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Analyzing the Adoption of productivity-enhancing, resource-conserving (PERC) technologies in Central America using a Logit and a Structural Equation Model

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Abstract

Despite of many efforts the adoption of soil conserving technologies is low in Central America (CA). This results from a technology design process that ignores differences between commercial and environmental innovations.

A case study on the adoption of the legume *Mucuna* as a cover crop in maize production systems in CA is presented. A Logit model describes factors influencing adoption. Further, a Structural Equation Model is built to identify links between food security, institutional factors and underlying choices on technology .

Results show that soil conserving technologies that do not have additional substantial short-term effects on productivity will always need external incentives for their adoption, while technologies combing both effects seem to be better suited for a rapid diffusion among small farmers in CA.

Keywords: Technology adoption, Logit Model, Structural Equation Model, Velvetbean, Guatemala

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1. Introduction

The development of technologies that seek to increase agricultural productivity while conserving natural resources is considered to be a key challenge for simultaneously meeting goals of economic growth, food security and protection of soil, water and biological resources from further degradation (Vosti and Reardon, 1997; World Resource Insti-tute, 1997). While the world population still rises and food production increases so far have not been sufficient, rising surplus demand is prevalent in many countries. At the same time resource degradation has become a serious problem in these countries with, for example, estimated worldwide losses of arable land of five to ten million hectares per year (IFPRI,1995).

Soil erosion and the subsequent loss of soil fertility have been considered for a long time as one of the main threats to agricultural productivity and the livelihood of small-scale farmers. But despite many long-lasting efforts, the adoption of soil conserving technologies still poses many difficulties for farmers, and thus adoption rates in general are low (Lutz *et al*, 1994). Not only economic factors, such as high labor costs, high prices for environmentally friendly inputs etc., may hamper adoption, but also ecological preconditions and social factors may contribute. This is also the case in Central America (CA).

The low adoption rates of soil conserving practices in CA can be partly explained by a gap between technology characteristics and the circumstances of adoption. The gap mainly arises because 1.) location-spe-cific factors of technology demand (step hills etc.), and 2.) differences between commercial (fertilizer, tractors etc.) and environmental innovations (terraces, intercropping practices etc.) were not taken into account in the technology design and promotion process (Zurek and Sain, forthcoming). Farmers seem not to value benefits of soil conservation practices despite of their economically proved advantages over traditional techniques in long run experiments. Unfortunately, field tests for sustainable techniques are not as simple as sometimes suggested. There are several theoretical answers to the problem (Ruttan, 1994). 1.)

It is suggested that local economic conditions do not meet experi-mental conditions despite of the same prices and input-output con-ditions. 2.) Discounting of small-scale farmers may differ from official in-terest rates. 3.) Differences in appreciation and knowledge on techni-ques appear. 4.) Risk aversion, skills etc. of farmers and researchers lead to different perceptions about the usefulness of environmentally in-tended innovations. The motivation for our research arises from obser-vations that most soil conservation techniques offer an insufficient com-bination of productivity enhancement (PE) and long term conservation (RC) elements (Vanclay and Lawrence, 1994; Zurek and Sain, forth-coming).

While empirical models to investigate the adoption of PE techniques are well developed, it is not yet clear if the same models apply when studying RC. With RC problem perceptions, opinions on long-term benefits and beliefs – all unobservable variables- play a much greater role. Thus one of the objectives of this study is to expand the traditional type of analysis by applying a different kind of model to better under-stand the RC adoption behavior of subsistence farmers in CA. A case study was developed using data from the Polochic Valley in north-eastern Guatemala to first develop a Logit model and then a Structural Equation Model (SEM) with latent variables. The second objective of the study is to investigate the use of the legume Velvetbean (*Mucuna spec.*) as a cover crop in the maize cropping system in this part of Guatemala. This technology was of interest as it is considered a 'productivity-enhancing, resource-conserving' (PERC) or 'overlap' (Vosti and Reardon, 1997) technology. Here the questions are: Do farmers use a PERC technology for its productivity enhancing, for its resource-conserving effects or for both? How can we model the intention of a farmer behind his technology choice? What are the factors that shape this intention? And what does this mean for technology development and policy design?

