ADAPTATION OF AGRICULTURAL PRODUCTION SYSTEMS TO CLIMATE VARIABILITY AND CLIMATE CHANGE: LESSONS LEARNED AND PROPOSED RESEARCH APPROACH

Walter E. Baethgen[1], Holger Meinke[2], Agustin Gimenez[3],

[1] IFDC – Uruguay, Juan Ma. Perez 2917 Apt 501, Montevideo 11300, Uruguay
[2] Department of Primary Industries, PO Box 102, Toowoomba, Qld, 4350, Australia
[3] INIA, Est. Exp. La Estanzuela, Colonia 70000, Uruguay

INTRODUCTION

Societies, cultures and economies in the world's history have successfully developed by mastering their abilities to adapt to climatic conditions. However, the last decades have been characterized by a dramatic growth in human population that is imposing unprecedented pressures on natural ecosystems and on existing agricultural production systems. In addition to this pressure, societies are expected to face changes in climate at also unprecedented rate. Agricultural production systems will require effective adaptive strategies to overcome these expected pressures in the immediate future.

Against the very unfavorable economic scenarios of the last decades, farmers around the world have been struggling to maintain their income by continuously trying to increase yields in their production systems. But these higher productive systems have often become more vulnerable to climate variability and climate change.

These existing pressures demand the development and implementation of methodologies to address issues of vulnerability to climate for assisting farmers and policy makers of the agricultural sector to further develop their adaptive capacity with improved planning and better management decisions.

This article will focus in the mixed livestock/crops production systems of South America and will discuss the lessons learned in the research on the climate variability (CV) and climate change (CC) interactions with agricultural production systems. It also discusses a path for building on such experiences to establish activities (research and capacity building) in the next generation of studies on climate variability and climate change.

BACKGROUND

During the last decade numerous studies have been conducted in SE South America to assess the impacts of climate change and interannual climate variability on agricultural production, and to develop applications of seasonal climate forecasts for the agricultural sector (e.g., Baethgen and Magrin, 1995; Baethgen, 1997, Magrin et al, 1997; Magrin et al., 1998; Baethgen, 1999; Podestá et al., 1999; Magrin et al., 1998; Magrin et al., 1999; Travasso et al., 1999; Hansen et al., 1996; Messina et al., 1999). Most of these studies have considered crops separately and have been oriented to identify agronomic management practices able to better cope with climate change and variability. Although this work has proven very valuable to advance in the understanding of the existing interactions of climate with agriculture, very few efforts have been oriented to work at the farm level integrating production activities. This is imperative since a farmer's decision made for one activity is likely to affect all other activities in the farm due to resource competition.

Given the multidimensionality of the interactions of climate variability with agricultural production systems, multidisciplinary research teams are being formed in Uruguay, Argentina and Brazil. These teams have been trying to improve the planning and decision-making processes in the agricultural sector by considering seasonal climate forecasts. Research has been concentrated in two main areas: (a) characterizing and understanding the observed climate variability and quantifying its impact on agricultural productivity; (b) tutoring farmers, agronomists (working in the public and private sector) and policy makers on the nature and possible applications of probabilistic climate forecasts.

National agricultural research centers in SE South America are also developing and establishing decision support systems for the agricultural sector which consider information on climate variability (Baethgen et al, 2001). In order to benefit from decision aid tools, stakeholders must possess flexibility to change their management practices in response to the improved information. For that reason, activities in the region have been aimed to specify alternative management options that are feasible and reasonable from the perspective of stakeholders. Research has been focused on crop production decisions that are sensitive to possible future climatic conditions and simulation models are being used to identify optimal management. Following this approach, a number of activities have been conducted to evaluate the acceptance and value of ENSO-based climate forecasts for agricultural decision making.

In Uruguay results of these activities are also being incorporated into an Information and Decision Support System (IDSS) that is currently being developed for the agricultural sector. The IDSS combines existing databases and modern information tools (simulation models, remotely sensed information, geographic information systems) to establish drought/flood alerts, monitor the vegetation condition, develop crop yield forecasts, identify best agronomic practices, define land use feasibility classes. The IDSS products are designed to provide agronomists, farmers, government agencies, rural insurance programs, etc., with relevant information for assessing risks and for improving risk management.

