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Adoption of Maize Conservation Tillage in Azuero, Panama

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CIMMYT

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Contents

Abstract

An aggressive research and validation program launched in 1984 in Azuero, Panama, yielded a recommendation advocating zero tillage for maize production. Ten years later, maize farmers in Azuero used three land preparation methods: conventional tillage, zero tillage, and minimum tillage (an adaptation of the zero tillage technology). This study aimed to quantify the adoption of zero and minimum tillage for maize in Azuero; identify factors influencing adoption of the different land preparation practices; and analyze the implications of the findings for future maize research and extension. Between 1985 and 1994, farmers in Region I of Azuero changed from conventional tillage to zero (33%) and minimum tillage (43%). In Regions II and III, most farmers still practiced conventional tillage in 1994, although 34% had switched to minimum tillage. Across regions, adoption of conservation tillage was motivated by potential cost savings rather than longer term considerations such as reduced soil erosion. The factors that limit adoption of conservation tillage vary by region. In Region I, adoption of conservation tillage is limited by land rental rather than ownership and by lack of conservation tillage planting equipment. In Regions II and III, lack of information about conservation tillage technology limits the probability of adoption. Future research should examine soil compaction, a key variable for understanding differences between the adoption of minimum and zero tillage. Another area that merits further research is the link between weeds and conservation tillage: several farmers reported using the technology to obtain better weed control. The long-term effects of conservation tillage should also be assessed. Extension in Regions II and III should seek to accelerate adoption of conservation tillage, particularly zero tillage. In Region I, extension should steer the change process from minimum to zero tillage.

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Introduction

In the mid-1980s, the Agricultural Research Institute of Panama (IDIAP), with support from the International Maize and Wheat Improvement Center (CIMMYT) and the Regional Maize Program (PRM), began an on-farm research program in the Azuero region, which lasted until the early 1990s. Azuero is the principal maize-producing region of Panama. The research program identified intensive soil erosion as a major problem in farmers' fields. Soil erosion has important consequences, expressed in the loss of soil productivity.

Researchers found that land preparation practices for maize were among the most important factors contributing to the erosion problem. Maize sowing practices were also linked to the high costs of producing maize in the region. The commercial maize farmers in Azuero prepared their land using conventional tillage practices (L_c). Conventional tillage consisted of making a pass with a disk plow or harrow to a depth of approximately 6 inches to turn the soil over. This was followed by two or more passes with a harrow or an implement called a "semi-roma" until the soil was ready for sowing (Pereira de Herrera et al. 1990).

Starting in the 1984–85 agricultural year, IDIAP launched an aggressive on-farm research and validation program to study zero tillage (L_0) as an alternative to L_c. This program had a threefold objective (to reduce the erosion in maize fields, conserve soil moisture, and reduce the costs of land preparation), with the ultimate goal of increasing the profitability of tillage.

Soon afterward, IDIAP began recommending the use of L_0 for land preparation. The recommended zero tillage practice consisted of a mechanical or manual weeding, application of a contact herbicide once weeds reappeared, and sowing with a precision planter adapted to L_0, or with a planting stick, depending on the plot size.

This recommendation was complemented by two synergistic factors. First, the Ministry of Agricultural Development (MIDA) promoted the L_0 technology in the area through demonstration plots and transfer activities. Second, some commercial firms simultaneously introduced precision planters adapted to the L_0 system.

At present, farmers in Azuero prepare land for sowing maize in three ways. A considerable number of farmers have adopted the IDIAP recommendation of L_0. Others have adjusted the recommendation by eliminating a pass with the plow and reducing the number of passes made with the semi-roma or harrow—a practice that could be regarded as minimum tillage (L_m). Still other farmers continue with L_c.

The coexistence of these three forms of land preparation motivated the study described in this paper. The study had three main objectives:

1. To identify the degree of adoption of zero and minimum tillage for maize in the Azuero region.
2. To identify the factors that influence the adoption of the different forms of land preparation.
3. To analyze the implications of this study for the maize research and transfer program in the Azuero region.

Study Area and Data Sources

Location and Data Sources

The study area is located in the coastal zone of the Azuero region, which consists of the provinces of Herrera and Los Santos. The study involved eight districts of these provinces and 50 localities distributed within them. Information for the study was obtained through a formal survey of 122 farmers in the principal maize-growing areas, where most farmers practice mechanized maize production and market most of their output.

No prominent climatological or soil differences are found in the study area, but there are clear differences in farmers' socioeconomic characteristics, such as the cultivation system, the level of productive resources, and access to information about conservation technology.

Taking these differences into account, the sample was stratified into three large areas or regions. Region I was formed by the districts of Las Tablas, Pedasí, Pocrí, and Guararé in Los Santos Province and included 28 localities. Region II consisted of the districts of Los Santos and Macaracas in Los Santos Province and included 12 localities. Region III, formed by the districts of Chitré and Parita in Herrera Province, included 10 localities. Figure 1 shows the location of the Azuero region within Panama and the study area.

In each region, the sample was stratified based on the size of the largest maize plot cultivated by farmers according to seven size ranges.

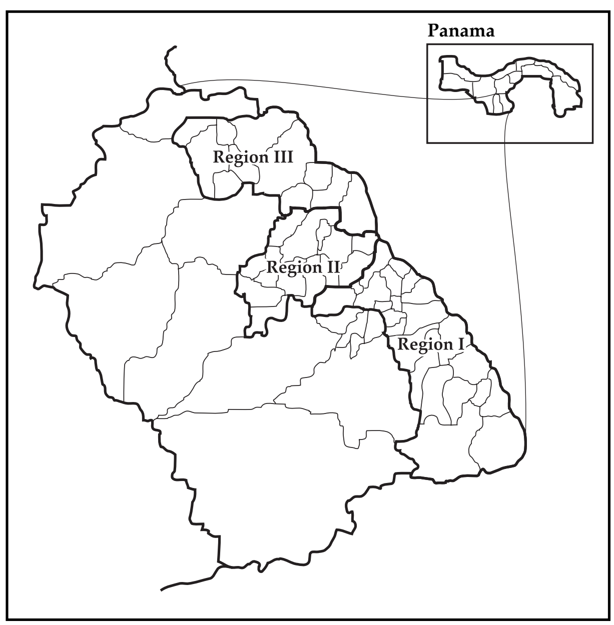

Figure 1. Location of the study area.

The following formula was used to determine the sample size in each size range of the maize plots:

$$[1] \qquad n = \frac{N\sigma^2}{(N-1)\frac{B^2}{4} + \sigma^2}$$

where N is the total number of farmers in each plot size range, σ^2 is the variance of the plot size, and B is the estimation error of the sample. The information on the number of farmers and size of the maize plots, as well as their regional distribution, was supplied by MIDA. The parameters used to select the sample in each plot size range are detailed in Appendix 1.

The sample, which consisted of 122 farmers (52 in Region I, 46 in Region II, and 24 in Region III), represented approximately 21% of the total commercial maize farmers in the Azuero region. The survey was done in March and April 1994, after the second cropping season, and gathered information on the 1993–94 agricultural year.

Main Physical Characteristics

The soils of the region are, for the most part, acidic or slightly acidic (pH 5.6 to 5.9), with a sandy clay loam texture. Phosphorus availability varies significantly, aluminum toxicity is very low, and organic matter content is low (Gordon et al. 1992). The study area is practically at sea level, with elevations ranging from 10 to 40 masl.

The average annual rainfall for 1980–93 was 975 mm, mainly distributed in the seven months from May to November. Months of high rainfall, such as August and September (102 and 124 mm, respectively), correspond to the sowing period and the first stages of maize development. In the dry or summer season from December to April, rainfall is minimal.

Most maize plots are located on flat land (65%), although there are some differences among the regions. In Region III, 79% of the maize plots were located on flat land, while in Regions I and II approximately 35% of the plots are on rolling terrain.

