2009-5 Working Paper

INTERNACIONAL CENTRO DE LA PAPA CIP

Assessing the impact of late blight resistant varieties on smallholders' potato production in the Peruvian Andes

Lina Salazar, Paul Winters, Luis Maldonado
Guy Hareau, Graham Thiele

USAID
FROM THE AMERICAN PEOPLE

ISSN 0256-8748
Social Sciences
Working Paper
No. 2009 - 5

Working Paper

Assessing the impact of late blight resistant varieties on smallholders' potato production in the Peruvian Andes

Lina Salazar
Inter-American Development Bank
Washington, United States of America

Paul Winters
American University
Washington, United States of America

Luis Maldonado
International Potato Center (CIP)
Lima, Peru

Guy Hareau
International Potato Center (CIP)
Lima, Peru

Graham Thiele
International Potato Center (CIP)
Lima, Peru

Assessing the impact of late blight
resistant varieties on smallholders' potato
production in the Peruvian Andes

ISSN 0256-8748

International Potato Center
P.O. Box 1558, Lima 12, Peru
cip@cgiar.org • www.cipotato.org

Produced by the CIP Communication and Public
Awareness Department (CPAD)

Correct citation:
Salazar, L., Winters, P., Maldonado, L., Hareau, G. and Thiele, G. Assessing the impact of late blight resistant varieties on smallholders' potato production in the Peruvian Andes. International Potato Center (CIP), Lima, Peru. Working Paper 2009-5. 30 p.

Layout
Zandra Vasquez

Printed in Peru by Comercial Gráfica Sucre
Press run: 100
December 2009

Table of Contents

Abstract ... iv
Acknowledgments ... v
1. Introduction ... 1
2. The Peruvian data and context ... 2
3. Methodology ... 8
   3.1 Analyzing Fungicide Use ... 8
   3.2 Analyzing Yields ... 9
   3.3 Issues in Evaluating the Impact of Adoption ... 12
4. Results ... 13
   4.1 The adoption decision ... 13
   4.2 Fungicide use ... 16
   4.3 Yields ... 20
5. Actual and Potential Impact of Amarilis ... 24
6. Assessment of economic benefits from Amarilis adoption ... 25
7. Conclusions ... 27
References ... 29

List of Tables

Table 1. Potato production, area and yield by Departments in Peru, 2004. ... 3
Table 2. Varieties, Adoption and Year of Release. ... 4
Table 3. Sample Means and Significance. ... 5
Table 4. Characteristics of Amarilis adopters (Probit Results) ... 14
Table 5. Estimation of the Impact of Amarilis Adoption on Fungicides. ... 18
Table 6. Contact and Systemic Fungicides. ... 19
Table 7. Estimation of the Impact of Amarilis Adoption on Yields. ... 22
Table 8. Net benefits from Amarilis, dollars per ha. ... 26
Table 9. NPV of benefits to farmers (million dollars). ... 27

List of Figures

Figure 1. Comparisons of adopters and non-adopters. ... 7
Figure 2. Predicted Probabilities for Amarilis and non-Amarilis adopters Huanuco excluded. ... 15
Figure 3: Estimated Amarilis adoption path, 1993 – 2020. ... 27

Abstract

In this study, we examine whether the adoption of late blight resistant cultivars has an effect on yields and fungicide use. We will focus on the Amarilis variety which is considered more resistant to late blight than other varieties adopted by the farmers in the sample. Using data from three main potato producer states in the Peruvian Andes, significant positive effects on yields and negative effects on fungicide use are found. Specifically, the damage abatement approach provides evidence that Amarilis adoption enhances output maximization mainly through the control of late blight. At the discount rate of 10%, the probable net present value (NPV) of the net benefits accruing to farmers through the adoption of Amarilis amounts to almost 9 million dollars.

Acknowledgments

The work reported here forms part of and benefited from a broader research project on the estimation of late blight losses conducted jointly with Greg Forbes (ICM Division), funded by the United States Agency for International Development (USAID).

The authors would like to thank Melinda Smale and Phil Simmons for their pertinent comments which helped to improve this paper.

Assessing the impact of late blight resistant varieties on smallholders' potato production in the Peruvian Andes

1. INTRODUCTION

Late blight, caused by the *Phythophtora infestans* fungus, is a major concern for potato growers around the world as it leads to direct yield losses and higher costs associated with higher levels of fungicide application. Under conditions of high humidity and cool temperature, the disease spreads rapidly, destroying plant foliage leading to lower potato yields and sometimes infecting tubers limiting their storability. At present, the International Potato Center (known by its Spanish acronym CIP) estimates the annual total yield losses associated with potato late blight at US$ 2.75 billion for developing countries (CIP, 2008). In Peru, the case studied here, losses are estimated at US$7 to US$25 million per year (Ortiz *et. al.*, 1997-1998).

Given the importance of late blight in potato production and its impacts on the welfare of potato producers, CIP and its partners have been involved in the development, diffusion and promotion of late blight resistant potato cultivars for more than two decades. Many of these cultivars have been widely adopted by potato-producing smallholders in developing countries. As with any new technology, questions are raised about the value of adoption. Estimating the economic benefits to smallholders from the use of these resistant varieties, in terms of their benefits, has proven to be difficult for many reasons. First, the level of resistance shown varies at different locations and as the late blight pathogen evolves over time resistance may be less effective. Second, late blight affects farmers in several ways, including income lost through fungicide applications, yield losses caused by damage to foliage and reduced photosynthetic capacity, efficiency losses if farmers decide not to grow potatoes because of the uncertainty related to late blight, and human health costs associated with fungicide use. Third, late blight is strongly weather driven so that disease intensity and potential losses may vary greatly across seasons. Fourth, the actual degree of adoption of resistant varieties may not be known at all locations.

In the past, studies of the impact of the introduction of late blight resistant varieties, particular those conducted by CIP, have calculated rates of return to these varieties based on predicted savings from reduced fungicide application and from higher yields using information from on-farm trials (Walker and Crissman, 1996). While useful for providing general estimates of the returns to investment in resistant varieties, they do not provide empirically-based estimates of impact. An evaluation of this type requires using plot-level data and econometric analysis to identify the impact of adoption of late blight resistant varieties on smallholder input use and yields. In particular, this study focuses on the adoption of Amarilis, a relatively recently released variety with a high-level resistance to late blight. In our study sites, seventy percent of the farmers who planted Amarilis categorize it as a strongly resistant cultivar and another 10 percent categorize it as moderately resistant.

The Amarilis variety was bred by CIP and released by Peru's National Institute of Agricultural Research (INIA) in 1993. A study in Cajamarca showed that resistance to late blight, excellent culinary attributes, high yield, and a short growing period (90-120 days) made Amarilis an excellent option for farmers since it reduced costs and assured a minimal level of output for consumption even under conditions of high late blight pressure (Bos, 2007). This paper provides an empirical estimate of the impact of Amarilis adoption by smallholders on fungicide use and yields, more than ten years after its release.

The remainder of the paper is structured as follows. The next section presents a brief background on the Peruvian context and case study sites and presents descriptive statistics of the data. Section 3 presents the methodology and the empirical estimation strategy for evaluating the effect of Amarilis adoption on fungicide use and yields. Section 4 presents the results of the analysis. Section 5 shows some simulations to estimate the actual and potential impact of Amarilis adoption, section 6 provides an assessment of the economic benefits, and section 7 summarizes the main conclusions that can be drawn from this analysis.

2. THE PERUVIAN DATA AND CONTEXT

Data used in this analysis came from a varietal adoption survey carried out in 2006 of the main potato crop of 2005. The survey area is broadly representative of three main potato producer Departments in the Peruvian Andes—Huanuco, La Libertad and Cajamarca. These departments represent approximately one-third of national potato production (Table 1). The departments have average yields similar to the country average and are characterized by production largely by smallholders.

The survey sample was originally composed of 308 farmers who planted 619 plots in the 2005 main cropping season. After deleting observations with missing values and outliers, the final sample used in this empirical estimation was 291 farmers and 588 plots[1]. The survey provides

[1] There does not appear to be systematic differences between households with some missing data and those included in the sample. This suggests the loss of data should not bias the results.

detailed plot-level information which is the unit of analysis used in this study. Moreover, information about economic and social household characteristics such as education, assets, access to credit and income from non-agricultural activities was also gathered in a detailed and comprehensive manner.

Table 2 shows the varieties adopted by surveyed farmers with the source and release date for improved varieties (native potatoes are landraces which have not been improved through scientific breeding). Although 29 varieties were planted, only four—Amarilis, Canchan, Libertena and Yungay—are grown by more than 10% of farmers. The first two are CIP-bred and INIA released varieties.

Table 1. Potato production, area and yield by Departments in Peru, 2004.

