Information architecture for crop growth simulation model applications

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Abstract. There is a growing concern that climate changes will lead to significant impact to agriculture, thus having a global effect in food production. The application of crop models to study the potential impact of climate change and climate variability provides a direct link between models, science and the concerns of the society. The objective of this work is to demonstrate an information architecture that consistently and coherently achieves the requirements for data availability and use model integration for crop models researchers. The system includes a database structure for storage of model input and output data. The information architecture, and its constituent crop models, is being applied in evaluating farming practices, technological innovation and climate variability/change impact on agriculture in Southern part of Brazil. This effort is part of the global Agricultural Model Intercomparison and Improvement Project (AgMip).

Keywords: climate change, technological innovation, food production, adaptation.

1 Introduction

Agricultural productivity in both developing and developed countries will have to improve to achieve substantial increases in food production by 2050 while land and water resources become less abundant and the effects of climate change introduce much uncertainty (Antle, 2009). There is a growing concern that the security and quality of global food production may be affected at large and local spatial scales by future climate and weather. Adaptation to climate change through changes in farming practices, cropping patterns, and use of new technologies will help to ease the impact (Huang et al., 2011).

In the last two decades, substantial efforts have been directed toward understanding climate change impacts on agricultural systems. The resulting advances in our understanding of climate impacts have come from the collection of better data and the observation of actual changes in climate and its impacts. Such knowledge is critical as we contemplate the use of crop models to design innovative

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technologies and policies to mitigate climate change and facilitate adaptation to the changes that now appear inevitable in the next several decades and beyond.

The application of crop models to study the potential impact of climate change and climate variability provides a direct link between models, science and the concerns of the society. Changing markets, technological innovation and organizational progress in recent years have increased the intensity and scale of agricultural land use.

The objective of this work is to demonstrate an information architecture that consistently and coherently achieves the requirements for data availability and use and model integration for crop models researchers. Here, we define information architecture as the structural design of an information space to facilitate task completion and intuitive access to content. The system includes a database structure for storage of model input and output data. The constituent crop models within the information architecture are being applied in evaluating farming practices, technological innovation and climate variability/change impact on agriculture in Southern part of Brazil. This data interface enables users to reproduce crop model simulations, to modify and re-simulate scenarios, and also serves as an archive. The system also provides the needed tools for databases management. A case study for the assessment of the impact of climate variability/change on crops such as soybean and wheat in the state of Paraná will be used to illustrate data flows between weather, crop models and to effectively perform analyses and present results. Finally, this effort is part of the global Agricultural Model Intercomparison and Improvement Project (AgMip) aiming to improve substantially the characterization of risk of hunger and world food security due to climate change and to enhance adaptation capacity in both developing and developed countries.

2 Material and Methods

2.1 Crop models overview

The CSM-CROPGRO: Soybean model and the CSM-CERES-CROPSIM: Wheat model contained within DSSAT (Jones et al., 2003) simulate plant growth and development from sowing to maturity using a daily time step, and ultimately predict yield. The physiological processes that are simulated characterize the crop's response to the major weather factors, including temperature, precipitation and solar radiation, and to soil characterizations such as the amount of extractable soil water and nutrients. Daily photosynthesis is a function of light interception and the pool of carbohydrates available for growth is estimated by daily maintenance and growth respiration. The remaining carbohydrates are partitioned to vegetative and reproductive growth as a function of the developmental phase (Boote et al., 1998). The soil water balance is calculated on a daily basis and is a function of precipitation, irrigation, transpiration, soil evaporation, and runoff from the soil surface and drainage from the bottom of the profile. The user distributes soil water among different horizontal soil layers with depth increments specified. The water content for any soil layer can decrease by soil evaporation, root absorption or flow to an adjacent layer (Faria and Bowen, 2003). Water stress causes a reduction in photosynthesis and canopy development, a change in partitioning of biomass and an increase in senescence or abscission of plant material, depending on the timing and severity of the stress. Biotic stresses such as those caused by foliar disease causes a reduction in available photosynthetic tissue and photosynthesis efficiency (Pavan and Fernandes, 2009).

2.2 Climate and soil data

Daily records of weather data are available from Parana Agronomic Institute (IAPAR) for 28 locations within different agroecological zones (Figure. 1) covering the state of Paraná, Brazil. For all locations historical records cover 30 or more years of observations. Changes observed between the period 1980-2009 in temperature and rainfall were used to develop a future climatic scenario using a weather generator. The stochastic weather generator can be used for the simulation of weather data at single sites. Required input data are daily time-series of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. The weather generator calculates a set of statistical properties of historical observations, creates empirical distributions and generates daily weather datasets. Similarly, GCM's (General Circulation Model) outputs from the IPCC Data Distribution Center, for example, can promptly be inserted in the database. For all locations which weather was recorded the soil profile data was also available. Soil data includes soil classification, surface slope, soil color, permeability, and drainage class. The whole state of Paraná was divided into agroecological zones. Therefore, crop simulation focused on indicated zones for growing wheat or soybean.

