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PROJECT:
INCORPORATION OF
THE CLIMATE CHANGE
TO THE STRATEGIES OF
RURAL DEVELOPMENT:

Synthesis
of the Latin American results

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INCORPORATION OF THE CLIMATE CHANGE TO THE STRATEGIES OF RURAL DEVELOPMENT:

SYNTHESIS OF THE LATIN AMERICAN RESULTS

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PRESENTATION

The Cooperative Program for Agri-food and Agroindustrial Technological Development of the Southern Cone - PROCISUR, established since 1980, is a cooperative effort of the National Agricultural Research Institutes (NARIs) of Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay, and the Inter-American Institute for Cooperation on Agriculture (IICA).

PROCISUR has sought, from its beginnings, to contribute to the discussion and analysis of those issues that are transcendental to the agriculture of the region. Within this context, since 2004 it has collaborated in the coordination and execution of the project on Climate Change and Rural Poverty financed and oriented by the World Bank, and which was executed by professionals of the Economy Department of the University of Yale, and the National Agricultural Research Institutes of Argentina, Brazil Chile, Colombia, Ecuador, Venezuela and Uruguay.

Upon the conclusion of this study, PROCISUR has initiated a series of actions destined to spread its results and contribute to their discussion and analysis in different fields. One of these actions is the publication of this document consisting of a synthesis of the results, not only from the regional point of view, but also from a more detailed perspective, at the level of each of the countries directly involved in the generation of information.

We hope that this publication will contribute to the discussion on the impact of future climate changes in the rural areas of South America regarding alterations of their productive systems and land values. We also wish to explore the possible adaptations that farmers are likely to adopt in response to the approaching climate change.

Estimations of the economic impacts on the different types of farms at a national and regional level, as well as of the value of the adaptation practices –those already implemented and those likely to be adopted-, will be beneficial for the intervention policies to be considered by governments and international development agencies.

Emilio Ruz
Executive Secretary
PROCISUR

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EXECUTIVE SUMMARY

This document presents a synthesis of the study developing during 2004/06 period to measure the impact of climate change on Latin American farmers and estimates likely adaptations that farmers will make in response to climate. Climate sensitivity is measured by looking at a cross section of farmers that face very different climates. The study compares outcomes of farms in temperate versus warm locations in order to measure the consequence of current climates. The study also examines whether farmers make different decisions in temperate versus warm climates. For example, do they choose to grow crops versus livestock or do they choose dryland farming or irrigation.

Data is gathered from 2500 farmers across Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay and Venezuela using a survey developed for this project. Districts are chosen to maximize the range of within country climates sampled. This survey information is matched with climate and soils data by district.

Regressing land value on climate and other control variables reveals that climate plays a large role explaining the variation of land values across the sample. Temperature has a hill-shaped relationship with land values and net revenues. Farmland values in cool locations are relatively low, values in temperate locations are high, and values in hot locations are relatively low. Slight increases in temperature have different effects on farms depending on their current temperature. The study finds that slight warming would generally reduce land values. However, these results vary across the sample. The farms located in cool places would increase in value with slight warming.

Small and large farms had similar but not identical responses to temperature. They both had hill-shaped relationships between land value and temperature but land value peaked at a lower temperature for large farms than for small farms. Dryland farms have similar results as above. However, irrigated farms were less sensitive to temperature.

The study also found that the land values of farms are higher in places with higher summer precipitation and the land values of farms with more winter precipitation are lower. On an annual basis, these effects are offsetting so that annual precipitation has only a small net effect. Irrigated farms were more sensitive to precipitation. Irrigation makes crops less dependent on rainfall. But irrigated farms tend to be located in dry places. Therefore, increased precipitation has a higher marginal impact on irrigated than dryland farms.

We then apply these estimated relationships to future climate scenarios. In this section, we apply the cross sectional results to predict the long run intertemporal impacts of climate change. Note that the analysis is not asserting the results can be used to model the year by year changes associated with weather but only the much more gradual changes associated with climate normals (30 year weather averages). Future climate scenarios for each country are obtained from three climate models.

The analysis is extrapolated form the sample to all countries in Latin America (Western Hemisphere south of the United States). We felt it was reasonable to extract from the sample to the region given the consistent climate, culture and technology in the region.

Several climate scenarios are tested. The scenarios represent a broad range of possible future climate outcomes for Latin America. The analysis reveals that Latin American agriculture will generally be harmed by global warming. With the more severe scenarios, farms could lose up to 62% of their value by 2100. With an "average" scenario of 3˚C warming by 2100, farms would likely lose about 30% of their value. With modest climate change scenarios, farms may lose only 15% of their value. In all tested scenarios, global warming will be damaging on net. The brunt of these impacts is likely to be felt by dryland farmers facing increasingly hot temperatures. Not every farming district will be affected alike however. Irrigated farms, farms in currently cool regions, and farms in regions with mild climate changes may actually benefit.

The adaptation analysis finds that farmers will change the type of farm, irrigation, crops, and livestock depending on climate. Farmers in temperate wet locations choose to grow crops, farmers in dry locations choose to raise livestock, and farmers in hot locations often choose to raise both crops and livestock. The analysis in Latin America found that irrigation is more likely if a farm is in a cool and dry location. Farms in hot locations will tend to grow fruits and vegetables whereas farmers in cool locations will grow potatoes and wheat. Farmers in mild and dry locations will favor beef cattle whereas they would otherwise favor dairy cattle. These results suggest that farmers will change basic aspects of their farm as climate changes.

These results have important implications for climate change policy: **i)** the study provides strong evidence that Latin American agriculture will be vulnerable to warming; **ii)** the study quantifies the magnitude of the resulting damages; **iii)** the study shows that farmers are likely to adapt by changing how they farm; **iv)** the study shows that the impacts will not be uniform across the continent but will vary a great deal from place to place. Governments must be thoughtful about providing assistance to prioritize programs to where they are needed.

A separate study was also conducted concerning the impact of climate change on Israel. This is the first climate change study in the Middle East. The study is particularly relevant to the Latin American analysis because it investigates advanced adaptation options that Israeli farmers have adopted to cope with high temperatures. The Israeli study followed the same general methods as the Latin American study and collected data across climate zones in the country. The study asked more detailed questions, however, about the technology that farmers have adopted to cope with climate. Specifically, the study explores the effect of irrigation, water supply, and cover. All three resources help farmers adapt to hotter temperatures. Future farmers facing higher temperatures have several technological alternatives they can deploy to reduce the damages of warming.

1. INTRODUCTION AND RATIONALE

The scientific community is increasingly confident that greenhouse gas emissions are causing global temperatures to rise (Houghton *et al.* 2001). The rapid buildup in greenhouse gases is highly correlated with the most recent rise in temperature (Houghton *et al*., 2001). Further, all climate models consistently anticipate some degree of future warming as greenhouse gases continue to accumulate (Houghton *et al*., 2001). As this prospect becomes clearer, there is growing interest in understanding the consequences of rising global temperatures (McCarthy *et al.,* 2001). There is already evidence that the small changes in temperature that have already occurred have caused changes in glaciers, snowmelt, and ecosystems (McCarthy *et al.,* 2001). What is not clear is how much the predicted temperature increases in the future will affect not only physical systems but mankind itself. Further, it is not clear how mankind will adapt to this new challenge.

Although climate change will most certainly affect the entire planet, it is likely to have different effects on people across the landscape. First, not everyone faces the same current temperature and precipitation levels. Warming to someone in the polar circle is likely to have very different consequences than warming to someone near the equator. Second, the consequences of warming might vary depending on what activities people are engaged in. The activities in a temperature controlled office building might hardly be affected (except for energy costs) whereas a farm might be very dependent on the climate. Third, some people may be more capable of adapting to warming than others. The ability of actors to substitute alternative inputs, outputs, or technologies to compensate for climate change may vary. It is therefore important to conduct regional climate impact studies that provide a sense of how impacts will vary in each region of the world.

There are three very important policy issues surrounding climate change: **i)** how much mitigation of greenhouse gases should be done and over what time period?; **ii)** what kinds of adaptations to climate change make the most sense?; **iii)** should emitters of greenhouse gases pay some compensation to the people being damaged by warming especially if the victims emit little and are poor?

Understanding the consequences of global warming helps answer all three policy questions. First, what is the magnitude of the global damages? Larger damages justify a more aggressive mitigation program. More aggressive programs imply that all countries undertake larger reductions of emissions and they do it sooner than later. Second, if mitigation cannot completely stop global warming, global warming will occur. It is critical that every country and district learn to adapt to what will happen. At the moment, however, very little is known about adaptation. How should individuals, firms, and governments respond to warming? When should they respond? Third, if the consequences of warming are not identical for everyone, some people will be disproportionately affected. Should emitters provide some compensation to victims who are especially hard hit, had little to do with emissions, and are poor?

This study has five major objectives. First, the study develops new methodologies to measure climate impacts and especially adaptation. Second, the study seeks to measure the damages of global warming to Latin American agriculture. Latin America is an important place to study because it spans the equator implying very hot current temperatures. Latin American agriculture in particular is important because many people in the region work in this sector, almost one third of the land is used for agriculture (World Resources, 2005), and agriculture is responsible for 8% of the GDP (World Development Indicators, 2006). Third, the study examines how Latin American farmers adapt to the current climate that they face. That is, the study measures how farmers in tropical settings make different choices compared to farmers in temperate settings. The study also tests the hypothesis that small household farms are more vulnerable to climate change than larger farms because they lack adaptation alternatives (Rosenzweig and Hillel, 1998). Fourth, the study explores how new technology might lead to new opportunities to adapt by examining some of the innovations in Israeli agriculture. Fifth, the study analyzes the feasibility of using new technology to adapt to warming by studying its applications in Israel. Agricultural experts in all the participating countries were taught new methods to measure climate impacts and measure adaptation. They then prepared reports of impacts and adaptations in their own countries.

New methods are needed to measure the damages from climate change because the future impacts of global warming are still uncertain. One contribution of this study is the development of a new methodology to measure the damages from global warming to agriculture that explicitly incorporates adaptation. The study extends current research on how farmers make choices dependent on the climate. For example, earlier studies in Africa have shown that farmers change their choice of irrigation (Kurukulasuriya and Mendelsohn, 2006a) and they change their choice of both the number of animals and which species of animal to raise (Seo and Mendelsohn, 2006a) depending on climate. In the integrated farm model, we explore whether farmers also change whether to grow crops, raise livestock, or do both depending on climate. Given the type of farm chosen, we also explore whether they adopt irrigation. Finally, for each type of farm, we explore the conditional net revenue and how that varies with climate. We label this new model an "integrated farm model" because it integrates the long separated literature on crops and livestock. The integrated farm model provides estimates of how climate alters farmer's decisions and how it alters their expected net revenue from the farm or land value. The model provides reliable estimates of the damages from warming but also insights into farm adaptation.

In addition to developing the integrated farm model, the study also relies on other existing methods. Many of these methods were shown to work on a continental scale in Africa. The traditional Ricardan model (Mendelsohn Nordhaus and Shaw, 1994) provided estimates of crop net revenues (Kurukulasuriya and Mendelsohn, 2006b) and livestock net revenues (Seo and Mendelsohn, 2006b). A variation of the Ricardian model that splits farms into dryland and irrigated farms (Schlenker *et al.,* 2005) was also estimated for Africa (Kurukulasirya and Mendelsohn, 2006b). The project also measures how the choice of crops and livestock species varies with climate.

In addition to developing new methods, the study applies these methods to study the potential damages to Latin American agriculture from future global warming. First, the study created new data. A survey was conducted of farmers in 7 Latin American countries. The countries include Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay, and Venezuela. The survey was designed to create a sample across diverse climate zones both across countries and within each country. The survey was also designed to sample both small and large farms. The survey data was then cleaned and matched with climate data and soil information. Second, the study engaged in the analyses listed above. The country studies estimated Ricardian models and looked at irrigation adoption. The regional studies estimated Ricardian models, the integrated farm model, crop choice, and livestock choice models. These analyses were then used to predict the impacts and adaptations associated with a range of climate scenarios.

A survey was also conducted in Israel to examine the question of technology. Israeli farmers have explored a number of options to cope with high temperatures including advanced irrigation methods and cover. This study explores the adoption of these technologies by farmers in Israel and how the inclusion of technology has affected the climate sensitivity of Israeli agriculture.

2. STRUCTURE AND ORGANIZATION OF THE PROJECT

This overall project was led by PROCISUR/IICA under the leadership of Emilio Ruz, Executive Secretary PROCISUR and Regional Specialist on T&I IICA. PROCISUR/IICA in turn was in charge of each of the seven Latin American country teams. The country teams are associated with the national agriculture institutions of each country as shown in **Table 1**. PROCIANDINO led by Nelson Rivas provided additional support to the Andean teams. IICA, with the support of the national offices, contracted each of the country teams to collect and clean data, conduct analysis, and prepare country reports. PROCISUR/IICA hosted the capacity building meetings for the project, guided the data collection, and supported the country reports.

Regional experts prepared papers to develop new methods, estimated Latin American scale models, and conducted capacity building meetings for the country teams supported by the World Bank. Finally, the World Bank funded a team from Israel to conduct an analysis of the role of technology as a means of adapting to climate change.

The outputs of this project include country reports and regional reports. Separate country reports were prepared by each country team. The country reports include a careful description of agriculture in each country, analyses of impacts using the traditional

Table 1. Structure and Country/regional teams

Country/ Region	Affiliation	Teams
Argentina	INTA	Jorge Lozanoff and Eugenio Cap
Brazil	EMBRAPA	Flavio Ávila, Luiz José María Irias and Magda de Lima
Chile	INIA	Jorge González Roberto Velasco
Colombia	CORPOICA	Jorge Granados Rocha, Irma Baquero, Margarita Ramírez Gómez and Fabiola Gómez
Ecuador	INIAP	Pablo Játiva
Uruguay	INIA	Bruno Lanfranco and Alfredo Albín
Venezuela	INIA	Rafael R. Pacheco and Luisa Caraballo
Israel	Hebrew University of Jerusalem	Aliza Fleischer, Ivgeni Shifrin and Ivgenia Lichtman
Regional	Yale University, USA Embrapa, Brazil World Bank, USA PROCISUR, Uruguay	Robert Mendelsohn and Niggol Seo Antonio Flavio Dias Ávila Ariel Dinar Emilio Ruz

Ricardian method (Mendelsohn *et al.*, 1994), and, for some countries, a logit analysis of irrigation adoption. Each country report also describes how the country will be impacted by a range of future climate scenarios.

Separate regional reports were conducted of the entire 7 country data set. A report on overall climate damages was prepared using the traditional Ricardian method and also the Schlenker *et al.* (2005) approach. This report compares the results from using land values versus net revenue as the dependent variable in a Ricardian model. A second regional report was estimates an integrated farm model that shows how farmers adapt to climate by shifting farm type and irrigation. Two more reports have been finished on crop choice and animal species choice.