2. Description of the study

2.1 Background

The study was conducted in the Polochic Valley, Guatemala. The valley lies in the transition zone between the Guatemalan highlands and the low-lying, humid rainforest area of the Petén. The area's climate can be characterized as hot, humid subtropical, with an average precipitation of about 2500 mm per year. The rainy season lasts from May to December, with July being the month of highest precipitation (see figure 1). Three agro-ecological zones can be identified: Hillsides with slopes up to 60%, dry plains and flood plains of the Polochic river (inundated during the first cropping season). The valley's population mainly con-sists of Kek'chi Mayans (92%), who farm the hillsides and parts of the dry plains using traditional methods for subsistence production of maize, beans and some cash crops in two cropping seasons during the rainy seasons (see table 1). *Ladino* and European settlers concentrate more on extensive cattle production and cultivate coffee, cardamom and some horticultural crops. Soil degradation is an apparent problem in all hillside areas and farmers report frequently that the soil has "become tired".

Table 1: Cropping Patterns in the Polochic Valley, Guatemala (own investigation, 1998)

Growing season	**Hillsides**	**Dry Flat Lands**	**Flood Plains**
Crops grown in the *first season* (May-Sept.)	maize, coffee, citrus, cardamom (Mucuna)	maize, chili, yucca,(beans) horticultural crops (Mucuna)	rice
Crops grown in the *second season* (Oct-Dec.)	maize, beans, coffee, citrus, cardamom (Mucuna)	maize, beans, chili, yucca, horticultural crops (Mucuna)	maize, beans
Crops grown in the dry season	(Mucuna)	(Mucuna)	maize, beans

Maize is the main crop grown in the valley. Traditionally farmers tried torotate their fields, but pressure on arable land drives farmers to aban-don this system (O. Garcia, A. Villafuerte and J. Cortéz, personal com-munication, 1998). Results of the conducted survey show that 47% of farmers have fields, in which they grow maize in both growing seasons. Land races are planted by about half of the farmers, though there is a rising tendency to use improved varieties. Here the white maize hybrid

ICTA HB83, which was released about 6 years ago, has gained in importance leading to substantial yield improvements.

The legume Mucuna was introduced into the Polochic Valley in the 1930's and is utilized since the 1950's on a large scale (Buckles *et al*., 1998; C. Chavez, personal communication, 1998). Today it's use is in decline going hand in hand with a decline in fallow periods and increased continuos cropping of fields (Chavez, 1994). Mucuna can produce between 5 to 12 t/ha*y of dry-matter, which makes it well suited as a cover and forage crop (Triomphe, 1996). It seems to be sensitive to shorter day length in October as then flowering and seed production begin, after which the plant dies naturally. The legume is sown in-between the maize rows about 45 to 70 days after maize planting and then left to grow during the dry and the following cropping season. The varieties in the valley need about eight to nine months until seed development. Farmers cut the vines before sowing maize the next year. The residues are left on the ground and maize is planted directly into the decaying biomass. In this system the farmer is able to use his field only once a year while it lies under Mucuna-fallow the rest of the time (see figure 1).

