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Impacts of climate change on agricultural systems of the La Plata Basin (South America) and the use of crop models to design adaptation strategies

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Introduction

Climate impacts directly agricultural systems. According to several studies, an increase in the mean temperature in many regions of the world is expected, and this will directly influence rainfall, evapotranspiration, among other environmental factors. Some regions expect a decline in precipitation, while others will face an increase in temperature and precipitation. The La Plata Basin is located in South America and plays a very important role in world's food system supply. The increase of 20% to 30% of annual precipitation during the last decades in the region shaped favorable conditions to a significant expansion and intensification of agriculture. Recent studies present a trend of increase in precipitation during the next decades in the region. However, while agriculture may benefit from a warmer climate and more precipitation, the change in climatic patterns and increased potential of extreme events occurrence pose challenges. The objective was to analyze the possible impacts of new climatic conditions on selected agricultural systems of the La Plata Basin, region which gathers parts of five countries (Argentina, Bolivia, Brazil, Paraguay and Uruguay), and which economic wealth strongly depends on agriculture (AQUASTAT, 2010). The basin is also the world`s main food exporter region. Due the size and heterogeneity of the Basin, this paper will focus on maize production in Southern Brazil.

Study region

The study region is located in Southern Brazil, West Santa Catarina State, inside the Brazilian part of the La Plata Basin (central coordinates: lat. -27.08°, long. -52.63°). The region is characterized by small farms – 90% of rural establishments have less than 30 ha – and a diversified production, ranging from intensive animal production (poultry and swine) to cash and subsistence crops. Maize plays an important role in the region being cultivated in more than 250 thousand hectares (IBGE, 2010), with considerable part being used animal feedstock. The climate of the region is Cfa according Köppen-Geiger, the annual mean temperature is 17,8°C and the annual rainfall mean is 1810 mm, and the region is characterized by cambisols.

Climate change and agriculture

The Intergovernmental Panel on Climate Change (IPCC, 2007) predicts that food production around the world could suffer a dramatic impact in the coming decades due to climate change caused by global warming. The impact of climate change on production of various crops varies markedly depending on the region, growing season, the crop specie/variety and their temperature thresholds. Cereals, oilseed and protein crops depend on temperature and, in many cases, day length and thermal sum to reach maturity.

Projected changes include increase of atmospheric CO_2 concentration, increase

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in temperatures, reduction of direct radiation and also changes in precipitation patterns. The general assumption is that temperature increments in mid latitudes may shorten the length of the growing period for crops and, in the absence of compensatory management responses, reduce yields (Tubiello et al. 2007). In contrast, a higher concentration of CO2 should increase photosynthesis efficiency and water use efficiency. Increases or decreases in precipitation will also impact agriculture. In conclusion, the impacts of climate change on crops yields will be the result of a balance between these negative and positive effects on plant growth and development (Magrin, 2005). These variations can change the area of cultivation by rendering unsuitable some currently cultivated areas and making suitable others not currently cultivated.

Increasing the prediction capacity of climate change impacts for stakeholders has become a major challenge in La Plata Basin, region which gathers parts of five countries (Argentina, Bolivia, Brazil, Paraguay and Uruguay), and which economic wealth strongly depends on agriculture (AQUASTAT, 2010). In this region, the agricultural landscape have faced major changes during the last 30 years due to new technologies for crops, a strong increase in cereal and oil crop world demand and also to favorable climate conditions showing increases of about 20%-30% in annual precipitation over large parts of the basin (Magrin, 2005). This increase of precipitation favored the expansion of crops from cultivated to marginal areas, though the last ones are most vulnerable to climate change and variation. As agricultural forecast, the world's demand for cereal and oil crops (and derived products) or animal products is likely to increase considering both the growing demand in food and biofuel. The consequences on land-use, on the sustainability of the soils and therefore on the rural development in La Plata Basin are still unknown.

Decision support systems

For this paper, decision support systems will be computer programs that include several models of soil, water, nutrients and plant growth, and can be also called crop models. Usually data of weather, soil, crop specie and agricultural management are inputs processed in a daily basis to predict crop development, yield, and maturity date, among other parameters.

The use of crop models in diverse agricultural situations and for different purposes is not recent. Crop models can be used for answering questions in research, crop management, policy analysis, and have been used to evaluate the consequences of climate change on crops (Boote et al, 1996). These decision support systems usually are constructed to have a broad range of application and are used to simulate crop performance over large areas or regions with general data, but producing in not very accurate results; In other hand, there are decision support systems that produce accurate results, requiring for this a large and specific data-set, including the same described above, but with a higher level of detail. Due the large amount of data, the use of these models is restricted to the data availability and the capacity of processing and analysis.

Methods:

- Data input and model calibration:

For this work, GIS data of soil was retrieved from regional soil survey (scale 1:250000) done by EMBRAPA (SOLOS, 2010). This data included not only classification, but also chemical and physical properties for different depts. When necessary, parameters where converted to meet the inputs requirements of the decision support system. Data of crop management like fertilization, sowing date, varieties characteristics (genetic coefficients) and past yields was obtained from several reports generated by national and state agricultural service. Observed data from various weather stations of the region and simulated climate data (Tmax, Tmin, precipitation and radiation in daily basis) was obtained from CLARIS-LPB Project data base (www.claris-eu.org). Soil and climate data were interpolated to create homogeneous areas.