The final output of the project is an analysis of Israeli agriculture. This study looks at a Ricardian analysis of Israeli agriculture and the adoption of advanced irrigation techniques and cover in Israel as an adaptation to warming. Israel leads the world in substituting capital for water so that they can grow food in hot dry conditions. They also invest in cover to help plants endure high temperatures. The purpose of the Israeli analysis is to understand whether these adaptations may help other countries adapt to climate change in the future.

3.1 RICARDIAN MODEL

This report relies on cross sectional analysis to measure the climate sensitivity of agriculture. The land values of different farms that face different climates are compared to determine the relationship between land value and climate. Because other factors may also explain the observed variation, they are also introduced in the analysis as controls to the extent possible. For example, characteristics of farmers, market access, and soils are all explored. Land values are regressed on climate and these other explanatory variables to estimate a "Ricardian model" (Mendelsohn *et al.*, 1994). Climate variables are introduced to allow the model to take an expected nonlinear shape. Specifically, the agronomic experimental literature suggests that crops will have a hill-shaped response to temperature (Reilly *et al.*, 1996). It is important that the economic model also be allowed to take that shape. Results in the US have suggested land value would have a hill-shaped relationship with temperature (Mendelsohn *et al.*, 1994; 1999).

The overall response of land values to climate is the result of farmers in each climate zone maximizing their profit given the climate they face as shown in **Figure 1**. Farmers in each temperature zone pick the crop and inputs that best fit their zone. For example, in a cool zone, the farmers will grow wheat. In a warm

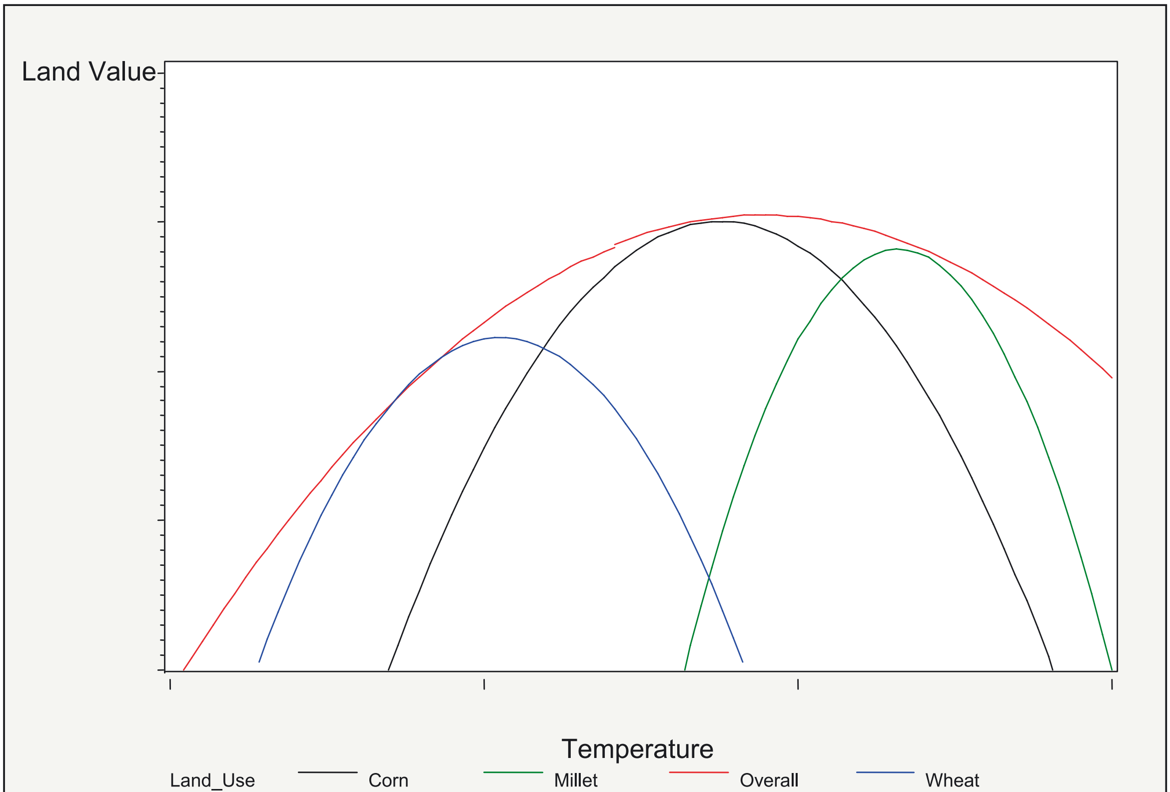


Figure 1. Conceptual Link Between Land Value and Temperature

temperate zone, they will grow maize and soybeans in the warmest zone they might shift to millet and tropical fruits. The overall land value response is the combination of all these different crops.

The impact of warming depends upon the farmer's initial climate conditions. As seen in **Figure 1**, if a farm is in a cool zone, the farmer may initially grow wheat. Warming would allow the farmer to switch to maize and increase net revenues. However, if the farm were already in a warmer zone growing maize and it warmed, the farmer might have to shift to lower valued heat-tolerant crops such as millet and earn less revenue. Finally, if the farmer is currently growing millet and temperatures warm further, the farmer may be driven out of growing crops entirely.

One concern with the cross-sectional approach is that it does not take irrigation into account (Cline, 1996). Farms that are irrigated are likely to have different responses to climate than farms that use dryland farming (no irrigation). One suggested solution is to analyze the irrigated and dryland farms separately (Schlenker *et al.*, 2005). We try this solution and estimate land value Ricardian functions for dryland and irrigated land separately.

Another concern that has been raised with the Ricardian model is that it does not take into account changes in prices (Cline, 1996). If there are large changes in output from climate change, the supply of crops that can no longer be grown will fall and that will increase the price of that crop. Similarly, if climate change increase the production of other crops, their supply will increase and their price will fall. The Ricardian model does not take these price changes into account. Consequently the Ricardian model will overstate both the benefits and damages from warming if there are large price changes. Similarly, large changes in farm productivity will likely affect labor demand in rural areas. If farms become unproductive, local labor demand will fall and wages will fall. Workers will bear some of the welfare losses associated with warming but the overall damages will be less. Again the Ricardian model will overstate the damages and benefits of warming (Mendelsohn and Nordhaus, 1996).

Another concern raised in the literature is that the future adaptation predicted by cross sectional studies will be costly to adopt (Quiggin and Horowitz, 1999; Kelly *et al.*, 2005). Farmers will have trouble anticipating what to plant and how to raise crops and will make many mistakes along the way. This is clearly the case when it comes to year to year weather. Farmers must make their choices of crops before it is clear what weather will come about each year. However, it is less clear it is still a problem when talking about long term climate. The technical definition of a climate normal is that it is the thirty year average of weather. Farmers will be able to observe climate even if they cannot predict what it will be like in the future. Given how short-lived most capital is on farms, it is not at all apparent that farmers may not have trouble adapting to climate change as it unfolds (Mendelsohn and Nordhaus, 1999).

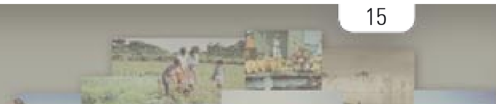
The project estimates Ricardian models at two scales: country level and regional (entire data set). The country level models are expected to be unique to each country because they capture country specific effects and the farms in each country cover a different range of climate. Because the cross sectional model requires climate variation to work, there is some concern whether a country level analysis could be estimated in smaller countries. However, there is a great deal of geographic variation within the countries in the sample (with the exception of Uruguay) so that there appears to be enough climate variation to estimate the country level models. Uruguay was combined with its neighbor Argentina for a single country study. In addition to the country studies, the Ricardian model was estimated across the sample countries. A dummy variable for the Andes countries was introduced to capture trade and technology variation across the sample.

3.2 INTEGRATED FARM MODEL AND ADAPTATION

In addition to developing Ricardian models of the impact of climate change, this research project also investigated adaptation. The project investigated whether farmers who face different climate conditions, make different choices. Specifically, the integrated farm model used a multinomial logit model to test whether farmers choose to adopt crops, livestock, or a combination of crops and livestock depending on the climate of their farm. The model also tests whether farmers of each type adopt irrigation depending on climate. Finally, the model tests whether the conditional income of each type of farm depends on climate. This analysis is similar to earlier studies that divide the sample of farms into different types (Schlenker *et al*., 2005). However, instead of assuming that each farm type is exogenous, the integrated farm model assumes farmers choose what to do in response to the conditions. In a recent study of Africa, it was shown that the choice of irrigation is endogenous, a function of climate (Kurukulasuriya and Mendelsohn, 2006a).

Separate analyses are conducted of crop choice and livestock species choice. These analyses compare which species farmers choose to adopt across different climate zones. In Africa, both livestock (Seo and Mendelsohn, 2000a) and crop choices (Kurukulasuriya and Mendelsohn, 2006c) were sensitive to climate. For both studies, multinomial choice models are estimated on climate and other control variables. The models provide quantitative estimates of how these choices change as climate changes. These adaptation models provide explicit empirical support for the implicit but hidden adaptation in the Ricardian model.

The final set of analyses is designed to study adoption of advanced irrigation techniques. A cross sectional analysis was conducted to determine whether climate affected the probability Israeli farmers adopt cover and irrigation. Irrigation was regressed on climate, farm size, and other characteristics using a logit regression. Another regression explored the choice by farmers to cover their crops with plastic. The Israeli report also includes a traditional Ricardian analysis.



4. DATA

4.1 CLIMATE

The temperature data comes from microwave imagers on US Defense Department satellites. This set of satellites pass over the entire land at 6AM and 6PM every day. In earlier research, the satellite temperature data was compared with interpolated temperatures made between weather stations. The satellites provide more effective temperature measures compared to the weather station data (Mendelsohn *et al.*, 2006a). However, satellites are not able to directly observe precipitation. The study therefore relied on precipitation data from the World Meteorological Organization (WMO). These measures were interpolated by WMO to each district from available weather station data.

The mean temperature and precipitation for each country is shown in **Table 2**. The current climate of the seven participating countries is quite different. Chile, for example, is quite temperate whereas Brazil and Venezuela are quite hot. Argentina, Chile and Venezuela are reasonably dry whereas Colombia is very wet. Even within countries, there is a substantial range of climates but this range of climates across countries is an important design feature of this study.

4.2 SOILS

Soils for each district were gathered from the digital soil map of the Food and Agriculture Organization (FAO 2003). This data set has geographically detailed information about the slope of each district, the texture of the soils, and the major soil types. Geographic Information Systems were used compute soil characteristics for each district from the FAO data set.

4.3 ECONOMIC

The economic data for this analysis was collected through farmer surveys by the country participants. A survey of farmers was modified from the survey used in Africa (Kurukulasuriya and Benhin, 2006). Several detailed questions about households and labor that had not been successful in Africa were removed to streamline the survey. The final survey was then translated into Spanish and Portuguese. The translated survey was pre-tested leading to the final survey.

The survey collected data on household characteristics such as household size and the gender and age of the farmer. The survey also collected detailed data about the farm such as the size and what each plot was used for. Annu-

Table 2. Climate and Sample by Country

Variable	Argentina	Brazil	Chile	Colombia	Ecuador	Uruguay	Venezuela
Temperature	14.4	20.2	9.3	16.8	14.8	15.2	21.8
Precipitation	72.1	122.6	77.8	162.9	99.6	101.4	83.8
N	395	639	369	341	174	119	226

Note: Temperature is measured in Centigrade and Precipitation in mm/month.

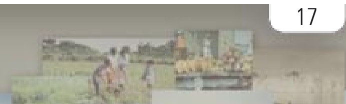
al data by plot was collected of inputs, costs, outputs, and land values. Net revenues could be inferred from the available data. A single growing year was sampled for 2003-2004.

The sampling design was created to obtain a random distribution of farms across a wide selection of climate zones within each country. Each country identified the climate zones within their boundaries and chose districts to reflect each climate zone. Within each district, a sample of about 10 farmers was interviewed. The farms were selected to observe a substantial sample of small and large farms.

Brazil collected the most data but it is geographically the largest country in the continent. Similarly, Uruguay collected a relatively small sample but it is the smallest country that was surveyed. **Table 3** presents the sample data by LA country.

Table 3. Climate change sample drawn for the LA study

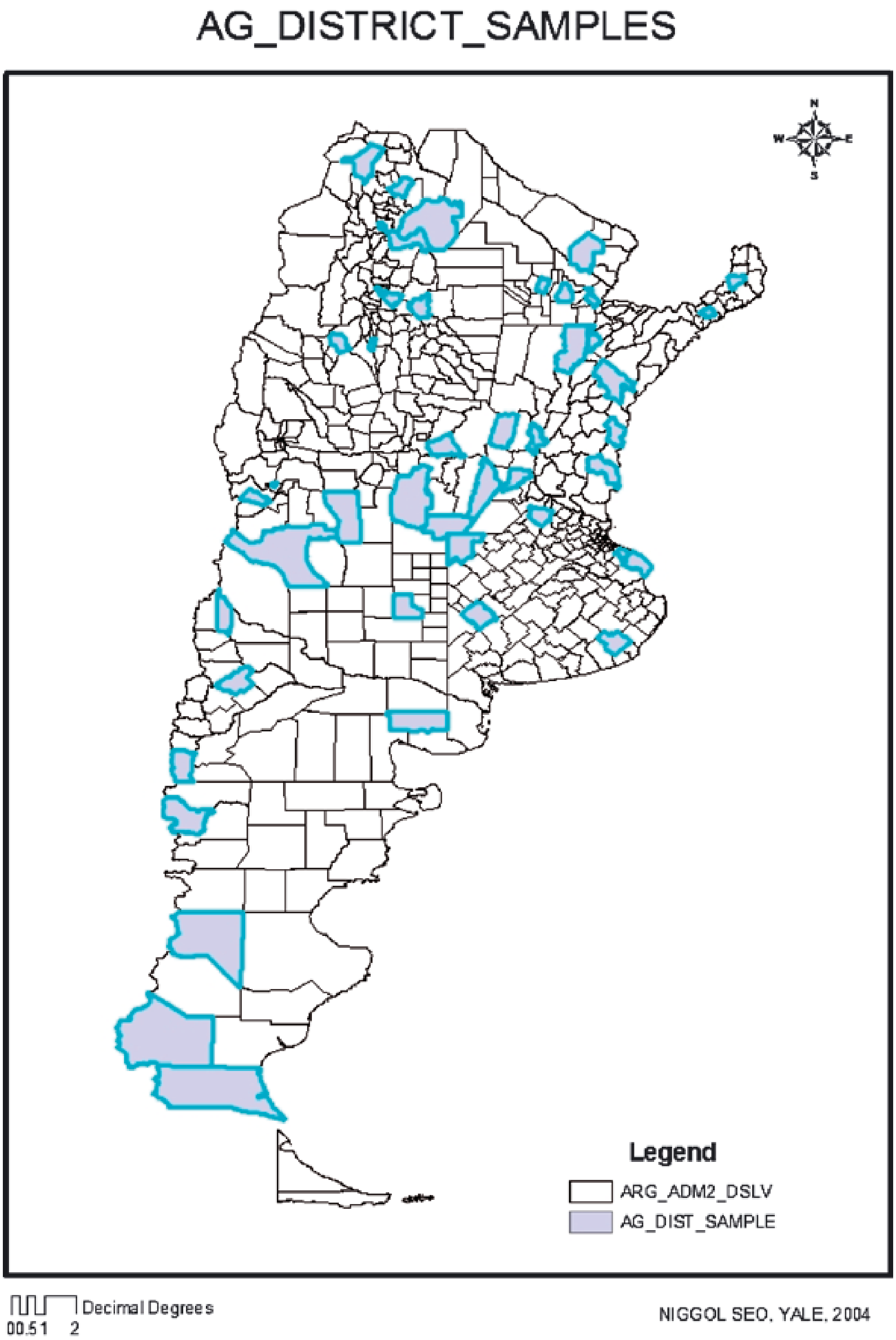
Countries	Number of surveys
Southern Cone:	
Argentina	402
Brazil	720
Chile	382
Uruguay	175
Andean region:	
Colombia	386
Ecuador	291
Venezuela	297
Total	**2,653**