Main Characteristics of the Maize Production System

Although in the Azuero region a highly mechanized production system coexists with a traditional or subsistence planting stick system, the former is more prevalent. In the 1994–95 agricultural year in Panama, the area sown to maize under the traditional system was 11,669 ha, or 80% of the total area sown to mechanized maize nationwide.

The mechanized production system is characterized by high use of external inputs such as fertilizers and certified seed. The system is used by commercial farmers who generally own their own machinery, receive technical assistance, have access to credit, and sell all of their production. Under this system, maize is generally cultivated on flat land with slopes smaller than 20°.

On the other hand, the traditional system is used over small areas, which are planted using a planting stick. This system is characterized by a low use of external inputs and limited access to credit and technical assistance. An important part of the production is retained for consumption on the farm.

Rainfall patterns divide the agricultural year into two seasons. The beginning of the first season coincides with the beginning of the rains in May and ends in September, when the second season begins. The second season extends from September until the beginning of the dry season or summer. Commercial maize is produced mainly during the second season so that afterwards livestock can graze the maize residues. The animals stay in the plot during the summer and all of the next first season, until land preparation for a new maize sowing begins.

This system, which could be termed a livestock–maize–livestock system, prevails in the three regions. More than 90% of the maize plots surveyed are cultivated under this system, although 10% of the farmers in Region II grew maize or vegetables during the first season.

In general, livestock are an important component of farming systems throughout Azuero. More than 70% of the maize farmers in the three regions dedicate between 60% and 90% of their area to livestock production (Table 1). Livestock herds range in size from fewer than 15 animals raised by small-scale cattle producers to more than 100. Although livestock are important in all three regions, the livestock herd is significantly larger on average in Region I than in the other two regions (Table 1).

Table 1. Number of animals and total average area dedicated to livestock, by region, Azuero, Panama, 1994

	Region I		Region II		Region III	
Number of livestock	**Number of farmers**	**Percent of farmers**	**Number of farmers**	**Percent of farmers**	**Number of farmers**	**Percent of farmers**
No livestock	14	26.9	7	15.2	8	33.3
5–15	7	13.4	5	10.9	3	12.5
16–30	3	5.8	8	17.4	3	12.5
31–50	14	26.9	9	19.6	3	12.5
51–100	4	7.8	5	10.9	3	12.5
101–200	7	13.4	12	26.1	3	12.5
>200	3	5.8	0	—	1	4.2
Total	52	100.0	46	100.1	24	100.0
Average number of animals	101		61		74	
Total average area dedicated to livestock	91		59		61	

The form of land tenure is linked with the number and size of a farmer's maize plots. Regions differ markedly with respect to the total area sown to maize as well as the number of plots. The average area sown to maize is significantly larger in Region I than in Regions II and III, while there are no significant differences between the average areas in Regions II and III (Table 2).

Table 2. Average maize area, by region, Azuero, Panama, 1994

Description	Region I	Region II	Region III
Average area (ha)	47.2	15.9	16.6
Variance	4,911	863	691
t-test probability of strata 1 and 2	0.002	–	–
t-test probability of strata 1 and 3	0.003	–	–
t-test probability of strata 2 and 3	0.461	–	–

Table 3. Total maize area, by region, Azuero, Panama, 1994.

Area sown (ha)	Percentage of farmers		
	Region I	Region II	Region III
0.5–5.0	25	50	46
5.1–10.0	19	27	13
10.1–50.0	29	15	37
50.1–100.0	8	4	0
>100.0	19	4	4

Table 3 shows that in Region III only 25% of the farmers grow maize on less than 5 ha, while 19% grow maize on areas greater than 100 ha. In contrast, 50% of the farmers in Region II and 46% in Region III produce maize on less than 5 ha, and only 4% produce it on more than 100 ha.

Farmers in Region I, who grow maize on a larger area, produce maize on several plots, which are either owned or rented. The number of plots used to produce the maize crop is larger in Region I than in the other regions. While most farmers in Regions II and III grow maize on one or two plots (78.3% and 62.4%, respectively), 32.7% of the farmers in Region I grow maize on three to five plots, and 19% grow maize on more than six plots (Table 4).

Crop Residue Management and Land Tenure

Given the climate of the Azuero region, especially the rainfall pattern, maize crop residues are an important element of livestock

Table 4. Number of plots sown to maize, by region, Azuero, Panama, 1994

Number of plots	Region I		Region II		Region III	
	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
1	14	26.9	25	54.4	5	20.7
2	11	21.6	11	23.9	10	41.7
3	8	15.4	3	6.5	4	16.7
4	8	15.4	2	4.3	3	12.5
5	1	1.9	2	4.3	2	8.4
6–10	8	15.4	3	6.6	—	—
>10	2	3.8	—	—	—	—
Total	52	100.0	46	100.0	24	100.0

diets during the dry months. The availability of crop residues and access to those residues for livestock feed ultimately depend on the tenure of the maize plot. Land tenure arrangements vary across the regions. Almost half of the maize plots in Region I are rented, while in Regions II and III most farmers cultivate maize on their own land (Table 5).

Plots are generally rented for maize production only during the cropping season, since the landowners are primarily cattle producers, and the rental contracts explicitly specify who has rights to the crop residues. In all of the regions, more than 85% of the farmers who grow maize on their own land use the residues to feed their livestock. Those that are not cattle producers sell the residues or the right to graze on them. On the other hand, most farmers who rent land to grow maize (75% in Regions I and II, and 86% in Region III) are required to leave the crop residues in the field as part of the rental agreement with landowners who raise cattle. This situation occurs independently of the length of time over which a farmer has rented the same plot of land to grow maize. In Region I, for example, 44% of the farmers who rented land for maize production had rented the same plot for more than four years.

These results confirm the critical importance of maize crop residues for feeding livestock during the dry season. This use of crop residues prevents them from being used for soil conservation.

Table 5. Land tenure of the largest maize plot, by region, Azuero, Panama

	Percentage of farmers		
Form of tenure	**Region I**	**Region II**	**Region III**
Own	52	76	71
Rented	48	22	21
Sharecropped	0	2	8

Diffusion of Conservation Tillage

Conservation tillage is defined as a system or sequence of operations that reduces the loss of soil or water in comparison to losses incurred under conventional tillage systems, and it includes systems ranging from zero tillage and reduced tillage to different forms of crop residue management (Kilmer 1982). The term "conservation tillage" has many meanings in the literature, however, particularly when its definition includes the management of crop residues. For this reason, the analysis of tillage practices in certain cases requires a working definition of conventional tillage and conservation tillage, as well as zero tillage and minimum tillage, which are two forms of conservation tillage.

Taking into account the fact that different forms of land preparation exist in Azuero but that crop residues are managed in the same way throughout the region, for the purposes of this paper we define land preparation systems as explained below.

Conventional tillage (L_c) is land preparation with a disk plow and one or two passes of a harrow. The practice that includes three passes of the semi-roma is also regarded as L_c, because it is very similar to conventional tillage in terms of soil and water losses. The practice of making one or two passes with a harrow and then one or two passes with a semi-roma, which is not very common, is also classified as L_c.

Minimum tillage (L_m) refers to land preparation with one or two passes of a semi-roma and the application of a herbicide.

Zero tillage (L_0) refers to land preparation done by mechanically or manually cutting the cover vegetation of the field and applying a herbicide.

Current Forms of Land Preparation

Survey information about the land preparation practices of maize farmers in 1994 allowed us to characterize current tillage methods and to improve our understanding of the process through which farmers adopt zero and minimum tillage practices. Table 6 shows marked differences among regions in the use of different tillage practices. While most farmers in Region I use some conservation practices—either L_m (43%) or L_0 (24%)—in Regions II and III the most widespread form of tillage is L_c. In these regions, the adoption of L_m is still incipient, while not even 10% of the farmers use L_0. The various forms of land preparation are described in greater detail here.

