Comparative Assessment of Agricultural Uses of ENSO-Based Climate Forecasts in Argentina, Costa Rica and Mexico

Project Summary

An IAI Initial Science Program (ISP)–III Project

Coordinated by the University of Florida
Dr. James W. Jones, Principal Investigator

About this summary

This summary is an abridged, general audience version of a more technical report submitted to the IAI in October 2000. The full report, which is almost 200 pages long, contains numerous graphs, charts, and statistical analyses for each of the three countries which participated in the project, as well as a comparative section which evaluates the project as a whole. Full bibliographical references are included.

A copy of the full report in Adobe Portable Document Format (PDF) can be downloaded from the Florida Consortium web site: http://www.coaps.fsu.edu/lib/Florida_Consortium

Flood control retention area in Irrigation District 10, Sinaloa, Mexico.

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Funding for this project was provided by grants from the Inter-American Institute for Global Change Research, and the National Oceanic and Atmospheric Administration Office of Global Programs.

Introduction

Dr. James W. Jones
Principal Investigator

Since the 1982–1983 El Niño event, often referred to as the "worst ever," the El Niño Southern Oscillation (ENSO) has been a popular news item. The very strong El Niño and La Niña events of the 1997–1998 season, especially the fires, flooding, and agriculturally destructive freezes which occurred in the United States, established the reputation of ENSO as a powerful force.

As the work of this project shows, a more complete understanding of ENSO can be very valuable to farmers and agricultural decision makers in our hemisphere. I am proud to introduce this summary of an Inter-American Institute for Global Change Research (IAI) collaborative research project for investigating the application of ENSO-based climate prediction in agriculture. This IAI Initial Science Program (ISP)–III project began in May 1997 and concluded in July 2000.

Project goals

Unlike some other climate prediction research efforts which have investigated ENSO-based methods, this project focused on end users—the people who could use the information gained from ENSO-based climate prediction to manage crops, set policies, and make other decisions. Our efforts began with farmers, but also included research scientists, political leaders, and government officials.

Five areas in three countries were selected for study: the Pampas and Pergamino regions of Argentina, the Los Chiles and Liberia regions of Costa Rica, and the State of Sinaloa, Mexico. The three sections of this summary each contain maps which show the study areas in detail.

The project was very diverse. Researchers worked in a variety of disciplines and professions. Many agricultural systems, producers, climates, and institutions were represented. Agricultural infrastructure varied widely across study locations. This diversity enabled us to determine the overall usefulness for a wide range of ENSO-based climate prediction methods.

As hoped, the participation and enthusiasm of scientists and researchers was matched by feedback from end users—our third goal of establishing a relationship of trust between researchers and end users.

Results

The project summarized here showed the promise of ENSO-based climate prediction. Researchers working at universities, government research centers, and for government agencies worked with farmers to model ENSO effects and educate those potentially affected. In each country, project cooperators isolated the features unique to their situation—in some cases developing very diverse techniques due to the wide variety of locations studied.

In Argentina, farms are often mechanized and are the most technically advanced of those studied. Argentine farmers are the most ready to respond to pressures of the global market. They grow a wide variety of crops—wheat, maize, soybeans, and sunflowers.

Back row, from left: Brad Wilcox, former IAI science officer, with project researchers James W. Jones, Jaime Collado, José Retana, and Roberto Villalobos. Front row: project researchers Graciela Magrin, María Travasso, and Fred Royce. Photo taken at International Potato Research Center (CIP) , Lima, Peru, May 2000.

A crop advisor and farmer discuss the current growing conditions and expectations. The crop shown is maize.

ENSO phases definitely alter precipitation patterns and crop yields. However, high variation in the location and intensity of changes caused by ENSO make climate prediction's economic value somewhat low (about 5%).

In Costa Rica, there are a wider variety of farm sizes, most in the small to medium range. Much of the work is done by hand, and there is little irrigation.

The focus of project research was end users—those who could use the information gained from ENSO-based climate prediction to manage crops, set policies, and make other decisions.

Rice and beans are the principal crops. In the north, El Niño decreases rice yield, while La Niña increases yield. But bean crops show little effect. Overall, ENSO-based climate prediction has helped to mitigate losses caused by weather patterns. However, infrastructure is weak, and communication is the greatest challenge.

In Mexico, farms are small and farmers are well organized. ENSO effects are not large enough to justify effective alteration of crop management practices. However, irrigation district management infrastructure provides a unifying influence, and using ENSO-based forecasts to better manage irrigation resources seems very promising.

The comparative work of University of Florida and other scientists offers an in-depth analysis of results generated from all three regions studied, using the final project reports (see page 2) and interviews with farmers as primary sources.

About ENSO and climate prediction

ENSO is short for El Niño Southern Oscillation—the technical name for oceanic and atmospheric conditions in the Pacific Ocean which have a tremendous effect on weather patterns in our hemisphere and around the globe.

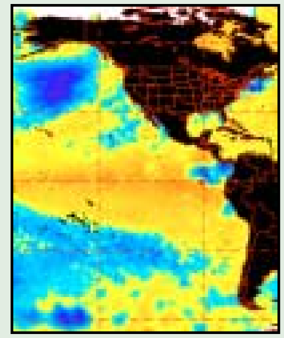


Figure one: elevated SST in equatorial Pacific during 1987 El Niño event (Courtesy NOAA).

ENSO phenomena are defined when sea surface temperatures (SST) in the tropical Pacific Ocean differ from normal. In the warm phase, better known as El Niño, SSTs are higher than usual. During the "La Niña" cold phase, SSTs are cooler than the norm. Awarenes of El Niño is nothing new—hundreds of years ago, South American fishermen noticed weather changes around Christmas of some years, and named this warming "El Niño" after the Christ child.

ENSO neutral years are more common than either cold or hot phase ENSO years. Since 1950 there have been 22 warm, 18 cold, and 23 neutral years. Ocean temperatures affect climate by providing a source of heat and moisture. This affects air temperature, wind currents, and perhaps most importantly, the timing and amount of rainfall. That's why ENSO can have huge impacts on crop production.

What is climate prediction?

Climate prediction is the science of using historical weather information and up to date weather observations to predict broad climatic patterns—unlike weather forecasting which focuses on the short term and is very localized. Most climate predictions look from three weeks to a year into the future. Enhanced capabilities to monitor the oceans and atmosphere, and computer modeling of weather data, continue to improve the accuracy of climate prediction.

Why is ENSO-based climate prediction important?

Because ENSO can drastically affect the amount and time of year when rainfall occurs, climate prediction can be a very important tool for agricultural decision making.

For example, if climate prediction shows more rain in the early part of a growing season, a farmer would select crops or hybrids which benefit from that early rain. If less rainfall or higher temperatures are predicted, a farmer could delay planting or choose a drought-tolerant crop—or decide not to plant at all.

But climate prediction is not a magic bullet. Work is needed to improve data collection, modeling, and methods for getting data to farmers. Those goals are at the heart of the current study.

Introduction, continued

Future work will continue the development of climate forecasting techniques. But as this study demonstrated, ways in which climate forecast information is delivered to the end user are equally important.

Overall the study showed clearly that there is considerable potential for climate prediction applications in each of the three regions studied. It is likely that other regions could benefit from similar climate prediction. However, there are risks associated and more work is needed to make certain these risks are fully understood. This summary, and the full report which goes with it, are one step toward understanding the ways researchers can work with end users to enable more effective decision making in every level of agricultural practice.

Future work will continue the development of climate forecasting techniques. This study demonstrated the ways that raw information is delivered to end users are equally important.

Dr. James W. Jones is a Distinguished Professor in the Department of Agricultural and Biological Engineering at the University of Florida.

South American schoolchildren like these can benefit directly from the improved yields and loss prevention possible with ENSO-based climate prediction.

Learning more

To learn more about the work encompassed by this project, get the full version of this report, which contains almost 200 pages of detailed project results and analysis. See page 2.

There are many web sites which provide excellent information on El Niño Southern Oscillation (ENSO), including historical data, up to the minute observations of Pacific Ocean conditions, and references to relevant research projects both on and off the Web.

The NOAA Tropical Atmosphere Ocean (TAO) theme page contains graphical and charted representations of ocean conditions and links to many other useful sites:
http://www.pmel.noaa.gov/toga-tao/el-nino/

The Center for Ocean-Atmospheric Prediction Studies (COAPS) at Florida State University also offers valuable materials pertinent to ENSO and climatology in general. The COAPS team continually updates its site to reflect current research with relevance for scholars, agricultural decision makers, and the general public:
http://www.coaps.fsu.edu/

Acknowledgements

We wish to thank the following individuals and organizations who provided financial support, advice, information, and other assistance which contributed to the success of this project.

Partial funding for the comparative assessment portion of the project was provided by the National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs (OGP).

Funding assistance for the production of this report was provided by IAI. Thanks to Marcella Ohira Schwarz for her suggestions about the formatting of this document.

Many farmers and growers in Argentina, Costa Rica, and Mexico spent hours working with researchers, answering questions, sharing information, and cooperating in extremely important ways. Without their commitment this work would not have been possible.

