AGROCLIMATIC ZONING AND CLIMATIC RISKS FOR SUGARCANE IN MEXICO—A PRELIMINARY STUDY CONSIDERING CLIMATE CHANGE SCENARIOS

By

O. BRUNINI, J.P. CARVALHO, A.P.C. BRUNINI, A.L. PADUA JUNIOR, S.F. ADAMI and P.L.G. ABRAMIDES

São Paulo State Agriculture and Food Secretariat, Brazil, Agronomic Institute
brunini@iac.sp.gov.br

KEYWORDS: Sugarcane, Crop Zoning, Climate Risks, Climate Change.

Abstract

IN THE EXISTING scenario of current agricultural management systems and climatic standards, a new source of uncertainties must be taken into account, namely, the temperature scenarios and water availability resulting from climate changes. In this aspect, agricultural zoning, supported by the climatic and edaphological potential of a region, and the climate scenarios, along with the associated risks, have become highly relevant. This paper considers an example of the sugarcane crop in Mexico, indicating possible potential areas for crop development, and what are the climatic risks during plant growth, based on crop zoning criteria, as well as the impact of global warming in future scenarios. The agro climatic scope and the edaphological and climatic zoning were defined through the quantification of physical resources and the water balance parameters of different regions, indicating the relationship between energy availability, water supply and crop water demand. The study further determined the influence of climate changes in the quantification of the water balance for the regions and the effects of this anomaly in sugarcane development. The study was based on meteorological data from historic series from Mexican research institutes and from the National Meteorological Service of Mexico, accessible via the Web. The available products are: a) monthly and annual air temperature; b) monthly and annual total rainfall, c) monthly and fortnightly values of water deficit and surplus; d) drought probability at monthly and fortnightly level and maps of frost. As a result, maps of agroclimatic suitability for the various regions in Mexico were produced with the current climate standards as well as considering the increase in meteorological adversities and the change in the scenarios due to global warming. Climatic risks associated with high or low temperatures and the probability of drought events are shown for both agrometeorological and meteorological factors, with an indication of the regions that are more suitable for the development of this crop.

Introduction

In the established scenarios based on the current agricultural management systems and the climate patterns that affect development of the sugarcane crop, a new source of uncertainty must be taken into account–the temperature and water availability scenarios resulting from climate changes and/or global warming.

Despite abundant discussion and a multitude of studies indicating future scenarios related to global warming and the current modifications resulting from those possible changes, or even the anomalies due to seasonal climate variability, very little is known as a fact, especially how crops respond to a new thermal regime, the physiological and metabolic adaptations, and the consequent modifications to which crops will be subject. Therefore, it is the responsibility of different agencies to propose adaptation measures in order to reduce the negative effects of climate adversities. An important procedure is the establishment of public policies for agricultural development based on climatic characteristics. In that sense, agricultural zoning followed by Agro-ecological Zoning, based on the climatic and edaphic potential of a region and its associated risks, are highly relevant. It is also important to mention that the agro-ecological zoning might provide complementary information about the climatic risk in certain phases of the crop such as: high or low temperatures, drought or excess rainfall, thus indicating the climatic risk and the feasibility of success and production.

In spite of its remarkable adjustment to climatic conditions, the sugarcane plant finds its best conditions when there is a hot and humid period, with high solar radiation in the growth phase, followed by a dry period, sunny and cooler, in the maturation and harvest phases. The main factors that determine the success of the crop and its economic use are air temperature and rainfall. Studies from Bacchi and Souza (1978) indicated that, in irrigated crops, growth stopped or was irrelevant for an air temperature below 18ºC whereas, for non-irrigated crops, this temperature was 19ºC. This crop reasonably endures high temperatures of 34/35ºC for a few hours. However, steady values above 38/40ºC may affect its development through the inhibitory effect of physiological activities such as the opening of stomata and CO_2 exchange. An aspect that is still important is flowering, as it may compromise productivity. During the flowering inductive period, both the water supply and temperature regimes are critical. Minimal air temperatures (at night) below 18ºC and maximum temperatures (daytime) above 30/32ºC affect flowering negatively, that is to say, inhibit it (Pereira *et al.*, 1983). After floral induction, the forming of new internodes ceases and the pith process of the basic tissue may start. For most varieties after flowering induction, as long as climatic conditions are suitable, the emission of panicles happens between 7 and 10 weeks. In a such a case, there is an inversion in the process of sucrose production which is directed towards panicle emission and final sugar content is reduced.

This study aims to indicate, in a preliminary form, the potential for agricultural use of the sugarcane crop in the Republic of Mexico and the climate factors that influence this potential. Additionally, a simulation of the effect of global warming on the agricultural suitability of the crop is also presented.

Materials and methods

The study of agricultural zoning or agro climatic suitability, followed by agro environmental zoning, comprises the determination, within a certain defined area, of the potential of agricultural use of crops in relation to their climate demands and of how much support the climate can offer in terms of temperature and water supply. It also includes evaluation of climatic risks associated with frost, water deficit, drought or high temperatures. The climate is generally the first element taken into account as it is considered a stability factor, although seasonal variations and climate variability must also be considered.

The methodology used for the definition of the appropriate areas for growth and production of sugarcane is based on studies of climate zoning of crops such as: Camargo and Ortolani (1964), Alfonsi *et al.* (1995), Brunini *et al.* (2008a); Brunini *et al.* (2008b); and Brunini *et al*, (2009). Despite being relatively work intensive, this methodology is efficient for qualitative climate comparison between the several regions of the globe to study agricultural zoning. Also, a better degree of refinement is reached when this methodology and the climate indexes are compared with indexes of crops in order to obtain the bioclimatic indexes for the referred crop. The widely known and widely used methodology in this type of agroclimatic zoning is the following:

1. Data collection and preparation of basic climatic charts representative of the region (average air temperature; annual and coldest month; and potential evapotranspiration, among others).

