SGP-HD003

Climate change and irrigated agriculture: Towards a better understanding of driving forces and feedbacks between decision makers and biophysical environment, and their impacts on hydrological cycle and land use

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The aim of this project was to assess the impacts of global change on the hydrological cycles in the American cordillera, and to evaluate regional and local adaptation capabilities, with an emphasis on alternatives and perceptions of decision makers. The project addresses strategic issues such as the vulnerability and adaptability of irrigated agricultural systems; impacts and feedbacks of changes in agricultural productivity as a consequence of farmer´s responses to changing water allocations; and the relationships between global environmental change, land use, and water supply for human uses in a quantitative framework.

Increasing competition for water resources combined with changes in temperature, precipitation and runoff all affect agriculture. As a consequence, farmers need to adapt their production systems, switching crops, changing sowing dates, increasing irrigation and possibly even selling land. With increasing value of water use rights they may also sell such rights. These decisions in turn reshape the process of change, may provide opportunities for land users and change irrigation and water management needs. Such feedbacks between decision processes and the biophysical environment need to be understood if adaptation research is to be policy-relevant.

This project provides an interdisciplinary collaboration to two CRN projects, “Land use change in the Rio de la Plata basin: Linking biophysical and human factors to predict trends, assess impacts, and support viable land-use strategies for the future” (CRN2031), and “Documenting, understanding and projecting hydrological changes in the American Cordillera” (CRN2047).

The objectives of this project were to:

1. Characterize the socioeconomic conditions of decision makers (mostly farmers)
2. Evaluate the impacts of climate and land use change on irrigated agriculture and characterize feedbacks between environment and adaptation decisions
3. Assess changes in water demands and irrigation needs at the regional level in response to changes in hydro-meteorological conditions and land use
4. Estimate the productivity of irrigated areas as a function of water availability (baseline scenario) and analyze the vulnerability of water and land use systems
5. identify and evaluate adaptation opportunities for farmers

The research team assembled databases of climate, soils and agricultural systems for two locations, the Maipo River Basin in Chile and the Córdoba Region in Argentina (especially, Rio Segundo Department in the central part of the Province), and, based on that, developed models to forecast water needs and crop yields under climate change in the years 2020 and 2080.

1. Socio-economic aspects

Mixed farming of arable agriculture in combination with a diversified livestock activity of dairy, beef cattle has been practiced in Rio Segundo Department since the middle of the 20th century. In the late 1980’s this area was characterized by the production of peanut, soybean, sorghum, meat, and dairy, identified as “the peanut core of Argentina”.

During the fourteen years between two censuses, production intensified, supported by larger investments in technological innovation packages since 1990, which included the introduction of direct seeding and genetically modified crops, an intensified use of agrochemicals, and more irrigation. As a consequence, the project team found a decrease in medium/small farms and an increase in larger farms. This concentration of production in fewer, larger farms proceeded through a combination of different modes of land tenure, with some land in ownership and some under lease. Smallholders now may choose to retire from agriculture and become lessors, because high international food prices have raised land rents sufficiently to allow them to live and support their families off the rent. All this has also expanded the agrarian frontier. Still, family farms and agricultural businesses exist alongside each other, with the businesses being the minority in numbers. Both forms of production contract farming services, principally at harvest. New forms of contractual integration, the “planting pools” stand out, and although not widespread yet in the district, they need to be assessed.

These land use changes also brought about a greater homogeneity in the productive landscape and a stronger predominance of soybean, corn and wheat. A drop in hay crops (57%) and livestock farms (50%) accompanied the growth of the cultivated area for grains (+125%) and oil seeds (+35%). Amongst the oil seeds, peanuts lost in importance (-83%) and soybean showed a pronounced expansion of the cultivated area (+1760%), doubling the total agricultural area in just about little more than a decade (Figure 2).

2. Evaluation of impact and feedbacks

In the Rio Segundo basin, climate information from two meteorological stations (Pilar and Manfredi) was used to calculate impacts of climate change on irrigation needs and yields using DSSAT crop simulation models. As in many zones of the Pampas region, precipitation and minimum temperatures showed a positive trend during the last decades of the 20th century (Figure 1). The distribution of rainfall along the year is uneven, with a clear pattern of low precipitation in winter and higher precipitation in spring-summer. Annual minimum temperatures also show a positive trend and contribute to longer frost free periods.