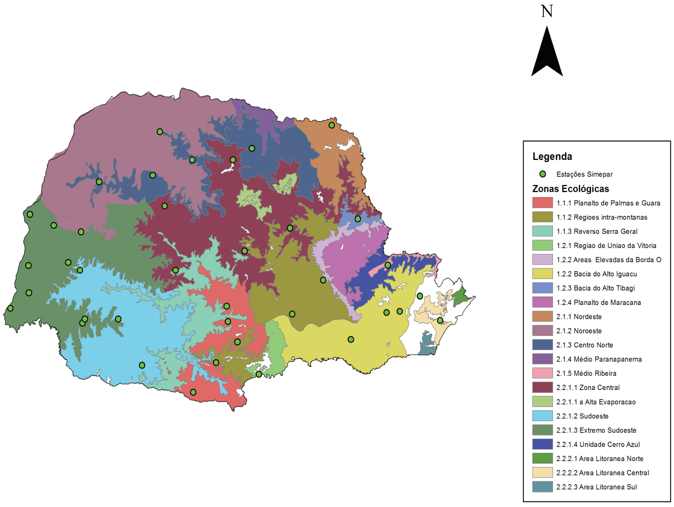


Fig. 1. Map of Paraná state showing the agroecological zones and locations (dots) with soil and climate data to serve as input to crop models.

2.3 Data management

The proposed study considers two approaches for simulating the effect of climate on wheat and soybean growth and development in the state of Paraná. First, the estimated potential impacts of past climate on agricultural productivity can be examined by driving wheat and soybean simulation models with observed weather data. Secondly the output from a stochastic weather generator can be used in order to produce climate change scenarios, which are suitable for use in agricultural impact assessment. In both, crop models can be integrated into geographic information systems with past and future climate data, to generate map layers representing interannually variability on phenological dates, yield, disease intensity among others.

The architecture we propose envisions a system designed and implemented on the top of the PostgreSQL database management system. PostgreSQL extends the relational data model with support for complex objects, and allows users to add new programming languages (procedural languages - PL) to be available for writing special functions and procedures. For the architecture proposed, among other technologies, we implemented R (pl/r) to sort, analyze and visualize data from crop model runs. In Figure 2, we present a general a schematic representation of system architecture that manipulates crop model’s input and output data, making available through generic web services, implemented to access the database and dynamically assemble data as requested.

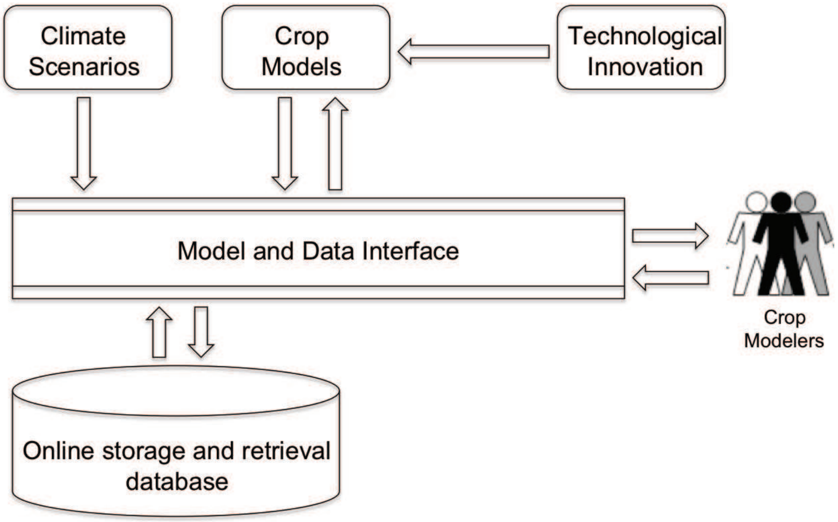


Fig. 2. Database management and exchange system schematic (Adapted from AgMip, 2011).

