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E C O N O M I C S

Working Paper 01-02

# The Impact of Conservation Tillage on the Productivity and Stability of Maize Cropping Systems: A Case Study in Western Mexico

**Damien Jourdain, Eric Scopel, and François Affholder**

CIMMYT®

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# Contents

**Page**

iv **Abstract**

v **Acknowledgement**

**1 Introduction**

**2 Stochastic Dominance**

**3 The Study Area**
3 Two contrasting agroeconomic zones
4 Existing cropping systems
6 Introduction of conservation tillage

**7 Description of the Model**
7 Economic analysis
7 Plant growth model to obtain yields
9 Weed control as a tactical choice
9 Farm prices and production incentives

**12 Results**
12 Costs of production
12 Return to land
14 Returns to labor

**15 Dominance Analysis**

**16 Sensitivity to the Price of Labor**

**17 Discussion: Consequences for Promotion of Conservation Tillage to Farmers**

## Abstract

This paper examines the economics of introducing conservation tillage into maize cropping systems in the state of Jalisco, in the western part of Mexico. A stochastic cost-benefit analysis (SCBA) of introducing conservation tillage in two contrasting agro-climatic zones in the four main maize management systems in the area was carried out. The SCBA takes into account the effects of conservation tillage on average returns and fully evaluates its potential risk-reducing aspect. The SCBA results were then used for a stochastic dominance analysis to evaluate farmers' incentives, characterized by their aversion to risk. The analysis reveals that although conservation tillage is economically viable, cash-constrained farmers, especially in the dry areas, may not readily adopt it. This is because conservation tillage is not adapted to small-scale farmers in Mexico, who lack seeding equipment and need techniques that are less reliant on herbicides. It is suggested that more work should be done with the participation of farmers in the region to attain a conservation tillage system that is better adapted to their circumstances.

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# The Impact of Conservation Tillage on the Productivity and Stability of Maize Cropping Systems: A Case Study in Western Mexico

***Damien Jourdain, Eric Scopel, and François Affholder***

## Introduction

Increases in productivity of land and labor are essential for farmers in Mesoamerica, who are facing increased competition from world markets (Sain and López-Pereira 1999). In response, conservation tillage (CT) has been promoted as a productivity enhancing and resource conserving technology that benefits maize farmers. Conservation tillage is defined as "any tillage or planting system that leaves 30% or more of the soil surface covered with residues at planting time" (Conservation Tillage Information Center 1994). It enhances moisture use efficiency, prevents soil erosion (Lal 1989; Scopel 1994), and results in higher and more stable maize yields, especially in areas where rainfall is low or scattered during the maize growing period (i.e., for rainfed maize grown under semiarid conditions).

In spite of these advantages, CT has not been widely adopted in Mexico, which has a large area of rainfed cultivated maize. This paper examines the costs and benefits of adopting CT in the state of Jalisco in the western part of Mexico.[1] The agronomic consequences of adopting CT, as well as the potential constraints to adoption have been documented elsewhere (Tripp et al. 1993; van Nieuwkoop 1993; van Nieuwkoop et al. 1994; Sain and Barreto 1996; Erenstein 1999).

The different cropping systems in Jalisco are compared and analyzed, using a stochastic cost-benefit analysis (SCBA), to see how returns would be affected by adoption of CT techniques. The SCBA model allows comparisons between cropping systems in terms of average expected returns and distribution of net returns. A stochastic dominance analysis of the SCBA results completes the study by addressing farmers' attitudes toward risk and the potential influence that this has on CT adoption. Two critical factors affecting farmers' decision-making are taken into account: average expected returns and risk.

Subsequent sections in this paper describe the stochastic dominance theory, the study area, the hypothesis and methods employed, and a discussion of the results with a stochastic dominance and a sensitivity analysis. Conclusions are then drawn about the likely adoption of CT techniques in the region and how adoption could be promoted.

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[1] This study is part of the CIMMYT / CIRAD / Instituto Nacional de Investigaciones Forestales y Agropecuarias (INIFAP) joint research project "Study of sustainable cropping systems based on conservation tillage for rainfed maize in Mexico."

## Stochastic Dominance

Analyzing farmers' decision making implies understanding how they rank potential activities with uncertain outcomes. When the decision maker's objectives and risk preferences are known, the most accepted procedure is to order alternatives according to their expected utility using the expected utility hypothesis (Anderson et al. 1977), leading to a complete and unique ranking. Along this line, it is assumed that the utility function is the straight financial outcome, and that the decision can be represented as a cost-benefit analysis (CBA) that compares different flows of benefits and costs for different alternatives. This method is popular because it is simple to implement and requires less data than other techniques (Pagiola 1994). However, by implicitly assuming that farmers are neutral to risk, CBA does not take into consideration farmers' attitudes toward risk.

A single preference measure is time-consuming and difficult to obtain (Anderson et al. 1977). Moreover, a decision maker's ranking is defined by his or her unique utility function and does not provide guidance for policy issues, such as the response of decision makers to well-defined changes in their choice sets. If we do not want to make excessively reductive hypotheses about farmers' preferences, a partial ordering of activities may be obtained by using the concept of stochastic dominance.

Stochastic efficiency[2] rules are implemented by pair-wise comparisons of cumulative distribution functions (CDF) of outcomes. Efficiency rules give the necessary and sufficient conditions of cumulative distributions preferred by all agents of a particular group. If the preferences can be represented by an expected utility function that is increasing and twice differentiable, groups of agents can be defined in terms of the properties of their utility function. A number of different stochastic efficiency criteria are used, depending on how broadly the group of decision makers is defined:

(a) First-degree stochastic dominance (FSD) is based on the hypothesis that the agents' utility function is increasing. By choosing the dominant alternative, it is assumed that decision makers prefer more rather than less of the uncertain quantity, regardless of their attitude towards risk. Here, a necessary and sufficient condition for FSD is that the CDF of the dominant alternative lies entirely to the right of other alternatives (Quirk and Saposnik 1962). However, if CDFs intersect, FSD alone cannot discriminate between alternatives.
(b) Second order stochastic dominance (SSD) applies to decision makers who have a positive marginal utility that decreases with increases in income, i.e., risk-averse farmers. Here, a comparison of the "cumulative of the cumulative" distribution function (CCDF) gives the necessary and sufficient conditions for dominance: in pair-wise comparisons, the dominant alternative is above the second alternative but is inconclusive when these CCDFs intersect (Hadar and Russell 1969).
(c) Third-degree stochastic dominance (TSD) applies to decision makers whose degree of risk aversion decreases with wealth (Whitmore 1970).

[2] The concepts of dominance and efficiency are considered equivalent.