An important lesson learned in the first years of activities is that although the scientific community has advanced significantly in the understanding of relevant large-scale phenomena and their effect on the climate variability in the region, climate predictability at the interannual scale is often quite low. Most of the seasonal forecasts are based on statistical methods, and the general consensus in the scientific community is that such methods are reaching their maximum predictive ability. Therefore, there is an increasing weight being placed on the development and improvement of dynamical climate models (General Circulation Models –GCMs, and Regional Climate Models –RCMs).

Given this limitation in predictability large efforts in the current research agenda are being placed in the identification of production systems which are most resilient to climate variability, i.e., production systems with the ability to adjust to or recover from negative impacts and take advantage of positive impacts of the current climate variability. One of the factors that contributes to increasing resiliency of agricultural systems is the identification of appropriate mixes of production activities. For example, establishing crop/livestock mixed systems; using a mix of crop species, cultivar types and sowing dates; combining less productive drought-resistant cultivars and high-yield but water-sensitive crops. In other words, modifying the production systems by introducing two strategies: (a) **increased diversification**, i.e., including activities that are less sensitive to drought and/or temperature stresses and activities that take full advantage of beneficial climate conditions; and (b) **escaping sensitive growth stages**, i.e., establishing crop practices that avoid the concentration of sensitive growth stages in the same period of the year (e.g., different season lengths, sowing dates, etc.). Another pathway for increasing resiliency is by eliminating the climate-related factor which is most limiting to crop productivity (e.g., introducing irrigation in water-limited summer crops).

Activities are also oriented to identify decisions based on the seasonal climate outlooks which have the least negative impact when the most likely forecasted scenario does not occur. Finally, research on seasonal climate forecasts in the region is quite new, and significant improvements are expected in the next few years. For that reason the GRAS research team also continues to explore best ways for including climate forecast information in specific activities such as rural insurance programs, crop yield forecasts, and drought/flood alert systems.

SUMMARY OF MAJOR LESSONS LEARNED ON THE INTERACTIONS OF CLIMATE VARIABILITY AND AGRICULTURE IN SE SOUTH AMERICA

IPCC (2001) defines climate variability as "variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on **all temporal and spatial scales beyond that of individual weather events**". This definition allows the consideration of climate change as a low frequency component of climate variability that can be managed using the same quantitative tools and research approaches (Meinke and Stone, 2003). This in time is the root for the basic premise of our proposed general research approach built on the experience of past work: "**one of the most effective manners for assisting agricultural stakeholders to be prepared and adapt to possible climate change scenarios is by helping them to better cope with current climate variability"**. An advantages of this approach is that it provides immediate assistance to the public and private agricultural sector: in addition to preparing stakeholders to possible future climate scenarios, it helps them to manage the existing climate variability that is affecting current agricultural systems. In developing countries where research priorities are strongly dependent on issues that require immediate action, this premise makes climate change studies more readily justifiable and more feasible to establish.

A second important lesson learned is that in order to take advantage of the incessant improvements in climate knowledge for developing applications in agriculture, climate information at any spatial or temporal scale needs to be communicated in terms of its consequences on agricultural production. This type of information is much more likely to influence decision-making at different levels (farmers, advisers, rural insurance/rural credit organizations, agribusinesses, planning agencies, etc.).

The scientific community is continuously advancing in the understanding of relevant phenomena and their effects on the climate variability and climate change. However, the level of uncertainty of expected climate scenarios at the local level (from seasonal climate outlooks to possible climate change scenarios) is still quite high. Although significant improvements are expected in the next few years, research on climate applications for the agricultural sector currently faces the intricate challenge of providing information that is useful for improving decisions under such high level of uncertainty.

The most effective applications of climate variability and climate change knowledge in the agricultural sector have been those focused on risk analysis and risk management. Such focus requires multidimensional approaches and consequently multidisciplinary research teams. Climate is clearly one of the key dimensions to be considered, but it must be positioned in a general framework that includes all variables and factors associated with agricultural production risk.