4.4. SIZE AND LOCATION OF SURVEYS

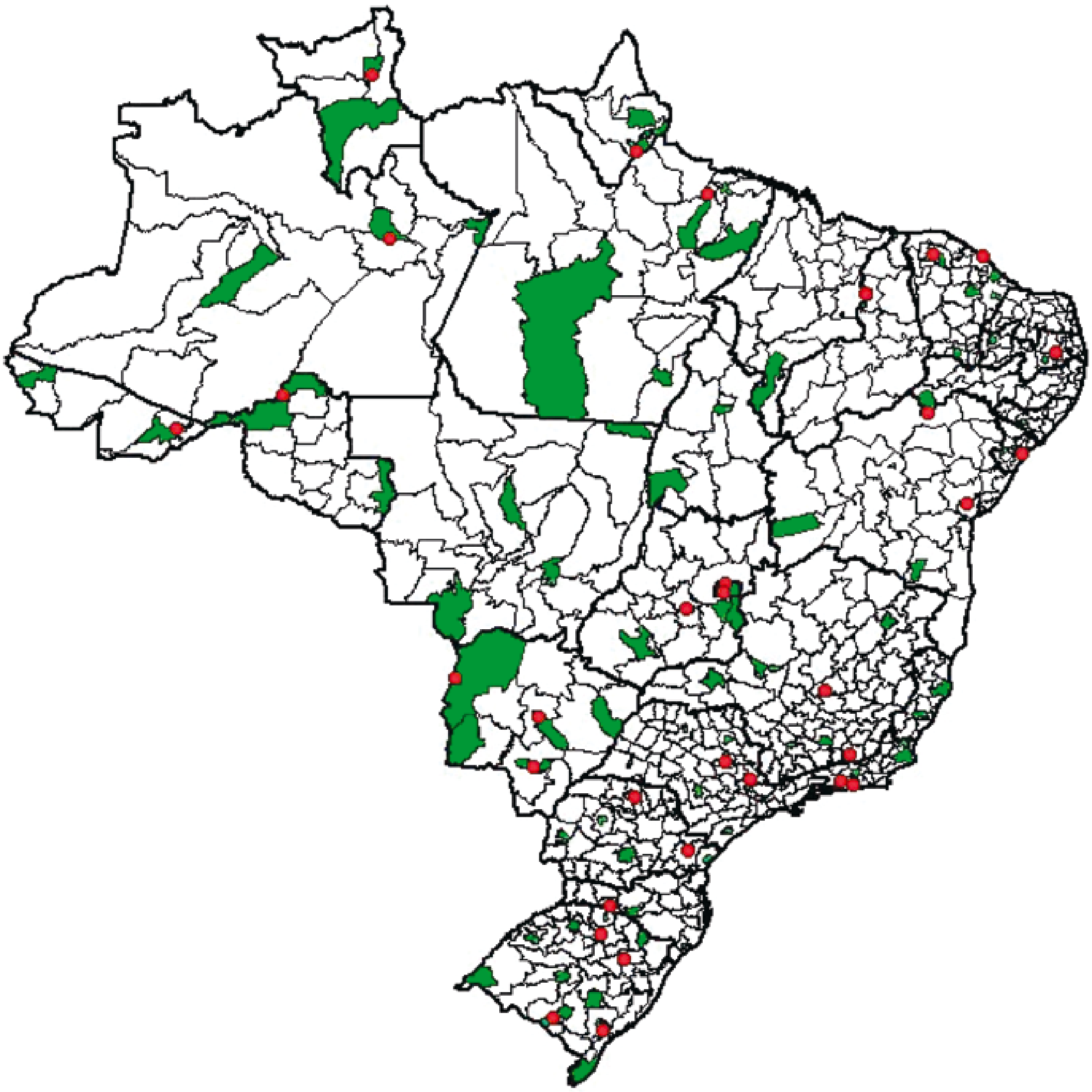
4.4.1. ARGENTINA

The surveys in Argentina were developed under the responsibility of the Experimental Stations of INTA - Instituto Nacional de Tecnología Agropecuaria, except for some cases in which they were carried out by the Extension Agencies. The surveyors consisted of INTA personnel and in general, economists or extension agents. A total of 402 farmers were interviewed.



4.4.2. BRAZIL

The initial forecast was to conduct 600 surveys but thanks to the support received from the Embrapa (Brazilian Agricultural Reserch Corporation) centers involved, as well as to the financial support of other Embrapa projects, it was possible to collect data from 720 farms. Below is a Brazilian map with the location of the surveys (in green) and the Embrapa centers that supported the data collection process (in red). The map shows that the surveys on climate change carried out in Brazil were well distributed given the diversity of the climatic regions of the country.

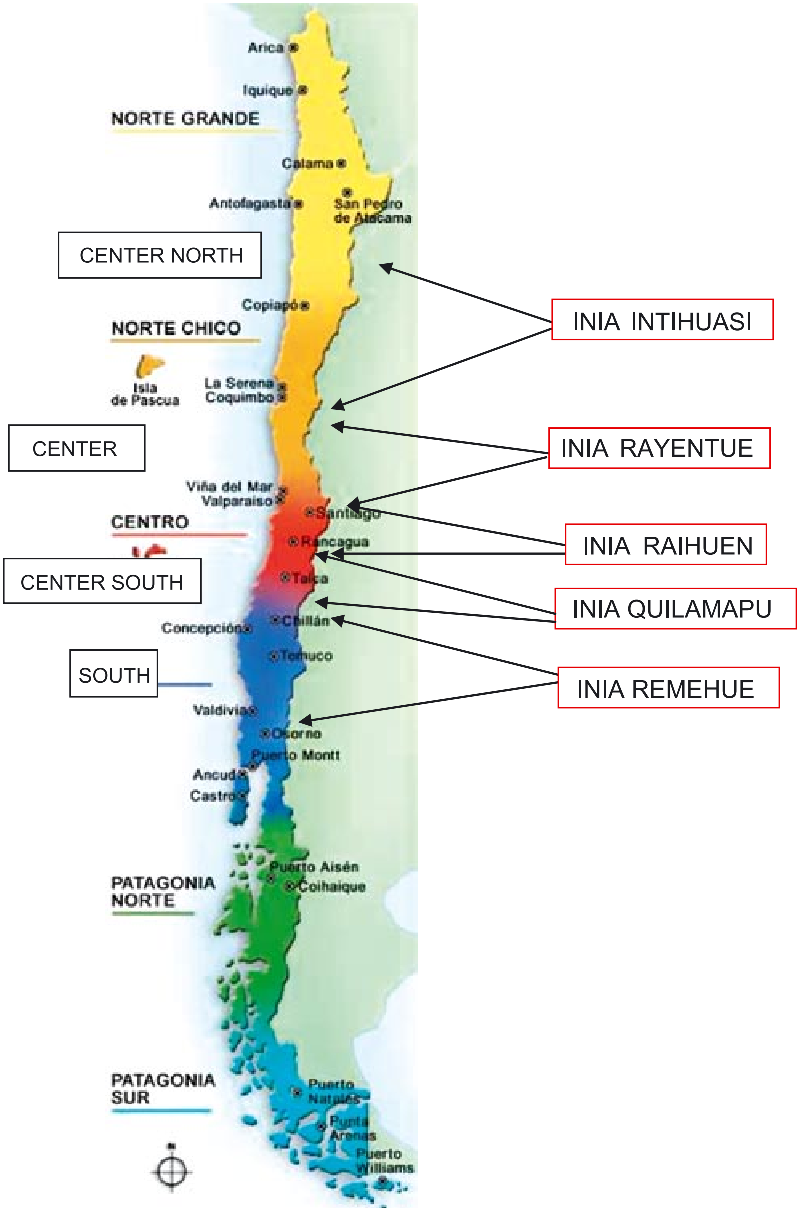


4.4.3. CHILE

Various Regional Centers of INIA Chile (Institute of Agricultural Research) were involved in the data collection process of the climate study. The Regional Center leading the surveys was INIA Quilamapu, which is located in the VIII Region (Southern-Central region).

All the producers surveyed were members of the National Program of Technological Transference Groups (GTT) of INIA. Approximately 80% are considered to be family agriculture farmers, while the remaining 20% are medium-size commercial farms. Each GTT has 12 to 15 farmers and is coordinated by an INIA professional.

Farmers from seven Chilean Regions were interviewed, from the Northern macro-areas to the small Central, Southern and Southern-Central areas, thus encompassing practically the totality of Chile's traditional agriculture, crops and bovine production (dairy and meat). Therefore, practically the whole agricultural zone of the country was taken into account, with the exception of Patagonia.



4.4.4. ECUADOR

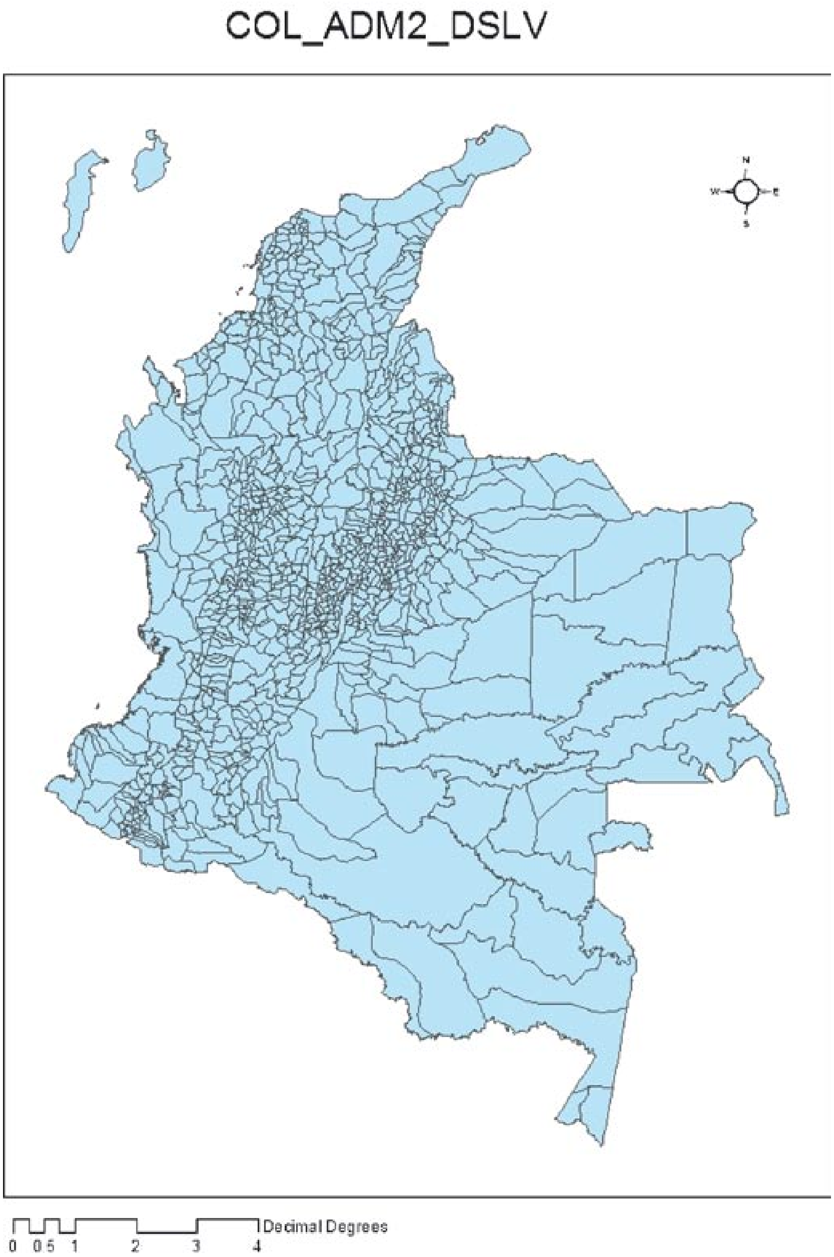
The surveys in Ecuador were developed under the responsibility of the National Institute of Farming Investigations (INIAP). A total of 291 farmers were interviewed, covering the most important climate zones of the country. See climate map below.

4.4.5. COLOMBIA

The study in Colombia was developed under the responsibility of CORPOICA - Coorporación Colombiana de Investigación Agropecuaria (Granados, Baquero, Gomez & Gomez, 2006). The sample was stratified according to the main crop areas and production zones.

The 386 surveys in Colombia were distributed along the municipalities of greater importance regarding agricultural production, according to type of crop or livestock production.

