Article

Crop prediction and diversification for Nuevo León, Mexico

Gustavo Andrés Ramírez-Gómez[1]
Edgar Vladimir Gutiérrez-Castorena[1§]
Carlos Alberto Ortiz-Solorio[2]
Ma. del Carmen Gutiérrez-Castorena[2]

[1]Faculty of Agronomy-Autonomous University of Nuevo León. Francisco I. Madero s/n, ex-hacienda el Canadá, General Escobedo, Nuevo León, Mexico. CP. 66050. (gustavormz440@gmail.com). [2]Postgraduate College-*Campus* Montecillo. Mexico-Texcoco highway km 36.5, Montecillos, Estado México, México. CP. 56230. (ortiz@colpos.mx; castor@colpos.mx).

[§]Corresponding author: edgar.gutierrezcs@uanl.edu.mx.

Abstract

The factors involved in the prediction of areas for food production are subject to cultural, socio-economic variables, water availability and particular characteristics of its management and production. Agriculture as a micro business activity is subject to risks that force to improve predictive mechanisms of climatic and edaphic variables. The main objective is to generate models from various databases and thematic maps at the same observation scale to locate areas with productive potential of 16 crops with economic value in the national and strategic market for the state of Nuevo León. This state was selected for belonging to three physiographic regions with great edaphoclimatic diversity, which requires proven methods both nationally (Ortíz, 2011) and internationally for zoning. Different databases such as aptitude in terms of thermal efficiencies, frost-free period and classification, degradation and water regime of the soils were used. The results show that with the information collected and analyzed, the areas on maps for basic grains, vegetables and fruit can be located and quantified in more than 50% of the state agricultural area and other crops in areas less than 10%. The best agricultural area is located in the central north of the state; however, the determining factor for the growth of the main crops is the frost-free period. It is recommended to grow early varieties of basic grains and vegetables to take advantage of the months with greater efficiencies.

Keywords: classification, crop suitability, soil degradation, thermal efficiency, yield.

Reception date: April 2020
Acceptance date: July 2020

Introduction

Given the growing concern about climate change, demographic increase, socioeconomic and migratory limitations, it is necessary to carry out predictive studies of a region with respect to the potential agricultural yield; furthermore, it is of paramount importance to implement methodological strategies and techniques that allow locating areas destined for intensive agricultural production.

Furthermore, it is necessary to consider not only crops that are economically viable with commercial value in the markets, but also to find other crops that can be incorporated to increase their diversity and agroecological sustainability (Hansen, 2004; Intergovernmental Panel on Climate Change, 2014). Johnson *et al*. (2016) indicate that early and reliable projections of crop yields in large areas allow authorities and producers to plan exports and imports for the benefit of rural areas.

According to Valin *et al*. (2014), food production is subordinated to dependent and independent variables that imply the behavior of the internal and external market of a region and socioeconomic elements of the population. The meteorological factor is the one that most influences production in opencast agriculture systems (Cai *et al*., 2016) and it is estimated that it will change more due to climate change. In fact, the predictions are not at all encouraging, since an increase of 60% is projected for the year 2050 in agricultural production and between 20% and 30% in livestock (Tilman *et al*., 2011). Consequently, applied science strategies and research are required to increase certainty about food production in the field (FAO, 1978), as a first alternative and preliminary studies of potentially agricultural areas that project the sustainability and diversification of crops (van Ittersum *et al*., 2013).

Crop simulation models offer robust results for the estimation and prediction of potential yield (van Ittersum *et al*., 2013) with the virtue that areas suitable and unsuitable for food production can be projected and limited. However, these yield projections are defined only by their biophysical capacity and not by biotic and abiotic stress (de Wit, 1965). For this reason, the Food and Agriculture Organization of the United Nations (FAO, 1978) proposed agroecological zoning (ZAE), being a methodology that uses climate databases and soil information to delimit areas, regions or even the entire country with older with greater agronomic and socioeconomic potential.