RESEARCH NEEDS AND PROPOSED APPROACH FOR FUTURE WORK ON CLIMATE CHANGE AND AGRICULTURE

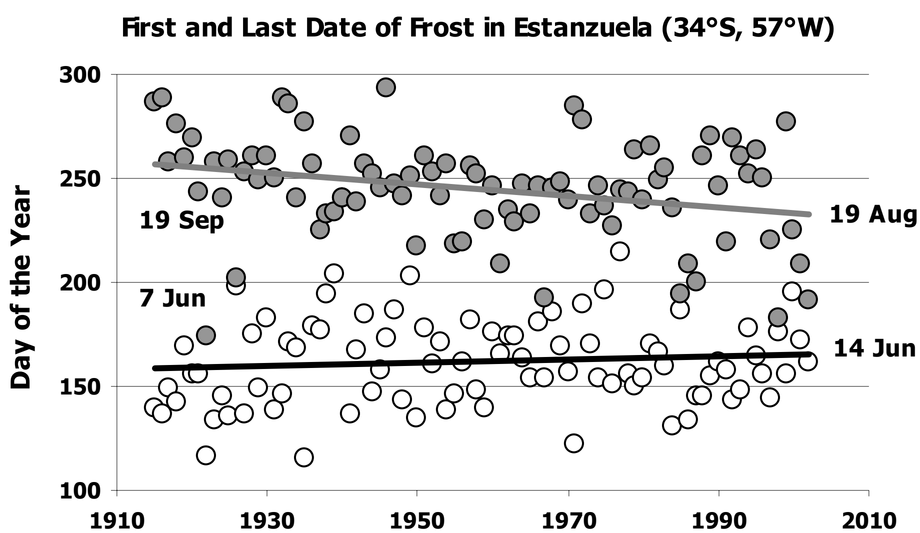
Climate Scenarios

There is a growing confidence among atmospheric scientists that increased greenhouse gas concentration will result in increased global temperatures. However, there is much less confidence on how the climate will change at regional or local scales, which is the scale where socioeconomic impacts will be felt. **Consequently, we propose to consider a range of possible climates for the assessment of the possible impacts of climate change on agricultural production.**

The newest versions of some GCMs and RCMs have proven to perform adequately for simulating climatologic temperatures (e.g., 30 year means of observed maximum and minimum temperatures) in SE South America (V. Barros et al., 2003, AIACC project unpublished). However, the models performance for simulating precipitation (even climatology) is often quite poor (Baethgen et al., 2003, AIACC work unpublished). Consequently one of the methods we propose for generating climate change scenarios is to use GCMs to estimate monthly anomalies of temperatures and rainfall (i.e., GCM output for 2030 SRES A2 or B2 minus GCM climatology). Then use these anomalies to modify the observed weather for 1970-2000. A possible variation of this method is consists of obtaining atmospheric variables from GCM output runs (e.g., SLP, geo-potential at 850mb, etc), and modify observed weather data considering the current existing relationship between those atmospheric variables and weather.

A second proposed method consists of studying the changes in climate during the last 100 years and project those changes for the near future (10-20 years). These projections need to take into account not only changes in mean, median, standard deviations, etc. of temperatures and rainfall, but also the distribution of wet spells, dry spells, absolute maximums, absolute minimums, frequency of storms, frosts, droughts etc. Two examples drawn from the activities of an AIACC project illustrate this method. One is the trend found in the changes in the dates of the first and last frost in SW Uruguay (Fig 1). These changes are crucial since farmers select the winter crop cultivars and sowing dates with the main objective of escaping frost during flowering.

Figure 1. Changes in the dates of first and last frost at Estanzuela (SW Uruguay) during the last century (expressed as a screen temperature of 2^{o}C or lower).



Another example of observed trends is found with the October rainfall also in Uruguay. Most winter crops in southern Uruguay reach anthesis in October. One of the potential problems found in Uruguay for wheat production is the infection with Fusarium sp., which result sin very low yields, low grain quality and the potential for human health problems due to a chemical substance produced by the fungus (DON). Fusarium infection severity largely depends on the relative humidity and temperature during anthesis, and usually rainy October months result in problematic harvests. The data presented in Table 1 (from work of an AIACC project in SE South America) shows that the frequency of high rainfall values in October has increased almost 5-fold in the last 40 years compared to the first half of the 20th century.