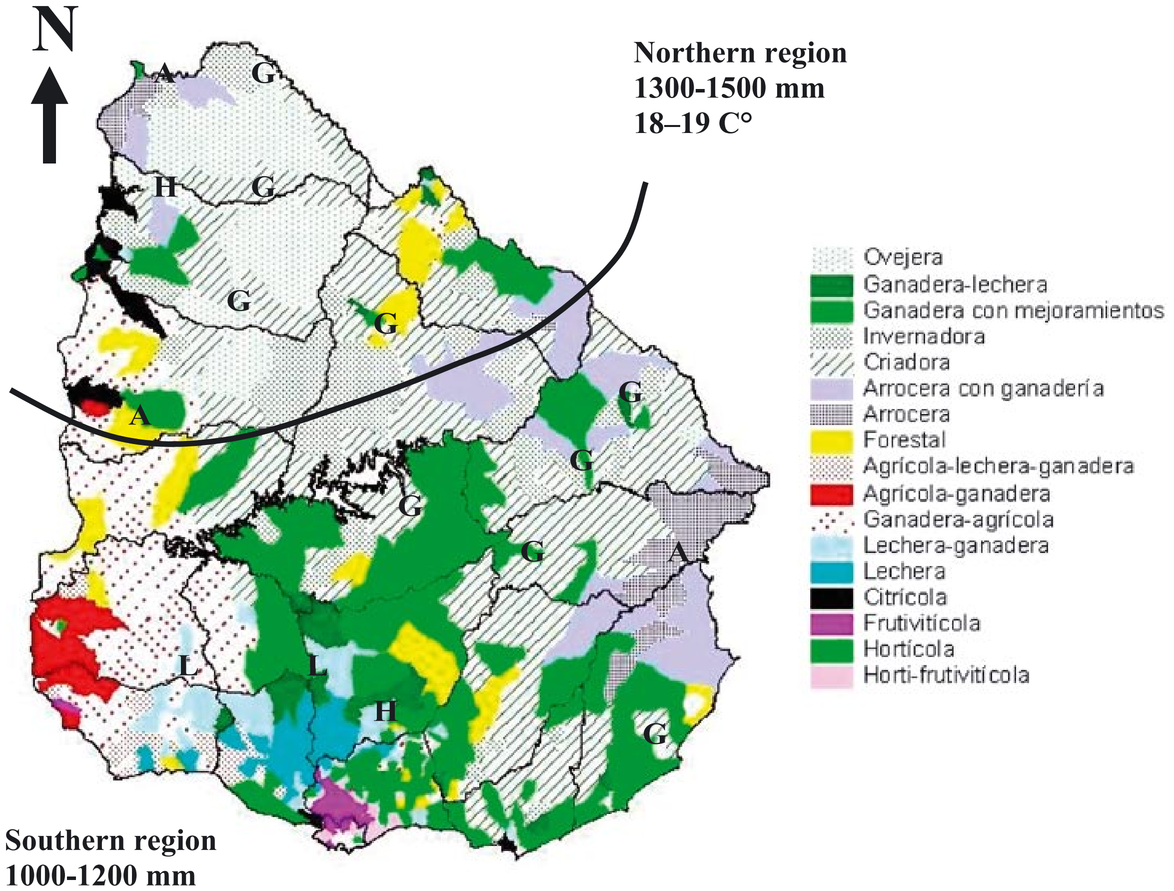
Likewise, they show the vast diversity of the country in relation to the different productive aspects: climates, cultures, size of property, automation, connection to the international markets, etc. Thus, there are nearly 1,000,000 cultivated hectares of coffee, the main Colombian crop. It is typically cultivated by small farmers with high levels of automation, in contrast to the large beef cattle farms to the east of the country which have low levels of productivity per hectare.



4.4.6. URUGUAY

The survey data in Uruguay was collected by INIA (National Agriculture Research Institute) in its two main climate regions: 1) to the north of the country where there are higher temperatures and rains; and 2) to the south of country where lower temperatures and less rains are recorded.

The 175 farms surveyed are distributed all over the country (see map) and the size and geographic distribution of the sample was considered adequate for the purpose of this research. Although only 5% of the interviewed individuals considered themselves as non-commercial farmers a later analysis considering farm size and production type allowed to categorize 36% of the farms as small farms, with an average size of 497 hectares. The remaining 64% were classified as medium and large commercial farms, with an average size of 818 hectares.



Fuente: MGAP-DIEA, Censo General Agropecuario 2000.

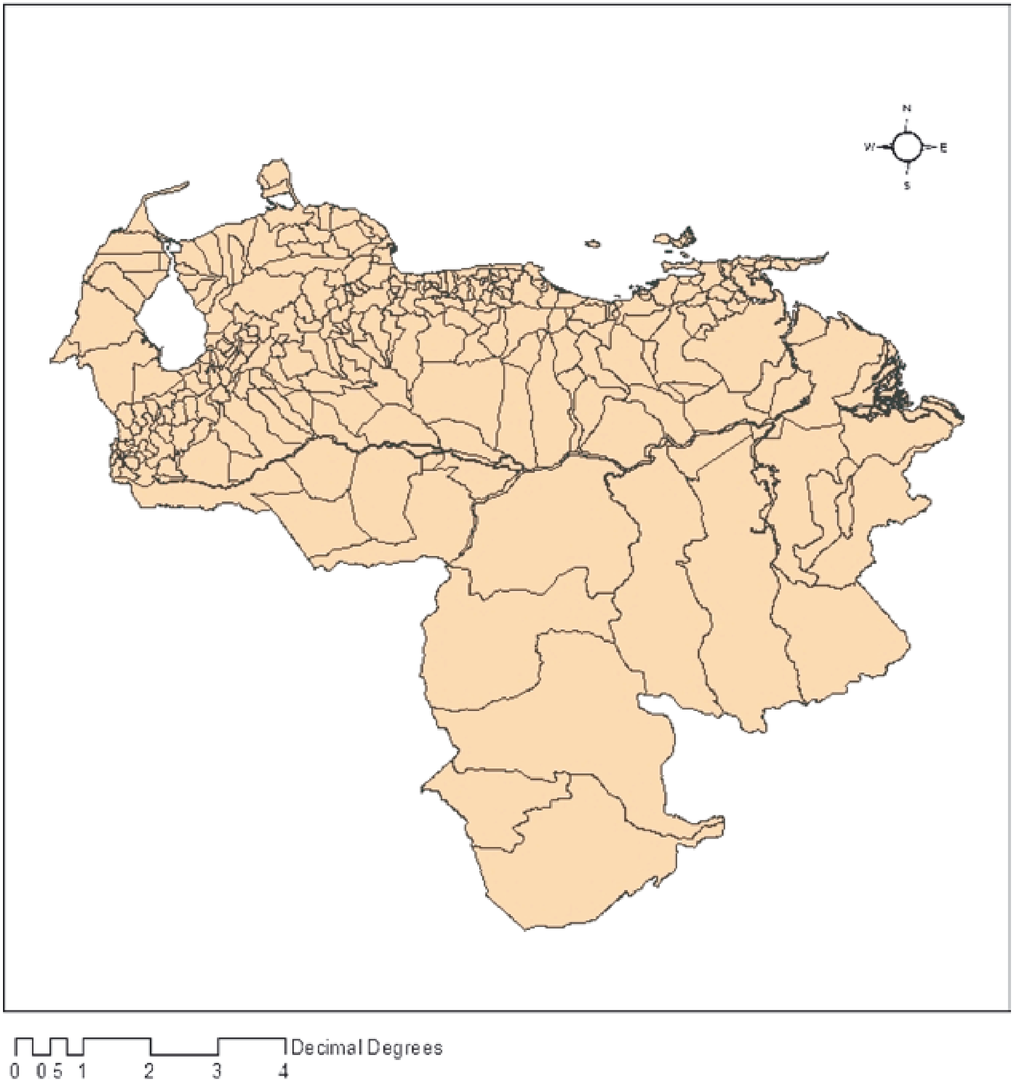
4.4.7. VENEZUELA

Surveys in Venezuela were executed with the support of the research centers of the INIA - Instituto Nacional de Investigaciones Agrícolas. The country's six climatic regions were covered by a total of 297 questionnaires.

Samples in Venezuela were taken in the areas where small farms were the predominant typology at the agricultural production units. Large commercial farms or enterprises intended for agribusiness (cereals, meat, dairy) were detected only in productive areas oriented towards agribusiness.

The data were then coded and analyzed. Several tests were run to see if the observations were internally consistent. Errant data were recoded when correctable or treated as missing. Net revenues could be inferred from the available data.

VEN_ADM2_DSLV



4.5. CLIMATE SCENARIOS

Sophisticated models of oceans and atmospheres have been developed to forecast the consequence of rising greenhouse gases on future climates across the globe. This study relies on three models to provide a range of forecasts of future climates that are plausible over the next century: the Canadian Climate Centre (CCC) (Boer *et al.*, 2000), the Center for Climate Study and Research (CCSR) (Emori *et al.*, 1999), and the Parallel Climate Model (PCM) (Washington *et al.*, 2000). The CCC models predicts average warming of 5˚C, the CCSR model predicts warming of 3˚C, and the PCM model predicts warming of 2˚C by 2100 for Latin America. The three models also provide a range of precipitation forecasts from a slight decrease for CCC and CCSR and an increase for PCM. This range of outcomes mirrors the range of forecasts by the Intergovernmental Panel on Climate Change (IPCC) for 2100 (Houghton *et al.*, 2001). The three scenarios provide policy makers with a sense of what would happen depending upon how global warming unfolds. We look at changes in 2020, 2060, and 2100.

For each climate model, we sum the predicted monthly climate change in each grid cell weighted by population to generate a country level forecast of climate change. The country level forecast of temperature is added to the actual temperature in each district. The country level forecast of percentage precipitation change is multiplied by the actual precipitation in each district. This process gives district specific forecasts of temperature and precipitation in each period. The climate changes are consequently not uniform across the region and vary by model.

5.1 COUNTRY RESULTS

5.1.1. ARGENTINA[1]

The Ricardian analysis of climate change in Argentina developed by Lozanoff and Cap (2006) demonstrates the existence of a strong correlation between net revenue and climatic variables. More specifically, the strong dependence of winter temperature and summer precipitations on the dependent variable is evidenced.

At the level of small and commercial producers the varying influence of the climatic variables was demonstrated on each type of farmer. It is observed that the curve of land value based on temperature presents optimal features at 15ºC for large producers, whereas the same curve is optimum at 17.5ºC for small farmers. This seems to indicate a greater capacity of large producers to adapt to the climatic change as the optimal curve practically reflects the average temperature of the sample. It can be observed that small producers present more elasticity before the change of climatic variables, but also that their optimal conditions are displaced in regard to the average, which indicates a lesser capacity of adaptation to this change.

Of the three raised scenarios, the PCM model practically does not indicate a trend of change, it is slightly incremental for the large producers and slightly decreasing for the small ones. What can in fact be observed is a marked difference between the evolution of both types. The second scenario (CCSR), of moderately severe conditions for the climatic change, presents a decreasing trend for both sub-samples, with a smaller marked difference between both types of farmers. By the end of the 21st century there will probably be a reduction of land value in the order of 20%. The third scenario (CCC), of severe change conditions, is the one that shows greater change trends, in both cases decreasing to similar rates, with a difference between both sub-samples favorable to large producers. At the end of the 21st century the reduction will be in the order of 50%.

Regarding the irrigation mechanism for adaptation to the climatic change, it can be observed that the temperature increase entails a fast adaptation of irrigation, whereas in the case of precipitation variations their decrease causes a fast adoption of irrigation mechanisms, and their increase slightly diminishes the probability of adoption of irrigation mechanisms.

5.1.2. BRAZIL[2]

The Brazilian study (Avila, Irias and Lima, 2006) estimated separate regressions for small and large farms. The results for small and large farms indicate that winter temperatures have the expected hill-shaped relationship with land value but that summer temperatures have a U-shape. The lowest land value for large farms was at 30˚C so that generally large farms located in warmer places had lower values. However, the lowest land value for small farms was recorded at 24˚C so that generally small farms located in warmer locations had lower values only up to a point. Precipitation had no incidence on the land values of large or small farms in the Brazilian sample.

1 - Synthesis based on the Argentinian paper: LOZANOFF, J & CAP, E. 'El Impacto del Cambio Climático sobre la Agricultura Argentina: Un Estudio Económico'. (The Impact of Climate Change on Argentinian Agriculture: An Economic Study). INTA. Buenos Aires. September 2006. 23p.

2 - Synthesis based on the Brazilian paper: AVILA, A. F. D; IRIAS, L. J. M & LIMA, M. 2006. Impact of Climate Change on Brazilian Agriculture. Embrapa, Brasilia. November 2006. 23p.

The analysis of the Brazilian surveys shows that 537 of the farmers informed that they perceived climate changes in the last years and 53.2% of them perceived changes in the periods and amounts of rain. Farmers also perceived changes in temperature (43.3%). The main adaptations consisted of changing the sowing date and using more resistant varieties (24.5 and 20.1%). One third of the interviewed Brazilian farmers indicated that lack of funds is the main obstacle to adapt to the climate change. The two other important difficulties were lack of water for irrigation and of technical orientation (15.9 and 11.2 %, respectively).

The best scenario in Brazil with AOGCM estimates is expected if the scenario generated by the PCM model would occur. The aggregate impact would be positive in 2020 (plus 15%) for small and commercial farmers (7 to 31%). The situation would be worse in this same scenario in 2060 and 2100 but better that expected compared to the other two scenarios. The worst scenarios for Brazilian land values in 2060 and 2100 are expected if the temperature and precipitation move in the magnitude estimated by the CCC model. The negative changes on land values at aggregate level would be between 19% and 38%, for small scale farmers 9% to 31% and for commercial farmers 47 to 80%.

In this context of climate changes and due to the serious effects expected on farmers given by the AOGCM scenarios for the next decades, the Brazilian Government should adopt policy measures to mitigate these impacts on the agricultural sector. The policy recommendations should be oriented to minimize the negative effects of changes in winter temperatures on small farmers. In the case of commercial farmers, these policies should try to mitigate the expected negative effects of changes in the precipitation levels during the summer.

At the agricultural research level, the Embrapa experience with its soybean breeding program during the 70-80's, which consisted of developing varieties for tropical regions (>4ºC warmer than temperate regions), should be expanded to other crops. Varieties that are more resistant to warm temperatures combined with technological innovations, such as irrigation, can minimize the effects of the temperature increase on the traditional production systems generally adopted by small farmers.

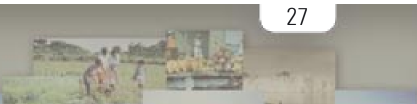
5.1.3. CHILE[3]

The Ricardian analysis of the climate change in Chile has shown that the variables of temperature and precipitation in summer and spring are the most important to explain changes in land values (González & Velasco, 2006). Other explanatory variables like farm experience, slope of the ground and soil texture do not make significant contributions to the explanatory power of the model.

These results are consistent with the "known" agricultural scenario for the country, because given its agro-climatic characteristics, factors as spring precipitation are extremely decisive in the viability of production systems in certain localities or soil types. As to the existence or not of a given system, aspects as the intensity of the agricultural use of the soil, feasible crops and expected yields are visualized as highly determining of the expectations of soil use capacity and therefore of its value in the market.

Given the characteristics of Chilean agriculture the analysis was made considering irrigated and non-irrigated fields. Both situations are important in the national distribution of agricultural area. Additionally, the characteristics, type of production systems and expected yield of the same are significantly influenced by this condition. Clearly it also strongly influences the land value.

3 - Synthesis based on the Chilean paper: GONZALEZ, J. & VELASCO, R. "Cambio Climático en sistemas agrícolas de Chile: I: Evaluación Preliminar del efecto de variables de clima sobre el valor económico estimado del suelo" (Climate Change in Chilean agricultural systems: I: Preliminary Assessment of the effect of climatic variables on the estimated economic value of the soil). INIA, Quilamapu. November 2006, 21p.