	Area	**Production**	**Yield**
Departments	(000 ha)	(000 t)	(t/ha)
Huánuco	37	479	13
Puno	49	433	9
Junín	23	318	14
La Libertad	20	286	14
Cajamarca	25	254	10
Lima	8	222	27
Cusco	26	188	7
Arequipa	6	156	25
Apurimac	15	141	9
Huancavelica	14	120	9
Ancash	10	89	9
Ayacucho	10	87	9
Pasco	9	83	9
Ica	2	54	30
Amazonas	4	50	13
Piura	1	9	9
Tacna	1	8	9
Moquegua	1	7	13
Lambayeque	1	4	5
Pro. Const. Callao	0	1	27
Total	261	2,988	11

Source: Ministry of Agriculture 2006, Peru.

Amarilis is considered significantly more resistant to late blight than other varieties and is one of the more recently released varieties (1993). Although it seed costs are similar to other varieties, farmers grow several varieties for a number of reasons. Home consumption of household production is important in the study region and although Amarilis' culinary attributes are viewed favorably by farmers, other varieties, particularly native varieties, may be preferred as tastier for home consumption even though they are less productive. Furthermore, other varieties, particularly Canchan, are favored in the Lima market because they fry well and are thus preferred by more market-oriented producers. Amarilis has been widely adopted by small and medium scale farmers in Cajamarca and La Libertad, but not in the more market-oriented Huanuco region where Canchan is preferred.

Table 3 provides descriptive statistics of the variables used in this analysis along with tests of difference between Amarilis adopters and non-adopters. Insecticides are not included, since in the case of highland Peruvian potato production, insecticides are used primarily to control the Andean Potato Weevil (*Premnotrypes spp).* Insecticide use enhances quality at harvest by reducing tuber damage but only has a small effect on yield (Ortiz *et. al*, 1996).

Table 2. Varieties, Adoption and Year of Release.

Variety	Freq.	Percent	Year Released	Source
Amarilis	139	23.64	1993	INIA, CIP related
Amarilla	8	1.36		Native
Blanca	4	0.68	1971	INIA
Bretaña	1	0.34		Native
Britani	2	0.34		Native
Canchan	151	25.68	1990	INIA, CIP related
Capiro	3	0.51	1961	INIA
Carhuamayo	3	0.51		Native
Chaucha Amarilla	1	0.17		Native
Chiquibonita	3	0.51		Native
Cholandray	3	0.51		Native
Colegiala	1	0.17		INIA
Huagalina	8	1.36		Native
Huayro	3	0.51		Native
Ishcopuro	2	0.34		Native
Lampina	1	0.17		Native
Liberteña	94	15.99	1977	INIA
Limeña	4	0.68		Native
Liza	1	0.17		Native
Maria Huanca	5	0.85	1987	INIA, CIP related
Mariva	1	0.17	1972	INIA
Nativas	1	0.17		Native
Perricholi	12	2.04	1984	INIA, CIP related
Peruana	44	7.48		Native
Renacimiento	1	0.17	1952	INIA
Tumbay	4	0.68		Native
Unica	1	0.17	1998	INIA, CIP related
Yungay	85	14.46	1971	INIA
Ñausa	1	0.17		Native
Total	**588**	**100**		

Source: Authors' calculation using Varietal Adoption Survey, CIP, 2006 and CIP.

Household heads in this sample are mainly men with low levels of education with limited assets, some income from non-agricultural activities and generally small plot sizes. Overall, farmers who plant Amarilis are similar to farmers who do not plant the resistant variety in general household characteristics. All sampled farmers have relatively small plots although interestingly, the total amount of land per plot owned by Amarilis adopters is greater than for non-adopters; a difference that is statistically significant. Smallholders plant just over one and a half hectares of land for potato production and use about half that amount of land per variety planted. Farmers who plant Amarilis allocate, on average, a smaller portion of their farms for potato production than non-adopters and plots planted with Amarilis tend to be smaller than plots planted with non-Amarilis varieties.

Table 3. Sample Means and Significance.

Variable	**Whole Sample**	**Amarilis Adopters**	**Non-adopters**	**Test of diff.**
	farms=291	farms=139	farms=152	
	plots=588	plots=139	plots=449	
Head of the Household Characteristics				
No education (%)	39.46	40.29	39.20	0.14
Primary (%)	44.56	42.45	45.21	0.33
Secondary (%)	11.05	12.23	10.69	0.61
Tertiary or higher (%)	4.93	5.04	4.90	0.01
Male (%)	95.58	97.12	95.10	1.03
Age HH (years)	42.60	43.08	40.97	1.48
Household Characteristics				
Assets (%)	55.10	53.96	55.46	0.09
Income accrued in non-agricultural activities (soles)	580.2	643.6	522.2	0.64
Distance to closest road (km)	0.46	0.45	0.49	0.55
Amount of land owned (hectares)	0.77	0.91	0.64	5.52**
Potato Production				
Total land planted with potato (hectares)	1.61	1.50	1.74	1.78*
Number of Varieties Planted	2.19	2.18	2.19	0.21
Inputs for Potato Production				
Land per plot (hectares per variety)	0.75	0.66	0.78	1.61
Number of applications	3.54	2.78	3.79	3.98**
Fungicides (kg)	3.90	1.95	4.50	5.78**
Systemic (kg)	3.23	1.63	3.72	5.55**
Contact (kg)	0.67	0.32	0.78	3.20**
Fertilizers (sacks/bags)	7.69	3.13	9.10	6.79**
Seeds (kg)	714.30	566.10	760.20	2.73*
Guano (sacks/bags)	45.12	61.71	39.98	5.81**
Abono Foliar (kg)	0.98	1.11	0.94	0.39
Paid labor (total jornales)	89.11	80.96	91.50	2.56**
Family labor (# family members involved)	3.46	4.23	3.22	4.74**

Notes: Test of difference between adopters and non-adopters: t-test for means, chi-square for percentages in absolute value; *=significant at 90%, **= significant at 95%.
Source: Authors' calculation using Varietal Adoption Survey, CIP, 2006.

Contact fungicides are mainly used by farmers in a preventive manner prior to infection by late blight while systemic fungicides are mainly used by farmers in a curative way after the infection has occurred (Terrazas *et al.*, 1998). Contact fungicides protect the potato plant from late blight disease only where the fungicide is actually applied (there is no translocation of the fungicide within the plant); therefore, these types of pesticides must be applied in a very careful manner in order to guarantee late blight protection. Systemic fungicides protect the plant as a whole and not only on those parts where the fungicide makes contact with the plant, and so could be effective even where application is not done carefully. The most common types of fungicides used in this sample are systemic fungicides; specifically, Ridomil 28% (*Metalaxyl*), Fitoraz 23% (*Cymoxanil and Propineb*), and Acrobat 12.5% (*Dimethomorph*). On average, farmers used 3.90 kg of fungicides per hectare and spray 3.50 applications per harvest; however, plots planted with Amarilis received 2.55 kg less of fungicides per hectare than other plots. This difference in fungicide application is statistically significant for both types of fungicides (contact and systemic), but it is markedly stronger for systemic fungicides. For the case of fertilizers and seeds, the figures suggest that Amarilis adopters used 5.9 bags less of fertilizers and 194 kg less of seeds than non-adopters. This difference is not the consequence of a higher price of Amarilis' seed since the costs of seeds do not tend to differ greatly between Amarilis and the second or first most important varieties planted in La Libertad or Cajamarca.[2] Also, Amarilis adopters employ nine fewer work days[3] of paid labor than non-adopters. On the other hand, the technology adopters tend to utilize 21.73 more bags of guano (organic fertilizer composed of bird droppings and rich in nitrogen and phosphorous) and one more unit of family labor per hectare than non-adopters. Overall, the difference on input application between technology adopters and non-adopters is significant for most of the conventional inputs considered in this study. This finding is interesting because it suggests Amarilis adopters substitute purchased inputs for inputs which require no cash outlay. These initial descriptive statistics indicate that although the household characteristics of adopters and non-adopters do not differ in household characteristics, they do in terms of potato production practices.

The evidence in Table 3 shows farmers who adopted the Amarilis variety use significantly less systemic and contact fungicides. To examine this more carefully, the top panel of Figure 1 shows the distribution of a logarithmic transformation of the fungicide quantity for Amarilis adopters and non-adopters. Logs are used since fungicide quantity has a log normal distribution. While a similar number of non-adopters and adopters use no pesticides (about 15%), for those applying

[2] In particular, the average cost of a kilogram of seeds of Amarilis in La Libertad was equal to S/ 0.55 (US$ 0.17) while the same was equal to S/ 0.59 (US$ 0.18) for Canchan. In Cajamarca, the average cost of a kilogram of seeds of Amarilis is equal to S/ 0.68 (US$ 0.20) while the same is equal to S/ 0.70 (US$ 0.21) for the Liberteña.

[3] Labor is measured in number of days worked per hectare.

pesticides there are clear differences. More than 70% of the plots planted with Amarilis have used 2 kg or less of fungicides per hectare while the same is true for only 45% of the plots planted with other varieties. Also, only 1% of the plots planted with Amarilis have used more than 10 kg per hectare while 12% of the plots planted with other varieties have utilized the same amount. In general, the results suggest Amarilis adopters are less likely to use larger quantities of fungicide.