Although robust, FSD, SSD, and TSD often fail to order distributions into smaller preferred sets. The most general form of stochastic dominance, the *stochastic dominance with respect to a function* (SDRF), overcomes this weakness (Meyer 1977a, 1977b; King and Robison 1981). SDRF classifies decision makers by the characteristics of their Arrow-Pratt risk aversion coefficient instead of their utility functions. The Arrow-Pratt risk aversion coefficient is defined as $r(x) = {}^{-U''(x)}/_{U'(x)}$ , where $x$ is income or wealth, and $U$ the utility function (Pratt 1964). The use of $r(x)$ instead of $U(x)$ allows a more accurate definition of the groups, and hence, greater discriminatory power. Finally, SDRF also allows a trade-off between the probability of Type I error (incorrect ranking), and Type II error (incomplete ranking), which is high in FSD and SSD (Cochran et al. 1985). FSD, SSD, and SDRF are used in this study.

## The Study Area

### Two contrasting agroeconomic zones

The study area is located in the state of Jalisco, in the western part of Mexico (Figure 1). Jalisco is the largest maize producing state in the country and features a diverse range of agroecological environments. The state has wide climatic variations because of its diverse topography and maritime influence. Climates range from semiarid in the north, to temperate in higher elevations, to semitropical in areas closer to the coast.

Most of the agronomic trials were conducted in the Ciudad Guzmán and San Gabriel municipalities in the southern part of the state. These two municipalities have contrasting agroecological conditions as well as diverse socioeconomic environments. The Ciudad Guzmán area is located on a plateau at 1,500 masl and is relatively homogeneous in terms of soils and rainfall (800-1,000 mm, well-distributed over the cropping cycle). It is also an economically dynamic region with good access to urban centers. San Gabriel, on the other hand, is more diverse and can be divided into two zones. The high elevation zone (1,300-1,500 masl) is close to the Nevado de Colima volcano and benefits from favorable rainfall conditions (600-800 mm, well-distributed). The low elevation zone (900-

**Figure 1. Map of San Gabriel and Cd. Guzmán.**

1,300 masl) features semiarid conditions (400-600 mm, evenly distributed through the cropping cycle) and is also more isolated. Access to Ciudad Guzmán and San Gabriel is difficult, and modern roads only reached the area within the past 20 years.

The main source of yield uncertainty in Ciudad Guzmán and San Gabriel is the variability of annual rainfall and rainfall distribution throughout the year. This analysis is divided into two agroclimatic zones—the dry zone corresponding to the lower areas in San Gabriel, and the well-watered zone, made up of Ciudad Guzmán and upper parts of San Gabriel.

**Existing cropping systems**

Surveys conducted since 1995 identified Jalisco's main farming systems and associated maize cropping systems (Glo and Martin 1995; Stephan 1996; Erenstein and Scopel 1997). Detailed information on maize management systems has also been collected from 15 representative farms through regular visits since 1996 by project staff. The four cropping systems identified by these studies are evaluated in this report. Although CT is practiced sporadically in Jalisco, none of the four traditional cropping systems fall under a CT regimen. They have been classified according to their degree of intensification: from extensive to intensive.[3] Indeed, variability exists within each of these systems, and those presented here are "synthetic constructs" retained for the analysis.

The extensive cropping system (EX) relies mainly on farm labor and farm-owned inputs. The field is weeded manually, burned, and then plowed using draft animals. Planting is also done with draft animals. Most farmers plant local varieties. Squash or beans are planted at irregular intervals between maize rows, thereby eliminating the need to use herbicides to control weeds. Weed control is manual and consists of one or two animal-drawn weedings (*escardas*), at 20 and 40 days after planting, on average. Low doses of fertilizers are applied during the first mechanical weeding operation. Generally, the doses applied depend heavily upon the weather: it is assumed here that in dry years, farmers reduce the quantities of fertilizers they apply by half. One hand weeding is also performed near the end of the season. Harvesting is done manually with family or contract labor. Maize residues are left on the soil surface and grazed by farm animals. Lands is often leased to other farmers on a per-hectare basis during the dry season (January to May) for grazing.

The semi-intensive 1 (SI1) cropping system relies more on external inputs and services and but resembles the extensive system in many aspects. The field is cleared at the beginning of the cycle (using herbicides to control spots of heavy infestation), but it is not always burned. Clearing is done every two to three years followed by one deep disk plowing (*arada*). One or two cultivations with disks (cover crop) usually follow. Farmers may use their own equipment or contract equipment from other farmers. A conventional tractor-drawn planter is used for planting and this operation is often contracted out. Most farmers using this system plant local varieties. Higher doses of fertilizers are applied, usually in two splits—the first

[3] Here, intensification refers to the increasing use of external inputs (fertilizers and pesticides) and increasing reliance on external services.

application usually during planting, and the second at weeding time. Weed control involves a mix of chemical application (post-emergent type 2,4-D) and mechanical and manual weeding. Harvest is still done manually, with heavy reliance on contracted workers.

The semi-intensive 2 system (SI2) requires more external resources. The main differences between this system and the two systems mentioned earlier are its use of modern varieties, higher doses of fertilizers, and soil insecticides. Furthermore, weed control is entirely chemical; mechanical and manual forms of control are not used. Pre-emergent herbicides, frequently atrazine, are applied. Harvest is mechanized and often involves the services of external contractors.

The intensive cropping system (IT) is similar to the SI2 system but differs in the levels of fertilizers used and in weed control practices. Chemical herbicides are applied twice: a pre-emergent application at planting time, and a post-emergent application 40 days before harvest.

Two remarks should be made here. First, the cropping systems described are not evenly distributed between the two zones. Extensive systems (EX and SI1) predominate in dry areas and more intensified systems (SI2 and IT) in better-watered areas. This does not prevent us from evaluating all four systems in both zones, especially when looking at the intensification of production systems in dry areas. Second, these cropping systems are not

**Table 1. Four traditional maize cropping systems**

| | **Extensive (EX)** | **Semi-intensive 1 (SI1)** | **Semi-intensive 2 (SI2)** | **Intensive (IT)** |
|---|---|---|---|---|
| Maize system | Intercrop[a] | Monocrop | Monocrop | Monocrop |
| Soil preparation | Slash and burn<br>Plowing with horse | Slash only<br>2 superficial plowings with tractor | 2-3 superficial plowings with tractor | 2-3 superficial plowings with tractor |
| Planting | With animals<br>Local varieties<br>Squash intercrop[a] | With tractor<br>Local varieties | With tractor<br>Hybrids | With tractor<br>Hybrids |
| Fertilization | 90 kg N<br>One application 40 days after planting | 150 kg N<br>100 kg P<br>Two applications: at planting, and 40 days after planting | 220 kg N<br>100 kg P<br>Two applications: at planting, and 40 days after planting | 250 kg N<br>Two applications: at planting, and 40 days after planting |
| Insect control | No insecticide | No insecticide | Soil insecticide | Soil insecticide |
| Weed control | No herbicide<br>Half mechanical weeding (escardas)<br>1 manual weeding | 1 herbicide application (post-emergence)<br>1 mechanical weeding<br>1 manual weeding | 1 herbicide application (pre-emergence) | 2 herbicide applications<br>- pre-emergence<br>- post-emergence |
| Harvest | Manual | Manual | Mechanical | Mechanical |

[a] Intercropping here refers to the farmers' actual system, not to the conventional concepts of the practice.

evenly distributed among farm types, as they result from farmers' adaptations and strategies to make best use of their resources. Without entering into a detailed analysis, it should be pointed and that extensive systems are usually the result of a strategy of minimizing risk and out-of-pocket expenses. Farmers with greater endowments, and who are better integrated with factor and credit markets, practice intensive systems.