2. Calculation of Water Balance for the determination of the following parameters: actual evapotranspiration; water deficit and surplus based on water balance parameters according to Thornthwaite and Mather, (1955).
3. Survey of climate demands of the crop–values estimated based on climate-sugarcane qualification (Brunini, 1997 a; Brunini, 1997b);
4. Comparison of these data obtained in item 3 with the data provided in items 1 and 2 and layout of agroclimatic maps for the referred crops.

After all the processes (1 to 4), a region may be classified for the growth of a plant, in one of three following categories.

- Adequate: when macroclimate conditions are normally favourable for commercial use**;**
- Restricted: when climate conditions present restrictions which frequently undermine certain phases of the crop. There might be some limitation, not too severe, in terms of temperature and/or water supply;
- Inadequate: when climatic characteristics are not adequate for commercial use. In this case, there are serious limitations in terms of temperature and water supply.

Meteorological parameters and water balance

The source of meteorological data for the execution of the studies was the existing climatic basis made available by the National Meteorological Service of Mexico, according to access and collection of information via the WEB in March, 2009 (http://smn.cna.gob.mx).

The basic information obtained was the average monthly air temperature in ºC, average monthly rainfall in mm, along with the geographic coordinates for later georeferencing.

In that preliminary phase of the study, 333 locations, scattered across the entire territory, were analysed.

The water balance for quantification and estimate of water availability in the soil and to indicate water deficit and surplus was developed using the methodology proposed by Thornthwaite and Mather (1955) using the software developed by Brunini and Caputi (2001).

In this case, the average monthly values of air temperature and rainfall were entered in the software and the corresponding water balance parameters were created to obtain the following indices:

a) total annual water deficit (mm);

b) water deficit of the crop's growth season (mm);

c) annual potential evapotranspiration (mm);

d) total annual water surplus (mm).

The scenario of climatic behaviour and water balance in terms of prospects established by IPCC was evaluated taking into account an average annual warming of 2ºC, considering the effect of such an increase in the period of water deficit, in other words, during the dry season, and its intensity (Assad and Pinto, 2008).

With the new scenario of air temperature, these new values are again inserted into the original data set and new water balances are created considering this increase in air temperature. Water balance has the precision as defined in methodology described by Brunini and Capuit (2001) and the major point is to use soil water holding capacity appropriate for the study.

After the development of the agroclimatic charts and the definition of crop demands in terms of temperature and water supply and the combination of these factors, the agroclimatic zoning was established. Its climatic adaptation regions were those indicated in Table 1 (Brunini *et al.*, 2007; Brunini *et al.*, 2008b; Brunini, 2008; Brunini *et al.*. 2009).

The characteristics used to quantify crop development and weather variables are used for general crop zoning and thjey are widely used. For sugarcane, the parameters were defined based on the work carried out by Brunini *et al*..(2007), Brunini *et al.* (2009), and Camargo and Ortolani (1964).

Table 1—Characteristics of climate and crop development conditions.

Average annual temperature (ºC)	Classification	Annual water deficit (mm)	Classification
< 18	Unsuitable	< 240	Suitable
18–19	Borderline to unsuitable	240–300	Borderline–Limitations
19–21	Marginal	300–400	Borderline
21–26	Suitable	400–600	Borderline–Restrictions
> 26	Borderline	600–800	Unsuitable–Adjustments
–	–	> 800	Unsuitable

Results and discussion

Based on weather parameters and crop response, the study was sub-divided into 2 major topics, one considering the actual climate scenario and an analysis considering global warming, based on a temperature increase of about 2ºC.

Actual climate scenario

Theme climatic maps were developed based on climatic information of the locations; they refer to temperature and water availability for Mexico, according to Figures 1 and 2. The maps were developed with the use of the ArcGis program and the information and data made available in shapefile form, which may be converted to Excel spreadsheets.