The distributions for log of the yield for adopters and non-adopters are presented in the second panel of Figure 1. While there is a greater segment of the population of non-adopters who obtained lower yields compared with the Amarilis adopters, there is also a greater percentage of the population of non-adopters who obtained the highest yields compared with the Amarilis adopters. In other words, the yield distribution of the non-adopters is more dispersed while the distribution of yields for Amarilis adopters is more skewed.

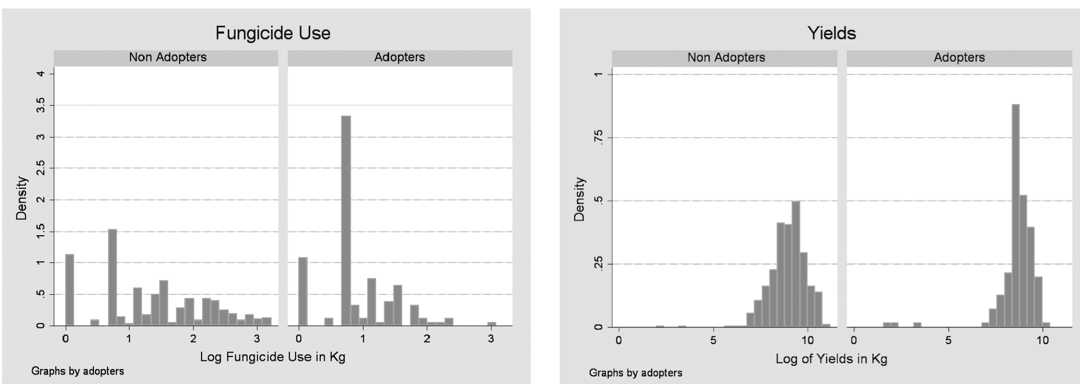

Figure 1. Comparisons of adopters and non-adopters.

Source: Authors' calculation based on Varietal Adoption Survey, CIP, 2006.

With respect to the patterns of yield utilization, the percentage of Amarilis production that is allocated for home consumption is, on average, 20% and 19% for other varieties with t-test of difference in means not suggesting they are significantly different. On the other hand, the production of Amarilis allocated for sale is significantly lower than for other varieties (54% versus 61%) while the percentage allocated for seeds is significantly higher (22% versus 15%). However, when Huanuco producers are dropped, these patterns differ. Specifically, the total production of Amarilis allocated for home consumption is equal to 20% while for the rest of the sample is equal to 28%. In addition, the percentage of Amarilis assigned for sale is 54% while for rest of the varieties is 42% in average. These differences are all statistically significant which means that Amarilis can be considered as an important variety for market in La Libertad and Cajamarca.

3. METHODOLOGY

The information provided in section 2 provides an initial assessment of the relationship between Amarilis adoption and fungicides use and yields and suggests a link between Amarilis and reduced pesticide use and slightly higher yields. However, to clearly establish the impact of Amarilis adoption on these variables, it is necessary to control for other factors that might affect the farmer's decision making. To do this we employ a regression framework first considering how to analyze fungicide use and then yields.

3.1 Analyzing Fungicide Use

To test the hypothesis that Amarilis adopters apply a smaller amount of fungicides than non-adopters, we use an OLS approach which has also been applied in other studies that test the effect of pesticide-reduce technologies on pesticide use (Huang *et al.,* 2001; Huang *et al.*, 2005). The logarithm of kg of fungicide per hectare and the number of applications are used as dependent variables. The total amount of kg per hectare is a measure of the intensity of fungicide use while the number of fungicide applications is a measure of the dispersion. The equation that is estimated is specified as follows:

$$F = \gamma + \rho C + \sum_t \alpha_t T_t + \sum_h \varphi_h H_h + \sum_m \nu_m R_m + \sum_n \delta_n N_n + \varepsilon \qquad (1)$$

where,

F is the log of fungicide kg per hectare or the number of applications;

γ is the constant term;

C is a dummy variable that takes the value of one if the farmer adopted Amarilis as part of his/her portfolio of potatoes;

T_t is the vector of characteristics that represents the inputs of production that influence fungicide use as well as the type of portfolio of potato chosen by the farmer—this vector is composed by two dummy variables that capture the number of varieties planted on the farm, the total land planted and the amount of family labor used in agricultural activities;

H_h is the vector of the head of the household characteristics such as education, gender, age and age squared;

R_r is the vector that represents the economic characteristics of the household such as access to assets, logarithm of the distance to the closest road and logarithm of the non-agricultural income;

N_n is a vector of dummy variables that represent the geographical location of the plot—the 108 community fixed effects that are primarily used as proxies for climate and soil;

ε is the error term; and

γ, ρ, σ_t, φ_h, ν_r, δ_n are the coefficients to be estimated.

If farmers adopt Amarilis as a strategy to substitute for fungicides, we expect to find a negative impact of Amarilis adoption on fungicide use. In other words, the coefficient ρ is hypothesized to be negative and significant.

3.2 Analyzing Yields

Along with testing the hypothesis that Amarilis adoption has a significant effect on fungicide reduction, the influence of Amarilis adoption on total production is assessed. This allows an investigation of whether Amarilis serves only as a fungicide substitute or whether it also works as a yield enhancing input *per se*. For this purpose, two different approaches are compared. First, we assume that pesticide use and adoption of resistant varieties behave as regular inputs by using a Cobb Douglas production function. This assumes that the adoption of Amarilis as well as the use of fungicides has a direct effect on improving output. The second approach used here is to use a damage control function which allows us to differentiate yield enhancement inputs (conventional inputs) and damage control inputs.

Using a Cobb Douglas approach, potato production can be modeled based on the following:

$$Y = AK^{\alpha}L^{\beta} \; F_k, F_L > 0 \; and \; F_{kk}, F_{LL} < 0 \; ; \; 0 < \alpha, \beta < 1 \qquad (2)$$

where

Y represents the total yield of the plot per hectare;

K represents the total inputs of production per hectare such as land, fertilizers, fungicides, abono foliar (type of fertilizer that is applied to the foliage) and guano;

L represents total labor used; and

A represents other factors that might affect total yield such as education, gender and age of the head of the household, income from other non-agricultural activities, assets, etc.

The advantage of using this type of production function is that it allows an estimation using linear methods, by transforming the variables into logs which is particularly convenient given inputs in the data have log normal distributions. The equation to be estimated is the following:

$$Y = \pi + \sum_j \tau_j J_j + \sum_h \theta_h H_h + \sum_r \omega_r R_r + \sum_n \lambda_n N_n + \sum_t \Omega_t T_t + \eta C + \mu \quad (3)$$

where,

Y is the log of total yield;

π, is the constant term;

J_j is the vector of the logarithm of the inputs of production per hectare (chemical fertilizers, organic fertilizers, fungicides, paid labor, unpaid labor and land);

H_h, R_r, N_n, T_t are defined as in equation (1);

C is a dummy variable that takes the value of one if the plot is planted with Amarilis;

μ is the error term; and

π, τ_j, θ_h, ω_r, λ_n, Ω_t, η are the coefficients to be estimated. It is important to notice that some of these coefficients represent interaction effects between the adoption of the resistant cultivar and the conventional inputs.

The main hypothesis to be tested in this model is that Amarilis adoption has a positive effect on yields; that is, the coefficient η is positive and significant.

Lichtenberg and Zilberman (1986) have questioned this approach mainly because it overestimates the marginal product of pesticide use by mis-specifying the marginal productivity curve of the damage control input. They note: "…a standard Cobb-Douglas specification will produce a marginal effectiveness curve whose elasticity is constant and, hence, which declines more slowly than the true marginal effectiveness curve" (p.266). This potentially generates an upwardly biased estimator. The Cobb Douglas approach has usually predicted an under use of pesticide application in developed countries (marginal product of pesticides greater than input price) which does not match with the actually observed higher use of these production inputs (Shankar and Thirtle, 2005). The suggested alternative approach is a damage control function which assumes damage control inputs are employed in the agricultural production to prevent damage and to maximize potential output rather than to increase yield per se (Lichtenberg and Zilberman, 1986). In other words, where damaging agents are nonexistent, the damage control inputs should not have a direct effect on yield. However, in the presence of damaging agents, such as the late blight disease, the damage control inputs reduce output losses. This specific characteristic of the damage abatement inputs can be captured by including a damage control

function G(X) in the production function. This function represents the reduction in lost output caused by the utilization of damage abatement inputs. "(It) gives the proportion of the destructive capacity of the damaging agent eliminated by the application of a level of control agent X" (Lichtenberg and Zilberman, 1986, p. 263). This framework has also been used by Huang *et. al.* (2001) for the case of Bt cotton in China, Shankar and Thirtle (2005) for the case of Bt cotton in South Africa and Qaim and De Janvry (2005) in Argentina, among others.
The properties of the damage control function are summarized as follows:

- G(X) is defined in the interval [0,1]; G(X)=1 when the damage abatement inputs (X) completely eliminate the destructive effects of the damaging agents; G(X)=0 when the damage abatement inputs did not eradicate any of the damaging capacity of the damaging agents.
- G(X) is monotonically increasing.
- G'(X)>0 ; G(X)→1 as X→ ∞; G(X)→0 as X→ 0. This means that the adopted technology (X) has a positive effect on the damage abatement function. Hence, as X increases the damage abatement function will be closer to one (total control of the damaging agent) while as X decreases the damage abatement function will be closer to zero (deficient control of the damaging agent); (Lichtenberg and Zilberman, 1986, p. 263).