**Introduction of conservation tillage**

Conservation tillage adoption is only possible when certain conditions are met. As the purpose of this paper is to discuss the consequences of adoption at the plot level and not the factors that influence adoption, the following hypotheses are made:

- *Farmers have full control over crop residues.* Farmers can remove, burn, or use crop residues for animal consumption, rent their plots to other farmers during the dry season, or combine some or all of these practices. To take into account the value of residues, even when they are not sold, crop residues are assigned a shadow value equal to their market price.
- *Farmers have access to planters either through contractors or through purchase.* The cost of planters' services was taken at market prices. Farmers also have access to all agricultural inputs, such as fertilizers and pesticides.
- *Only short-term effects on profitability were considered.* It was assumed that farmers do not take long-term or external effects of their decisions into consideration (e.g., increase of soil organic matter or reduction of soil erosion).

Introducing CT into cropping systems implies changes in practices. While these changes are minor for intensive systems, they can imply a radical departure from traditional systems. The following "best practices" or changes from the traditional systems should be adopted in a CT system:

- *Stop burning residues.* This is necessary to protect the soil. Farmers burn to "clean" the field of weeds and residues at the beginning of the cycle. This is often seen as a way to prevent the spread of insects and diseases from one cycle to another. Abandoning burning means losing a cheap and rapid way of destroying diseases and soil pests.
- *Reduce the amount of residues removed from the fields or grazed by animals.* Other sources of fodder are therefore needed. However, Scopel (1994) has shown that low levels of residues left on the soil are sufficient to prevent soil loss, increase water retention, and boost yields. Consequently, it is assumed that farmers forego only half of the value of residues when adopting conservation tillage.
- *Avoid any soil movement, including plowing and cultivation.* This will reduce the time for soil preparation and costs.
- *Contract seed drill operator, or buy a new seed drill that can plant seeds through a layer of residues.*
- *Herbicides remain the only means of controlling weeds,*[4] *as neither burning nor soil movement are permitted.* The use of herbicides to control weeds may be new for some farmers. The

[4] Herbicides remain the only way of controlling weeds when no intercropping or alternative methods, such as cover crops between rows or crop rotations, are considered. While not discarding these possibilities, much research is still needed on these alternatives to provide satisfactory weed control.

risk of herbicide failure is therefore important for them, particularly when they are learning which products to use, the correct dosages, and the correct calibration of equipment.

- *Stop intercropping.* Herbicide use precludes the planting of squash or beans that are present in the traditional system.

Two important aspects of adoption of CT techniques should be underlined here. First, farmers who adopt CT have to move from a labor-intensive to a more complex or knowledge-intensive system. Consequently, the high opportunity cost of labor should strongly influence farmers' decisions towards adoption of CT. At the same time, the learning curve will be steep and this will constitute a strong barrier to entry. Crop failures are likely while farmers become acquainted with the techniques, especially with the use of herbicides.

Second, it is often argued that the low rates of adoption of CT techniques can be explained by the discrepancy between the short-term private goals of farmers and long-term public goals (Pearce and Turner 1990). While not negating this, on-farm CT trials in the Jalisco region showed an immediate impact on maize mean yields and variability, at least in the drier zones (Scopel et al. 1998). At this stage, therefore, we will consider only the short-term (one-year) private consequences of farmers' decisions. The long-term increases in productivity resulting from, among other, decreased erosion, are not taken into account here. This may lead to an underestimation of the likely benefits of CT but better represents farmers' decisions.

## Description of the Model

### Economic analysis

A stochastic cost-benefit analysis was used to evaluate the impact of introducing CT into the existing cropping systems. The unit of analysis is an indivisible hectare of land cropped with maize. Farmers must use one of the management systems described earlier.

The *@Risk* software package (Palisade Corporation 1996) allows the introduction of uncertain values into the model. For this analysis, the prices of inputs, outputs, and crop yields were considered uncertain. Other technical coefficients were treated as constants, with the exception of weed control techniques. For each uncertain value, a specific probability distribution was selected. Probability distributions of gross returns to land and labor were then obtained by using the Latin hypercube sampling method. Cumulative distribution functions of returns generated by @Risk were then analyzed using the GSD or "generalized stochastic dominance" software (Cochran and Raskin 1988; Goh et al. 1989).

### Plant-growth model to obtain yields

Maize yields are difficult to predict, especially in the dry zone because of rainfall variation from year to year. Rainfall is concentrated between late June and late September. Rainfall distribution throughout the year is an important, if not the most important, factor of yield risk: late rains or dry spells at critical stages of plant development may have important effects on yields. Most of the rain falls in a few intense storms that cause significant runoff, especially if they come early in the season when there is little or no cover crop. Moreover,

water valorization depends heavily on crop management because some management practices reduce water runoff more efficiently. To capture the variability of maize yields arising from climatic conditions, modeling over long series of climatic data is needed and the cumulative distribution function for maize yields must be estimated.

The CIMMYT / CIRAD / INIFAP[5] project has several medium-term, on-farm, and controlled trials located within the Ciudad Guzmán and San Gabriel area (e.g., Scopel 1996) that reflect the contrasting agronomic conditions. Predictions of maize yields under different cropping systems were derived from these trials through the development and calibration of STICS,[6] a crop-growth model.

Crop-growth models have been widely used to study crop production that is difficult to research in controlled experiments. The simulated yield observations are random observations that depend primarily on daily weather conditions and farmers' management practices. They can simulate long series of crop yield data and can therefore address the common problem of yield data limitations.

The STICS model was chosen because it represents a good compromise between precise results and data requirements. More generic crop growth models such as EPIC (Jones et al. 1991) or CERES[7] demand a large amount of data, some of which require costly measurements and some of which are not available for on-farm conditions in the developing world. Moreover, an on-farm diagnosis showed that any available crop model had to be modified to adequately simulate the effects of the main factors limiting yields in the region. Because of its modular structure and given that support from its authors was available, STICS was easier to modify than other crop models.

