# MAIZE FOR ETHANOL PRODUCTION: REGIONALIZATION OF RESPONSES TO CLIMATE SCENARIOS, N USE EFFICIENCY AND EFFECTIVENESS OF ADAPTATION STRATEGIES

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**Abstract**
Maize, besides being a food source, is also a source of energy. As any other crop, maize yield – and therefore the ethanol produced from it – is a response to environmental factors such as soil, weather and management. In a context of climate change, understanding responses is crucial to determine mitigation and adaptation strategies. Crop models are an effective tool to address this. The objective is to present a procedure to assess the impacts of climate scenarios on N use efficiency, yield, so as the effect of crop cultivar (n=2) and planting date (n=5) as adaptation strategy. The study region is Santa Catarina State, Brazil, where maize is cultivated on more than 800,000 ha (average yield: 4.63 t $ha^{-1}$). Although not adopted in this region yet, there is a growing tendency for using maize as biofuel source. Surveying and mapping of crop land was done using satellite data, allowing the coupling of weather and 253 complete soil profiles in single polygons (n=4135). DSSAT crop model was calibrated and validated using field data (2004-2010 observations). Weather scenarios generated by RCMs were selected according capability of reproducing observed weather. Simulations were run for the 2012-2040 period (437 ppm of [$CO_2$]) showed without adaptation strategies reductions of 12.5% in total maize production. By only using the best maize cultivar for each polygon (soil + weather), total production was increased by 6%; when using both adaptation strategies – cultivar and best planting date – total production was increase by 15%. The modelling process indicates N use efficiency increment ranged from 1 – 3% (mostly due [$CO_2$] increment, but also due soil properties and leaching).

This analysis showed that N use efficiency rises in high [$CO_2$] scenarios, so that crop cultivar and planting date are effective tools to mitigate deleterious effects of climate change, supporting energy crops in the study region.

**Keywords**
Climate change, crop model, efficiency use.

## 1. Introduction

Understanding climate change and impacts on crops is critical to determine anthropogenic responses in terms of mitigation and adaptation. While the soil resource is relatively constant over time, the weather is subject to remarkable variability, making it the most challenging and unpredictable aspect of agriculture (Nadler and Bullock, 2010). Despite all efforts mobilized to identify the directions of climate change, the high level of uncertainty entrenched in climate scenarios is still a challenge for future predictions. On the other hand, the comprehension on how crops respond to environmental factors and management variables relays in mathematical models that could explain with accuracy key physiological and phenological processes.

### 1.1. Crop models for impact assessment

As crop science represents an integration of the disciplines of biology, physics and chemistry, plant and crop simulation models are a mathematical representation of this system (Hoogenboom, 2000). Lobell and Burke (2010) state that those process-based models are typically developed and tested using experimental trials and thus offer the distinct advantage of leveraging decades of research in crop physiology and reproduction, agronomy, and soil science, among other disciplines. In order to correctly simulate the physiological and phenological processes, these models require specific input data of soil, weather, crop or cultivar, as well as management practices such as planting date, plant population and fertilization. The models need to be adapted to local conditions by calibration to achieve high level of accuracy. Simulations are usually run for single or few sites and are important for farmers and technicians during decision making process; nevertheless, the scaling up of model outcomes can bring a more complete picture, allowing a better understanding of the regional impact. Examples of regional applications are food security early warning and market decisions (Parry et al., 2007). If local estimates are averaged to obtain regional mean yields, the procedure is likely to introduce aggregation error that depends on the degree of non-linearity of the crop model functions as well as the heterogeneity of sites in the region. Furthermore, in a climate change study the selection of individual sites that are representative of present-day conditions may be inappropriate, if the projected future climate is likely to shift the suitability of a crop into new regions (Saarikko, 2000).

## 2. Methodology

The study region is the Santa Catarina State, located in Southern Brazil. The State covers an area of 95,703 $km^2$, with a population estimated in 6.2 million inhabitants (IBGE, 2012). The agricultural production plays an important role in the State, contributing with more than 7% of the State GDP (Epagri/Cepa, 2011). The state has a structured agro-industrial complex, were main part of coarse grains produced are used for animal feeding: in the case of maize, 100% of the local production is directed to attend the local agro-industry demand.