The most common form of L_c is to wait approximately 15 days between the pass made with the plow and the passes subsequently made with the harrow. Another variation on this practice was to make the first pass of the plow and the harrow at the same time, and to perform the second harrowing after 15 days.

For L_m, farmers who make two passes with the semi-roma generally leave a period that varies broadly from 15 to 30 days between one pass and another. Nevertheless, one group of farmers made two passes with the semi-roma one after the other.

Table 6. Forms of land preparation for maize, by region, Azuero, Panama, 1994

	Region I		Region II		Region III		Total	
Land preparation practice	**Number of farmers**	**Percent of farmers**	**Number of farmers**	**Percent of farmers**	**Number of farmers**	**Percent of farmers**	**Number of farmers**	**Percent of farmers**
Plowing and harrowing (1 or 2 passes)	8	16	24	52	11	46	43	36
Three passes with semi-roma	9	18	8	17	3	13	20	17
Up to 2 passes with semi-roma	22	43	8	17	7	29	37	31
Zero tillage	12	24	6	13	3	13	21	17
Total	51	100	46	100	24	100	121	100

Farmers that use L_0 as well as L_m apply a burning herbicide, generally glyphosate or paraquat, generally in the first 15 days before sowing. It should be noted that mechanical weeding, which was part of the recommended practice, is not a common practice among maize farmers, regardless of the type of tillage used.

Farmers' use of herbicides differs by region. In Region I, L_m or L_0 is accompanied by the use of systemic herbicides such as glyphosate and/or burning herbicides such as paraquat, while farmers in Regions II and III use paraquat and not glyphosate. This difference would be explained by a greater presence of weeds in Region I, mainly *Cyperus rotundus*.

The Dynamics of Tillage Practices

The adoption of new technologies is a dynamic process. Farmers almost continually seek new ways of improving efficiency by increasing productivity or decreasing costs. To enable us to analyze how zero tillage technology spread and to identify the factors that motivated the technology's development, our survey in Azuero included a section on the type of technological change and time frame over which farmers changed their land preparation practices for planting maize.

Across the survey area, 60% of farmers had changed land preparation practices in the six years before the survey, while the remaining 40% had made no change. When the data are disaggregated by region, however, a different dynamic appears for each region under study.

Most farmers who made no changes (69%) maintained conventional tillage practices, particularly in Region II. In a small number of cases (13%), farmers used conservation tillage before the on-farm research program began in 1985. These farmers were concentrated in Regions II and III. Other farmers (19%) continued to practice minimum tillage without any changes (Table 7). These cases will be analyzed in detail later in this paper, in relation to the factors that influence the adoption of conservation tillage.

Table 8 presents the types of changes in tillage practices for each region and for the entire study area for those farmers who changed their method of land preparation between 1985 and 1994. At the aggregate level, the most relevant changes observed are the elimination of plowing and

Table 7. Farmers who have not changed their land preparation and tillage practices, Azuero, Panama, 1994

Form of land preparation	Number of farmers by region			Total Azuero	
	I	II	III	Number of farmers	Percent of farmers
Zero tillage (L_0)	0	4	2	6	13
Minimum tillage (L_m)	4	2	3	9	19
Conventional tillage(L_c)	7	21	5	33	69
Total	11 (23%)	27 (56%)	10 (21%)	48	100

Table 8. Changes in land preparation between 1988 and 1994, by region, Azuero, Panama

Description of changes		Region I		Region II		Region III		Total	
1988	1994	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
Plow followed by harrow or 3 or more passes of semi-roma (L_c)	1 or 2 passes of semi-roma (L_m)	17	43	6	32	5	36	28	38
Plow followed by harrow or 3 or more passes of semi-roma (L_c)	3 or more passes of semi-roma (L_c)	7	18	5	26	4	29	16	22
Plow followed by harrow or 3 or more passes of semi-roma (L_c)	Manual weeding and herbicides (L_0)	13	33	3	16	1	7	17	23
Mechanical weeding or burning herbicide (L_0)	Plow followed by harrow or 3 or more passes of semi-roma (L_c)	1	3	1	5	0	0	2	3
Various passes of semi-roma (L_m)	Plowing and harrow (L_c)	1	3	3	16	3	21	7	10
Manual chopping and burning (L_0)	Plowing and harrow (L_c)	1	3	1	5	1	7	3	4
Total		40	100	19	100	14	100	73	100
Percentage over total			55		26		19		100

harrowing in land preparation (the first three types of change in Table 8). About 83% of the farmers who said they changed their land preparation practice also reported that they replaced plowing and harrowing with zero tillage (23%), minimum tillage (28%), or with three or more passes with the semi-roma (22%). Less than 20% said they had used some form of conservation tillage in the past but had then returned to conventional tillage practices (the last three types of change in Table 8).

Of the three regions studied, Region I seems to have been the most dynamic. Thirty-three percent of farmers in Region I switched from L_c to L_0, and forty-three percent switched from L_c to L_m. In Region II, 16% of farmers switched from L_c to L_0, and 32% from L_c to L_m. For Region III, the figures are 7% and 36% of farmers, respectively. The most common changes in land preparation in Regions II and III were the elimination of plowing and the use of one or two passes with the semi-roma.

The number of farmers who changed to L_0 is less than the number of farmers currently using this tillage system. This indicates that a group of farmers use the L_0 practice without ever having changed from conventional tillage to zero tillage.

Time Diffusion of Conservation Tillage

Most changes in land preparation were made between 1991 and 1993. Table 9 shows that most farmers who did make a change in land preparation made it during this period. The five-year gap between the technology generation and transfer process and the massive diffusion of the technology is consistent with the dynamics of a generation and transfer process in an on-farm research program (Sain and Martínez 1986).

Table 9. Periods when major changes in land preparation practices were made in Azuero, Panama

Region	Change	Percentage of farmers per period			Total period 1985-93 (number of farmers)
		1985-87	1988-90	1991-93	
I	From L_c to L_0	0.0	15.4	84.6	13
	From L_c to L_m (<3 passes with semi-roma)	0.0	23.5	76.5	17
	From L_c to 3 or more passes with semi-roma	14.3	42.9	42.9	7
II	From L_c to L_0	0.0	0.0	100.0	3
	From L_c to L_m (<3 passes with semi-roma)	0.0	0.0	100.0	6
	From L_c to 3 or more passes with semi-roma	0.0	20.0	80.0	5
III	From L_c to L_0	0.0	100.0	0.0	1
	From L_c to L_m (<3 passes with semi-roma)	20.0	40.0	40.0	5
	From L_c to 3 or more passes with semi-roma	0.0	75.0	25.0	4
	From L_c to L_0	0.0	17.6	82.4	17
Total Azuero	From L_c to L_m(<3 passes with semi-roma)	3.6	21.4	75.0	28
	From L_c to 3 or more passes with semi-roma	6.3	43.8	50.0	16

The speed with which technological change took place varied between Regions II and III. For example, 90% of the farmers who changed practices in Region II did so within the three years prior to the survey, whereas farmers in Region III had changed practices in the preceding three to five years. This difference between the two regions can be attributed to the fact that Region II is closest to the areas in Region I where the adoption of conservation tillage has been more dynamic. In Region III, which is geographically farther away from Region I, conservation technologies were promoted as part of a wider extension program some years ago. That program gave little attention to whether appropriate equipment was available for zero tillage, which is critical for the adoption process.

The adoption of minimum and zero tillage is very different across the regions. In Regions II and III, minimum tillage has been partially adopted, but not zero tillage, while in Region I there is a high adoption level of both minimum and zero tillage.

The survey results show that most farmers in Region I adopted zero tillage or minimum tillage over 1990–93, between five and eight years after the extension effort began. This diffusion pattern was corroborated with additional information on sales of planting equipment for zero tillage in Azuero. The COPAMA company, a distributor of this type of machinery, indicated that from 1990 onward, sales substantially increased, and six machines were sold each year in Azuero.