The STICS model simulates total yield (aboveground biomass and leaf area index) on a daily basis, the driving process being the conversion of intercepted radiation into biomass, taking plant density into account. Plant development is computed using the classical approach of thermal time. Biomass is allocated to grain production during grainfilling, using the harvest index concept. Biomass, leaf area index (LAI), and harvest index growth are limited by water and nitrogen constraints. Up to five pedological layers may be considered in the model. Water and nitrogen fluxes in soil are simulated using the classical reservoir analogy applied to 1 cm elementary layers. Root distribution in the soil is accounted for. The original water balance module was modified to simulate the effects of a residue cover on rainfall infiltration, soil evaporation, water storage in residue straw, and its evaporation (Scopel et al. 1998). A weed module takes into account weed competition for light, water, nitrogen, and the efficiency of chemical controls used by farmers.

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[5] CIMMYT (International Maize and Wheat Improvement Center), CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), INIFAP (Insituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias).

[6] STICS (Simulateur multidisciplinaire pour les cultures standards).

[7] EPIC (Erosion-Productivity Impact Calculator). CERES (Crop Estimation through Resource and Enviroment Synthesis).

Maize yields were obtained using STICS calibrated against trial and on-farm data collected in the region since 1994 (Affholder and Scopel, forthcoming). Yield data for the eight maize cropping systems were simulated using STICS with the 15-year weather data available for the zone. The simulated means and standard deviations for each of the eight cropping systems are reported in Table 2.

**Table 2. Average and standard deviations of simulated yields (kg/ha)**

| | | EX | EXCT | SI1 | SI1CT | SI2 | SI2CT | IT | ITCT |
|---|---|---|---|---|---|---|---|---|---|
| Well-watered zone | Average | 2,983 | 5,025 | 3,390 | 5,251 | 6,295 | 6,771 | 6,369 | 6,856 |
| | Std. Dev. | 1,281 | 984 | 1,190 | 820 | 1,463 | 1,224 | 1,433 | 1,201 |
| Dry zone | Average | 2,159 | 3,715 | 2,235 | 3,859 | 3,747 | 4,049 | 3,801 | 4,103 |
| | Std. Dev. | 875 | 1,161 | 956 | 1,169 | 1,184 | 1,304 | 1,190 | 1,303 |

Theoretical distributions were fitted to each cropping system data set using the Anderson-Darling test. Results showed that the probability distribution that best fits the data was, in most cases, the normal distribution function.

## Weed control as a tactical choice

Good weed control is crucial for CT practices to succeed. A good representation of weed control practices and their impact on yield was required for the modeling exercise. More specifically, two important problems were addressed that were not traditionally encountered: the decision to apply herbicide was integrated into the agronomic model, and the efficiency of weed control was allowed to vary.

Initially, the number and dates of chemical control were fixed for all simulated years. One problem encountered with this approach was that some systems would systematically fail when rains occurred early in the production cycle. With no possibility of other forms of control, weeds would overwhelm the maize and ultimately lead to unusually low yields. Thus, these systems would have greater yield variance than found in farmers' fields, because farmers counteract this problem with other forms of weed control. Therefore, a small procedure was added to the crop-growth model to represent farmers' tactical choices. This was an "if-then" type of rule: if LAI of weeds > 0.8 just before sowing, then apply a contact chemical treatment. This representation of farmers' tactical choices greatly enhanced yield representation.

## Farm prices and production incentives

Prices for inputs, services, and the sale of farmers' products are subject to market forces and policies that modify the economic environment.

### Output prices

In recent years, agricultural output prices in Mexico have been influenced by changes in the policy environment as a result of the opening of trade and reduced distortion of maize prices in Mexico. Since 1995, the Programa de Apoyos Directos al Campo (PROCAMPO)

has progressively phased out its price supports for agricultural commodities and introduced direct payments to support farmers' revenue. Farmers now receive prices that are comparable to international prices. They are paid a production incentive (PROCAMPO) on a per-hectare basis to compensate them for any eventual revenue losses. Indifference prices, calculated for each state and published as a base for negotiations between farmers and buyers, are implicit prices at which buyers see no difference between buying local or imported products. These prices are the sum of cost, insurance and freight (CIF), imported product prices (at port of entry), import taxes, and transportation costs to the zone of consumption.

To analyze farm-level prices of maize, indifference prices calculated in Mexican pesos (Mx$) were deflated by the consumer price index (base 1994 = 100). As can be seen in Figure 2, real maize prices have fluctuated considerably since 1994. International maize prices were exceptionally high during 1995/96, although they have since returned to their previous low levels. The devaluation of the peso in December 1994 also increased the relative price of imported goods, and in turn the indifference prices of maize.

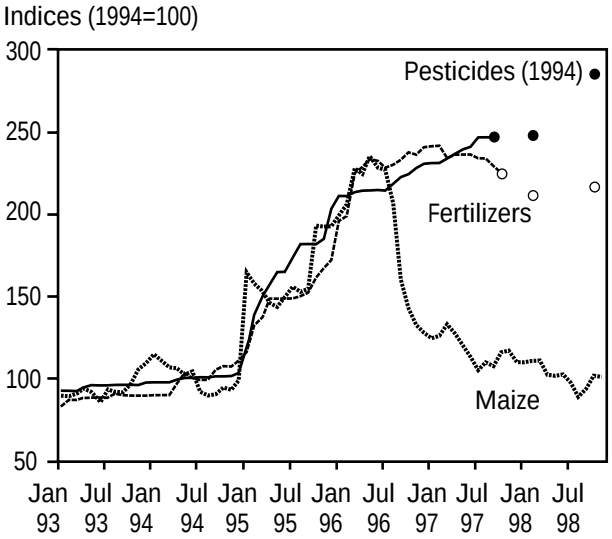


**Figure 2. Price indices for inputs (fertilizers, pesticides) and maize grain (1994 = 100).**

Source: Adapted from World Bank Commodity Price Data (1990-1990) and SAGARPA-ASERCA on line data (1997-1999).

Price uncertainty is introduced into the simulation by assuming that prices of maize follow triangular cumulative distribution functions, using the maximum, mean, and minimum prices during 1994–98 (in 1998 constant pesos) (Table 3). Similarly, the price of squash seed follows a cumulative triangular distribution function with values inferred from an ongoing survey in Jalisco.

Input prices

In sharp contrast to maize prices, real prices of inputs, particularly fertilizer and pesticides, which are mainly imported, rose steadily during this period (Figure 2). Input prices rose primarily because of the 1994 peso devaluation and the slow but continuous decline of the peso for some time afterward. Low international prices for nitrogen products caused fertilizer prices to level off in 1998, but pesticide prices continued to rise.