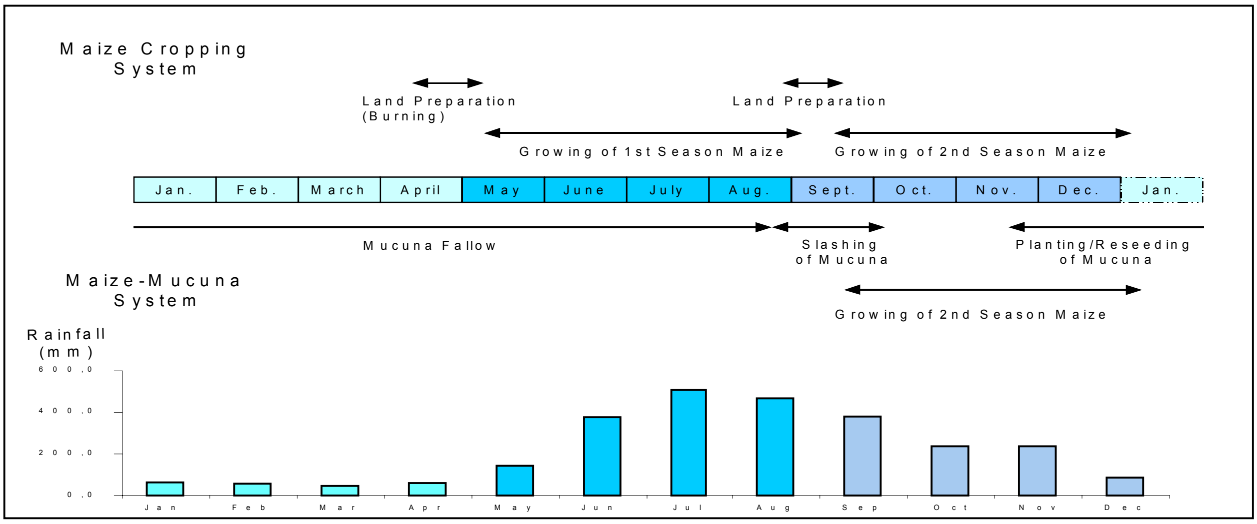


Figure 1: The Maize and the Maize-Mucuna System in the Polochic Valley, Guatemala (own investigation, 1998)

Traditionally farmers intercrop maize of the second growing season with the legume as this goes along with it's physio-logical cycle. Due to increased growing of maize in both seasons there is a tendency to plant the bean already in the first season. Then nitrogen from the legume is released at the beginning of the dry season, when there is no maize to profit from it.

Positive effects of Mucuna on soil fertility are (Triomphe, 1996):

- Source of nitrogen for the maize crop (experiments in the valley report up to 55% yield increases)
- Protective cover against heavy rains (erosion prevention)
- Improvement of physical soil properties (texture, water holding capacity, microbiological activity, etc.)
- Allows continous land use without long-term fallow
- Easy to integrate into existing maize cropping practices
- Saves labor by reducing weeding and land preparation time
- No burning of fields

Mucuna is also associated with some important disadvantages:

- Use of field only in one cropping season possible (farmer needs another plot to grow maize in other season)
- Benefits received only with a time lag of 2 - 3 years

2.2 Material and Methods

In 1998 a survey of 137 randomly chosen, maize producing farmers (about 2,5 % of inh.) was conducted in the main county, Panzós. The farmers were interviewed about their perceptions on soil erosion, use of Mucuna, other soil conservation techniques, access to markets, information, credit, and participation in community organizations. Half the farmers were asked in detail about their maize production system in the first season, the other half about the second season.

For both data sets a Logit Model with ungrouped data (see table 2) was developed using a cumulative logistic probability function with the following specification (Pindyck and Rubinfeld, 1981):

$$\text{Log}\,(\text{Prob(use)} / 1\text{-Prob(use)}) = ß_0 + ß_1{*}X_1 + ß_2{*}X_2 + \ldots + ß_n{*}X_n \quad (1)$$

with X_1 to X_n = different farm household characteristics

Table 2: Variables and expected signs for the Logit Analysis of the two data subsets of the Polochic Valley, Guatemala

Variable	Expected sign	Hypothesis
% maize fields with slope	+	The higher the % of maize fields in hillsides the more inclined is the farmer to use Mucuna as he is more likely to face erosion problems and unstable yields than farmers in the flatter zones.
% inundated fields	-	The higher the % of fields inundated during one season, the less likely is the farmer to use Mucuna as it can not grow there and he needs the rest of his land for food production.
Age of farmer	+	Older farmers are more likely to use Mucuna as they have more experience with this system that is already know in the area for a long time.
Family labor endowment	-	As the Maize-Mucuna system is a labor saving technology, a farmer with little family labor to rely on is more likely to use it than one with a large family labor endowment.
% of land with secure land title	+	Farmers, who have secure land use rights, are more likely to use Mucuna as they usually have a longer planning horizon.
Farm size	+	The bigger the farm, the more likely is the farmer to use Mucuna as he has more land available to take into production while the rest lies under Mucuna fallow in one season.
% of without annual crops	+	The higher the % of land without annual crops, the more likely is the farmer to use Mucuna as he has more land available to take into production while the rest lies under Mucuna fallow in one season.
Use of HB 83	-	The Maize-Mucuna system seems to be replaced by an intensified production system, in which farmers plant maize twice a year using the hybrid HB83. Thus farmers growing the hybrid are less likely to use Mucuna.

