are undoubtedly quite variable, however, and rely entirely on the conservation of the residues left by the cover crop, an issue discussed below in relation to regional burning practices.

The impact on erosion of planting a mucuna relay crop in summer maize has not been determined for the Sierra de Santa Marta, but experiments under similar conditions in Chiapas suggest that soil loss is reduced from 50 t/ha/yr under traditional management to 4 t/ha/yr with a mucuna relay crop (López 1993, p. 86). The impact of reduced erosion on the productivity of the maize cropping system is unknown, but given that soils in the Sierra de Santa Marta are a limited resource highly susceptible to erosion, this benefit can be assumed to contribute to the long-term sustainability of maize production.

The direct costs associated with mucuna relay crops are minimal. Fields are weeded normally before planting the cover crop, and 2-4 seeds are planted every meter or so using the maize rows as guideposts. Depending upon the timing of mucuna planting, maize harvesting may be encumbered by the abundant growth of vines, and volunteer plants may need to be controlled to avoid competition with maize. An aggressive cover crop such as mucuna is incompatible with food intercrops and consequently imposes a significant opportunity cost in areas where beans and other intercrops are planted in association with maize. Nevertheless, in monocropped maize systems now common in the Sierra de Santa Marta, these indirect costs are not encountered.

Mucuna is not the only legume suitable for use as a cover crop in the Sierra de Santa Marta. *Canavalia ensiformis* is also well adapted to the regional agroecology and has been used successfully as a cover crop by regional farmers. The management of this crop is similar to that of mucuna, although it can be intercropped in summer maize earlier, thereby providing additional erosion-control benefits. Similar fertilizer substitution rates and weed control effects have also been reported for canavalia (Barreto 1994). Other legumes such as *"arnica"* (*Tithonia* sp.), pigeon pea (*Cajanus cajan*) and *"chipilín"* (*Crotalaria* sp.), all of which are known in the region, have also been used by farmers as cover crops or improved fallows with positive results. There is, however, a need to evaluate other species of legumes as cover crops, especially for use in the cooler climate of the upland zone.

While the cover crop management practices outlined above can help intensify maize systems and improve their productivity, various factors affect their potential impact and adoptability (Buckles and Barreto 1996; Buckles and Perales 1995; Soule 1995). First, the magnitude of cover crop impacts on maize productivity varies considerably from field to field, especially during the first few years of use. This is largely the result of variations in the quantity of biomass produced by the crop during a growing season. Empirical evidence from various sites suggests that a minimum of 2-3 t/ha of dry matter is needed for cover crops to significantly improve maize productivity (Buckles and Barreto 1995; Lobo Burle et al. 1992). In the Sierra de Santa Marta, mucuna does not grow vigorously in the first year on all fields; more commonly mucuna growth does not reach this minimum during the first year or two. Qualitative evaluation suggests, however, that even these relatively poor fields can produce more than 3 t/ha of mucuna dry matter after two or three years of continuous management as a relay crop in summer maize. Initial nodulation problems, the degraded condition of many maize fields in the Sierra de Santa Marta and the positive incremental impacts on soil conditions of continuous mucuna use may explain this initial variability and improvement over time. One implication is that two to three years of continuous mucuna relay cropping in summer maize may be needed before significant benefits are realized on most fields. This feature of the technology, in turn, has implications for farmer planning horizons and the use of incentives, issues discussed below.

Second, the delayed impact of cover crops on maize productivity means that only farmers with secure access to land can be expected to adopt the technology. Uncertain access to land in *ejidos* that are dividing collective lands into individual parcels has proven to be a significant barrier to the adoption of cover crops and hedgerow practices in these communities.

Third, farmers must have access to seed and accurate information on the use of cover crops. Preliminary extension efforts with velvetbean in the Sierra described below indicate that local knowledge of this practice can be accelerated by supporting farmer-to-farmer communication and adaptive research (Buckles, Pare, and Arteaga 1995).

Commercial fertilizers

Empirical evidence to date suggests that while cover crops can improve soil fertility and reduce weed populations, they cannot on their own solve problems of low soil productivity. The use of plant nutrients available or generated on the farm by cover crops in tandem with moderate amounts of externally derived nutrients (e.g., commercial fertilizer) may be the most appropriate approach to soil productivity constraints when fertilizers are costly and the impact of cover crops relatively slow.

While experimental evidence of maize response to commercial fertilizers in the Sierra de Santa Marta is limited, most maize fields would probably benefit from the application of commercial fertilizers at rates higher than those currently used. Improved methods of fertilizer application may also improve the efficiency of fertilizer use. Empirical evidence suggests that the application of 75 kg/ha of di-ammonium phosphate (18-46-00) at maize planting, and 100 kg/ha of urea (46-00-00) 30 days after planting, both buried at the base of the maize plant, could improve maize yields over non-fertilized fields by 700 kg/ha, (i.e., over 50% of average maize yields) (see Buckles and Perales 1995; Bello 1994; Tasistro 1994). This is a dramatic response to a single input and a clear indicator of the degree to which low soil fertility constrains maize productivity. In the upland zone, where fertilizer use is still virtually absent, the above rates seem adequate. However, in the relatively more degraded lowland zone, with a longer (though still recent) use of fertilizer, higher rates may be needed to give an initial boost to productivity. Although fertilizer application efficiency can be raised by burying the fertilizer,[6] this is a rather laborious process and may not be directly adopted by farmers in the region. A lower response to fertilizer than the experimentally measured response thus seems likely.

[6] Especially some of the N-fertilizers such as urea and ammonium sulfate, which can lose substantial amounts of nutrient through NH_3 volatilization.

The relatively high initial level of commercial fertilizer needed to boost productivity may be reduced after several years of cover crop use and the application of other soil conservation practices. However, some fertilizer input (especially P) may remain a necessity for some time to ameliorate severe soil fertility problems. Land degradation in the Sierra de Santa Marta has progressed to such a degree that recovery of historic levels of soil fertility may not be possible.

Conservation of crop residues

The conservation of crop residues as "dead mulch"[7] in the field has a number of advantages, including soil conservation, water conservation, and weed control. A soil conservation effect is achieved through the presence of the mulch as a protective layer that reduces the erosive impact of the rain. In addition, the mulch reduces erosion by slowing runoff with new physical barriers and by improving the soil's physical structure (and thereby increasing water infiltration). Both these features are of special relevance in a region where tropical rain storms are common and steep slopes are cultivated.[8] The water conservation effect is mainly a result of reduced water losses (less runoff, more infiltration, less evaporation) resulting in more available soil moisture, which can reduce the productive losses during dry spells, especially during the *tapachole* season. The weed-control effect is mainly a result of inhibiting weed emergence.

To achieve these beneficial effects, farmers must maintain sufficient residue[9] to form a mulch layer. In the study area, such benefits are often undermined by the burning that occurs during land preparation for the *temporal* season. This practice tends to reduce all residue to ashes and to leave fields entirely bare and extremely susceptible to erosion. The practice also eliminates the residues of cover crops, annulling their benefits as well. To realize the benefits of conserving crop residues, farmers should also limit soil movement during weeding, especially on steeper fields. To achieve an adequate weed-control effect without substantially increasing labor costs, farmers can make limited use of herbicides.

Again, no long-term data on the impact of this practice have been collected for the Sierra de Santa Marta, but evidence from experiments under similar conditions elsewhere suggests that the impact can be substantial. On a 65% slope in a similar region in Chiapas, for example, soil erosion was reduced from 50 t/ha/yr under traditional management to 4.6 t/ha/yr with conservation of crop residues (López 1993, p. 92). On a 15% slope in a similar region in Nigeria, soil erosion was reduced from 13.4 t/ha/yr under traditional management to 0.1 t/ha/yr with conservation of crop residues (Lal 1976, as cited by Tasistro 1994, p. 90). Reduced erosion and other benefits translate into substantially higher yields in the mid- to long term. Data from other similar conditions in Nigeria also suggest a 1 ton yield differential (amounting to a 30% yield increase) in favor of conserving crop residues from the third to fifth year of continuous use (Ezumah 1983, as cited by Tasistro 1994, p. 96).

7 In contrast to the term "living mulch" used to describe cover crops.

8 The soil conservation effect of the dead mulch is generally complementary to that of the living mulch, as the dead mulch is most effective at the on-set of the rainy season when the living mulch is still absent or still in the process of establishment.

9 Of crops, weeds, or other vegetative material.

In the Sierra de Santa Marta, direct costs associated with residue conservation are mainly related to the use of herbicides, which present direct cash costs,[10] an important consideration in a subsistence-oriented agricultural system. However, herbicides allow for major labor savings so that the actual costs are far from prohibitive, as is illustrated by their already widespread adoption. Another cost is the slightly increased labor demand for sowing because the residues make manual sowing a little more cumbersome.

A potentially prohibitive cost is related to alternative uses of the crop residue, especially as animal fodder. However, in the study area, alternative (and better) fodder sources are abundant, and the use of maize stover as a fodder source is limited. Consequently, crop-livestock interactions do not represent a significant constraint on the conservation of crop residues.

While the conservation of residues can help intensify maize systems and improve their productivity, various factors lower their potential impact and adoptability. A major issue is the reliance on herbicides to achieve adequate weed control. Although herbicides are already relatively widespread in the lowland zone, their use in the upland zone is still relatively limited. Furthermore, although some farmers may have used herbicides for the last few years, knowledge of the basic properties of the products and application requirements is generally limited (Tasistro 1994). Farmers in the region still need training, especially on health and safety issues (including issues related to environmental safety, such as the cleaning of back-pack sprayers in streams). Such training will increase the cost of widespread and safe adoption of the technology.

Another major issue concerns burning as a field-preparation measure for the *temporal* season.[11] Farmers burn for a variety of reasons, and although not all of these are applicable in the current systems (see Tasistro 1994), the practice is deep-rooted and difficult, albeit not impossible, to change. An additional problem is that, even when farmers are motivated to conserve crop residues, others may accidentally burn those residues. Thus, unless and until everyone adopts no-burning practices, the danger remains that fires will accidentally spread from other fields or even other regions.[12] On the positive side, however, the conservation of crop residues will potentially be facilitated by the adoption of other complementary activities, such as the use of cover crops and hedgerows.

Contoured hedgerows and maize rows

While the conservation of crop residues is an effective means of reducing soil erosion and enhancing nutrient cycling, the amount of crop residues left on the field may provide insufficient cover under conditions of low maize productivity. An additional soil conservation technique adapted to field conditions in the Sierra de Santa Marta is the use of leguminous trees and grasses as contoured living hedgerows and the contour planting of maize crops. Over time, these practices facilitate the gradual formation of terraces.

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10 Both of a recurrent (herbicides) as well as an investment (back-pack sprayer) nature.

11 Interestingly enough, all farmers who grow maize in the tapachole season already conserve their crop residues, albeit frequently as “standing” mulch. This is, however, mainly related to the necessary overlap between the two seasons: the *temporal* crop cannot yet be harvested when the *tapachole* crop needs to be established.

12 Occasionally fires travel large distances, especially towards the end of the dry season. Burning is a relatively common practice in livestock areas to regenerate pasture, and in 1994, for example, pasture fires in the lowlands reached up to the Soteapan *ejido* in the lowland zone.

Contoured hedgerows, an agroforestry practice known in various parts of the world, were adapted to the neighboring Sierra de Los Tuxtlas, Veracruz, by Mexico's national agricultural research system (INIFAP) (Zúñiga et al. 1993). The technology involves the establishment of contoured hedgerows using *Gliricidia sepium*, a leguminous tree native to the region. Contour guidelines are traced on the field at distances determined by the slope of the land (on steeper land, the contour lines are closer together; on flatter land, they are farther apart). A small furrow is made on the contoured line into which gliricidia seeds are placed and covered. Once the crop germinates, phosphate fertilizer is applied to the hedgerow, and it is weeded once or twice during the first season. In subsequent seasons, crop residues are used to reinforce the base of the hedgerow while the hedgerow itself is pruned twice a year to 30-40 cm so that it does not shade field crops. Replanting to fill gaps in the hedgerows may also be required in the second year. In all, some 22 person days per hectare are required to establish the hedgerows, and 5 person days per hectare are needed for annual maintenance (Zúñiga et al. 1993).

The main conservation benefit of contoured hedgerows is their potential to reduce soil erosion. The velocity of rain runoff down field slopes is greatly diminished by contoured hedges at periodic intervals, an effect that in turn reduces the extent of sheet erosion. Under experimental conditions, soil losses have been reduced with hedgerows compared to farmer practices in the Sierra de Los Tuxtlas (Oropez, Ríos, and Nicolás 1994).

Another potential benefit associated with the establishment of contoured hedgerows is the potential modification of farmer land-preparation and maize-planting practices. As noted above, farmers in the Sierra de Santa Marta burn crop residues prior to planting maize in rows up and down the slope of fields, practices that under current circumstances increase soil erosion. Nevertheless, while some farmers with contoured hedgerows already avoid burning crop residues (because burning may damage the hedgerow) and plant their maize in contours by using the hedgerow as a guide, most farmers experimenting with hedgerows have not modified these features of their farming practice. Further farmer experience will reveal whether adoption of these additional practices can be expected.

While gliricidia has proven to be an effective material for the establishment of hedgerows, the plant provides no direct economic benefit. As a result, adaptive research with other hedgerow materials has been initiated in the region by the PSSM to identify potential dual-purpose hedgerow species (i.e., soil conservation and crop production) that could significantly increase the profitability of the practice.[13]

Recent extension efforts with contoured hedgerows using gliricidia in the Sierra de Santa Marta suggest that the technology is of interest to regional farmers (Buckles, Pare, and Arteaga 1995). However, various factors affect the potential of the technology. First, farmers must have access to gliricidia seed and the technical assistance needed to establish the crop (notably the contours). Although the seed is available locally, it must be collected and transported in relatively large quantities. Farmer promoters trained by the PSSM demonstrated their ability to provide technical assistance during the 1994 summer season when contoured hedgerows

[13] The PSSM is currently assessing lemon grass (*Cymbopogon citratus*) for use as a hedgerow material; lemon grass is currently grown on house compounds in the region for use as tea. The stem of the grass is an ingredient in Thai cuisine popular in the United States, where commercial opportunities are being explored by the PSSM.

were established on more than 300 hectares of farmland in the context of an inter-institutional extension campaign described below.