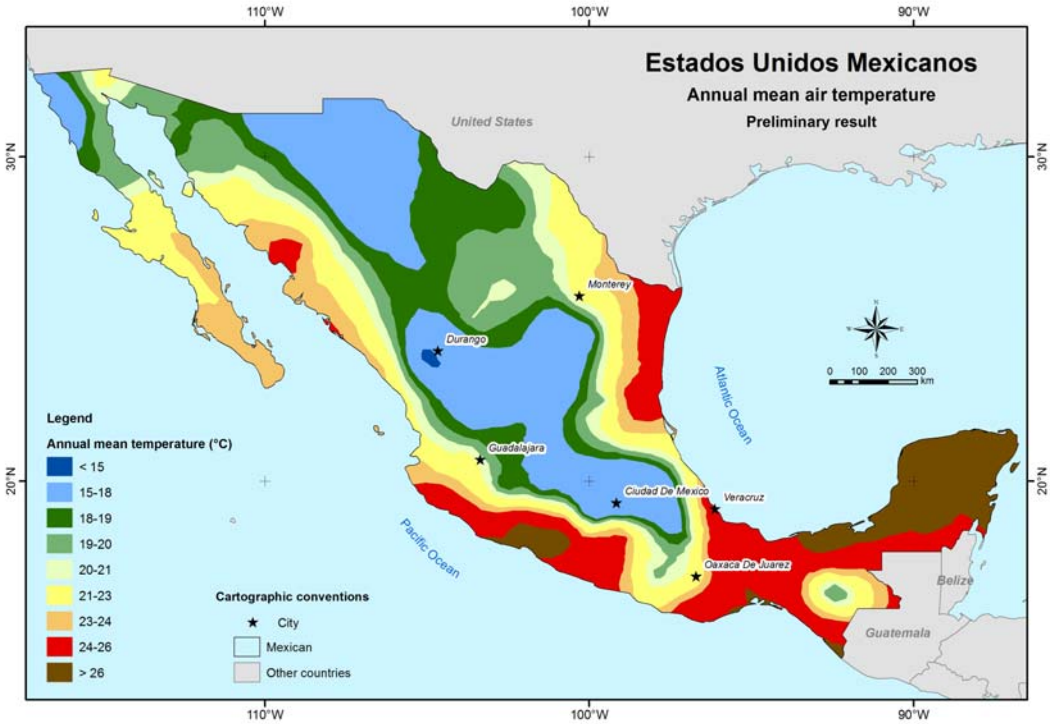

Fig. 1—Average annual air temperature for the Republic of Mexico (preliminary analysis).

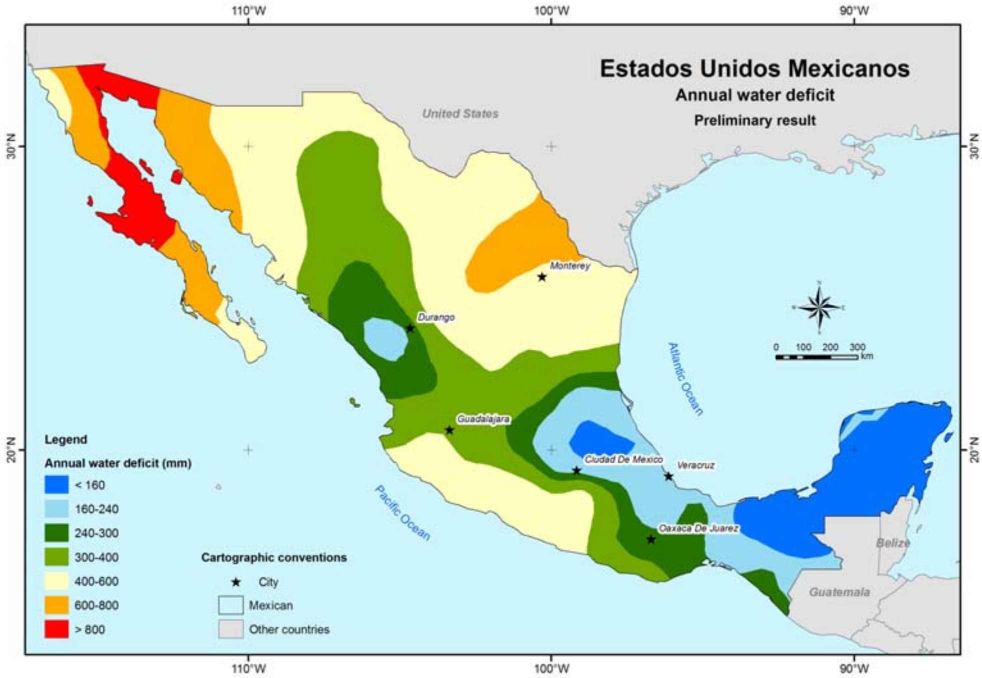

Fig. 2—Average annual water deficit for the Republic of Mexico (preliminary analysis).

The edaphological and climatic suitability map of the crop, with the different conditions of adaptation and soil type, was based on the crossing of information from these maps. This information is presented in Figure 3. Basic suitability information for each location and the indication of suitable or unsuitable areas generated the restrictive factors which are specified for each location in each growing stage of the crop, allowing the evaluation of the degree of risk and the most restrictive factor. The basic characteristic for obtaining the results in Figure 3 was the crossing of temperature and water deficit suitability. After this initial process, the information was then compared to the parameters of water balance during the crop growth season, which occurs from September to May, when the climatic restrictions related to water deficit or surplus and effects of temperature in the cycle and productivity are extremely important.