Some authors have observed that the highest land values are found in localities with moderate temperatures that fluctuate between 7ºC and 11ºC. Otherwise, the results showed that high land values were associated to average moderate precipitations that fluctuate in periods of three months, between 50 and 90 mm. Localities with higher precipitations present lower land values. This coincides with the situation observed in the south of Chile when compared to zones located more to the north of the country.

5.1.4. COLOMBIA[4]

The results of the application of the Ricardian model in Colombia showed that when faced to climate change, producers adapt their production systems instead of abandoning their land (Granados *et al*., 2006). In times of significant droughts it is expected that they implement irrigation systems, diminish the intensity of land use, change agriculture for cattle raising and/or change to other crops or varieties. This also happens in connection with increases in temperature, when one expects crops or varieties to be modified. Colombian farmers showed that they feel they have no options in the short term although some have applied rotational methods and introduced changes in the technology they use. The following factors are important in the long term: irrigation, changes of crops and varieties and works in order to obtain and regulate water such as reservoirs or wells.

The results of the application of the Ricardian method in Colombia show that the land values depend on climatic variables such as precipitation and average temperature, on technological advance and information (Internet), population density and soil quality. When one separates large producers from small farmers the results indicate that precipitation is not statistically significant for commercial farmers.

4 - Synthesis based on Colombian paper: GRANADOS R, J.; BAQUERO IR.; GOMEZ, M. R. & GOMEZ, F. Efectos del Cambio Climático Global en la Agricultura Colombiana (Effects of the Global Climatic Change on Colombian Agriculture). CORPOICA. Bogotá. October 2006.

The simulation model sample at the level of the Colombian territory demonstrates an important effect of the climatic change on the price of land. It also indicates a very serious effect on the productive capacity of the Colombian agricultural sector. In fact, in the most serious of the possible predictions, up to 94% of the production could be lost. It must also be noted that an increase in rains would have negative effects on the value of the Colombian agricultural production, whereas a decrease would have a favorable effect on it. Due to its high level of precipitations there are serious problems of pests and diseases which would be reduced if the rains should decrease.

The effect is much more significant on small farmers who would lose a lot when temperature increases. On the contrary, variations in precipitations, either an increase or a decrease, would enhance their production. Large producers, on the contrary, would benefit from the climatic change when temperature increases, and as land values do not depend on the precipitation levels they would not be affected by changes in this variable.

These results are worrying because large producers have better financial standing and management to make investments which, like irrigation, can allow them to better adapt to the climatic change. Small farmers will suffer a larger income and patrimony reduction which represents a challenge to their vulnerability and survival capacity. Also they have soil conditions, such as rugged slopes, that prevent the technical installation of irrigation systems.

It is important to point out that producers consider that technological change, new varieties more resistant to droughts and change of crops are important alternatives to productively face the approaching climatic change. This makes it more urgent to emphasize research on soil and water management as well as new varieties and crops that are more resistant to high temperatures and severe droughts or water excess.

5.1.5. ECUADOR[5]

The study collected data from farmers in representative climatic zones across Ecuador (Jativa and Niggol, 2006). A sample of small-scale and commercial farms was gathered totaling 291 establishments. At most farms the person in charge was a man and also most had electricity. The average age of farmers was 52 and they had 9 years of schooling.

Land values in Ecuador are highly dependent on soil type. Some soils are positively correlated with land value while others are negatively correlated. Land values also depend on climate variables such as summer/winter temperature and precipitation. Estimated land value charts are hill shaped for a range of annual mean temperature for both small and large farms. For annual precipitation land values are U shaped for small farms, but there is an almost linear increase for large farms.

A small increase in the annual mean temperature will result in a small damage to small farms, but in a small gain to large farms. The harmful summer temperature increase is offset by the beneficial winter temperature increase. A small increase in the annual mean precipitation level will lead to a substantial loss to small farms. A harmful effect of the winter precipitation increase is offset, although to a low degree, by a summer precipitation increase.

The prediction of the impacts of the climate change using three climate scenarios showed that small farms and large farms will lose half of their income by 2100 if a hot and dry scenario such as CCC becomes true. On the other hand, small farms and large farms will gain from warming with a moderate increase in temperature and a moderate increase in precipitation such as PCM in 2020. The impact will amount to a 60% loss of income as a maximum and to a minimum 50% gain of income for large farms by 2100. Small farms are more vulnerable to higher temperatures, whereas large farms are more sensitive to an increase in precipitation.

Policy makers need to pay attention to the findings of this paper, which predicts that agricultural income will be reduced by half at the end of this century. Given that the country largely depends on the support of agricultural production, the climate will impose a significant burden on farmers and on the public in general. Further studies of possible measures to reduce these harmful effects should be implemented.

5.1.6. URUGUAY[6]

The study developed by Lanfranco and Lozanoff (2006) shed some light over the potential economic effects of global warming on the Uruguayan agricultural sector. A Ricardian model was used to determine the potential effects of the climate change on agricultural production in terms of productivity gains and losses. The marginal contribution of temperature and precipitation changes to land values, used as a model for productivity, was measured and the results corresponding to both commercial and non-commercial farms were presented.

These results suggest that changes in both temperature and precipitation affect productivity and therefore land value. The effects would probably be different according to the type of production entity. Although the magnitudes would be different in the presence of different possible future scenarios, the effects are expected to derive in net losses for producers.

According to the results obtained in this research, commercial farms appear to be more sensitive to climate changes; this suggests that small non-commercial farmers could adapt better to changing climate conditions.

5 - Synthesis based on the Ecuadorian paper: JATIVA, P. & NIGGOL, S. Efecto del Calentamiento Global en la Agricultura Ecuatoriana: Evaluacion del Impacto Económico Sobre el Valor de la Tierra (Effect of the Global Warming on Ecuadorian Agriculture: Assessment of the Economic Impact on the Value of Land). INIAP & University Aberdeen. Quito, Dec. 2006. 33p.

6 - Synthesis based on the Uruguayan paper: LANFRANCO, B & LOZANOFF, J. Economic Impact of Global Warming on the Uruguayan Rural Sector. INIA. Montevideo. October 2006. 15p.

In any case, this is the first study carried out for the Southern region of South America and conclusions should be managed with caution. More research is necessary in order to confirm and confidently rely on these results.

5.1.7. VENEZUELA[7]

There are 297 farms in the total sample taken in Venezuela (Pacheco, Caraballo & Niggol, 2006). The most common are small family farms. Large commercial farms are present only in the most productive areas. These large farms are engaged in cereals, meat, and dairy production. Farms in Venezuela recorded the lowest average land values of all the survey countries.

In order to analyze the vulnerability of Venezuela's agricultural production to global warming the authors regressed farm land values against exogenous variables such as climates, soils, and socio-economic variables. Assuming that climate sensitivities do not change over time, they predicted climate change impacts for the century to come.

Farming activities in Venezuela are revealed to be sensitive to climate variables. Socio-economic variables and different soil types are also important determinants of land values across the country. Farms using technology have a higher land value. Farms on mixed soils are preferred to those on clay soils.

Land value is related to summer temperature in a hill-shaped quadratic function and with summer precipitation in a U-shaped quadratic function. Winter temperature and precipitation are also significant. It is predicted that a small increase in temperature may harm agricultural productivity therefore reducing land value. A small increase in precipitation is also thought to reduce land value.

7 - Synthesis based on the Venezuelan paper: PACHECO, R. CARABALLO, L. & NIGGOL, S. Global Warming and Agriculture in Venezuela: An Economic Valuation. INIA Venezuela & University of Aberdeen. Caracas, Dec. 2006, 22p.

The analysis of the impacts of the climate change on Venezuelan agriculture was based on the three AOG Climate Models: CCC, CCSR and PCM. The simulation indicates that the climate change will harm as much as 100% of the farmers in Venezuela by the end of this century. It was revealed that a temperature increase would be very harmful to agriculture. In earlier years, a significant reduction of precipitation is likely to damage current agriculture significantly.

In terms of climate policy, the results reasserted that a warming climate will mean significant stress to farming in the developing countries. Regardless of farm size, agricultural productivity is expected to drop significantly due to warming. The results also show that a dramatic reduction in the precipitation levels predicted within the PCM scenario is likely to cause significant damage to agriculture.

5.2 REGIONAL STUDIES

5.2.1. RICARDIAN STUDY

The Ricardian analyses of land value reveal that farm values vary across the landscape with climate. As can be seen in **Figure 2**, the estimated relationship between land value and temperature is hill-shaped. Farm properties are highest in temperate climates and decline as temperatures increase towards tropical climates. Because the average farm in Latin America is slightly to the right of this hill, slight warming will cause farms to fall in value. **Figure 3** displays the results for precipitation and land value. Precipitation has a U-shape implying that more precipitation is beneficial and less is harmful.

Figure 2 also shows that small farms and large farms have similar responses to temperature. Despite concerns that small farms may be more vulnerable to warming, the analysis implies that their temperature sensitivity is almost the same as large farms. However, small farms do have different precipitation response functions compared to large farms. **Figure 3** shows that more precipitation is beneficial to both small

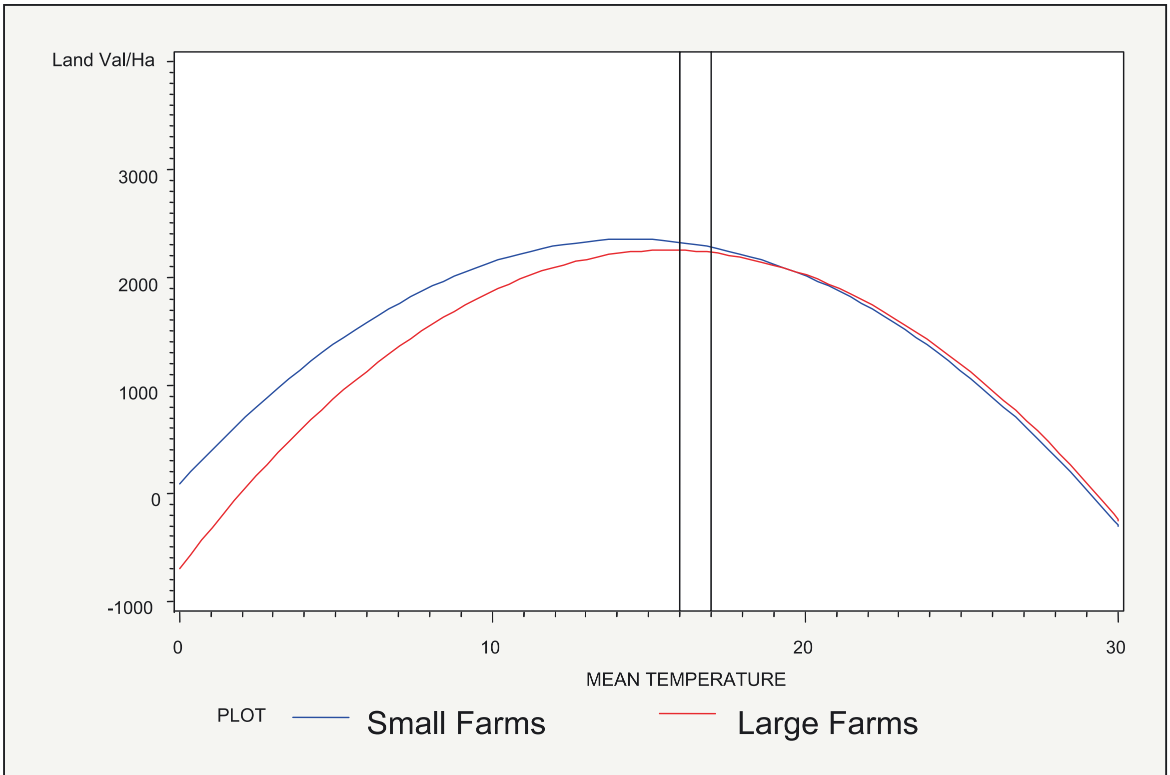


Figure 2. Estimated Response of Land Values of Small and Large Farms to Temperature

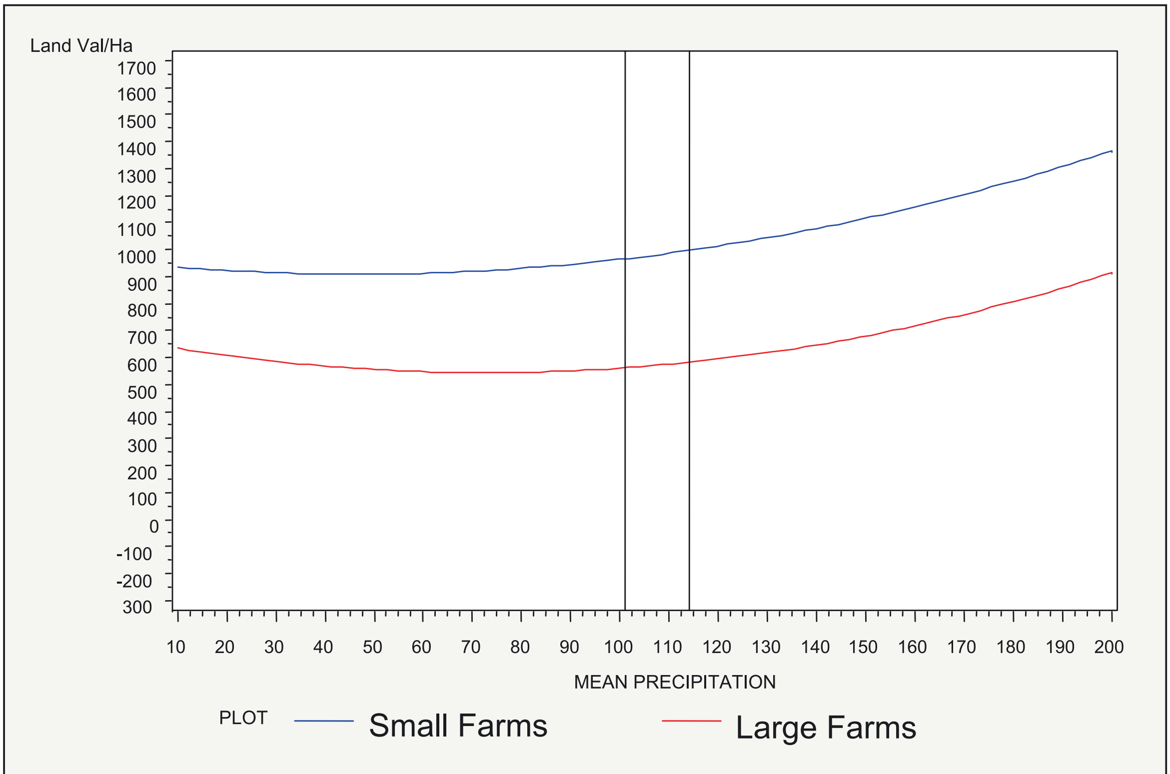


Figure 3. Estimated Response of Land Values of Small and Large Farms to Precipitation

and large farms. Small farms have higher values per hectare but the same shaped response function. The higher value per hectare reported by small farms may be due to the fact that own labor is not measured.