The most important factor for the huge increase in arable land mentioned above is the increase in rainfall and the advent of improved technologies, in particular the adoption of zero till, agrochemicals and new varieties – all also contributing to higher yields in this area. However, crop yields in the period 1971-2005 showed also an important interannual variability (Figure 3), mainly attributable to the El Nino (ENSO) phenomenon. Higher precipitation during El Niño years increased grain yields of summer crops, and lower rainfall in La Niña years led to yield reductions. The opposite trend was found for winter wheat, the yields of which were higher under La Niña and lower during El Niño years (Figure 4).

3. Changed water demands

During the last ten years a number of farmers in the basin has adopted supplementary irrigation as a way to cope with the climatic variability that has constrained their production. Results from the National Institute of Agricultural Technology (INTA) demonstrate that irrigation improves grain yields and helps to stabilize production. The greatest impact was observed in wheat (Table 1).

Irrigation needs were estimated through modeling with CROPWAT (a crop-water model) for wheat, maize, soybean as first crop and soybean as second crop, using data from the Pilar and Manfredi weather stations for the period 1971-2005. Results for Pilar indicate that it would be necessary to add, on average for each crop cycle, 400 mm of irrigation water for wheat, 280 mm for maize, 260 mm for soybean (1st crop) and 200 mm for soybean (2nd crop). For Manfredi, these figures are 380, 280, 270 and 210 mm, respectively. Adding 400 mm for wheat corresponds to adding 50% of the total annual precipitation. Particularly important is that, as winter precipitation is, with only 200 mm, quite low, this crops requires significant amounts of water by end of winter beginning of spring. Likewise, adding 200 mm of irrigation water for summer crops represents one quarter of total rainfall, or an additional 1/3 of summer season rainfall (600 mm).

4. Productivity and water demand: vulnerability and opportunities

4.1. Summer river flow modeling

A stochastic model of monthly summer (October – March) river flows in the Rio Maipo at Manzano, Chile, constructed on the basis of climate variables, allows simulating interannual flow variability under the current climate, under influence of ENSO, under other (random) factors; as well as under a warming climate, especially considering winter snowpack accumulation. Project activities focused on the analysis of climatological relationships between eastern tropical Pacific (Niño 3.4) sea surface temperatures (SSTs) with winter precipitation, and the combined effects of winter precipitation and winter minimum temperature on summer river flows.

A new disaggregation technique, based on a Principal Component Analysis of historical monthly flows at Manzano, was devised to apportion the simulated summer flows into individual monthly values suitable for driving hydrological simulations. This simulation model is now ready for use.

The summer hydrology of the region is driven by melting of mountain snow that has accumulated over the previous winter. Winter (May – August) precipitation is well related to ENSO. Winter minimum temperature is significantly and negatively related to summer flow, because warmer winters result in more winter precipitation falling as rain and less as snow.

4.2 *Water rights and vulnerability*

Chile has adopted market mechanisms for water allocation, and, despite some intersectorial problems, property rights have been secured under limited governmental regulation since 1981. The national water code defines water as “national property for public use”, granting permanent and transferable water-use rights to individuals. These rights are defined by the Directorate General of Water (DGA) considering a minimum stream flow (the flow that is exceeded in 85% of the years). These rights are given to users after an assessment that demonstrates the availability of the resource and the absence of water conflicts. After the water rights have been assigned, the users are free to conduct economic transactions. Water rights grant security to their owners so the resource cannot be expropriated without economic compensation. At this time, all permanent water rights have been granted, leaving few exceptional water rights - and groundwater exploitation - as the only possibilities to increase the irrigated area.

An important feature of the water policy is the definition of an ecological streamflow as a certain amount of water that has to be left in the river to maintain biological activity and preserve biodiversity in the basin. Although most of the rights were allocated before the establishment of ecological streamflow regulations, the fact that permanent rights are based on the 85% probability rule, and that the remaining non-permanent (occasional) rights represent only a small fraction of the river flow, leaves sufficient water for ecological services.