In order to assess the actual land use of Santa Catarina State data from different sources was merged within a single GIS data bank. Further environmental information like water bodies, islands, wetlands and urban regions were obtained from 1:50,000 and 1:100,000 scale digital maps from Epagri/IBGE (2012). In addition, maps of vegetation and land use (like agriculture, pastures, agriculture + pasture, etc.) were obtained from Environment (2012) in a 1:250,000 scale; soil map (1:250,000 scale) was obtained from SOLOS (1999).

### 2.1. Impact assessment

The Decision Support System for Agrotechnology Transfer – DSSAT v. 4.5 contains the CERES – Maize model (Jones, 1986) and was used to determine best planting dates, fertilization strategies, nutrients use efficiency and to examine potential effects of climate change on agriculture. In the embedded model the development and growth of the crop was simulated on a daily basis from the planting until the physiological maturity. In order to ensure a correct simulation of the model, field experiments were set up in different locations of Brazil to obtain genetic coefficients required for each maize cultivar, as proposed by He et al. (2009), as well as to proceed with the model validation. Four varieties of maize were tested: three open pollinated varieties (MPA01, Ivanir and Fortuna) and one commercial hybrid (AS 1548). The field experiment was conducted according the recommendations of Soler et al. (2007), and the validation was done using observed data from different field experiments containing all required data set for model validation (Hunt and Boote, 1998). A specific fertilization scheme was use for each soil (to attend the crop N requirements), ranging from 50 to 120 kg/N/ha. The two best calibrated cultivars were chosen to perform further assessments.

### 2.2. Weather scenarios

In order to define which Regional circulation model (RCM) will be used in the simulation, a comparison was done between yields based on RCM`s as well as observed weather data. The formulated hypothesis states that the best RCM or ensemble of RCM`s would be the one providing the best fit of simulated versus observed yields. Yield for different planting dates (01.08 until 01.12, each 15 days) was simulated using observed weather (1982-2012, 30 cropping seasons) from selected weather stations. RCM`s were provided by CLARIS-LPB Project Data Archive Center and were restructured to match the model input criteria using Weatherman Software version 4.5.0.0 (Wilkens, 2004).

### 2.3. Regionalization

Results were organized and plotted on GIS maps on areas discriminated as agricultural land use. Yield change in the scenarios was calculated based on recorded yields from the last 30 years. Nitrogen use efficiency was calculated according the recommendations of Eulenstein et al. (2014) using simulations with past weather as base line, followed by comparisons with efficiency obtained using climate scenarios.

## 3. Results

The main findings from the results are the following:

- Simulations run for the 2012-2040 period (437 ppm of [$CO_2$]) without adaptation strategies showed reductions of 12.5% in maize total production (Fig. 1);
- The modelling process indicates that the N use efficiency increment ranged from -20% to +12% (according to the model, mostly due [$CO_2$] increment, but also due soil properties and leaching) (Fig 2);
- By only using the best maize cultivar for each polygon (soil + weather), total production was increased by 6%; when using both adaptation strategies – cultivar and best planting date – total production was increase by 15% (Fig 3);
- N use efficiency rises in high [$CO_2$] scenarios, but is also determined by soil and weather in nonlinear correlations;
- Crop cultivar and planting date are effective tools to mitigate deleterious effects of climate change, supporting energy crops in the study region;
- The potential for maize production – and therefore ethanol – will be increased at the South-eastern region, while the West region will suffer strong reductions in its production potential.