In the case of the state of Nuevo León, like any other federal entity, it is necessary to locate potentially productive areas with the possibility of diversification and without climatic limitations (frost). Therefore, it is necessary to generate modeling systems that guarantee land information with the possibility of going from a monoculture system (spring-summer) such as: potatoes, tomatoes and grasses (SIAP, 2018), to a crop rotation system in two cycles. Fraisse *et al*. (2006)- mention that the analysis of climatic and edaphic data offers an alternative for large territorial extensions with direct influence on the potential of crops. Although caution should be exercised in the management of scalar variation (Grassini *et al*., 2015) and geospatial interpolation reflected in the digital quality of the thematic maps (Van Wart *et al*., 2015) of each region.

Based on the above, the objectives of the present investigation were: 1) to generate models from different databases, and thematic maps at the same observation scale; 2) identify and locate potentially agricultural areas with the possibility of implementing intensive food production throughout the agricultural year; and 3) incentivize the diversity and planning of the agricultural zones destined to the production of food with economic interest.

Materials and methods

The methodological sequence and integration of predictive models consists of: 1) digital vectorization of agricultural areas under the Google Earth Pro® platform; 2) use of climatic, edaphic and crop requirements databases; 3) interpolation of results on thematic maps; 4) extraction of polygons from agricultural areas through map algebra; and 5) integration of potential yield databases with thematic maps of agricultural areas.

Location

This study was carried out in the state of Nuevo León, Mexico, which is located between the coordinates 23° 10’ 27” and 27° 46’ 06” north latitude and 98° 26’ 24” and 101° 13’ 55” west longitude, with an area of 6 455 500 ha.

Delimitation of the study area

The digitization of the state consisted of first delimiting the federal entity and municipalities of Nuevo Leon through vector masks in shape file format, taking as a reference the study carried out by the Ministry of the Environment and Natural Resources (SEMARNAT) and the College of Postgraduates (CP). (2001-2002). Subsequently, areas with agricultural potential were identified with interaction and direct visualization on the screen on the Google Earth Pro® digital platform.

Satellite images with a flight height (eye height) of Google Earth Pro® of 2.19 km were photointerpreted to map at an average scale of 1:50 000, in addition, associative interpretation methods were used considering elements both in the field and in the cabinet to generate the agricultural facets (Ortiz-Solorio and Cuanalo de la Cerda, 1984).

Databases and thematic maps

The database with climatic information of the state was extracted from the National Meteorological Service (SMN) using the climatological normals of climatic stations (1951-2010). 83 climatic stations, located geospatially, were considered within the entity, and 24 in the neighboring states, as follows: 10 in Coahuila, 5 in San Luis Potosí and 9 in Tamaulipas with a total of 107 stations, for analysis (Figure 1).

Another database used was the ECOCROP platform which is integrated with climatic and edaphic information on the requirements and needs of the crops. On this basis, data on economically viable crops for the federal entity were extracted, such as: a) type and agricultural cycle; b) temperature needs (maximum and minimum) and annual precipitation; and c) edaphic requirements of: depth, texture, salinity, pH and drainage of the profile.

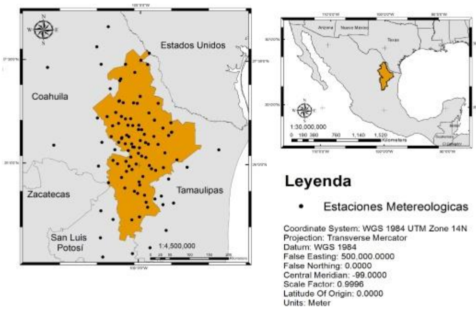


Figure 1. Geospatial distribution of meteorological stations.

In relation to the edaphic resource, the thematic maps used were: a) those generated by the National Institute of Statistics, Geography and Informatics at a scale of 1:1 000 000 (INEGI, 2005) using the soil classification of the world reference base (WRB, 2015); b) 1: 250 000 scale maps of dominant soil degradation caused by man in the Mexican Republic (SEMARNAT-CP, 2001-2002); and c) the maps of soil moisture and temperature regimes prepared by de Sánchez *et al*. (2009).

Tours and field verification of agricultural areas

The field trips were made in transects from North to South and from East to West on roads and direct access to the selected points was considered, which were used as verification and correction points (Figure 2).