Second, the erosion-control benefits of hedgerows are not immediate. Preliminary evidence from the Sierra de Los Tuxtlas suggests that the erosion-control benefits of the hedgerows are generally not realized until after two years. This gap between short-term costs and longer-term benefits is an important feature of contoured hedgerows, with implications for farmer planning horizons and estimates of the costs of adoption presented below.

Increased maize planting density

As noted, low maize planting densities currently limit the productivity per unit of land for maize-based cropping systems in the Sierra de Santa Marta. Alternative maize planting densities cannot be determined at this time, however, in the absence of further adaptive research on the interaction of planting density with maize variety and varying levels of soil fertility. Increased plant density would require maize varieties of an appropriate height so as to minimize competition for light under higher densities. Also, the potential of higher plant densities would depend upon the medium-term impacts on soil fertility of other technologies such as cover crops and contoured hedgerows.

Other considerations

The technological options described above apply broadly speaking to both the lowland and the upland zones. Environmental factors may constrain the performance of both cover crops and contoured hedgerows in the upland zone, at least with the proposed plant species. Cooler temperatures in the upland zone seem to slow the growth of mucuna, which attained about two thirds of the biomass achieved in the lowland zone.[14] Gliricidia hedgerows were also about two thirds as high in the upland zone after one season of growth as compared to hedgerows in the lowland zone. For these reasons, impacts of the two technologies in the upland zone can be expected to be delayed further than in the lowland case, and impacts may be less pronounced over the long term. The following economic analysis takes these differences into account. If production constraints continue, the cover crop and contoured hedgerow systems currently proposed would need to be modified through research with other plant species and possibly management practices as well.

The Economics of Intensification

The previous section outlined alternative strategies for intensifying maize-based cropping systems with special reference to their productivity and sustainability impacts in qualitative terms. This section will elaborate on these impacts in economic terms. First, however, a few observations are in order.

The present study is not based on a comprehensive survey of the area. Therefore, the various estimates of input and output levels as well as farm resource endowments are only indicative. Nonetheless, these values are estimated with reference to extensive field work in the area over several years and consequently can be considered reasonably precise and reliable for the purpose of this study.

The subsequent analysis examines the economic effects of intensification on a *model* farm in each of the two zones. The term *model* is used here in the sense of typical and representative and

[14] In some very high communities (e.g. the *ejido* Santa Marta), mucuna did not grow well at all.

consequently, as with any typology of reality, some farms in each zone will approximate this typology better than others. Furthermore, the typology emphasizes some of the differences between the two zones both in terms of technology use (e.g., fertilizer and herbicide use) and resource endowments.

In conventional agricultural economics, benefits and costs are usually expressed on an area basis. However, in extensive land use systems, land is not the *most* limiting factor. In fact, the forces that made such land use systems extensive are generally directly related to the scarcity of other production factors such as capital and labor.[15] Consequently, looking at intensification *solely* on an area basis is inadequate, and a systems perspective that takes into account the various factors of production seems more appropriate. In the following, we will therefore first assess the implications of intensification at the field level (i.e., for a specific unit area in the model farm in the *with* and *without* situation). The field-level data are subsequently used as input to assess the farm-level implications (i.e., for the entire model farm in the *with* and *without* situation).

In addition, the entire analysis is based on a number of assumptions, the most important of which are that the analysis:

- *Limits itself to the farm level.* As a result, financial on-farm prices are used in the calculations, and off-farm effects (externalities) are excluded.
- *Assumes that maize production remains subsistence oriented over time.* It is assumed that the main objective of maize production is to safeguard subsistence needs. Area and input use on the model farm are geared to achieve this objective, not to produce a marketable surplus. As a result, intensification can be expected to decrease the maize area required to meet these needs. This response to intensification reflects factors that dissuade farmers from producing a marketable surplus, factors such as the limited (even negative) financial returns to maize cultivation (see below), weak marketing channels, and restricted availability of labor and capital.
- *Implicitly assumes a negligible opportunity cost of land.* In a remote extensive land use system, the opportunity cost of land is very low. Consequently the analysis does not deduct the cost of land from the various economic indicators, but rather calculates the returns to the specific factors of production, including land. Furthermore, the current analysis attaches no specific value to the land freed by intensification of the maize production system. Intensification theoretically frees land for more maize area, diversification into other agricultural land uses, or conversion to secondary forest. The economic benefits derived from these alternative uses have not been included in this analysis, but would make the *with* case potentially more attractive.[16]

[15] It can be argued that the breakdown of extensive slash-and-burn systems is directly related to a reduction in the availability of land, an effect that would seem to suggest that land is the most limiting factor. However, such an argument ignores the simultaneous constraints imposed by the other factors of production, or implicitly assumes that the levels of these other factors are fixed. We argue that it is within the limitations imposed by labor and capital constraints that land may eventually become limiting in extensive systems. The breakdown arises from the reduction of fallow periods and the lengthening of cultivated periods *without* an adequate adjustment of the existing ("traditional") practices to the new circumstances, adjustments that would simultaneously ease the land constraint, at least in the near term.

- *Assumes a 15% discount rate*. All cost and benefits are discounted[17] at this rate to bring them to their present value. It is assumed that this rate adequately reflects the time preference of the farmer. However, as this rate is difficult to estimate empirically, the analysis also includes the sensitivity of the outcomes to changes in the discount rate.

The analysis follows the accounting convention proposed by Gittinger (1982, p. 95) (i.e., that each transaction occurs at the end of each year). In addition, this convention reserves Year 1 for initial investments. As a result, Year 2 is the first accounting period in which increases in operating cost and incremental benefits occur.[18] Due to the differences between the upland and lowland zone, results are presented separately for each.

Upland Zone: Field-level implications

Cropping pattern. It is assumed that in the actual situation (the *without* case) the model farmer cultivates a plot for three consecutive years. Afterwards, the respective plot is fallowed for six years before being cleared and cultivated again. As a result, the entire cycle amounts to nine years, resulting in a land use intensity (LUI) of only 33%.

The previous section has already presented a combination of technologies which would allow for a sustainable intensification of the current system in the upland zone. It is assumed that under this combination (the *with* case), fallow periods can be drastically reduced to only one year due to the combined use of fertility increasing technologies (cover crops and commercial fertilizer) as well as a better conservation of the available fertility (cover crops, conservation tillage, and contoured hedgerows). If we assume that the cultivation period will remain three years, the entire cycle amounts to four years, resulting in a land use intensity of 75%. This apparently drastic intensification is also facilitated by the fact that the upland zone allows for only one maize crop a year (i.e., the fields are actually resting for more than half of the time even during the three years of cultivation).[19] This inter-season fallow allows fields to regenerate to a certain degree, especially in the *with* case under a cover crop.

Crop budget. The *without* case crop budget[20] confirms the low profitability of the current maize production systems. In the absence of external inputs, yields are low and decline rapidly over the three-year cultivation period, from a high of 1.25 ton per ha to a low of 0.8. Labor use per unit area is relatively constant, amounting to 76-80 labor days per ha cultivated. The relatively constant labor needs are the result of two forces that largely offset each other over time: weed problems increase the demand for weeding; declining yields decrease the demand for harvesting and processing. However, although labor needs remain relatively constant, labor productivity declines rapidly over the cultivation period: from a high of nearly 16 kg of maize per labor

[16] The potential benefits derived from agricultural diversification will be examined in another study in the collaborative GEF/PSSM/CIMMYT effort to estimate the incremental cost of conservation. Including them here would result in double-counting for the overall study.

[17] Discounting is used to take into account the differences in terms of timing between the cost and the benefits streams.

[18] As a result, the first year is the same for the *with* and *without* case, with the exception of initial investments in the *with* case.

[19] Although this interseason fallow includes a pronounced dry period (March-April), soil moisture in the other months is sufficient to allow for continued weed growth and biological activity.

[20] Tables A-2 and A-3 present detailed crop budgets for the *without* and *with* case in the upland zone.

day in the first year of cultivation to a low of about 10 kg per labor day in the third and last year of use. Valuing labor at its opportunity cost (assumed equal to the local wage rate of a day laborer) generates a negative net benefit (or return to land) in each year. As a result, the return to a labor day (and land) does not surpass the assumed opportunity cost of US$ 2.5, and furthermore drops from US$ 2.4 to 1.3 per labor day over the three years. Maize production in the current system is relatively uncompetitive with imported maize, as production costs amount to US$ 170 per ton in the first year of cultivation and spiral up to US$ 250 per ton in the third. However, when one considers farmers' subsistence orientation and limited alternative sources of income, maize production remains of vital importance to farm households.

The *with* case crop budget provides a more favorable outlook, although overall profitability remains low. With the combination of limited external inputs and vegetative conservation measures, yields are raised and eventually maintained at about 2.2 tons per ha. Labor use per unit area is increased substantially, especially in the first year of cultivation (Year 2), but eventually oscillates around 100-105 labor days per ha cultivated. As a result, labor productivity increases from an initial low of 14 kg per labor day to stabilize around 21-22 kg per labor day from the fourth year. Valuing labor at its opportunity cost generates a positive net benefit (or return to land) only after the sixth year. As a result, the return to labor day (and land) hovers below the assumed opportunity cost of US$ 2.5 in the first five years (the first and fifth year are fallow), with a low of US$ 1.2 per day in the second year and climbing to about US$ 2.5 per day in the fourth. In the sixth and subsequent non-fallow years, the return to labor oscillates between US$ 2.6 and 2.8 per labor day. Maize production in the proposed system becomes gradually more competitive with imported maize, as production costs decrease from US$ 230 per ton in the first year of cultivation to US$ 130 per ton in the later years.

Upland Zone: Farm-level implications

The field-level implications seem to suggest that intensification could make maize production a little more attractive, at least in the mid-term on a unit area basis. However, as stated, land is relatively abundant in extensive systems and an 'extensive' land use system may be entirely rational in view of limited resources (including labor) and a subsistence orientation. To make the comparison more realistic, we therefore need to consider the farm-level implications of intensification.

Land use. Figure 4 conceptualizes the land-use implications of the actual and proposed cropping patterns for the "model" farm in the upland zone.[21] It is assumed that in the actual situation (the *without* case), the farmer cultivates a plot for three consecutive years and subsequently shifts his productive activities to a new plot. As a result, although the farmer only cultivates one plot, he needs two similarly sized plots resting at any given time. We assume 2 ha of maize are cultivated annually on the model farm, an amount which, on average, barely covers subsistence needs. The entire system would thus require 6 ha of cultivable land per household.

It is assumed that in the improved situation (the *with* case) the model farmer adopts the new system progressively on his lands, thereby rotating the portion left fallow over his fields. Such a gradual implementation is preferable

[21] In view of the accounting convention adopted, the first year is similar for both the *with* and *without* case.

for farmers as it would satisfy both their annual consumption and fallowing needs, and simultaneously smooth the labor peaks. For various reasons, the comparison begins with a new cropping cycle (in Year 2).[22] Nevertheless, changes in the starting stage are not expected to result in major changes in the overall outcome of the analysis.[23] Furthermore we assume that under the improved situation annual maize area will be reduced to 1.5 ha from the original 2 ha per household (as production

ACTUAL (*without* case)

Year	Season	Field A	B	C
1	Temp	F	F	3
2	“	1	F	F
3	“	2	F	F
4	“	3	F	F
5	“	F	1	F
6	“	F	2	F
7	“	F	3	F
8	“	F	F	1
9	“	F	F	2
10	“	F	F	3

Where: n Maize (actual)
F Fallow (actual)
▭ Cropping cycle

At equilibrium at any given time:

Plots in production	1 plot(s)
Plots fallowed	2 “
Plot area	2 ha
Annual maize area	2 ha
Annual system area	6 “
Duration use	3 years
Duration fallow	6 “
Cycle length	9 “
LUI Annual	33.3%

PROPOSED (*with* case)

Year	Season	Field A1	A2	A3	A4	C
1	Temp	F	F	F	F	3
2	“	1	F	1	1	
3	“	2	1	F		
4	“	3	2	1a	F	
5	“	Fi	3	2a	1a	
6	“	1	Fi	3	2a	
7	“	2	1	Fi	3	
8	“	3	2	1	Fi	
9	“	Fi	3	2	1	
10	“	1	Fi	3	2	

Where: n Maize (improved) a Adjusted
n Maize (actual)
Fi Fallow (improved) ▭ Cropping cycle
F Fallow (actual)

At equilibrium at any given time:

(Sub)Plots in production	3	plot(s)
(Sub)Plots fallowed	1	“
(Sub)Plot area	0.5	ha
Annual maize area	1.5	ha
Annual system area	2	“
Duration use	3	years
Duration fallow	1	“
Cycle length	4	“
LUI Annual		75.0%

Note: Field A divided in 4 sub-plots; fields B+C (2 ha each) available for other purposes (C after year 1). Adjusted reflects lower yields due to reduced fallow period.

Figure 4. Observed and proposed cropping patterns for the model farm in the buffer zone, Sierra de Santa Marta, Veracruz.

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[22] A major reason is simplicity. Including additional starting points complicates the analysis and presentation with limited added precision. In addition, coefficients in the initial years of the *with* case are based on implementation in a rested field. Implementation in used fields would require scaling down the relevant coefficients. Another reason is realism. For an adequate comparison between the two systems over time, both should start at a similar reference point (first year after fallow). This is especially true in the upland zone where yields and benefits drop substantially over the 3-year cultivation period.

[23] This is mainly because a different starting stage would only affect the initial years. In subsequent years the equilibrium situation would prevail anyway whatever the starting stage. Even so, the expected difference in the initial years will be limited because: the effect partly cancels out during the transition years because part of the area is still under the observed system anyway; a different starting stage would require the scaling down of technical coefficients, so that the net effect will probably be marginal.

will still be largely subsistence oriented, whereas productivity is higher). As still 25% of the area would remain fallow, the improved system would require 2 ha of cultivable land per household, a substantial reduction from the original 6 ha. The land freed from maize production (4 ha per farm household in the upland zone) could become available for agricultural diversification and/or conversion to secondary forest, thereby reducing the pressure of the maize cropping system on the forest margins.

Economic implications.[24] Going from the field to the farm level naturally does not make the economics of maize cultivation in either the *with* or *without* case more attractive. However, expanding to the farm level does allow for a more adequate assessment of the implications of adopting the *with* case on the model farm and of the relative savings or additional costs this would imply.

To assess the economic farm-level implications, we have estimated the annual costs and benefits in relation to maize cultivation at the farm level over the time period considered (equal to the cycle length of the actual system) for both the *with* and *without* case. These have subsequently been discounted at a 15% rate.