Table 1: Frequency of years with October rainfall larger than 140mm, and less than 45mm in Estanzuela (SW Uruguay).

October rainfall	1915 - 1958	1959 - 2002
	Frequency of years (%)	
>140mm	6.80%	29.50%
<45mm	27.30%	22.70%
	Once every	
>140mm	14.7 years	3.4 years
<45mm	3.7 years	4.4 years

Finally, we propose that synthetic scenarios should also continue to be constructed using incremental changes to observed rainfall means (e.g., plus or minus 10%, 20%, 30%), temperature means (e.g., +1°C, +2°C, +3°C, etc.) as well as changes in their variability. Although these synthetic scenarios are often unrealistic and physically implausible, they are still very valuable for studying the sensitivity of different production systems to possible ranges of climatic variations (IPCC-TGCIA, 1999).

Impacts and Adaptation Studies in the Agricultural Sector

Considerable pay-offs can be achieved by using climate information and forecasts to better manage crops and cropping systems. Farmers, planning agencies and other decision makers need to be able to compare alternative crop management strategies that will allow them to cope better with climate variability. The potential value of untried alternatives needs to be explored using a **systems approach** that allows an unambiguous quantification of associated risks and opportunities. The importance of risk analysis and understanding of risks associated with use of forecasts is a key element in this approach.

Decisions in the agricultural sector of both, developed and developing countries are never value free. They are made within a given physical and socio-economic context and based on incomplete and sometimes erroneous information. Any decision includes the risk of economical losses and/or negative environmental impacts. Consequently, a key role for discussion support tools based on systems approach is the ability to evaluate the consequences of alternatives to provide decision makers with a sound knowledge on which to base their actions (Nelson et al., 2002).

Although the actual decisions at the farm level are made by the farmers, their actions are strongly influenced by government agencies, private consultants, insurance/credit programs, research institutions, neighbor farmers, etc. In other words, the existing formal and informal knowledge networks also play an important role in the decision making process. Consequently, applied agricultural system tools must be oriented not only to individual needs but must be able to provide objective information to (and hence influence) these networks. This requires that tools in each region must be developed in close coordination with the existing formal and informal networks which directly affect the farmers' decisions, rather than only working directly with small groups of farmers.

Our proposed approach for research on climate impacts on agriculture has already been presented by Meinke et al. (2003, these proceedings): we need to focus on **risk assessment and risk management**, rather than on specific disciplines to have an impact on agricultural systems. Furthermore, we propose to expand and strengthen the existing international networks (such as ResAgricola), and attain full coordination in establishing common research approaches and methodologies to address locally relevant issues.

Multidimensionality of risk

Risk is the basically the possibility of adversity, and refers to "uncertainty that matters" (Harwood et al., 1999). Consequently, **risk management** consists of selecting alternatives that reduce the effects of risk. Understanding risk is a starting point to help agricultural stakeholders make good management decisions in situations where adversity and loss are possible. Distinguishing the different types of risks that an agricultural stakeholder confronts is useful to explore the different actions required for managing them.

Most of the research on the interactions of climate with agriculture has been focused on **yield or production risks**, which occur because agriculture is subjected to uncontrollable events usually related to weather such as low rainfall, hot spells, hail, insects and diseases. Technology plays a crucial role in this type of risk since it can lead to both, a reduction in the variation of productivity levels (e.g., introducing irrigation in a water limited environment), or an increase in yield variability (e.g., rainfed systems based on high-yielding cultivars, well fertilized but receiving very variable rainfall). As stated above, we have been using systems approach to compare alternative crop management strategies that allow farmers to cope better with climate variability.

However, a comprehensive approach of risk assessment and risk management needs to consider also other types of risk which are also important in agricultural production. Among them, **price or market risks** that are those incurred when prices of outputs or inputs occur after the commitment to production has started. Activities in agricultural production can be quite lengthy, and frequently the expected prices change after the production process began (e.g., foreign countries limiting imports, large increases in world stocks, governmental regulations taxing inputs, etc.). Other risks that need to be considered are **institutional risks** (changes in policies and regulations that affect agriculture), **asset risks** (damage to equipment, livestock, etc.), and **financial risks** (fluctuations in interest rates on borrowed capital, cash flow difficulties, etc.).