Based on the previously mentioned assumptions, the function that illustrates the output behavior is composed by two main parts:

$$Y = F(Z)*G(X) \qquad (4)$$

Where **Y** is total yield, **Z** represents the usual yield enhancement inputs such as fertilizers, labor, land, etc, and **X** represents the damage control inputs such as Amarilis adoption, systemic fungicides and contact fungicides. Following the approach suggested by Shankar and Thirtle (2005), the damage abatement function **G(X)** is proportional to **Y** and is estimated using a logistic representation. In this examination, the conventional inputs of production are interacted with the late blight resistant technology mainly because it is presumed that Amarilis variety has an effect on output other than by its interaction with fungicide use. Hence, the production function that characterizes the yield of potato fields is the following:

$$Y = A_0 \prod_{i=1}^{I} Z_i^{b_i + a_i C} \left[1 + \exp\{\mu_1 - \psi_1 X_1 - \psi_2 X_2 - \phi C\}\right]^{-1} \qquad (5)$$

Taking logarithms at both sides of equation (5) facilitates the estimation of the damage abatement model and provides a more accurate representation of the log normal distribution presented by the inputs of production. This transformation is represented by:

$$Ln\,Y = Ln\,A_0 + (b_i + c_i C) Ln\,Zi - Ln[1 + \exp\{\mu_1 - \psi_1 X_1 - \psi_2 X_2 - \phi C\}] + \varrho \quad (6)$$

where,

A_0 is the vector that represents household characteristics (*R* in equation 1 and 3), head of the household characteristics (*H* in equation 1 and 3) and community fixed effects (*N* in equation 1 and 3) that might have an effect on total output;

Zi is the vector of conventional yield enhancement inputs (seeds, fertilizers, guano, abono foliar, labor and land);

C is a dummy variable that takes the value of 1 if the plot is planted with Amarilis and 0 otherwise;

$c_i C$ is the vector of interaction terms between the late blight resistant technology and the conventional inputs;

X_1, X_2 are the variables that represent the total kgs of fungicides per hectare. Fungicides are divided into systemic and contact in order to analyze the impacts of each fungicide type separately;

ϱ is the error term; and

b_i, c_i, μ_1, ψ_1, ψ_2 and ϕ are the coefficients to be estimated;

This model will allow us to corroborate the hypothesis that Amarilis adoption has a positive effect on damage abatement by decreasing losses of production as long as the coefficient ϕ is positive and significant. Equation (6) will be calculated by using a nonlinear estimation.

3.3 Issues in Evaluating the Impact of Adoption

Evaluating impact of adopting a resistant cultivar on pesticide use and yields is complicated by the fact that households choose to adopt the variety. This raises concerns over the ability to identify the impact of Amarilis adoption since adopting households may be fundamentally different from non-adopting households. The evidence presented in Section 3 indicates that in general the household characteristics of adopters and non-adopters are similar and the differences are principally in variables related to input utilization in potato production. To verify this we run a probit model on adoption (where adopting Amarilis equals one and zero otherwise). As discussed by Feder, Just and Zilberman (1985), this technique is one of the most widely applied in the literature when describing adoption behavior. It allows a determination of which observable factors differ across adopters and non-adopters and provides insight into whether non-adopters are an appropriate comparison group to adopters. To do this, the predicted probability of adoption for both groups can be compared to see if there is *common support*—meaning that the range of observable characteristics of adopters and non-adopters are comparable and that non-adopters can act as a reasonable counterfactual to adopters.[4] If there is complete overlap in the predicted probabilities, it can be assumed that the range of characteristics of each group is similar. If there is partial overlap, it may be that a subset of households are similar and those outside this range should be excluded—referred to as "trimming" the sample—from the analysis. If there is no overlap, and thus no common support, it is not reasonable to compare the two sets of households.

However, it may that there are some unobservable characteristics of Amarilis adopters that induce them to adopt and that the coefficient is biased because it captures these unobservables. There are options for dealing with this problem such as the use of an instrumental variable (IV) approach, but this also has difficulties. Furthermore, as argued below, much of the differences in adopters and non-adopters are due to observable differences that can be controlled for in a regression framework. Finally, to avoid capturing unobservables linked to differences in agroecology or other location variables, community level fixed effects are included in all cases.

4. RESULTS

4.1 The adoption decision

The probit estimation on the decision to adopt Amarilis incorporates exogenous variables that are assumed to influence the decision to adopt the late blight resistant variety. Farmers from Huanuco are not included in the estimation because none of them adopted Amarilis. However, subsequent analysis demonstrates that the inclusion of these Huanuco farmers as a comparison group is appropriate since they have similar characteristics. The results of the probit are reported in Table 4 with marginal effects, evaluated at the sample mean, reported rather than coefficients and the corresponding p-values.

The results do not indicate marked differences between Amarilis adopters and non- adopters. Having secondary education increases the probability of adopting Amarilis with farmers who finished secondary education 22% more likely to adopt Amarilis than farmers with no education. This may be because they are better able to obtain information on the benefits of new varieties.

[4] The range of characteristics included in the probit must be exogenous to the decision to adopt Amarilis.

Income from non-agricultural activities has a negative effect on Amarilis adoption possibly indicating a lack of emphasis on potato production. Further, the number of years planting potatoes reduces the probability of Amarilis adoption perhaps because younger farmers tend to be risk takers and older farmers follow custom. Additionally, more experienced farmers face higher opportunity costs of learning about a newer variety. Specifically, one extra year planting potatoes decreases the probability of adopting Amarilis by 0.8%.

To determine if adopting and non-adopting farmers are systematically different, Panel 1 of Figure 2 shows the kernel density of the predicted probabilities of adoption (or propensity scores) based on the probit estimation for each type of farmer excluding farmers from Huanuco.[5] The figure confirms there is an area of common support as can be seen by the overlapping densities presented for both types of farmers. This area of common support corresponds to the interval of predicted probabilities located between the two vertical dotted lines presented in Figure 2 and provides evidence of the validity of the non-adopters sampled as a counterfactual.

Table 4. Characteristics of Amarilis adopters (Probit Results).

Variables	**Marg. effect**	**P>z**
Area		
Area for potato production (hectares)(log)	0.040	0.394
Head of the Household Characteristics		
Age	-0.023	0.285
Age sqr	0.000	0.275
Male	0.061	0.757
Children (no)	0.001	0.950
Primary	0.053	0.467
Secondary	0.227	0.048
Tertiary	0.159	0.377
Years Planting Potatoes (no.)	-0.008	0.046
Household Characteristics		
Distance to the closest road (mts) (log)	-0.002	0.869
Assets owned	0.033	0.680
Income accrued in non-agricultural activities (soles) (log)	-0.019	0.067
Family Labor (no) (log)	0.102	0.272
Portfolio of Potatoes		
2 Varieties Planted	0.045	0.837
3 Varieties Planted	0.217	0.277
Location		
La Libertad	0.225	0.016
Constant	1.224	0.448

Observations: 200 R2: 0.16
Note: No education is the omitted category; 1 variety planted is the omitted category; Cajamarca is the omitted category.
Source: Authors' calculation based on Varietal Adoption Survey, CIP, 2006.

[5] The densities are kernel densities calculated using the predicted probabilities from the probit model.

Panel 2 of Figure 2 presents the same kernel density of predicted probabilities of adoption from the probit estimation when the farmers from Huanuco are included.[6] The area of common support between the predicted probabilities for both types of farmers is unaffected when Huanuco is included. This conclusion is also confirmed by the distribution of the propensity scores of the farmers from Huanuco shown in Panel 3 of Figure 2. The analysis does not suggest that farmers from Huanuco do not adopt Amarilis as part of their portfolio of potatoes because they are substantially different from adopters in basic household or plot characteristics. On the contrary, it supports the idea that farmers from Huanuco prefer to plant other varieties such as Canchan because of its demand in the Lima market. Since distance to market is observable, it can be controlled for in a regression framework and suggests that Huanuco represents a good counterfactual for the analysis. However, as a check, results are run with and without the Huanuco data included.