The research team analyzed the vulnerability of permanent water rights under two climate change scenarios (Baseline, B2 and A2) for four different Maipo river sections, based on monthly mean river flow data, and data from the Chilean agricultural census and the Directorate General of Waters. Figure 5 shows that under two different IPCC climate change scenarios, the probabilities of these water rights to supply the required demand may fail in up to 40-50% of the cases, compared to 6-20% failure rate in the baseline scenario (BL in Figure 5). This type of analysis was also extended to irrigation districts (not shown here). An important lessons of these scenarios is that water rights for highly stressed basins will provide the same yields under future climate change, and that adaptation will be imperative.

4.3 Impacts of climate change on crop production

The research team used biophysical models of DSSAT v. 4.02 to assess the possible impacts of climate change on irrigated crop production (wheat, maize, soybean) in the Rio Segundo Basin (Córdoba, Argentina). These models run at a daily time-step to simulate crop development, growth and yield considering water and nutrient availability. Input requirements include climate, soil, crop management and cultivar characteristics. The models, CERES and CROPGRO, were calibrated and validated under Argentinean conditions at the plot and field level and low estimation errors were found.

5. Future scenarios

Individual crops: under IPCC scenario A2, wheat and soybean will increase their yields in the future under irrigated and rainfed conditions, while maize will suffer yield reductions that will become more important towards the end of the century under both conditions. Irrigation needs will mostly decrease, especially towards 2080.

Crop rotations in 2020. Under typical crop rotations (wheat/soybean-maize and wheat/soybean-maize-soybean), yield changes will be positive for wheat and soybeans and slightly negative for maize. The magnitude of these changes is higher under rainfed conditions, probably because of CO_2 effects. Season length (days to crop maturity) will be reduced by some 5 days in wheat and maize and by about 2 days in soybeans. Lower irrigation requirements were found by the model for the two crop sequences; even if daily evapotranspiration is higher because of warmer conditions, the interaction with CO_2 leads to reduced irrigation needs by some 50 mm in the rotation WH/SB-MZ-SB and by 30 mm in WH/SB-MZ, representing a 5% reduction.

Crop rotations in 2080. Towards the end of the century, yield changes could be greater. Under irrigation, soybeans as 2nd crop following wheat could increase yields by some 30%, while as 1st crop in the wheat/soybean-maize-soybean rotation it would increase only by 5%. This is inverted under rainfed conditions, with a 40% yield increase for soybean when it is planted as 1st crop. Under wheat/soybean-maize, irrigation needs could decrease by 145 mm (28%), and under wheat/soybean-maize-soybean by 100 mm (15%).

Adaptation strategies. Considering that soybean is likely to benefit from climate change, farmers can be expected to increase the soybean area. If soybeans are planted continuously as monoculture, organic carbon and nitrogen losses from the soil profile over 30 years are much higher than if planted in rotation with wheat and maize. These losses are still higher under irrigation. Thus, planting soybean in rotations should be promoted for soil conservation.

Planting dates and irrigation strategies in 2020: warming projected for 2020 is close to 1ºC, sufficient to modify the crop calendar by advancing planting dates. New planting dates are 10/6 for wheat, 20/11 for soybean, 7/9 for maize and 15/1 for soybean as 2nd crop after maize. These results indicate that once planting dates are moved, it is possible to modify the crop sequence by incorporating soybeans as a 2nd crop after maize, as farmers could then harvest four crops in two years. This intensification does not put soil sustainability at risk, as total organic carbon and nitrogen losses would be lower than under current conditions. Comparing irrigated with rainfed yields, the best option in 2020 could be to irrigate only wheat and maize. Thus, soybean yields would be slightly lower but water savings will be important and losses of total organic carbon and nitrogen lower (-10%).

Planting dates and irrigation strategies in 2080: by the end of the century, temperatures will increase by more than 3ºC, so that new, even earlier planting dates in the above-mentioned crop sequence would be 20/5 for wheat, 5/11 for soybean, 30/8 maize and 10/1 for soybean as 2nd crop after maize. This would allow reducing losses in maize and increasing gains in wheat and soybean. Comparing yields obtained under irrigated and rainfed conditions, the most sustainable option could be to irrigate only soybean as 1st crop and maize. Wheat yields would be slightly lower but water savings of up to 30% would be possible.