Fred Royce provided many photographs, the best of which we are proud to include here.

Several members of the Florida Consortium, especially Dr. Guillermo Podestá of the University of Miami, provided valuable assistance and advice as well as conducting preliminary research which facilitated much of the work of this comparative analysis.

We are also grateful to:

- Enrique Mejia of the Colegio de Postgraduados, Texcoco, Mexico
- James Hansen, Columbia University International Research Institute for Climate Prediction (IRI)
- Anthony Hall, Universidad de Buenos Aires.

The amount of work project researchers put into this study may not be represented by this brief summary. We want to thank all of them one more time, and look forward to more work in this exciting area of global research.

Argentina

Instituto Nacional de Tecnología Agropecuaria

The diversity of crops cultivated in the Pampas region, the growing importance of agriculture in the area, and the profound effects of ENSO on Pampas agriculture make study of ENSO in Argentina very productive. This study focused on three sites in the area: Pergamino, Pilar, and Santa Rosa. On-farm trials augmented the historical analyses and modeling common to the other participant countries.

The study region

The Pampas Region is a broad, flat plain between 30–39° South latitude and 57–65° West longitude. The area has occasional rolling hills and rises generally to the north and west. Generally speaking, soil quality does not constrain agriculture, though recent expansion of land use into marginal areas has created the risk of land quality degradation in some areas.

The climate is temperate and humid with no dry season—rainfall normally occurs during all months—and a very hot summer. Mean annual temperatures range from 14°C in the south to 19°C in the north. Weather can be extreme, with droughts and excessive precipitation leading to flooding and losses in planted areas.

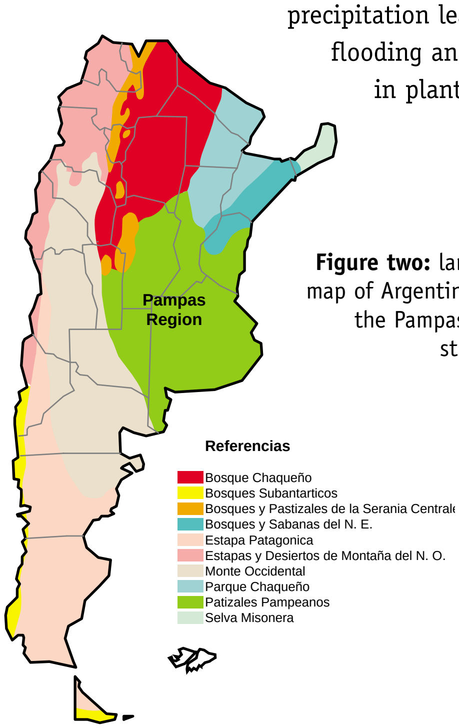


Figure two: land-cover map of Argentina shows the Pampas Region study area.

Annual precipitation varies from 400 mm in the southwest to 1100 mm in the northeast. Rainfall generally increases from southwest to northeast. The highest rainfall occurs in December and March (up to 120 mm) and the lowest in July and August (often less than 20 mm). Rainfall is the main factor which determines crop yield by affecting the reproductive phases as well as the severity of fungal diseases.

The sometimes severe climate of the Pampas creates high variability in crop production. Grain output averages 37 million tons (Mt) but has varied from 23 to 59 Mt between 1988 and 1998. Recently soybean has been the most important crop, followed by wheat, sunflower, and maize. However, since land in the Pampas is used for both grazing and cropping, the area sown as well as the yield of a particular crop can fluctuate greatly over time. Figure three (at the far right of the next page) shows annual production for the area.

Pampas farmers often attend farm exhibitions to shop for the latest machinery, such as this four wheel drive articulated tractor.

Crop production in Argentina has increased in recent years as the technological sophistication of farmers has increased. Between 1991 and 1996 agricultural investment increased from US$300 to US$700 million, the use of fertilizers quadrupled, and irrigation installations appeared for the first time. Crop management procedures modernized as well, with less aggressive tilling, use of herbicides and insecticides, and drying and storing of grain becoming more common.

Production systems vary from pasture and crop rotation in the south and west to almost continuous cropping in the northeast. Farm ownership has increased from 43% in 1947 to 75% today. Farm size has also grown, with many medium size farms and a smaller number of very large farms, though most farms (93%) are smaller than 1,000 hectares (ha).

ENSO effects on climate and agriculture

Historical analysis of data from government statistics showed that El Niño has a significant impact on yield at the national level. In 15 of 20 El Niño events (75%) maize yield was equal to or as much as 36% higher than the mean historical value, while in 17 of 23 La Niña events (74%) it was as much as 56% lower than the mean.

In soybeans, an even greater impact from La Niña was observed, with yield reductions in 71% of events. In El Niño and neutral years, yield residuals were positive in 58% and 62% of cases, respectively. (See figure four, below, and figure seventeen, on page 22.)

Sunflowers presented less association between yield and ENSO phases, with only one trend: a 59% probability of achieving higher yield during La Niña years. Wheat showed the least response of all, with only 57% of La Niña years showing lower yields. Neither sunflowers nor wheat showed consistent trends during El Niño years.

An analysis at the county level showed broad reproduction of these national trends, but indicated several areas where ENSO effects on crop production consistently differed from the norm.

Historical analyses of maize and wheat yield, harvested area, and crop production were completed for three areas representative of humid (Pergamino), sub-humid (Pilar), and semi-arid (Santa Rosa) zones.

In Pergamino and Pilar, maize crop production is significantly reduced in La Niña years, due to yield reduction in Pergamino and yield and harvested area reduction in Pilar. In Santa Rosa, maize production tends to decrease in La Niña years and increase in El Niño years, though results were not significant because of great variability.

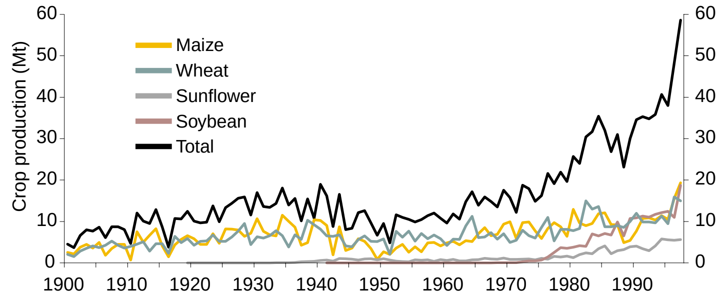


Figure three: annual crop production for maize, wheat, soybean, and sunflower (1900-1997) in the Pampas region.

Wheat shows no significant difference at any site, though trends do follow the general pattern established for maize.

Agricultural decision makers

The high spatial and temporal variability of weather on the Pampas continually challenges area decision makers, making the availability of climatic information a necessity.

Many Argentine government agencies provide climatic information at monthly or weekly intervals. Historical information is also available. In climate forecasting, both the National Meteorological Service (SMN) and the INTA provide monthly forecasts which consider ENSO impacts on rainfall and temperature.

A 1999 survey by Ignacio Llovet (University of Belgrano, Buenos Aires) and Dave Letson (University of Miami) investigated the relationship between farmers, climate variability, and climate prediction. The survey indicated—somewhat unexpectedly for an area where climate is so important—that 30% of farmers were "indifferent" to climate prediction. Product prices were the most important factor influencing production decisions (50%), and agronomic factors such as crop rotation were second (29%). Climatic forecast was the most important factor for only 8% of farmers.

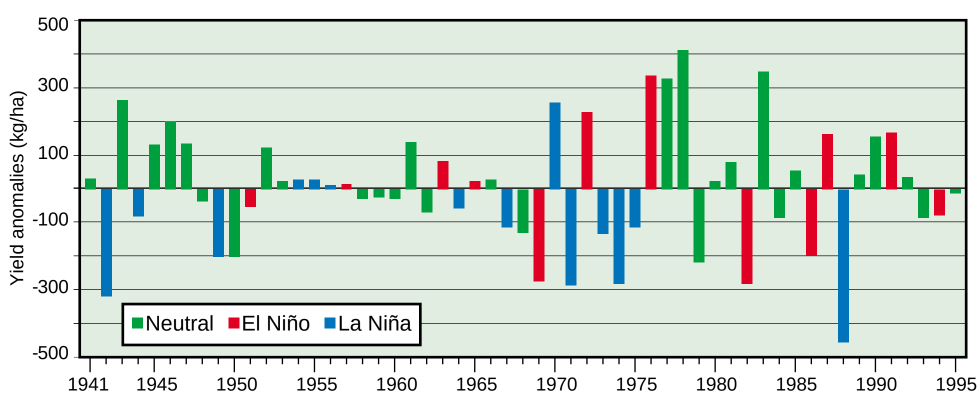


Figure four: yield anomalies in Argentine soybean crop (kg/ha), 1941–1995.

Argentina, continued

When farmers do consider climate variability, 66% draw upon their own experience, and 20% on the experience of "elders." Only 12% rely on technical or formal knowledge.

