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Informing Decisions and Policy: the national agricultural information system of Uruguay

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ABSTRACT

Agricultural production systems confront the challenge of achieving sustainable intensification, i.e., increase productivity without affecting the environment in ways that could compromise the development of future generations. In many developing countries the availability of information for assisting public and private stakeholders to achieve this goal is often not a critical limitation. Moving the relevant information from research institutes to extension agents, policy makers, agribusinesses and farmers has been a more frequent limitation.

New approaches, tools and information systems are needed to effectively embed the knowledge generated in the research systems into actual decisions and in the elaboration of public policy. These new approaches and tools must consider, understand and map the existing knowledge networks through which the information flows and reaches public and private. The new systems should incorporate the scientific and technological advances achieved in the different disciplines and generate integrated knowledge for effectively assisting actual decisions and policies.

This article describes the process that led to the establishment of an information and decision support system in Uruguay (SNIA) that is being led by the IRI in collaboration with INIA and the Ministry of Agriculture. The article discusses the general approach and goals that the IRI and its partners are using for establishing the SNIA, and introduces some of its characteristics, the components and capabilities. Finally, the article contains examples of the information, products and tools that are being included in the SNIA.

1. Introduction

Research and development efforts in developing countries are confronting two important challenges. Firstly, the push for increasing agricultural productivity in a sustainable basis, i.e., increase the output per unit area of land in ways that minimize damage to the environment and the natural resource base (i.e., achieve sustainable agricultural intensification). The second concern is the growing awareness that the restricted information flows between farmers, researchers, extension workers, policy makers, and agribusinesses is a serious impediment to achieve sustainable development. The difficulties raised by these concerns, coupled with the complexity of most agroecosystems, the necessity of taking a long term view of biophysical processes, and the limited research resources available, all contribute to support the notion that new approaches, tools and methodologies are required to study the problems of sustainable production, suggest solutions, and assess their impacts at different spatial scales (global, region, local).

Agricultural production systems in developing countries are going through great changes determined by industrialization and modernization, eliminated subsidies, environmental constraints, land use conflicts, biotechnology, and increased overall risk. On the other hand changes in the mean climate and in climatic variability result in even greater challenges for establishing sustainable agricultural production systems. In this context the availability, accessibility and application of relevant agricultural information is of high priority for policy makers, farmers, technicians, and researchers.

The availability of information in many developing countries is often not a major limitation: many countries have adequate research systems that generate relevant information. International institutions such as the Consultative Group for International Agricultural Research (CGIAR) have also been generating valuable knowledge to sustainably improve agricultural production systems. Moving the relevant information from research institutes to extension agents, policy makers, agribusinesses and farmers has been a more frequent limitation. In addition to the traditional mechanisms to obtain information, agricultural stakeholders have increasing access to information systems through different channels including the Internet. Difficulties in these cases are often caused by the massive amount of information and the lack of tools for its analysis and prioritization which often results in inadequate or inefficient use of such information.

Colossal advances have been achieved in the last decades in sciences that are relevant to agricultural production systems. Research in biotechnology, soil chemistry, crop physiology, agrometeorology, among many others have been generating huge volumes of knowledge in aspects that are critical for agricultural production. Still, a relatively small proportion of that knowledge is effectively incorporated in planning, decision-making or in the elaboration of public policy in agriculture. One possible cause for this low adoption of new knowledge may be related to the differences in the way that scientists and decision-makers work. Scientific research typically advances using a reductionist approach that produces increasingly specialized and detailed knowledge on particular issues. Decision makers, on the other, hand approach risk holistically and often intuitively, and the specialized and detailed scientific knowledge often fail to effectively assist the actual process of decision-making. Frequently the narrowly focused sciences that provide knowledge and information on specific fields creates "islands of knowledge in a sea of ignorance" (MEINKE et al., 2006).

Informing actual decisions and policy requires connecting such "islands of knowledge". Tools are currently available for farmers, government planners and decision makers that allow them to obtain and analyze massive quantities of information and assist them in the planning and decision making processes. Examples of such tools include among many others: simulation models, expert systems, remote sensing, seasonal climate forecasts, models and statistical methods for defining possible climate change scenarios, geographic information systems (GIS), global positioning systems (GPS). However, the main constraint to effectively use this tools and approaches is the typical complexity involved in their application and the consequent need for training.

Some developing countries have responded to this challenge by establishing research and development programs, often with cooperation of developed countries, that include training in the use of such tools. However, and even if extension agents, public and private advisers become well trained in the use of these approaches and tools, the generated knowledge may still not inform policy and decision-making. First, it is critical to assess the decision systems that are in place and to understand the actual problems/challenges that decision-makers face as well as the objectives that policy makers seek. This requires effective interaction of scientists and practitioners, and work as collaborating partners from the initial stages of developing science-based information and decision support systems. It also requires good understanding and mapping of the networks through which the knowledge flows for informing decisions and for detecting information needs (i.e., "knowledge networks" or "knowledge systems"). For example, if the main goal of an activity is to inform government agencies for assisting the elaboration of policy, it is crucial to understand what processes and institutional arrangements are in place, what are the sources of information for the different nodes in the existing knowledge network, and how these links can be strengthened.

The subsequent section of this article describes the process that led to the establishment of an information and decision support system (IDSS) in Uruguay that is mainly focused in improving climate risk management in the agricultural sector. The third section of the article discusses the general approach and goals for establishing the IDSS, and the fourth section describes some of the characteristics, the components and some capabilities of the system that is currently being developed in the country. The fifth section contains examples of the type of the information, products and tools that are being included in the IDSS. A final section of the article summarizes some of the lessons learned and includes some conclusions.

2. Informing Decisions and Policy: building trust

The activities that led to the creation of the decision support system for Uruguay described in this paper were closely related to the work of the International Research Institute for Climate and Society (IRI, Columbia University) in climate risk management. These activities started soon after the first Regional Climate Outlook Forum (RCOF) for Southeast South America (SESA) held in Uruguay in December 1997.

During the months prior to the RCOF the world and regional media had been intensely covering the impacts of the strong 1997/98 El Niño event. Consequently, the RCOF roused considerable attention of the general public and particularly of the agricultural and hydroelectricity sectors (hydroelectricity is a key source of energy in the region). It was the first time that staff of the meteorological services in the region met with scientists from the IRI and elaborated the first consensual climate outlook for January-March 1998). The RCOF was partially funded by regional and national farmer associations; therefore, during the meeting and while the meteorologists discussed the climate outlook, a workshop was organized to discuss climate predictability and its implications for planning and decision-making in the agricultural sector. RCOFs in Southeast South America have been organized without interruption since then. The RCOF also triggered the establishing of collaborative activities of the IRI in Uruguay that have continued for the last 15 years.

The first RCOF was a landmark in the work of applications of climate prediction in the region; immediately after the RCOF several research projects were initiated, mainly in the agricultural and hydroelectricity sectors. The National Agricultural Research Institute of Uruguay (INIA-Uruguay) started a project with participation of international institutes including the IRI, in which agricultural researchers collaborated with climate scientists to assess the impact of ENSO on agricultural production and to identify agronomic practices best adapted to the different ENSO phases (BAETHGEN, 1998). The project also created a workgroup of climate scientists, meteorological service staff, and representatives of the agricultural community (researchers, advisers, extension agents) who met periodically, usually after an RCOF was organized, and discussed the implications of the climate outlooks on agricultural production.