Institutions That Participated in the Diffusion of Conservation Tillage

In analyzing the adoption of a new technology, it is important to identify who recommended it to farmers. In this way we can analyze the mechanism by which the technology spread and correctly attribute the benefits of the research.

In Azuero, the technology transferred by IDIAP and MIDA corresponds to L_0. In practice, however, a number of farmers adapted the recommendation to their own circumstances, and their adaptations correspond to L_m. During the survey, farmers were asked how they had obtained information on zero and minimum tillage practices. Both L_0 and L_m were grouped together in the analysis as conservation tillage practices. The results are summarized in Table 10,

Table 10. Origin of use of conservation tillage (zero or minimum tillage) in maize, Azuero, Panama, 1994

	Region I		Region II		Region III	
Origin	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
Recommendation	34	65.4	21	45.6	19	79.2
MIDA	6	17.7	1	4.8	5	26.3
IDIAP	8	23.5	1	4.7	5	26.3
Other	20	58.8	19	90.5	9	47.4
Subtotal	34	100.0	21	100.0	19	100.0
Other origins	18	34.6	25	54.4	5	20.8
Total	52	100.0	46	100.0	24	100.0

which shows the importance of IDIAP's and MIDA's work in generating and diffusing conservation tillage technology. Most farmers in Regions I (65%) and III (79%), and almost half (45%) in Region II, reported that they knew about conservation tillage through some recommendation. Both IDIAP and MIDA were important sources of this recommendation in Regions I and III, although not in Region II. This discrepancy is explained by the fact that IDIAP and MIDA had and still maintain an active research and extension program on conservation tillage in Regions I and III, whereas their operations in Region II are minimal.

A key feature of the technology transfer process in all three regions is that the farmers who began to adopt zero or minimum tillage practices were to a large extent leader farmers. These farmers, generally large-scale farmers, introduced the zero tillage planting equipment and also rented out agricultural machinery, exercising an influence on other maize farmers. This is the reason why many farmers said that they had known about conservation tillage through other farmers' recommendations.

Other Technological Changes Associated with Conservation Tillage Technology

Form of maize sowing

Under zero or minimum tillage, planting is done with a planter that has corrugated disks. Alternatively, planting can be done with a conventional planter that has an adaptation for these disks.

Survey data indicated that changes in land preparation practices took place together with the changes in the type of planting equipment that farmers used. For example, farmers in Region I switched from using conventional planters (John Deere 7,000 or Giraldi) to zero tillage planters. As many as 75% of the farmers from this region said that they had been using the zero tillage planter for four years or less.

The method of sowing and use of planting equipment vary considerably across the regions, however. About 70% of the farmers interviewed in Region I used a zero tillage planter or conventional equipment adapted for conservation tillage (Table 11). Most farmers said that they either owned or could rent this equipment. Thus a lack of equipment does not constitute an obstacle for the adoption of zero tillage technology in this stratum. On the other hand, in Regions II and III the use of conventional tillage and planting equipment prevails, generally on land prepared under the conventional tillage system. Moreover, in Region II more than 40% of farmers continue to plant maize with a stick, which is also used to a lesser extent in Region III (Table 11).

These data indicate that in Regions II and III the adoption of minimum tillage practices has not been accompanied by the use of the zero tillage planter, as in Region I. Farmers who prepare their land under the zero tillage system in Regions II and III sow their maize with a planting stick. As will be seen later, the zero tillage planter is used less because it is less available in the area.

Use of insecticides

Zero tillage technology has been associated with a greater use of insecticides, which has been attributed to higher populations of soil pests. Pest populations are thought to increase as a result of a greater quantity of residues in the soil, enhanced by the effects of the livestock component of the system. Results of this study, however, showed no meaningful association between the use of soil insecticides and the adoption of zero and/or minimum tillage (Table 12).

Impact on maize yields

Conservation tillage technology has been hypothesized to reduce yields in the short run. This study showed significant differences between the mean maize yield of farmers who adopted conservation tillage and those who did not. The average yield among farmers using L_0 and L_m was 3.3 t/ha, in comparison with 2.8 t/ha obtained by farmers using L_c (Table 13).

The yield increase is not necessarily associated with the use of conservation tillage, however; it could be linked to other technological factors. Because the survey collected only partial

Table 11. Type of planting equipment and planting method used in the second season of 1993 for maize, by region, Azuero, Panama, 1994

	Region I		Region II		Region III	
Planting equipment and method	**Number of farmers**	**Percent of farmers**	**Number of farmers**	**Percent of farmers**	**Number of farmers**	**Percent of farmers**
Plate	1	2.08	15	55.6	8	40.0
Conventional	13	27.08	11	40.7	12	60.0
Zero tillage	34	70.84	1	3.7	–	–
Does not know	–	–	–	–	–	–
Total	48	100.0	27	100	20	100.0
Used mechanical planter	48	92.3	27	58.7	20	83.3
Used planting stick	4	7.7	19	41.3	4	16.7
Total	52	100.0	46	100.0	24	100.0

Table 12. Use of insecticide on maize seed by adopters and nonadopters of zero tillage, Azuero, Panama, 1994

	Adopters	Nonadopters
Used insecticides (%)	47.27	52.73
Did not use insecticide (%)	40.00	60.00
Pearson Chi-Square coefficient	0.6176	
Probability	0.4319	

Table 13. Average maize yields of adopters and nonadopters of conservation tillage, Azuero, Panama, 1994

	Adopters	Nonadopters
Average yield (t/ha)	3.3	2.8
Standard deviation (t/ha)	1.0	1.1
Observations (no.)	51	70
t-statistic	2.7	
Probability	0.00***	

Note: *** indicates average difference is different from zero with 99% confidence (two-tailed test).

information on production technology, the relationship between maize yield, plot size, importance of livestock, form of tillage, and region was estimated. The functional form was:

[2] $Y = \beta_0 * S^{\beta 1} * IG^{\beta 2} * e^{\beta 3 * L} * e^{\beta 4 * R}$

where *Y* represents maize yields in kg/ha; *S* is the maize area sown in 1994 in hectares; *IG* is the importance of livestock, measured as a proportion of the total area of the farm allocated to this activity; *L* is a qualitative variable that takes a value of 1 if the farmers used L_0 or L_m and 0 if the farmer used L_c; and *R* is a qualitative variable that takes a value of 1 if this observation is in Region I and 0 if it is in Regions II or III.

To estimate the parameters of Eq. [2], natural logarithms were taken to make it linear, and the method of ordinary least squares was applied. The results were:

[3] $\text{Ln}(Y) = 2{,}121 + \underset{(4.1)^{***}}{0.09\ \text{Ln}(S)} + \underset{(1.69)^{*}}{0.15\ \text{Ln}(IG)} + \underset{(0.23)}{0.01\ L} + \underset{(1.64)^{*}}{0.11\ R}$

$R^2 = 0.20$; n = 114

where the values in parentheses represent values of the t-statistic. Three asterisks indicate that the coefficient is different from zero with a confidence interval of 99%, while one asterisk alone indicates a confidence interval of 90%.

Although Eq. [3] explains only 20% of the variation in yields, which was expected given the absence of explicit technological variables, it does show that the type of tillage does not significantly explain the variation in yield. Variables such as cultivated area and importance of livestock, which are associated with the level of farmers' revenues, seem to explain this variation better. In addition, a meaningful difference was found between yields in Region I and those in the other two regions.

Farmers' Perceptions about Conservation Tillage

Before analyzing which factors affect farmers' decisions on whether to adopt conservation tillage (zero or minimum tillage), we analyzed farmers' reasons for using different land preparation methods. The results are discussed next for the various methods.