Most interestingly, adoption of the *with* case does not substantially alter the labor demand at the farm level. In fact, over the period considered, the *with* case would generate a net savings of some 20 days. Although labor demand per unit area is substantially higher for the *with* case, this is fully offset by the smaller productive area. In addition, the *with* case alleviates the labor bottleneck in the busy months of May-July.[25]

Farm production levels are not hampered by the reduction in cropped area, as this is offset by the substantially higher yield levels. In fact, the *with* case only runs a relative deficit (compared to the *without* case) in the second year, whereas in the subsequent years the gap widens in favor of the *with* case to eventually oscillate between an additional 750 and 1,700 kg annually. Over the entire period, the *with* case produces an additional 8 tons of maize per farm, averaging 800 kg annually. This relative surplus would ensure that subsistence needs are more adequately met (under the current system households occasionally do not meet subsistence needs). In addition, some of the increased production could be sold locally.

Although farm-level labor requirements are similar in the *with* and *without* case, physical input requirements are substantially larger in the *with* case. As a result, total input costs are higher in the *with* case, amounting to a discounted increase of US$ 190 per farm over the period considered. But total production is also larger in the *with* case, resulting in a discounted increase in gross benefits of US$ 360 per farm, or a benefit-cost (B/C) ratio of 1.9. Deducting the increased costs from the increased gross benefits would generate a net benefit of US$ 170 per farm over the time period considered.

Notwithstanding the fact that the *with* case seems to be economically more viable than the *without* case over the entire time period considered, there is a marked difference between the early and late years. In particular, the first five years of the *with* case are not especially attractive. In fact, changing from the *without* to the *with* case would imply a net deficit of approximately US$ 70 over these five

[24] Table C-1 presents the detailed outcome of the cost-benefit analysis (CBA) for the *with* and *without* situation in the upland zone. Here only the salient results will be highlighted.
[25] Appendix B presents the temporal distribution of labor (by month and year) in more detail.

years. This is mainly a result of the substantially larger input requirements (a discounted increase of US$ 140) which is only partially offset by higher gross benefits (a discounted increase of US$ 70), resulting in a B/C ratio of 0.5. Once fully established, the *with* case is substantially more attractive than the *without* case, generating a net surplus of US$ 230 over the subsequent five years, resulting in a B/C ratio of 5.6. However, some form of incentive may well be required to overcome the prohibitively expensive initial period.

The annual B/C ratios further support the need for some incentive in the initial period. Because resource-poor farmers in the tropics operate in high-risk conditions, it is generally accepted that the B/C ratios of new technologies should surpass 2.0 to be attractive to farmers (CIMMYT, 1988, pp. 34-35). In none of the first five years does the B/C ratio surpass this threshold value, but in the subsequent years it easily does so. This seems to suggest that the incremental costs of adopting the *with* case generate sufficient benefits after the sixth year to be self-supporting (i.e., any calculation of the "incremental cost" of adoption for farmers need only consider the first five years).
In view of the above, it should be clear that simply alleviating the US$ 70 deficit in the first five years would not be enough to lure farmers into adopting the *with* case, as this would only raise the B/C ratio to a meager 1.0 during the start-up period. It may be more appropriate to cover all the incremental costs farmers incur during the start-up period (i.e., a discounted sum of US$ 140 per farm household). The additional benefits generated during the start-up phase would then provide a further incentive to the farmer to adopt the *with* case.[26]

Sensitivity analysis.[27] The following section briefly presents the sensitivity of the farm-level implications to changes in the discount rate, the opportunity cost of labor and the assumed yield increase in the *with* case.

- *Discount rate.* In view of the timing of costs and benefits, it is not surprising that a lower discount rate favors the *with* situation. Lowering the discount rate to 10% raises the gross benefits more than the input costs, resulting in an overall 54% higher net benefit. Conversely, increasing the discount rate to 20% would lower the gross benefits more than the input costs, resulting in a 35% lower net benefit. The incremental costs during the start-up phase amount to a discounted US$ 165 and 115 per farm household, for the 10 and 20% discount rates respectively. Overall, however, most of the observed differences between the *with* and *without* case remain valid and are not very sensitive to changes in the discount rate.

- *Opportunity cost of labor.* Although labor is the major input in the production process in the *with* and *without* cases, the solution is not very sensitive to the actual value of the opportunity cost of labor. This is not surprising: recall that the above discussion showed that labor demand at the farm level is largely similar for the *with* and *without* situation.

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[26] Strictly speaking, a lesser amount of cost sharing may suffice to raise the B/C ratio above the threshold value. However, in view of compatibility with the other study components we use the sum of incremental costs to farmers during the start-up period, without correcting for increased benefits in this phase, along the lines suggested by Cervigni (1995, p. 8).

[27] Table C-2 presents the detailed outcome of the sensitivity analysis in the upland zone. Here, only the salient results will be highlighted.

- *Assumed yield increase.* The original *with* case assumes an initial yield increase of 40% relative to the *without* case.[28] Reducing the initial yield increase to only 30% would naturally make the *with* case less attractive because the annual gross benefit is reduced proportionally. However, lower yields would also reduce labor needs for harvesting and shelling (resulting in a 70-day decrease relative to the *without* case over the entire 10-year time period), so that labor costs would also be reduced. As a result, the gross benefit of changing will drop to US$ 220 per farm whereas the total costs will drop to US$ 140. This results in a net benefit of only US$ 80 per farm over the time period considered (a 54% decrease) and a B/C ratio of only 1.6. On average, the model farm would produce an additional 560 kg of maize annually in the *with* case, still sufficient to more adequately meet subsistence needs. The initial five years, however, would become even less attractive, presenting a cumulative discounted net loss of US$ 100 and a B/C ratio of 0.1. This decrease is mainly the result of a substantial decrease in benefits, as the incremental costs in the start-up period only drop to US$ 120 per farm household.

  Increasing the initial yield increase to 50% would naturally make the *with* case more attractive, although labor demand would also be affected (resulting in a 30-day increase relative to the *without* case). Overall, the net benefit would be increased to an accumulated discounted total of US$ 260 over the 10-year time period (a 54% increase), resulting in a B/C ratio of 2.1. The start-up period will also become relatively more attractive, generating a net loss of only US$ 30. The reduced loss is mainly the effect of a substantial increase in benefits, as the incremental costs in the start-up period increase to US$ 160 per farm household.

Lowland zone: Field-level implications

Cropping pattern. It is assumed that in the actual situation (the *without* case) the model farmer cultivates a plot for three consecutive seasons (1.5 years, including two *temporal* and one *tapachole* season). Afterwards, the respective plot is fallowed for five seasons (2.5 years, including two *temporal* and three *tapachole* seasons) before being cleared and cultivated again. As a result the entire cycle amounts to four years, resulting in an annual land use intensity (LUI) of 75% (or a seasonal LUI of only 38%).[29] This relatively high level of cropping intensity is unsustainable under the current cropping practices.

It is assumed that in the *with* case the number of fallow seasons can be reduced to three (including one *temporal* and two *tapachole* seasons, totaling 1.5 years of fallow) for each four years due to the combined use of fertility-increasing technologies (cover crops and fertilizer) as well as a better conservation of the available fertility (cover crops, conservation tillage, and contoured hedgerows). For the same cycle length, the number of crops increases to five (including three *temporal* and two *tapachole* seasons, totaling 2.5 years of cultivation). As a result, annual land use intensity would increase to 125% (or seasonal LUI to 63%).

Crop budget. The *without* case crop budget[30] again confirms the low profitability of the current maize production systems. With

[28] The yield increases in the subsequent two years are a multiple of the initial increase.
[29] Annual LUI is calculated here as the number of crops divided by the number of years; seasonal LUI is calculated as the number of crops divided by the number of seasons.
[30] Table A-3 and A-4 present the detailed crop budgets for the *without* and *with* case in the lowland zone.

limited use of external inputs in the lowland zone, yields are low and decline rapidly over the three-season cultivation period. *Temporal* season yields decline from a high of 1.4 ton per ha in the first year of cultivation to a low of 1.0 ton per ha in the second year, whereas *tapachole* yields average only 0.5 ton per ha. Labor use per unit area is relatively constant in the *temporal* season, amounting to around 75 labor days per ha cultivated, but averages less than 30 days in the *tapachole* season. Labor productivity declines from 18 to 14 kg per labor day over the cultivation period. Valuing labor at its opportunity cost generates a negative net benefit (or return to land) in each season. As a result, the return to a labor day (and land) does not surpass the assumed opportunity cost of US$ 2.5, and drops from US$ 1.8 to 1.2 per labor day over the cultivation period. Again, maize production in the current production system is relatively uncompetitive with imported maize. Production costs increase from US$ 180 per ton in the first season to US$ 240 per ton in the last. However, as in the upland zone, maize production remains of vital importance to smallholder households in view of their subsistence orientation and limited alternative sources of income.

The *with* case crop budget again provides a better outlook, although overall profitability remains low. With a combination of increased external input use and vegetative conservation measures, yields are raised and eventually maintained at about 2.5 tons per ha for the *temporal* season and about 0.9 tons per ha for the *tapachole* season. Labor use per unit area is increased substantially, especially in the first year of cultivation, but eventually oscillates around 105 labor days per ha cultivated in the *temporal* season and 30-46 days per ha cultivated in the *tapachole* season. As a result, labor productivity in the *temporal* season increases from an initial low of 17 kg per labor day to stabilize around 24 kg per labor day as of the fourth year. Labor productivity in the *tapachole* season is similar and oscillates between 20 and 26 kg per labor day. Valuing labor at its opportunity cost generates a positive net benefit (or return to land) as of the fourth year. As a result, the return to labor day (and land) hovers below the assumed opportunity cost of US$ 2.5 in the first three years, with a low of US$ 1.1 per day in the second year and climbing to about US$ 2.2 per day in the third (the first year is fallow). In the fourth and subsequent non-fallow years, the return to labor oscillates between US$ 2.7 and 2.8 per labor day in the *temporal* season and between US$ 2.5 and 3.3 per labor day in the *tapachole* season. Maize production in the proposed system becomes gradually more competitive with imported maize. Production costs decrease from US$ 220 per ton in the first year of cultivation to stabilize between US$ 110 and 140 per ton in the later years.

Lowland zone: Farm-level implications

Land use. Figure 5 conceptualizes the land-use implications of the actual and proposed cropping patterns for the model farm in the lowland zone. It is assumed that in the actual situation (the *without* case) the model farmer cultivates a plot for three consecutive seasons (two *temporal* and one *tapachole* season). During the second *temporal* season, the farmer clears a second field which will be used for the subsequent three seasons, abandoning the first plot after completion of the second *temporal* season. Something similar happens every year, so that the farmer cultivates two plots each year, progressively shifting his productive activities to a new field each year. As a result, the farmer will have two *temporal* plots and only one *tapachole* plot in production each year. If we recall that the fallow period is assumed to total five seasons, then the farmer can return to the first plot in the fifth year of the cycle. Therefore, whereas the farmer may only cultivate two plots annually, he needs two similarly sized plots resting at any given time. We assume that 1.33 ha of *temporal* maize and 0.67 ha of *tapachole* maize are cultivated annually on the model farm. On average, these amounts barely cover subsistence needs. The entire system would thus require 2.67 ha of cultivable land per household.

ACTUAL (*without* case)

Year	Season	Field A	B	C	D
1	Temp	F	F	3	1
	Tap	F	F	F	2
2	Temp	1	F	F	3
	Tap	2	F	F	F
3	Temp	3	1	F	F
	Tap	F	2	F	F
4	Temp	F	3	1	F
	Tap	F	F	2	F
5	Temp	F	F	3	1
	Tap	F	F	F	2
6	Temp	1	F	F	3
	Tap	2	F	F	F
7	Temp	3	1	F	F
	Tap	F	2	F	F
8	Temp	F	3	1	F
	Tap	F	F	2	F
9	Temp	F	F	3	1
	Tap	F	F	F	2
10	Temp	1	F	F	3
	Tap	2	F	F	F

Where: n Maize (actual); F Fallow (actual); ▭ Cropping cycle

PROPOSED (*with* case)

Year	Season	Field B2	A1	A2	B1	C	D
1	Temp	F	F	F	F	3	1
	Tap	F	F	F	F	F	2
2	Temp	1	1	1	F		
	Tap	Fi	2	2	F		
3	Temp	2	1a	3	1		
	Tap	Fi	Fi	F	2		
4	Temp	3	2a	1a	3		
	Tap	4	Fi	Fi	F		
5	Temp	Fi	3	2a	1a		
	Tap	5	4	Fi	Fi		
6	Temp	1	Fi	3	2a		
	Tap	Fi	5	4	Fi		
7	Temp	2	1	Fi	3		
	Tap	Fi	Fi	5	4		
8	Temp	3	2	1	Fi		
	Tap	4	Fi	Fi	5		
9	Temp	Fi	3	2	1		
	Tap	5	4	Fi	Fi		
10	Temp	1	Fi	3	2		
	Tap	Fi	5	4	Fi		

Where: n Maize (improved); n Maize (actual); Fi Fallow (improved); F Fallow (actual); a Adjusted; ▭ Cropping cycle

At equilibrium at any given time (actual):

	Temp.	Tap.	Overall	
Plots in production	2	1		plot(s)
Plots fallowed	2	3	"	
Plot area			0.67	ha
Annual maize area	1.33	0.67		ha
Annual system area			2.67	"
Duration use/cycle	2	1	3	seasons
Duration fallow/cycle	2	3	5	"
Cycle length			8	"

LUI Annual 75.0% Seasonal 37.5%

At equilibrium at any given time (proposed):

	Temp.	Tap.	Overall	
Sub)Plots in production	3	2		plot(s)
(Sub)Plots fallowed	1	2		"
(Sub)Plot area			0.33	ha
Annual maize area	1.00	0.67		ha
Annual system area			1.33	"
Duration use/cycle	3	2	5	seasons
Duration fallow/cycle	1	2	3	"
Cycle length			8	"

LUI Annual 125.0% Seasonal 62.5%

Note: Fields A+B each divided in 2 sub-plots; fields C+D (0.67 ha each) available for other purposes after year 1. Adjusted reflects lower yields due to reduced fallow period.