This seminal work revealed the importance of identifying and mapping the networks through which the climate knowledge flows and reaches decision-makers that were discussed in a previous section of this paper. For example, the interaction of climate and agricultural scientists stimulated research in the agricultural sector to identify ways in which seasonal climate forecasts could be embedded in planning and decision systems in the agricultural sector. Crop simulation models were linked to seasonal forecasts and to ENSO-related information to identify agronomic practices best adapted to expected climate conditions. Climate scientists interacting with agricultural researchers and advisers started to understand the importance of different types of climate information (products, timing, formats) that had the best potential to inform agricultural production. For example, representatives of the agricultural community developed "decision calendars" that identified moments when climate products would be of maximum use to decision-making (e.g., decisions about selecting crops to be sown, strategies for buying/selling livestock, or planning feed stocks, etc.)

The interaction within the knowledge networks also revealed that in order to improve the salience of seasonal climate forecasts, and of climate information in general the information had to be "translated" into agronomic products (CASH & BUIZER, 2005; BAETHGEN, 2001; HAMMER et al., 2000). As a result of this need, the IRI started collaborating with INIA-Uruguay and used the climate data to establish, for example, soil water balances to provide information on the amount of soil water that is available for plants every 10 days. Simultaneously, the IRI established research in the region to use climate and ENSO information to improve crop disease forecasts (DEL PONTE et al., 2011).

In addition, the IRI also established research to explore the predictability of climate variables that could provide relevant and actionable information to the agricultural sector. An example of advances in this type of work is the relationship found between ENSO phases and the duration of dry spells during the maize growing season (BAETHGEN et al., 2009). The resulting information identified crop management practices that farmers can apply to improve their adaptive capacity in La Niña years.

Working throughout the knowledge networks helped the mutual learning in the different communities. Climate and agricultural researchers improved their understanding of user needs, and in turn, decision makers (including policymakers) learned about the capabilities and limitations of climate information, and provided ideas to link it more effectively to agronomic knowledge. Engaging in this process of continued, shared learning and joint problem solving between disciplines probably helped to generate ownership of the information, a critical issue in improving the actual use of climate-related information (GLANTZ, 2003; GLANTZ, 2005).

By engaging in this type of work the IRI also realized the importance of recognizing the different ways in which various communities manage climate-related risks and make decisions. Informing actual decisions and policy requires connecting the "islands of knowledge" described earlier in this paper, and IRI's activities tried to build those connections in Uruguay via two main strategies.

First, by promoting the interaction of the climate and agricultural communities at different levels (researchers, advisers, meteorological service, farmers, government agencies, etc.). A second strategy that the IRI employed for informing decision-making and planning in Uruguay was collaborating with INIA to develop and establish a general research approach that integrates the climate information, products, and tools with agronomic, economic, environmental, and social information (Information and Decision Support System or IDSS.

From the very beginning, the use of this approach proved to be effective in informing actual decision-making at different levels of the agricultural sector. For example, during a severe drought that occurred in Uruguay in 1999, the IRI and INIA provided the Ministry of Agriculture and the National Emergency System with information on seasonal rainfall outlooks produced by the IRI, on the evolution of the vegetation status (NDVI anomalies) based on remote sensing, and on the changes in soil water content for the whole country (updated every 10 days). This information was used to establish early warnings and to prioritize aid in response to the drought. In a letter from the then-Minister of Agriculture (Ing. J. Notaro) to our working group, the Minister stated, "(...) from the strictly political standpoint, your work provided us with objective information to defend our prioritization of regions, in a moment in which every governor, politician and farmer in the country was asking for aid. We received no complaints in this respect. In the same line, your work also allowed to mitigate pressures since we provided the press and the general public with transparent, technically sound and precise information" (BAETHGEN & GIMÉNEZ, 2009).

Ten years later, during the severe drought of December 2010, the Minister of Agriculture issued an official declaration of emergency for some administrative divisions in the country, based on the information on vegetation status and soil water content. In this case, the soil water balances were performed at the administrative division level as opposed to soil types. The idea was that it is more useful for decision-making to "degrade" the precision in the information produced, but to ensure that the resulting product is implementable (decisions at policy level are not made by soil type but by administrative unit – see Figure 1). Moreover, one month later and while the drought was still affecting the country, the Minister of Agriculture requested additional funding to the Central Government to cope with the drought effects. He opened his presentation to the Parliament with a copy of the most recent seasonal climate outlook from the IRI, which showed an enhanced probability of low rainfall.

IRI's work in Uruguay considered three characteristics that are crucial to ensuring that the information be translated into real-life actions, as discussed by (CASH & BUIZER, 2005) namely: saliency, credibility, and legitimacy. "Saliency" refers to the perceived relevance of the produced information and tools (i.e., is it needed by users? Is it provided in a form and at a time that they can use it?). "Credibility" indicates the perceived technical/scientific quality of the information (i.e., is it perceived to be valid, accurate? Has it been tested?). Finally, "legitimacy" addresses the perception that the information does not serve to push an agenda or interests of other actors.

The collaboration of IRI with INIA and with government agencies prompted a participatory process that helped to translate technical and scientific information into actionable knowledge. This, in turn, resulted in building trust among the different agricultural stakeholders, which was likely facilitated by the fact that the IRI is perceived as a reliable institution with a recognized international reputation and with solid scientific and technical capabilities to create knowledge.

IRI's activities in Uruguay followed the demand-driven, problem-focused research approach described in Goddard et al (2014). Since the early 2000's the IRI faced an increasing demand to assist the different sectors in improving their adaptive capacity to climate change. This increasing demand was probably the result of a combination of factors, including an escalating awareness of the general public on the general issue of climate change, and the importance that the issue gained in the agendas of development agencies with the consequent increased availability of funds.

Responding to this new demand the IRI proposed a research approach to assist in the improvement of adaptation to climate change. The main elements of this approach are described elsewhere (GODDARD et al, 2014; BAETHGEN, 2010; BAETHGEN & GODDARD, 2013). One way to describe the approach as it applies to the agricultural sector is by basing it on four main pillars (BAETHGEN, 2010):

a. Identifying vulnerabilities and potential opportunities due to climate variability/change for a given production system (livestock, grains, horticulture, etc.) in close collaboration with stakeholders. For example, livelihoods where food security depends mainly on the crops that the community sows (as opposed to communities with off-farm income and ability to purchase food) are especially vulnerable to climate variability. On the other hand, accessing timely information on the most likely rainfall scenario for the following season can result in better planning and higher income in crop or livestock production, more efficient irrigation use, etc.

b. Understanding, characterizing, and, when possible, reducing uncertainties in climate information in order to improve the use of that information in the agricultural sector. Understanding the climate aspects of vulnerabilities, challenges, and opportunities requires: (a) learning from the past, i.e., understanding the characteristics of climate at different time scales and assessing its impacts; (b) monitoring the present conditions of relevant environmental factors (climate, vegetation, streamflow, diseases, etc.); and (c) providing the best possible information of the future, at relevant time scales (weeks to decades). The relevance of temporal scales (days, seasons, years or decades) is defined by the stakeholders' demand. Farmers and water managers usually need information at scales of days to seasons; development banks and national planners may be interested in climate at scales of decades; while national authorities designing mitigation strategies may require climate scenarios for the next 50 years or more.

c. Identifying technologies and practices that optimize results in normal or favorable years and/or reduce vulnerabilities to climate variability and change. Examples in agriculture include crop diversification, crop rotations, improved tillage systems, increased water soil storage, improved crop water use efficiency, and drought-resistant cultivars.

d. Identifying policies and institutional arrangements that reduce exposure to climate hazards and enable users to take advantage of favorable climatic conditions. Exposure reduction can be achieved, for example, with improved early warning and early response systems, and by transferring portions of the existing risks with different forms of insurance.