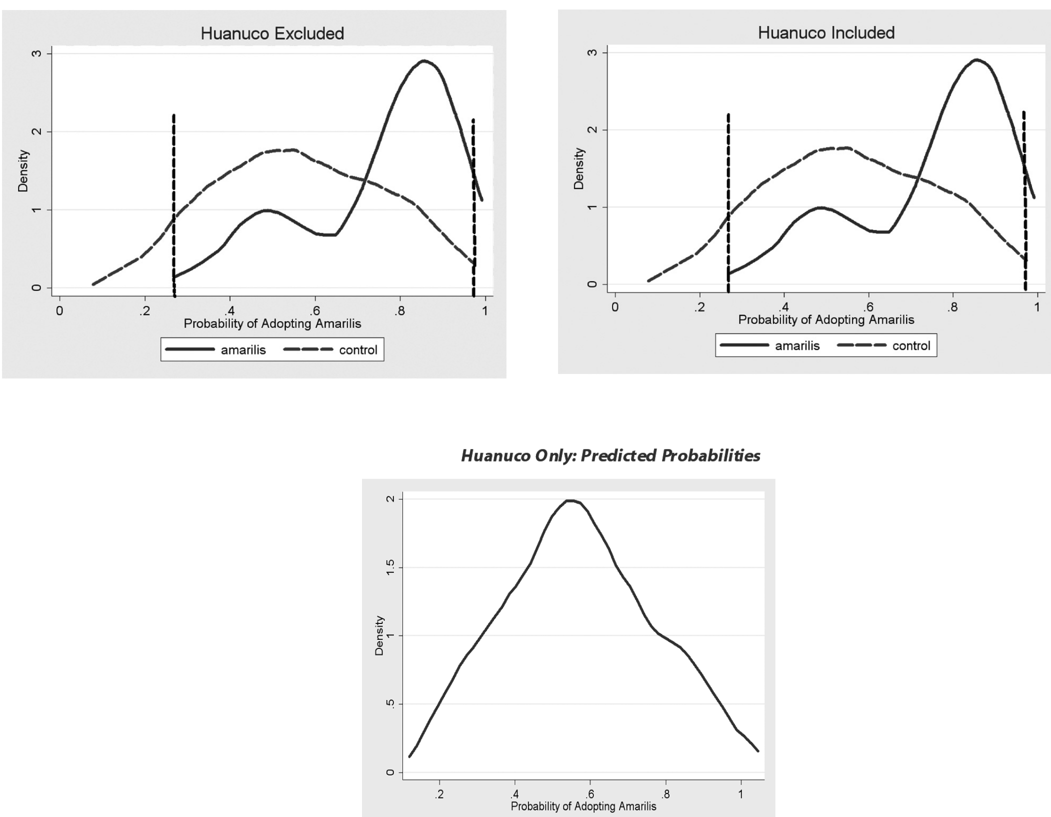

Figure 2. Predicted Probabilities for Amarilis and non-Amarilis adopters.

Source: Authors' calculation based on Varietal Adoption Survey, CIP, 2006.

[6] This involves out of sample prediction for the Huanuco observations. That is, the results of the probit of the other regions are used to predict the probability of adoption of Huanuco households.

4.2 Fungicide use

The results to the estimation of equation (1) are presented in Table 5. The first three columns show the estimations obtained by using the logarithm of total kg of fungicide per hectare as the dependent for the whole sample, the trimmed sample (outside common support as shown in Figure 2) and excluding the farmers from Huanuco. The last three columns show the estimations using the logarithm of total number of applications as the dependent variable for the same three groups. A separate estimation for systemic and contact fungicides has been incorporated to capture the impact of Amarilis adoption on each of these types of fungicides. The latter results are showed in Table 6.

The adoption of Amarilis appears to have a negative significant effect on fungicide use. This can be seen in both the results for total kg of fungicide and total number of applications. The coefficient on the Amarilis variable is significant across all the specifications and with similar magnitude strongly supporting to the hypotheses that Amarilis adoption does in fact reduce fungicide use. Particularly, the reduction in fungicide use caused by the adoption of Amarilis is mainly driven by the lower amount of systemic fungicides used by adopters (Table 6).

For the fungicide quantity regression, the total amount of land and superior education have a positive significant effect on fungicide use. The result for land is expected since small land holders are more likely to face liquidity and credit constraints and therefore, are less able to purchase inputs of production. The positive effect of education on fungicide use is also expected since more educated individuals are more likely to have access to credit and resources needed to purchase inputs and to have access to information regarding the correct amount of fungicides that must be applied. However, this variable becomes insignificant when Huanuco is excluded from the sample of farmers. This could be explained by the fact that 44% of the farmers who have tertiary education are dropped when farmers from Huanuco are not included.

When using number of applications as the dependent variable, family labor and male head of household are significant. The former result could be explained by the fact that households with greater access to family labor are better able to overcome labor constraints for fungicide application. The positive effect of male head of households on number of application of fungicides reveals some gender issues in the application of fungicides. Female-headed households often do not have a spouse which means that these households are more likely to face male labor constraints which has a negative effect on fungicide application since this is mainly done by men. Taken together, the results indicate access to physical and human capital have greater influence on the total amount of fungicide used as measured by kg per hectare while variables associated with access to inexpensive labor have greater explanatory power in the number of applications of fungicides per harvest. These findings are important because they verify the existence of different patterns of fungicide use among farmers who face different constraints.

As noted, Table 6 shows that the negative effect of Amarilis adoption on fungicide use is mainly driven by the reduction on systemic fungicides. The coefficient associated with Amarilis adoption is negative but not significant for the contact fungicides regressions. This indicates that Amarilis adoption serves as a substitute for systemic fungicides probably because farmers are using systemic fungicides when they have a late blight infection which is out of control and with Amarilis this is less likely.

Among the inputs that increase the utilization of systemic fungicides are total land, family labor and number of varieties planted. However, family labor and number of varieties planted become insignificant when Huanuco is excluded from the sample of farmers. This can be explained by the fact that farmers from Huanuco use on average 1.2 units of family labor while farmers from la Libertad and Cajamarca use on average 4.2 units of family labor. However, when the t-test for family labor is conducted between la Libertad and Cajamarca, it is not statistically significant, which allows us to conclude that there is not enough variability in family labor used in agriculture when Huanuco is excluded from this sample. The same analysis applies in the case of number of varieties planted.Farmers from Huanuco tend to be more specialized and plant fewer varieties. This means that once Huanuco is excluded, there is not enough variability for the number of varieties planted with respect to the base category which is equal to one variety planted. In other words, the number of varieties planted does not differ much between farmers located in Cajamarca and La Libertad which explains the statistical insignificance of these variables when Huanuco is not included.

For the case of contact fungicides, the age of the head of the household is the independent variable with higher explanatory power among the different types of specifications. Older head of households apply less contact fungicides than younger ones. Other variables such as education and assets seem to have some explanatory power on the utilization of contact fungicides; however, the significance of these variables is not consistent across all the estimations.

Table 5. Estimation of the Impact of Amarilis Adoption on Fungicides.

	Log Kg of Fungicides per Hectare						**Log Number of Applications**					
Variables	Whole		Trimmed		Without Huanuco		Whole		Trimmed		Without Huanuco	
	kg	P>t	kg	P>t	kg	P>t	No.	P>t	No.	P>t	No.	P>t
Amarilis (dummy)	-0.184	0.048	-0.179	0.061	-0.164	0.085	-0.230	0.012	-0.230	0.014	-0.235	0.015
Inputs												
Log area (hectares)	0.123	0.003	0.133	0.006	0.125	0.015	0.061	0.108	0.049	0.182	0.046	0.311
Log family labor (no)	0.053	0.471	0.077	0.315	-0.028	0.774	0.177	0.009	0.208	0.003	0.200	0.035
Variedad2 (dummy)+	0.071	0.602	0.132	0.331	0.022	0.898	0.062	0.577	0.113	0.297	0.155	0.523
Variedad3 (dummy)+	0.201	0.203	0.247	0.115	0.068	0.693	0.052	0.713	0.076	0.584	0.079	0.756
Head of HH Characteristics												
Primary (dummy)*	0.089	0.177	0.042	0.521	-0.042	0.573	0.085	0.183	0.041	0.527	0.005	0.945
Secondary (dummy)*	0.173	0.133	0.138	0.245	0.008	0.954	0.114	0.275	0.082	0.451	-0.101	0.495
Superior (dummy)*	0.422	0.002	0.327	0.033	0.329	0.133	0.084	0.447	0.056	0.592	0.213	0.118
Age head of household (no)	-0.016	0.351	-0.011	0.499	-0.003	0.873	-0.005	0.786	-0.002	0.903	0.009	0.693
Age squared	0.000	0.286	0.000	0.417	0.000	0.711	0.000	0.896	0.000	0.975	0.000	0.651
Male head of household (dummy)	0.082	0.571	0.132	0.374	0.204	0.344	0.224	0.060	0.288	0.018	0.395	0.028
Household Characteristics												
Log distance closest road (mts)	0.012	0.190	0.013	0.153	-0.010	0.371	-0.002	0.815	-0.002	0.855	-0.013	0.258
Log income non agriculture (soles)	-0.017	0.163	-0.016	0.185	-0.010	0.485	-0.003	0.806	0.000	0.989	0.000	0.976
Assets (dummy)	-0.083	0.311	-0.070	0.384	-0.063	0.544	-0.051	0.481	-0.029	0.696	0.000	1.000
Location												
Community fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
constant	1.478	0.000	1.325	0.000	0.337	0.026	1.420	0.000	1.271	0.000	0.417	0.419
R2	0.710		0.73		0.56		0.61		0.63		0.57	
Observations	584		560		415		584		560		415	

Notes: * No education is the omitted category; One variety planted is the omitted category;
Source: Authors' calculation based on Varietal Adoption Survey, CIP, 2006.