Figure 5. Observed and proposed cropping patterns for the model farm in the lowland zone, Sierra de Santa Marta, Veracruz

It is again assumed that in the improved situation (the *with* case) the model farmer adopts the new system progressively on his lands, thereby gradually expanding the improved system over his plots. Furthermore we assume that under the improved situation annual *temporal* maize area will be reduced to 1.0 ha, whereas annual *tapachole* maize area remains at 0.67 ha per household (because production will still be largely subsistence oriented, whereas productivity is higher). Because 25% of the *temporal* area (and 50% of the *tapachole* area) would still remain fallow, the improved system would require 1.33 ha of cultivable land per household (i.e., half of the original 2.67 ha), and 1.33 ha per farm household in the lowland zone would be freed from maize production.

Economic implications.[31] To assess the economic farm-level implications, we have estimated the annual costs and benefits in relation to maize cultivation at the farm level over a 10-year time period for both the *with* and *without* case.[32] The discount rate is again 15%.

Although labor demand per unit area is substantially higher for the *with* case, at the farm level this is partially offset by the smaller productive area in the *temporal* season. As a result, adoption of the *with* case only increases labor demand at the farm level by some 80 days over the 10-year time period, averaging around 11 additional days annually once the *with* case stabilizes. However, the *with* case does not represent a too substantial increase in labor requirements in the busy months of May-July.[33]

Farm production levels are not hampered by the reduction in cropped area, which is offset by the substantially higher yield levels. In fact, the *with* case only runs a negligible relative deficit (compared to the *without* case) in the second year, whereas in the subsequent years the gap widens in favor of the *with* case to an additional 1,200 kg annually. Over the entire 10-year period, the *with* case produces an additional 7 tons of maize per farm, averaging 680 kg annually. This relative surplus would ensure that subsistence needs are more adequately met, whereas some of the increased production could potentially be sold locally.

The *with* case presents an increase in both labor and non-labor costs over the *without* case, resulting in a discounted increase in costs of US$ 140 per farm over the time period considered. Total production is however also larger in the *with* case, resulting in a discounted increase in gross benefits of US$ 360 per farm, or a benefit-cost (B/C) ratio of 2.6. Deducting the increased costs from the increased gross benefits would generate a net benefit of US$ 220 per farm over the time period considered.

Although the *with* case seems to be more economically viable than the *without* case over the entire time period considered, there is again a marked difference between the early and late years. In particular, the first five years of the *with* case are not very attractive. In fact, changing from the *without* to the *with* case would imply a net loss of US$ 10 over these five years. This is the result of the larger input requirements (a discounted increase of US$

[31] Table C-3 presents the detailed outcome of the CBA for the *with* and *without* case in the lowland zone. Here only the salient results will be highlighted.

[32] To facilitate comparison, the time period for the two zones is the same. In any case, a single four-year cycle would not be sufficient to adequately capture changes over time as the improved system only stabilizes after the fifth year of implementation. Therefore the time period had to be expanded to at least include two full cycles of the actual system.

[33] Appendix B presents the *temporal* distribution of labor (by month and year) in more detail.

110) not being offset by higher gross benefits (a discounted increase of US$ 100 only), resulting in a B/C ratio of 0.9. Once fully established, the *with* case is substantially more attractive than the *without* case, generating a net surplus of US$ 230 over the subsequent five years, with a B/C ratio of 9.7. Again, however, some form of incentive may well be required to overcome the relatively costly initial period.

The annual B/C ratios further support the need for some incentive in the initial period. In none of the first five years does the B/C ratio surpass the 2.0 threshold value, but in the subsequent years it easily does so. This seems to suggest that the incremental costs of adopting the *with* case generate sufficient benefits after the sixth year to be self-supporting. If farmers are to find the practice attractive, it may be appropriate to cover all the incremental costs farmers incur during the start-up period (a discounted sum of US$ 110 per farm household). The additional benefits generated during the start-up phase would then provide a further incentive to the farmer to adopt the *with* case.

Sensitivity analysis.[34] The following section briefly presents the sensitivity of the farm-level implications to changes in the discount rate, the opportunity cost of labor, and the assumed yield increase in the *with* case.

- *Discount rate.* In view of the timing of costs and benefits, a lower discount rate again favors the *with* situation. Lowering the discount rate to 10% raises the gross benefits more than the input costs, resulting in an overall 45% higher net benefit. Conversely, increasing the discount rate to 20% would lower the gross benefits more than the input costs, resulting in a 30% lower net benefit. The incremental costs during the start-up phase amount to a discounted US$ 130 and 90 per farm household, for the 10 and 20% discount rates respectively. Overall, however, most of the observed differences between the *with* and *without* case remain valid and are not very sensitive to changes in the discount rate.

- *Opportunity cost of labor.* With a marked difference of nearly 80 labor days between the *with* and *without* case, the solution is sensitive to the actual value of the opportunity cost of labor. Lowering the opportunity cost of labor to US$ 1.5 decreases the labor cost differential to a discounted sum of only US$ 50, resulting in an overall 20% higher net benefit and an overall B/C ratio of 3.7. Conversely, increasing the opportunity cost of labor to US$ 3.5 increases the labor cost differential to a discounted sum of over US$ 130, resulting in a 20% lower net benefit, and a B/C ratio of 2.0. The incremental costs during the start-up phase amount to a discounted US$ 90 and 130 per farm household, for the lower and higher rates respectively.

- *Assumed yield increase.* The original *with* case assumes an initial yield increase of 40% relative to the *without* case. Reducing the initial yield increase to only 30% would again make the *with* case less attractive as the annual gross benefit is reduced proportionally. However, lower yields would also reduce labor needs for harvesting and shelling (resulting in a 30-day decrease relative to the *without* case over the entire 10-year time period), so that labor costs would also be reduced. As a result, the gross benefit differential will drop to US$ 230 per farm, whereas the total costs will drop to US$ 90.

[34] Table C-4 presents the detailed outcome of the sensitivity analysis in lowland zone. Here only the salient results will be highlighted.

This results in a net benefit of only US$ 140 per farm over the time period considered (a 36% decrease), and a similar B/C ratio of 2.5. On average, the model farm would produce an additional 460 kg of maize annually in the *with* case, still sufficient to more adequately meet subsistence needs. The first five years, however, would become less attractive, presenting a cumulative discounted net loss of US$ 40 and a B/C ratio of 0.6. This decrease is mainly the result of a substantial decrease in benefits, as the incremental costs in the start-up period drop to US$ 90 per farm household.

Raising the initial yield increase to 50% would naturally make the *with* case more attractive, although labor demand would also be affected (resulting in a 120-day increase relative to the *without* case). Overall, the net benefit would be increased to an accumulated discounted total of US$ 300 over the 10-year time period (a 37% increase), resulting in a B/C ratio of 2.6. The start-up period will also become relatively more attractive, generating a net benefit of US$ 20. This is mainly the effect of a substantial increase in benefits, as the incremental costs in the start-up period increase to US$ 130 per farm household.

Challenges for Implementation

The farm-level analysis of costs and benefits of technical options for intensifying maize-based cropping systems in the Sierra de Santa Marta indicates that while the use of plant nutrients available or generated on the farm by cover crops in combination with vegetative barriers and limited external inputs would eventually make maize production substantially more attractive, the overall profitability of the system would remain low. Household subsistence requirements would, however, be assured more adequately than under the current circumstances and some land would be freed from maize production for other uses. The freeing of land is the combined result of a reduction in actual maize area (increased productivity of subsistence-oriented production) in addition to a reduction in the required fallow area, amounting to 1.33 ha per household in the lowland zone and up to 4 ha per household in the upland zone. This land is potentially available for the production of more commercially oriented crops or conversion to secondary forest, thereby reducing the pressure of the maize cropping system on the remaining forest resources of the region.

A major constraint is the timing of the benefits, as adopting the proposed technologies requires a substantial initial investment by the farmer. In the upland zone, for example, farmers face an incremental cost amounting to a discounted sum of US$ 140 per farm household over the five-year start-up period, resulting in a B/C ratio of only 0.5 during that initial phase. In the lowland zone, farmers face an incremental cost amounting to a discounted sum of US$ 110 per farm household over the five-year start-up period, resulting in a B/C ratio of only 0.9 during that phase. After the start-up phase, the improved technologies are potentially self-supporting in both zones with B/C ratios easily surpassing the 2.0 threshold. Alleviating the incremental cost during the start-up phase through the appropriate use of financial incentives therefore may be enough to facilitate farmer adoption, assuming that a broader strategy for ongoing adaptive research and extension is also developed.

Experience to date in the Sierra de Santa Marta suggests that neither the incentives nor the research and extension effort needed to effectively implement an incentive plan can be expected from the current national agricultural support services. Since the 1980s, the National Agricultural and Forestry Research Institute (INIFAP) has been severely weakened and the branch of the Agricultural, Ranching and Rural Development Secretariat (SAGAR) responsible for technical assistance has practically been eliminated. State withdrawal from the provision of agricultural research and extension has been justified by arguments that the private sector can provide these services more efficiently and effectively. In effect, however, the policy has cleared the rural landscape of agricultural institutions and severely restricted farmer access to information and technology needed to improve productivity. This withdrawal is perhaps less severe in marginal areas such as the Sierra de Santa Marta where agricultural research and extension have always been weak anyway.

Credit has been provided in recent years to small-scale farmers in the Sierra de Santa Marta through programs managed by the National Indigenous Institute (INI) and SAGDR with funding from SEDESOL, the mega-Secretariat established during the early 1990s to finance poverty alleviation programs in marginal areas. These programs have stimulated the recent adoption of fertilizer (and herbicide) in the lowland zone, thereby defraying increased input costs for some farmers. Coverage has been limited, however, to less than 10% of the farming population (Bello 1994), virtually all of whom are *ejidatarios* with secure land tenure, leaving the poorer and younger farmers who are not *ejidatarios* virtually without access to credit. Furthermore, recovery of the credits has been poor and the programs have not been replenished with new funds or expanded since they were initiated. Despite the complexities of the technologies promoted, none of the credit programs provides technical assistance; the result has been inefficient and unsafe farming practices. PROCAMPO, a program of direct payment to farmers intended to facilitate the reorientation of agriculture away from less profitable basic grain production into other agricultural activities, has also completely neglected the provision of technical assistance and market studies needed to facilitate this shift. As a result, the impact of the program in many areas, including the Sierra de Santa Marta, has been limited or simply reinforced existing patterns of agricultural decline. For example, farmers in the region have cleared more forested land for maize production so as to qualify for PROCAMPO subsidies, but without increasing the productivity of the land already under cultivation (Buckles, Pare, and Arteaga 1995).

Over the years, there has been virtually no adaptive research with agricultural innovations in the Sierra de Santa Marta and no systematic study of technology needs, two activities that are essential for the successful implementation of the alternative strategies outlined above. While they appear to be robust practices (based on limited local experience and experience in other regions), learning costs, including further adaptation and extension to the general farming population, are likely to be considerable. The virtual withdrawal of the public sector from agricultural research and extension, however, leaves an institutional vacuum in the countryside; farmers in the Sierra de Santa Marta and elsewhere have to rely more than ever on local innovation, adaptation, and diffusion as sources of technical change. Nevertheless, even autonomous action is hampered by the political and organizational weakness of civil society in the Sierra de Santa Marta. Farming communities in the region are plagued with internal problems of political conflict and inadequate management skills. There are few mechanisms through which farming communities can offer alternatives of their own or demand from the state policies and programs which meet their needs. Thus, the central challenge for implementation of the alternative strategies for agricultural intensification described in this paper lies in the development of means to catalyze and accelerate local processes of innovation and to strengthen local capacity for self-management and for informed negotiation with outside agencies.

Cooperation between government agencies and non-governmental organizations may have a role to play in helping to create the conditions for farmer-based agricultural development by providing communities with access to appropriate information, skills, and financial resources. In 1991 and 1992, the PSSM and CIMMYT undertook a campaign to facilitate farmer access to cover crops and to strengthen local capacity to generate and diffuse appropriate agricultural technologies (Buckles, Pare, and Arteaga 1995). This effort was expanded in 1994 through cooperation with the State Government of Veracruz to facilitate farmer access to the inputs and information needed to adopt contoured hedgerows as well. While the initial PSSM-CIMMYT approach emphasized farmer access to appropriate information and seed, the coordinated strategy with the state government also involved the use of incentives to cover the estimated costs of establishing the technologies and providing technical assistance through farmer paratechnicians. The following description refers to the latter approach.

Project implementation began with a process of farmer training in appropriate technologies through local workshops. Contact farmers known to regional institutions (municipal and *ejido* authorities, NGOs, government agencies, farmer organizations) were invited to a two-day workshop in various locations during which problems confronting regional farmers were discussed using participatory exercises, a few promising technical options were presented (cover crops and contoured hedgerows), and a program of incentives for farmers was outlined. During the workshops the farmers were trained in the use of the technologies (including the A-frame for tracing contour lines) by a small team of professional extensionists.

The contact farmers were invited to take the lead in establishing the technologies by building their own A-frames and tracing the contours for their own fields, work done without compensation. They were also asked to form a small group in their community which in turn formally requested participation in the program. The formation of self-selected small groups provided a cohesive target for delivery of the program and facilitated collective action by participating farmers. The risk of diversion of the program to more powerful members of communities was reduced through the original selection of contact farmers by a variety of formal and informal institutions.

Contact farmers who had voluntarily and successfully formed farmer groups and drawn contours on their own fields were invited to help implement the program; activities included tracing contours in the fields of other group members. These farmers, supported by periodic visits and additional training by the professional team, were accredited by the program as paratechnicians (*promotores*) in their communities and compensated for their work. *Promotores* provided technical assistance about establishing and maintaining contoured hedgerows, using cover crops, and the contour planting of maize. They also interviewed farmers regarding their perspectives on the technologies. *Promotores* participated in evaluation workshops at the end of the season, during which progress and problems associated with the campaign were discussed and plans made for future activities.

The 1994 campaign cost an average of US$ 172 per participating farmer. This estimate includes the cost of the incentives, the technical assistance, and the campaign coordination. Incentives were the major cost, totaling some US$ 102 per farmer. As compensation for their work, farmers received 5 kg of mucuna seed worth US$ 7; 5 kg of gliricidia seed worth US$ 35; 50 kg of fertilizer (calcium superphosphate) valued at US$ 10; a food package worth US$ 10 (beans, rice, cooking oil); and US$ 40 in cash. With the exception of the mucuna seed, all of these incentives were to facilitate establishment of the contoured hedgerows, the most costly of the technologies promoted.