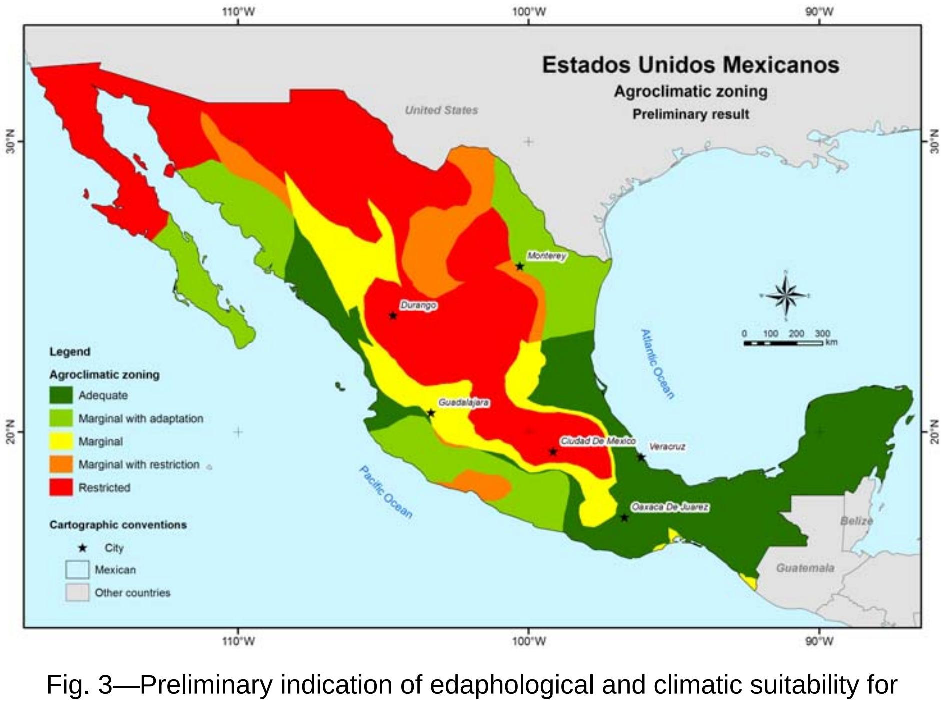

Fig. 3—Preliminary indication of edaphological and climatic suitability for sugarcane crop in the Republic of Mexico.

Figure 4 presents the climatic availability conditions in the crop growth season. The climatic restriction is seen in various regions, although in a great part of the regions considered adequate, based on annual climate factor, this situation is reinforced by this more restricted analysis, both in terms of temperature and water availability.

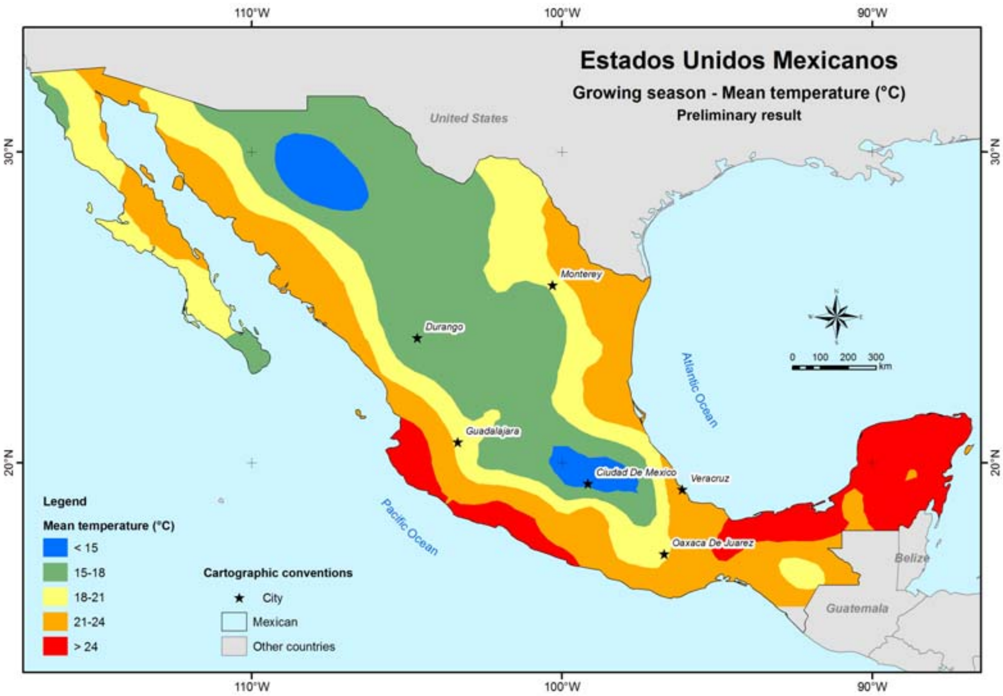

Fig. 4a—Preliminary indication of edaphological and climatic suitability for sugarcane crops in the Republic of Mexico, during the crop growth season (temperature restriction).

Fig. 4b—Preliminary indication of edaphological and climatic suitability for sugarcane crops in the Republic of Mexico, during the crop growth season (water availability restrictions).

Climatic changes and crop adaptation

The aspects of climate change and global warming cannot be viewed based only on a single climatic characteristic, whether it is temperature or rainfall. The processes involved in changes in the crop's response to environmental stress do not depend only on the interaction of plant and environment, but also on the crop's adaptation processes and metabolic adjustments to the new climatic levels.

Thus, in this study, a simple analogy between a possible global warming scenario is presented considering an average air temperature increase of 2ºC. This anomaly was incorporated in the monthly water balances, and the results of water deficit and surplus were then associated.

Figure 5 presents the comparison of results in terms of water balance when an average of 2ºC was added to the average air temperature for some locations, although the analogy was performed for the 333 locations. It is possible to note that the dry period for the different locations, in other words, its beginning and its end, is practically the same, but the drought intensity, as represented by the total annual water deficit, increases.

These results lead to two different considerations; a) **duration of the drought period**: in the aspect of annual range of drought period duration, the crop would not be totally affected, indicating that there would be conditions for development and agricultural use; b) **intensity of drought**: in this case, the varieties would be more exposed to stronger water stress, which could lead to reduction of productivity in sugar, and indicate a greater need for irrigation; and that, in addition to water stress, the low availability of water in the soil would increase the flow of sensitive heat (warming of the air, exposing crops to double stress).

A new scenario indicated by annual water deficit, as shown in Table 2, would be available based on the ratio between the beginning and the end of the drought period, and the intensity of the drought.