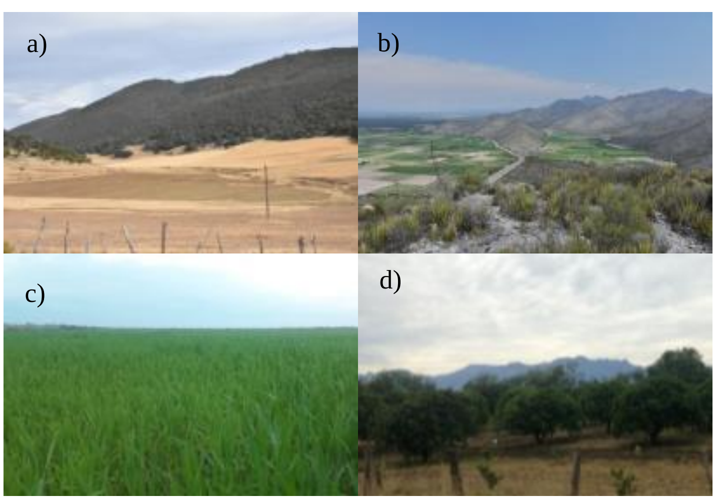


Figure 2. Tours in municipalities (projection in UTM). a) Galeana (2737650, 394916); b) Aramberri (2669386, 393500); c) Anahuac (3015776, 386979); and d) Linares (2752594, 437753).

Crop diversification

Crop diversification in the study area consisted of selecting crops of different species based on their climatic efficiency for both the spring-summer cycle and the autumn-winter cycle, estimating their maximum yields per unit area in specific regions of the state.

Potential yield

The potential yield of each crop was estimated with the established methodology of the agro-ecological zones (GAEZ, 2006) based on the work of Wit (1965). The modifications proposed by Ortiz (2011) were also used to estimate the fresh weight from of the dry weight proposed by the agroecological model in vegetables and fruit trees and photosynthetically active radiation on very clear days, daily gross photosynthesis rate on closed days and daily gross photosynthesis rate on clear days.

Crop index and potential thermal efficiency

To estimate the index and thermal efficiency of each crop, the methodology of Neild and Boshell (1976) was used for the main crops in the state of Nuevo León, based on monthly maximum and minimum temperatures reported in the climatic normals. Subsequently, the indices were valued using rating tables that range from to 'zero' as a minimum to 'five' as the maximum monthly thermal value for each crop and region in the state.

Frost free period

The frost-free period (PLH), which corresponds to sequential cumulative days that did not present said event throughout the year using, was determined using the methodology proposed by Ortíz and Pájaro (1985). The PLH uses average monthly minimum and average temperature information for its prediction, which was obtained from the climatological normals (SMN, 2018).

Soil classification system with the world reference base (WRB, 2015)

The soil classification system is based on diagnostic criteria for one or more horizons and subhorizons, which are presented in the soil reference groups, which are reported in the thematic maps of the soil charts produced by INEGI (2005). Each reference group, with several hierarchically assigned diagnostic horizons, were adapted to quantitative values of '-1', '0' and '1' corresponding to low suitability, medium suitability, and high suitability respectively, both for rainfed agriculture and under irrigation.

Soil moisture regime

The evaluation of the efficiency of the soils by the type of humidity regime is considered by the amount of water and the time that the control section remains consecutively humid (Ortíz *et al*., 2014). The thematic map of humidity regime was estimated based on the Newhall model reported by Sánchez *et al*. (2009). This model uses the temperature and precipitation of each climatic station and the allocation process was as follows: aridic and aquic regime: low fitness (value of '-1'), due to the absence or waterlogging of the control section, to the ustic regime, medium aptitude (value '0') due to reporting favorable conditions for the growth of plants with water limitations and the udic regime: high aptitude (value '1'), when presenting accumulated humidity for 90 consecutive days in normal years or be irrigated.

Results and discussion

With the digital vectorization of the state on the Google Earth Pro® platform, the geospatial distribution of exclusively agricultural areas (17.03% of the total area, 1 099 372 ha) used in the state zoning was located. Each of the edaphoclimatic databases that allowed estimating the productive potential of the agricultural area of the state of Nuevo León is analyzed below.