2.4 Data analysis

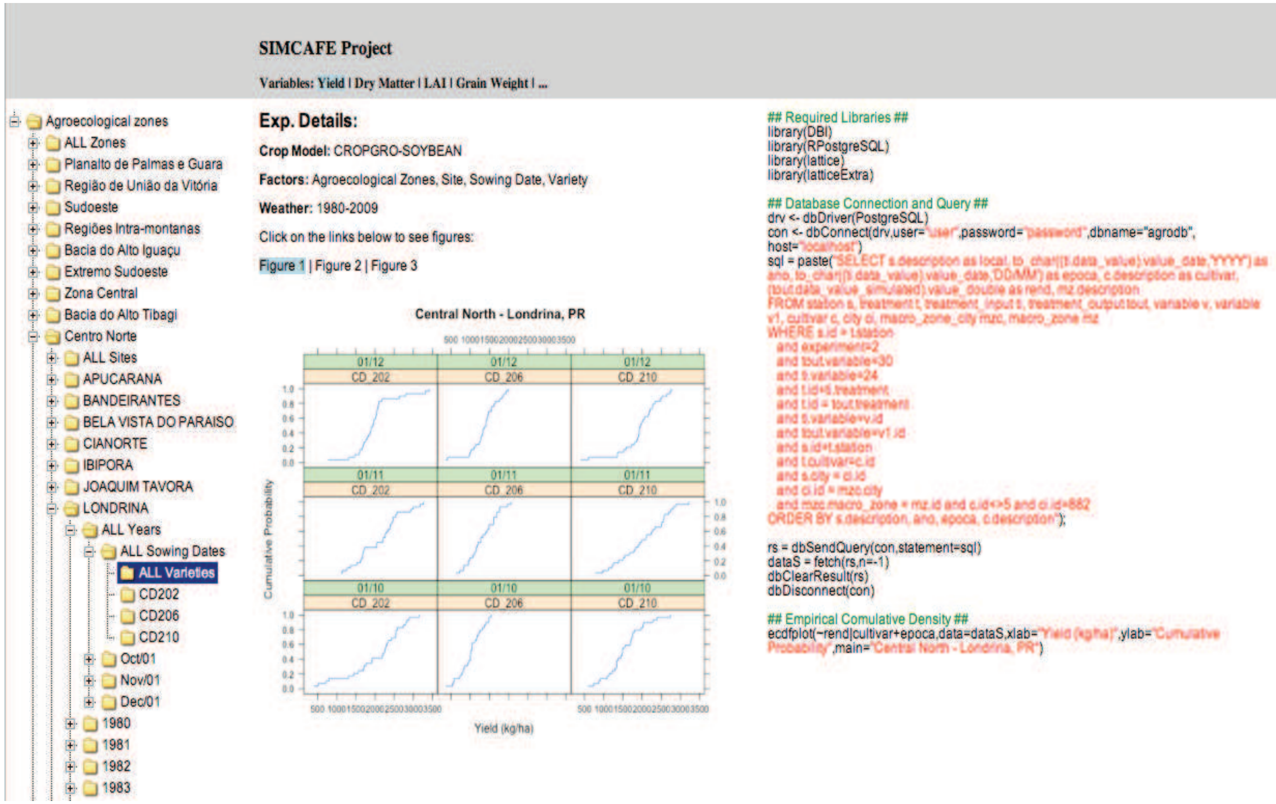
The information architecture evaluates performance of CSM-CERES-CROPSIM: Wheat and CSM-CROPGRO: Soybean model by calculating the Pearson correlation coefficient (r) and root mean squared error (RMSE) between the modeled and the corresponding observed yield series at both the crop model local scale and state scale. Furthermore, temporal and spatial changes of wheat and soybean productivity can be presented in a probabilistic framework, based on simulation outputs. For example, probability density functions (PDFs) of wheat and soybean yield changes during 2030s, 2050s, and 2080s, respectively, relative to 1980–2009, at the representative locality. Across all the wheat and soybean cultivation regions in the state of Paraná, the system is also programmed to derive histogram and cumulative distribution function (CDF) of wheat and soybean yields during 1980–2009, and wheat and soybean yield changes during 2030s, 2050s, and 2080s, respectively. Finally, the system can plot the spatial changes of mean and standard deviations of wheat and soybean productivity during 1980–2009, and their changes during 2030s, 2050s, and 2080s, across the study region.

3. Results

A dynamically build webpage provides access to figures and code from the simulation experiment. It can be viewed with any standards compliant browser with Javascript and CSS support enabled. User can click on the treatments links for treatment details and a listing of links for corresponding plots (Figure 3).

Lattice (Sarkar, 2008), which is an R data visualization package, proved to be very useful for handling multivariate simulation output data. The attraction to lattice is derived from wide variety of displayable graphics, its portability as it is written entirely in R. Customizability is owing to a variety of graphical parameters, flexible use of panel functions, extensibility through the object model and its leverage of the underlying R grid graphics system (R Development Core Team 2011) upon which it is built. The nature of lattice is shown in the multipanel graphic (Figure 4.). Here, yield is numeric while Agroecological Zones, Variety and Sowing Dates are factors. These illustrated the simulation of soybean yield in two contrasting agroecological zones. Soybean crop was simulated using three sowing dates with observed weather data during the period of 1980 through 2009.