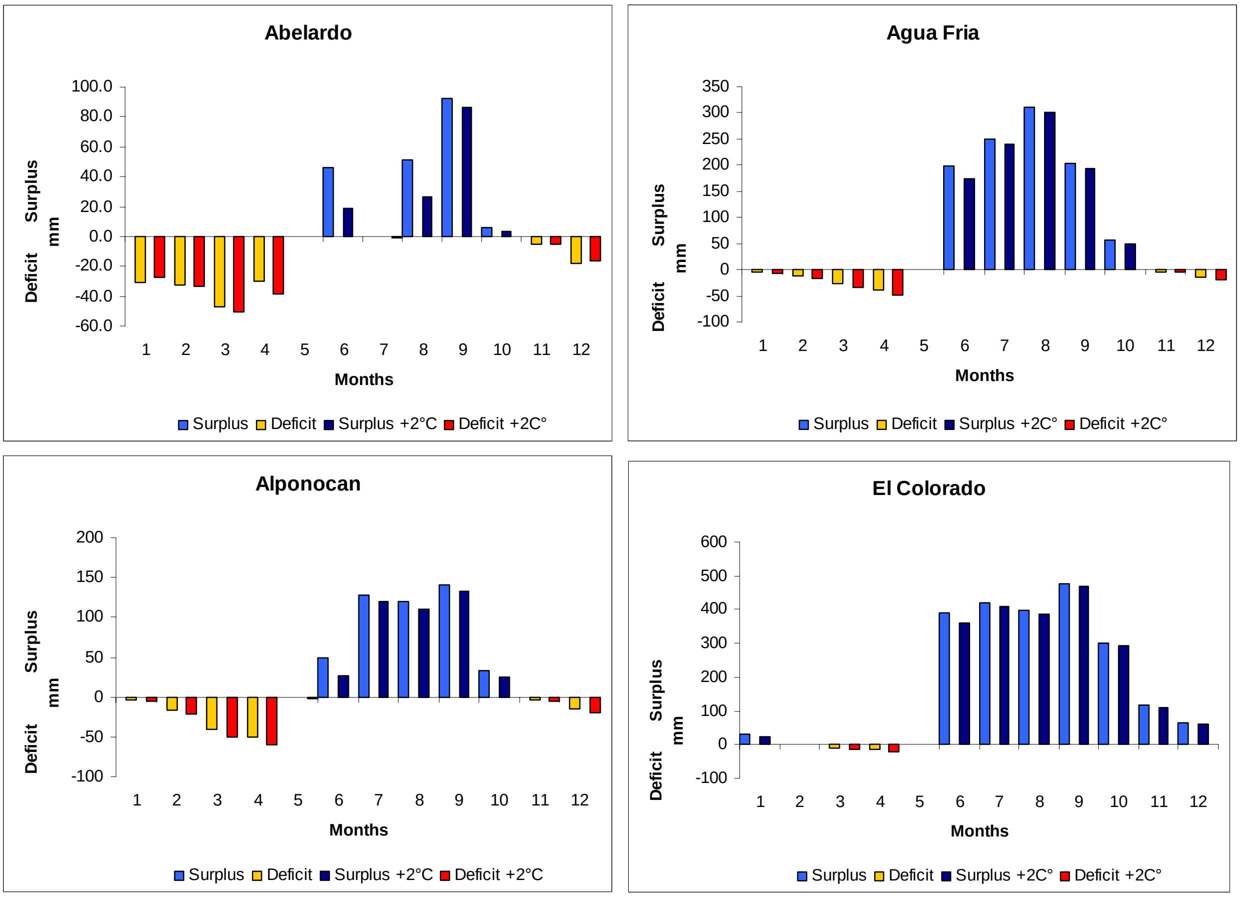

Fig. 5—Comparison of the monthly water balance terms for some locations in the Republic of Mexico, for current scenarios and with a 2ºC air temperature increase.

Table 2—Scenario of water deficit climatic characteristics, with a 2ºC average air temperature increase, and behaviour of sugarcane crop.

Average temperature (ºC)	Classification	Water deficit + 2°C (mm)	Classification
< 18	Suitable	< 240	Suitable
18–19	Borderline to unsuitable	240–300	Suitable–Limitation
19–21	Borderline	300–400	Borderline–Limitation
21–26	Suitable	400–600	Unsuitable–Adjustment
> 26	Borderline	> 600	Unsuitable

This is also reflected by the climatic availability map, concerning growth and stabilisation period of the crop, normally from September to May .The representative maps of annual temperature availability (average temperature) and annual water deficit were redone based on these analyses, as presented in Figures 6 and 7

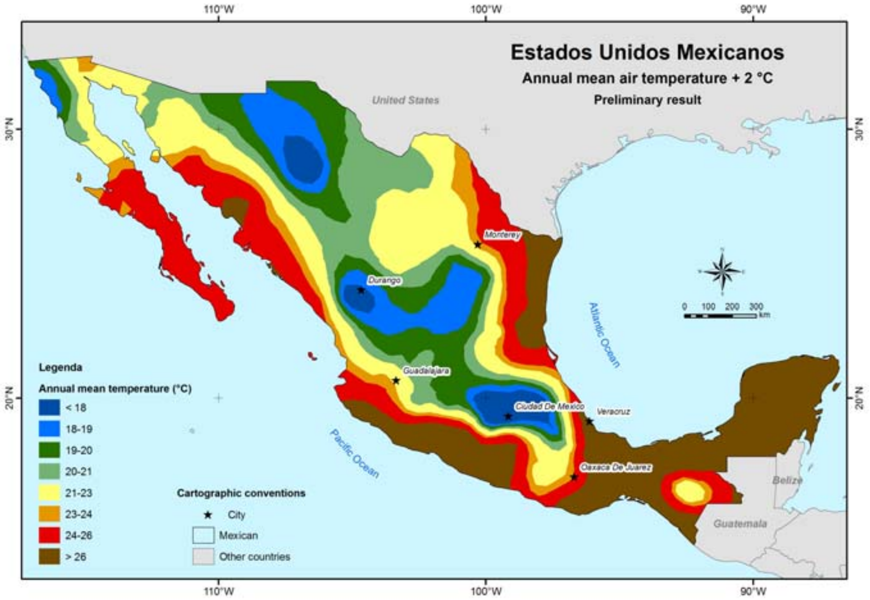

Fig. 6—Estimate of average annual air temperature for the Republic of Mexico, with a 2ºC linear average air temperature increase (preliminary analysis).