However, a majority of farmers indicated they considered climate forecasts before all else during the 1997–1998 season—likely due to the well-publicized El Niño event which occurred that year. This event may have affected farmers in several ways. First, the accuracy of predictions from that year may have created unrealistic expectations for many farmers. Survey data shows that 42% of farmers made decisions for 1998–1999 based on a forecasted La Niña. Second, the success of 1997–1998 resulted in several very different forecasts being published in 1998–1999. This confusion, coupled with the inaccuracy of even the most reputable forecasts that year, may have caused some loss in the overall credibility of climate forecasting.

Analysis of decision options

The Decision Support System for Agrotechnology Transfer (DSSAT) was used with crop models to optimize management practices and net returns for crop (wheat, maize, soybean, and sunflower) as well as for ENSO phase (El Niño or La Niña). Climatic inputs were obtained from four meteorological stations (Pergamino, Santa Rosa, Junín, and Nueve de Julio).

To test crop model performance at the field level, experimental trials were carried out on farms all over Argentina. The necessary data were available from fields in Pergamino, Alberdi, Carmen de Areco, and Catriló. Simulated yield showed good performance (figure five, below).

Management options including planting dates and nitrogen fertilization rates were defined for the farms selected, and trials of those options were carried out during the 1998–1999 and 1999–2000 growing seasons.

Argentine researchers count and weigh maize kernels as part of validation of the simulation model for new hybrids.

For **maize,** advancing the planting date and increasing fertilizer worked well during El Niño years, while delaying planting and reducing fertilizer were good options for La Niña years.

Wheat was less uniform. In the north, better results were obtained by planting earlier during La Niña years. In the south, advancing planting dates during El Niño was the best option. Nitrogen applications needs varied widely.

With good soil water availability, early sowings of **soybean** during El Niño years and late sowings during La Niña years were the best options. Significant exceptions to these results underscored the importance of climate variability.

Analyses of **sunflower** growth indicate early sowing is the best option for El Niño conditions, but offer no differences under La Niña conditions. More fertilizer should be used during El Niño years.

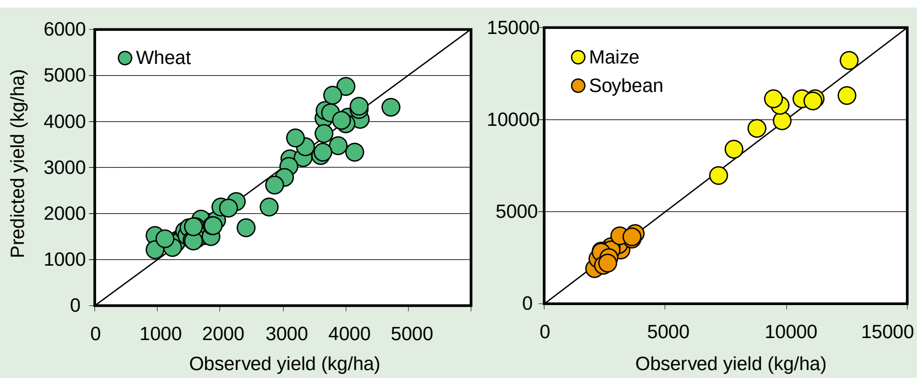


Figure five: observed yield and predicted yield (both kg/ha) simulated by computer models for maize, soybean and wheat from several farms selected for on-farm trials.

The economic value of climate forecasting was calculated for maize, soybean, and wheat, as the difference between net returns obtained using historical data and returns obtained considering the three forecasted phases (see maize forecast values in figure six, at right).

Naturally, the value of forecasting depended to some extent on product price, though maize results for Santa Rosa indicate clearly that in some years more drastic reductions are quite possible.

Conclusions and recommendations

- El Niño and La Niña alter precipitation patterns and crop yields in the Pampas Region.
- ENSO effects show high spatial and temporal variability (difference in strength depending on location and time of year).
- Early planting dates and higher nitrogen fertilizer doses are likely the best strategies during El Niño years. During La Niña years planting dates should be delayed and nitrogen fertilizer doses reduced.
- High spatial and temporal variability diminish the economic value of forecasts based solely on ENSO phase (El Niño, La Niña or neutral).
- The economic value of the forecast increases substantially under extreme economic conditions (low product prices or high input prices).
- Based on long-term probabilities, climate predictions can help farmers manage climate-related risk.

Generally speaking, Argentine agricultural decision makers are extremely interested in climate forecasts, especially after the El Niño event of 1997–1998. The collaboration, enthusiasm and goodwill typical of farmers involved in this project confirm the value of forecast information.

However, farmers' expectations may exceed the capacities of climate forecasts due to the variability of ENSO effects. Though selecting a crop or altering management practices if it is a La Niña, El Niño, or neutral year will likely benefit farmers in the long term, climate variation could cause discouraging short-term economic losses in any particular year or site.

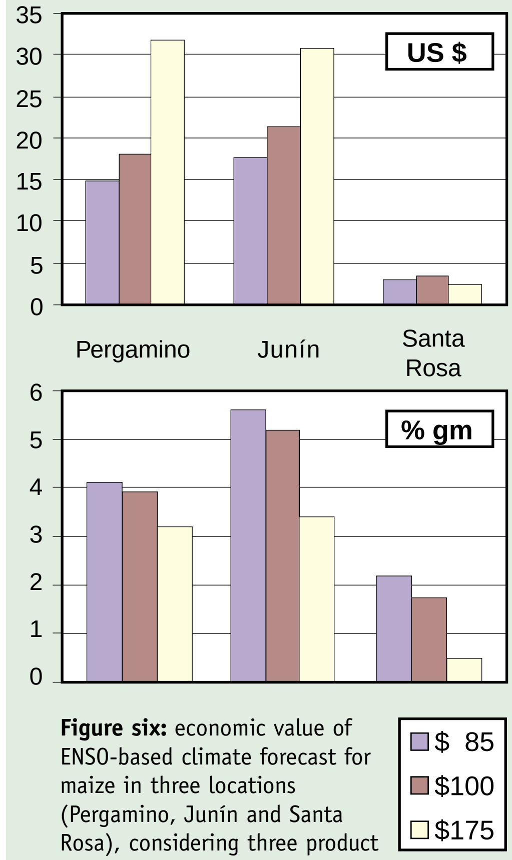


Figure six: economic value of ENSO-based climate forecast for maize in three locations (Pergamino, Junín and Santa Rosa), considering three product prices (US$85, 100, and 175). The top graph shows value in US$/ha; the bottom graph as a percentage of gross margin.

Argentine researcher inspects a soybean experiment

Costa Rica

Instituto Meteorológico Nacional

Costa Rica is a noteworthy area for ENSO climate forecasting for two reasons. First, agriculture constitutes 19% of the GDP and employs 24% of the economically active population. Second, Costa Rica shows a strong ENSO influence on climate variability. In Costa Rica, this study examined the ENSO impact on the bean crop in the northern Caribbean area (Los Chiles), on the rice crop in the northwestern Pacific area (Liberia), and on the climate in both areas.

The study region

The Los Chiles region is an hilly area located in the extreme north of Costa Rica, near the border with Nicaragua. Its vegetation and soil are classified as lowland tropical rain forest. The climate of Los Chiles is heavily influenced by the Caribbean Sea. The mean annual precipitation is 2,223 mm, with March the driest month and July the wettest. The temperature varies little over the course of the year, with a mean average temperature of 26°C.

Land use in Los Chiles has traditionally been extensive, with permanent crops, livestock, and forestry each playing an important role. Bean production is of increasing importance in this area, both as a major source of protein and a cash crop for local farmers. Los Chiles is currently one of the most important bean production areas in the country.

Liberia is located west and slightly south of Los Chiles, in the Northwestern Pacific region. It is a geographically diverse area that includes both gently undulating river valleys and ruggedly mountainous areas. Like Los Chiles it is a small region, measuring approximately 70 km along its widest (north-south) axis. The prevailing vegetation is deciduous and semi-deciduous lowland forest, and it is classified as tropical dry forest transition. The proximity of the Pacific Ocean affects Liberia, where the dry season lasts from December through May. Mean annual precipitation is 1,653 mm with September averaging 343 mm and January averaging only 4 mm. Temperatures are fairly consistent; 33° C is the annual mean.

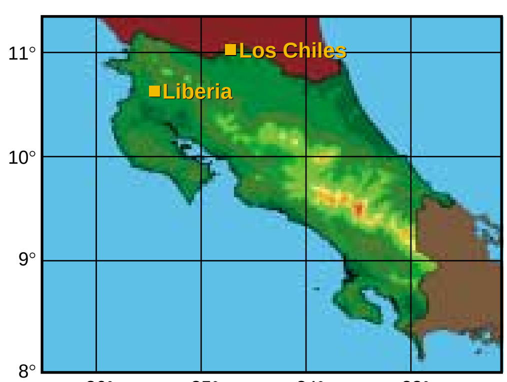
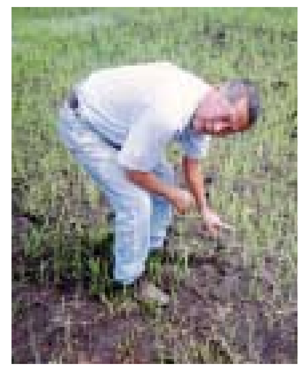


Figure seven: digital elevation map (DEM) of the study area in Costa Rica, showing both the Los Chiles and Liberia areas.