Furthermore, a Structural Equation Model (SEM) with latent variables was built to model the causal relationships between food security needs of farmers, institutional factors, the intention behind a certain technology choice, and the adoption of more production or soil conservation oriented technologies (see figure 2). As the adoption of environmental innovations often depends not only on short term cost-benefit relationships but also on perceptions and opinions 1.) about the serious-ness and the effects of a particular resource degradation problem, 2.) the benefits anticipated in the future from the use of a certain techno-logy and 3.) the social and economic situation of the farm household - all non-observable, latent variables difficult to incorporate into a Logit Model - a SEM seemed appropriate.

SEMs, which have so far been used mainly in social sciences, psychology or marketing research, try to model interactions between a set of

theoretically constructed, latent variables that describe important underlying factors. Each latent variable is characterized by a number of measurable indicator variables. Thus each SEM consists of an internal causality and an external information structure. The coefficients or 'weights' resulting from "regressions" between the latent variables confirm the hypothesized links between the variables and show the strength of their relationship (Nuppenau and Hedden-Dunkhorst, 1998, Maruyama, 1998).

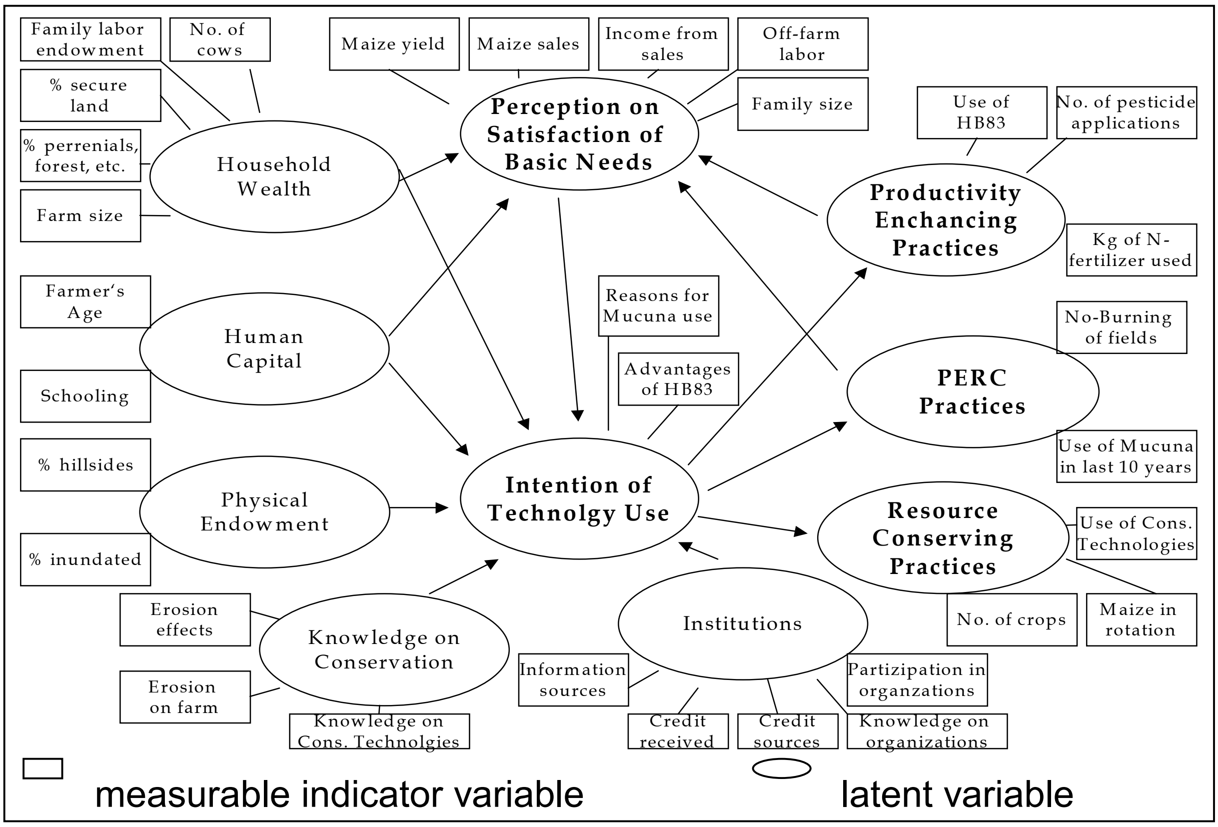


Figure 2: Structural Equation Model for the use of Mucuna in the Polochic Valley, Guatemala

2.3 Some Preliminary Results

Mucuna is used by the majority of the farmers in at least one of their maize plots (48% of surveyed farmers, see figure 2). Nevertheless, about one fifth of the farmers abandoned Mucuna use in the last years.