Reasons for using L_m and L_0 in maize

The two most common reasons for using conservation tillage (either L_m or L_0) were reduced costs and soil conservation (Table 14). The reduction in production costs per unit of land (ha) using L_0 or L_m varies, depending mainly on the number of passes made with the semi-roma and on the type of burning

Table 14. Farmers' reasons for using minimum or zero tillage in maize, Azuero, Panama, 1994

	Percentage of farmers		
Reason	**Region I**	**Region II**	**Region III**
Reduces costs	46	37	38
Conserves soil	26	32	38
Better weed control	10	5	12
Other	18	26	12

herbicide used. The average cost of land preparation for farmers using L_m was 12% less than that of farmers using L_c. The cost reduction is 41% in the case of farmers using L_0 (Table 15). This last figure represents a reduction of almost 10% in total production costs.

The differences observed among regions in the importance that farmers give to cost reduction versus soil conservation may be explained by differences in the land tenure arrangements for maize plots. In Region I almost half (48%) of the plots where maize is cultivated are rented during the cropping season (Table 5). For farmers in this region, a reduction in production costs is more important than soil conservation as a motive for adopting conservation tillage. In Regions II and III, however, farmers own more than 70% of the plots used to produce maize. Farmers in these regions also have smaller production areas with greater resource limitations than farmers in Region I, and their need to conserve soil outweighs even their need to reduce costs.

Although it is of lesser importance to farmers, another potential reason for farmers' use of L_0 or L_m is more effective weed control. The use of conventional tillage or the semi-roma in fields infested with *Cyperus rotundus* incorporates and disseminates this weed, worsening the problem. Under zero tillage, the undisturbed soil and application of glyphosate limit weed germination, and after several years weed infestation is considerably reduced.

Reasons for not using L_m and L_0 in maize

Two factors external to the farm (lack of planting equipment and lack of information) and one internal to the farm (problems with the maize plot) are the three factors that, according to farmers, limit use of conservation tillage in Azuero (Table 16).

Table 15. Land preparation costs of different tillage systems, Azuero, Panama, 1994

	Land preparation costs ($/ha)		
Statistics	**Conventional tillage**	**Minimum tillage**	**Zero tillage**
Mean	77.72	68.32	45.45
Median	75	50	48
Standard deviation	25.09	24.42	18.00
Minimum	40	50	10
Maximum	143	133	83
Observations	62	37	22
Degree of confidence (95%)	6.37	8.14	7.98

Table 16. Farmers' reasons for not using zero or minimum tillage for maize, Azuero, Panama, 1994

	Percentage of farmers		
Reason	**Region I**	**Region II**	**Region III**
Lacks planting equipment	27	46	50
Has conventional planting equipment	–	5	20
Does not know the technology	26	21	10
Problems with the maize plot	26	10	10
Other factors	–	17.9	—
Does not like conservation tillage system	–	—	10.0

In Region I these three factors all have a similar degree of importance, while in Regions II and III the most important factor (about 50% of responses) corresponded to the lack of planting equipment for L_0. This market failure is illustrated in Table 17, which shows a marked lack of access to this type of planting equipment in Regions II and III.

Lack of information about the technology was a factor particularly mentioned in Regions I and II. This limiting factor can be related to the dynamics of the diffusion process, which is still in an early phase, and to the declining budget for extension work, which has caused a substantial reduction of field activities. In fact, technology transfer activities in Region II were minimal.

Another factor that merits discussion is the extent to which conventional tillage equipment is available (including conventional planting equipment) in Region III. This factor acts as a barrier to change, since it represents an investment that the farmer must recover. In fact, if the land preparation practice were to change, this machinery would represent a sunk cost that would be greater than the cost savings from conservation tillage.

Factors Affecting the Adoption of Conservation Tillage

Several circumstances, internal and external to the farm, have been identified as important in farmers' decisions to adopt soil conservation technologies in temperate or subtropical environments (Anderson and Thampapillai 1990; Napier 1991; Thampapillai and Anderson 1991). The factors mentioned in the literature are associated with their impact on the net present value of the differential flow of the expected benefits between conservation and conventional tillage. For example, factors such as topography, soil type, rainfall, and cultivation system affect the flow of differences in yields between both technologies. At the same time, factors such as incentives, access to credit, input subsidies, and product prices are associated with the value of the differences in net benefits. The planning period and the farmer's discount rate are two important variables in the farmer's perception of the costs and benefits of this type of technology. The form of land tenure, welfare level (farm size), age, the farmer's degree of knowledge about the problem of soil erosion, and the farmer's level of education are some of the factors associated with these two variables.

Table 17. Farmers' opinions on access to planting equipment for zero tillage, by region, Azuero, Panama, 1994

	Region I		Region II		Region III	
Planting equipment easily available?	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
Yes	38	73.1	13	28.3	3	12.5
No	14	26.9	33	71.7	21	87.5
Total	52	100.0	46	100.0	24	100.0

The relative importance of each factor is an empirical issue and depends on the case under consideration. Napier (1991) found that factors such as land tenure, access to credit, availability of public land, and the development of the land market were important factors in the adoption of conservation tillage. Other studies have identified factors such as topography (slope), type of rotation, soil type, degree of soil erosion, family composition, farm size, sensitivity to changes, and level of education (Crosson 1981; Ervin 1982; Saliba 1983; Rahm and Huffman 1984; Anderson and Thampapillai 1990).

In the case of Azuero, the information presented in the previous section on factors that farmers consider important in their decisions to adopt L_0 and L_m permits us to formulate some hypotheses on the factors that affect the adoption of these technologies. Of particular importance is the fact that farmers perceive the reduction of land preparation costs to be an important advantage of the conservation practice over the conventional one. This perception emphasizes the short-term advantages of the technology over the longer term ones and also emphasizes the importance of understanding the limitations on farmers' ability to appropriate this cost savings. One of the most important limitations is ownership of conventional tillage equipment, which represents a sunk cost whose magnitude neutralizes any cost reduction from conservation tillage. Poor availability of conservation tillage equipment is another factor that could limit adoption, particularly on large farms where manual sowing is unprofitable.

Given the relative importance of the short term in determining the profitability of conservation tillage technology, factors related to the farmer's planning horizon, such as the form of land tenure, lose relevance. The mechanization of L_0 and L_m in Azuero, however, means that factors associated with farmers' welfare level, such as land ownership and plot size, influence the adoption decision.

The hypothesis that technical personnel of IDIAP and MIDA use to explain why some L_0 farmers adapted the technology to L_m is related to soil compaction. According to this hypothesis, excessive soil compaction (occurring when animals graze the maize plot after the growing season) prevented farmers from following the planting practices recommended for L_0. Instead, farmers had to make one or two passes with a harrow to sow their maize. Although factors related to crop residues were not included in the definition of conservation tillage, factors related to management of the livestock herd (grazing pressure) might be important in the decision to use L_0 or L_m.

Other elements that the farmers judged important in deciding to adopt conservation tillage were the degree of knowledge or information about the practice and the type of plot.

Many of the factors affecting farmers' tillage decisions were of greater or lesser importance in some regions than in others. For example, access to or availability of zero tillage planting equipment seemed to be a strong limitation to adoption in Regions II and III but not in Region I. Likewise, the lack of information on these technologies seemed to be more of a limiting factor in Regions II and III than in Region I.

Given the differences between Region I and Regions II and III with respect to physical and socioeconomic conditions, adoption levels, and the factors that potentially influence adoption of the technology, it was decided to regard the groups as two distinct populations and analyze the factors affecting adoption separately.

The Model for Selection of Tillage Type

It is assumed that the farmer decides which tillage practice to use in the maize plot on the basis of the benefits that she or he expects to obtain. The benefits per unit area are expressed as:

$$[4] \qquad \pi_{in} = \beta_i' Z_n + \varepsilon_{in}$$

where π_{in} represents the level of benefits per unit perceived by the n-th farmer upon using the i-th tillage type; β_i is a vector of parameters to be estimated; Z_n is the vector of plot and farm characteristics, which depends on the benefits level; and ε_{in} is an error term associated with the presence of nonobserved factors and with other causes out of the researcher's control.