This area is heavily agricultural and was once considered the granary of Costa Rica, although a series of dry spells have reduced the rice yield in recent years. Nevertheless, rice remains a basic commodity and its production has historically received preferential treatment from the state.



A Costa Rican farmer makes a point regarding his rice crop.

Rice production in the Liberia Region is in the hands of medium and large growers who cultivate anywhere from 10 to 770 ha. Small and subsistence growers make up only a small and dwindling percentage. Cultivation is increasingly concentrated, with 1% of growers utilizing 23% of the cultivated land. In contrast, bean production in the Los Chiles area remains in the hands of small and medium growers, with most plots between 20 and 200 ha. While the crops and type of producer are very different in these two areas, both are heavily dependent upon rain distribution. In addition, proximity to the Caribbean and the Pacific also affects agriculture in both areas.

ENSO effects on climate and crop production

In Liberia, rainfall figures are above average in La Niña phases and below average during El Niño phases (see figure eight), both annually and during the growing season. Additionally, during El Niño phases, maximum air temperature increases, although minimum temperatures are not consistently different from those of other phases. During La Niña, temperature were not significantly different from neutral years.

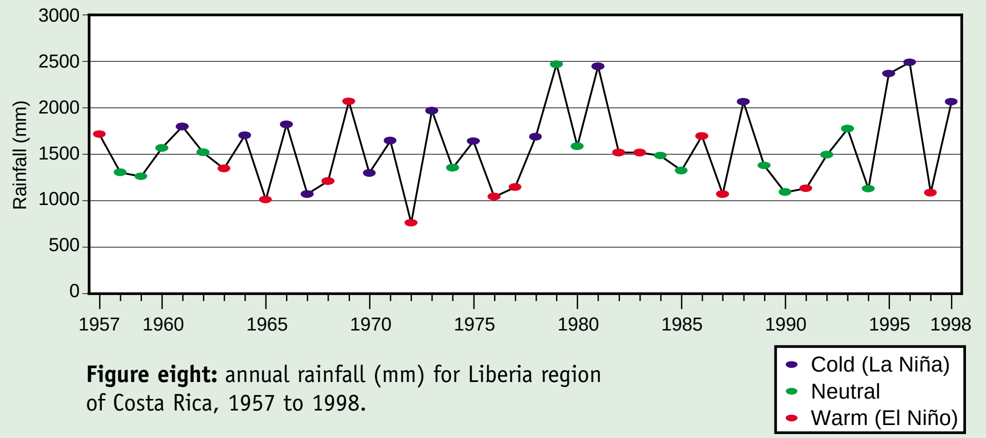


Figure eight: annual rainfall (mm) for Liberia region of Costa Rica, 1957 to 1998.

In La Niña phases non-irrigated rice yield surpassed the mean yield, but during El Niño, three out of five (60%) were below average (figure nine). This tendency is associated with rainfall during the growing season, which increased during La Niña and decreased during El Niño. The major issue is rainfall distribution, not rainfall quantity. During flowering, water availability is critical to success in grain development. However, too much water can ultimately diminish yield and quality of the grain.

Historical climate records for Los Chiles do not show ENSO-related statistical differences for either annual or seasonal precipitation, or for mean temperature. Bean yield comparisons likewise showed little ENSO influence. These data indicate that ENSO phases are less important for this region. Other climate variations, like cyclonic activity and northeastern wind, have a greater impact.

Agricultural decision makers

As a result of the impact of ENSO-related dry spells and floods, decision makers are concerned about climate variability. Actions implemented to mitigate dry spells and floods are now based on ENSO forecasts and potential effects on the climate of Costa Rica. While this has made it possible to issue some timely forecasts, other problems, such as loan suspension, have arisen due to weather uncertainty and production hazards. Only recently (since 1982) has the ENSO effect on agriculture been seriously studied. Most of these studies have focused on ENSO warm phases and the attendant dry spells in the Pacific watershed. These studies are based largely on information submitted by cooperatives and farmers, and lack scientific analysis.

Prediction of the development of the 1997 ENSO warm episode, as well as the spread of information and bulletins, helped the National Emergency Committee (CNE) coordinate responses to the consequences of this episode. Recommendations for sowing time and resource exploitation

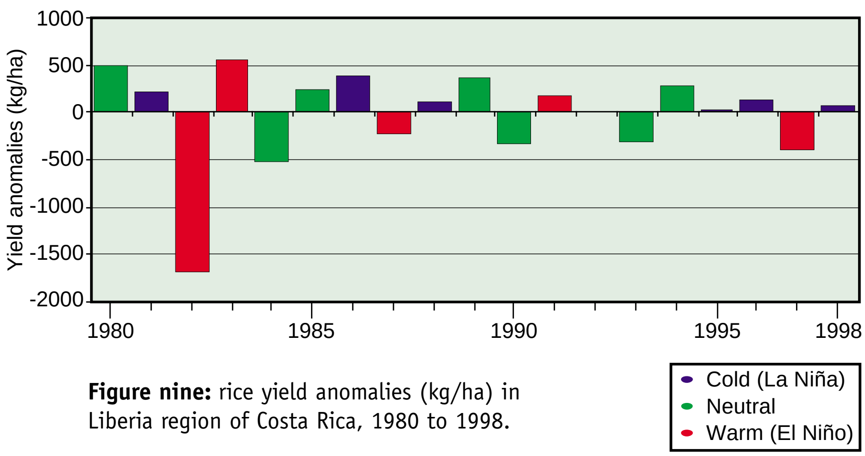


Figure nine: rice yield anomalies (kg/ha) in Liberia region of Costa Rica, 1980 to 1998.

Costa Rica, continued

based upon information from the National Institute of Meteorology (IMN) helped maintain yields of rice, maize, citrus, melon, beef cattle and sugar cane within recent averages. This was considered a success both for agriculture and for the decision makers involved, largely because of the experience gained and new emphasis on climate data and forecasting.

Researchers and rice farmers meet in the field near Liberia, Costa Rica.

Despite these advances in forecasting and planning, ENSO events have caused notable losses in agriculture. Figure ten (below) shows the losses caused by the ENSO droughts of 1997-1998 (primarily in the Pacific and central regions). Some of these losses could potentially be reduced. However, obstacles which limit actions to prevent losses include:

- limited implementation of weather event contingency plans (often due to the lack of forecasting credibility)
- difficulty maintaining and expanding the national meteorological network
- bureaucratic obstacles, such as the lack of national action plans
- a restructuring of insurance policy that has left many producers without coverage
- a lack of research specific to certain crops or areas.

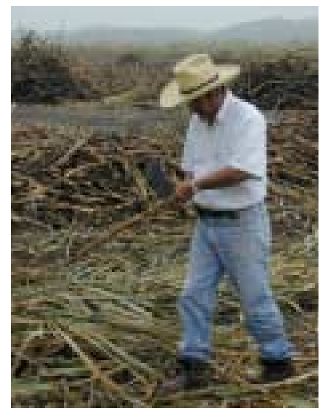
Product	Losses	Cost (million US$)
Rice	40,425 tons	11.4
Bean	13,598 tons	10.9
Maize	8,083 tons	1.7
Sugar cane	200,000 tons	3.0
Others*	n/a	6.2
Beef cattle	2,000 head	7.2
Poultry	n/a	1.4

Figure ten: losses in agriculture caused by drought, 1997–1998. "Others" includes orange, melon, palmetto, tuber, mango, papaya, and plaintain.

Despite advances in forecasting and planning, ENSO events have caused notable losses in agriculture.

While professional decision makers are usually very concerned with ENSO-based climate forecasting, political decision makers are often ill-informed, and their attitude toward adverse weather conditions is, at best, unclear.

Weather variations during crop growth may affect production and yields, but weather is not the only influence. If forecasts provide alerts of risks, flexible management mechanisms should be implemented. However, due to the problems ranging from a lack of support for alternate crops and the behavior of grain importers, the potential for implementing flexible management is limited, especially for small farmers (see the Comparative Assessment which begins on page 20).



Even irrigated crops such as this sugarcane can benefit from climate predictions.

Analysis of decision options

One option for ensuring production is crop rotation during adverse weather conditions. In spite of flooding associated with La Niña, the correlation between La Niña and high rice yields in Liberia indicates that rice cultivation should be encouraged during La Niña phases. Conversely, 93% of dry spells correspond to El Niño years, as shown in figure eleven, at right. Lower rice yields are associated with these dry years, and crop rotation might appear to be an alternative, yet suitable crops such as maize and sugar cane are also affected by extended dry spells. A better alternative might be forage crops for cattle, or fruit trees, although these require a large investment. Irrigation remains the best option for preventing damage to rice cultivation during dry spells.

