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Vulnerability of the agricultural systems of Argentina to climate change

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ABSTRACT: Agricultural production is one of the pillars of the Argentinean economy. The contribution of this sector is expected to keep growing in the near future as a consequence of the current technological development trend. However, the projected changes in climate and in the atmospheric concentration of CO_2 in the coming years is likely to affect the productivity of crops, thus causing an impact on the national economy. This paper addresses climate change impact on the production of the main crops of the Argentinean pampean region by means of crop growth and development simulation models for wheat, maize and soybean included in DSSAT v. 3.0 (Dension Support System for Agrotechnology Transfer, Univ. of Hawaii, Honolulu). The weather data used includes temperature, global solar radiation and precipitation values from 23 sites within the region (current climate conditions) and the corresponding GISS general circulation model projections for the year 2050 (future climate) with CO_2 concentrations of 330 and 550 ppm respectively. According to the results obtained, a generalized increase in soybean yield and a decrease in maize yield would occur. Wheat yield is likely to increase in the southern and the western parts of the region and decrease towards the north. Wheat and soybean production in the pampean region would increase by 3.6 and 20.7% respectively, while maize production would be reduced by 16.5%.

KEY WORDS: Climate change · Argentina · Models · Wheat · Maize · Soybean

1. INTRODUCTION

Global climate change, caused mainly by an increase in atmospheric CO_2 and other greenhouse gases, will affect the productivity of natural and cultivated ecosystems. The increase in CO_2 will have positive direct effects on vegetation as a result of a higher net photosynthetic rate (Gifford & Morison 1993) and water use efficiency. However, indirect effects related to climate change will also occur. According to IPCC (1990) projections, the Earth's temperature will rise 1.5 to 4.5°C by the middle of the 21st century. General circulation models (GCMs) predict that this increase will be higher at high latitudes than at low latitudes (Rosenzweig & Hillel 1995). Important changes in the precipitation and radiation patterns are also predicted by the GCMs. Variations in the productivity of plant species would consequently occur. These variations would either be positive or negative, depending on the sensitivity of the soil-plant-climate system, which would be indicative of the degree of vulnerability.

Biological models, which simulate crop development and growth, are a valuable tool to assess vulnerability and to estimate the impact of climate change in different regions. The DSSAT v. 3.0 (Decision Support System for Agrotechnology Transfer) (IBSNAT 1994) is a system that integrates crop growth dynamic models with crop, weather and soil data and with application programs which allow for evaluating different strategies of agricultural production. The DSSAT v. 3.0 models can predict crop growth responses to the main yield-determining factors, i.e. climate (maximum and minimum temperature, precipitation and radiation), soil (physical and chemical properties), cultivar

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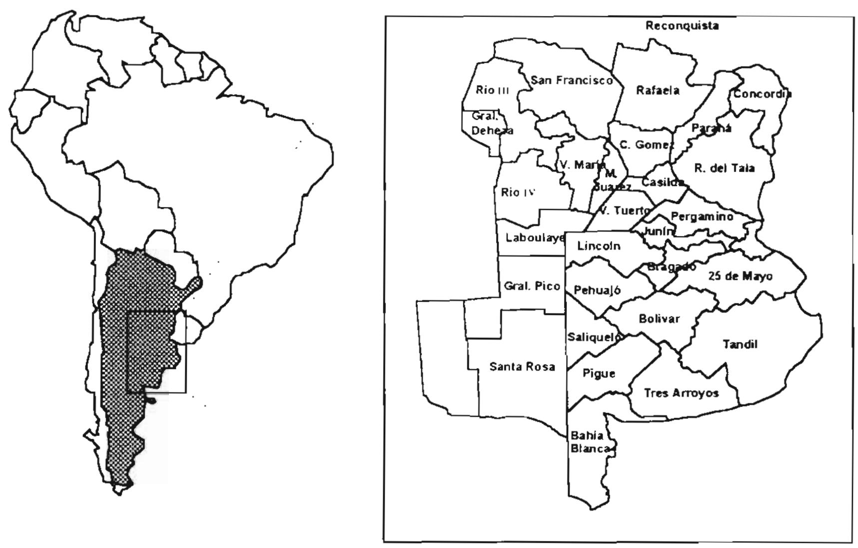

Fig. 1. Location of the Argentinean pampean region and the 29 districts considered for this study

(genetic characteristics) and management practices (planting date, fertilization, irrigation). They can also assess the effect of climate change and the direct effects of CO_2 on crop growth.