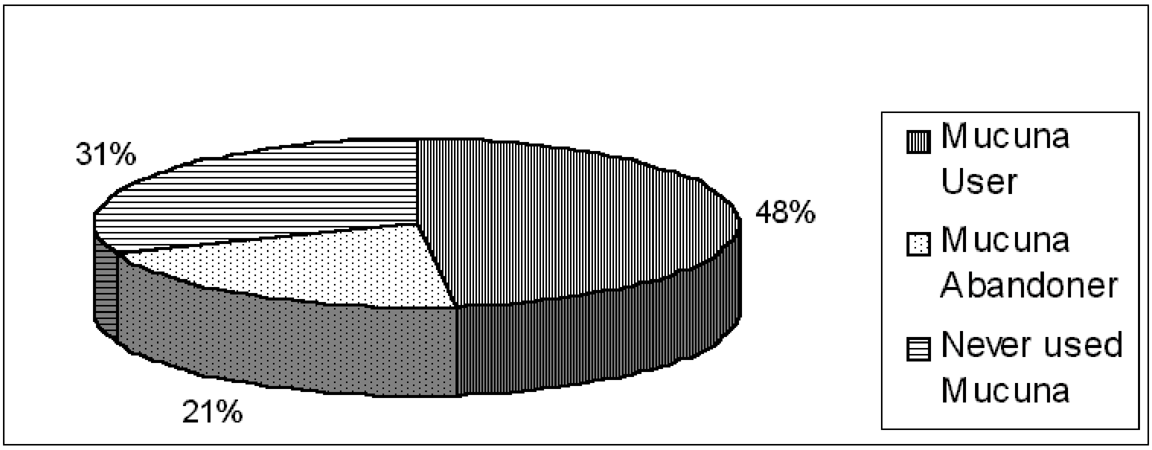


Figure 2: Mucuna use in the Polochic Valley in 1997 (own investigation, 1998)

Reasons given by farmers for their use, non-use or abandonment of Mucuna can be found in table 5. It is important to notice that most farmers see the legume as a good fertilizer that enhances yields. Also saving labor through weed suppression is regarded as an important aspect, while erosion control is mentioned by only 4% of the farmers. Furthermore, it should be pointed that, though Mucuna non-users or abandoner value the benefits of Mucuna intercropping, there are many structural factors, like a not functioning infrastructure for seed distribution and information or changes in cropping patterns (as land is becoming a scarce resource in the valley), which are nowadays interfering with the use of this soil improvement technique. This becomes even more evident when the factors that lead to the slow abandonment of Mucuna in the last 10 years are studied.

Table 5: Most important reasons given by farmers for the use, non-use or abandonment of Mucuna in 1997 (own investigation, 1998)

Reasons FOR Mucuna use	% of farmers
Good fertilizer	79
Higher yields	36
Less weeds	29
Less erosion	4
Reasons AGAINST Mucuna use	**% of farmers**
No seeds available	26
Farmer needs field for another crop	23
Mucuna cannot grow in the field (inundations etc.)	19
Missing information	9
Reasons for ABANDONING Mucuna use	**% of farmers**
Farmer needs the field for other crops	36
No seeds available	21
Mucuna cannot grow in the field (inundations etc.)	18

Results of the Logit analysis (table 6 and 7) show differences in the factors that influence the use of Mucuna in each growing season. While, for example, the use of the maize hybrid HB83, which goes along with an intensification of land use, is not relevant for the legume adoption in the first growing season, farmers that plant maize using the hybrid in the second season are much more likely to intercrop it with Mucuna. Maize prices in the second season are higher and the legume use in this season has a higher effect on yield than in the first season. This goes along with the perception of the majority of farmers that Mucuna is a good fertilizer but it is not seen as a way to fight soil degradation.