5.1 Climate perception of irrigating farmers in Rio Segundo, Córdoba

The main perceived climate risks affecting agricultural production in Rio Segundo, besides shortages of irrigation water, are early frosts during April and late frost in the middle of November. The latter are particularly harmful and affect yields seriously. Second comes hail; many farmers having contracted insurance for this risk. Wind was reported as another major problem, especially strong winds around harvest, particularly damaging if associated with hail. Both flooding from excessive rains, and drought (which requires more intensive irrigation) lead to increased production cost and are important climate risks.

Farmers pointed to the impossibility to observe climate change phenomena in the short term. Farmers' interest in climate becomes stronger at certain moments of the productive cycle. Roughly half of the interviewed farmers claimed not to perceive climate change effects, or they do not identify them as deviant from "normal" variability. Climate information is usually obtained from media weather reports, not from the National Institute of Agricultural Technology (INTA). However, some changes were noted. Farmers start to show interest in the frequency and the intensity of climate events, as a necessity for current production. One of the irrigating farmers installed a meteorological station on his farm, and others would like follow, but complained about the involved high costs. It seems that the recent changes towards larger farms with technological innovation and attempts at improving farm management efficiency are key factors that affect the subjective perception of the climate variability.

5.2 Irrigating farmers' strategies in relation to climate dynamics

Current and potential adaptation strategies in face of the changing climate were addressed in discussions of the concept of adaptation.

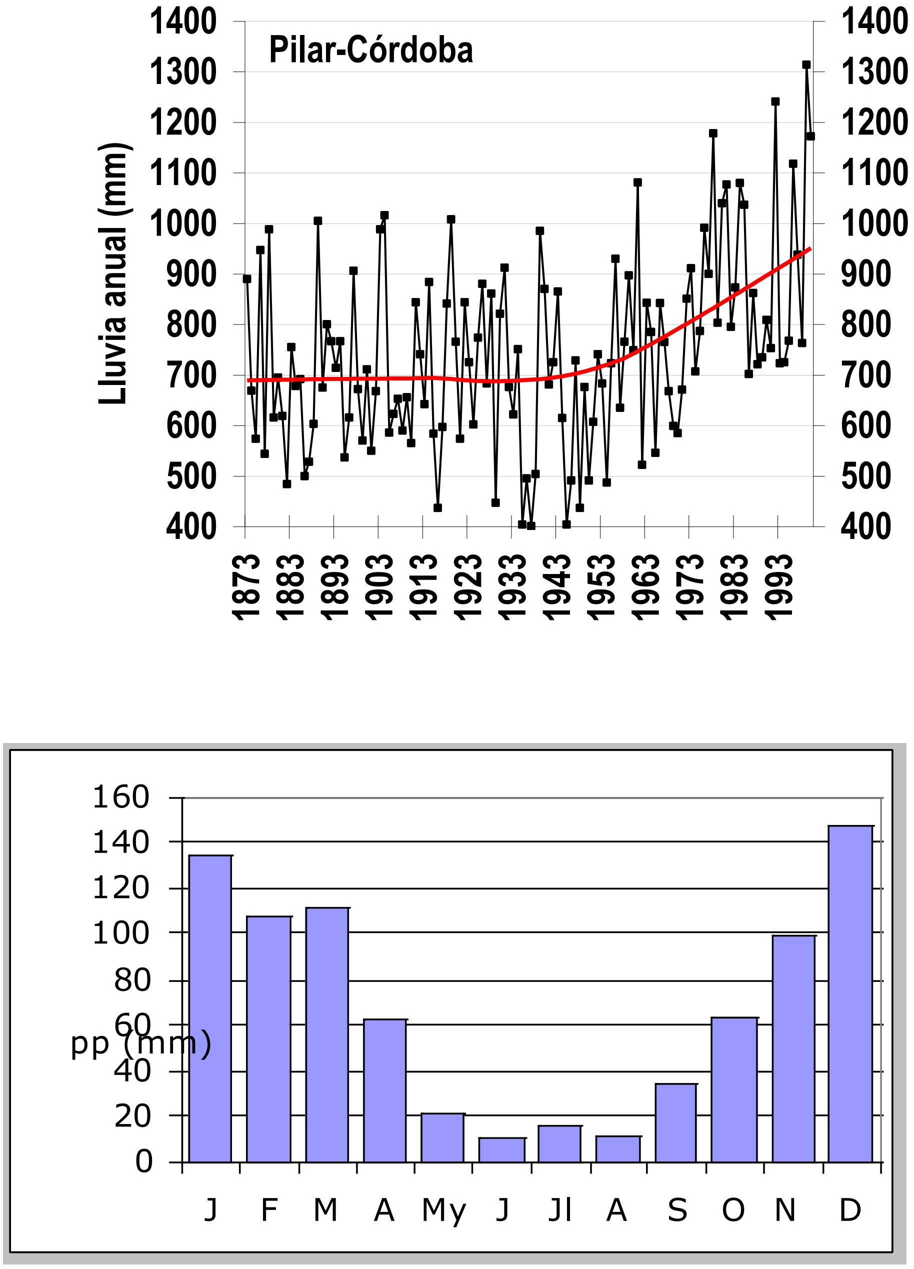
In the current production system, the adoption of irrigation is clearly understood as a strategy towards increasing productive efficiency to maximize profits. Irrigation makes the productive systems less vulnerable to climate, allowing better planning and maintaining constant sowing dates. Irrigation reduces climate risks and stabilizes crop yields at higher levels. Nevertheless, irrigation systems are being implemented in reaction to the historical water shortages, rather than as a way of adapting to climate change.