Argentina is one of the most important countries in America for grain production and trade. The pampean region, a vast plain of 60 million ha, is the major production region. Twenty million ha are planted each year. The mean annual grain yield is 35 million t, but may range from 21 to 45 million t depending on interannual climate variability. Since approximately 50% of the crop production is exported, this sector represents one of the main socio-economic pillars of the country.

The pampean region lies between 30° and 41° S latitude. The climate of the region is temperate-humid-subhumid, with occurrence of seasonal droughts. Annual precipitation values range from 1200 mm in the east to 600 mm in the west. The annual mean temperature is 17°C in the north and 14°C in the south. The agricultural production system basically consists of extensive rainfed production, which is heavily dependent on weather conditions.

During the last decade, agricultural production in the region has been particularly intensive as a consequence of a relative increase in prices (Basualdo 1995) as well as in rainfall (Hoffman 1989). Both factors have contributed to the enlargement of the planted area (by about 40% in the Buenos Aires province). Further, the agricultural boundaries have shifted towards the western part of the region. This process has caused an increase in the vulnerability of the natural resources.

Recently, an increase in the use of inputs (particularly fertilizers and fungicides) has added to the intensification of production, thus allowing higher yields to be obtained with no irrigation. This situation, which improves the income-yield expectations of the sector and the volume of exports, will not only amplify the impact of interannual climate oscillations on production, but will also magnify the effects of extreme climatic events (water excess and deficiency).

The goal of this study is to assess the vulnerability of wheat, soybean and maize production in the pampean region to the climate change conditions projected for the middle of the next century, and to estimate the impacts of such changes on the production capability of the region.

2. MATERIALS AND METHODS

2.1. Study area

The study area is the Argentinean pampean region, comprising the provinces of Buenos Aires, Entre Ríos, Santa Fé and Córdoba and the eastern part of La Pampa. The subdivisions made by the Secretaría de Agricultura y Ganadería for the regional assessment of grain and oilseed production was used for this study; it includes 29 districts (Fig. 1), corresponding to a grouping of 2 or more counties ('departamentos' or 'partidos') depending on the province. The number of districts are: 12 in the Buenos Aires province (Bahía Blanca, Bolívar, Bragado, Junín, Lincoln, Pehuajó, Pergamino, Pigué, Saliqueló, Tandil, Tres Arroyos and 25 de Mayo), 7 in Córdoba (Laboulaye, Marcos Juárez, Río IV, Río III, General Deheza, San Francisco and Villa María), 5 in Santa Fé [Cañada de Gómez, Casilda, Rafaela, Venado Tuerto and Avellaneda (Reconquista in Fig. 1)], 3 in Entre Ríos (Concordia, Paraná and Rosario del Tala) and 2 in La Pampa (General Pico and Santa Rosa).

2.2. Crop models

The CERES-Wheat, CERES-Maize and CROPGRO (soybean) models from DSSAT v. 3.0 were used. They were first experimentally calibrated under non-limiting production conditions in order to characterize the cultivars most commonly sown in Argentina. These models had already been previously evaluated at 11 sites of the region under limiting production conditions. In that case a mean error in the yield estimate of 8% for wheat, 12.4% for maize and 13.5% for soybean was found (Magrin et al. 1991, Magrin 1994). In the case of wheat and maize, an additional calibration had been carried out for this region in order to evaluate the adjustment of the estimates at the county level. In that particular case the mean error of the estimate was 6.6% for wheat (Magrin 1994) and 10% for maize (Boullon et al. 1996).