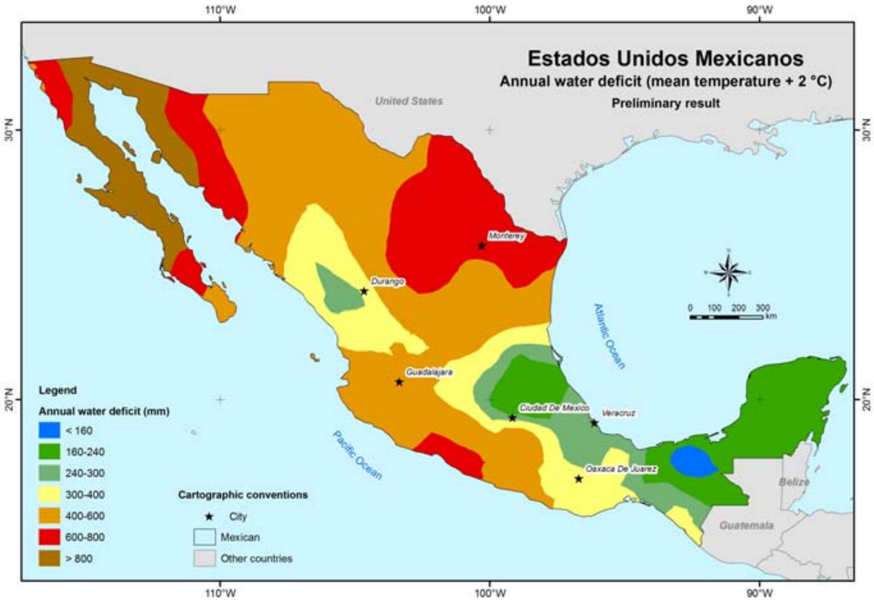

Fig. 7—Estimate of average annual water deficit for the Republic of Mexico with a 2ºC linear average air temperature increase (preliminary analysis).

In addition to that, an analysis for the growth period and complete establishment of the crop was made, also with the scenario of a 2ºC linear average air temperature increase. The confrontation of these data presents a new dynamic of agricultural use of that crop in Mexico, as shown in the map in Figure 8. These analyses, when compared to water deficit characteristics in the growth season (Figure 9), indicate that a better varietal management and choice of varieties that are more adapted to longer periods of water stress and high night time temperatures should be used.

It is important to mention that these studies are preliminary and that a wider range of data and locations, as well as deeper evaluation of the global warming scenarios, should be incorporated. Moreover, the study of the climatic scenario was based only on warming, with no modification of rainfall pattern.

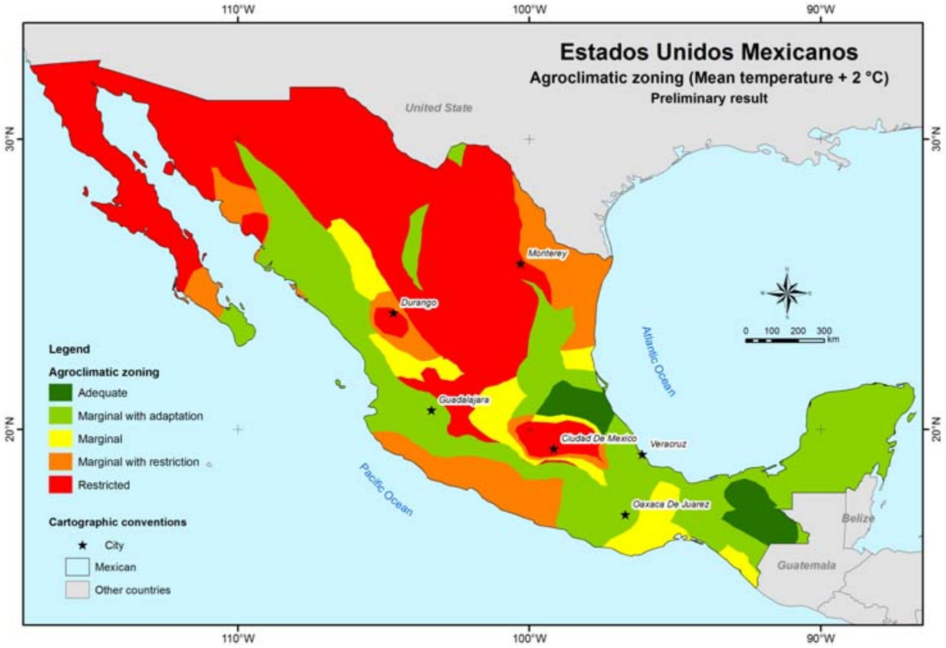

Fig. 8—Indication of edaphological and climatic suitability for sugarcane crop in the Republic of Mexico, with a 2ºC linear average air temperature increase (preliminary analysis)