Given that several tillage options are available, the farmer will choose the one that gives a greater benefit. If the index corresponding to traditional tillage is defined as $i = 0$, then the farmer will choose the i-th alternative if the following condition is met:

$$[5] \qquad \beta_i' Z_n - \beta_o' Z_n > (\varepsilon_{on} - \varepsilon_{in})$$

If the error term ε_{in} follows a Weibull distribution, then the difference between the two random variables in brackets follows a logistic distribution (Domencich and McFadden 1975), and the probability that the i-th tillage alternative will be selected is:

$$[6] \qquad P_{in} = \frac{e^{bi^*Zin}}{\sum_i e^{bi^*Zjn}} \; ; \qquad i = 0, 1; \; y \; n = 1, N.$$

where P_{in} is the probability that the i-th tillage type will be selected by the n-th farmer.

Eq. [6] illustrates the standard multinomial logit model (MLM) in which the parameters vary according to the alternatives but not according to farm characteristics. Thus the number of parameters to be estimated is equal to the number of factors multiplied by the number of alternatives. To estimate the probability of adoption of minimum tillage and zero tillage, however, the expression in Eq. [6] is normalized in terms of the alternative of nonadoption (i.e., conventional tillage) and the two following functions are estimated (Gujarati 1988; Train 1990):

$$\textbf{[7]} \qquad L1 = \ln[\frac{\Pr(Y = 1/Zi)}{\Pr(Y = 0/Zi)}] = \alpha 10 + \sum b1iZi$$

$$\textbf{[8]} \qquad L2 = \ln[\frac{\Pr(Y = 2/Zi)}{\Pr(Y = 0/Zi)}] = \alpha 20 + \sum b2iZi$$

The proposed empirical model attempts to capture the effects of factors that affect the costs and benefits obtained with the alternatives under consideration. The evidence indicates, however, that the type of tillage has a relatively small impact on maize yield levels. Therefore the most important factors, at least in the short run, will be associated with the costs of conservation and conventional tillage.

The variables included in the model are described below.

Dependent variable

Maize farmers who changed from a conventional land preparation system to zero or minimum tillage between 1985 (beginning of the technology recommendation and diffusion by the research program) and 1994 (the time of the survey) will be considered adopters. Thus farmers who used L_0 or L_m before 1985 and continued to do so in 1994 are eliminated from the analysis. In other words, our model does not attempt to explain the *current use* of conservation tillage practices but to identify the factors that positively or negatively influence *the change* from L_c to L_0 or L_m.

When this criterion was applied to Regions II and III, however, it became clear that although nine farmers (approximately 13% of the sample) used L_0, six of them had already adopted the practice before 1985. This left only three farmers (less than 5% of the sample) in the category of adopters. This small number made it impossible to estimate the model and showed that the process of change in these regions was mainly from L_c to L_m. For these reasons, in Regions II and III only the change from L_c to L_m was considered.

The dependent variable **tillage** is a qualitative variable that classifies farmers into three categories in Region I and two in Regions II and III. The value 0 represents a farmer who has not adopted zero or minimum tillage and continues using conventional tillage. The value 1 represents a farmer who has adopted minimum tillage (i.e., who changed from using conventional tillage with a plow to tillage without a plow and up to two passes with the semi-roma). The value 2 (in Region I only) represents a farmer who adopted zero tillage (i.e., who changed from the conventional system to not using the plow, applying herbicides, and possibly using a zero tillage planter). Table 18 shows the proportions of each of these categories in the sample.

Table 18. Dependent variable, proportion of each category in the sample

	Percentage in sample	
Category	**Region I**	**Regions II and III**
Nonadopter ($Y_i = 0$)	32.7	70.0
Minimal tillage adopter ($Y_i = 1$)	40.4	30.0[a]
Zero tillage adopter ($Y_i = 2$)	26.9	0
Number of observations	52	64

[a] Includes three cases (5%) that changed from conventional to zero tillage.

Independent variables

Variables or factors that are assumed to be important in the adoption decision for L_m or L_0 are grouped into three categories: those related to farm resources, those related to soil quality, and those related to implementation costs and transaction costs.

A higher level of farm resources has traditionally been associated with higher adoption rates. Farmers with higher resource levels generally tend to be the first to adopt new technologies, especially if adoption implies an initial investment in new machinery, such as planting equipment or special equipment to adapt conventional equipment. Farmers with higher resource levels often are also more integrated into the market, have greater access to credit, and are willing to take more risks. In our analysis, three variables are included to capture the level of resources: the form of tenure of the maize plot, the total area dedicated to maize production, and the importance of livestock on the farm. Furthermore, an interaction term between the form of land tenure and maize area is included.

Soil quality is an important factor in the decision to adopt a conservation technology, since the benefits expected by the farmer depend on the initial quality of the soil and the degree of improvement that the farmer expects with the new technology. In addition to a variable related to the degree of soil compaction, a variable for topography or slope of plot was included in the model.

With respect to implementation costs, the adoption of conservation tillage implies using a certain type of machinery, such as an appropriate planter, especially when the area sown is large. In these cases, ownership or rapid, timely access to this machinery will facilitate adoption. On the other hand, if a farmer already owns conventional tillage equipment, such as a plow and conventional planter, the probability of adopting conservation tillage is reduced because of the sunk costs effect. The farmer will want to recover the investment in this machinery by using it as planned, which will postpone the adoption of conservation tillage technology. Two variables were incorporated to capture these effects: the availability of machinery for L_0 and ownership of machinery for L_c.

With respect to transactions costs, a factor that greatly influences the adoption of a given technology is the level of information or knowledge that a farmer has about the technology. The more information a farmer has about conservation tillage, the greater the probability that he or she will adopt the technology.

The variables and their expected effects are described below.

Tenure is a qualitative variable that takes a value of 1 if the farmer owns the maize plot and 0 if any other tenure arrangement applies. The form of land tenure influences the probability of adoption through its impact on the farmer's welfare level and planning horizon. Since conservation tillage has long-term effects on soil quality and conservation, it can be expected that farmers who own land are more interested in adopting such technology than farmers who only rent land during the cropping season. This effect may or may not be important in cases such as this, however, in which the alternatives of L_0 and L_m have lower operational costs than L_c. Therefore, it is not possible to predict this variable's sign *a priori*.

Area planted to maize is a variable that attempts to measure whether adoption of conservation tillage is neutral with respect to maize plot size or whether adoption levels are biased toward the extremes of the size distribution. This relationship is not expected to be linear; therefore it is incorporated in its natural logarithmic form. It is not possible to predict this variable's sign *a priori*.

The **importance of livestock** is defined as the proportion of total farm area allocated to livestock production. In addition to measuring the resource level and type of farm, this variable also influences the adoption of conservation tillage through its effect on soil compaction. A positive relationship between this variable and the probability of adoption would be expected, because high values of this variable indicate a moderate to high resource level. The sign of the variable, however, remains undefined since this variable also acts as an approximation of the degree of soil compaction. A high level of compaction means that farmers need to plow the soil to improve its structure and negatively influences the decision to adopt L_0. In fact, soil compaction is thought to have motivated some farmers to modify the L_0 recommendation and replace it with L_m.

Because the level of soil compaction is difficult to observe and measure, its effect must be approximated by variables that are strongly related to it. If the farm has a high proportion of area dedicated to livestock production, there is greater grazing pressure on maize crop residues in the dry season, the likelihood of soil compaction is greater, and the possibilities of adopting L_0 and/or L_m will be smaller.[1]

Slope is a qualitative variable that takes a value of 1 when the maize plot is on flat land and 0 when the plot is on rolling terrain or steep slopes. A negative relationship is expected with the probability of adoption, because it is in hillside areas where mechanization leads to more soil degradation.