2.3. Climatic scenarios

Two scenarios were considered: current and future. The current scenario was derived from daily radiation, maximum and minimum temperature and precipitation data recorded at a weather station from each of 23 different districts of the pampean region. The records from the closest station were used for the 6 remaining districts. The 1971 to 1994 time period was considered, with a CO_2 concentration of 330 ppm.

The climate projections for the future scenario were derived from the general circulation model GISS (Goddard Institute for Space Studies; Hansen et al. 1988) on the basis of the same climate period and under a CO_2 concentration of 550 ppm.

2.4. Yield and production

The different models were used to estimate the yield for each crop under rainfed conditions, for the cultivar or hybrid most commonly sown and at the optimum planting date and density for each zone. The mean yield was simulated for the 1971 to 1994 period and under the 2 climatic scenarios at each district. The average production data were calculated for the average area planted annually at each district during the 1980 to 1990 period (obtained from official statistics) and considering the mean simulated yield for the current and the future climate at each district.

3. RESULTS AND DISCUSSION

3.1. Wheat

According to the climate projections derived from the GISS model, precipitation during the growth cycle of wheat crops will proportionally decrease over the region, while the maximum and minimum temperatures will generally increase. These climatic conditions combined with the direct effect of CO_2 would cause wheat yields to increase by up to 15% in the southern part of the pampean region and to decrease in the same proportion in the north. The northern part of the Buenos Aires province (Fig. 2) represents the area of transition between both situations. However, the western part of the northern zone would also be subject to slight increases (between 0 and 5%).

Rodríguez & Fernández (1993) have observed a similar trend in the evolution of yield. The regions where yield is projected to increase are those where the lowest temperatures currently occur—particularly with regard to minimum temperature values—as a result of latitude, continental climate condition, and topography.

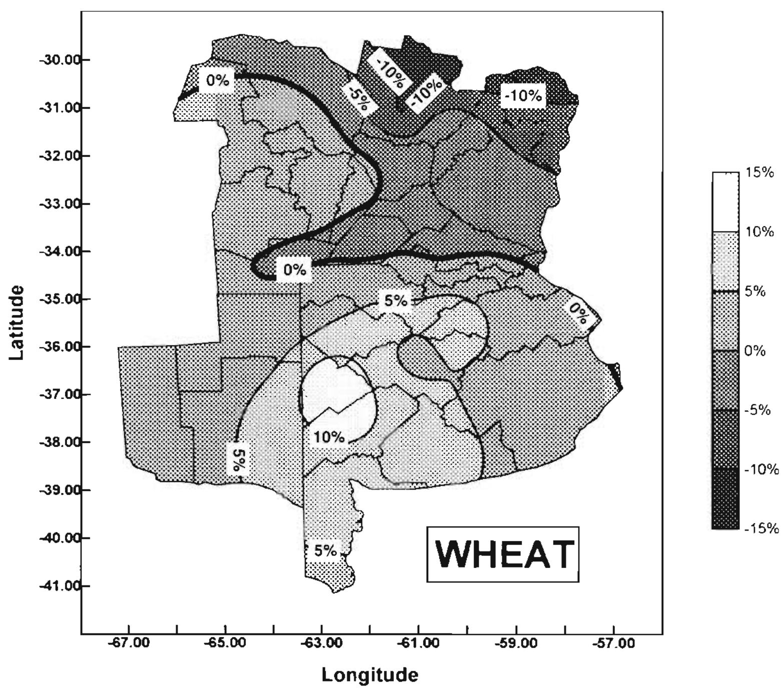

Fig. 2. Differences in percentage between CERES-Wheat simulated yields under the current and future climate scenarios for the Argentinean pampean region

Results of an earlier study by Baethgen & Magrin (1995) suggest that changes in temperature would be more significant than precipitation variations in this region.