The Decision Support System for Agrotechnology Transfer (DSSAT) CERES-Rice computer model was used to study other alternatives for rice crops. With management optimized by ENSO phase, model results indicate that rice yields in the

Liberia region during ENSO cold phases could reach 3.5 tons/ha with a growing cycle of 119 days. Warm phase yields could also be increased above current levels.

In the northern (Los Chiles) region, although there was no relationship between bean yields and ENSO episode, bean crops in this region have been severely affected by weather events, especially dry spells and heavy rains. For the 1999-2000 bean cycle, growers in the northern region were told to change the sowing time from mid-November and mid-December to the first half of January. According to the conversations held with some growers, those who followed the suggestions were able to harvest in the driest part of the cycle, which is ideal for maturing and drying the grain.

Conclusions and recommendations

The National Meteorological Institute (IMN) currently uses information from various sources to predict rainfall, which is increasingly being used in agriculture as well as other sectors. The information available to date has been well received by decision makers at the technical and professional levels.

> Political decision makers are often ill-informed, and their attitudes toward adverse weather conditions are, at best, unclear.

However, work still will be needed to get political decision makers to develop real, sustainable, multi-sector plans for the medium and long term.

Costa Rican farmers in the research area reported that economic conditions have decreased their capacity to purchase and maintain farm machinery.

Climate variability has affected basic grain production in Costa Rica, though its effect varies strongly over time and in different locations. In the areas examined, using varieties with shorter growing cycles and coordinating planting time with expected rainfall can improve rice and bean production.

A real agricultural forecast is not yet available in Costa Rica. However, demand continues to grow for this type of service. More studies of the actual ENSO influence over crops and agricultural regions are needed.

Year	Liberia	Cañas	Filadelfia	Santa Cruz
1972	D	SD	D	D
1976	D	D	D	D
1977	D	D	D	D
1982	N	N	N	SD
1983	N	SD	N	N
1986	N	N	SD	D
1987	D	D	D	SD
1991	D	SD	D	N
1992	N	D	SD	N
1994	D	N	SD	N
1997	D	D	D	D

Figure eleven: annual precipitation during years influenced by the ENSO warm phase in four stations of the rice producing area of the Liberia region. N (grey): normal; SR (blue): slightly rainy; R (green): rainy; SD (orange): slightly dry; D (red): dry.

Mexico

Instituto Mexicano de Tecnología del Agua

The work of Mexican researchers included the only irrigated agriculture considered in this study. The area investigated showed much weaker ENSO effects than other countries considered. The small but very well-organized farmers of the Mexican irrigation districts showed that climate prediction data could be useful in planning even if it was not very relevant to farm-based decision making.

The study region

Several areas of Mexico were studied, principally Irrigation District 010 (ID-010), Culiacan-Humaya-San Lorenzo, in the center part of the State of Sinaloa in northwestern Mexico. The district is a 2,700 km^2 area, mostly flat coastal plain with some low hills. Climate is diverse, but generally warm and temperate, with most average temperatures from 24 to 26° C. Precipitation is irregular, with rainfall generally higher in the northern mountains and lower along the southern coast. Most rainfall occurs between July and October. Average precipitation in the study area ranges from 586 to 710 mm.

The irrigation districts are well organized, with elected farmer representatives playing a large role in district management.

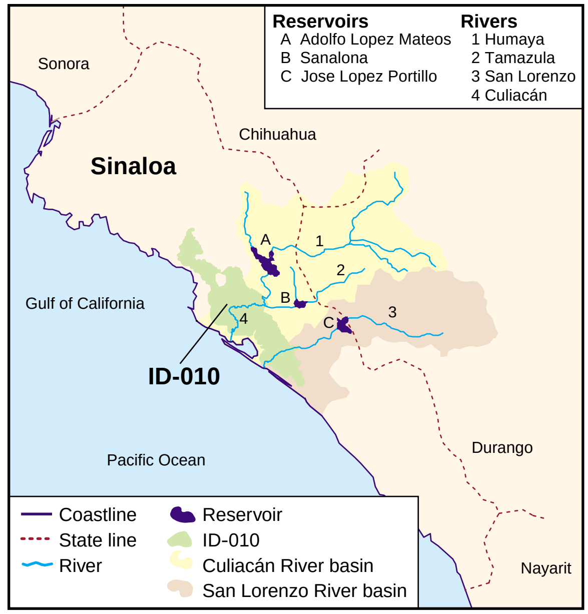


Figure twelve: detail of Sinaloa, the irrigation district, and the surrounding area, showing the two river basins, rivers, and reservoirs.

ID-010 is noted for the variety of crops in its irrigated agriculture fields. Many products are cultivated, producing 4.043 million tons annually. Crops include basic grains and forages, produce and vegetables, and sugar cane and fruits. The average volume of production in the district is almost 14 tons/hectare (ha).

Agriculture is the basis of Sinaloa's economy and directly influences development including commerce and construction. In Sinaloa, 1,333,450 ha are used for agriculture of which 743,500 ha are irrigated. Current trends in land use show a gradual increase in the proportion of irrigated crop land.

The irrigation district is divided into three systems, six units and sixteen irrigation modules with a surface of 272,800 ha. There are 27,500 district users with an average farm size of about 10 ha. Three rivers and three reservoirs are interconnected through canals and other waterworks (see figure twelve, above). The irrigation districts are very well organized, with elected farmer representatives playing a large role in district management.

Figure thirteen: map of Mexico showing the State of Sinaloa to the left in green.

ENSO effects on climate and agriculture

For most weather stations in the district, analyses showed that the ENSO effect is not significant in either precipitation or temperature. There is, however, a weak impact on streamflow during the fall-winter season. As shown in figure twelve (on left, previous page), streamflows originate in river basins mostly outside the irrigation district itself, and therefore do not depend only, or even mainly, on precipitation in the district. In particular, El Niño events have coincided with an increase of water available for irrigation. Historical analyses were also performed for the most important crops in the irrigation district, and for rain-fed agriculture for Sinaloa as well. These analyses found little or no ENSO significance for any agricultural indicator. Finally, statistical analyses were done for other Mexican states that are important producers of corn, and for grain production in Mexico as a whole. The very limited ENSO effects found can be reviewed in the full report.

Availability of water in the district is closely related to the streamflows in the Culiacan and San Lorenzo watersheds. An analysis of streamflow shows ENSO impacts on yearly, fall-winter, October, November, December streamflows in the San Lorenzo River and the watersheds. Figure fourteen (below) shows the impact on streamflow.

This irrigation canal near Culiacan, Sinaloa needs maintenance, yet scarce resources must be divided between irrigation and drainage works. Accurate climate predictions will permit allocations based on expected conditions.

Agricultural decision makers

Sign at a Sinaloa irrigation district office: "The water you waste today will be missed tomorrow."

A wide range of agricultural decision makers, from small farmers to national irrigation district planners, stand to benefit from climate predictions. District farmers are relatively unconcerned about on-field rainfall, but they must make a variety of planting decisions. Module-level planning includes determining the timing and amount of water to release from each reservoir, estimating a crop mix that is feasible given available water, and allocating resources to specific maintenance needs within the system.

ENSO influence increases the availability of irrigation water during El Niño events, yet decreases availability in the La Niña phase.

Several government agencies provide climate and weather information which aid decision making. Most of these forecasts are used in the short term only, and are not routinely used for long-term agricultural management and planning.

Average annual streamflows, million cubic meters (Mm³)

Location	La Niña	Neutral	El Niño
Humaya River, Culiacan watershed	1,772.8 (-8.55%)	1,938.6	2,212.0 (+14.11%)
Tamazula River, Culiacan watershed	784.4 (+3.91%)	754.8	904.4 (+19.82%)
San Lorenzo River San Lorenzo watershed	1,517.9 (+0.36%)	1,512.4	2,067.7 (+36.71%)
Total ID-010 streamflow, Culiacan + San Lorenzo	4,075.0 (-3.11%)	4,205.8	5,184.1 (+23.26%)

Figure fourteen: effect of ENSO phase on average annual streamflows for three locations in ID-010. Percentages shown are differences from neutral years. The amount of usable irrigation water in each district is closely related to streamflows.

Mexico, continued

Mexican farmers and decision makers are broadly aware of ENSO, due to newspaper reports and observed impacts in agriculture and fishing. In 1991–1992 excessive rain and floods damaged 55,000 ha with economic losses of US$54.5 million. For many farmers, the economic effects of these problems lasted well into 1997. In part because of awareness generated by these losses, most look favorably on the use of climate forecasting in agriculture planning. From irrigation district authorities to individual farmers, decision makers at all levels have expressed interest in working with researchers to develop methods for using ENSO-based climate prediction.

Analysis of decision options

Although historical production data do not reveal a significant ENSO impact on Sinaloa agriculture, interviews indicate that producers are eager to use climate forecasts to introduce modifications in agriculture management options, such as changing planting and harvest dates, rotating crops, selecting crops and crops varieties for cultivation, consuming water for irrigation, using fertilizers, and choosing tillage practices.

Streamflow effects

Following a year of slightly below normal or above normal streamflow into the reservoir, water extraction will be substantially reduced during La Niña years.