Table 6: Results of the Logit Model for the Data set of the **First** Growing Season (*primera*)

Variable	Coefficient	Standard Error	p-Level
Constant	-5.36*	1.80	0.00
% Maize in hillsides	2.15*	1.33	0.11
% Inundated area	0.80	1.20	0.51
Farmers age	0.07*	0.03	0.01
Family labor endowment	-0.01	0.27	0.97
% Land with secure title	1.82*	0.96	0.06
Farm size	0.31*	0.21	0.14
Use of hybrid HB83	-0.63	0.76	0.41
% Land without annuals	2.04	1.79	0.26

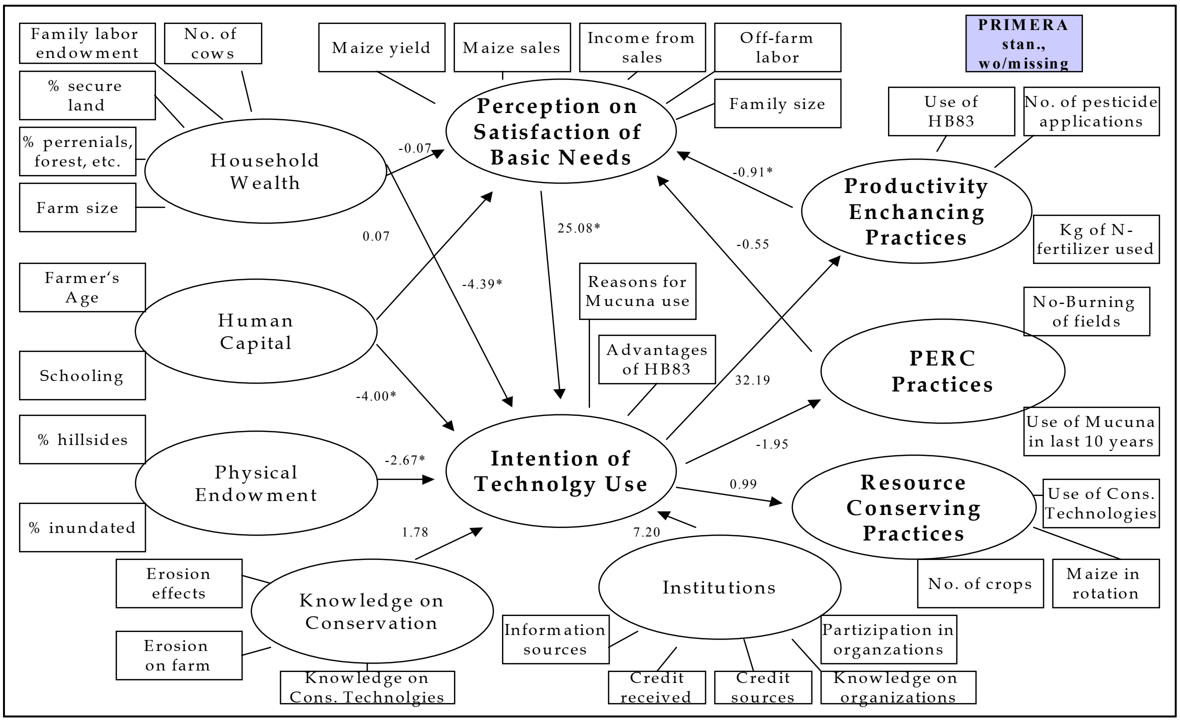
N = 63, χ^2 = 21,34**, % 0s predicted correctly = 67.9, % 1s predicted correctly = 77.1
* significant at 5 % level

Table 7: Results of the Logit Model for the Data set of the **Second** Growing Season (*segunda*)

Variable	Coefficient	Standard Error	p-Level
Constant	-2.65*	1.54	0.09
% Maize in hillsides	0.15	1.23	0.90
% Inundated area	-2.80*	0.91	0.00
Farmers age	0.04*	0.02	0.09
Family labor endowment	0.23	0.22	0.30
% Land with secure title	0.37	0.79	0.64
Farm size	-0.06	0.14	0.68
Use of hybrid HB83	1.32*	0.67	0.05
% Land without annuals	-0.12	1.85	0.95

N = 74, χ^2 = 25,79**, % 0s predicted correctly = 86.0, % 1s predicted correctly = 65.5
* significant at 5 % level