Table 6. Contact and Systemic Fungicides.

Variables	Log Kg of Fungicides per Hectare						Log of Contact Fungicides per Hectare					
	Whole		Trimmed		w/o Huanuco		Whole		Trimmed		w/o Huanuco	
	Coef	P>t	Coef	P>t	Coef.	P>t	Coef.	P>t	Coef.	P>t	Coef.	P>t
Amarilis (dummy)	-0.183	0.041	-0.174	0.062	-0.167	0.069	-0.059	0.213	-0.073	0.130	-0.032	0.497
Inputs												
Log area (hectares)	0.155	0.000	0.142	0.001	0.147	0.004	-0.022	0.507	-0.011	0.753	-0.003	0.927
Log family labor (no)	0.137	0.052	0.146	0.047	0.064	0.492	-0.109	0.164	-0.065	0.399	-0.196	0.003
Variedad2 (dummy)	0.089	0.531	0.144	0.315	0.181	0.321	0.009	0.958	0.027	0.872	-0.124	0.397
Variedad3 (dummy)	0.275	0.085	0.318	0.048	0.281	0.131	-0.056	0.738	-0.043	0.799	-0.177	0.226
Head Characteristics												
Primary (dummy)	0.042	0.528	0.003	0.966	-0.090	0.234	0.109	0.066	0.087	0.163	0.033	0.497
Secondary (dummy)	0.106	0.348	0.066	0.571	-0.062	0.657	0.159	0.149	0.156	0.178	0.021	0.718
Superior (dummy)	0.340	0.061	0.162	0.384	0.067	0.820	0.206	0.224	0.394	0.030	0.206	0.150
Age head of household (no)	0.003	0.888	0.008	0.657	0.015	0.504	-0.027	0.094	-0.031	0.057	-0.004	0.768
Age squared	0.000	0.856	0.000	0.639	0.000	0.537	0.000	0.063	0.000	0.041	0.000	0.546
Male head of household (dummy)	0.235	0.237	0.261	0.208	0.383	0.207	-0.261	0.142	-0.141	0.416	-0.167	0.350
Household Characteristics												
Log distance closest road (mts)	0.007	0.424	0.011	0.241	-0.019	0.092	0.009	0.270	0.000	0.996	0.015	0.012
Log income non agriculture (soles)	0.007	0.424	-0.011	0.393	-0.009	0.513	-0.015	0.118	-0.013	0.162	-0.003	0.753
Assets (dummy)	-0.162	0.046	-0.162	0.043	-0.112	0.259	0.089	0.175	0.118	0.071	0.033	0.572
Location												
Community fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
constant	0.795	0.038	0.673	0.086	0.330	0.775	1.274	0.000	1.129	0.001	0.345	0.418
R2	0.67		0.68		0.51		0.53		0.56		0.57	
Observations	584		560		415		584		560		415	

Notes: No education is the omitted category; One variety planted is the omitted category;
Source: Authors' calculation based on Varietal Adoption Survey, CIP, 2006.

4.3 Yields

The results of the estimation of equations (3) and (6) are presented in Table 7. The different specifications for the whole sample, the trimmed sample and excluding Huanuco are included. The first three columns show the results for the Cobb Douglas production function while the last three columns provide the estimates for the damage abatement function with interaction effects.

Interestingly, the results obtained from the Cobb Douglas and the damage abatement estimations are quite similar even across specification. In particular, both provide evidence that output enhancement inputs such as seeds and non-organic fertilizer have a positive effect on yields. Moreover, other conventional inputs such as guano, abono foliar and paid labor are positive but not significant.

In addition, the adoption of the Amarilis variety has a positive effect on yields when it is assumed to be a conventional input (Cobb Douglas approach) and also has a positive effect on the reduction of yield losses (damage abatement framework). The coefficients associated with this variable are significant for the estimations where Huanuco is not included (farmers who actually adopted Amarilis) while when Huanuco is included, the coefficient is nearly significant. It is important to notice that Amarilis is the only damage abatement input that has a positive significant effect on reducing yield losses.

Standard inputs such as land and family labor have a negative effect on output. These coefficients might be the result of the diminishing returns associated with these inputs which means that a marginal increase on any of these inputs will have a negative effect on total productivity when holding other inputs of production constant. In other words, increasing the number of hectares of land without increasing other inputs will reduce the physical productivity of land.

Interestingly, the parameters associated with systemic and contact fungicides are not significant. In fact, these coefficients are negative for the whole sample and the trimmed sample. However, when Huanuco is excluded from the sample of farmers or when interacted with Amarilis the coefficient of systemic fungicides becomes positive. These findings imply the following three statements: First, the lack of significant effect on the use of fungicides when Huanuco is included suggests that, at least in the period of study, farmers from Huanuco are over-utilizing systemic and contact fungicides (7.24 kg of systemic fungicides and 1.60 kg of contact fungicides per hectare) with respect to farmers from the other two locations (1.78 kg of systemic fungicides and 0.33 kg of contact fungicides per hectare), possibly because of their market orientation. Second, farmers from this sample will not be able to attain any extra output or to reduce yield losses to a greater extent by increasing the amount of fungicides. Third, there is some evidence that suggests that systemic fungicides are more effective in controlling pest damage than contact fungicides. These results corroborate the findings of Terrazas *et. al.* (1998) who found similar results in analyzing potato productivity in Bolivia.

In the case of the head of the household characteristics, there is some evidence of positive but declining returns to education. Having primary education is positive across most of the estimations and significant when Huanuco is excluded from the sample. Also, accessing secondary education has a positive effect on yields for most of the estimations while having superior education has a negative effect on yields although not significant. This negative effect of higher education on yields could be explained by the fact that individuals with more education prefer to allocate their time to other more profitable non-agricultural activities and therefore, they tend to be less involved in agricultural activities.

For the case of the variables associated with the household characteristics, access to roads and income from non-agricultural activities have a positive significant effect on yields for the whole sample and the trimmed sample while the same coefficients are not significant when Huanuco is excluded. The influence of access to roads on total output could be explained by two factors. First, the access to roads facilitates the purchase of conventional inputs by the farmers which could have a direct effect on output. Second, access to roads facilitates the transportation of products to the market which is an incentive for better crop management. On the other hand, the positive effect of non-agricultural income is associated with a reduction in liquidity constraints increasing input use to enhance yields.

In conclusion, all the estimations corroborate the hypothesis that the adoption of Amarilis variety has a positive effect in yields either by increasing yields per se or by effectively reducing yield losses associated with late blight disease.

Table 7. Estimation of the Impact of Amarilis Adoption on Yields.

	Cobb Douglas						Abatement					
Dependent:	Whole		Trimmed		w/o Huanuco		Whole		Trimmed		w/o Huanuco	
Yield per hectare (kg)(log)	Coef.	P>t	Coef.	P>t	Coef.	P>t	Coef.	P>t	Coef.	P>t	Coef.	P>t
Inputs												
Area (hectares)(log)	-0.415	0.003	-0.436	0.002	-0.556	0.000	-0.412	0.003	-0.431	0.002	-0.557	0.000
area*amarilis	0.055	0.799	0.086	0.709	0.116	0.572	0.069	0.736	0.100	0.654	0.127	0.525
Seed (kg) (log)	0.353	0.006	0.388	0.003	0.418	0.002	0.353	0.005	0.386	0.003	0.426	0.001
Seed*amarilis	-0.254	0.084	-0.283	0.066	-0.316	0.029	-0.258	0.061	-0.287	0.049	-0.322	0.019
Abono Foliar (kg) (log)	0.101	0.240	0.082	0.364	0.165	0.106	0.110	0.204	0.091	0.318	0.177	0.076
Abono Foliar*amarilis	-0.052	0.542	-0.045	0.600	-0.042	0.626	-0.002	0.984	0.008	0.946	0.007	0.951
Guano (sacks/bags) (log)	0.013	0.791	0.019	0.719	0.035	0.490	0.013	0.795	0.020	0.717	0.030	0.554
Guano*amarilis (sacos) (log)	-0.010	0.847	-0.013	0.808	-0.015	0.758	-0.023	0.637	-0.026	0.593	-0.028	0.536
Fertilizer (sacks/bags) (log)	0.117	0.020	0.150	0.006	0.123	0.029	0.114	0.024	0.146	0.008	0.110	0.052
Fertilizer*amarilis	0.104	0.198	0.089	0.276	0.115	0.163	0.137	0.070	0.124	0.115	0.148	0.064
Family labor (no)(log)	-0.231	0.073	-0.267	0.058	-0.149	0.281	-0.229	0.071	-0.265	0.056	-0.143	0.296
Family labor*amarilis	0.160	0.392	0.156	0.396	0.136	0.379	0.163	0.391	0.159	0.394	0.134	0.386
Paid labor (no)(log)	0.051	0.302	0.004	0.951	0.039	0.531	0.052	0.289	0.005	0.925	0.053	0.384
Paid labor*amarilis	-0.078	0.232	-0.060	0.401	-0.060	0.376	-0.078	0.253	-0.060	0.414	-0.058	0.397
Systemic fungicides (kg)(log)	-0.002	0.832	-0.005	0.569	0.015	0.409						
Systemic*amarilis	0.033	0.265	0.034	0.265	0.032	0.254						
Contact fungicides (kg)(log)	-0.041	0.066	-0.032	0.178	-0.012	0.879						
Contact*amarilis	-0.110	0.366	-0.121	0.314	-0.108	0.263						
Amarilis (dummy)	1.615	0.184	1.771	0.162	1.999	0.079						
2 varieties (dummy)	0.348	0.099	0.147	0.149	0.027	0.922	0.138	0.165	0.156	0.127	0.026	0.928
3 varieties (dummy)	0.203	0.359	-0.012	0.934	-0.094	0.747	-0.048	0.733	-0.001	0.994	-0.095	0.751