For this study, it is assumed that fertilizer, pesticide, and other input prices follow triangular cumulative distribution functions. The 1998 minimum, mean, and maximum values were taken from the 1996–99 farm survey (Glo and Martin 1995; Stephan 1996; Erestein and Scopel 1997) (Table 3). Estimated prices for seed for local maize varieties were based on the opportunity cost of maize grain (the previous year's farmgate price). A quality premium for local varieties was added.

**Table 3. Input and output price distribution parameters (current Mx$/unit)**

| Type | Item and unit | Expected value | Min. | Mean | Max. |
|---|---|---|---|---|---|
| Seed | Hybrid seed (kg) | 24.667 | 20 | 22 | 32 |
| Fertilizers | 18-46-00 (kg) | 2.300 | 2.2 | 2.3 | 2.4 |
| | Ammonium sulfate (kg) | 1.000 | 0.8 | 0.9 | 1.3 |
| | Superfosfato triple (kg) | 1.867 | 1.7 | 1.9 | 2 |
| | Urea (kg) | 1.833 | 1.7 | 1.8 | 2 |
| Herbicides | Faena (l) | 80.00 | 70 | 80 | 90 |
| | Tordon 101 (l) | 85.00 | 75 | 80 | 100 |
| | Calibre 90 (kg) | 110.00 | 90 | 110 | 130 |
| | Sanson (l) | 320.00 | 300 | 310 | 350 |
| | Counter 15% (kg) | 42.83 | 40 | 42.5 | 46 |
| Contracting services | Sowing (ha)[a] | 265.00 | 250 | | 280 |
| | Harvester (ha)[a] | 400.00 | 380 | | 420 |
| | Plow (ha)[a] | 250.00 | 240 | | 260 |
| Products | Maize hybrids (kg) | 1.23 | 1 | 1.3 | 1.4 |
| | Squash seed (kg) | 12.00 | 8 | 13 | 15 |

[a] Uniform distribution was used.

Labor

Labor is undertaken by family members or by hired labor. Hired labor is used frequently for labor-intensive operations, such as manual weed control and harvest. Farmers in the study area did not report major difficulties in finding or hiring labor. The daily wage rate for unskilled agricultural labor was approximately US$ 3.25 (Mx$ 45).[8] Labor prices are slightly higher at harvest because of high demand at that time of the year.

Family labor was priced at its opportunity cost—the wages that could have been earned working off the farm (US$3.25 / day (Mx$45)). However, market values do not necessarily reflect the opportunity cost of labor. For example, the opportunity cost of family labor could be higher if household members have opportunities to work in non-agricultural activities. The influence of higher or lower opportunity costs of labor is examined later in the paper.

Harvesting, whether manual or with a combine harvester, was not included as a factor in this study because we considered it as an independent technical choice that could potentially distort calculations on labor productivity.

Production incentives

Farmers have received government subsidies on a per-hectare basis since 1994. These incentives have varied in real terms from their inception. In 1996, the government decided to fix them in real terms until the end of the 15-year PROCAMPO program; 1998 level incentives were taken into account.

[8] US$ 1= Mx$13.9 (International Financial Statistics Yearbook 1999).

# Results

## Costs of production

Average production costs in the dry zone[9] are presented in Figure 3.

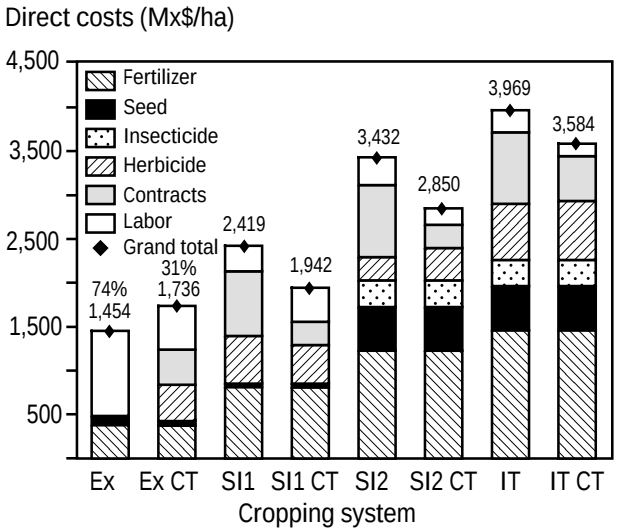


**Figure 3. Costs of production (dry zone).**

A distinction should be made between the traditional system (EX) and the more intensive systems. The traditional system (EX), which relies on internal inputs (seed, labor), is designed to minimize cash expenses; therefore changing to another system implies greater expenses. This is particularly true if CT is introduced. More importantly, the introduction of CT will increase out-of-pocket expenses. If family members meet all labor needs, out-of-pocket expenses represents 29% of expenses in the EX system; this increases to 69% in the EXCT system. This new cost structure means that farmers need more cash at the beginning of the production cycle. This will be difficult for cash-strapped farmers without access to some form of credit. Even with access to credit, farmers also need to believe that the CT system is superior to justify, in cash terms, more investment at the beginning of the cycle.

Conservation tillage decreases expenses in the other systems (SI1, SI2, IT) with minor changes to the cost structure. As it does not incur additional cost before getting results, it is easier to convince farmers to adopt the new technology.

## Returns to land

Mean returns, standard deviations, coefficients of variation, and probabilities of negative returns are presented in Table 4. The effects of introducing CT into existing systems are analyzed and the relative profitability of all the systems available to farmers are compared.

In all systems, introduction of CT brings higher average returns to direct costs. Adoption also reduces the coefficient of variation with the exception of the EXCT system in the dry zone. Negative results are substantially reduced in most cases. The introduction of CT in these systems results in a “win-win” situation in terms of land productivity and risk.

In addition to studying the profitability implications of introducing CT techniques, the eight systems were compared in terms of distribution of returns. To accomplish this, the cumulative distribution functions (CDF) of returns to land were analyzed. Figure 4 presents the different cropping system CDFs. The Y-axis represents the probability that returns are

[9] Results are very similar for the well-watered zone, and therefore are not presented here. As mentioned earlier, these costs do not include harvesting or indirect costs

less than the values of the X-axis value. To interpret this figure, it should be noted that: (1) the most profitable systems are on the right side of the graph; (2) the steeper the slope of the curve, the less variable (risky) are the returns; (3) the intersection of the curve with the Y-axis gives the probability of negative returns; and (4) when two CDFs are crossing, the only way to identify the dominant strategy is to use one of the stochastic dominance tests.

The extensive system (EX) constitutes a sound solution for farmers in the dry zone. Intensification from EX to SI1, SI2, or IT, while beneficial in terms of maize yields, does not bring higher average returns and increases the risk of negative returns. Yield increases are gained at substantial costs that cannot be justified given maize prices. It is therefore not surprising that intensified cropping systems are rarely found in this zone.