The municipality of Allende, NL was selected to exemplify the results. It has an agricultural area of 44 676 ha, where annual maximum, minimum and average temperatures of 28 °C, 13.2 °C and 20.5 °C respectively are reported; with an average annual rainfall of 933 mm, an edaphic aptitude for potato cultivation: High located in the southern area of the agricultural area (51%), average in the north-center (44%) and low in the northern area (5%). It was also found that the area may have a fitness: high for sorghum in 100% of the area. The soils that dominate in this area are Vertisols (72% of the agricultural area) located in the north and center with the pelic subunit, Leptosol (7%) and Phaeozems (21%) in the center with the haplic subunit.

The humidity regime is udic covering 95% in the central and southern zones, along with the ustíco with 5% in the northern zone. The area has two frost-free periods between the months of February and November in the southern area with an area of 7% and from February to December in the northern and central area with an area of 93%. This information is concentrated on each of the crop maps to determine suitability and yield in agricultural areas.

Thermal index and efficiency

Table 1 reports the ratings for the maximum and minimum temperatures for the potato crop, where 5 means the optimal conditions for the development of this crop.

Table 1. Qualification of maximum and minimum monthly temperatures (Neild and Boshell (1976) for potato cultivation (five months), in the municipality of Allende, NL, based on the optimal requirements established by ECOCROP.

Potato (five months)						
Max temperature (°C)			Score	Min temperature (°C)		
	33		0		19	
31		32.9	1	18		18.9
29		30.9	2	17		17.9
27		28.9	4	16		16.9
24	25	26.9	(optimal) 5 (max.)	14	15	15.9
22		23.9	4	13		13.9
19		21.9	3	12		12.9
16		18.9	2	9		11.9
13		15.9	1		8.9	
	12.9		0		<8.9	

Table 2 shows the procedure for calculating the Monthly thermal index and the potential thermal efficiency for the entire five-month potato crop cycle. For example, in January an average monthly maximum and minimum temperature of 20.6 ºC and 5.1 ºC respectively were reported, these values are located between the intervals of <21.9 ºC and <8.9 ºC (Table 1), which correspond to the qualification cumulative of 3 (3 + 0).

Table 2. Monthly index and thermal efficiency of potato cultivation (Allende station, NL).

Potato/ month	January	February	March	April	May	June	July	August	September	October	November	December
Tmax	20.6	23.2	27.8	31.7	35.1	37.6	38.3	38.1	35.3	30.9	25.7	21.8
Tmin	5.1	7	10.3	13.9	17.5	20.2	20.6	20.5	18.5	14.5	9.5	5.7
C(Tmax)	3	4	4	1	0	0	0	0	0	2	5	3
C(Tmin)	0	0	2	4	2	0	0	0	1	5	2	0
IT	3	4]	6	5	2	0	0	0	1	[7	7	3

Tmax= maximum temperature; Tmin= minimum temperature; C (Tmax)= Tmax rating; C (Tmin)= rating of Tmin; IT= thermal index (months with maximum values). ET= thermal efficiency.

The maximum accumulated estimated value of the thermal index starts from the sum of individual qualifiers of monthly maximum and minimum temperature, reaching a total of 10 (Table 1). The theoretical consecutive monthly sum is 50 and corresponds to five months of the agricultural cycle, in this case of the potato. Equation 1 exemplifies the thermal efficiency for potato cultivation for the entire cycle, where the sum of the continuous monthly thermal indices (7+7+3+3+4) is divided by the theoretical maximum rating multiplied by the number of months (10 × 5) of the crop, and its result in turn is multiplied by 100 to obtain the percentage of the agricultural cycle. $ET_{potato}=\frac{7+7+3+3+4}{5\times10}\times100=\frac{24}{50}\times100=48$; where: ET_{potato}= thermal efficiency for the five-month potato crop.

The diversification of crops for the municipality of Allende, NL is shown in Tables 3 and 4. The rotations that can be made in this municipality in the same agricultural cycle without interference in its agronomic management are: potato cultivation for the autumn-winter cycle and sorghum in spring-summer, because sorghum has a high aptitude (77.54%) and can be grown without risk the months between May and August (sowing-harvest).

Table 3. Index and thermal efficiency for sorghum cultivation with a four-month cycle.

	Four-month sorghum											
C(T max)	0	1	2	3	5	4	4	4	5	3	1	0
C(T min)	0	0	0	0	2	4	4	4	2	0	0	0
IT= C(Tmax)+C(Tmin)	0	1	2	3	[7	8	8	8]	7	3	1	0

Table 4. Potato-sorghum rotation for the area of influence of the Allende station per month.