The technical assistance was provided by the paratechnicians at an estimated cost of US$ 40 per participating farmer. The paratechnicians were paid US$ 30/ha to trace the contour lines on each farmer's field; they were paid a total of US$ 200 over the season to provide other forms of technical assistance to the farmer group as a whole. The latter payment averaged approximately US$ 10 for each of the 1,457 farmers assisted.

The institutions coordinating the program provided the staff time of three professional extensionists and two assistants; periodic assistance was also provided by several administrators and technical people during a six-month period. Implementation costs included frequent visits to farming communities by the professional team, communications, office and administrative support, the delivery of inputs such as the fertilizer, and food disbursement. While detailed records of these costs were not kept, Table 2 estimates that the cost of campaign coordination in 1994 averaged some US$ 30 per participating farmer.

During the 1994 campaign, some 1,457 farmers were organized into 56 groups, each led by a paratechnician. More than 1,064 hectares of contoured hedgerows were established by farmers and paratechnicians and more than 9 tons of cover crop seed were planted on some 450 hectares of farmland. Farmer adoption of the technologies resulting from this and earlier campaigns has not been formally evaluated, although farmer interest in the technologies and expression of commitment to their continued use has generally been strong (Buckles, Pare, and Arteaga 1995). Work by Soule (1995) suggests that approximately 55% of the farmers receiving cover crop seed through the earlier campaigns continued to experiment with the technology the following year.

The campaign did not consider incentives and technical assistance needed to implement other features of the alternative strategy proposed in this paper, such as the efficient use of commercial fertilizers, the conservation of crop

Table 2. Estimated costs of campaign coordination, 1994

Activity	US$
Workshops (4)	2,800
Salaries, professional extensionists (3)	16,200
Salaries, field assistants (2)	7,200
Field coordination (transportation and per diems for five coordinators)	8,870
Communications	1,670
Transport of seed, fertilizer, and food	3,500
Administration (10%)	4,024
Total	44,264

residues, increased maize planting densities, the use of improved plant varieties, and effective seed storage. Furthermore, without a formal assessment of adoption rates resulting from the campaign, it is impossible to estimate the intensity and period of promotion needed to achieve widespread adoption.

While generally successful, the 1994 campaign encountered a number of problems and fell well short of broader goals of organizational development. Excessive and contradictory bureaucratic procedures and late payment of some incentives created tensions and disagreements among farmers and between farmers and the coordinators in various communities. In addition, insufficient attention was paid to key questions of farmer training in communication skills, the impact of incentives on farmer motivation, and the means to enhance farmer participation in project management (Buckles, Pare, and Arteaga 1995).

With these important qualifications in mind, the campaign described above helps identify the major elements of a potential implementation strategy and the order of magnitude of implementation costs. To be effective, however, an implementation strategy should not be limited to technical considerations alone. In our view, the appropriate intensification of agriculture also requires concerted attention to broader issues beyond the scope of this paper (e.g., regional development plans, land use policies, and grassroots community participation).

Conclusions

Farmers in the Sierra de Santa Marta have traditionally grown maize in relatively extensive slash-and-burn production systems to meet their subsistence needs. While these production practices were relatively sound and sustainable in the past, they are no longer so in the current environment. Shorter fallow periods brought on by land use intensification and insufficient technical adjustments by local farmers to changing circumstances have severely undermined the current maize cropping system. Economic analyses presented in the paper indicate in quantitative terms the low profitability of the current maize production systems. Quite simply, land, labor, and capital are very poorly remunerated in economic terms. Soil erosion, weed invasion and the mining of soil fertility can be expected to further reduce the viability of the cropping system and to give rise to broader social costs associated with out-migration and further deforestation.

Despite problems of low profitability and land degradation, maize production remains of vital importance to smallholders concerned with meeting their subsistence needs, and it is one of the few productive uses of land and labor currently available to them. Incomes in the region are extremely low and employment both on- and off-farm are very limited—conditions that reinforce customary reliance on the production of maize for household sustenance. Growing maize is a survival strategy few farmers can do without.

The use of plant nutrients available or generated on the farm by cover crops in combination with vegetative barriers and limited external inputs could allow for the appropriate intensification of maize-based cropping systems in both the lowland and upland zones of the Sierra de Santa Marta. Farm-level analysis of the costs and benefits of adoption indicate that while profitability would remain low, the alternative cropping system would be considerably more attractive than the current one. Soil conservation objectives both at the farm and watershed levels might also be more effectively attained if the practices perform as suggested by qualitative experience from other similar regions, thereby improving the sustainability of the cropping system. In addition, some land could be freed from maize production as a result of a reduction in the maize area needed to meet subsistence needs and a reduction in the fallow area needed to maintain the system—savings that amount to 1.33 ha per household in the lowland zone and up to 4 ha per household in the upland zone. This land is potentially available for the production of more commercially oriented crops or conversion to secondary forest, thereby reducing the pressure of the cropping system on the region's remaining forest resources.

Economic analysis reveals that the timing of adoption benefits is a significant constraint. The proposed technologies require a substantial initial investment by the farmer: a discounted sum of US$ 140 per farm household over five years by farmers in the upland zone and a discounted sum of US$ 110 per farm household over five years in the lowland zone. After the initial investment period, the proposed technologies may be self-supporting, but cash-poor farmers would need help in alleviating the investment cost. Both the continuing economic crisis of the Mexican state and the historical pattern of neglecting the region's agricultural concerns suggest that these needs will not be met through current schemes. This paper provides an outline of a farmer-based approach to implementing the alternative strategies and a quantitative assessment of the level of investment needed to stimulate adoption and support a broader process of sustained technology development and adaptation in the region.

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Appendix A

Crop Budgets

Appendix A presents the crop budgets underlying the analysis in more detail. However, before looking at the specific crop budgets for each zone, a few observations are in order in relation to the prices and yield adjustment factors used.

Prices

Prices in the crop budgets are in US$. A major reason for using US$ denominated prices is the still uncertain impact the recent economic crisis may have on actual and future domestic prices through an unstable exchange and inflation rate. It is assumed that US$ denominated prices of most inputs and outputs will remain relatively constant over time and thereby present a more viable alternative to use as constant 1995 prices over the time period considered. A notable exception is the assumed opportunity cost of labor (assumed equal to the local wage rate of day laborers). Local labor costs in Mexican peso terms are still relatively constant (compared to one year ago and to other costs), and thereby have declined substantially in US$ terms. The sensitivity analysis therefore specifically includes changes in the assumed labor cost. Prices are indicative only and should be treated with caution.

The on-farm price of maize is relatively high in view of the subsistence orientation of the farm household. The price is therefore not a reflection of the actual on-farm sales price, but more an estimate of the on-farm purchase price. This is appropriate as most households under the current maize production systems do not meet subsistence requirements adequately (and are thereby net-purchasers), whereas even in the proposed maize production system, production remains largely subsistence oriented, with only an occasional sale of excess production.

Yield Adjustment Factors

The data presented in the crop budgets assume a rested field as the starting situation. However, in the transition years, this is not the case for all the subplots. The gradual transition from the observed to the proposed case results in some subplots starting in a previously used field (if we assume the surplus plots to be put to another use). Because these fields have a lower productive potential, the yield response to the package is adjusted downwards in the first two transition years through a yield adjustment factor. The adjustment factor for the first year is based on the rate of yield decline in the observed situation. The adjustment factor for the second year is assumed to be half that of the first year. In later years, the proposed situation is presumed to prevail. In Figure 4 and Figure 5 the plots affected by yield adjustment factors are labeled with an "a" (adjusted). Table A-1 presents the yield adjustment factors used in the analysis.

Table A-1. Yield adjustment factors

Zone	Plot	Year	Yield adjustment factor
Upland	A3	4	90%
		5	95%
	A4	5	82%
		6	91%
Lowland	A1	3	71%
		4	86%
	A2/B1	4/5	60%
		5/6	80%

Because labor use for harvest and shelling is assumed to be proportional to yield, labor use for these activities is also affected by the yield adjustments.

Crop Budgets: Upland Zone

Table A-2 presents a detailed crop budget for the actual cropping system (the *without* case) for the model farm in the upland zone. The budget is on a ha basis and presents data annually for a specific field. It is assumed that a field is cultivated for three years and is subsequently fallowed for six years. The overall implications of the budget are discussed in the main text. Some details follow:

*Field preparation***:** Assumes manual clearing of *acaual* in the first year and therefore labor demand is higher relative to subsequent years.

Crop establishment: Sowing is manual with *espeque* (dibble stick).

Weed control: Weeds become more problematic in the subsequent years after clearing, and consequently labor demand rises. Although a number of farmers have started using herbicides in the upland zone, such use is

Table A-2. Crop budget for the *without* case in the upland zone (ha basis)

Activity	Unit	Price (US$/units)	Quantity (units/ha)					Cost (US$/ha)				
Year			1	2	3	4	5-10	1	2	3	4	5-10
INPUT			**Fallow**				**Fallow**	**Fallow**				**Fallow**
Field preparation	Labor	2.5	“	20	16	16	“	“	50	40	40	“
			“				“	“	0	0	0	“
Crop establishment	Labor	2.5	“	6	6	6	“	“	15	15	15	“
	Seed	0.21	“	16	16	16	“	“	3.4	3.4	3.4	“
Weed control	Labor	2.5	“	25	30	35	“	“	62.5	75	87.5	“
	Herbicide	5.5	“	0	0	0	“	“	0	0	0	“
Fertilizer applic.	Labor	2.5	“		0	0	“	“	0	0	0	“
	Urea	11	“		0	0	“	“	0	0	0	“
	DAP	14	“		0	0	“	“	0	0	0	“
Doubling	Labor	2.5	“	6	6	6	“	“	15	15	15	“
Harvest	Labor	2.5	“	10.4	8.3	6.7	“	“	26.0	20.8	16.8	“
Shelling	Labor	2.5	“	12.5	10	8	“	“	31.3	25.0	20.0	“
Additional mgt	Labor	2.5	“		0	0	“	“	0	0	0	“
	Other		“		0	0	“	“	0	0	0	“
Depreciation implements	Annuity		“		0	0	“	“	5	5	5	“
Subtotal labor		2.5	“	80	76	78	“	“	200	191	194	“
Subtotal non-labor			“				“	“	8.4	8.4	8.4	“
Total input												
OUTPUT			**Fallow**				**Fallow**	**Fallow**				**Fallow**
Maize grain consumption	kg	0.14	“	1250	1000	800	“	“	175	140	112	“
Other byproduct	lump sum	1	“	25			“	“	25	0	0	“
Total								“	200	140	112	“
Net benefit (Return to land, US$/ha)								“	-8	-59	-91	“
Cost price per kg (US$/kg)								“	0.17	0.20	0.25	“
	Labor							“	0.16	0.19	0.24	“
	Non-Labor							“	0.01	0.01	0.01	“
Return to labor and land (US$/ha)								“	192	132	104	“
Labor productivity (Kg maize output/day)								“	15.6	13.1	10.3	“
Return to labor day (and land) (US$/ld)								“	2.4	1.7	1.3	“

less widespread than in the lowland zone for a variety of reasons. The budget for the model farm in the upland zone assumes manual weeding only.

Fertilizer application: External input use, including chemical fertilizers, is limited in the upland zone. The budget for the model farm in the upland zone assumes no use of chemical fertilizers.

Harvest: Harvesting labor is directly related to yield, with an assumed manual harvesting rate of four bags (30 kg of grain each) per person per day.

Shelling: Shelling labor is directly related to yield, with an assumed manual shelling rate of 100 kg per day.

Maize yields: Yields decline over time as fields become exhausted.

By-product: An estimated value for firewood collected from the *acaual* at time of clearing. Nevertheless, the opportunity value of wood is low in view of large supply and only limited demand for subsistence needs. The actual estimate assumes that *acaual* clearing generates a 10-day savings in time normally spent collecting firewood.

Table A-3 presents a similar crop budget for the improved cropping system (the *with* case) for the model farm in the upland zone. Again the budget is on a ha basis and presents data annually for a specific field. It is assumed that a field is cultivated for three years, and subsequently fallowed for one year. However, for a variety of reasons (see below), input and output levels are different for subsequent periods of use, and the budget therefore presents data for both the first four years as well as the subsequent four years (Years 6-9). In even later years input and output levels similar to the Years 6-9 are supposed to prevail. The overall implications of the budget are discussed in the main text. Some details follow:

Field preparation: Labor demands in the first year are assumed to be similar to the *without* case, except for the absence of burning. In subsequent years, labor savings occur because preparing the fields becomes relatively easier.

Crop establishment: Labor needs for sowing are assumed to be slightly higher than in the *without* case due to the presence of crop residue and mulch.

Weed control: Weeds become less problematic over time as the cover crop, once fully established, shades out most weeds thereby substantially reducing labor needs for weeding. Weed control remains manual only.

Fertilizer application: Fertilizers are included in the improved system. Whereas fertilizers provide most of the N in the initial three years (at an annual rate of 60 kg N per ha), most of the subsequent N needs of the maize crop are met by the cover crop (once it is fully established). Consequently the N application rate and the labor needs for its application drop over time (stabilizing at 13.5 kg N per ha). P application rates are assumed stable (35 kg P_2O_5 per ha).

Harvest: Harvesting labor is again directly related to yield. In this case the assumed manual harvesting rate is only 3.5 bags per person per day due to the presence of the cover crop, which slows harvesting.

Shelling: Shelling assumes the same rate as in the actual system (100 kg per day).

Additional management of the cover crop: Labor needs for sowing the cover crop in the first year are assumed to be one-third those for maize sowing (i.e., two days per ha). Although the cover crop is sown with a dibble stick at similar densities to maize, the maize rows provide a guide to planting and less care is needed to cover the cover crop seed (Eilitta, personal communication). Furthermore, an additional two days per ha are required to prune mucuna where needed (i.e., at times and places when it competes with maize). In subsequent years, labor for sowing the cover crop may diminish as some natural reseeding will occur. However, such savings will be offset by an increased need to prune mucuna plants that sprout in the field. In addition, one day per season per ha is required for cover crop seed collection; generally, seeds can be gathered from plants left to mature along the edge of fields. Other costs include the initial seed requirements for the cover crop (only for the first year as the farmer's own seed is used in subsequent years).