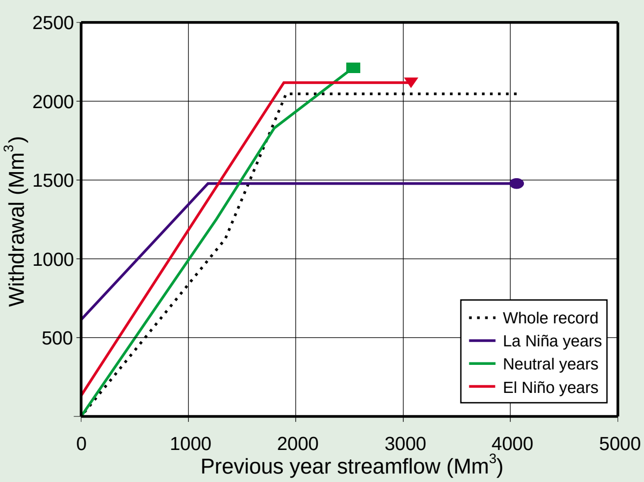


Figure fifteen: water availability estimates for the Jose Lopez Portillo Reservoir, Sinaloa, as a function of ENSO phase and previous year streamflow.

The project plan proposed to use the Decision Support System for Agrotechnology Transfer (DSSAT) package to optimize crop management practices based on ENSO phase, taking advantage of positive conditions and mitigating the impact of negative ones. Unfortunately, there were not enough maize experimental data available from this district to enable DSSAT validation and use. The suggested model-based methodology was ultimately employed in Mexico however, using data from preliminary experimentation in different regions of Mexico (see "A second irrigation district" on the far right, next page).

Interviews indicate that Mexican producers are eager to use climate forecasts to introduce modifications in agriculture management options.

On the other hand, climate forecasts could be used in reservoir operation policies. Up to now, ENSO activity has not been a factor in the annual determination of reservoir operating rules. Since, as is demonstrated in this study, ENSO is an important factor in streamflow into some reservoirs, it may be possible to define operating policies based on ENSO activity. An example of how to define ENSO-based optimal operating rules has been presented in this work. (see "Streamflow effects," below left).

In addition to ENSO, other persistent and perhaps predictable meteorological phenomenon affect Mexico's climate. The eventual integration of these into climate models should lead to greatly improved predictions.

Solis dam and reservoir in Guanajuato, Mexico,

Conclusions

Although the ENSO signal is not statistically significant for Sinaloa agriculture, producers are eager to use climate forecasts to introduce modifications in agricultural management.

Preliminary results from the Alto Rio Lerma irrigation district show a role for ENSO-based optimization of crop management using simulation models, even under irrigated conditions.

Streamflow in certain rivers was one of the few ENSO effects established. This indicates that climate forecasts could be used in reservoir operation policies.

A second irrigation district

The Alto Rio Lerma irrigation district in the north central Mexican state of Guanajuato is organized along the same lines as the Sinaloa district.

Unlike the Sinaloa farmers, those in the Alto Rio Lerma district count on rainfall to provide part of their spring-summer crop water requirements. There is usually sufficient reservoir water for one irrigation to start the crop, and sometimes enough for a second watering, but without late-season rains, there is no harvest. Furthermore, since the Alto Rio Lerma district is at higher elevation, over 1,700m above sea level, crops are sometimes damaged by freezes and hail.

The relationship between these climatic vulnerabilities, field level management, and ENSO phase was explored using the DSSAT crop simulation model. Although this maize model has been used in a number of studies in Mexico, no data from systematic comparisons of its performance compared to actual crop results were available. Therefore, these encouraging results are only tentative.

- Best management varied substantially between La Niña and El Niño phases.
- Simulated yield under La Niña conditions is improved by earlier planting, more irrigation, and more nitrogen fertilizer.
- El Niño climate provides the potential for substantially higher profits.
- The value of adjusting management to ENSO phase may be over US$25 per hectare.

Engineers from the irrigation district in Sinaloa indicate the placement of a planned flow-monitoring station.

Comparative Assessment

University of Florida

This section of the summary compares the methods used and results obtained in the three countries studied. The primary source for this comparative work is the full project report, augmented by surveys, a crop management optimization methodology, and observations from visits to the three countries studied.

Focus on the "end user"

This project emphasized understanding end-user attitudes toward climate prediction and the application of predictions to agriculture. Farmers were recognized as important end users. The inclusion of other decision makers from government and industry enriched the research results.

Locations compared

To focus the comparisons, a single site from Argentina and Costa Rica, and two sites from Mexico are highlighted. Two Mexican sites are presented because different application methodologies were used for two areas.

For Costa Rica, Liberia in the Chorotega region is the obvious choice, since its climate shows a strong ENSO correlation. On the Argentine Pampas, the zone around Pergamino in Buenos Aires province is the most extensively investigated.

The situation in Mexico is quite different—none of the locations examined show a strong ENSO influence. In spite of these limitations, adjustments were made to the same methodology used in the Argentine and Costa Rican studies, and implemented for Santa Julia in the state of Guanajuato. A different approach toward using climate predictions in agricultural planning was demonstrated for the other Mexican site, the Culiacan-Humaya-San Lorenzo Irrigation District in Sinaloa.

Historical and social context

Each of the agricultural areas under consideration has been powerfully affected by globalization, the general shift toward a uniform, enforceable set of rules governing international trade. In agriculture, these rules focus on reducing government intervention, opening markets to competition from imports, and permitting local producers to compete globally. Overall, this liberalization appears to make economically weaker producers more vulnerable to market fluctuations, and is concentrating ownership and control of agricultural land.

Participation in the world market is not new to Pergamino farmers. Argentine grain producers have been directly subject to world market forces longer than grain farmers of other areas examined. Their large, highly mechanized farming systems have the economic efficiency required to compete worldwide. Most Argentine producers seem to welcome the opportunities offered by reduced barriers to trade.

Nearly the opposite situation exists in northwestern Costa Rica. Liberalization has increased hardship and uncertainty for most rice growers in the Liberia region. The weakening or removal of government price guarantees and oversight of seed quality and import restrictions has affected the economic viability of many smaller rice producers, and most view globalization as a severe threat.

During the 1990's nearly all Mexican irrigation districts experienced a transfer of management authority from the federal government to elected representatives. In the two districts examined in this study this transfer appears to have been successful. Not only are the districts better managed at a local level, but the effort has helped farmers organize and deal with the problems of globalization.

From the dam to the field outlet, Mexican farmers are organized to manage their own irrigation systems.

Agricultural context

The cases selected span a considerable range of climate and ENSO effects, but include an even greater diversity of production systems. Usually comprizing hundreds of hectares, the Pampas farms around

Pergamino are the largest of those considered. These lands tend to be highly mechanized, though usually not irrigated. Usage of hybrid seed and chemical inputs is common.

At five to ten hectares, the average-sized farm in a Mexican irrigation district is tiny by Pampas standards. Yet district farmers have access to irrigation, thus reducing a key source of uncertainty and risk. Tillage and harvesting of the usual grain crops (wheat, maize, sorghum and beans) are mechanized, though securing affordable, timely equipment services is often a challenge.

The rice growers of the Liberia region of Costa Rica occupy a middle ground in size, between ten and 500 hectares. The smaller farms have the lowest market interaction of any examined here: little credit is available, seed is selected from the previous harvest, there are few chemical inputs, and the farm family supplies most of the labor. Larger farmers own much of the usual field machinery, yet even their operations tend to be partially mechanized: planting, fertilizing and chemical weed control are often performed by hand. Few of these upland rice farmers have access to irrigation.

Overall, globalization appears to make economically weaker producers more vulnerable to market fluctuations, and is concentrating ownership and control of agricultural land.

The smaller farmers of Liberia do not commonly practice crop rotation, although they may change crops in response to market conditions. Nor do livestock play a significant role in their operations. By contrast, farmers around Pergamino commonly rotate some combination of wheat, maize, soybeans and cattle, and on many large farms, operations are vertically integrated to include grain brokering, transformation of agricultural products into livestock feed, and livestock into food products. Despite small farm size, more Mexican farmers are also vertically integrating through cooperative arrangements within their irrigation districts.

End user attitudes

First impressions from Pergamino indicate a farming population of “early adopters”: conservation tillage, computer-based accounting systems, and genetically modified (GM) crops are all becoming common.

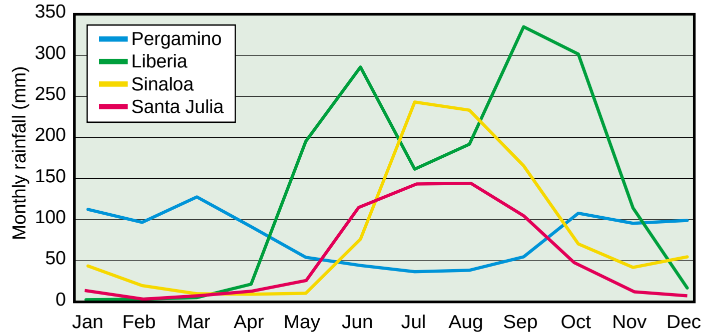


Figure sixteen: monthly mean rainfall at four locations studied. Blue: Pergamino; Green: Liberia; Yellow: Sinaloa; Red: Santa Julia.