January	February	March	April	May	June	July	August	September	October	November	December
Potato]				[	Sorghum	]			[Potato		

Table 5 shows the estimated thermal efficiencies for each crop in the entire state of Nuevo Leon. The 2-month bean, 3-month onion and grapefruit crops obtained the highest suitability values in 51%, 51% and 41% respectively of the agricultural area. In addition, this table reports the percentage of the state area that must be established during the months with the highest thermal efficiency. In this sense, the five-month potato crop can cover 82.2% of the surface during the months of October, November and December, while the sorghum crop can cover up to 80.4% if sown in May. In Figure 3 cartographically locates the agricultural areas with the greatest agricultural potential in the potato-sorghum rotation.

Table 5. Percentage of state agricultural area with respect to the aptitude of crops.

Grain	Low	Mid	High	Vegetables	Low	Mid	High	Fruit trees	Low	Mid	Alta
Rice	27	50	23	Broccoli	49	51	0.2	Grapefruit	32	27	41
Bean (2)	22	27	51	Onion (3)	22	27	51				
Bean (9)	49	51		Onion (6)	46	49	4				
Corn	44	27	30	Habanero	29	71	0.2				
Sorghum	14	69	17	Potato (3)	43	42	15				
Soy	39	27	34	Potato (5)	49	51					
Wheat	20	71		Cucumber	49	51	0.1				
				Tomato	48	48	4				

The numbers within the parentheses represent the crop cycle in months.

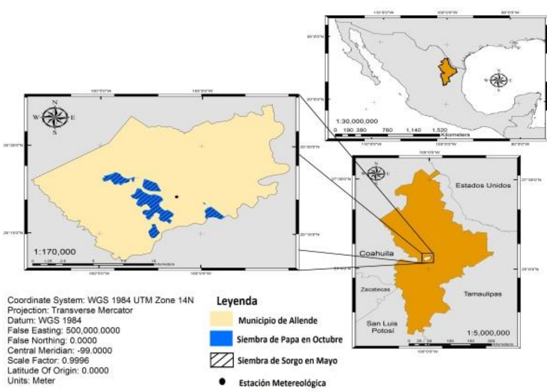


Figure 3. State zone with projected areas for potato-sorghum diversification and rotation.

Agricultural diversification

The efficiencies and planting dates of annual crops generate the combinations of the groups of basic grains and vegetables projected as crop rotations to increase agricultural diversification with a reduction in the incidence of pests, diseases or weeds difficult to control with agrochemicals Ball *et al*. (2005). As well as the conservation of water resources and minimization of salinity problems (Turner, 2004) (Table 6).

Table 6. Crop rotations in the state.

Rotation	Jan	Feb	March	April	May	June	July	August	September	October	November	December
Broccoli-tom					13.9				29.2	48.1	14.1	
Broccoli-potato(3)					2.5				29.2	48.1		
Broccoli-hab			49.3						29.2	48.1		
Ceb(3)-corn			26.1						18.7	0.2		
Ceb(3)-sorghum				19.6					18.7	0.2		
Ceb(5)-sorghum				19.6						78.6		
Ceb(5)-corn				73.8						78.6		
Bean(2)-corn			26.1	73.8						62.8		
Hab-wheat			49.3						5.3	3.6		
Potato(3)-wheat							65.4	16.1				53.8
Potato(5)-wheat						2.1						53.8
Sorghum-bean(2)				19.6					17.4	62.8		
Tom-wheat						24.4	21.2	40.4				53.8
Wheat-bean(2)							6.3	13.5	17.4			53.8

Ceb= onion; hab= habanero pepper; tom= tomato; the square brackets represent the cycle in months.

Biophysical yield

The biophysical yield of the crops allows determining the maximum potential that can be achieved in an area, considering a forecast of the capacity to be developed by the crops with record of their production (de Wit, 1965). In the state of Nuevo León, the basic grains, horticultural and fruit that reach the highest yield are: corn (10 t ha^{-1}) located in the central, north and northeast zone, 6-month onion (65 t ha^{-1}) located in the southern and grapefruit zone (45 t ha^{-1}) in the southern and central-eastern zone (35 t ha^{-1}) of the state. According to GAEZ (2006), the maximum average potential of corn is 11.8 t ha^{-1}, onion 10.1 t ha^{-1}; however, the yield for grapefruit does not report it.