The study also tests the relationship between climate and annual net revenue. The results from the Ricardian analysis of net revenues are very similar to the results from the land value analyses. The temperature responses are hill-shaped and the net revenues of small farms peak at the same temperature (16˚C). However, the net revenues of large farms peak at (8˚C) which is a much cooler temperature than the land value results.

Separate analyses were also conducted of dryland versus irrigated farms. Dryland and irrigated lands react differently to temperature and precipitation. Dryland farms are very sensitive to summer temperatures. The land values of large and especially small farms are much lower in places with higher summer temperatures. The land value of small irrigated farms do not respond to summer temperature and the land values of large irrigated farms are higher in places with warmer summer temperatures. Warmer winter temperatures are associated with higher land values for small dryland farms but lower land values for both small and large irrigated farms. Summer precipitation has a consistent beneficial effect across farm types especially for large irrigated farms. Places with more winter precipitation reduce the land values of large dryland farms and small irrigated farms but increase the land values of large irrigated farms. Irrigation clearly allows crops to tolerate regions with higher temperature. But irrigation is often applied in places with very low precipitation so that actual irrigated farms are often more profitable with more precipitation.

5.2.2. INTEGRATED FARM MODEL

The Integrated Farm Model examines the decision of whether a farmer will grow crops, livestock or both and whether the farmer will adopt irrigation (Mendelsohn and Seo, 2006). For each of these farm types, the model estimates how land values are affected by climate. In contrast to the Ricardian model, the Integrated Farm Model makes the adaptations of each farmer explicit. Cross sectional data is used to test whether farmers in warmer or wetter places make different choices than farmers in cooler or dryer places. Specifically, models are developed to test whether the choice of adoption of crops, livestock, or both crops and livestock depends on climate. The results from these models revealed that the farm type does depend on climate. Farms located in wet temperate settings tended to grow crops alone. Farms in dry locations tended to raise livestock. Farms in hot locations opted for a combination of livestock and crops. The type of farm is therefore one of the most basic adaptations a farmer can choose.

Another important adaptation available to the farmer is irrigation. In earlier Ricardian analyses, irrigation was treated as though it were exogenous, beyond the choice of the farmer (Schlenker *et al.*, 2005; Seo and Mendelsohn, 2006c). However, regressing the choice of irrigation on climate reveals that irrigation is endogenous, farmers choose irrigation depending on the climate (as first found in Africa by Kurukulasuriya and Mendelsohn, 2006a). For example, looking at crop-only farms, farmers are less likely to choose irrigation if the farm is located in a hot climate. Although irrigation water can compensate for higher temperatures, crops perform more poorly at high temperatures. Farmers do not want to invest the high fixed cost of irrigation into marginal crop lands. Farms in locations with higher precipitation are also less likely to choose irrigation. Again, the marginal contribution of irrigation falls as precipitation increases. Farmers do not need irrigation in places with high precipitation. The results for the crop-livestock farms are similar but less significant.

Examining the land value regressions specifically for each land use reveals that the different farm types react to climate differently. Warmer temperatures are especially hard on crop-only dryland farms and livestock farms. Latin American livestock operations depend heavily on beef cattle which tend to be heat sensitive. Dryland crop farms are sensitive to heat because they tend to be located in warm places and have little substitution possibilities. In contrast, irrigated farms and crop-livestock farms have a great deal of substitution possibilities to compensate for heat and therefore are much less vulnerable. Additional precipitation is beneficial across all farm types but especially to irrigated crop-only farms and livestock farms. These farms are located in especially dry places where additional rainfall is especially beneficial.

Applying these cross sectional models to future climate scenarios, reveals that future impacts depend heavily on the climate scenarios (see **Table 4**). If one uses a mild warming and wet scenario such as PCM in 2100, the damages in the future are relatively small with losses of 15% of land value or net revenue. However, if one uses a severe warming scenario that is dry such as CCC in 2100, the damages in the future could be high as a loss of 62% of land value or net revenue. Clearly these large impacts would be quite a blow to agriculture in Latin America.

The impacts, however, are not expected to be uniform. We graph the expected effect for all Latin American countries (Western Hemisphere south of the United States). Although the projection is outside the sampled countries, there is reason to believe that all the countries in the region share common cultural and technological backgrounds. The impacts to each district depend on the initial climate and the country specific climate change scenario. **Figure 4** displays the predicted impacts to the land values of small farms if the PCM 2100 scenario occurred. The model predicts overall benefits to the region but losses in Central America and northern South America. In comparison, **Figure 5** looks at the impact of CCC on small farms. CCC is generally harmful to the region but some regions such as the Amazon and northern Argentina and especially Bolivia and Paraguay are damaged the most. However, even with this generally harmful scenario, there are farms in Peru and southern Argentina that benefit.

Table 4. Impacts of Climate Change on Latin American Farmland Values

Climate Scenarios	Large Farms	Small Farms
Baseline	1135	1728
	2020	
CCC	-173 (-15%)	-272 (-16%)
CCSR	-154 (-14%)	-223 (-13%)
PCM	-61 (-5%)	13 (+1%)
	2060	
CCC	-373 (-33%)	-570 (-33%)
CCSR	-248 (-22%)	-387 (-22%)
PCM	-138 (-12%)	-121 (-7%)
	2100	
CCC	-702 (-62%)	-1060 (-61%)
CCSR	-397 (-35%)	-617 (-36%)
PCM	-191 (-17%)	-228 (-13%)

Note: Values are in USD/ha. Percentage changes are in parentheses.

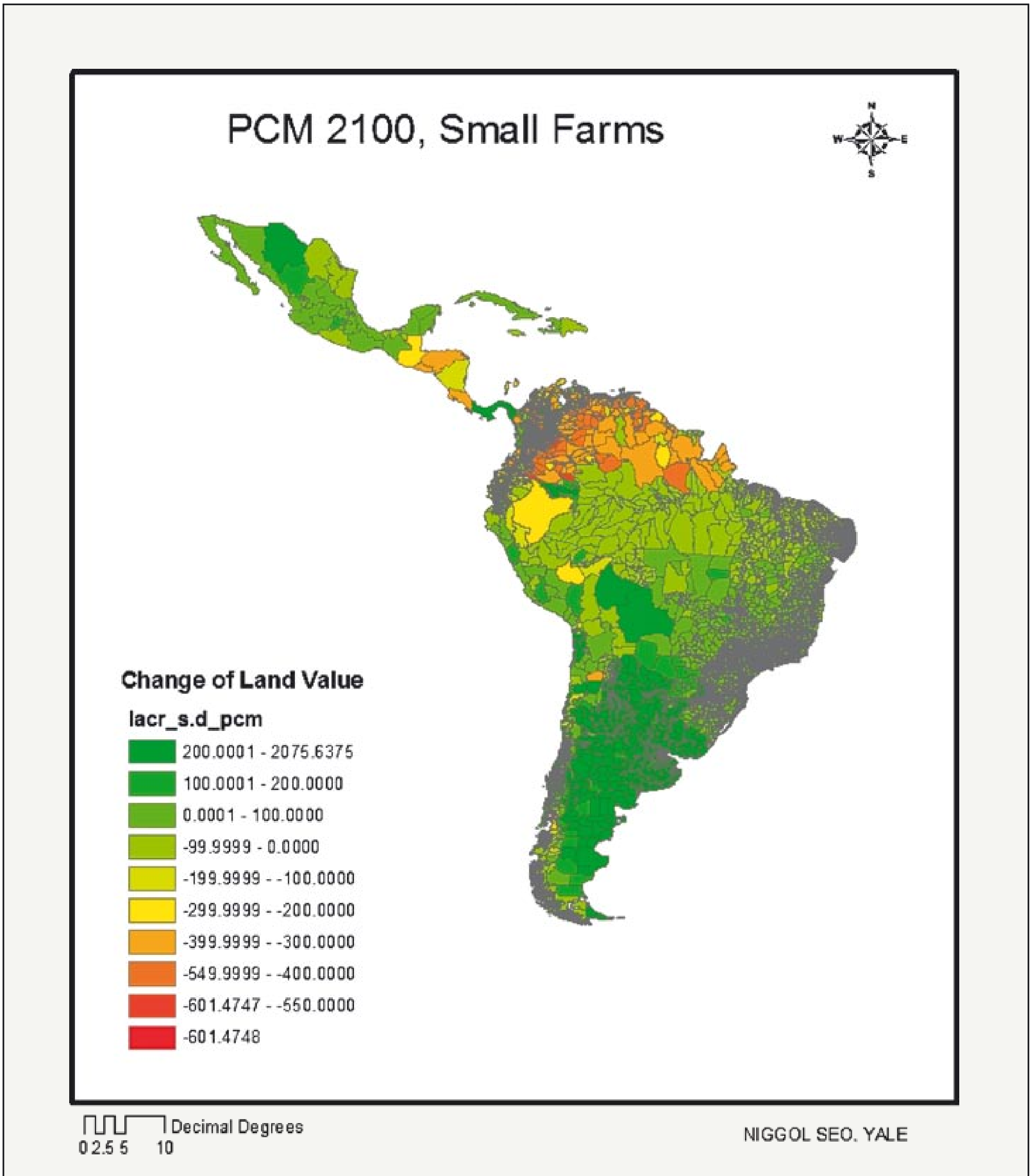


Figure 4. Impact on Farmland Values of the PCM 2100 Climate Scenario.

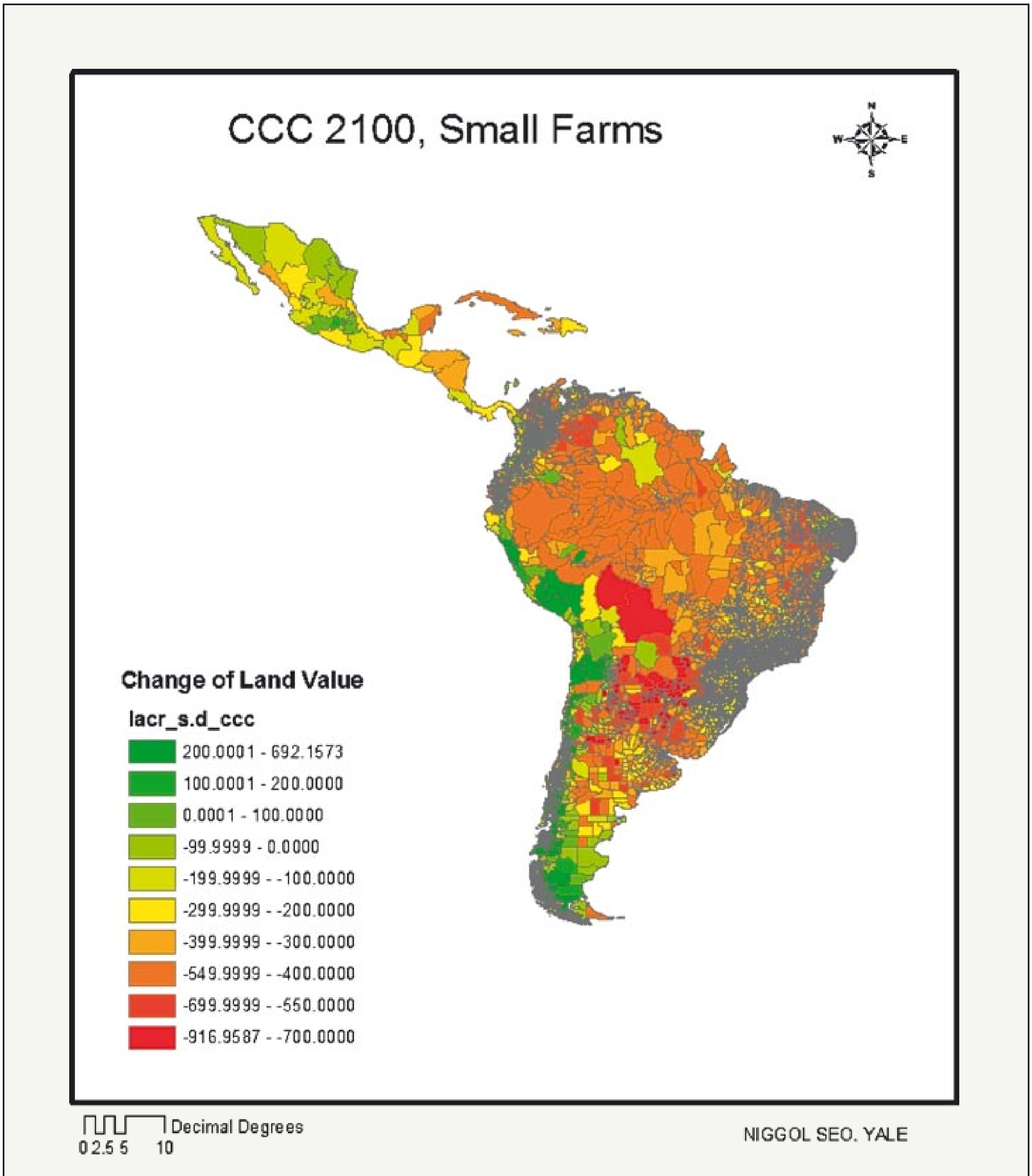


Figure 5. Impact on Farmland Values of the CCC 2100 Climate Scenario.

The effects are similar but not identical for large farms. **Figure 6** examines the effect that the PCM scenario has on the land values of large farms. There are damages in Panama and northern South America but in general, the effects of PCM are beneficial to most farms in the region. With the CCC scenario, however, most large farms are damaged (see **Figure 7**). The harmful effects are greatest in Bolivia and Paraguay. However, even in this scenario, some farms increase in value. Farms in Peru, Argentina, and Chile all benefit from CCC.