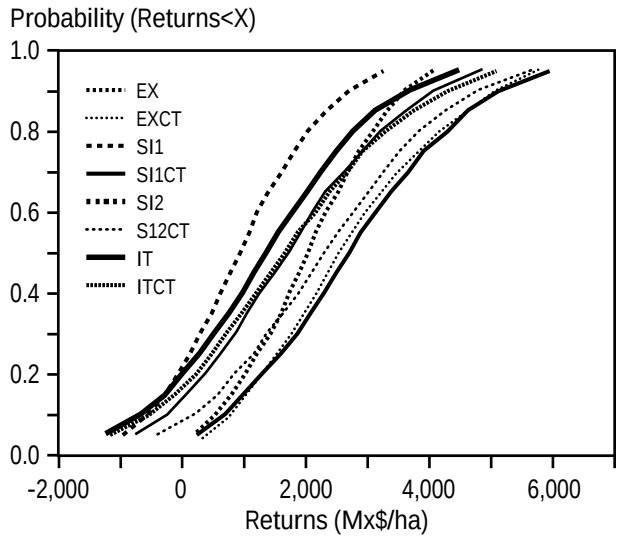


**Figure 4. Returns to land (dry zone).**

Intensification accompanied by CT practices does improve economic results. The most interesting system combines extensive systems (EX or SI1) with CT.[10] In other words, under present conditions, higher levels of fertilizer and hybrid seeds do not produce enough high yields in the dry area to justify their use, even when using CT.[11]

IT systems may have better results in favorable years than the EX system, but on average, they bring lower returns. Similarly, the IT curve is smaller and spans from negative to high returns. In dry conditions, IT systems are more variable: the large amounts of fertilizers

**Table 4. Returns of management systems to direct cost in dry and well-watered zones (Mx$/ha)**

| | EX | EXCT | SI1 | SI1CT | SI2 | SI2CT | IT | ITCT |
|---|---|---|---|---|---|---|---|---|
| **Dry Zone** | | | | | | | | |
| Mean | 2,092 | **2,763** | 1,018 | **2,857** | 1,838 | 2,427 | 1,465 | 1,771 |
| Std. Dev. | 1,177 | **1,687** | 1,262 | **1,768** | 1,722 | 1,820 | 1,707 | 1,877 |
| C. Var | 0.56 | **0.61** | 1.24 | **0.62** | 0.94 | 0.75 | 1.17 | 1.06 |
| Prob (X < 0) | 2.93% | **2.08%** | 21.19% | **3.33%** | 13.88% | 8.29% | 19.75% | 16.88% |
| **Well-watered zone** | | | | | | | | |
| Mean | 2,986 | 3,903 | 2,151 | 3,704 | 4,659 | **5,279** | 4,257 | 4,712 |
| Std. Dev. | 1,759 | 1,903 | 1,811 | 1,858 | 2,351 | **2,144** | 2,315 | 2,196 |
| C. Var | 0.59 | 0.49 | 0.84 | 0.50 | 0.50 | **0.41** | 0.54 | 0.47 |
| Prob (X < 0) | 3.70% | 0.30% | 11.96% | 0.47% | 1.06% | **0.14%** | 2.55% | 0.18% |

[10] Unlike the previous section, here we are considering pure economic results without taking into account the cost structure.

[11] Doses of fertilizers applied for the systems described may already seem high.

applied in the field may result in poor yields because of water deficits. Conservation tillage does little to improve this.

In the well-watered zone, EX systems are less advantageous than IT systems under CT because the risk of negative returns is considerably lower. Farmers with reasonable risk-aversion already have incentives to intensify, and many are doing so. In contrast to the dry zone, the combination of an IT system and CT techniques brings both higher average returns and greater stability of results over time. The slopes of the CDFs are also almost identical, regardless of the system. Where water is not a limiting factor, CT does not diminish risks and increases average returns. The SI2 with CT proved to be the most advantageous in terms of average returns and downside risk.

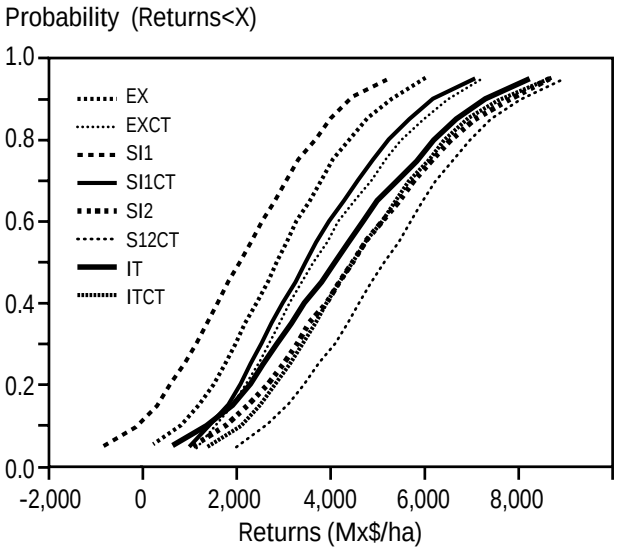


**Figure 5. Returns to land (well-watered zone).**

Given these results, it appears that CT could be an interesting solution for farmers in both zones. However, the introduction of CT into the dry zone should not be linked to higher consumption of external inputs, such as hybrid seed and fertilizer, as the water conserved by better infiltration and lower run-off is still not sufficient to justify their use. It would certainly be interesting to investigate the effects of lower doses of fertilizer on economic returns under traditional and CT systems.

In terms of policy, it has been shown that access to credit is critical for cash-constrained farmers to adopt CT. In terms of returns, however, credit for external inputs such as fertilizer and seed may not be necessary in the dry zone given their poor efficiency. Credit for the purchase of a low-cost direct drill designed for small-scale farming (animal drawn) would certainly be more appropriate, because, once the investment is made, it would reduce out-of-pocket expenses.

### Returns to labor

Results for returns to labor for the dry area are presented in Figure 6. The EX system is characterized by small but very stable (steep CDF) returns to labor. Introducing CT does not seem to have dramatic impact on returns to labor, except for the EX system, where the labor productivity increases substantially while its variability remains equal.

Findings are similar in the well-watered zone. Intensive systems result in substantially higher returns to labor, and adoption of CT in these IT systems considerably reduces the risk of negative returns.

In EX systems, the introduction of CT does not affect the returns to labor significantly. In IT systems, CT slightly increases returns to labor.

## Dominance Analysis

Farmers' attitudes toward risk are expected to play an important role in their decision to adopt CT techniques. Stochastic dominance analysis was performed for both zones to determine the likely adoption pattern for different classes of farmers.