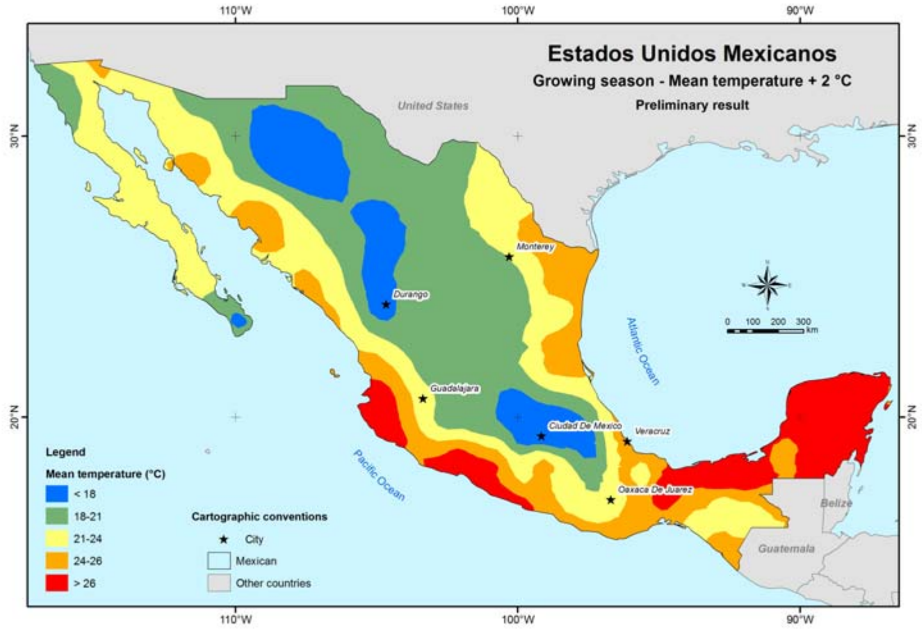

Fig. 9a—Preliminary indication of edaphological and climatic suitability for sugarcane crop in the Republic of Mexico, during crop growth season, with a 2ºC linear increase in the average air temperature (preliminary analysis—temperature restriction).

A previous study made by Brunini *et al*. (2008a), when comparing recharge of aquifers determined by the difference between rainfall and potential evapotranspiration, indicates that, if the warming is accompanied by an increase in monthly rainfall of at least 20%, there will be a reduction in the total of estimated water deficit, and greater aquifer recharge.

Conclusions

The results analysed indicate that, in terms of edaphological and climatic aspects, the Republic of Mexico presents plentiful conditions for the commercial use of the sugarcane crop.

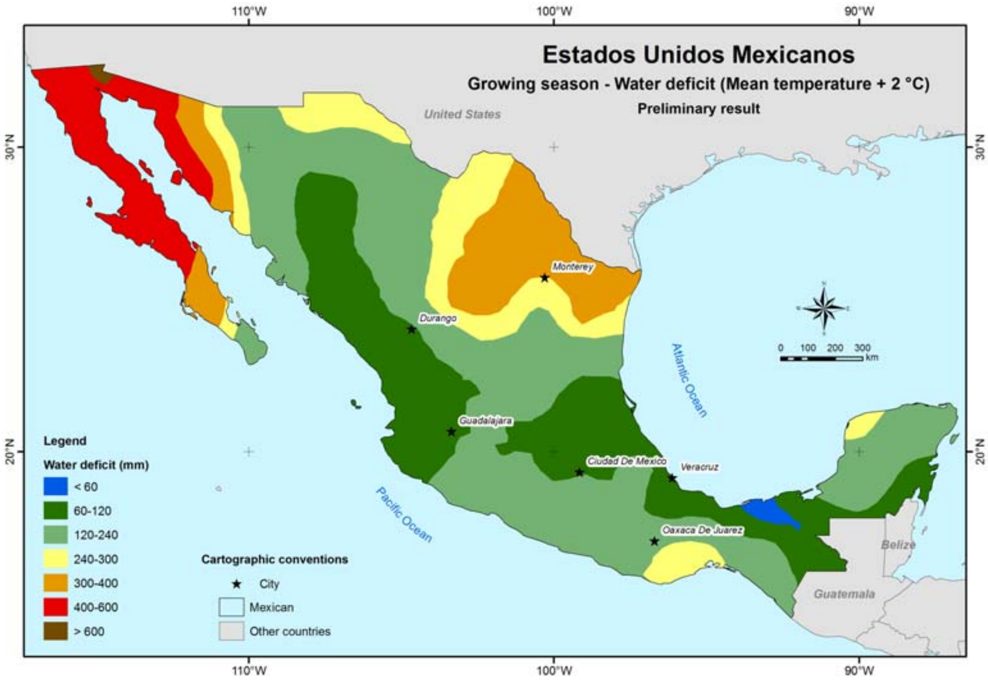

Fig. 9b—Preliminary indication of edaphological and climatic suitability for sugarcane crop in the Republic of Mexico, during crop growth season, with a 2ºC linear increase in the average air temperature (preliminary analysis—water availability restrictions).

With the incorporation of the global warming factor, of up to 2ºC, the areas indicated as fully adequate for the development of the crop undergo modification in the water restriction aspect and some areas become restrictive due to the high values of average air temperature, above 26ºC, although it does not make commercial use impractical.

Furthermore, the climatic modification study was developed based only on the increase of average annual temperature, not taking into account factors such as: rainfall distribution and total rainfall, increase and/or decrease of frost, and increase in likelihood of drought risks, which may change the scenario presented.