On the other hand, the rest of yields with a maximum and minimum are: in basic grains such as rice between 6 and 8 t ha^{-1}, 2-month beans between 1 and 2 t ha^{-1}, beans (9 months) between 5 and 7 t ha^{-1}, sorghum between 4 to 5 t ha^{-1}, soybeans between 4 to 6 t ha^{-1}, wheat between 6 to 9 t ha^{-1}; while vegetables such as broccoli are quantified between 14 and 19 t ha^{-1}, onion (3 months) between 16 to 23 t ha^{-1}, habanero pepper between 32 to 36 t ha^{-1}, potato (3 months) between 20 to 30 t ha^{-1}, potato (5 months) between 42 to 48 t ha^{-1}, cucumber between 32 to 40 t ha^{-1} and tomato between (15 to 23) t ha^{-1}.

Frost free period (PLH)

PLH varies by state; for example, in the central-north zone the largest agricultural area (59%) is free of frost; while in the southern zone it is where the highest incidence of frost occurs, shortening free periods during the February-December periods; February-November; March-November and April-October (with 20%, 1%, 9% and 10% respectively), as can be seen in Figure 4. These areas would be limited for tropical crops (Ortíz and Pájaro, 1985; Duman and Wisniewski, 2014).

Soil classification system

The reference groups with high fitness of the agricultural areas that occur in the state are: Cambisols (0.8%) located in the center-southeast, Kastanozems (0.9%) in the central-east zone and isolated in the northwest, Luvisols (0.7%) in the central-southeast zone, Phaeozems (5.2%) in the center and south, Vertisols (22.7%) in the center-east and north. Pelico subunits (7%) in the center southeast. (WRB, 2015). In addition, the soils with medium aptitude correspond to Calcisols with 26% and finally 43% with low aptitude to Leptosols (26.2%), Regosol (10.2%) and Solonchak (6.9%), together with subunits that have 67% aptitude average to Calcaric (13.1%), Calcic (40%), Chromic (4%), Eutric (0.03%), Haplic (5%), Luvic (5%) and lastly of low fitness with 5% to Gypsic horizon (4.3%), Ortic (0.4%).

Soil moisture regime

The humidity regime (Figure 4), is important to know the number of months that humidity is conserved in the soil (Ortiz *et al*., 2014) and the problems that can be met to meet the water demand of crops during the cycle of production. In the study area, there is a 'low and medium fitness' in the northern, central and southern areas of the state when there is an aridic and ustic humidity regime (46 and 43% respectively) and 'high aptitude' (11%) in the central zone of the state when a udic regimen occurs.

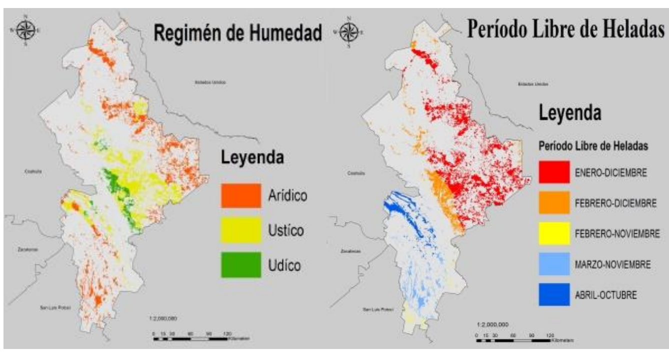
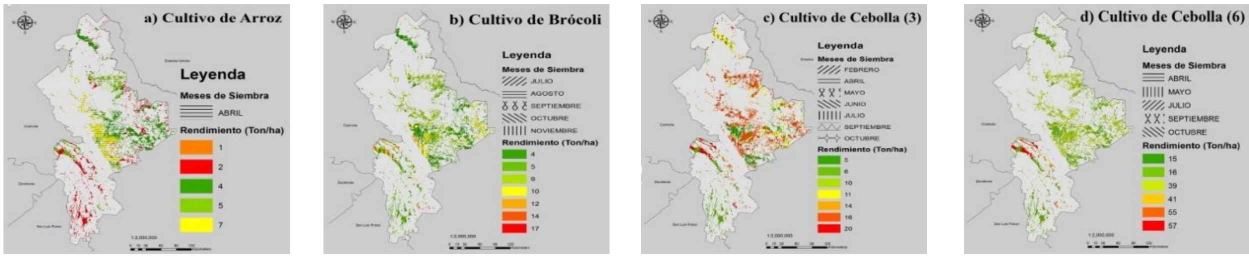


Figure 4. Soil moisture regime and frost-free periods.