6. Additional Areas of Research

The research has started to include four new areas of work in a wider context of sustainability under climate change which include:

1. Use of remote sensing data and MM5 (hydrology) forecasts to improve the temporal and spatial resolution of climate data in the Maipo river basin, Chile.
2. The invasive potential of *Maconellicoccus hirsutus* (Green), the mealybug (Pseudococcidae) in Chile under climate change scenarios.
3. Potential conflicts between agriculture and urban areas. Analysis of the vulnerability of water rights in a utility company
4. Climate change impacts on Mediterranean ecosystems. Assessing land use changes in the Maipo Basin.

Figures



Annual	**Summer**	**Winter**
816	**663**	**233**

Figure 1. Project SGP-HD003. Time series of precipitation (top) in Córdoba, Argentina, and seasonal distribution (bottom) (SGP003)

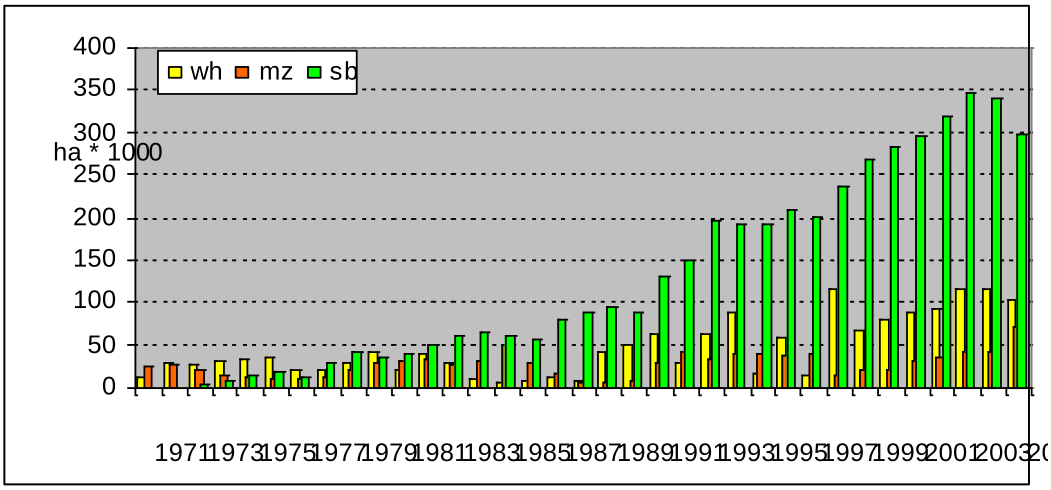


Figure 2. Project SGP-HD003. Area planted to wheat (wh), maize (mz) and soybean (sb) in the period 1971-2005 in Rio Segundo, Cordoba, Argentina. Note the huge increase in soybean.