Acknowledegement

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ZONAGE AGROCLIMATIQUE ET RISQUES CLIMATIQUES DE LA CANNE A SUCRE AU MEXIQUE: ETUDE PRELIMINAIRE TENANT COMPTE DE SCENARIOS DE CHANGEMENTS CLIMATIQUES

Par

O. BRUNINI, J.P. CARVALHO, A.P.C. BRUNINI, A.L. PADUA JUNIOR,
S.F. ADAMI et P.L.G. ABRAMIDES
São Paulo State Agriculture and Food Secretariat, Brazil, Agronomic Institute
brunini@iac.sp.gov.br

**MOTS CLES: Canne a Sucre, Zonage de Cultures,
Risques Climatiques, Changement Climatique.**

Résumé

DANS LES SYSTEMES de culture et climats existants, une nouvelle source d'incertitude doit être prise en compte: les scénarios de température et de disponibilité en eau résultants du changements climatiques. A ce niveau, le zonage agricole, établi à partir du potentiel climatique et édaphique d'une région, des scénarios climatiques et des risques associés, devient indispensable. Ce papier prend en compte un exemple de culture de canne à sucre au Mexique, précise les surfaces de développement possibles de la culture et indique les risques climatiques durant la croissance sur les critères de zonage, ainsi que l'impact du réchauffement climatique dans les futurs scénarios. Le domaine d'application agroclimatique et le zonage édaphique et climatique ont été définis en quantifiant les ressources physiques et les paramètres du bilan hydrique de différentes régions, et en indiquant les relations entre disponibilité en énergie, fourniture en eau et besoin en eau de la culture. De plus, l'étude a déterminé l'influence des changements climatiques sur la quantification du bilan hydrique de ces régions et les effets de ces changements sur le développement de la canne. L'étude a été basée sur des séries historiques de données climatiques accessibles sur le web, provenant des instituts de recherche Mexicains et du département météorologique national de Mexico. Les produits disponibles sont: a) la température de l'air mensuelle et annuelle, b) la pluviométrie totale mensuelle et annuelle, c) les valeurs mensuelles et bimensuelles des déficits et excès d'eau, d) la probabilité mensuelle et bimensuelles de sécheresse ainsi que des cartes de gel. Ainsi, des cartes d'aptabilité agroclimatique des diverses régions du Mexique ont été réalisées en prenant en compte les conditions climatiques actuelles, l'augmentation de conditions climatiques défavorables et les changements de scénarios dus au réchauffement climatique. Les risques climatiques associés aux températures élevées ou basses et la probabilité de sécheresses sont indiqués à la fois pour les facteurs météorologiques et agro météorologiques. Les régions les plus adaptées au développement de cette culture sont également présentées.

ZONIFICACIÓN AGROCLIMÁTICO Y RIESGOS CLIMÁTICOS PARA LA CAÑA DE AZÚCAR EN MÉJICO- UN ESTUDIO PRELIMINAR CONSIDERANDO LAS PERSPECTIVAS DE CAMBIO CLIMÁTICO

Por

O. BRUNINI, J.P. CARVALHO, A.P.C. BRUNINI, A.L. PADUA JUNIOR,
S.F. ADAMI y P.L.G. ABRAMIDES

São Paulo State Agriculture and Food Secretariat, Brazil, Agronomic Institute

brunini@iac.sp.gov.br

PALABRAS CLAVES: Caña de Azúcar, Zonificación de Cultivos, Riesgos Climáticos, Cambio Climático.

Resumen

EN LA PERSPECTIVA existente de los actuales sistemas de manejo agrícola y estándares climáticos se debe considerar una nueva fuente de incertidumbre a saber: los escenarios térmicos y la disponibilidad de agua como consecuencia de los cambios climáticos. En este aspecto, la zonificación agrícola, basada en el potencial climático-edafológico de una región, y las perspectivas climáticas, junto con los riesgos asociados, resultan altamente relevantes. Este trabajo contempla un ejemplo para el cultivo de caña de azúcar en Méjico, indicando posibles áreas potenciales para el desarrollo del cultivo, y cuales son los riesgos climáticos durante el crecimiento de la planta, basado en criterios de zonificación del cultivo, y también considera el impacto del calentamiento global en las perspectivas futuras. El ámbito agro climático y la zonificación climático-edafológica se definieron mediante la cuantificación de recursos físicos y de parámetros del balance hídrico de diferentes regiones, indicando la relación entre la energía disponible, el suministro hídrico y la demanda de agua del cultivo. Además, el estudio determinó la influencia de los cambios climáticos en la cuantificación del balance hídrico por regiones y los efectos de esta anomalía en el desarrollo de la caña de azúcar. El trabajo se basó en series históricas de datos meteorológicos obtenidos de institutos de investigación de Méjico y del Servicio Meteorológico Nacional de Méjico, accesibles en la Web. Los datos disponibles son: a) temperatura del aire mensual y anual; b) precipitaciones totales mensuales y anuales; c) valores mensuales y quincenales de déficit y excedentes hídricos; d) probabilidad mensual y quincenal de sequías y mapas de heladas. Como resultado se obtuvieron mapas agroclimáticos apropiados para varias regiones en Méjico, considerando los estándares climáticos actuales y también el incremento de las adversidades meteorológicas y el cambio en las perspectivas debido al calentamiento global. Los riesgos climáticos asociados con altas o bajas temperaturas y la probabilidad de sequías fueron demostrados para factores agrometeorológicos y meteorológicos, con una indicación de las regiones que son más adecuadas para el desarrollo de este cultivo.