The SEM also confirms the inclination of farmers to use technologies aimed at increasing productivity (figures 3 and 4). In the calculated model the "intention" behind farmers' choice of technology influences significantly their choice of technologies. But the weights put on soil



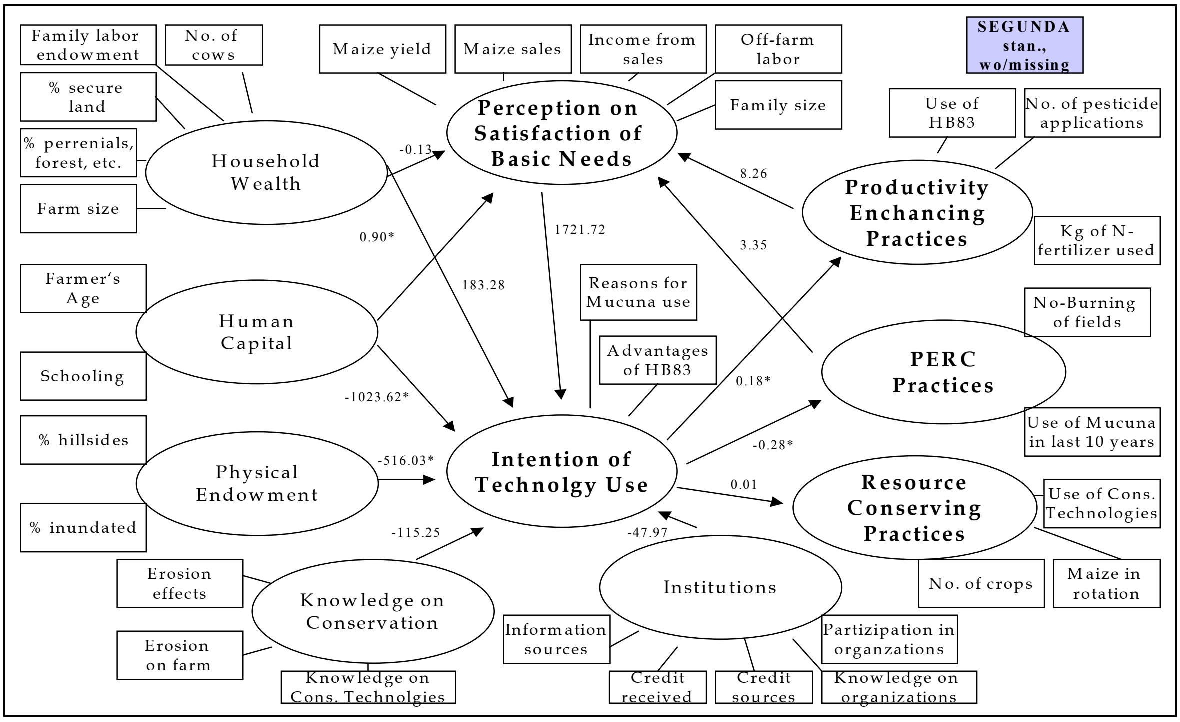


Figure 3 and 4: Results of the Structural Equation Model with Latent Variables for the Datasets of the first (*primera*) and second (*segunda*) cropping season in the Polochic Valley, Guateamala

conserving technologies as well as on PERC practices are very small in comparison to productivity. This leads to the conclusion that conservation practices without a strong productivity-enhancing component are not very likely to be adopted by small farmers in the valley. New soil conserving technologies designed or promoted in the areas will have to take this into account.

2.4. Some Preliminary Conclusions

The results obtained so far from the case study allow the conclusion that soil conserving technologies that do have limited additional short-term effects on increasing productivity will need strong external incentives (e.g. subsidies in different forms, transfer payments etc.) for their adoption. Technologies combing both effects seem to be better suited for a rapid diffusion among small farmers in CA. As suggested yield increases achieved through the PERC technology can substantially improve intrinsic incentives for farmers to adopt also conservation components, thus fostering sustainability. This conclusion might seem quite simple, but it should be noted that the development of new agricultural technologies so far was primarily aimed at either conservation or production. A stronger combination of both will considerably improve adoption of conservation elements without strong external incentives. Thus the question should not only be of how short-term production aspects can be better incorporated into conservation technologies, rather vice versa. Conservation and sustainability can be only achieved if significant productivity increases are included.

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