Availability of L_0 machinery is a qualitative variable that takes a value of 1 if the farmer owns or has access to either a zero tillage planter or conventional planting equipment adapted to zero tillage, and 0 if the farmer does not own or have access to this type of machinery. This variable measures the restrictions that the market imposes on adoption. Therefore a positive relationship with the probability of adopting L_0 and L_m is expected.

Ownership of L_c machinery is a qualitative variable that takes a value of 1 if the farmer owns some of this machinery and 0 if she or he does not. A negative relationship between ownership of conventional machinery and the decision to adopt zero tillage must be expected.

Information is a qualitative variable that takes a value of 1 when the farmer has access to information on conservation tillage technology and 0 when she or he does not. A farmer has had "access to information" if he or she has received a recommendation about the technology either from the research and extension institutions that promoted this technology or from other farmers.

[1] The correlation between this variable and grazing pressure, defined as the number of animals per unit area of cultivated maize, was estimated. A positive and significant correlation coefficient was found between both variables ($\rho = 0.56$).

Table 19 summarizes the expected effects and the principal sample characteristics of the variables for each of the two regions considered in the analysis.

Results

The estimated parameters of the conservation tillage adoption model for both regions are presented in Table 20. In general, the estimated logit model for each region was statistically significant, with 99% confidence according to the maximum likelihood test. The other measurements of goodness of fit of both models were also satisfactory. Table 21 shows the estimated model's capacity to predict farmers' classification into the different categories.

As expected, land tenure does not seem to influence the adoption decision in any of the regions considered. In other words, in the decision to adopt conservation tillage technology, the potential savings in short-term costs outweigh considerations about soil quality and farmers' planning horizon.

Notably, the two variables related to resource availability were different from zero but with opposite signs in the two regions considered. In Region I, plot size and importance of livestock positively influence the adoption of L_0 and L_m, whereas in Regions II and III their effects are negative. Thus in Region I the adoption of L_0 is biased toward larger maize plots, whereas in Regions II and III farmers with smaller plots have a greater probability of adopting L_m.

Table 19. Expected effect and descriptive statistics of the variables used in the conservation tillage model, Azuero, Panama, 1994

Region and variable	Expected effect	Mean/ proportion	Standard deviation	Minimum	Maximum
Region I (n=52)					
Log maize area	?	2.75	1.59	0	5.56
Tenure	?	0.52	0.50	0	1
Importance of livestock	?	0.48	0.33	0	0.99
Slope of field	-	0.63	0.49	0	1
Availability of zero tillage equipment	+	0.77	0.43	0	1
Ownership of conventional tillage equipment	-	0.12	0.32	0	1
Information	+	0.65	0.48	0	1
Regions II and III (n=64)					
Log maize area	?	1.96	1.29	0	4.83
Tenure	?	0.77	0.43	0	1
Importance of livestock	?	0.64	0.34	0	0.98
Slope of field	-	0.75	0.44	0	1
Availability of zero tillage equipment	+	0.33	0.47	0	1
Ownership of conventional tillage equipment	-	0.20	0.41	0	1
Information	+	0.61	0.49	0	1

In Region I farmers who have a greater livestock component in their enterprises have a greater probability of adopting conservation tillage, whereas the opposite is true for farmers in Regions II and III. In Region I factors related to the availability of resources seem to predominate in the adoption decision, whereas in Regions II and III grazing pressure plays a more important role.

The availability of L_0 machinery and ownership of conventional tillage machinery had the expected signs and were statistically significant in Region I but not in Regions II and III. The availability of machinery for L_0 positively affects adoption of L_0 and $L_{m,}$ while ownership of L_c machinery strongly restricts adoption of both types of conservation technologies. These results are related to farm structure in the different regions. In Region I, farms with large maize plots

Table 20. Factors affecting adoption of conservation tillage, Azuero, Panama (multinomial logit model)

	Normalization with respect to not adopting[a,b]		
	Region I		Regions II and III
Variable	Minimum tillage	Zero tillage	Minimum tillage[c]
Constant	-1.406 (-1.17)	-7.091 (-2.85)	-0.199 (-0.13)
Tenure (0/1)	-0.110 (-0.11)	-0.224 (-0.19)	0.597 (-0.68)
Log maize area (ha)	0.072 (0.230)	0.736 (1.89)**	-0.958 (-2.27)**
Importance of livestock	2.348 (1.62)*	3.631 (1.72)*	-2.983 (-2.77)***
Slope (0/1)	-1.119 (-1.3) †	1.150 -0.890	0.882 (-1.04)
Availability of zero tillage equipment	2.232 (1.93)**	2.010 (1.34) †	0.586 (-0.66)
Ownership of conventional tillage equipment	-2.743 (-2.08)**	-2.816 (-1.82)*	0.041 (-0.03)
Information (0/1)	-0.150 (-0.17)	1.378 -1.090	2.363 (2.61)***
Observations	52		64
Test of maximum likelihood	$c^2_{(14)} = 33.7$***		$c^2_{(7)} = 18.5$***
McFadden pseudo R^2	0.30		0.24
Correct prediction (%)	65		73

[a] Values in brackets are asymptotic t-values.
[b] *, **, and *** represent values of parameters different from zero with 90%, 95%, and 99% confidence (two-tailed test). † represents parameters different from zero with 90% confidence (one-tailed test).
[c] Includes three cases with adoption of zero tillage.

predominate, and there is less livestock pressure than in Regions II and III. In this system, L_m and/or L_0 are done with planting equipment, and thus its availability becomes more important than in Regions II and III, where farmers have smaller maize plots and manual sowing is economically feasible. The importance of owning conventional machinery confirms the relevance of costs in the adoption decision in Region I.

The availability of information was positively related to adoption of L_m in Regions II and III but it was not important in Region I. This finding is congruent with the fact that extension agents focused on promoting conservation tillage in Region I, so lack of information did not limit adoption. These results point to the importance providing good information about conservation tillage technology in Regions II and III, where access to information does play an important role in the adoption decision.

Table 22 shows the probability of adopting L_m and L_0 for a typical farmer in the regions identified. The "typical farmer" is defined using the most frequent values of the qualitative variables and the average values of the quantitative variables. According to the values presented earlier in Table 19, a typical farmer in Region I has a maize plot averaging 47 ha, owns the plot (52%), and devotes almost half (48%) of the total farm area to livestock production. The maize plot is on flat land (63%). The farmer has good access to L_0 machinery (77%), does not possess conventional tillage machinery (88%), and knows about the technology (65%).

In Regions II and III, the typical farmer has a maize plot averaging 16 ha, owns the plot (77%), and devotes most of the total farm area (64%) to livestock. The maize plot is on flat land (75%). The farmer does not have access to L_0 machinery (33%), does not possess L_c machinery (80%), and knows about the technology (61%).

In addition to presenting the probability that a typical farmer in these areas will adopt conservation tillage technology, Table 22 shows the probability of adoption if one of the significant qualitative variables changes, *ceteris paribus*. Thus Table 22 depicts each variable's impact on the probability of adoption.

Table 21. Results observed and predicted by the model

	Predicted			
Observed	**Conventional tillage**	**Minimum tillage**	**Zero tillage**	**Total**
Region I				
Conventional tillage	13	3	1	17
Minimum tillage	4	12	5	21
Zero tillage	1	4	9	14
Total	18	19	15	52
Regions II and III				
Conventional tillage	39	6	–	45
Minimum tillage	11	8	–	19
Total	50	14	–	64

The results in Table 22 confirm the importance of the variables related to ownership and availability of machinery in Region I, and of information in Regions II and III. Ownership of L_c machinery, for example, reduces the probability of adopting L_m by 70% and of L_0 by 74%. However, it does not have a significant impact on the adoption of L_m in Regions II and III. A similar effect is seen when the farmer does not have L_0 machinery. Access to information about the technology remains important for Regions II and III, given that the probability of adoption is reduced by 87% when the farmer has not had access to information about conservation tillage. This variable does not have a significant impact in Region I.