The projected rise in temperature would accelerate the development rate, reducing the growth cycle by 24 d on average. The reduction would be proportionally higher during the planting-anthesis stage (22 d) than during the anthesis-maturity stage (2 d). Thus, a generalized yield decrease would be expected as a consequence of a lower use of resources such as radiation. However, this process might either not take place or be reverted if the photosynthetic efficiency increases.

The predicted increases and reductions in yield suggest that temperature could also affect dry matter production, which might explain the differences encountered. The potential accumulation of biomass is dependent on solar radiation (Gallagher & Biscoe 1978) and is likely to decrease under nutrient or water limiting conditions or under unfavorable temperature conditions (Monteith 1981). According to the CERES-Wheat model the optimum day temperature for growth is 18°C, with a decrease in biomass production when temperature values are higher or lower.

The effect of temperature on growth was assessed for 3 districts: Pigué (in southeastern Buenos Aires) and Río III (at the center of Córdoba), where yields are expected to increase, and Avellaneda (in northern Santa Fe), where yields are expected to decrease (Fig. 2). Minimum and maximum temperatures in these districts are projected to increase during the growth cycle by 3°C at Pigué and Río III and by 4°C at Avellaneda (Table 1). Therefore, the mean day temperature during the growth cycle (estimated as 25% of the minimum temperature and 75% of the maximum temperature) would be 17.7°C at Pigué, 19.9°C at Río III and 22.6°C at Avellaneda. The values during the vegetative stage would be 17.1, 18 and 21.6°C, respectively.

In these districts yield variations are related to changes in biomass and in the number of grains per unit area (Table 2), as well as to increases in day temperature differentially affecting dry matter accumulation. The southernmost areas would have temperature conditions close to the 18°C optimum, while an increase in temperature in the north of the region would enhance unfavorable conditions.

Total wheat production in the pampean region would be favored by the predicted yield variations. According to the mean values obtained for each district during the 1980 to 1990 decade, the total planted area is estimated at about 5 million ha, with a mean yield of 1.83 t ha^{-1} and a total production of 9.15 million t. According to the projected variations in yield and assuming that the planted area in each district remains unchanged, an increase in production by 325000 t (3.6%) would be expected. Mean yield would thus increase by 1.9 t ha^{-1} (4%). Pigué and Tres Arroyos districts (located in the south-southwestern part of Buenos Aires province) would be the major contributors to the total increase in production, while the highest losses would take place in Cañada de Gómez, Casilda and Rafaela districts (Santa Fé province).

3.2. Maize

Maize yields would decrease by 5 to 30% throughout the pampean region (Fig. 3) as previously stated by Paruelo & Sala (1993) and R. O. Rodríguez, G. O. Magrin & N. Fernandez (unpubl.). The lowest relative decreases (5 to 10%) would occur in the north, and the highest (25 to 30%) in the southeast. In the production nucleus or central zone (northern part of Buenos Aires, southern part of Santa Fé and eastern part of Córdoba) intermediate decreases would take place (10 to 20%).

The cause of these decreases was analyzed for 4 districts: (1) Rafaela, in the northern sector of the region; (2) Junín and (3) Pergamino, both in the nucleus zone; and (4) Tandil, in the southeastern sector of the region. The predicted increase in temperature would cause a considerable reduction of the growth cycle duration.

Table 1. Minimum temperatures (mT) and maximum temperatures (MT), in °C, during the growth cycle of wheat under the current and future climate scenarios for 3 districts of the pampean region of Argentina

District	Current mT	Future mT	Current MT	Future MT
Pigué	5.2	8.6	17.5	20.7
Río III	6.1	9.2	20.3	23.4
Avellaneda	10.3	14.4	21.4	25.3

Table 2. Wheat yield (kg ha^{-1}), no. of grains m^{-2}, 1000-grain weight (g) and aboveground biomass (kg dry matter ha^{-1}) for current (Cu) and future (Ft) climate scenarios in 3 districts of the pampean region of Argentina