Additional management of the hedgerow: Labor needs for establishing a hedgerow in the first year are assumed to total 22 labor days (as estimated by Zuñiga et al. 1993); this estimate includes seed collection, plus an additional three days for reseeding hedgerows). Additional installation costs

Table A-3. Crop budget for the *with* case in the upland zone (ha basis)

Activity	Unit	Price (US$/units)	Quantity (units/ha)								Cost (US$/ha)							
Year			1	2	3	4	5	6	7-8	9	1	2	3	4	5	6	7-8	9
INPUT			Fallow				Fallow			Fallow	Fallow				Fallow			Fallow
Field preparation	Labor	2.5	“	18	14	14	“	16	14	“	“	45	35	35	“	40	35	“
		“				“			“	“					“			“
Crop establishment	Labor	2.5	“	7	7	7	“	7	7	“	“	17.5	17.5	17.5	“	17.5	17.5	“
	Seed	0.21	“	16	16	16	“	16	16	“	“	3.4	3.4	3.4	“	3.4	3.4	“
Weed control	Labor	2.5	“	25	20	15	“	20	15	“	“	62.5	50	37.5	“	50	37.5	“
	Herbicide	5.5	“	0	0	0	“	0	0	“	“	0	0	0	“	0	0	“
Fertilizer applic.	Labor	2.5	“	8	8	8	“	4	4	“	“	20	20	20	“	10	10	“
	Urea	11	“	2	2	2	“	0	0	“	“	22	22	22	“	0	0	“
	DAP	14	“	1.5	1.5	1.5	“	1.5	1.5	“	“	21	21	21	“	21	21	“
Doubling	Labor	2.5	“	6	6	6	“	6	6	“	“	15	15	15	“	15	15	“
Harvest	Labor	2.5	“	16.7	19	20.8	“	20.8	20.8	“	“	41.8	47.5	52	“	52	52	“
Shelling	Labor	2.5	“	17.5	20	21.9	“	21.9	21.9	“	“	43.8	50.0	54.8	“	54.8	54.8	“
Additional mgt cover crop	Labor	2.5	“	5	5	5	“	5	5	“	“	12.5	12.5	12.5	“	12.5	12.5	“
	Other	1	“	7.5		0	“	0	0	“	“	7.5	0	0	“	0	0	“
Additional mgt hedgerow	Labor	2.5	“	22	5	5	“	5	5	“	“	55	12.5	12.5	“	12.5	12.5	“
	Other	1	“	30		0	“	0	0	“	“	30	0	0	“	0	0	“
Depreciation implements	Annuity		“		0	0	“	0	0	“	“	5	5	5	“	5	5	“
Subtotal labor		2.5	“	125	104	103	“	106	99	“	“	313	260	257	“	264	247	“
Subtotal non-labor											“	89	51	51	“	29	29	“
Total input											“	402	311	308	“	294	276	“
OUTPUT			Fallow				Fallow			Fallow	Fallow				Fallow			Fallow
Maize grain consumption	kg	0.14	“	1750	2000	2188	“	2188	2188	“	“	245	380	306	“	306	306	“
Other byproduct	lump sum	1	“				“			“	“	0	0	0	“	0	0	“
Total											“	245	380	306	“	306	306	“
Net benefit (Return to land, US$/ha)										“	“	-157	-31	-2	“	13	30	“
Cost price per kg (US$/kg)										“	“	0.23	0.16	0.14	“	0.13	0.13	“
	Labor									“	“	0.18	0.13	0.12	“	0.12	0.11	“
	Non-labor									“	“	0.05	0.03	0.02	“	0.01	0.01	“
Return to labor and land (US$/ha)										“	“	156	229	255	“	277	277	“
Labor productivity (Kg maize output/day)										“	“	14.0	19.2	21.3	“	20.7	22.2	“
Return to Labor day (and land) (US$/ld)										“	“	1.2	2.2	2.5	“	2.6	2.8	“

include one bag of DAP fertilizer and US$ 16 for technical assistance in tracing contours. Labor needs in subsequent years mainly relate to hedgerow maintenance.

Maize yields: In the first year, yields are assumed to increase a net 40% relative to the *without* case, mainly as a direct response to fertilizer application. In the second and third years, yields are expected to rise a further 20 and 15% relative to the first year yields in the *without* case. These yield increases are mainly a result of the other measures (cover crops, residue conservation, hedgerows) starting to take effect, thereby increasing fertility and available soil moisture. The presence of the hedgerows reduces available crop area and thereby potentially reduces yields. However, this "productive loss" has already been considered in the net yield increases. Once the system is fully established, yields are assumed to remain constant over time.

Crop Budgets: Lowland Zone

Table A-4 presents a detailed crop budget for the *actual* cropping system (the *without* case) for the model farm in the lowland zone. The budget is on a ha basis and presents data for each season (*temporal* and *tapachole*) annually for a specific field. It is assumed that a field is cultivated only for three seasons (1.5 years), and is subsequently fallowed for five seasons (2.5 years). The overall implications of the budget are discussed in the main text. Some details follow:

Field preparation: Assumes manual clearing of grassy *acaual* for the *temporal* season in the first year and therefore labor demand is higher than for the second year. Manual clearing for the *tapachole* season only involves reweeding/clearing of the *temporal* maize field since *tapachole* maize is sown as an intercrop between the doubled temporal maize.

Crop establishment: Labor needs for sowing the *tapachole* intercrop are assumed to be two-thirds of the *temporal* labor needs because the doubled maize plants used during the *temporal* season can serve as guides.

Weed control: Weeds become more problematic in the subsequent years after clearing; consequently, labor demand rises in the second *temporal* season. Labor demand for weeding in the *tapachole* season is relatively low as a result of limited rainfall and the presence of doubled temporal maize stalks. Labor demand for weeding in the lowland zone is lower than in the upland zone due to the combined use of herbicides and manual weeding (the upland zone budget assumes manual weeding only).

Fertilizer application: Fertilizer application is relatively common in the lowland zone, but is mainly limited to the *temporal* season due to production risks in the *tapachole* season.[1] Annual application rates at the model farm are assumed to average 55 kg N per ha and 23 kg P_2O_5 per ha.

Doubling: In contrast to *temporal* maize, *tapachole* maize is not doubled.

Harvest: Harvesting labor is directly related to yield, as in the *without* case in the upland zone (four bags per person per day).

Shelling: Shelling assumes the same rate as in the *without* case in the upland zone (100 kg per day).

Maize yields: Yields decline over the *temporal* seasons as fields become exhausted. Yields in the *tapachole* season average only 500 kg/ha.

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1 Fertilizer use in the lowland zone was relatively common in the years prior to the 1995 *temporal* season. The economic crisis during 1995 limited fertilizer use during that cycle, but it is expected that fertilizer use will rebound in the *without* case in the subsequent years.

Table. A-4 Crop budget for the *without* case in the lowland zone (ha basis)

Activity	Unit	Price (US$/units)	Quantity (units/ha)									Cost (US$/ha)								
Year - Season			**1**	**2-Temp**	**2-Tap**	**3-Temp**	**3-Tap**	**4-Temp**	**4-Tap**	**5-Temp**	**5-Tap**	**1**	**2-Temp**	**2-Tap**	**3-Temp**	**3-Tap**	**4-Temp**	**4-Tap**	**5-Temp**	**5-Tap**
INPUT			**Fallow**				**Fallow**	**Fallow**	**Fallow**	**Fallow**	**Fallow**	**Fallow**				**Fallow**	**Fallow**	**Fallow**	**Fallow**	**Fallow**
Field preparation	Labor	2.5	”	18	8	16	”	”	”	”	”	”	45	20	40	”	”	”	”	”
			”				”	”	”	”	”	”				”	”	”	”	”
Crop establishment	Labor	2.5	”	6	4	6	”	”	”	”	”	”	15	10	15	”	”	”	”	”
	Seed	0.21	”	20	20	20	”	”	”	”	”	”	4.2	4.2	4.2	”	”	”	”	”
Weed control	Labor	2.5	”	15	8	20	”	”	”	”	”	”	37.5	20	50	”	”	”	”	”
	Herbicide	5.5	”	3	1.5	3	”	”	”	”	”	”	16.5	8.25	16.5	”	”	”	”	”
Fertilizer applic.	Labor	2.5	”	7		7	”	”	”	”	”	”	17.5		17.5	”	”	”	”	”
	Urea	11	”	2		2	”	”	”	”	”	”	22		22	”	”	”	”	”
	DAP	14	”	1		1	”	”	”	”	”	”	14		14	”	”	”	”	”
Doubling	Labor	2.5	”	6		6	”	”	”	”	”	”	15		15	”	”	”	”	”
Harvest	Labor	2.5	”	11.7	4.2	8.3	”	”	”	”	”	”	29.3	10.5	20.8	”	”	”	”	”
Shelling	Labor	2.5	”	14	5	10	”	”	”	”	”	”	35.0	12.5	25.0	”	”	”	”	”
Additional mgt	Labor	2.5	”				”	”	”	”	”	”				”	”	”	”	”
	Other		”				”	”	”	”	”	”				”	”	”	”	”
Depreciation implements	Annuity		”				”	”	”	”	”	”	10	10	10	”	”	”	”	”
Subtotal labor		2.5	”	78	29	73	”	”	”	”	”	”	194	73	183	”	”	”	”	”
Subtotal non-labor			”				”	”	”	”	”	”	52.7	22.5	52.7	”	”	”	”	”
Total input			”				”	”	”	”	”	”	247	95	236	”	”	”	”	”
OUTPUT			**Fallow**				**Fallow**	**Fallow**	**Fallow**	**Fallow**	**Fallow**	**Fallow**				**Fallow**	**Fallow**	**Fallow**	**Fallow**	**Fallow**
Maize grain consumption	kg	0.14	”	1400	500	1000	”	”	”	”	”	”	196	70	140	”	”	”	”	”
Other byproduct	lump sum	1	”				”	”	”	”	”	”				”	”	”	”	”
Total												”	196	70	140	”	”	”	”	”
Net benefit (Return to land US$/ha)												”	-51	-25	-96	”	”	”	”	”
Cost price per kg (US$/kg)												”	0.18	0.19	0.24	”	”	”	”	”
	Labor											”	0.14	0.15	0.18	”	”	”	”	”
	Non-labor											”	0.04	0.04	0.05	”	”	”	”	”
Return to labor and land (US$/ha)												”	143	48	87	”	”	”	”	”
Labor productivity (Kg maize output/day)												”	18.0	17.1	13.6	”	”	”	”	”
Return to labor day (and land) (US$/ld)												”	1.8	1.6	1.2	”	”	”	”	”

By-product: In contrast to the upland zone, *acauales* in the lowland zone are generally grassy and thus produce only a negligible amount of firewood.

Table A-5 presents a similar crop budget for the improved cropping system (the *with* case) for the model farm in the lowland zone. Again, the budget is on a ha basis and presents data for each season (*temporal* and *tapachole*) annually for a specific field. It is assumed that a field is cultivated annually, with seasonal fallows (two tapachole fallows, one temporal fallow) spread out over the four-year cycle. However for a variety of reasons (see below) input and output levels are different for subsequent periods of use, and the budget therefore presents data for both the first four years as well as the subsequent four years (Years 6-9). In even later years, input and output levels similar to the Years 6-9 are supposed to prevail. The overall implications of the budget are discussed in the main text. Some details follow:

Field preparation: Labor demands for the first year are assumed to be similar to those in the *without* case, except for the absence of burning. In subsequent years labor savings occur as a result of relatively easier preparation (slashing) of fields with cover crops (both for *temporal* and *tapachole* seasons).

Crop establishment: Labor needs for sowing are assumed to be slightly higher than in *without* case due to the presence of crop residue and mulch.

Weed control: Weeds become less problematic over time as the cover crop, once fully established, shades out most weeds, thereby substantially reducing labor and herbicide needs for weeding in both seasons.

Fertilizer application: Fertilizers levels in *temporal* season are increased in the improved system. Whereas fertilizers provide most of the N in the initial two years, most of the subsequent N needs of the maize crop are supplied by the cover crop (once it is fully established). Consequently, the application rate and the labor demand for application drop over time. Application rates are assumed to total 110 kg N per ha and 46 kg P_2O_5 per ha in the early years, and only 60 kg N per ha and 35 kg P_2O_5 per ha in the later years.

Harvest: Harvesting labor is directly related to yield, as in the *with* case for the upland zone (3.5 bags per person per day).

Shelling: Shelling assumes the same rate as in the *without* case in the upland zone (100 kg per day).

Additional management of the cover crop: Establishment and maintenance costs of the cover crop are assumed to be similar to those in the upland zone. Labor required for resowing cover crop for temporal fallow is assumed to total only one day per ha.

Additional management of the hedgerow: Establishment and maintenance costs of the hedgerow are assumed to be similar to costs in the upland zone.

Maize yields: In the first year, yields are assumed to increase a net 40% relative to the *without* case, mainly as a direct response to increased fertilizer application. In the second and third years, yields are expected to rise a further 30 and 10% relative to the first year in the *without* case. These yield increases are mainly a result of the other measures starting to take effect (cover crops, residue conservation, hedgerows), thereby increasing fertility and available soil moisture. Once the system is fully established, yields are assumed to remain constant over time.