Table 7. Estimation of the Impact of Amarilis Adoption on Yields *(continued).*

	Cobb Douglas (continued)						Abatement (continued)					
Continued	**Whole**		**Trimmed**		**w/o Huanuco**		**Whole**		**Trimmed**		**w/o Huanuco**	
	Coef.	**P>t**	**Coef.**	**P>t**	**Coef.**	**P>t**	**Coef**	**P>t**	**Coef.**	**P>t**	**Coef.**	**P>t**
Head Characteristics												
Primary (dummy)	-0.015	0.820	0.028	0.757	0.170	0.040	0.022	0.798	0.022	0.804	0.148	0.068
Secondary (dummy)	0.139	0.142	0.244	0.046	0.605	0.000	0.215	0.071	0.241	0.045	0.609	0.000
Superior (dummy)	-0.825	0.025	-0.443	0.332	-1.068	0.176	-0.358	0.391	-0.451	0.341	-1.097	0.178
Age head of household (no)	0.006	0.761	0.002	0.912	-0.006	0.771	-0.003	0.857	0.003	0.871	-0.005	0.799
Age head of household squared (no)	0.000	0.732	0.000	0.979	0.000	0.707	0.000	0.808	0.000	0.963	0.000	0.745
Male head of household (dummy)	-0.194	0.139	-0.035	0.843	0.195	0.164	0.076	0.652	-0.007	0.968	0.233	0.116
Household Characteristics												
Distance to closest road (mts)(log)	-0.026	0.024	-0.039	0.004	-0.011	0.393	-0.043	0.001	-0.040	0.002	-0.014	0.264
Non-agricultural income (soles)(log)	0.053	0.000	0.022	0.058	0.013	0.331	0.028	0.011	0.023	0.054	0.016	0.194
Assets (dummy)	-0.108	0.126	-0.098	0.431	0.089	0.381	-0.066	0.559	-0.114	0.355	0.050	0.601
Damage Control Function												
µ1							7.517	.	7.341	.	8.728	.
Systemic (kg)(log)							0.000	0.977	-0.003	0.750	0.022	0.211
Contact (kg)(log)							-0.045	0.047	-0.037	0.119	-0.026	0.708
Amarilis (dummy)							1.662	0.152	1.816	0.136	2.059	0.059
Location												
Community fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
constant	5.326	0.000	5.213	0.000	5.717	0.000	12.818	0.000	12.534	0.000	14.245	0.000
Observations	584		560		415		584		560		415	
R2	0.73		0.73		0.75		0.73		0.73		0.75	

Note: 1 variety planted is the omitted category for varieties planted.
Source: Authors' calculation based on Varietal Adoption Survey, CIP, 2006.

5. ACTUAL AND POTENTIAL IMPACT OF AMARILIS

The results shown in the previous sections support the hypotheses that Amarilis adoption reduces fungicide use and yield losses. In this section, simulations are used to identify the actual and potential impact of Amarilis on yields and fungicide use under different case scenarios where actual impact measures the benefits of the current level of adoption and the potential impact measures the benefits of more widespread adoption within Libertad and Cajamarca as well as in Huanuco.

The actual impact of current adoption of Amarilis on yields and fungicide use is calculated by subtracting predicted yield and fungicide use if adopters had not planted Amarilis from the actual predicted yield and fungicide use given they did plant Amarilis. The predicted values are determined by using the estimations of equations (1) and (6) for farmers located in Cajamarca and La Libertad after trimming. Following the notation specified below:

$\hat{F}_{(1)(a=1)}, \hat{Y}_{(1)(a=1)}$ = *predicted values of fungicide use and yield for amarilis adapters*

$\hat{F}_{(1)(a=0)}, \hat{Y}_{(1)(a=0)}$ = *predicted values for adapters assuming they did not plant amarilis*

The actual impact of Amarilis is then calculated as follows:

$$\text{Actual impact on yields} = [\hat{Y}_{(a=1)} - \hat{Y}_{(a=0)} \mid i = \text{Amarilis adapter}] \quad (7)$$

$$\text{Actual impact on fungicide use} = [\hat{F}_{(a=1)} - \hat{F}_{(a=0)} \mid i = \text{Amarilis adapter}] \quad (8)$$

Equations (7) and (8) are calculated for each farmer *i* and the mean value for all farmers gives the average actual impact. The calculations suggest that the adoption of Amarilis allowed adopters to obtain, on average, an additional 717.48 kg per hectare, a 9.4% increase in yields. The calculation for fungicide use shows that technology adopters were able to reduce fungicides by 0.5 kg per hectare, a 24.9% decrease.

The next step is to estimate the potential impact of Amarilis on yields and fungicide use. This is done by subtracting the predicted outcomes obtained by assuming that no farmers adopted Amarilis from the predicted outcomes assuming that all farmers adopted Amarilis. This calculation is first done for the whole sample of farmers in Cajamarca and La Libertad. The mean difference provides the average potential effect of adoption for the region. Following the notation specified below:

$$\hat{F}_{(d=1)}, \hat{Y}_{(d=1)} = \textit{Predicted values for the sub-sample assuming that Amarilis was always adopted}$$

$$\hat{F}_{(d=0)}, \hat{Y}_{(d=0)} = \textit{Predicted values for the sub-sample assuming that Amarilis was not adopted}$$

The potential impact of Amarilis will be calculated as follows:

$$\textit{Potential impact of Amarilis on yields} = [\hat{Y}_{(d=1)} - \hat{Y}_{(d=0)}] \quad (9)$$
$$\textit{Potential impact of Amarilis on fungicide use} = [\hat{F}_{(d=1)} - \hat{F}_{(d=0)}] \quad (10)$$

The potential impact of Amarilis on yields predicts that if all the plots had been planted with Amarilis, the yield increase for La Libertad would have been 917.4 kg per hectare (a 11.9% increase) while for the case of Cajamarca the yield increase would have been 360.1 kg per hectare (a 5.1% increase). In addition, if all the farmers from La Libertad and Cajamarca had adopted Amarilis, average fungicide use would have been reduced by 0.58 kg per hectare in Cajamarca (a 19% decrease) and 0.37 kg per hectare (a 31% decrease) in La Libertad.
The same simulation was conducted for Huanuco and the calculations obtained predict limited effects on yields. Here if all the farmers had adopted Amarilis the average reduction in fungicide use would have been 1.54 kg per hectare (16.6% reduction). Given that Huanuco farmers could benefit from late blight resistant cultivars, this suggests a need to develop a variety that not only is resistant to late blight but has market acceptance.

6. ASSESSMENT OF ECONOMIC BENEFITS FROM AMARILIS ADOPTION

An economic assessment of the actual and potential benefits accruing to farmers from Amarilis adoption is estimated using the predicted yield increases and reduction on fungicides use calculated in the previous section, and combining two additional information sources:
a) production costs for La Libertad and Cajamarca developed from the same survey data for Amarilis adopters and estimated by Maldonado et al. (2008).
b) adoption area at the national level estimated for Amarilis based on expert surveys and reported in Thiele et al. (2008).

The procedure estimates the net economic gains per hectare to farmers in La Libertad and Cajamarca from the adoption of Amarilis and assumes these gains are similar across all adopters at the national level. A logistic adoption curve is estimated from the year of release of Amarilis until the year 2020, using data for 2007 for which the information about adoption area is available. The net gains per hectare applied to the diffusion curve show the total net benefits to farmers during the period, at the proper discount rate.

Current Amarilis adopters in La Libertad and Cajamarca spend on average 50.5 dollars per hectare on fungicides and have an average yield of 7.66 tons per hectare. The average price received by farmers for their Amarilis crop in 2007 is 183 dollars per ton. Combined with the above information of a predicted yield increase of 9.4% and a predicted reduction in fungicide use of 24.9%, the estimated net gain to farmers who adopt Amarilis is 137 dollars per hectare, 88% of which pertain to the yield effects[7] (table 8).

Table 8. Net benefits from Amarilis, dollars per ha.