The IRI has been using this approach in several research activities in the agricultural sector of countries across Latin America. In 2012 the government of Uruguay established a large project entitled, "Development and Adaptation to Climate Change" (DACC) in the agricultural sector. The project which is still ongoing, is funded by The World Bank, the Adaptation Fund, and the Inter-American Development Bank.

A key characteristic of the DACC project is that it is focusing its efforts to improve adaptation to climate change by advancing in the adaptive capacity of the agricultural sector to current climate variability. Some of the activities dealing with infrastructure plans (e.g., designing water reservoirs) will be informed with plausible climate scenarios for the near future (from 5-30 years). However, the vast majority of the activities are focused on interventions that aim to improve current climate-related risks. The DACC project's postulation is that reducing the vulnerability of the agricultural production to current climate risks will result in production systems that are better adapted to future climate (BAETHGEN, 2010).

The advantage of this approach is that the actions required for improving adaptation to climate change are needed now, and their impacts on risk management can also be assessed in the present as opposed to a distant future. Efforts in improving adaptation to climate change have often been obstructed by the perceived need to focus in possible climate scenarios that were too far in the future and too uncertain at the spatial scales that are most needed to inform decisions and policies (regional to local scales). Efforts have also been hampered by the frequent need to demonstrate that the efforts to improve adaptation to climate change are additional to the normal efforts needed to achieve socioeconomic development.

The DACC project is based on the premise that achieving sustainable development in sectors that greatly depend on climate, such as agriculture, requires the explicit consideration of improving adaptation to climate variability and change. The project may become influential in the way that development agencies start approaching adaptation to climate change. In fact, The World Bank is already considering the establishment of efforts similar to the DACC project in some of their existing projects in other developing countries.

IRI's participation in the DACC project started in late 2013 and its main role is to lead the establishment of a National Agricultural Information System (i.e., an IDSS), based on the four pillars of IRI's climate risk management approach described above. For the IRI, the DACC project constitutes evidence to the effectiveness of embedding the climate information, tools, and products into integrated decision support systems. It is also a confirmation of the benefits of establishing sustained collaborations, and developing trust with stakeholders from the private and public sectors. Finally, it is an excellent opportunity to demonstrate the usefulness in establishing IRI's general approach to improving climate risk management in the agricultural sector of a developing country. Lessons learned in this comprehensive project are expected to be very helpful for establishing similar efforts across the developing world.

3. The national agricultural information system of Uruguay (SNIA)

The main objective of the DACC project is to assist the Uruguayan farming community to implement sustainable strategies to manage the natural resource base for improving adaptation to climate variability and change. The project also promotes the modernization of the Ministry of Agriculture and Fisheries of Uruguay in two key areas: improving information systems and providing services related to climate and natural resources (mainly soils, water and natural grasslands).

The DACC project defined the small rainfed farmers as the most vulnerable subsector and established a series of special credit lines to assist them in accessing technologies oriented toward mitigating their climate-related risks (e.g., for improving water resource management and enhancing the use and conservation/improvement of the natural grasslands).

The National Agricultural Information System (SNIA, for its Spanish acronym) integrates existing, and produce new information, products, and tools for improving climate risk management and to assist decision-making and the elaboration of policy in the public and private agricultural sectors. Stakeholders of the Uruguayan agricultural sector can access vast amounts of scientific and technological information. The country's agricultural research system includes good institutions such as INIA and the Faculty of Agronomy of the University of Uruguay, with a good record of publications in peer-reviewed journals as well as in technical bulletins. Institutions in the private sector also generate information on plant and animal breeding, agrochemicals, biotechnology, etc. Finally, the Ministry of Agriculture and Fisheries also produce large volumes of information dealing with crop and livestock production statistics, soils, land use, water resources, economics, etc. Furthermore, Uruguay has good connection to the Internet throughout the country (4G/3G/GPRS) and hence, agricultural stakeholders can access huge amounts of scientific and technical information from all over the world.

Therefore, accessing scientific and technical information is not an important constraint for the Uruguayan agricultural sector. In fact, a likely limitation of the effective use of information in actual decisions and planning is probably the lack of tools and resources to prioritize and organize the huge amount of information, identify the "good sources" from the "not so good ones", convert data into useful and relevant information, etc. One of the objectives of developing the SNIA is to assist the public and private stakeholders to overcome some of those challenges.

Another impediment for effectively using the information that is available for the agricultural sector of Uruguay is that different institutions often generate data and information with no connection to similar or complementary information that is generated in other institutions. For example within the Ministry of Agriculture and Fisheries several departments and divisions produce excellent information, sometimes on the same topics, but their information systems are not connected to each other. This results in inefficient use of the material and often in the inability to integrate knowledge that could effectively contribute to decisions and policy making. Responding to these challenges the SNIA is utilizing tools such as IRI's Data Library (BLUMENTHAL et al., 2014; DEL CORRAL et al., 2008) which uses raw data (e.g., climate, geophysical, agriculture, economics, markets, etc.) generated by numerous providers with different formats, and compiles them into a common framework that allows powerful cross-disciplinary research and analysis. Also, IRI's Data Library include "Map Room" mapping tools that allow users to select and manipulate variables to create custom spatial visualizations of regions, timeframes, and subjects of interest.

The Data Library is fully built on open source and free software and it is unique in the breadth and depth of its data, as well as for its flexibility to serve as a platform for users to build up their own services and programs. As part of the SNIA activities, IRI's Data Library was installed in computers of the Ministry of Agriculture and Fisheries and is now being populated with Uruguayan datasets on crops, livestock, census data, climate, etc.

In sum the SNIA is being built seeking two main goals: firstly to facilitate the access of public and private agricultural stakeholders to relevant information and products, and assist them to screen, prioritize, and understand the information and products that they can access. This goal follows the concept of "one stop service" where users can go to one place (e.g., the SNIA web site) for a large portion of their needs.

The second general goal of the SNIA is to connect data and information that are now available in separate publications, bulletins and web sites, and combine different layers of information to generate products with integrated knowledge (e.g., climate, vegetation, land uses, prices, plans, markets, etc.). The motivation of this second general goal of the SNIA is that decision makers, including policy makers, approach problems holistically (DE NEUFVILLE, 2003; MEINKE et al., 2009) and therefore, integrated and multidimensional information is usually more effective for assisting decision-making, planning and elaboration of policy.

4. Description of the SNIA

The work of the SNIA was organized into three main information categories: climate, agriculture, and integrated information. The initial activities were oriented to identify existing databases, perform quality control, and explore the needed steps to incorporate them into the SNIA Data Library. The work in the three areas is oriented to produce information and tools, and to develop the local capacities to further develop the SNIA after the DACC project ends.