Hopefully, this information system will prove to be worthwhile in the assessment of impact of climate variability/change in agriculture across a wide region. Thus, enhancing capabilities in the developed and developing world for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific and policy communities.



SIMCAFE Project

Variables: Yield | Dry Matter | LAI | Grain Weight | ...

Exp. Details:

Crop Model: CROPGRO-SOYBEAN

Factors: Agroecological Zones, Site, Sowing Date, Variety

Weather: 1980-2009

Click on the links below to see figures:

Figure 1 | Figure 2 | Figure 3

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## Required Libraries ##
library(DBI)
library(RPostgreSQL)
library(lattice)
library(latticeExtra)

## Database Connection and Query ##
drv <- dbDriver(PostgreSQL)
con <- dbConnect(drv,user="user",password="password",dbname="agrodb",
host="localhost")
sql = paste("SELECT s.description as local, to_char((ti.data_value).value_date,'YYYY') as
ano, to_char((ti.data_value).value_date,'DD/MM') as epoca, c.description as cultivar,
(tout.data_value_simulated).value_double as rend, mz.description
FROM station s, treatment t, treatment_input ti, treatment_output tout, variable v, variable
v1, cultivar c, city ci, macro_zone_city mzc, macro_zone mz
WHERE s.id = t.station
  and experiment=2
  and tout.variable=30
  and ti.variable=24
  and t.id=ti.treatment
  and t.id = tout.treatment
  and ti.variable=v.id
  and tout.variable=v1.id
  and s.id=t.station
  and t.cultivar=c.id
  and s.city = ci.id
  and ci.id = mzc.city
  and mzc.macro_zone = mz.id and c.id<>5 and ci.id=882
ORDER BY s.description, ano, epoca, c.description");

rs = dbSendQuery(con,statement=sql)
dataS = fetch(rs,n=-1)
dbClearResult(rs)
dbDisconnect(con)

## Empirical Comulative Density ##
ecdfplot(~rend|cultivar+epoca,data=dataS,xlab="Yield (kg/ha)",ylab="Cumulative
Probability",main="Central North - Londrina, PR")
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Fig. 3. Webpage screen capture showing experiment list, corresponding plots and R code.

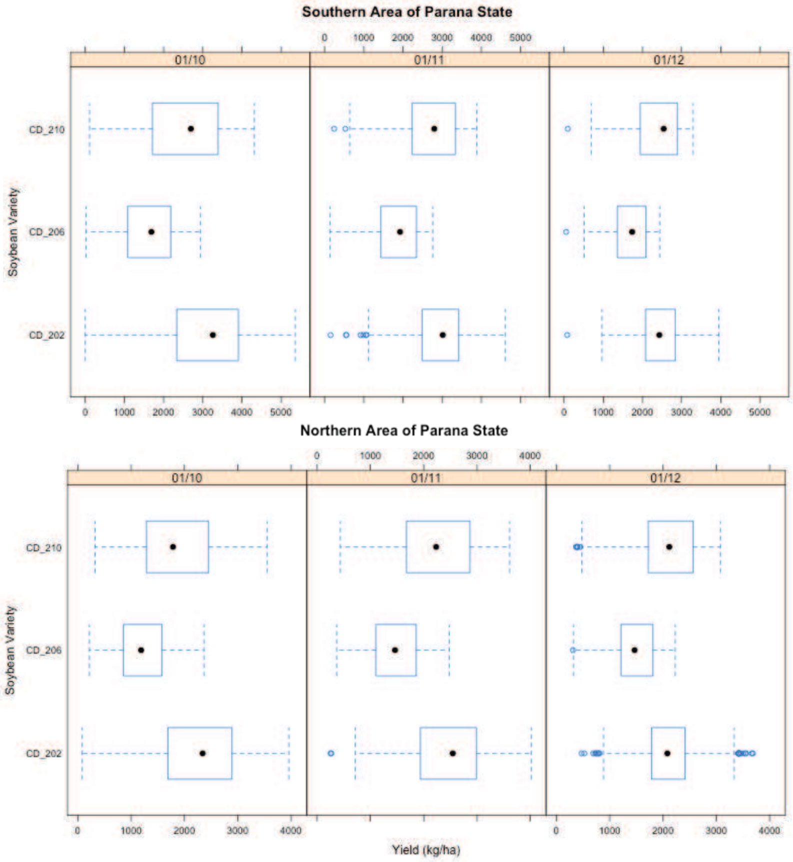

Fig. 4. Simulated soybean yield (Kg/ha) of three soybean varieties, three sowing dates (October 1st, November 1st and December 1st), using observed weather data during 1980-2009 in the agroecological zones of Southern and Northern of Paraná state, Brazil.

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