In spite of nominal membership in cooperatives, small and medium rice farmers in the Liberia region are not very well organized. Furthermore, they face a very adverse economic situation, including low credit availability, competition from imports and reduced government support. Each of these factors appears to limit the practical appeal of incremental, farm-level innovation.

As a group, the Mexican irrigation district farmers are by far the smallest landowners within the overall study. Relatively few own field machinery, or computers. Yet their capacity for adopting and benefiting from innovations may rival much larger Pampas growers due to their high level of organization. Although the system exists to operate and maintain the irrigation infrastructure, its effects go well beyond water control and delivery. At all levels, there was enthusiasm for better solutions, backed up by a growing local support infrastructure including computers, automatic weather stations, and technical personnel. Farmer participation in collective decision-making, and communication between different decision-making levels both appeared to be functioning.

ENSO influences on climate

Rainfall was judged to be the ENSO-related climate parameter most relevant to agriculture in each location. As seen in figure sixteen, above, all locations show some tendency toward higher rainfall in summer than in winter months (winter in Pergamino, Argentina, is from late June through late September).

Both Pergamino and Liberia rainfall data show strong ENSO influence, with the months most affected by ENSO occurring during the season for the crop of interest. In Pergamino El Niño is the wetter phase, while in Liberia La Niña brings above average rainfall.

District engineers in Sinaloa demonstrate a new method for delivering water to this field of maize

The timing of the ENSO effect differs between Pergamino and northeastern Costa Rica. The most important months for ENSO-related precipitation differences are July and August in Liberia and November and December of the same year in Pergamino. Therefore, the lead-time for decision-making based on a particular ENSO phase prediction, is about four months longer in Pergamino than in Liberia.

Rainfall was judged to be the ENSO-related climate parameter most relevant to agriculture in each location.

Compared to Pergamino and Liberia, statistical analysis of rainfall data from Santa Julia, Mexico shows weaker ENSO influence. Even so, the most important phase-related rainfall differences occurs in August during the maize growing season, making ENSO knowledge a potentially useful criterion for determining planting date, irrigation amount and timing, and possibly other management options.

ENSO influences on crop production

Among all the crops analyzed for this study Argentine maize yields showed the strongest correlation to ENSO phase (figure seventeen, below). ENSO phase precipitation differences fall squarely during the maize growing season, and the low rainfall that characterizes La Niña years creates the likelihood of water stress during maize flowering (figure eighteen, top far right).

Rice yield data from Liberia show some ENSO influence, with yields generally above average in La Niña years. The correlation is much weaker than Pergamino maize, due to the comparatively reduced risk of drought, market fluctuations, and fewer years of data available for analysis.

No significant ENSO signal was observed for crop production or yield data from either irrigation district in Mexico. This is not surprising, given the short data series, the relatively weak ENSO-rainfall correlation, and the availability of irrigation.

Results of model-based analyses

For El Niño years in Pergamino, higher water availability associated with El Niño during the mid-growing season permits higher yield, particularly if plant density and nitrogen fertilizer are increased. The late-season (January–February) increase in La Niña rainfall favors later planting dates that result in more available water during the crop's grain filling phase.

The value of ENSO optimized management showed symmetry between the Niño and Niña phases: knowledge of either of these two conditions has practically the same value, while there is practically no value to knowledge of a neutral year.

Like the Pergamino example, in Santa Julia, Mexico the most widely divergent planting dates occur in El Niño and La Niña optimizations, and greater economic value is associated with ENSO-based management during the El Niño and La Niña

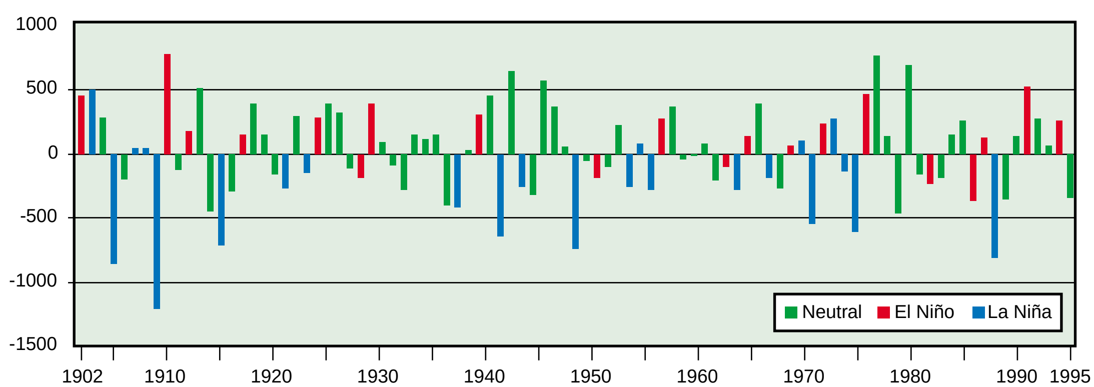


Figure seventeen: yield anomalies (kg/ha) for maize in Pergamino, Argentina, from 1902 to 1995. ENSO phase is shown by color.

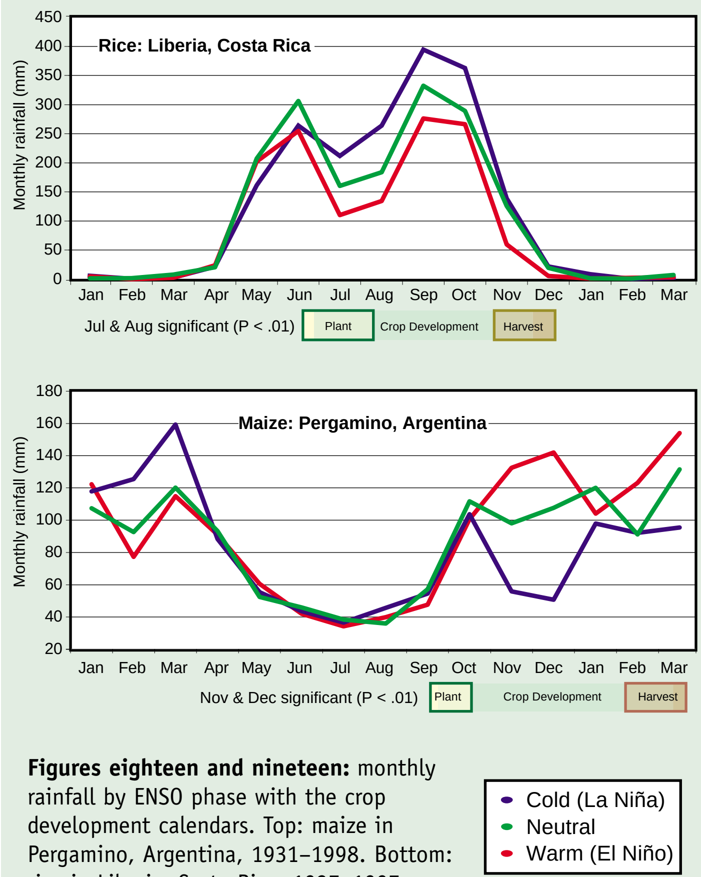
Comparative assessment

phases, rather than the neutral phase. Best simulated management for the drier La Niña phase included an additional irrigation application, higher nitrogen application and increased planting density. Since model results for Mexican varieties had not been validated, the absolute yields and profits cannot be meaningfully compared between the Pergamino and Santa Julia results.

ENSO phase optimization of rice for the Liberia region of Costa Rica was begun, but only preliminary results were achieved. Excess water from heavy La Niña rains is probably less of a problem than water stress during El Niño years. The higher water availability during the La Niña years (figure eighteen, at right) appears to permit the crop to utilize more nitrogen and attain higher yields. Also in Costa Rica, simulation model runs using climate predictions led researchers to recommend that farmers delay planting beans during the 1999-2000 season from the usual period of mid-November through mid-December, until the first half of January. Indications from the field are that the farmers who followed the recommendations have benefited.

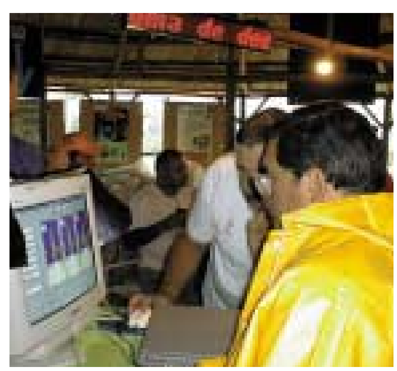
> At one Argentine site, the 1999-2000 season was a typical La Niña year: very dry. The recommended treatment outperformed both the El Niño management and the farmer's usual management.

Argentine researchers also tested simulated results at various Pampas locations during the 1999–2000 La Niña. In most locations the recommendations corresponding to La Niña did not perform the best, probably because in most Pampas areas the rainfall recorded for 1999–2000 was well above the average for La Niña years. At a site near Pergamino, the 1999–2000 season was typical for a La Niña year: very dry. In that case, the treatment recommended for La Niña indeed outperformed both the El Niño management, and the farmer's usual management.