Work in the area of "climate" is being organized into three main groups:

a. Provide historical analysis which implied analysis of historical climate and the impacts of climate variability on agricultural production.

b. Establish real-time monitoring of climate and climate-related variables (e.g., rainfall, temperatures, frost, remotely sensed vegetation indices, soil water balances, drought severity indices, etc.)

c. Generate information and products to assess the expected future impacts of climate. This in turn includes improved sub-seasonal to seasonal climate forecasts (2 weeks to 3 months) and improving "near-term climate change" scenarios (10-30 years in the future).

The work in the area of "agriculture" includes:

a. Assess the climate-related risks in the agricultural sector by evaluating the impacts of historical climate on agricultural production (crops and livestock), and evaluating the performance of different agricultural management practices and technologies to cope with past climate variability. This is being achieved by analyzing historical agricultural records and with simulation models using historical climate records.

b. Evaluate and compare the expected results of using different technologies and crop management practices on the yields and economical results of the main annual crops (soybeans, maize, sorghum, wheat, rice).

c. Establish crop yield outlooks by linking climate information (monitoring and subseasonal-seasonal climate outlooks) with crop simulation models.

d. Input data from all agricultural censuses to assess the evolution of agriculturally relevant data such as socioeconomic characteristics of the farming population (farm size, number of farmers, sources of income), land uses, beef / milk / wool / crop production, etc.

e. Use data from the Ministry of Agriculture and the National Meat Institute (INAC1) to estimate the evolution of beef production (kg beef/ha for 1996-present) per agroecological zone based on the data by county. This in turn can thereafter be used to study relationships between beef production and climate, prices received by farmers, etc.

f. Organize and enter the soil survey information for the entire country including soil maps with associated databases. Input also the map of soil units by agricultural production potential (CONEAT) at a scale of 1:40,000.

g. Enter maps and associated databases of basic cartography, as well as maps of rivers, roads, cities and towns, ports, political boundaries (departments –equivalent to states or provinces-, counties), topography (digital elevation maps), etc.

h. Establish linkages to INIA's GRAS web site to access, visualize and use data and information that this group develops and connect them to other data and information to generate new, integrated products.

i. Enter the information of soil use plans elaborated by farmers and their advisors. In 2014 the Uruguayan government passed a law that obligates crop producers to present a plan of the crop sequences they will establish in the following years. The objective of these plans is to ensure that the planned crop sequences do not result in severe soil erosion problems. All soil use plans are uploaded to the web site of the Ministry of Agriculture and it becomes available to the SNIA. The information thus includes the location of all fields with different annual crops in the country which is very valuable to calibrate and validate remote sensing tools to identify crops.

The Uruguayan Ministry of Agriculture and Fisheries has established the National System of Livestock Information (SNIG), a multipurpose system that gives support to operational and strategic decisions in livestock production. The SNIG was developed as a traceability system with national scope and all of the national herd is now tagged with a device (chip) that collects information of every movement and transaction of each animal in the country. So far, Uruguay is the only country in the world with fully traceable livestock population.

Each livestock transaction (transportation, ownership change) must be authorized and it is recorded in real time. As a result, every year the SNIG receives information of about 350,000 operations, and this information is stored in a database and managed through a web portal. This allows the SNIG to store updated data on each animal in the country (where the animal is, where it was) from birth until it is sent to slaughter.

The SNIA will include the capability to establish queries to the SNIG and collect information on for example, the livestock population (calves, steers, heifers, cows, bulls, etc.) at near real time, which in turn can be used to estimate stocking rates in different sub-regions, to calculate beef production per region, etc. More generally, linking the SNIG and the SNIA will allow users to access crucial multidimensional data that can be used for conducting research on key issues for assisting decision making, planning and the elaboration of public policy.

The key partners for establishing the SNIA in Uruguay are: INIA (mainly its GRAS Unit2), the Department of Natural Resources of the Ministry of Agriculture (RENARE3), IRI-Columbia University4, and the SNIG5. In addition the DACC project hired a team of specialists in Geographic Information Systems, programmers, and system analysts to support the establishment, maintenance and improvement of the SNIA.

During the initial stages of the project, the SNIA team organized workshops with the participation of several Departments, Divisions, and Units of the Ministry of Agriculture, as well as from public and private institutions from the agricultural sector, to discuss activities, tools and products that could be developed as part of the general SNIA effort. These workshops were important to encourage the participation of the wider agricultural community in the elaboration of the SNIA, and to promote the ownership of the tools and products that are being developed. As a result of those workshops, nine activities/products were defined for populating the SNIA. The nine activities defined in those workshop are: (a) early warning systems for livestock production (climate and diseases); (b) control of agrochemical applications; (c) monitoring and control of effluents from agricultural systems (dairy, crops, feedlots); (d) characterization of climate related risks as input for index insurance policies in horticulture and beef production; (e) integration and standardization of farmers registry; (f) land use plans for crop production; (g) analysis of the results of the evaluation of crop cultivars; (h) analyses of hydrographic basins for irrigation studies; and (i) establishing a forest fire risk index.

5. Examples of SNIA information, products and tools

As stated above, IRI's participation in the SNIA activities started in late 2013. In this section we present some examples of ongoing work to develop information, products and tools that are available at the time of preparation of this article. We also describe work that is going on to establish products that will become available and operational in the next few months.

5.1 Improved rainfall monitoring system

The work was carried out by two scientists from Uruguay (Pablo Alfaro in representation of the Uruguayan Meteorological Institute -INUMET, and Alejandra De Vera, Faculty of Engineering, University of Uruguay) during a 2 week internship at IRI. The purpose of the work was to improve climate monitoring, in particular of rainfall values, using combinations of rain gauge observations and satellite estimates to improve the spatial coverage of rainfall information.

Rainfall observations in developing countries are often not uniformly distributed in the territory and typically data is interpolated to overcome this limitation. However, interpolation of daily rainfall data is challenging for several reasons, including the overestimation of the occurrence or spatial extent of rainfall and the underestimation of high rainfall events. The utilization of satellite rainfall estimates with appropriate techniques can help alleviate these problems. Although their accuracy is not very reliable at a daily timescale, they can provide information about the spatial structure of rainfall, including where rainfall did or did not occur. These characteristics are used to improve on the interpolation of station measurements

Two different satellite products were evaluated for the SNIA: Tropical Rainfall Measuring Mission (TRMM) multi--satellite precipitation analysis (TMPA; HUFFMAN et al. 2007; and National Oceanic and Atmospheric Administration Climate Prediction Center (NOAA/CPC) morphing technique (CMORPH; JOYCE et al. 2004). These products are both available at a 3-hourly frequency and a spatial resolution of 0.25º lat/long.

Station rainfall data came from 144 stations provided by INUMET, with records covering the period 1998 - 2014. In order to combine station with satellite data, a first needed step is the gridding of the station data on the same grid as the satellite data. Different methods were assessed to accomplish this: (a) interpolate at 0.25-deg using Kriging, (b) Interpolate at 0.25-deg using Inverse Distance Weighting (IDW), and (c) interpolate at 0.05-deg using Inverse Distance Weighting and then average at 0.25-deg (called Block IDW).

Several statistics were used to compare the observed and satellite data in the same grid points (WILKS, 2006; DINKU et al., 2007; DINKU et al., 2010). For rainfall detection the statistics were: probability of detection (POD), false alarm ratio (FAR), frequency bias (FBS), and the Heidke skill score (HSS). For rainfall amount we used the linear correlation coefficient, the multiplicative bias (BIAS), the mean error (ME), and the mean absolute error (MAE). Finally, for rainfall distribution we used the empirical cumulative distribution function (CDF).