Table A-5. Crop budget for the with lease in the lowland zone (ha basis)

Year 1-5 Activity	Unit	Price (US$/unit)	Quantity (units/ha)									Cost (US$/ha)								
Year - Season			1	2-Temp	2-Tap	3-Temp	3-Tap	4-Temp	4-Tap	5-Temp	5-Tap	1	2-Temp	2-Tap	3-Temp	3-Tap	4-Temp	4-Tap	5-Temp	5-Tap
INPUT			Fallow		Fallow		Fallow			Fallow		Fallow		Fallow		Fallow			Fallow	
Field preparation	Labor	2.5	"	16	"	14	"	14	6	"	8	"	40	"	35	"	35	15	"	20
			"		"		"			"		"		"			"		"	
Crop establishment	Labor	2.5	"	7	"	7	"	7	4.7	"	7	"	17.5	"	17.5	"	17.5	11.7	"	17.5
	Seed	0.21	"	20	"	20	"	20	20	"	20	"	4.2	"	4.2	"	4.2	4.2	"	4.2
Weed control	Labor	2.5	"	15	"	15	"	12	6	"	6	"	37.5	"	37.5	"	30	15	"	15
	Herbicide	5.5	"	3	"	2	"	1.5		"		"	16.5	"	11	"	8.25		"	
Fertilizer applic.	Labor	2.5	"	8	"	8	"	7		"		"	20	"	20	"	17.5		"	
	Urea	11	"	4	"	4	"	2		"		"	44	"	44	"	22		"	
	DAP	14	"	2	"	2	"	1.5		"		"	28	"	28	"	21		"	
Doubling	Labor	2.5	"	6	"	6	"	6		"		"	15	"	15	"	15		"	
Harvest	Labor	2.5	"	18.7	"	22.7	"	24	6.7	"	8.6	"	46.8	"	56.8	"	60.0	16.8	"	21.5
Shelling	Labor	2.5	"	19.6	"	23.8	"	25.2	7	"	9	"	49.0	"	59.5	"	63.0	17.5	"	22.5
Additional mgt																				
cover crop	Labor	2.5	"	5	"	5	"	5		"	2	"	12.5	"	12.5	"	12.5		"	5
	Other	1	"	7.5	"		"			"		"	7.5	"		"			"	
Additional																				
mgt hedgerow	Labor	2.5	"	22	"	5	"	5		"	5	"	55	"	12.5	"	12.5		"	12.5
	Other	1	"	30	"		"			"		"	30	"	0	"			"	
Depreciation																				
implements	Annuity		"		"		"			"		"	10	"	10	"	5	5	"	10
Subtotal labor		2.5		117		107		105	30		46	"	293	"	266	"	263	76	"	114
Subtotal non-labor												"	140	"	97	"	60	9	"	14
Total input												"	433	"	363	"	323	85	"	128
OUTPUT			Fallow		Fallow		Fallow			Fallow		Fallow		Fallow		Fallow			Fallow	Fallow
Maize grain																				
consumption	kg	0.14	"	1960	"	2380	"	2520	700	"	900	"	274	"	333	"	353	98	"	126
Other byproduct	lump sum	1	"		"		"			"		"		"		"			"	
Total												"	274	"	333	"	353	98	"	126
Net benefit (Return to land/ha) US$												"	-159	"	-30	"	29	13	"	-2
Cost price per kg (US$/kg)												"	0.22	"	0.15	"	0.13	0.12	"	0.14
Labor												"	0.15	"	0.11	"	0.10	0.11	"	0.13
Non-labor												"	0.07	"	0.04	"	0.02	0.01	"	0.02
Return to labor and land (US$/ha)												"	134	"	236	"	292	89	"	112
Labor productivity (Kg maize output/day)												"	16.7	"	22.3	"	24.0	23.1	"	19.7
Return to labor day (and land) (US$/ld)												"	1.1	"	2.2	"	2.8	2.9	"	2.5

(Table A-5 continued)

Year 6-9 Activity	Unit	Price (US$/unit)	Quantity (units/ha)								Cost (US$/ha)							
Year - Season			**6-Temp**	**6-Tap**	**7-Temp**	**7-Tap**	**8-Temp**	**8-Tap**	**9-Temp**	**9-Tap**	**6-Temp**	**6-Tap**	**7-Temp**	**7-Tap**	**8-Temp**	**8-Tap**	**9-Temp**	**9-Tap**
INPUT			**Fallow**		**Fallow**			**Fallow**			**Fallow**		**Fallow**			**Fallow**		
Field preparation	Labor	2.5	14	“	14	“	14	6	“	8	35	“	35	“	35	15	“	20
			“		“			“			“		“			“		
Crop establishment	Labor	2.5	7	“	7	“	7	4.7	“	7	17.5	“	17.5	“	17.5	11.7	“	17.5
	Seed	0.21	20	“	20	“	20	20	“	20	4.2	“	4.2	“	4.2	4.2	“	4.2
Weed control	Labor	2.5	12	“	12	“	12	6	“	6	30	“	30	“	30	15	“	15
	Herbicide	5.5	1.5	“	1.5	“	1.5		“		8.25	“	8.25	“	8.25		“	
Fertilizer applic.	Labor	2.5	7	“	7	“	7		“		17.5	“	17.5	“	17.5		“	
	Urea	11	2	“	2	“	2		“		22	“	22	“	22		“	
	DAP	14	1.5	“	1.5	“	1.5		“		21	“	21	“	21		“	
Doubling	Labor	2.5	6	“	6	“	6		“		15	“	15	“	15		“	
Harvest	Labor	2.5	24	“	24	“	24	8.1	“	8.6	60.0	“	60.0	“	60.0	20.3	“	21.5
Shelling	Labor	2.5	25.2	“	25.2	“	25.2	8.5	“	9	63.0	“	63.0	“	63.0	21.3	“	22.5
Additional mgt cover crop	Labor	2.5	5	“	5	“	5		“	2	12.5	“	12.5	“	12.5		“	5
	Other	1	“		“			“			“		“			“		
Additional mgt hedgerow	Labor	2.5	5	“	5	“	5		“	5	12.5	“	12.5	“	12.5		“	12.5
	Other	1	“		“			“			“		“			“		
Depreciation implements	Annuity		“		“			“			10	“	10	“	5	5	“	10
Subtotal labor		2.5	105		105		105	33		46	263	“	263	“	263	83	“	114
Subtotal non-labor											65	“	65	“	60	9	“	14
Total input											328	“	328	“	323	92	“	128
OUTPUT				**Fallow**		**Fallow**			**Fallow**			**Fallow**		**Fallow**			**Fallow**	**Fallow**
Maize grain consumption	kg	0.14	2520	“	2520	“	2520	850	“	900	353	“	353	“	353	119	“	126
Other byproduct	lump sum	1		“		“			“		“		“			“		
Total											353	“	353	“	353	119	“	126
Net benefit (Return to land, US$/ha)												24	“	24	“	29	27	“ -2
Cost price per kg (US$/kg)											0.13	“	0.13	“	0.13	0.11	“	0.14
	Labor										0.10	“	0.10	“	0.10	0.10	“	0.13
	Non-labor										0.03	“	0.03	“	0.02	0.01	“	0.02
Return to labor and land (US$/ha)											287	“	287	“	292	110	“	112
Labor productivity (Kg maize output/day)											24.0	“	24.0	“	24.0	25.6	“	19.7
Return to labor day (and land) (US$/ld)											2.7	“	2.7	“	2.8	3.3	“	2.5

Appendix B

Labor Use

Labor is an important farm resource that potentially limits intensification efforts. Therefore, determining the labor requirements in both the *with* and *without* cases helps to assess the potential for intensification. Furthermore, it is useful to distinguish between labor requirements by operation and by month (Gittinger 1982, p. 102). The crop budgets in Appendix A highlighted labor use by operation. Appendix B presents the temporal distribution of labor use in more detail.

Table B-1 is the key used to assign labor requirements per activity for respective months. April has been chosen as the start of the cropping year because field preparation activities for the main *temporal* season generally start in this month. Table B-2 presents the labor distribution by year and month on a ha basis for the upland zone. Because the *with* case exhibits higher annual totals, it is not too surprising it also generally presents slight increases in the monthly requirements. However, due to differences in acreages, a farm-level comparison offers a more realistic means of determining eventual labor bottlenecks. Table B-3 presents the labor distribution by year and month on a farm basis for the upland zone. At the farm level, annual labor requirements are similar for both the *with*

Table B-1. Assumed temporal distribution of activities

Zone	Crop	Activity	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Upland & lowland	Maize temporal	Field preparation	******	*****										
		Crop establishment			******									
		Weed control & fertilizer			*****	*****	*****							
		Doubling							******					
		Harvest (see footnote)								*******	*******	*	*	* *
		Shelling									* * *	* * *	* * *	* * *
Upland & lowland	Cover intercrop	Sowing					******							
		Pruning						* * *	* *					
		Seed collection									***			
Lowland	Cover sole crop	Sowing			******									
		Seed collection							***					
Upland & lowland	Hedgerow	Establishment (1st year)	*****	*****	*****									
		Reseeding (1st year)				***								
		Maintenance (2nd year on)		******										
Lowland	Maize tapachole	Field preparation							******					
		Crop establishment									******			
		Weed control & fertilizer									******	*****		
		Harvest												******
		Shelling	* * *	* * *	* *									

Harvest in lowland zone generally concentrated in the early months; in the buffer zone harvest generally extended over the longer and *without* situation. The *with* situation gives a more uniform distribution of labor requirements over the year. Especially in the busy months of May-July, the *with* situation alleviates the original labor peak.

Tables B-4 and B-5 present similar data for the lowland zone, where annual labor requirements are higher for the *with* case. As a result, monthly labor requirements per ha and for the farm as a whole are generally higher too. Nevertheless, the *with* case only represents a slight increase in labor requirements in the first month of the busy period of May-July, and actually reduces labor requirements in the subsequent two months.

The following observations in relation to the tables are in order:

- Monthly labor requirements are indicative only. Requirements have thus been rounded to the nearest day. As annual totals were calculated before rounding, these may differ slightly from the sum of monthly (rounded) totals.
- Annual totals in the lowland zone occasionally differ from the respective annual totals reported in the crop budgets. This is mainly the result of the *tapachole* season, which causes an overflow of labor (for shelling) into the subsequent cropping year (see Table B-1).
- Column maxima before rounding are highlighted in bold.

Table B-2. Labor distribution by year and month on ha basis, upland zone

	Labor days/Month													
	Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
Without case	2	7	13	12	13	6	0	6	4	4	5	5	5	80
	3	5	11	13	16	7	0	6	3	3	5	4	3	76
	4	5	11	15	**17**	9	0	6	3	3	3	3	2	78
	5-10													*Fallow*
With case	2	**11**	**24**	**20**	**17**	**10**	**1**	**7**	7	8	7	7	6	126
	3	5	14	14	14	9	**1**	**7**	8	9	8	**8**	7	104
	4	5	14	13	11	8	**1**	**7**	**9**	**10**	**9**	**8**	**8**	103
	5													*Fallow*
	6	5	16	13	12	8	**1**	**7**	**9**	**10**	**9**	**8**	**8**	106
	7-8	5	14	12	9	7	**1**	**7**	**9**	**10**	**9**	**8**	**8**	99
	9													*Fallow*

Table B-3. Labor distribution by year and month on farm basis, upland zone

	Labor days/Month													
	Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
Without case	2	**14**	**26**	24	26	12	0	**12**	8	8	11	10	9	160
	3	10	22	26	32	14	0	**12**	6	6	10	8	7	153
	4	10	22	**30**	**34**	**18**	0	**12**	6	6	7	7	4	155
With case	2	13	25	22	22	11	1	10	8	8	9	8	8	143
	3	11	25	24	24	13	1	10	9	10	10	10	8	153
	4	11	**26**	24	21	14	**2**	11	12	13	12	11	10	**164**
	5	11	**26**	24	21	14	**2**	11	11	12	11	11	10	162
	6	8	22	20	19	13	**2**	11	13	14	**13**	**12**	11	154
	7	8	22	19	16	12	**2**	11	**14**	**15**	**13**	**12**	12	154
	8->	8	22	19	15	11	**2**	11	**14**	**15**	**13**	**12**	12	152

Note: For the *without* case, years after year 5 are repetitions of years 2-4.

Table B-4. Labor distribution by year and month on ha basis, lowland zone

	Labor days/Month													
	Year	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Total**
Without case	2	6	12	11	12	5	0	6	14	12	11	5	8	102
	3	8	13	13	13	7	0	6	4	4	4	3	3	78
	4-5													Fallow
With case	2	**10**	**20**	**18**	**14**	**8**	**1**	**7**	10	10	7	7	6	117
	3	4	15	13	11	**8**	**1**	**7**	12	12	8	8	8	107
	4	4	15	12	9	7	**1**	**7**	**18**	**20**	**13**	**8**	15	129
	5	4	8	1	0	0	0	1	8	9	4	0	9	44
	6	9	19	12	9	7	**1**	**7**	12	13	9	8	8	114
	7	4	15	12	9	7	**1**	**7**	12	13	9	8	8	105
	8	4	15	12	9	7	**1**	**7**	**18**	**20**	**13**	**8**	**16**	**130**
	9	5	9	1	0	0	0	1	8	9	4	0	9	45

Table. B-5. Labor distribution by year and month on farm basis, lowland zone

	Labor days/Month													
	Year	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Total**
Without case	2->	**9**	17	16	17	8	0	8	12	10	10	5	7	120
With case	2	7	15	13	13	6	0	6	13	11	10	6	7	107
	3	**9**	20	18	**17**	9	**1**	**9**	12	12	9	7	8	131
	4	**9**	**21**	**19**	16	**10**	**1**	**9**	13	13	9	7	9	136
	5	7	19	15	11	8	**1**	7	14	15	9	6	11	124
	6	7	19	13	10	7	**1**	7	16	17	11	8	13	128
	7	7	19	12	9	7	**1**	7	**17**	**18**	**12**	**8**	13	131
	8->	7	19	12	9	7	**1**	7	**17**	**18**	**12**	**8**	**14**	131

Appendix C

Cost Benefit Analysis Results

Table C-1. Farm-level implications over time of intensifying model farm in upland zone (farm basis)

Discount rate	**15%**													
			Quantity (units/farm per year, where US$ are discoun											
	Year ->	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1-5**	**6-10**	**TOTAL**
WITHOUT CASE	**Unit**													
Total labor	ld	155	160	153	155	160	153	155	160	153	155	783	776	1559
Labor costs	US$	338	302	251	222	199	165	146	131	108	96	1311	646	1958
Non-labor costs	US$	15	13	11	10	8	7	6	5	5	4	56	28	84
Total input costs	US$	352	315	262	232	207	172	152	136	113	100	1368	674	2041
Total output	kg	1600	2500	2000	1600	2500	2000	1600	2500	2000	1600	10200	9700	19900
Gross benefit	US$	195	302	184	128	199	121	84	131	80	55	1008	471	1479
Net benefit	US$	-158	-12	-78	-104	-8	-51	-68	-5	-34	-45	-359	-203	-562
WITH CASE														
Total labor	ld	155	143	153	164	162	154	154	152	152	152	777	763	1539
Labor costs	US$	338	269	251	236	204	168	144	124	108	94	1299	638	1936
Non-labor costs	US$	15	40	49	55	48	29	21	14	13	11	206	87	293
Total input costs	US$	352	309	300	291	252	197	165	138	120	105	1504	725	2229
Total output	kg	1600	2125	2375	2881	2761	3098	3281	3281	3281	3281			
Gross benefit	US$	195	244	219	231	192	187	173	150	131	114	1080	754	1835
Net benefit	US$	-158	-65	-81	-60	-61	-9	8	12	10	9	-424	30	-395
NET (WITH - WITHOUT)														
Total labor	ld	0	-17	0	9	2	2	-2	-8	-1	-4	-6	-13	-19
Labor costs	US$	0	-33	0	14	6	3	-2	-7	-1	-2	-13	-8	-21
Non-labor costs	US$	0	27	38	45	39	21	14	9	8	7	150	59	209
Total input costs	US$	0	-5	38	59	45	24	13	2	7	4	137	51	188
Total output	kg	0	-375	375	1281	261	1098	1681	781	1281	1681	1543	6523	8065
Gross benefit	US$	0	-59	35	103	-7	66	88	19	251	58	72	283	355
Net benefit	US$	0	-53	-4	43	-52	42	76	17	44	54	-65	233	168
B/C ratio	NR		-1079%	91%	173%	-15%	272%	699%	887%	726%	1330%	52%	559%	189%