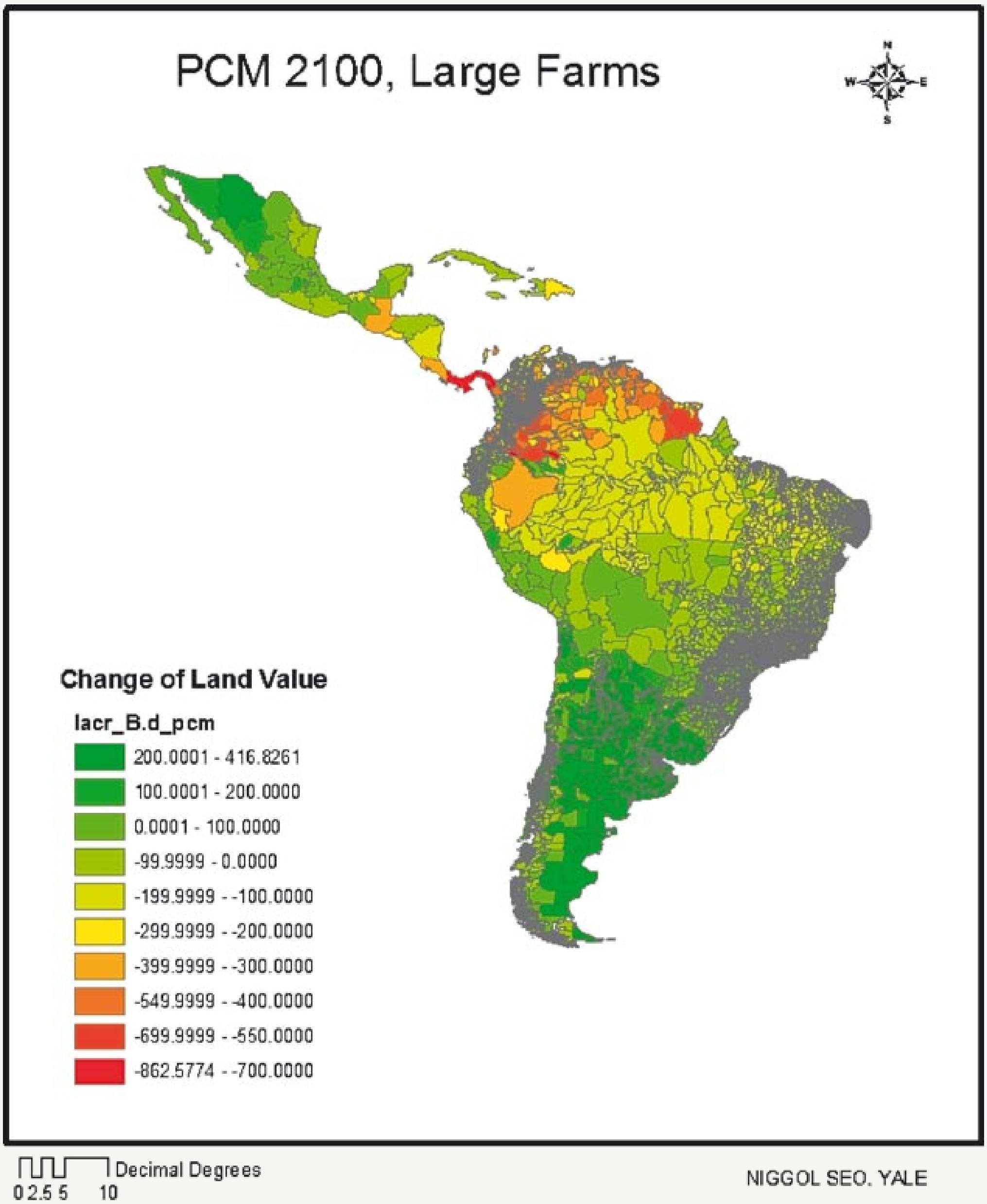


Figure 6. Impact on Farmland Values of the PCM 2100 Climate Scenario.

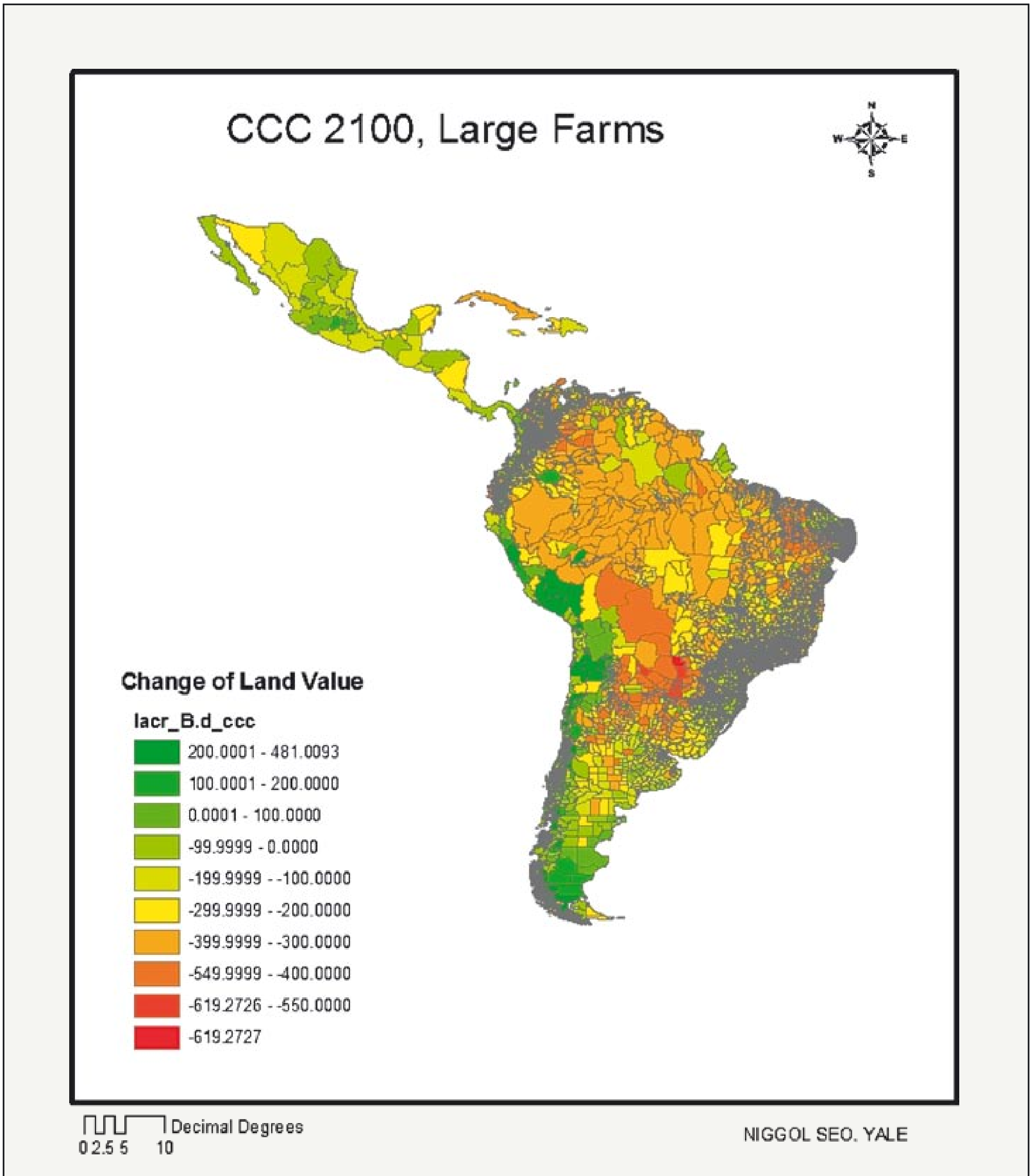


Figure 7. Impact on Farmland Values of the CCC 2100 Climate Scenario.

5.2.3. CROP CHOICE STUDY

This paper explores how Latin American farmers adapt to climate by changing crops (Seo and Mendelsohn, 2006d). Estimating the model across over 2000 farmers in seven countries, the study finds that both temperature and precipitation affects the crop species Latin American farmers choose. For example, farmers choose fruits and squash in warmer locations and wheat and potatoes in cooler locations. Farms in wetter locations are more likely to grow rice, fruits, and squash and in dryer locations maize and potatoes.

Figure 8 shows how crop choice relates to annual temperature. Altogether there are nine crops shown in the diagram. Note how wheat and potatoes fall precipitously with higher temperatures. In contrast, fruits rise with temperature. The remaining crops exhibit a hill-shaped relationship with temperature. The temperature where the hill peaks varies. For example, the peak for maize is on the cool side whereas rice, soybeans, and squash have warmer peaks.

Figure 9 shows how crop choice relates to annual precipitation. Maize and potatoes are more likely to be grown in drier locations. Fruits, rice, and squash are all more likely to be chosen in wetter locations. Wheat and soybeans exhibit a hill shaped relationship peaking in moderately wet places.

These results imply that as temperatures warm, farmers will tend to switch away from wheat and potatoes and towards fruits and vegetables. If warming also causes farms to get wetter, farmers will grow more rice, fruits, and squash. If warming causes farms to become drier, Latin American farmers will switch to growing more maize and potatoes.

5.2.4. LIVESTOCK CHOICE STUDY

This paper explores how Latin American livestock farmers adapt by changing their choice of livestock species (Seo and Mendelsohn, 2006e). Estimating the models across over 1200 livestock farmers in seven countries, we find that both temperature and precipitation affects the species Latin American farmers choose. For example, **Figure 10** shows the how temperatures and livestock choice are related. Beef cattle and chicken are more likely to be chosen in the cooler parts of Latin America. Dairy cattle, sheep, and pigs, in contrast, are more likely in the warmer regions. The results imply that as Latin America warms, farmers will move away from beef cattle and chickens towards these other species.

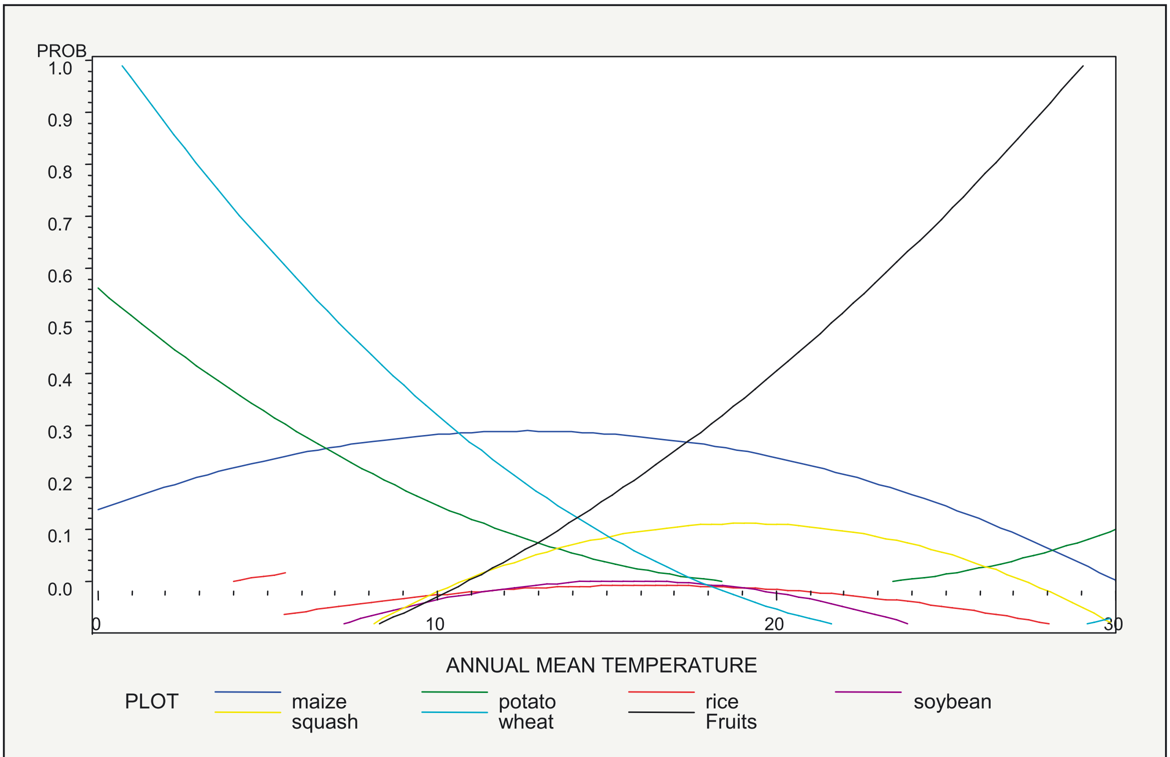


Figure 8. The effect of annual temperature on the probability of choosing a crop.

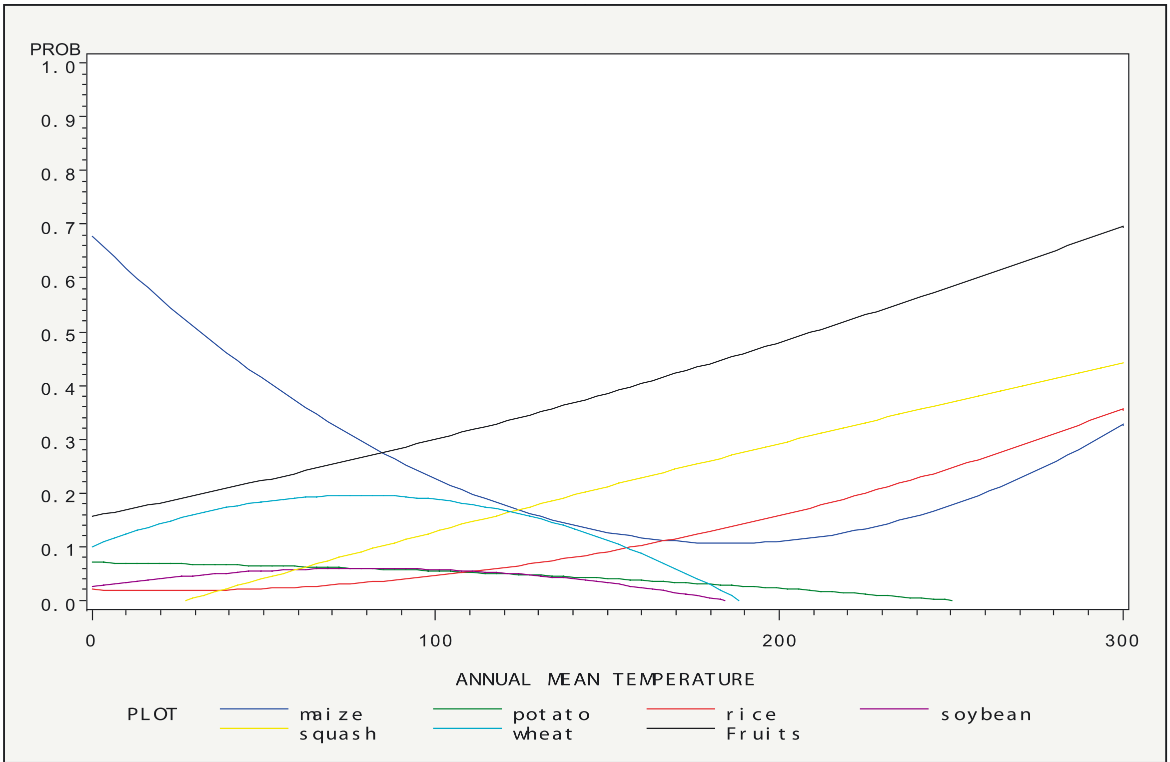


Figure 9. The effect of annual precipitation on the probability of choosing a crop.