Comparisons between the different satellite products with these parameters revealed that CMORPH showed better performance, with unusually good values of some of the statistics, such as correlation (r = 0.79) and probability of detection (POD = 0.82). Therefore, CMORPH was selected as the source of satellite-estimated rainfall.

The next step consisted of merging the station rainfall data with the satellite estimates. The merging technique used in this work followed four basic steps: (a) bias removal from satellite grid; (b) regression of the station data on the (unbiased) satellite data; (c) interpolation of the regression residuals at station locations to the entire grid; and (d) application of a rain/no rain mask to prevent the overestimation of the occurrence of rainfall. An example of the information and the resulting map of the improved rainfall monitoring system can be found in Figure 1.

5.2 Improved seasonal rainfall forecasts

The agricultural sector in Uruguay has been using seasonal climate forecast for several years. Since the first Regional Climate Outlook Forum (RCOF) for Southeast South America that was organized in Montevideo in 1997, agricultural stakeholders have had access to climate forecasts from several sources. One is the "net assessment" forecasts produced and published by the IRI every month (http://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts/). Also, the meteorological community of Southeast South America has organized RCOFs uninterruptedly at least once per year and one of the outputs of the forums is a seasonal climate outlook for the region (https://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html#RAIII). More recently, the International Center for Research in El Niño (CIIFEN) started producing seasonal outlooks every month for eight South American countries (http://www.ciifen.org/). Finally, the INUMET and the University of Uruguay have established a working group that periodically produce seasonal climate outlooks for the country (http://www.meteorologia.com.uy/ServCli/tendenciasClimaticas).

All of these forecasts have been useful to inform decisions in the agricultural sector, and have served as a good reference of climate outlooks given the abundance of seasonal forecasts available in the region. A typical situation in the region is that users can have access to a vast amount of seasonal forecasts, but many of them are poorly documented, they lack of good descriptions of methods used, and have no information on verification.

However, all climate forecasts available in Uruguay are established at coarse spatial resolution. Responding to this challenge, IRI started collaborating with INUMET and the University of Uruguay to establish rainfall outlooks at a much higher resolution. The work is still in progress and researchers are assessing the skill of forecasts considering different predictors for different seasons. The skill of all forecasts is being assessed and the final product will be an automated tool that will select the predictors with best performance for each season. The product will include, in addition to the actual forecasts, information in the skill as measured by different indices (correlation, 2AFC index, Heidke index, etc.). Figure 3 shows an example of rainfall seasonal outlooks established in June 2015 for September--October-November 2015 based on 5 predictors.

5.3 Agro-climatological monitoring system

As stated earlier in this article, INIA and IRI had been collaborating for about a decade to establish information, products and tools to assist agricultural stakeholders in their decision-making and planning. That work included a system for monitoring the vegetation status based on remote sensing (NDVI, EVI), as well as establishing simple soil water balances at country level that consider soil types and weather data (rainfall, temperature, solar radiation, wind). The information is published and updated every 10 days in INIA-GRAS web site7. These products were successfully used by the Ministry of Agriculture of Uruguay in two recent droughts: 1999/2000 (BAETHGEN & GIMÉNEZ, 2009) and 2010/11 (BAETHGEN, manuscript in preparation). In both cases the acting Ministers of Agriculture used the near-real time information to prioritize aid responses and to declare official emergency status in different regions of the country.

Current work in the SNIA is building upon these products and adding new layers of information with the objective of assisting to improve the preparedness and response to droughts. Firstly, a “Drought Severity Index (DSI)” was developed exclusively based on remotely sensed data. The idea behind developing the DSI is that on the one hand the best indicators of water deficits in agriculture are those that combine different indices. Some are good to monitor climate anomalies, others are suitable for monitoring the soil water content and others provide useful information on the vegetation status. The information obtained with the combination of this type of indices is usually better than that provided by any individual one. On the other hand, and as stated above, the distribution of weather stations in Uruguay is not homogeneous and some regions in the country do not have good climate monitoring. Using remote sensing products with nationwide coverage overcome this limitation (this situation is changing due to the recent creation in SNIA of databases with merged observed and satellite-based rainfall data described in an earlier section of this article). Finally, a good real-time monitoring system requires near-real time climate observations, and some times the access to such information from the meteorological institutes may take a few to several days. The DSI developed in the SNIA is based on information that is available in near-real time and thus it becomes independent of the accessibility to observed data.

The DSI developed for the SNIA was built by combining indices of rainfall, vegetation status and surface temperature. Several vegetation indices were assessed and the one that showed best performance for Uruguay was the anomalies of the Normalized Difference Water Index (NDWIa, from NASA’s MODIS dataset8). The DSI was thus built following Rhee et al. (2010) method combining three sources of remotely sensed information: Land Surface Temperature (LST from the MODIS dataset), the NDWIa, and rainfall estimation with CMORPH.

All the data is gridded at 25km to match the resolution of the coarser dataset (CMORPH), and the DSI is now producing real-time maps for the entire country. The SNIA is also assisting the Ministry of Agriculture to establish an index insurance system for dairy production in Uruguay, and the DSI is one of the indices that will be assessed for this work.

The agro-climatological monitoring system that is being developed in SNIA is intended to inform decisions, planning and policy. One of the layers of information that is critical for this purpose is the cattle stocking rate that exists in different regions. For example, a situation where soil water content is low, vegetation shows signs of stress and stocking rate is high, results in a combination that is particularly vulnerable to persistent low rainfall and high temperature conditions. On the other hand, policies should not be oriented to protect situations where vulnerabilities are unnecessarily increased due to farmer management decisions to, for example, work with excessive stocking rates (e.g., for speculating with price variations).

The traceability system implemented in Uruguay and described above (SNIG) provides real time information of the stocking rates at regional and even at the farm level. The SNIA is also considering this information to define vulnerable situations. Hence, in addition to taking into consideration the climate anomalies, the vegetation status, the soil water content, and the drought severity index, the SNIA is overlaying data on stocking rates to monitor and identify regions that are most vulnerable to drought. For example, in May 2015 the Ministry of Agriculture declared an official emergency in a some departments (equivalent to provinces) of Uruguay based on those layers of information. In the following months, emergency was declared in other departments also based in these layers of information. The declaration of emergency triggered the implementation of special credit lines to assist farmers to buy feed and to solve problems of access to drinking water for the cattle.

This is a good example of the effectiveness of considering "translated" climate information (i.e., soil water balances, vegetation status, drought indices) and integrating it with other information (e.g., stocking rates) for informing actual decisions and policies such as the declaration of emergencies. This type of translated and integrated information is also critical for informing decisions at the farm level (e.g., selling or buying livestock, ensuring adequate levels of feed, etc.).

The SNIA team is now continuing work for establishing an improved Early Warning Systems for Agriculture by combining all of the layers of information mentioned above, and adding the improved seasonal climate forecasts. I.e., the early warning system is being developed by linking a good, real-time monitoring system with the best possible seasonal climate forecasts (sub-seasonal forecasts will be added in the near future) to improve climate risk management with better preparedness and early response. Figure 3 shows the schematic representation of the layers of information that constitute SNIA's agro-climatological monitoring system that is already being used for the declaration of emergencies, prioritizing early response, and for assisting decisions at national, regional and farm levels.