Figures eighteen and nineteen: monthly rainfall by ENSO phase with the crop development calendars. Top: maize in Pergamino, Argentina, 1931–1998. Bottom: rice in Liberia, Costa Rica, 1937–1997.

Growing seasons are shown in bars below the graphs. Variations in average monthly rainfall between ENSO phases indicate potential effects on yield due to water stress during critical phases of plant development.



Argentine researcher demonstrates computer simulation results at a 1999 trade show "Expo Chacra."

User attitudes toward ENSO forecasts

Climate predictions, even with a lead-time of up to a year, are not entirely new in the areas studied. In Liberia (Costa Rica) and around Pergamino (Argentina), farmers were eager to recount traditional methods of weather and climate prediction that are still used by some in those areas. The use of traditional forecasting methods may affect a farmer's ability to understand the uses and limitations of scientific forecasts. Conversely, local terminology, time frames, or other concepts of traditional systems may be useful guides in the application of our forecasts to agricultural activity.

Individuals' beliefs regarding specific ENSO effects have shifted rapidly in some locations. The 1997–1998 El Niño event brought above normal rainfall to much of the Pampas, confirming predictions issued by meteorologists, leading some to believe that knowledge of the current ENSO phase was equivalent to a near-certain spring-summer rainfall forecast. But, the ensuing "ENSO euphoria" was short-lived; however, as neither of the two subsequent La Niña years was as dry as predicted. In the Mexican irrigation districts, several years of well-publicized, but not very accurate predictions have left serious doubts regarding the usefulness of ENSO as a climate predictor. In Costa Rica awareness of the ENSO climate effect is high, but with limited options, forecasts have not led to widely adopted management changes.

Grassland in Costa Rica, used primarily for grazing

Potential applications

In each of the areas compared, decision makers expressed or even demonstrated ways that climate forecasts could benefit agriculture. At the field level, ideas varied with the nature of the production system, and the options available to farmers. Larger Pampas growers stressed adjusting the amount of land in each crop; irrigation district members focused on timing of planting; only the small farmers of Liberia suggested that given an unfavorable prediction, they would consider not planting at all.

Beyond the field scale, Argentine farmers and commodity brokers were intrigued with the possibility of using climate forecasts for other grain-producing regions to inform decision-making. In Costa Rica, some institutional responses were detrimental to farmers: insurance companies reduced coverage for ENSO-related crop loss, grain importers increased imports, lowering prices, and some banks have begun to condition agricultural loans on predicted climate, further restricting scarce agricultural credit. In Mexico, irrigation district administrators suggested prediction-based allocation of resources for maintenance of irrigation infrastructure: if a drier season is predicted, focus on water delivery canals; if a wetter season is predicted, on drainage ditches.

ENSO Phase	ENSO Phase Management		All Years Management		ENSO Value $/ha
	Yield kg/ha	Profit $/ha	Yield kg/ha	Profit $/ha	
El Niño	7701	280.85	7150	260.18	20.67
La Niña	5216	154.93	5395	134.67	20.26
Neutral	6678	226.86	6677	226.32	0.54
El Niño	8967	138.85	8561	113.13	25.72
La Niña	9099	86.50	7667	48.12	38.38
Neutral	8601	104.83	8349	97.72	7.11

Figure twenty: value of ENSO phase for maize production using historical weather data.
Top: Pergamino, Argentina.
Bottom: Santa Julia, Mexico.

Comparative assessment

Implications of Research

What is the current state of climate predictions in agriculture?

All researchers involved in the project expressed the need for improved forecasts, whether based on atmospheric/oceanic simulation models, or on improved statistical models that besides ENSO will include other predictable phenomena such as Atlantic sea surface temperatures. Future advances notwithstanding, caution will always be required when making recommendations based on climate predictions: they will sometimes be wrong.

The integration of climate prediction into agriculture appears to represent a useful technology for farmers and other agricultural decision makers. In particular, climate prediction research in agriculture should probably retain a strong focus on smaller farmers. Methods developed with smaller farmers will be appropriated by larger farmers if deemed useful; whereas those developed exclusively with a large-farmer focus may not be readily applicable on resource-limited small farms.

Where can climate predictions be most appropriately applied?

The accuracy of existing predictions for a particular agricultural area, the scale of farming operations, and the agricultural and economic options available to growers are some of the factors that affect the relevance of climate prediction to a given operation. Blanket statements regarding applicability that do not account for specific conditions are bound to be misleading.

Large, technologically sophisticated producers, such as many of those in the Argentine portion of this study, often have the management flexibility to incorporate climatic forecasts.

A field worker with onions in hand explains how tomatoes are harvested in ID–011, Guanajuato, Mexico.

For climate forecasts to be applicable to smaller farmers like some of those in the Costa Rican portion, they will have to be well targeted, and probably combined with other organizational, technical, or social initiatives.

Maize experiment at Pergamino, Argentina.

The irrigation districts stand out since some decisions are based on events occurring over several months at a watershed scale. Decision makers in irrigation districts can integrate predictions at spatial and temporal scales that are well suited to most climate prediction methodologies. Furthermore, in the Mexican case, irrigation districts of small, well-organized farmers have the central administration and support personnel to use the kind of data that climate prediction most often provides.

What partners should be sought for development and application of methodologies?

Researchers lamented the limitations imposed both by scarce international cooperation and shrinking national government budgets. Part of the solution may be to form partnerships with farmer organizations. This project received significant cooperation and input from a variety of organizations: the irrigation district user associations in Mexico, and the farmer organizations Argentine Association of Regional Consortiums for Agricultural Experimentation (AACREA) and Cambio Rural in Argentina. The possibility of such organizations providing direct budgetary support for this type of research should be investigated for the future.

Cooperation among researchers is the most promising consequence of this multinational study, which could not have been accomplished without collaboration among researchers with diverse talents and among institutions with diverse mandates.

Glossary of terms

anomaly—difference from observed or historical norms.

climate prediction or climate forecasting—the science of using historical and/or observed weather data and climatic patterns to predict weather trends on a long-term and large-scale basis.

Committee Nacional Emergencia (CNE)—Costa Rican national emergency committee

crop management—the growing techniques used in agriculture, including planting and harvest scheduling, variety or crop selected, crop rotation, and pesticide, herbicide, fertilizer, and irrigation usage.

crop modeling—computer based calculation of a particular crop's life cycle from planting to harvest. Often used with historical and/or forecasted weather data to aid in agricultural decision making.

Decision Support System for Agrotechnology Transfer (DSSAT)—A computer-based decision support system developed by a consortium of universities and technical institutions, including many involved in this project.

El Niño—ENSO warm (or hot) phase, characterized by positive SST anomalies.

El Niño Southern Oscillation (ENSO)—the global weather patterns characterized by SST anomalies near the equator in the Pacific Ocean, east of South America between 10°N and 10°S latitude and 140°E and 100°W longitude.

globalization—the liberalization of trade through the removal of regulatory barriers such as tariffs and import/export restrictions.

hectare (ha)—Metric unit of area equal to 10,000 square meters. One hectare is about 2.5 acres.

Inter-American Institute for Global Change Research (IAI)—an international intergovernmental organization, headquartered in Brazil, which facilitates an increased understanding of global change phenomena and their socio-economic consequences for the Americas.

Instituto Metorológico Nacional (IMN)—Costa Rican National Meterological Institute.

Instituto Nacional de Tecnología Agropecuaria (INTA)—Argentine National Institute for Agricultural Research.

Instituto Mexicano de Tecnología del Agua (IMTA)—Mexican National Hydrotechnology Institute.

La Niña—ENSO cool (or cold) phase, characterized by negative SST anomalies.

National Atmospheric and Oceanic Administration (NOAA)—United States government agency responsible for a large portion of ENSO research, as well as the Tropical Atmosphere Ocean (TAO) project, which is critical for ENSO detection.

remote sensing—usage of satellite or other technology for observation of natural phenomena. Used frequently to collect weather data.

sea surface temperature (SST)—temperature of water on the surface of the ocean, which affects ocean currents, wind patterns, rainfall, and many other weather events. SST anomalies usually indicate an ENSO event.

significance—the statistical importance, or lack thereof, of the result of a scientific experiment or set of observations. Often expressed as a number between 0 and 1, with lower numbers representing higher significance.

streamflow—the measure of the amount of water flowing through streams or rivers

variety—the breed or hybrid of a crop. Different varieties can have very different growth characteristics, drought tolerance, expected yield, insect resistance, etc.

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Left: Researchers at Pergamino, Argentina measure the results of a soybean experiment.

Cover background: Irrigation canal in need of maintenance near Huacho, Peru.

Cover: Costa Rican researcher, extensionist and farmer compare notes on ENSO climate variability (top); detail from “Sugar Industry” by Diego Rivera, Cuernavaca, Mexico (middle); Mexican farmer transporting irrigated sugarcane for processing (bottom).

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