The upper and lower bounds of risk aversion coefficients are shown in Table 5. A negative value of $R(x)$ indicates risk inclination, a zero value indicates risk neutrality, and a positive value indicates risk aversion. Classes 1 and 2 would be risk-inclined farmers, while classes 3 to 6 include increasingly risk-averse farmers. The values in Table 5 were selected to include the full range of risk coefficients reported in previous studies (Kramer and Pope 1981).

The probability distribution of returns for the different cropping systems is shown in Tables 6 and 7. Dominant solutions have been marked with a "yes"; an empty cell means that the distribution is either dominated by others or that the class is not unanimous in its ranking.

First-degree and second-degree stochastic dominance rankings were made for reference. Rankings for the different groups were also made using the GSD program (Cochran and Raskin 1988; Goh et al. 1989).

In the dry zone, a polarization of technical alternatives confirms the results reported earlier. The second-degree stochastic dominance test retains only the less intensive systems as dominant. Risk-inclined or slightly risk-averse farmers would be ready to intensify their crop (IT/CT). Strongly risk-averse farmers will be reluctant to depart from the traditional EX system.

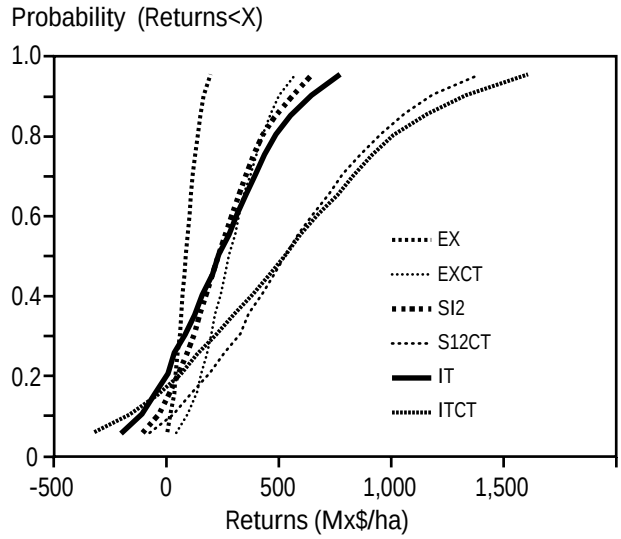


**Figure 6. Returns to labor (dry zone).**

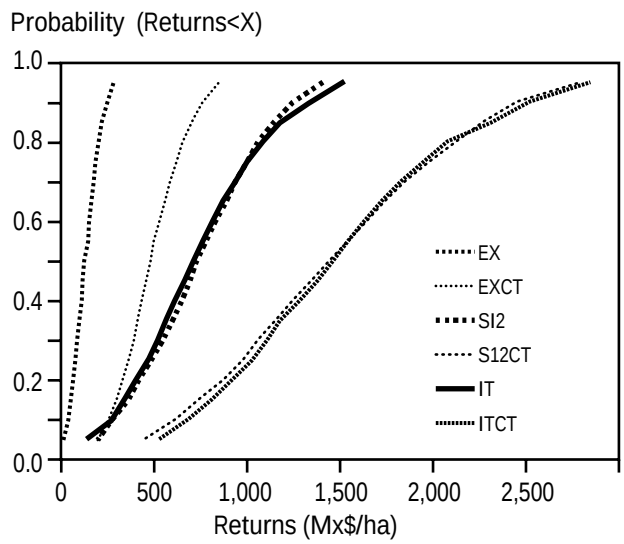


**Figure 7. Returns to labor (well-watered zone).**

**Table 5. Risk aversion coefficients**

| Farmer classes | $R_1(x)$[a] | $R_2(x)$[b] |
|---|---|---|
| Class 1 | -0.02 | -0.01 |
| Class 2 | -0.01 | 0.00 |
| Class 3 | 0.00 | 0.00125 |
| Class 4 | 0.00125 | 0.00250 |
| Class 5 | 0.00250 | 0.00500 |
| Class 6 | 0.00500 | 0.00750 |

[a] Lower bound on the risk-aversion coefficient.
[b] Upper bound on the risk-aversion coefficient.

The results are less divergent in the wellwatered zone (Table 7), where the SI2CT system is dominant for a wide range of risk attitudes, including the most risk-averse farmers. Risk considerations favor CT.

These results show that the farmer's attitude toward risk may be crucial for the adoption of CT, at least in the dry zone. The model suggests that depending on their risk inclinations, farmers tend to be attracted toward one of the two solutions: the traditional EX system for strongly risk-averse farmers, and a combination of slight intensification and CT for less risk-averse farmers. In the well-watered zone, risk attitude does not seem to hinder adoption, since SI2CT is dominant for all ranges of risk aversion.

**Table 6. Stochastic dominance ranking (dry zone)**

| | Utility class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Dry Zone** | **1st Deg SD** | **2nd Deg SD** | **1** | **2** | **3** | **4** | **5** | **6** |
| EX | Yes | Yes | | | | Yes | Yes | Yes |
| EXCT | Yes | Yes | | Yes | Yes | Yes | | |
| SI1 | | | | | | | | |
| SI1CT | Yes | Yes | | Yes | Yes | | | |
| SI2 | | | | | | | | |
| SI2CT | Yes | | | Yes | | | | |
| IT | | | | | | | | |
| ITCT | Yes | | Yes | Yes | | Yes | | |

**Table 7. Stochastic dominance ranking (well-watered zone)**

| | Utility class | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Well-watered Zone** | **1st Deg SD** | **2nd Deg SD** | **1** | **2** | **3** | **4** | **5** | **6** |
| EX | | | | | | | | |
| EXCT | | | | | | | | |
| SI1 | | | | | | | | |
| SI1CT | | | | | | | | |
| SI2 | Yes | | Yes | Yes | | | | |
| SI2CT | Yes | Yes | | Yes | Yes | Yes | Yes | Yes |
| IT | | | | | | | | |
| ITCT | Yes | Yes | | | | | | |

## Sensitivity to the Price of Labor

Labor use is central to the proposed technical change. Different labor opportunity costs were examined because the real opportunity costs of off-farm employment vary significantly by location, skill, and/or education level. Therefore, an investigation of the sensitivity of the conclusions to the price of labor was deemed necessary.

Four simulations were conducted in which the daily wage rate was increased and lowered by 20% and 40%, respectively. Results are presented for the dry zone (Table 8) and for the well-watered zone (Table 9). Given the linearity of the model, a price change creates a simple shift in the distribution function of returns, without really affecting the shape of the distribution. The most important shift is in the labor-intensive EX system: an increase in the opportunity cost of labor shifts the distribution to the left more rapidly than the IT and ITCT systems.

As the daily wage rate increases, the comparative advantage of IT systems and systems with CT increases. However, even important changes in daily wage rates do not affect the results obtained earlier in terms of technical choices.