Districts		Yield	No. grains m^{-2}	1000-grain weight	Biomass
Pigué	Cu	2470	6770	36.5	6290
	Ft	2740	7740	35.4	7130
Río III	Cu	1340	3650	36.6	3500
	Ft	1460	4170	35.0	3750
Avellaneda	Cu	1915	5040	38.0	4520
	Ft	1465	4100	35.7	3540

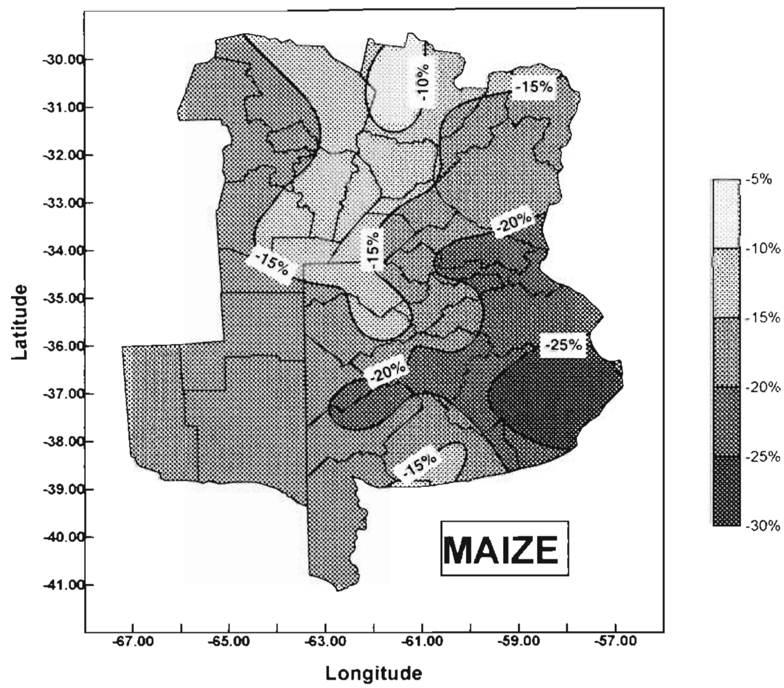

Fig. 3. Differences in percentage between CERES-Maize simulated yields under the current and future climate scenarios for the Argentinean pampean region

Significant differences in this behavior are expected to occur, depending on the latitude. The planting–anthesis stage would be, on average, 15 d shorter throughout the area, while the anthesis–maturity stage would be 5 d shorter in the northern sector, 11 d in the central zone or nucleus, and 20 d in the southeastern sector.

The analysis of yield components indicates that the number of grains per plant would remain constant, while their weight would be the yield-determining factor. Grain weight would decrease by 12% in the north, 7% in the nucleus zone and 21% in the south, in proportion to the reduction of the grain filling period.

Maize production in the pampean region would be seriously affected as a result of these reductions. The average maize-planted area in the 1980 to 1990 decade was estimated at 2.35 million ha, with a production of 8 million t and a mean yield of 3.4 t ha^{-1}. The predicted reductions would entail a decrease in total production by 16.5% (1.32 million t). The Junín and Pergamino districts would be the most affected.

3.3. Soybean

Soybean yields (Fig. 4) would increase remarkably thoughout the entire pampean region. The largest changes would occur in the south (30 to 60%) and the smallest in the north (10 to 20%). As is the case for wheat, the increase would be more significant in the southern districts, where there is a smaller planted area. In the soybean production nucleus zone, which is the same as for maize, increases would be on the order of 20 to 30%. Similar increases have been found in some areas of the USA, where these models were applied by Curry et al. (1995).

Unlike the other crops under study, the duration of the soybean cycle was slightly reduced (3 to 4 d) in all districts. The reduction in the planting–anthesis stage was larger than in the grain-filling period. This behaviour could be related to the high photoperiodic sensitivity of this crop during the reproductive stage.