Understanding the nature of all of these types of risks is crucial because the actions required to reduce them are different. Interestingly climate can affect all of the mentioned risk types. In addition to the evident of its impact on production and asset risks, exceptionally favorable (or unfavorable) climatic conditions in one region of the world may result in a significant increase (or decrease) in grain stocks with the consequent impact on the International market prices (i.e., price/market risk). On the other hand, in some environments climate variability redeem unfeasible rural insurance programs. However, public policies can be oriented to subsidize rural insurance (or rural credit) programs that can lead to important reductions on the financial risks that farmers confront.

Our proposed approach for research on climate impacts on agriculture focused on **risk assessment and risk management** is oriented to tackle the types of risks mentioned above, to understand their interactions with climate at different spatial and temporal scales (from local to regional, and from interseasonal climate variability to climate change), and to explore ways to reduce them. As stated before, this approach requires establishing multidisciplinary research teams able to provide information relevant to the multidimensionality of the climate-agriculture interactions, i.e., agronomic management decisions, policies affecting insurance/credit programs, information on trends of market prices of inputs and outputs, etc.

An example of the effect of climate variability on rural insurance programs can be found in Uruguayan crop production. Using 10 years of data from samples of 600-800 farmers, Baethgen (2003) estimated the funds (US$/ha) that would be required for a multiperil crop insurance (MPCI) program to insure crop yields equivalent to 70% of the farmers' expected yields. The methodology differentiated two levels of yield risk and variability: that associated with extreme conditions (catastrophic yields) and the rest of the variability up to the yield level to be insured (in this case 70%). The reason for differentiating these two levels is that catastrophic yields are usually covered by National Emergency Systems, while the rest of the yield reductions can be incorporated in private insurance programs. The results for maize ands sunflower (Table 2) show the difference in the yield variability of these crops and their consequent impact on the funds required to establish an insurance program. Maize is highly sensitive to water deficiency and consequently yields are much ore variable than those of sunflower. The resulting needed fund levels for both, covering catastrophic situations and insuring 70% of the expected yields are much higher and variable for maize compared to sunflower. Also, the impact on maize yields of the drought which occurred in Uruguay in the 1999/2000 La Niña year, was much higher than the corresponding to sunflower. Consequently, the mean catastrophic funds calculated for maize with all years was 41% higher than the mean catastrophic funds calculated excluding the 1999/2000 season.

Adequate insurance programs and National Emergency Systems require precise estimations of the probability expected for the occurrence of a growing season such as 1999/2000 (in this case associated with ENSO). On the other hand, the results of the longer-term trends observed in frosts and rainfall mentioned before, emphasize the need to consider these changes when calculating the probability of occurrence of extreme seasons in the future. In addition, the yield variability and associated risk of any crop can be drastically changed by improving the water use efficiency (e.g., managing fallows), or introducing irrigation. For example, even in the severe drought of 1999/2000, approximately 20% of the maize in Uruguay had yields that were higher than the 70%

level of expected yield and therefore, would have required no insurance. Thus, adequate technological decisions can reduce risks, and farmers making the right choices should pay lower insurance rates, and borrow capital at lower interest rates. Moreover, public agencies can use this type of tools (lower insurance payments, lower interest rates) to establish policies oriented to stimulate agronomic practices leading to more "climate-proof" production systems.

Table 2: Calculated funds required for covering catastrophic situations and for insuring a yield level corresponding to 70% of the farmers' expected yields in Uruguay for maize and sunflower. (Mean (1) = all years, Mean (2) = all years except 1999/2000).