- Validation of model with past data:

For the modeling process, the first step was to include soil, management, crop and observed climate data in the decision support system. After running the model, simulated yields were compared with observed yields. As the results of simulated x observed yields did not differ more than 20%, the decision support system is considered able to simulate the yields in scenarios of future climate.

- Validation of the scenarios:

After using past climate data, the model was feed with preliminary climate data from distinct scenarios of climate change. These scenarios were generated from GCM`s and RCM`s downscaled for the study region by the CLARIS-LPB Project. The climate scenarios are then run for the past (1980-2008) to observe if the climate model that generated that scenarios is able to reproduce observed weather, and therefore the same yields. As second option, if the scenarios are not able to reproduce the same results of yields, then the past climate data is used as base-line and precipitation, temperature and radiation are modified according suggestions of literature in order to simulate climate change.

- Simulation with scenarios:

In this step the decision support system is feed with the same initial data-set of soil, management, crop variety, but with the climate data from scenarios or from the modified climate data. Yields were calculated for each combination of soil and climate station, three sowing dates (1st Sept, 1st Oct, 1st Nov) and the final result was calculated proportionally according the contribution of each homogeneous area. The baseline is the average yield from last 30 years.

- Simulation of different sowing dates:

The crop model was instructed to run simulations with different sowing dates, from August 2nd until December 2nd, monthly. This simulation was done specifically for the region of Chapeco due availability of experimental data to support validation for sowing dates.

Results - Impacts

The model validation presented acceptable results, showing that the variability between simulated and observed yields was inside the accepted range (20% of difference).

However, the validation of scenarios of climate change failed due high variance between simulated and observed values. For this reason, the second option was used. The data of observed climate (1980-2008) was then modified by increments of 1℃, 2℃ and 3℃ in Tmax and Tmin, and the precipitation increased and reduced by 30% (Figure 1).

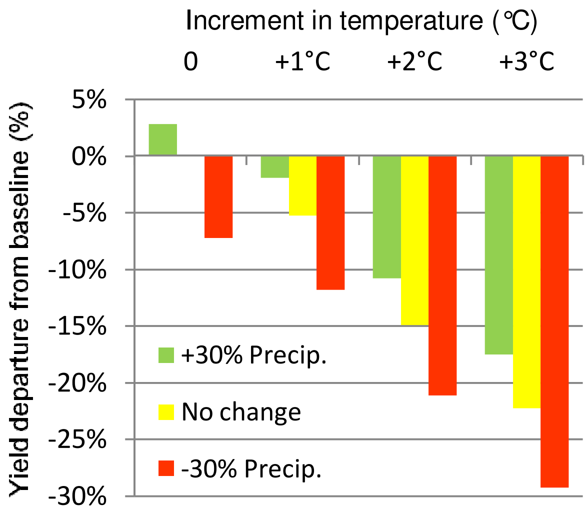

Figure 1. Simulation of maize yield departure from baseline (7.098 Kg/ha^{-1}) under different combinations of temperature and precipitation.

This simulation showed that in all scenarios of increase in temperature the mean yield of maize will be reduced in a linear way. The effect of reduction or increase in precipitation also impacts the yield, being even stronger than the effect of temperature. The only situation were yield is increased in with actual temperature and increase in precipitation. This shows that the study region is near the superior threshold of temperature for maize. In cooler regions increases in temperature can improve maize yields, but in tropical and subtropical higher temperatures will cause stresses that reduce the potential yield. It is also important to note that the increase in precipitation can help to reduce the negative impact of higher temperatures, but not compensate it.

Regarding sowing dates in Chapeco, the yields also varied within dates and different increments in temperature and changes in precipitation (Figure 2). For this simulation was assumed an increment of 1℃ in temperature and -30%, 0 and +30% of precipitation. The results suggest that in a scenario of increase in 1℃ the best sowing date will be October for no change or +10% of precipitation. Early and late sowing dates will face reductions in yield, no matter if precipitation changes. This simulation shows also the effect of precipitation: the reduction by 30% is much more impacting than the increase by 30%. According literature, changing the planting date is one of the ways farmers can adapt to climate change, and this is already being done in the last decades.

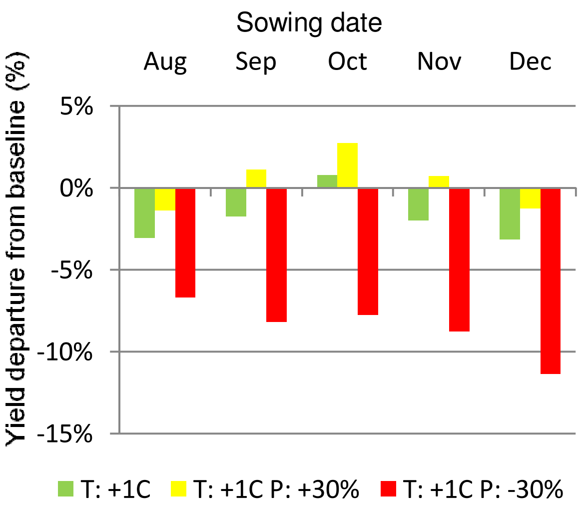

Figure 2. Maize yield departure from baseline (actual yield) under different combinations of temperature and precipitation and different planting dates in Chapecó, Brazil.

Conclusions

- Climate change can impact negatively maize yields in the study region;
- Expected increases in precipitation can reduce the impact of higher temperatures, but will not compensate it;
- October will be the best sowing date in a scenario with +1℃ and no change or increase by 30% in precipitation;

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