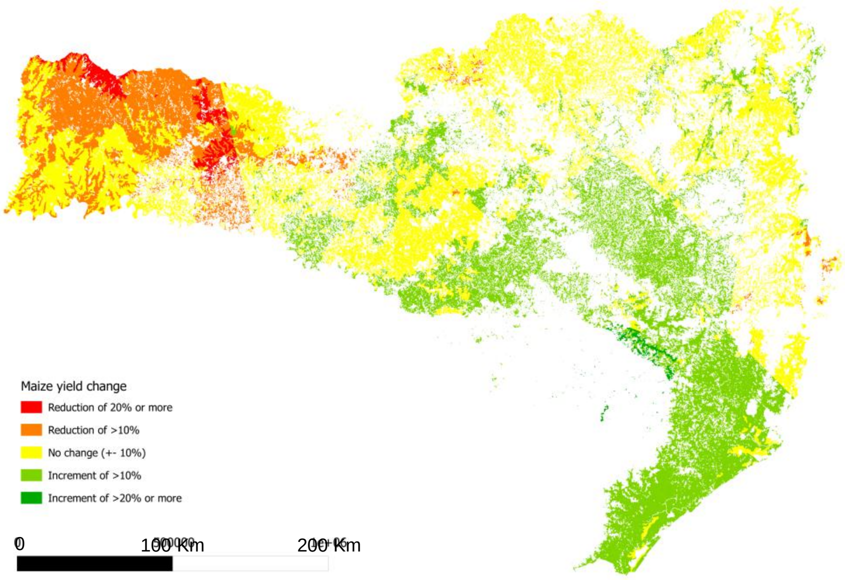


Fig. 1 Change in maize yield (%) in Santa Catarina State, Brazil, due impact of climate scenarios without any kind of adaptation strategy (planting date or cultivar, for example).

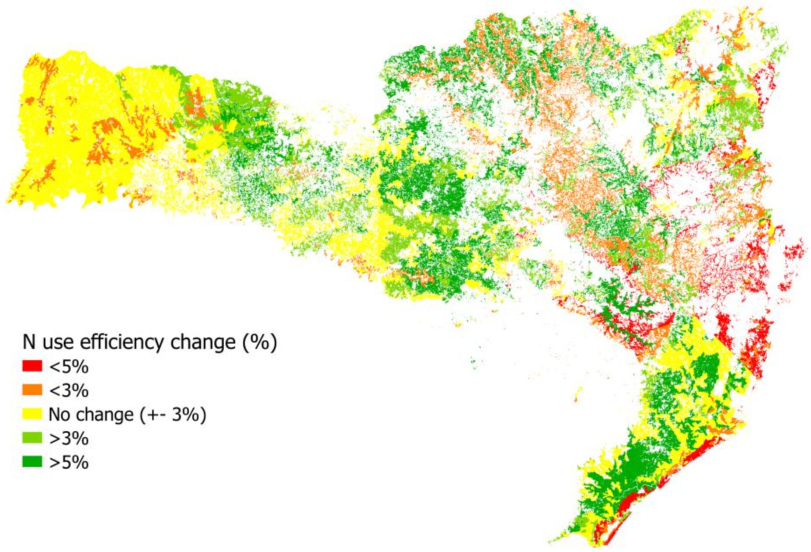


Fig. 2 Nitrogen use efficiency change under impact of climatic scenarios for Santa Catarina State, Brazil. Changes are relative to the actual values (baseline calculated with climatic data from the last 30 years).

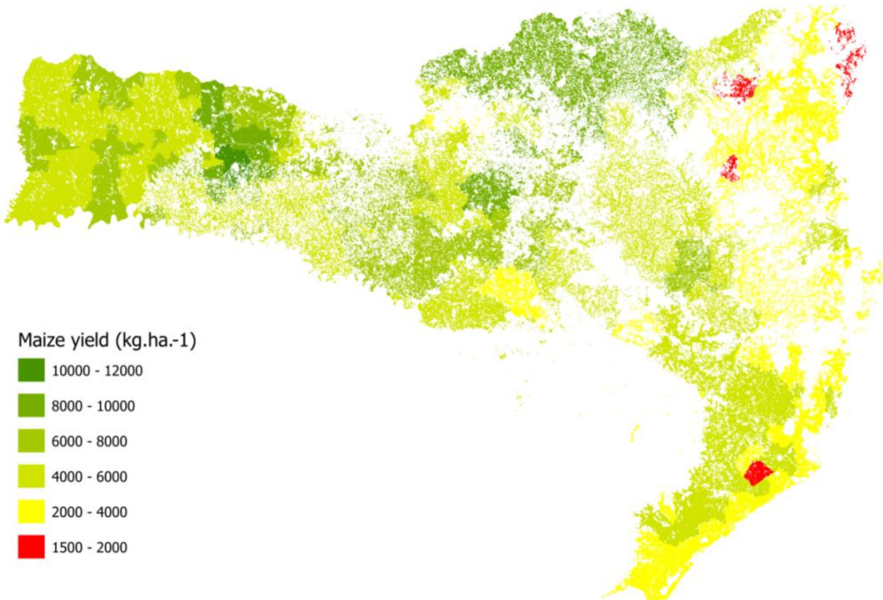


Fig. 3 Expected maize yields under climatic scenarios for the 2012-2040 period. When adaptation strategies are employed, yields can potentially raise in many regions, increasing the State`s production up to 15% from actual levels.

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