**Table 8. Sensitivity to price of labor (dry zone, Mx$/ha)**

| | | EX | EXCT | SI1 | SI1CT | SI2 | SI2CT | IT | ITCT |
|---|---|---|---|---|---|---|---|---|---|
| -40% | Mean | 2,477 | 2,953 | 1,185 | 3,011 | 1,948 | 2,495 | 1,556 | 1,818 |
| | Std. Dev. | 1,189 | 1,657 | 1,265 | 1,769 | 1,657 | 1,802 | 1,694 | 1,857 |
| -20% | Mean | 2,301 | 2,854 | 1,108 | 2,939 | 1,867 | 2,466 | 1,510 | 1,790 |
| | Std. Dev. | 1,243 | 1,663 | 1,270 | 1,775 | 1,595 | 1,836 | 1,688 | 1,830 |
| Orig. | Mean | 2,086 | 2,742 | 1,027 | 2,856 | 1,821 | 2,432 | 1,467 | 1,757 |
| | Std. Dev. | 1,177 | 1,628 | 1,312 | 1,734 | 1,665 | 1,830 | 1,720 | 1,811 |
| +20% | Mean | 1,891 | 2,650 | 936 | 2,784 | 1,764 | 2,388 | 1,410 | 1,736 |
| | Std. Dev. | 1,192 | 1,620 | 1,270 | 1,754 | 1,671 | 1,834 | 1,704 | 1,872 |
| +40% | Mean | 1,704 | 2,564 | 844 | 2,702 | 1,709 | 2,350 | 1,363 | 1,716 |
| | Std. Dev. | 1,186 | 1,669 | 1,262 | 1,748 | 1,722 | 1,820 | 1,707 | 1,877 |

Increasing employment opportunities outside of agriculture, both within or outside of Mexico, would increase the use of agricultural inputs and make CT techniques more attractive than they are now.

## Discussion: Consequences for the Promotion of Conservation Tillage to Farmers

In the dry zone, the introduction of CT into existing systems always results in higher returns to direct costs. Yet adoption of CT is unlikely to be easy. In the EX system, the area's most important cropping system, the changes will affect the cost structure. Cash for out-of-pocket expenses before crop returns is much more important. Access to credit will be essential to enable farmers to adopt the new technology, but even given greater access to credit, many farmers would spend it on higher doses of fertilizer (Jourdain and Scopel, 2001). In economic terms, higher levels of fertilizer and hybrid seed do not bring better results in this zone, since water is the most limiting factor. Access to credit alone may lead to undesired results, at least in the short term. Moreover, given the complexity of the CT technology, it is unlikely that farmers will be willing to switch from one system to another without tangible and long-lasting proof of the efficacy of the technology. Last but not least, farmers using traditional systems often mention their unwillingness to use herbicides

**Table 9. Sensitivity to wage rates (well-watered zone, Mx$/ha)**

| | | EX | EXCT | SI1 | SI1CT | SI2 | SI2CT | IT | ITCT |
|---|---|---|---|---|---|---|---|---|---|
| -40% | Mean | 3,369 | 4,068 | 2,323 | 3,840 | 4,759 | 5,350 | 4,364 | 4,751 |
| | Std. Dev. | 1,717 | 1,913 | 1,798 | 1,918 | 2,326 | 2,148 | 2,289 | 2,108 |
| -20% | Mean | 3,161 | 3,980 | 2,254 | 3,767 | 4,703 | 5,317 | 4,301 | 4,724 |
| | Std. Dev. | 1,728 | 1,885 | 1,860 | 1,873 | 2,336 | 2,173 | 2,289 | 2,131 |
| Orig. | Mean | 2,971 | 3,868 | 2,150 | 3,702 | 4,648 | 5,289 | 4,257 | 4,704 |
| | Std. Dev. | 1,706 | 1,741 | 1,853 | 1,885 | 2,334 | 2,205 | 2,299 | 2,127 |
| +20% | Mean | 2,781 | 3,821 | 2,064 | 3,622 | 4,594 | 5,250 | 4,196 | 4,673 |
| | Std. Dev. | 1,751 | 1,929 | 1,845 | 1,857 | 2,318 | 2,161 | 2,245 | 2,130 |
| +40% | Mean | 2,585 | 3,721 | 1,957 | 3,559 | 4,537 | 5,213 | 4,161 | 4,640 |
| | Std. Dev. | 1,715 | 1,832 | 1,835 | 1,771 | 2,319 | 2,167 | 2,313 | 2,143 |

because of the residual effects. Pre-emergence herbicides used in IT systems (usually triazines) remain in the soil for many years after application, preventing farmers from planting intercrops such as squash or beans for several years.

New maize cropping systems based on some form of CT and more adapted to farmers' circumstances still need to be developed with farmers. Such new systems need to be aimed at small-scale farmers who are the least likely to adopt CT systems. Developing cropping systems that depend less on herbicide while reducing out-of-pocket expenses for weed control might be one avenue for further research. Crop rotations and diversification of cropping systems could also be part of the solution. Fostering the development of seed drills adapted to small-scale farmers will also be essential. Equipment developed in other countries where CT adoption has been more widespread, such as Brazil, may provide useful ideas in this respect.

If economic conditions change, notably with an increase in labor wages relative to other input prices, CT becomes more attractive for EX systems. However, as adoption requires radical changes in management practices, again the challenge is to develop a package of practices that is acceptable to farmers and brings them from their traditional system to a more intensified system that incorporates CT.

In the well-watered zone, the prospects of adoption are brighter because the introduction of CT brings tangible economic returns. There are no major changes in cost for farmers who already rely on herbicides and other external inputs, and CT substantially reduces their expenditures. The technology should be accepted once informational and machinery bottlenecks are overcome.

While these findings can serve as a basis for understanding the low levels of CT adoption in Mexico, the limits of the study should be pointed out. The analysis is grounded in plot-level data. Since opportunity costs are not always satisfactorily reflected through market values, scaling up from the plot level to the farm level necessitates an accurate estimation of the opportunity cost of labor and residues (estimates here are based on market prices). Whole-farm models for representative production systems would overcome this. Moreover, the time dimension should also be integrated into the analysis. Although agronomic data are becoming available for the study area, it is still difficult to translate them into effects on yield. This problem was encountered elsewhere as well (Lal 1987; Pagiola 1994). Yield effects can be expected to increase over time with improvements in soil fertility (structure, organic matter, and biological activity). Provided we assume that farmers integrate long-term productivity into their management decisions, this factor should be included in follow-up studies. Finally, our analysis did not take into account, on the negative side, externalities associated with increased herbicide use, or on the positive side, soil conservation and carbon fixing. These issues will be considered in later phases of the project once the necessary data become available.

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