Table C-2. Sensitivity analysis of farm-level implications of intensifying model farm in upland zone (farm basis)

		Quantity (units/farm per year, where US$ are discounted values)										SUBTOTAL		TOTAL
	Year ->	1	2	3	4	5	6	7	8	9	10	1-4	5-10	1-10
SENSITIVITY ANALYSIS DISCOUNT RATE														
Discount rate: 10%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-17	0	9	2	2	-2	-8	-1	-4	-6	-13	-19
Labor costs	US$	0	-36	0	17	7	4	-2	-10	-1	-4	-12	-13	-24
Non-labor costs	US$	0	30	43	54	49	28	20	13	12	11	176	82	259
Total input costs	US$	0	-6	44	71	56	32	17	3	10	7	165	70	234
Total output	kg	0	-375	375	1281	261	1098	1681	781	1281	1681	1543	6523	8065
Gross benefit	US$	0	-64	39	123	-8	87	121	28	76	91	90	402	492
Net benefit	US$	0	-58	-4	52	-64	55	103	25	66	84	-75	332	257
B/C ratio		NR	-1079%	91%	173%	-15%	272%	699%	887%	726%	1330%	54%	577%	210%
Discount rate: 20%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-17	0	9	2	2	-2	-8	-1	-4	-6	-13	-19
Labor costs	US$	0	-30	0	12	5	2	-1	-5	-1	-2	-13	-6	-19
Non-labor costs	US$	0	25	33	38	32	17	11	6	5	4	128	43	172
Total input costs	US$	0	-5	34	50	36	19	9	2	5	3	115	38	152
Total output	kg	0	-375	375	1281	261	1098	1681	781	1281	1681	1543	6523	8065
Gross benefit	US$	0	-54	30	87	-5	51	66	14	35	38	58	204	261
Net benefit	US$	0	-49	-3	36	-42	33	56	12	30	35	-57	166	109
B/C ratio		NR	-1079%	91%	173%	-15%	272%	699%	887%	726%	1330%	50%	543%	171%
SENSITIVITY ANALYSIS OPPORTUNITY COST LABOR														
Opportunity cost labor: US$ 1.5 / day														
NET (WITH - WITHOUT)														
Total labor	ld	0	-17	0	9	2	2	-2	-8	-1	-4	-6	-13	-19
Total labor	ld	0	-17	0	9	2	2	-2	-8	-1	-4	-6	-13	-19
Labor costs	US$	0	-20	0	8	3	2	-1	-4	0	-1	-9	-5	-14
Non-labor costs	US$	0	27	38	45	39	21	14	9	8	7	150	59	209
Total input costs	US$	0	8	38	53	42	23	13	5	7	5	141	54	195
Total output	kg	0	-375	375	1281	261	1098	1681	781	1281	1681	1543	6523	8065
Gross benefit	US$	0	-51	35	103	3	66	88	26	51	58	89	290	379
Net benefit	US$	0	-59	-3	49	-39	44	75	21	44	53	-52	236	185
B/C ratio		NR	667%	91%	192%	8%	290%	662%	531%	697%	1092%	63%	539%	195%
Opportunity cost labor: US$ 3.5 / day														
NET (WITH - WITHOUT)														
Total labor	ld	0	-17	0	9	2	2	-2	-8	-1	-4	-6	-13	-19
Labor costs	US$	0	-46	0	20	9	5	-2	-9	-1	-3	-17	-12	-28
Non-labor costs	US$	0	27	38	45	39	21	14	9	8	7	150	59	209
Total input costs	US$	0	-19	38	65	48	26	12	-1	7	3	133	48	181
Total output	kg	0	-375	375	1281	261	1098	1681	781	1281	1681	1543	6523	8065
Gross benefit	US$	0	-66	35	103	-17	66	88	13	51	58	54	277	331
Net benefit	US$	0	-48	-4	37	-65	40	77	13	44	55	-79	229	151
B/C ratio		NR	-357%	90%	157%	-35%	255%	739%	-2532%	759%	1700%	41%	582%	183%
SENSITIVITY ANALYSIS YIELD INCREASE														
Initial yield increase: 30%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-19	-3	4	-3	-4	-9	-15	-8	-11	-21	-47	-68
Labor costs	US$	0	-35	-5	7	-1	-4	-8	-12	-6	-7	-34	-37	-70
Non-labor costs	US$	0	27	38	45	39	21	14	9	8	7	150	59	209
Total input costs	US$	0	-8	33	52	39	18	6	-3	2	0	116	23	138
Total output	kg	0	-438	219	1014	4	778	1330	430	930	1330	799	4797	5596
Gross benefit	US$	0	-65	20	81	-25	47	70	3	37	46	11	203	215
Net benefit	US$	0	-58	-13	29	-63	29	64	7	35	46	-104	181	77
B/C ratio		NR	-847%	61%	157%	-64%	267%	1132%	-96%	1748%	41833%	10%	901%	155%
Initial yield increase: 50%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-16	3	14	7	8	5	-1	6	3	8	21	29
Labor costs	US$	0	-30	5	22	12	10	5	-1	4	2	9	20	29
Non-labor costs	US$	0	27	38	45	39	21	14	9	8	7	150	59	209
Total input costs	US$	0	-3	43	67	51	31	19	8	12	9	159	79	237
Total output	kg	0	-313	531	1548	519	1417	2033	1133	1633	2033	2286	8248	10534
Gross benefit	US$	0	-52	49	124	11	86	107	35	65	70	132	364	496
Net benefit	US$	0	-49	6	57	-40	54	88	28	53	62	-26	285	258
B/C ratio		NR	-1695%	113%	185%	22%	274%	559%	454%	545%	814%	83%	461%	209%

Table C-3. Farm level implications over time of intensifying model farm in lowland zone (farm basis)

Discount rate	**15%**														
		US$ are discounted values													
Year ->		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1-5**	**6-10**	**TOTAL**
WITH CASE															
Total labor	ld	120	120	120	120	120	120	120	120	120	120	120	120	120
Labor costs	US$	261	227	197	172	149	130	113	98	85	74	1007	500	1507
Non-labor costs	US$	74	64	56	49	42	37	32	28	24	21	286	142	428
Total input costs	US$	335	292	253	220	192	167	145	126	110	95	1292	643	1935
Total output	kg	1933	1933	1933	1933	1933	1933	1933	1933	1933	1933	1933	1933	1933
Gross benefit	US$	235	205	178	155	135	117	102	88	77	67	907	451	1358
Net benefit	US$	-100	-87	-76	-66	-57	-50	-43	-38	-33	-28	-385	-191	-577
WITH CASE															
Total labor	ld	120	110	131	137	127	128	131	131	131	131	625	653	1278
Labor costs	US$	261	209	219	202	164	140	123	107	93	81	1054	545	1599
Non-labor costs	US$	74	73	80	69	53	36	27	23	20	18	349	124	473
Total input costs	US$	335	282	299	270	217	176	150	131	114	99	1403	669	2072
Total output	kg	1933	1920	2226	2478	2400	2848	3053	3103	3103	3103	10958	15210	26167
Gross benefit	US$	235	203	205	198	167	172	161	142	123	107	1009	706	1715
Net benefit	US$	-100	-79	-94	-72	-50	-3	11	11	10	8	-395	37	-357
NET (WITH - WITHOUT)															
Total labor	ld	0	-10	11	17	7	8	10	11	11	11	25	52	77
Labor costs	US$	0	-18	21	30	14	10	10	9	8	7	48	44	92
Non-labor costs	US$	0	9	24	20	11	-1	-5	-4	-4	-3	63	-18	45
Total input costs	US$	0	-10	45	50	25	9	5	5	4	4	111	26	137
Total output	kg	0	-13	293	545	467	915	1120	1170	1170	1170	1292	5544	6836
Gross benefit	US$	0	-1	27	44	32	55	59	54	47	40	102	255	357
Net benefit	US$	0	8	-18	-6	7	46	54	49	42	37	-9	229	219
B/C ratio	%	NR	15%	59%	87%	129%	613%	1272%	1111%	1111%	1111%	92%	969%	259%

Table C-4. Sensitivity analysis of farm level implications of intensifying model farm in lowland zone (farm basis)

		Quantity (units/farm per year, where US$ are discounted values)										SUBTOTAL		TOTA
	Year ->	1	2	3	4	5	6	7	8	9	10	1-5	6-10	1-10
SENSITIVITY ANALYSIS DISCOUNT RATE														
Discount rate: 10%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-10	11	17	7	8	10	11	11	11	25	52	77
Labor costs	US$	0	-20	25	36	18	14	13	13	12	11	58	63	122
Non-labor costs	US$	0	10	27	24	14	-2	-7	-6	-6	-5	74	-26	48
Total input costs	US$	0	-11	52	60	32	12	6	7	6	6	133	37	170
Total output	kg	0	-13	293	545	467	915	1120	1170	1170	1170	1292	5544	6836
Gross benefit	US$	0	-2	31	52	41	72	80	76	69	63	122	362	484
Net benefit	US$	0	9	-21	-8	9	60	74	70	63	57	-11	325	314
B/C ratio	%	NR	15%	59%	87%	129%	613%	1272%	1111%	1111%	1111%	92%	980%	285%
Discount rate: 20%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-10	11	17	7	8	10	11	11	11	25	52	77
Labor costs	US$	0	-17	19	26	12	8	7	7	6	5	39	32	71
Non-labor costs	US$	0	8	21	17	9	-1	-4	-3	-3	-2	55	-13	42
Total input costs	US$	0	-9	40	42	20	7	3	3	3	2	94	19	113
Total output	kg	0	-13	293	545	467	915	1120	1170	1170	1170	1292	5544	6836
Gross benefit	US$	0	-1	24	37	26	43	44	38	32	26	86	183	268
Net benefit	US$	0	8	-16	-5	6	36	40	35	29	24	-8	164	156
B/C ratio	%	NR	15%	59%	87%	129%	613%	1272%	1111%	1111%	1111%	91%	958%	238%
SENSITIVITY ANALYSIS OPPORTUNITY COST LABOR														
Opportunity cost labor: US$ 1.5 / day														
NET (WITH - WITHOUT)														
Total labor	ld	0	-10	11	17	7	8	10	11	11	11	25	52	77
Labor cost	US$	0	-11	12	16	7	6	6	6	5	4	24	26	50
Non-labor costs	US$	0	9	24	20	11	-1	-5	-4	-4	-3	63	-18	45
Total input costs	US$	0	-2	36	36	18	4	1	1	1	1	88	8	96
Total output	kg	0	-13	293	545	467	915	1120	1170	1170	1170	1292	5544	6836
Gross benefit	US$	0	-1	27	44	32	55	59	54	47	40	102	255	357
Net benefit	US$	0	1	-9	7	15	51	58	52	46	40	14	247	261
B/C ratio	%	NR	61%	75%	120%	182%	1272%	8110%	4841%	4841%	4841%	116%	3193%	372%
Opportunity cost labor: US$ 3.5 / day														
NET (WITH - WITHOUT)														
Total labor	ld	0	-10	11	17	7	8	10	11	11	11	25	52	77
Labor costs	US$	0	-26	31	44	22	15	14	13	11	10	71	63	134
Non-labor costs	US$	0	9	24	20	11	-1	-5	-4	-4	-3	63	-18	45
Total input costs	US$	0	-17	55	64	33	14	9	9	7	6	134	45	179
Total output	kg	0	-13	293	545	467	915	1120	1170	1170	1170	1292	5544	6836
Gross benefit	US$	0	-1	27	44	32	55	59	54	47	40	102	255	357
Net benefit	US$	0	16	-28	-20	-0	42	50	45	39	34	-33	210	178
B/C ratio	%	NR	8%	49%	68%	100%	404%	690%	628%	628%	628%	76%	571%	199%
SENSITIVITY ANALYSIS YIELD INCREASE														
Initial yield increase: 30%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-11	9	13	2	2	4	5	5	5	13	20	32
Labor costs	US$	0	-20	18	24	8	4	4	4	3	3	29	17	46
Non-labor costs	US$	0	9	24	20	11	-1	-5	-4	-4	-3	63	-18	45
Total input costs	US$	0	-11	42	44	19	2	-1	-1	-1	-1	93	-1	92
Total output	kg	0	-60	178	337	230	613	790	827	827	827	686	3885	4570
Gross benefit	US$	0	-6	16	27	16	37	42	38	33	29	53	178	231
Net benefit	US$	0	5	-25	-17	-3	35	43	39	34	29	-40	179	139
B/C ratio	%	NR	55%	40%	62%	85%	1548%	-2816%	-5531%	-5531%	-5531%	57%	-2E+04	252%
Initial yield increase: 50%														
NET (WITH - WITHOUT)														
Total labor	ld	0	-9	13	21	11	14	17	18	18	18	36	85	121
Labor costs	US$	0	-17	25	37	21	17	16	15	13	11	66	71	137
Non-labor costs	US$	0	9	24	20	11	-1	-5	-4	-4	-3	63	-18	45
Total input costs	US$	0	-8	49	56	31	16	11	10	9	8	129	53	183
Total output	kg	0	33	408	753	703	1217	1450	1512	1512	1512	1898	7203	9102
Gross benefit	US$	0	4	38	60	49	74	76	69	60	52	150	332	482
Net benefit	US$	0	12	-12	4	17	58	66	59	51	45	21	278	299
B/C ratio	%	NR	-44%	76%	107%	156%	472%	715%	672%	672%	672%	116%	622%	264%

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