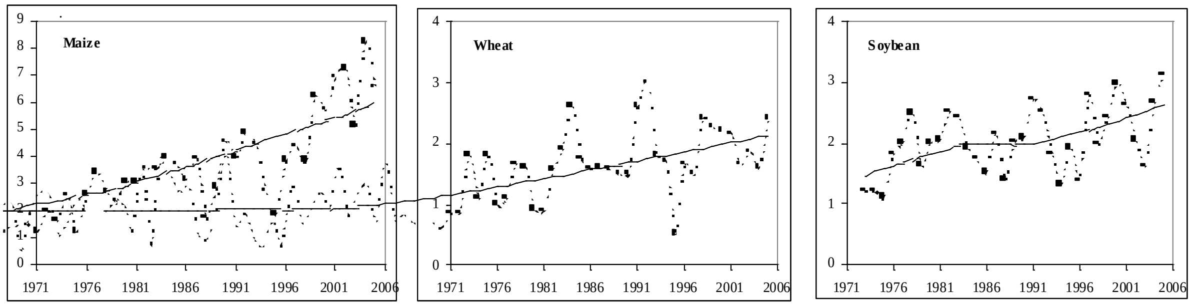


Figure 3. Project SGP-HD003. Yields (t/ha) of maize, wheat and soybean and trend (solid line) obtained by lowess.

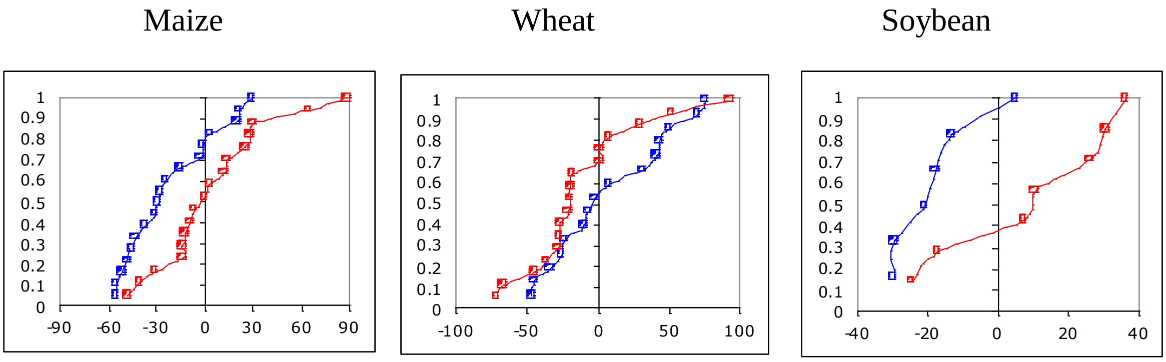


Figure 4. Project SGP-HD003. Cumulative probability of yield anomalies (%) for El Niño (red) and La Niña (blue) years (for wheat and maize 1925-2005 and for soybean 1973-2005)