5.4 Decision/Discussion system for assessing options in crop production

Given the climate characteristics of Uruguay, crop production systems can have considerable flexibility with respect to management options. For example, summer crops (maize, soybeans, sorghum) can be sown as early as September and as late as December (even early January). These crops can be sown after fallow, after a winter cover crop (such as oats, ryegrass, etc.), or after a winter cereal crop (wheat, barley). Similarly, winter crops can be sown as early as March or April and as late as July (shorter or longer growing season cultivars). On the other hand, farmers may choose to add different types and rates of fertilizers, and may apply those fertilizers at different dates/growth stages. Finally, crops can be grown rainfed or irrigated: the area under supplementary irrigation has been growing in the recent years and is expected to increase at even higher rates in the near future.

These crop management options in Uruguayan production systems help farmers to manage risks related to climate and prices. For example, farmers can diversify their crop production systems (use a mix of crops and crop sequences, planting dates, fertilizer strategies) to avoid situations when climatic stressful conditions such as droughts impact all crops at the same sensitive growth stage (e.g., flowering).

On the other hand, the large number of alternatives causes difficulties for assessing a priori what mixes of crops and crop management practices are more likely to optimize economic results. Moreover, given a seasonal climate forecast, and/or given outlooks of commodity prices, the mixes of optimal management options may change.

Responding to these challenges the SNIA team established a decision support system to assist stakeholders to compare crop yields obtained with different crops and crop management options. Thus, users can select different crops, cultivars, planting dates, fertilizer strategies, irrigation, etc.; they can select a site in the country (weather data and soil type); and the system generates outputs with the yields for the last 30 years expected for the different combinations of locations, soils and crop management options. The results are expressed in boxplots and in curves with probability of exceedance, and therefore, the user can assess the expected mean yield values but also the expected yield variability caused by the climate characteristics of the different seasons. Users can also input information on basal production costs, prices of fertilizers and irrigation, and prices of the grain and the system generates information on the expected gross margins (mean, median, quartiles, variability).

The system was created using the DSSAT crop models (JONES et al., 2003) of soybeans, maize, rice, sorghum, wheat and barley that had been previously calibrated in Uruguay. We built two different versions of the system targeting different types of users. In one of the versions, aiming inexperienced users, the crop models were pre--run with many combinations of: (a) locations (weather) and soil types representing a wide range of Uruguayan conditions, (b) crops (soybeans, maize, sorghum, rice, wheat, barley), (c) generic cultivars representing ranges of growing season lengths, maturity groups, sensitivity to photoperiod, etc., typical of the genetic material available in Uruguay, and (d) crop management options (planting dates, fertilizer use, irrigation, etc.). These runs generated a database with the output variables of the DSSAT crop models (i.e., grain yields, biomass production, yield components, soil nitrogen losses, etc.) with hundreds of thousands of results. We then built a system to query that database in which a user can select different options of crops, locations, soils, management practices, etc., and compare the results of up to five different combinations. The results are expressed as boxplots and as curves of probability of exceedance so that users can assess the expected yields with each combination and also consider the variability, probability of obtaining yields below certain thresholds (e.g., equilibrium yields), etc.

Another version of the system was built targeting more advanced/experienced users. In this case an interface was developed in a way that users can select different locations, weather, crops, cultivars, etc., and then the system runs the DSSAT model in the SNIA web site. The main advantage of this version is that a user can evaluate combinations that may not be present in the pre-run options. The results are also expressed as boxplots and curves of probabilities of exceedance.

At the time of the preparation of this article, two capabilities were being added to the decision support system. One is the consideration of grain prices and costs of production to perform economical analyses. The other one is the capacity to link the crop models with weather generators so that users can evaluate different combinations of soils, weather and management practices under different climate conditions such as El Niño/La Niña years, "dry or wet" years (e.g., 25th or 75th percentiles), etc.

This decision support system will require some training of targeted users such as extension agents, advisers, consultants, agronomists, etc., in the interpretation and use of probabilistic results (boxplots, probability curves). Users will also receive training in the use of the system as a "discussion support tool" (NELSON et al., 2002). For example, extension agents and agronomists can use the tool to assess the expected results of different crop management options selected by farmers and/or by the advisers, consider different scenarios of expected prices and climate (e.g., ENSO phases, seasonal forecasts) and discuss the benefits and disadvantages of different options under different scenarios.

Farmers and their advisers often engage in discussions to assess different crop production options when making decisions on crop plans for the upcoming season. Typically, the only information available to them for introducing quantitative analyses in those discussions is that based on their own experiences. The premise of the decisions/discussion tool that is being developed under SNIA, is that it introduces quantitative information of a wide range of options, including some options for which farmers and agronomists may not have previous experiences (e.g., new crops, irrigation).

5.5 SNIA Tools and products under development

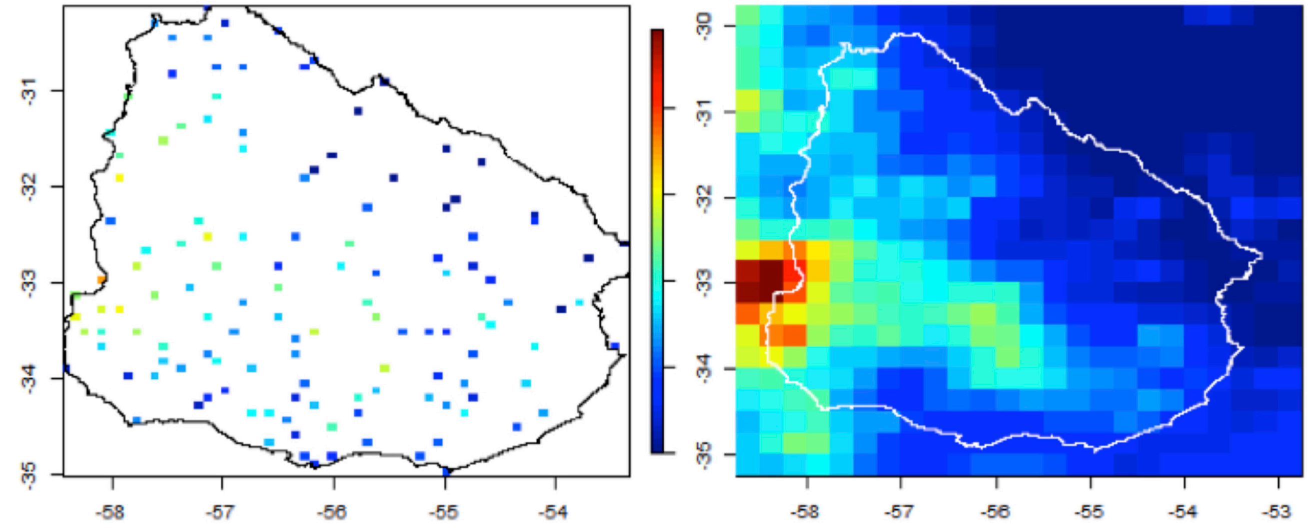
At the time of the preparation of this article several products were being developed and were expected to become functional in the SNIA platform in the near future. In this section we describe a few of these new capabilities.

5.5.1 Crop production forecasts

Information on expected crop production in food insecure countries is critical to issue early warnings and improve preparedness in cases of expected food shortages. The experiences that we are acquiring in developing tools and products for the SNIA in Uruguay will be used to establish similar systems in other countries where the IRI and collaborators work, including those with food security challenges. In more developed countries, the information of the expected crop harvest is helpful to estimate storage needs, plan transportation and logistics and to estimate the expected volume of grain for export or for use in local agricultural industries.