Source of benefit	$/ha
Increase in revenue (yields)	120.5
Cost reduction (fungicides)	16.7
Average net benefit	137.3

Source: Authors calculations and Maldonado et al., 2008.

Applying the net gains to the adoption area in each year gives an estimate of the total net benefits received by farmers who adopted Amarilis since its release[8]. Thiele et al. (2008) report for 2007 a total adoption area of Amarilis in Peru of 18,210 hectares, 7.3% of the area planted to potatoes in the country. Based on an estimated ceiling of 10% of the total area by the year 2020 (25,000 hectares), a logistic adoption curve is fitted to define the adoption path depicted in Figure 3.

At the normal discount rate of 10%, the net present value (NPV) of the net benefits accrued to farmers during the period since Amarilis was released in 1993 until 2007 amounts to 3.6 million dollars. If the projected adoption path until 2020 continues to provide the same benefits, then at the end of the period the net present value of benefits would have increased to almost 9 million dollars. With lower discount rates, these figures increase as showed in table 9.

[7] The cost reduction is, in this calculation, underestimated. A reduction in the amount of fungicide applied normally entails a reduction in the number of fungicide applications and therefore a reduction in the amount of labor used, which is not accounted for in this simulation.

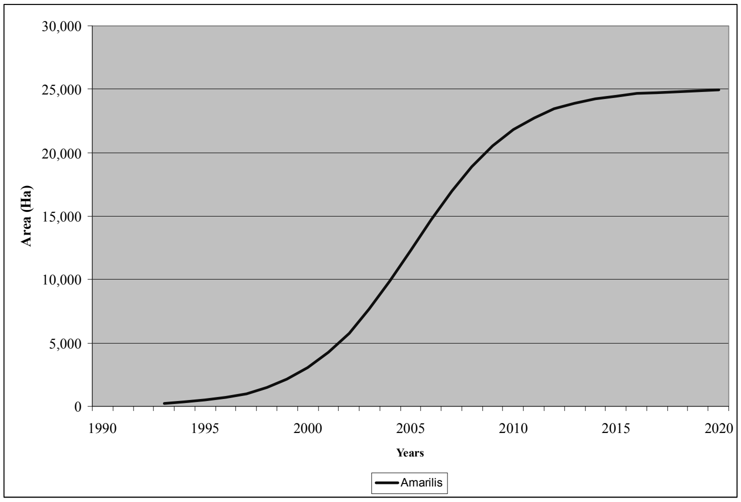

Figure 3. Estimated Amarilis adoption path, 1993 – 2020.

Table 9. NPV of benefits to farmers (million dollars).

Discount rate	1993 - 2007	1993 -2020
5%	6.2	20.6
10%	3.7	9.0

7. CONCLUSIONS

Late blight is a considerable problem facing potato farmers in the Peruvian Andes and the application of fungicides is the main strategy implemented to overcome this disease. This paper provides compelling evidence to confirm that the development of alternative technologies, specifically, the adoption of improved varieties can be considered as an effective substitute for fungicide use. The different estimations confirm that adoption of Amarilis, which is a cultivar with a higher than average level of resistance, reduces the amount per hectare of fungicides used and the number of applications of fungicides. Specifically, simulations predict 24% reduction on the amount of fungicide use per hectare on average for the overall sample of farmers in La Libertad and Cajamarca. In addition to fungicide reduction, the adoption of Amarilis has a positive effect on yields as seen in both the Cobb Douglas and a damage abatement production function. Simulation analysis predicts an average increase on yields of about 9% per hectare for farmers in La Libertad and Cajamarca. These two findings (fungicide reduction and yield enhancement)

[8] At 2007 prices.

corroborate the positive impact of resistant cultivars on agricultural production as it allows farmers to increase their revenues through higher yields and reduce costs of production associated with fungicide use. These two technology improvements from the adoption of Amarilis may produce in the long run benefits to farmers which range between 3.7 and more than 20 million dollars.

While the findings indicate clear benefits to Amarilis adoption, the lack of adoption in Huanuco indicates that other varietal attributes and the market acceptance of varieties play an important role in the adoption decision. Canchan is the preferred variety in the Lima wholesale market making up one third of the total 500 thousand tons per year of potato sold while Amarilis only satisfied 1% of the demand. The high demand for Canchan is explained by the high consumption of fried potatoes by the pollerias in Lima for which Canchan is ideally suited. Although in 2006 the average price for Amarilis was equal 0.61 soles per kilo and for Canchan was equal to 0.51 soles per kilo (Mi Chacra, 2008), the market for Amarilis is much thinner indicating little market acceptance in the broader Peruvian market. For market-oriented farmers to adopt varieties that reduce fungicide use and increase yields, the varieties must have attributes demanded in the market and find market acceptance. Hence, we can conclude that late blight resistance per se is not a sufficient characteristic to motivate farmers to adopt a given variety since resistance to this disease is only one of the many dimensions considered by them when choosing their portfolio of potatoes. Therefore, the development of varieties that could fulfill the market expectations and provide a higher level of resistance to late blight must be considered as a more comprehensive strategy to reduce fungicide use and overcome the harmful consequences of late blight disease.

REFERENCES

Bos, S. 2007. Bridging differences. Case Studies on Social Networks and Brokerage in Potato Farming in Peru (MSc-thesis; Wageningen:Wageningen University. The Netherlands, 2007).

CIP. 2008**.** "Potato / Late Blight/ Late blight Overview" http://www.cipotato.org/potato/pests_diseases/late_blight/, Accessed August, 20, 2008.

Feder, G., Just, R.E. and Zilberman, D. 1985: Adoption of Agricultural Innovations in Developing Countries: A Survey. In: Economic Development and Cultural Change 33 (2): 255-298.

Huang, J., Hu, R., Rozelle, S. and Pray, C. 2005. Insect-Resistant GM Rice in Farmers' Fields: Assessing Productivity and Health Effects in China. In: Science 308: 688-690.

Huang, J., Hu, R., Rozelle, S., Qiao, F. and Pray, C.E. 2001. Small holders, Transgenic Varieties, and Production Efficiency: The Case of Cotton Farmers in China. UC-Davis, Dept. of Agricultural & Resource Economics. Working Paper No.01-015.

Lichtenberg, E. and Zilberman, D. 1986. The Econometrics of Damage Control: Why Specification Matters. In: American Journal of Agricultural Economics 68 (2): 261-273.

Maldonado, L., Suárez, V., and Thiele, G. 2008. Estudio de la adopción de variedades de papa en zonas pobres de Perú. International Potato Center (CIP), Lima, Peru. Social Sciences Working Paper Series 2008–2. 37 pp.

MI CHACRA. 2008. www.michacra.net, Accessed September, 4, 2008.

Ortiz, O., Alcazar, J., Catalan, W., Villano, W., Cerna, V., Fano, H. and Walker, T.S. 1996. Economic Impact of IPM Practices on the Andean Potato Weevil in Peru. In: Walker, T. and Crissman, C. 'Case Studies of the Economic Impact of CIP-Related Technologies', (CIP) International Potato Center, Lima, Peru.

Ortiz, O., Winters, P., Fano, H., Thiele, G., Guaman, S., Torrez, R., Barrera, V., Unda, J. and Hakiza, J. 1997-1998. Understanding Farmers' Responses to Late Blight: Evidence from Peru, Bolivia, Ecuador and Uganda. CIP Program Report (1997-1998).

PERUINFO. 2008**.** www.peru.com/peruinfo/info_dptos/in_dptos.htm, Accessed September, 6, 2008.

Qaim, M. and de Janvry, A. 2005. Bt Cotton and Pesticide Use in Argentina: Economic and Environmental Effects. In: Environment and Development Economics 10: 179–200.

Shankar, B. and Thirtle, C. 2005. Pesticide Productivity and Transgenic Cotton Technology: The South African Smallholder Case. In: Journal of Agricultural Economics 56 (1): 97-116.

Terrazas, F., Suarez, V., Gardner, G., Thiele, G., Devaux, A. and Walker, T. 1998. Diagnosing Potato Productivity in Farmer's Fields in Bolivia. International Potato Center (CIP). Working Paper ISSN 0256-8748.

Thiele, G., Hareau, G., Suarez, V., Chujoy, E., Bonierbale, M. and Maldonado, L. 2008. Varietal change in potatoes in developing countries and the contribution of the International Potato Center: 1972 – 2007. International Potato Center (CIP), Lima, Peru. Social Sciences Working Paper Series 2008–6. 46 pp.

Walker, T. and Crissman, C. 1996. Case Studies of the Economic Impact of CIP-Related Technologies. (CIP) International Potato Center, Lima, Peru.

CIP's Mission

The International Potato Center (CIP) works with partners to achieve food security and well-being and gender equity for poor people in root and tuber farming and food systems in the developing world. We do this through research and innovation in science, technology and capacity strengthening.

CIP's Vision

Roots and tubers improving the lives of the poor.

CIP is supported by a group of governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR).
www.cgiar.org

International Potato Center
P.O. Box 1558 Lima 12, Perú • Tel 51 1 349 6017 • Fax 51 1 349 5326 • email cip@cgiar.org