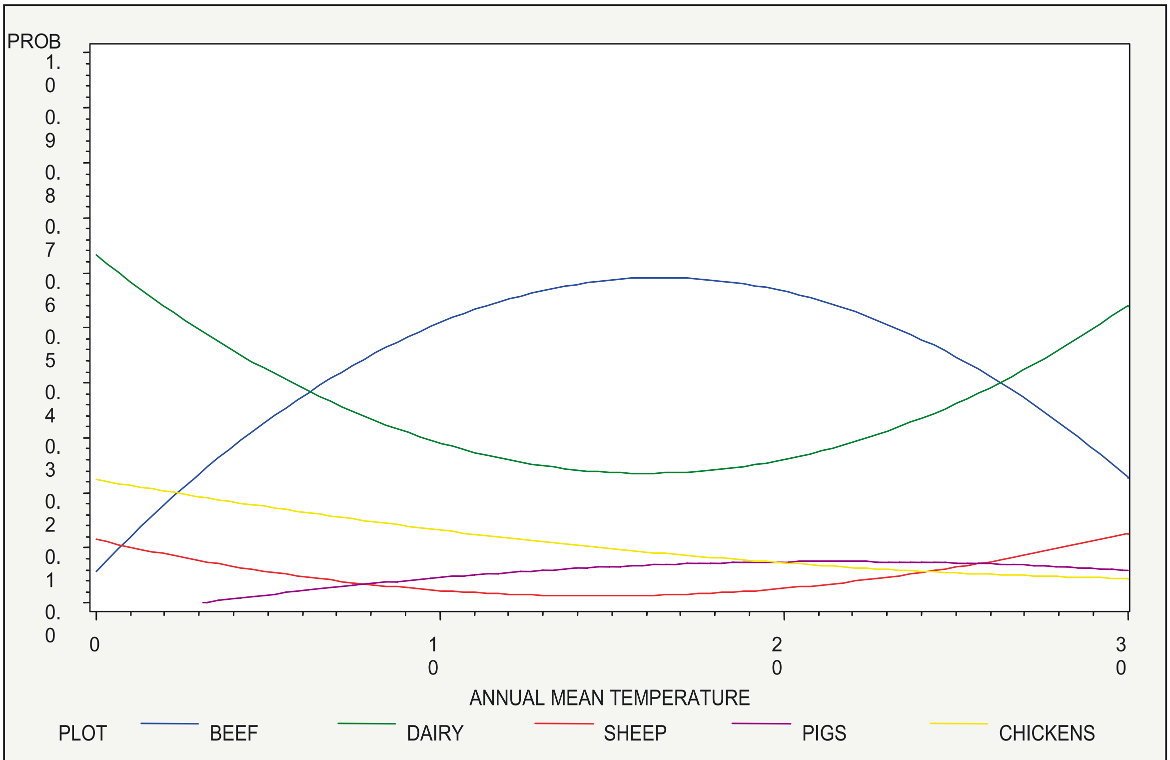


Figure 10. Estimated probability of selecting species given annual temperature.

Figure 11 shows how precipitation affects the choice of livestock. Beef and sheep are more likely in the drier regions of Latin America whereas dairy cattle are more likely in the wetter regions. Pigs and chickens are hardly affected by precipitation. Drying would consequently favor beef cattle and sheep whereas increases in precipitation would favor dairy cattle.

5.3 CLIMATE CHANGE, TECHNOLOGY, AND ISRAELI AGRICULTURE

5.3.1. ISRAELI RICARDIAN STUDY

A study was conducted in Israel to estimate a Ricardian model (Fleischer *et al.*, 2006a). A total of 381 farmers were interviewed across the three different types of farms in Israel: kibbutz, moshav, and "other". A traditional Ricardian regression was estimated using annual net revenue as the dependent variable with climate, soils, and other controls as independent variables. The study carefully explored the importance of including irrigation water as an independent variable. If available water is not included, the climate coefficients are biased. The study found a U-shaped relationship with temperature because Israeli farms in very hot locations have high values. By combining capital intensive irrigation and cover, Israeli farmers have been able to create a very profitable though small agricultural sector in a high temperature region of the country. The study also revealed that farms with more precipitation had higher net revenues, as expected.

5.3.2. ISRAELI TECHNOLOGY ADOPTION

The technology analysis examined the adoption of advanced irrigation techniques and cover (Fleischer *et al.*, 2006b). The analysis of irrigation shows that farms in Israel are less likely to adopt irrigation if they are in warmer locations. These results mirror the findings in the Latin American study (Mendelsohn and Seo, 2006) and Africa (Kurukulasuirya and Men-

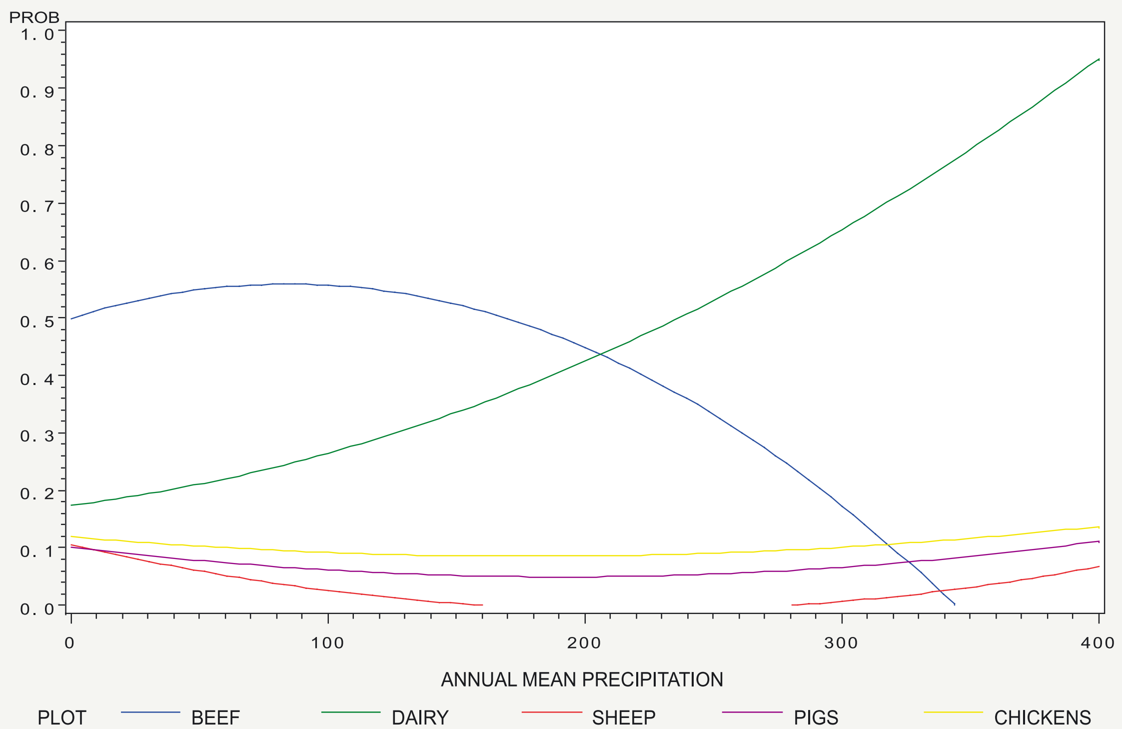


Figure 11. Estimated probability of selecting species given annual precipitation.

delsohn, 2006a). Irrigation may permit crops to survive warmer temperatures but irrigation is more profitable in cooler locations.

The Israeli study also examined the use of cover (usually plastic) by farmers. The study found that farmers chose to use of cover in hotter locations. Covering plants from the sun is an adaptation against the heat. Both cover and irrigation have no relationship with precipitation. Interestingly, both investments were less likely with clay soils confirming that farmers will only make these high capital investments if conditions are otherwise ideal. The Israeli study also revealed that both investments were less likely the larger the farm. Irrigation and cover systems are more ideally suited for small targeted operations.

6. CONCLUSION AND POLICY RECOMMENDATIONS

6.1. REGIONAL LEVEL

Using cross sectional evidence from more than 2500 farmers from 7 countries in South America, land values follow a hill-shaped pattern with respect to temperature. Land values are low in cool areas, rise to a maximum in temperate areas, and then fall again in hot tropical areas. Because the average temperature in farms is warmer than the "optimum", the results suggest that warming will in general be harmful to Latin American agriculture. Results using net revenues yield similar results with respect to temperature. Irrigated farms are relatively less sensitive to temperature compared to dryland farms.

Farms in places with more/less precipitation have slightly higher/lower land values. Dryland farms follow the same pattern as described above but the land values of irrigated farms are more sensitive to precipitation. The high sensitivity of irrigated farms to precipitation is likely due to their location in relatively dry places.

The cross sectional results have implications for global warming. Because most farms in Latin America are already warmer than in the temperate zone, the average farm will lose land value or net revenues as temperatures rise. Further, if farms in hot climates in the future react like farms in hot places today, there could be very large damages associated with severe climate scenarios. CCC predicts a gradual increase in average damages per farm from about 16% in 2020, to 33% in 2060, to 61% in 2100. In contrast, the CCSR model predicts damages of about half that size and the PCM model about one fourth as large.

The impacts of warming, however, vary a great deal across the landscape. Depending on the scenario, some areas are especially hard hit and some areas benefit. Farmers need to be prepared for what will happen in their local area. Governments need to consider what areas will need relief and what areas are likely to prosper. They should be careful to target assistance to where it will be needed because the effects of climate change will vary across the landscape.

Another interesting result from the research is that small and large farms have very similar final impacts in Latin America. Warming will cause about the same percentage loss in land value and net revenue for both small and large farms. Both small and large farms are equally vulnerable to global warming.

The project also investigates whether current farmers have adapted to the climates that they are in. That is, the study explores whether farmers make different choices in different climates. The study finds that farmers change whether they plant crops, grow livestock, or raise both crops and livestock depending on the climate. Farmers in places that are temperate and wet tend to raise crops. Farmers in places that are dry tend to raise livestock. Farmers in places that are hot tend to raise both crops and livestock. Another choice that depends upon climate is irrigation. Farmers are more likely to choose irrigation if their farm is in a cool and dry location. Earlier studies that assumed irrigation is exogenous consequently produce biased welfare estimates since they assume the fraction of farms that irrigate will not change with global warming. Finally, farmers will witch crops and livestock species as well as climate changes. These effects will reduce the damages that would otherwise occur but the analysis still predicts there will be overall damages from warming.

The adaptation results provide strong evidence that farmers will make adjustments in how they grow crops in order to cope with global warming. Impact studies that fail to include these adaptations will overstate the damages from future warming. Of course, it is important to recognize that adaptation does not eliminate damages. Even with the projected adaptation in Latin America, the impact models still predict that warming will lead to substantial damages to the agricultural sector.

Several important factors that have not been accounted for in this study include carbon fertilization, technical change, and changes in prices. Carbon fertilization is predicted to increase crop productivity (Reilly *et al.*, 1996). Technical change is predicted to make large changes in productivity (Evenson and Gollin, 2003). Technical change may also be able to change the sensitivity of crops to climate. For example, crop scientists could use the tools of modern genetics to design crops for hot and dry conditions. This would make a large difference to farmers who currently have few alternatives. Finally, the study does not explicitly consider prices. If there are large changes in production, both input and output prices could change. These price changes would tend to reduce the size of the damages estimated in this study. For example, farmers would get higher prices if productivity and supply falls or they would have to pay lower wages if there is much less work.

6.2. COUNTRY LEVEL

The seven studies developed regressing land value on climate and other control variables revealed that climate plays a significant role in explaining the variation of land values across the sample. Temperature has a hill-shaped relationship with land values and net revenues. Farmland values in cool locations are relatively low, values in temperate locations are high and values in hot locations are relatively low. Slight temperature increases have different effects on farms depending on their current temperature. The study finds that slight warming would generally reduce land values. However, these results vary across the sample. The farms located in cooler places would increase in value with slight warming.

Small and large farms showed similar but not identical responses to temperature. They both had hill-shaped relationships between land value and temperature, but land value peaked at a lower temperature for large farms than for small farms. The study also revealed that farm land values are higher in places with higher summer precipitation, and that farm land values with higher winter precipitation are lower. On an annual basis, these effects are offsetting so that annual precipitation has only a small net effect.

Future climate scenarios for each country were obtained from three AOG Climate Models. The scenarios represent a broad range of possible future climate outcomes for Latin America. The analysis revealed that Latin American agriculture will generally be harmed by global warming. Within the more severe scenarios, farms could lose up to 62% of their value by 2100. Within an "average" scenario of a 3˚C warming, by 2100 farms would likely lose about 30% of their value. Within modest climate change scenarios farms may lose only 15% of their value. In all tested scenarios global warming will damage net values.

The adaptation analysis revealed that farmers will change the type of farm, irrigation, crops and livestock depending on climate. Farmers in wet temperate locations choose to grow crops, farmers in dry locations choose to raise livestock, and farmers in hot locations often choose to raise both crops and livestock.

The study also investigates the impacts of climate change in Israel. The Israeli study found that farmers are more likely to choose to cover their crops if the temperature is higher. Israelis have also invested in intensive irrigation systems. This result has enabled some Israeli farmers to grow crops in very hot locations. The Israeli study suggests there may be further adaptations that Latin American farmers can make in the future to cope with global warming.

These results have important implications for the climate change policy. First, the study provides strong evidence that Latin American agriculture will be vulnerable to warming. Second, the study quantifies the magnitude of the resulting damages. Third, the study shows that farmers are likely to adapt by changing the way in which they farm. Fourth, the study shows that the impacts will not be uniform across the continent but will vary a great deal from one place to another. Governments must consider providing assistance to prioritize programs where needed.

In this context of climate changes and due to the serious effects expected to be felt by farmers given the AOGCM scenarios for the next decades in the Southern Cone and in the Andean region, each country's Government should adopt policy measures to mitigate these impacts on the agricultural sector. The policy recommendations should be oriented at minimizing the negative effects expected by the changes in winter temperature on small farmers. In the case of commercial farmers, these policies should try to mitigate the negative effects expected from changes in the precipitation level during the summer.

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8. GLOSSARY

AOGCM - Atmosphere-Ocean General Circulation Model

CCC - Canadian Climate Centre

CCSR - Center for Climate Study and Research

CORPOICA - Coorporación Colombiana de Investigación Agropecuaria

EMBRAPA - Brazilian Agricultural Reserch Corporation (Brazil)

INIA - Institute of Agricultural Research (Chile)

INIA - Instituto Nacional de Investigaciones Agrícolas (Venezuela)

INIA - National Agriculture Research Institute (Uruguay)

INIAP - National Autonomous Institute for Agricultual Research (Ecuador)

INTA - Instituto Nacional de Tecnología Agropecuaria (Argentina)

IPCC - Intergovernmental Panel on Climate Change

PCM - Parallel Climate Model

PROCISUR - Cooperative Program for Agri-food and Agroindustrial Technological Development of the Southern Cone

WMO - World Meteorological Organization

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