Crop production outlooks require measuring the areas sown to different crops and estimating grain yields expected in different regions. Research teams in Uruguay (INIA, RENARE) and the IRI are testing remote sensing tools and products to identify and measure areas with annual crops (as opposed to pastures or forests). Tools are also being tested to distinguish the different annual crops (e.g., maize or sorghum vs. soybeans). Success in this work will result in good estimations of the areas under crops for each growing season.

Crop yields in the different regions of the country, the other variable needed to produce crop production outlooks, are being estimated by following a stepwise approach. Work starts by assessing the correlation of observed crop yields (provided by collaborators in the private sector) with simple variables such as vegetation indices (NDVI, NDWI, EVI) and/or soil water content in the crop fields at critical growth stages such as flowering. The next steps consist of using crop simulation models with observed data up to the date of the outlook and different sources of climate information thereafter (e.g., climatology, seasonal climate forecasts). Finally, remote sensing information and climate information are assimilated with crop simulations to further refine the model runs. The gains in skill of the different steps are then evaluated to select the best tool for establishing crop yield forecasts.


(a) Observed rainfall

(b) Estimated rainfall with CMORPH

Figure 1. Example of a map obtained by merging station observations and satellite (CMORPH) estimations of rainfall.

5.5.2 Warning system for agrochemical applications

Food safety and water quality related to agricultural production are major concerns of the government of Uruguay. Crop, fruit and horticultural production in the country typically requires the use of herbicides and pesticides and consequently, the potential for contamination of human settlements or water courses with agrochemicals has become a critical challenge.

The SNIA platform includes maps and databases with the location of water courses, towns, rural schools, hospitals, etc., and it also includes the location of commercial bee hives. The minimal distances that must exist between the sites where agrochemicals will be applied and different sensitive environments, are legally regulated in the country. A new regulation obligates operators to include a GPS device in the equipment used to apply herbicides and pesticides. The regulation also obligates operators to install a device that sends the geo-referenced location of the equipment when the pump is turned on to start applying the agrochemical. The SNIA includes a system that receives the location of the equipment and overlays it with a map that includes the location of towns, water courses, schools, hospitals, commercial bee hives, etc. The SNIA system then calculates the distance between the location of the equipment and the sensitive environments, and automatically sends a message to the equipment operator via cellular telephone (SMS) with the authorization or the prohibition to apply the agrochemical.

5.5.3 Index insurance program for dairy production

Rainfall variability in Uruguay at the interannual scale is huge: often months with excess rainfall are followed by a drought, sometimes within the same crop growing season. Consequently, agricultural production systems need good insurance policies to enable transferring at least a portion of the climate related risks. However, traditional agricultural insurance policies are quite expensive and often require large government subsidies, which is usually prohibitive in developing countries.

Responding to this challenge the Financial Instrument Team (FIT) of the IRI[9] has been working with partners to help developing countries to overcome climate risks through financial tools such as index insurance and index-based disaster risk management (e.g., Norton et al., 2014; Carriquiry and Osgood, 2012). IRI work in financial tools has unlocked many constraints for enabling index insurance to fight poverty at large scales, overcoming what have previously been considered impossible hurdles in technology, information, poverty levels, and farmer involvement. The approach that FIT-IRI has been using is based on strong science knowledge, cooperative design and validation, and strategic integration into development efforts.

The IRI is leading the efforts in the DACC project of Uruguay to establish an index insurance program for the dairy production sector. Work started by interacting with representatives of the dairy sector (industry, advisers, farmers) to understand the key climate or climate-related variables that affect dairy production. The work also included the organization of workshops in different regions of the country in which dairy farmers identify the most problematic years for their production systems due to climate and/or to other factors such as prices. The next step consists of identifying the climate or climate-related va-

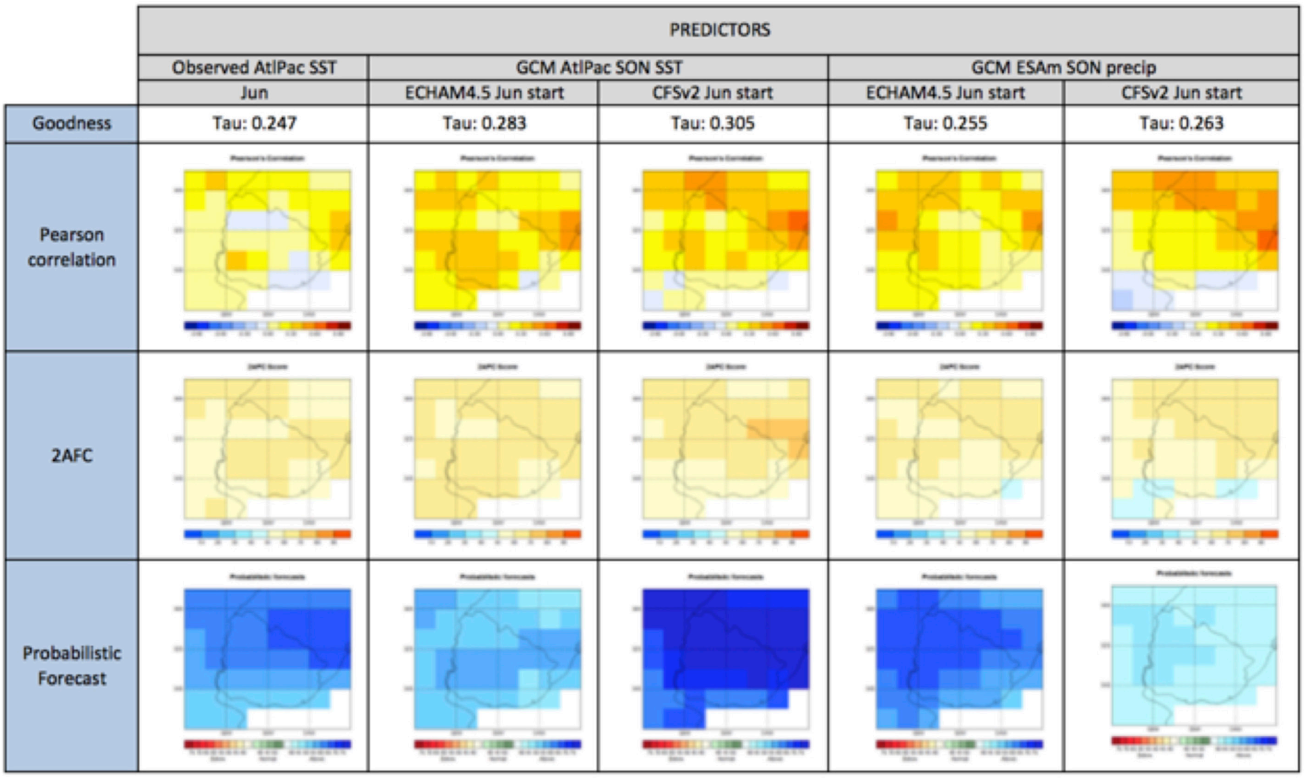


Figure 2. Example of a rainfall seasonal forecast issued in June 2015 for September – October – November (SON) 2015, based on 5 predictors: (a) Observed sea surface temperature (SST) in the Atlantic and Pacific oceans, (b) SST as simulated by the ECHAM general circulation model (GCM), (c) SST as simulated by the CFSv2 model, (d) precipitation as simulated by the ECHAM model, and (e) precipitation as simulated by the CFSv2 model.