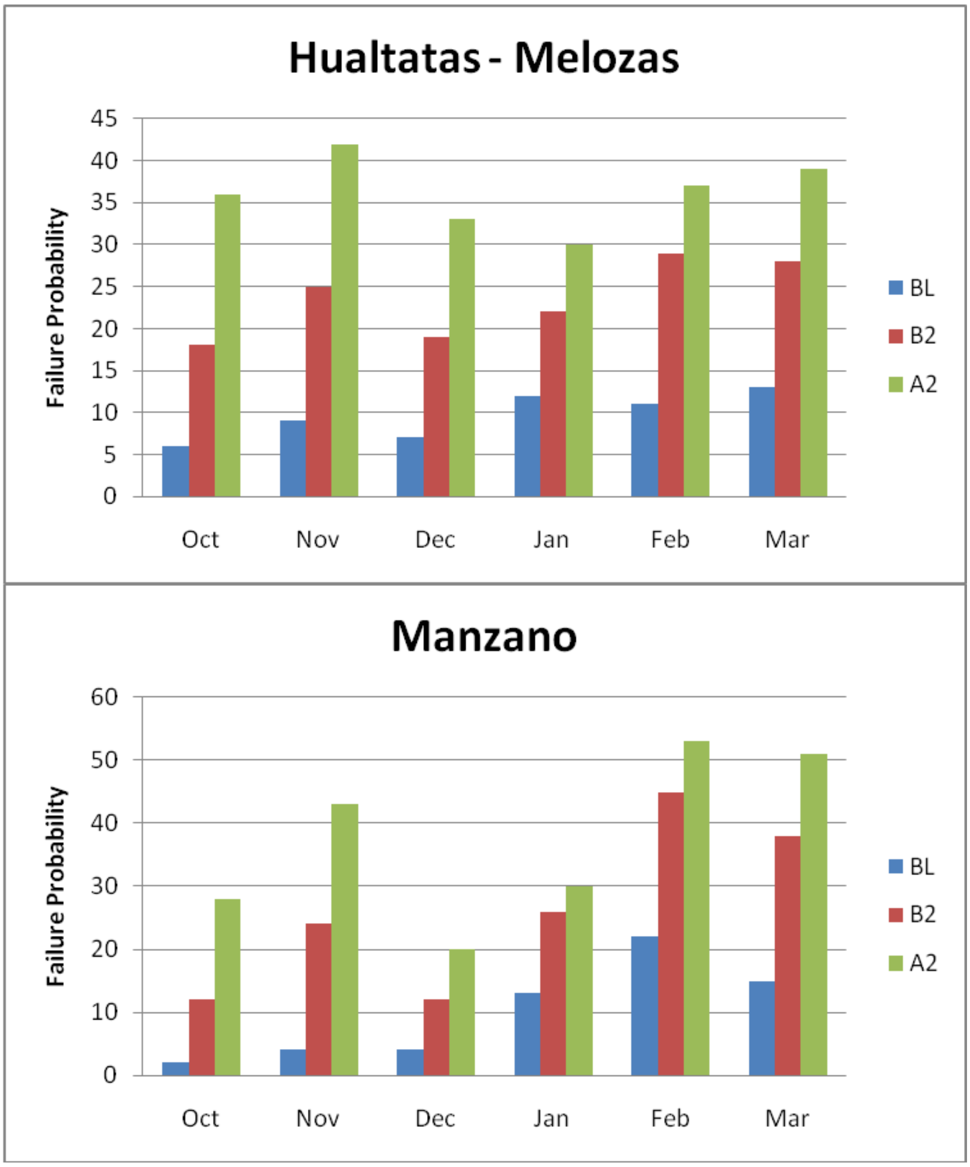


Figure 5. Project SGP-HD003. Vulnerability of permanent water rights in the Maipo basin (two of the four analyzed river tracts are shown) under baseline (BL) and two IPCC climate scenarios (B2, A2)

Tables

Table 1. Project SGP-HD003. Mean yield in kg/ha for wheat, maize and soybean under irrigated and rainfed conditions in Manfredi (Cordoba region, Argentina) for the period 1996-2006 shows the yield increase under irrigation, most marked for wheat. SD = standard deviation

	MeanYield (SD) kg/ha	
	Irrigated	Rainfed
Wheat	4,964 (1,360)	2,092 (1,150)
Maize	11,745 (1821)	8,526 (2,492)
Soybean	3,985 (655)	3,003 (623)

Table 2: Project SGP-HD003. Changes (in percent, referring to present-day values) in yield and irrigation water needs under scenario A2, model forecasts for irrigated crops in 2020 and 2080, respectively.

Changes in yields		
	2020	2080
Maize	-2	-17
Wheat	2	10
Soybean	15	4
Changes in irrigation water needs		
	2020	2080
Maize	-11	-19
Wheat	0	-5
Soybean	-4	-6