The increase in yield results from the production of a larger number of grains per unit area. The development of soy-

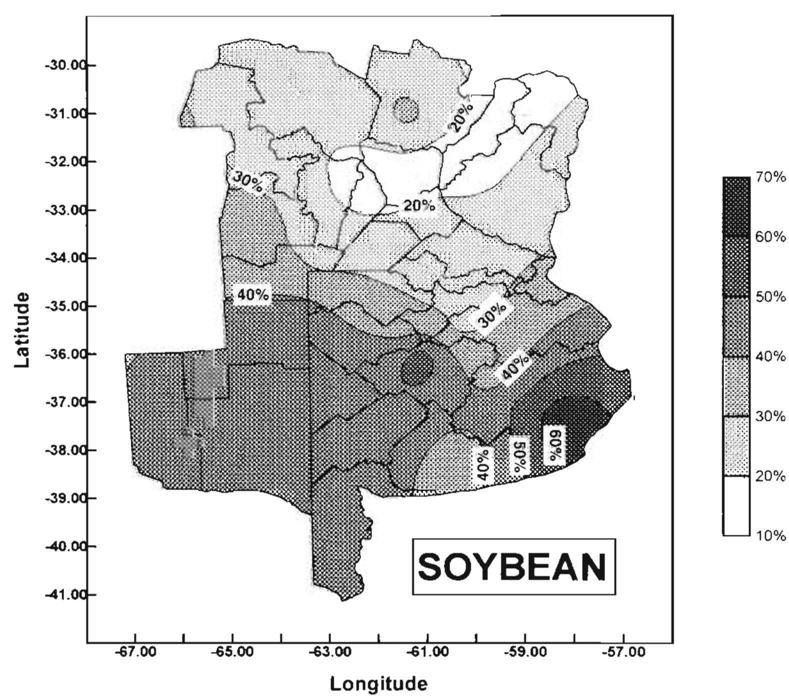

Fig. 4. Differences in percentage between CROPGRO model simulated soybean yields under current and future climate scenarios for the Argentinean pampean region

bean pods, which is highly dependent on temperature, is slowed down when the night temperature is lower than 22°C and is interrupted when it is below 14°C (Hesketh et al. 1973, Thomas & Raper 1978). Thus, the higher temperature values predicted by GISS outputs would enhance the production of a larger number of grains per unit area. This would occur mainly in those zones which are presently colder, e.g. the southeastern sector of Buenos Aires province, where the potential increase in grain number is estimated at 50%.

The production conditions would be remarkably improved as a result of such increases. The planted area in the 1980 to 1989 decade was 2.67 million ha, with a production of 5.43 million t and a mean yield of 2.03 t ha^{-1}. Under a future climate change scenario the production is expected to increase by 20.7%, with a mean yield of 2.45 t ha^{-1}.

4. CONCLUSIONS

The climate changes projected by the GISS model combined with a rise in the CO_2 concentration to 550 ppm are expected to cause generalized increases in soybean yield and decreases in maize yield in the Argentinean pampean region. Wheat yields are likely to increase in the southern and western sectors and decrease in the northern sector of the region.

With regard to wheat, the projected variations in yield would be related to the effect of temperature on growth. An increase in yield would occur in areas with day temperatures close to 18°C while a decrease would occur in the areas where temperatures are beyond this threshold.

The reductions in maize yields would be associated with a shorter cycle (particularly as regards the reproductive stage), and with the consequent reduction in grain weight.

The highest soybean yields would be due to a rise in temperature during the pod development stage, which would cause an increase in the number of grains per unit area.

While wheat and soybean production in the pampean region would increase by 3.6 and 20.7% respectively, maize production would be reduced by 16.5%.

The climate projections available for this study did not allow for the analysis of information at a more detailed scale. The adaptation of general circulation models to the regional level would enable a better evaluation of the system's vulnerability to the predicted changes.

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