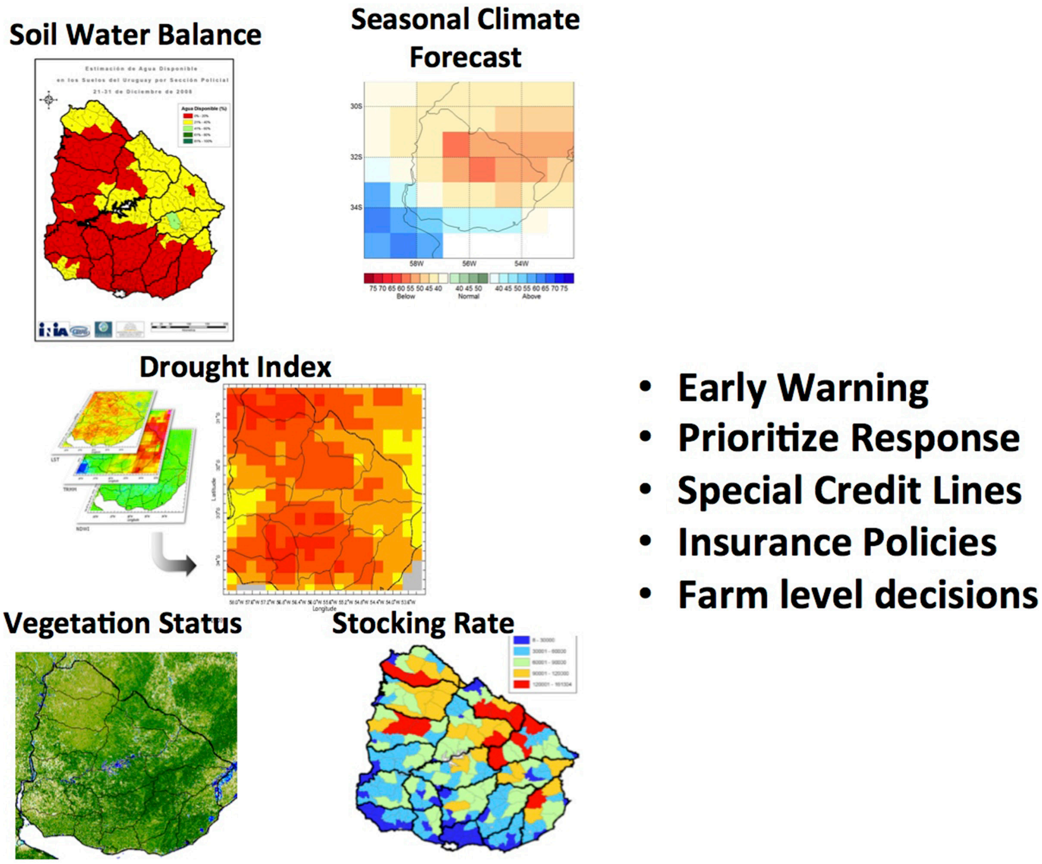


Figure 3. Schematic representation of layers of information that constitute SNIA's Agro-climatological monitoring system

riables that are best correlated with the problematic years identified by farmers, and to work with the insurance sector to develop financial products that are both, effective for transferring risks of dairy farmers and feasible to implement by insurance companies. This work results in establishing a pilot program that is then tested for assessing the feasibility for expansion to National scale. Throughout this process technical staff of the dairy sector, of the Ministry of Agriculture and of insurance agencies receive training in all of the key issues related to index insurance programs. In order to ensure total transparency in the implementation of the insurance program, the information of the climate variables used for the index insurance is placed and updated in the INIA-GRAS web site and linked to the SNIA platform.

6. Conclusions

Agricultural production systems are confronting the challenge of achieving sustainable intensification, i.e., increase productivity without affecting the environment in ways that could compromise the development of future generations. In many developing countries the availability of information for assisting public and private stakeholders to achieve this goal is often not a critical limitation. International institutions such as the CGIAR and National research organizations often generate good information to support sustainable development. Moving the relevant information from research institutes to extension agents, policy makers, agribusinesses and farmers has been a more frequent limitation.

In addition, agricultural stakeholders have increasing access to the Internet and therefore to huge amounts of information that could also inform decision making and planning. Here a typical constraint to effectively use the available material is the lack of tools to assist users in the screening, prioritization, organization, translation, adaptation of the vast volume of information.

New approaches, tools and information systems are thus needed to effectively embed the knowledge generated in the research systems into actual decisions, plans and in the elaboration of public policy. These new approaches and tools should consider and understand the existing knowledge networks through which the information flows and reaches public and private stakeholders (farmers, agronomists, agribusinesses, advisers, ministers). The new systems should incorporate the scientific and technological advances achieved in the different disciplines and generate integrated knowledge for effectively assisting actual decisions and policies.

In 2012 the Ministry of Agriculture and Fisheries of Uruguay started a large project to improve “Development and Adaptation to Climate Change” (DACC) in the agricultural sector. One of the key components of the DACC project is the establishment of an information and decision support system (SNIA) that is being led by the IRI in collaboration with INIA and the Ministry of Agriculture. This article describes the process that led to the establishment of the SNIA. The system is mainly focused in improving climate risk management in the agricultural sector and it integrates information, products and tools from a wide range of disciplines. The article also discussed the general approach and goals that the IRI and its partners are using for establishing the SNIA, and introduced some of its characteristics, the components and capabilities. Finally, the article contains examples of the information, products and tools that are being included in the SNIA.

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Informando decisões e políticas: o sistema nacional de informação agrícola do Uruguai

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RESUMO

Os sistemas de produção agrícola enfrentam o desafio de alcançar a intensificação sustentável, ou seja, aumentar a produtividade sem afetar o ambiente de uma forma que possa comprometer o desenvolvimento das gerações futuras. Em muitos países em desenvolvimento a disponibilidade de informações para auxiliar os interessados, tanto os agentes públicos quanto os privados, para atingir esse objetivo, muitas vezes, não é uma limitação crítica. Levar as informações relevantes de institutos de pesquisa para os agentes de extensão, agricultores, agroindústrias e formuladores de política tem sido uma limitação mais frequente. Novos enfoques, ferramentas e sistemas de informação são necessários para efetivamente incorporar o conhecimento gerado nos sistemas de pesquisa em decisões reais e na elaboração de políticas públicas. Estas novas abordagens e ferramentas devem levara em consideração, entender e mapear as redes de conhecimento existentes, através das quais a informação flui e atinge os agentes públicos e privados. Os novos sistemas devem incorporar os avanços científicos e tecnológicos alcançados nas diferentes disciplinas e gerar conhecimento integrado para efetivamente auxiliar políticas e decisões reais. Este artigo descreve o processo que levou ao estabelecimento de um sistema de informação de apoio à tomada de decisão no Uruguai (SNIA) que está sendo liderado pelo IRI em colaboração com INIA e o Ministério da Agricultura. O artigo discute a abordagem geral e os objetivos que o IRI e seus parceiros estão usando para estabelecer o SNIA e introduz algumas das suas características, componentes e recursos. Por último, o artigo apresenta exemplos de informações, produtos e ferramentas que estão sendo incluídas no SNIA.

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