	Maize		Sunflower	
	Catastr. US$/ha	70% US$/ha	Catast. US$/ha	70% US$/ha
1992	0.79	15.89	1.81	10.64
1993	2.91	32.06	1.29	8.26
1994	1.72	15.43	0.78	4.27
1995	4.32	62.88	0.60	5.02
1996	2.13	29.00	0.05	3.22
1997	1.22	15.23	2.03	16.38
1998	2.15	14.89	1.31	3.52
1999	23.45	132.78	6.28	37.10
2000	4.71	17.18	0.26	3.87
2001	6.50	57.83	1.76	3.59
2002	0.33	15.79	1.25	9.35
Mean (1)	4.57	37.18	1.58	9.57
Mean (2)	2.68	27.62	1.17	7.01
Change	*41%*	*26%*	*26%*	*27%*

FINAL COMMENTS

The lessons learned in SE South America, Asia and Australia under the currently loose network known as RES AGRICOLA, are leading to the development of 'climate proof' farming systems. Future research on the interactions of agriculture and climate variability (from interseasonal to climate change) should be focused on **risk assessment and risk management**. Work should be oriented to tackle the different types of risks mentioned in this article to understand their interactions with climate at different spatial and temporal scales (from local to regional, and from interseasonal climate variability to climate change), and to explore ways to reduce them. This in turn will require the establishment of multidisciplinary research teams (climate, agricultural and social sciences) as well as the participation of all relevant agents acting in the agricultural sector (farmers, advisors, rural insurance/rural credit programs, planning agencies, agribusinesses).

REFERENCES

Baethgen W. E. y G.O. Magrin. 2000. Applications of Climate Forecasts in the Agricultural Sector of South America. In: Proceedings of the International Forum on Climate Prediction, Agriculture and Development, (pp. 38-44), International Research Institute for Climate Prediction (IRI), Palisades, NY.

Baethgen, W.E. 2003. A basis for crop insurance programs in Uruguay: variability of crop yields obtained by farmers and estimation of catastrophic yields in Uruguay. (In Spanish). MGAP web site www.mgap.gub.uy.

Baethgen, W.E. and G.O. Magrin. 1995. Assessing the impacts of climate change on winter crop production in Uruguay and Argentina using crop simulation models. IN: C. Rosenzweig et al. (eds.), Climate Change and Agriculture: Analysis of Potential International Impacts. American Society of Agronomy Special Publication 59, Madison WI, pp 207-228

Harwood, J; R. Heifner, K. Coble, J. Perry, and A. Somwaru. 1999. Managing Risk in Farming: Concepts, Research, and Analysis. ERS, USDA, Agricultural Economic Report No. 774, 130pp. Washington, DC.

Magrin G.O., Díaz R.A., Travasso M.I., Rodriguez G., Boullón D., Nuñez M., Solman S. 1998. Vulnerabilidad y Mitigación relacionada con el Impacto del Cambio Global sobre la Producción Agrícola. En Proyecto de Estudio sobre el Cambio Climático en Argentina, proyecto ARG/95/G/31-PNUD-SECYT, (eds. Barros V., Hoffmann J.A., Vargas W.M.), (290 p).

Magrin G.O., Díaz R.A., Travasso M.I., Rodriguez G., Boullón D., Nuñez M., Solman S. 1998. Vulnerabilidad y Mitigación relacionada con el Impacto del Cambio Global sobre la Producción Agrícola. En Proyecto de Estudio sobre el Cambio Climático en Argentina, proyecto ARG/95/G/31-PNUD-SECYT, (eds. Barros V., Hoffmann J.A., Vargas W.M.), (290 p).

Meinke, H.; W.E.Baethgen, P.S.Carberry, M.Donatelli , G.L.Hammer, R.Selvaraju, and C.O.Stockle. 2001. Increasing profits and reducing risks in crop production using participatory systems simulation approaches. Agric. Systems 70:493-513.

Messina, C.D., J.W.Hansen and A.J.Hall. 1999. Land allocation conditioned on El Niño-Southern Oscillation phases in the Pampas of Argentina. Agric. Systems, 60:(197-212).

Podestá G.P, Messina C.D., Grondona M.O. and Magrin G.O. 1999. Associations Between Grain Crop Yields in Central-Eastern Argentina and El Niño-Southern Oscillation. Journal of Applied Meteorology Vol. 38, No. 10, pp. 1488-1498.