The impact of the individual quantitative variables on the probability of adopting L_m and L_0 is estimated through the calculation of each factor's elasticity.[2] Table 23 shows results for the two quantitative variables included in the model, the size of the maize plot and the importance of livestock.

Table 22. Probabilities of farmers adopting zero and minimum tillage in two groups of regions, Azuero, Panama

	Adoption probability (%)		
	Region I		Regions II and III
	Minimum tillage	Zero tillage	Minimum tillage
Typical farmer	37	46	30
With conventional tillage equipment	11	12	nr
With zero tillage equipment	15	23	nr
Without property rights over farm	nr	nr	nr
Without information about conservation tillage	nr	nr	4

Note: nr = not relevant.

Table 23. Elasticity of the probability of adoption (percentage change in the probability owing to a 10% increase in the factor) for a typical farmer, Azuero, Panama

	Region I		Regions II and III
Factor	Minimum tillage	Zero tillage	Minimum tillage
Maize plot area	nr	4.0	–6.7
Importance of livestock	7.1	9.4	–13.3

Note: nr = not relevant.

[2] The elasticity δ measures the percentage change in the adoption probability owing to a percentage change in the factor. It is calculated as: $\delta_i = \Delta * X_i/P = b_i * X_i * (1-P)$, where: $\Delta = \frac{\partial P}{\partial Xi} = bi * P * (1-P)$ represents the marginal impact of factor *i*.

According to these results, both variables have a relatively greater impact in Regions II and III than in Region I. In Regions II and III, an increase in the relative area allocated to livestock leads to a more than proportional reduction in the probability of adopting L_m. The relative change induced by an increase in maize plot area has a similar, although smaller, effect. These results are consistent with the adoption pattern observed in both regions, where conservation tillage has spread on small farms devoted mainly to agriculture rather than cattle production.

For Region I, the coefficients associated with these variables show positive and inelastic changes. Proportional increments in each variable induce changes in the same direction but less than proportional to the probability of adoption. The importance of livestock has an elasticity close to the unit with respect to L_0 and of 70% in the case of L_m, reflecting the importance of the livestock component. In this region, a proportional increment in the importance of livestock increases the probability of adopting L_0 almost proportionally and that of adopting L_m less than proportionally. An increment in maize plot size gives a less than proportional increase in the probability of adopting L_0 and does not affect the adoption of L_m. The two variables (importance of livestock and maize plot size) are not interrelated (correlation coefficient, $\rho = -0.18$).

These results show a different pattern of farm type for the adoption of conservation tillage (L_0 and L_m) in the regions. In Region I, conservation technology is more likely to be adopted on large farms that devote a greater proportion of resources to livestock production. In Regions II and III the opposite is true; L_m is more likely to be adopted on smaller farms where agricultural production is more important than livestock production.

Summary and Conclusions

Land preparation and maize planting practices vary considerably in the regions studied. The technological change occurring between 1985 and 1994 has also varied by region. The most important change was the progressive elimination of plowing and a reduced number of harrowings. Farmers in Region I switched from conventional to zero tillage (33%) and minimum tillage (43%). In Regions II and III, most farmers still practice conventional tillage, although some switched to minimum tillage (34%).

In all regions, adoption was motivated more by potential cost savings than by longer term considerations, but the specific factors that limit or promote adoption of conservation tillage have differed in the regions. In Region I, conservation tillage is more likely to be adopted on large farms where livestock play an important role, while in Regions II and III the opposite occurs: small agricultural farms have a greater likelihood of adopting L_m. This contrasting pattern can be explained by structural differences between the regions. Large farms prevail in Region I, and although they are typically dedicated to livestock production, they allocate a relatively small area to this activity. Approximately half of the plots allocated to maize are also rented to cattle producers, and the rights to crop residues are taken into account in determining the land rental price.

In Region I, the two qualitative factors that most negatively influence the decision to adopt conservation tillage (L_0 and L_m) are lack of ownership or access to conservation tillage equipment. These factors have little influence on the probability of adopting L_m in Regions II and III, where access to information about the technology has a far greater influence on adoption decisions.

This study has rejected the hypothesis that L_m and L_0, in comparison with L_c, are associated with greater use of insecticide because of greater populations of insects in the soil. Similarly, the hypothesis that L_m or L_0 affects short-term maize yields was also rejected. Yields seem to be affected by factors associated with the technological level, such as the region under consideration, plot size, and the importance of livestock in the system.

Although an important percentage of farmers recognized the participation of IDIAP and MIDA in generating and transferring conservation tillage technology, the most common mechanism for diffusion of this technology was from farmer to farmer. When we consider the time pattern of technical change and of the on-farm research program, however, we see that they coincide perfectly. Therefore it can be concluded that the origin of conservation tillage practices in the study area must be attributed to the impact of the on-farm research program, supported by the action of commercial firms that made the new tillage equipment and inputs available to the farmers.

Several findings from our study would be useful points of departure for future research. The impact of conservation tillage on soils, especially on levels of soil compaction brought about by grazing livestock, is a key variable for better understanding the difference between the adoption of L_m and L_0. A better characterization of these factors could yield a better evaluation of the potential for zero tillage in the study area. It would also provide a more precise assessment of which farmers might change from L_m to L_0.

Another area that merits further research is the link between weeds (mainly *Cyperus rotundus*) and conservation tillage, since several farmers reported that they used this technology to obtain better weed control. Finally, the long-run effects of conservation tillage on the soil should be assessed to incorporate them into the analysis.

The results of our study suggest that in Regions II and III a greater extension effort is required to accelerate adoption of conservation tillage, particularly L_0. Limiting factors that are important elsewhere—the ownership of land or availability of planting equipment—are not as important in these two regions, where most farmers are landowners and a considerable percentage sow maize manually. In Region I, extension must focus on steering the change process from L_m toward L_0, and the importance of other factors linked with conservation tillage must be stressed. For farmers to learn about the long-run advantages and importance of conservation tillage, for example, they must learn more about soil and crop residue management.

Appendix 1

Indicators Used in Selecting the Sample

Size of maize plot(ha)	N (1)	Total maize area (2)	Average plot size (3=2/1)	Variance of average plot size, s^2 (4)	B^2 (5)	Sample size (n) (6)
Stratum 1						
0.1–2.5	18	28.5	1.58	0.2426	0.056	9
2.6–5.0	41	164.0	4.00	0.7000	0.360	7
5.1–10.0	57	464.0	8.14	2.5871	1.491	6
10.1–30.0	73	1,445.0	19.79	32.1933	8.816	12
30.1–50.0	25	1,045.0	41.80	36.9167	39.313	3
50.1–100.0	20	1,342.0	67.10	134.7260	101.304	4
>100.0	13	2,337.0	179.77	8,256.19	727.132	10
	247	**6,825.5**				**51**
Stratum 2						
0.1–2.5	96	144.5	1.50	0.3183	0.051	20
2.6–5.0	71	290.5	4.09	0.6236	0.377	6
5.1—10.0	40	310.3	7.76	2.5061	1.354	6
10.1–30.0	27	448.0	16.59	18.0969	6.194	8
30.1–100	6	322.5	53.75	277.975	65.004	5
	240	**1,515.8**				**45**
Stratum 3						
0.1–1.0	18	12.2	0.68	0.0936	0.029	8
1.1–2.5	5	9.5	1.90	0.0500	0.226	1
2.6–5.0	19	78.0	4.10	0.7661	1.053	3
5.1–10.0	22	174.5	7.93	2.0547	3.932	2
10.1–30.0	15	237.5	15.83	37.0595	15.668	6
>30	7	325.0	46.43	796.925	134.726	6
	86	**836.7**				**26**
Total	**573**	**9,178.0**				**122**

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