Potential crop yield

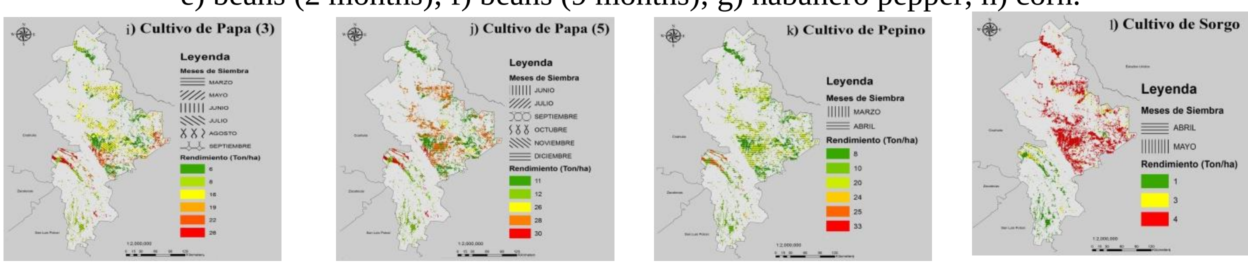
The potential yield and location on the thematic map in Figure 5. The crops with potential were: a) basic grains such as beans (2 and 9 months) and sorghum are proposed in 51%, 51% and 69% of the area, with an estimated potential yield between 2, 4 and 4 t ha^{-1} respectively; b) vegetables such as: habanero pepper with 63% of the agricultural area and an estimated yield of 21 t ha^{-1} and c) with fruit trees such as grapefruit proposed in 41% of the area, with an estimated yield of 35 t ha^{-1}.

Between 2006-2015, there was an average yield of 37.3 t ha^{-1} for habanero peppers (municipalities of Hualahuises, General Terán and Cadereyta Jiménez), for beans of 0.8 t ha^{-1} (to refer to some municipalities of Cadereyta Jiménez, Linares and Rayones); sorghum with 3.3 t ha^{-1} (to name a few municipalities of Anahuac, China, Doctor González, General Bravo and Salinas Victoria); and grapefruit with 13.2 t ha^{-1} (to mention some General Terán, Linares and Montemorelos municipalities).

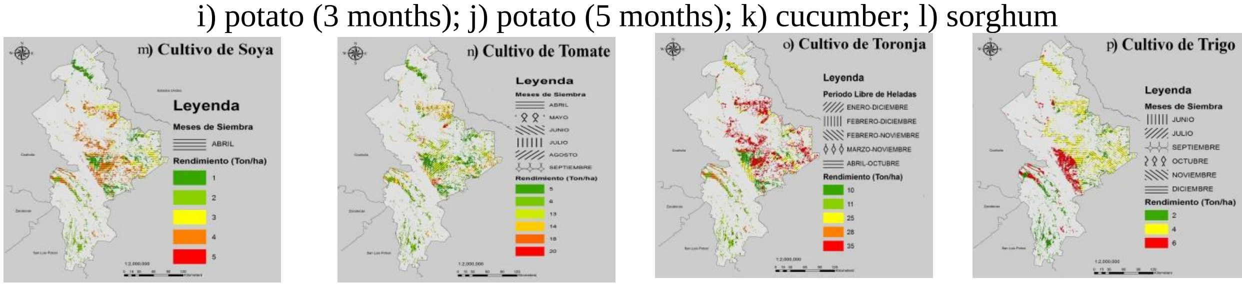


a) rice; b) brocoli (6 months); c) onion (3 months); d) onion (6 months).

e) beans (2 months); f) beans (9 months); g) habanero pepper; h) corn.



i) potato (3 months); j) potato (5 months); k) cucumber; l) sorghum



m) soy; n) tomato; o) grapefruit; p) wheat.

Figure 5. Potential yield (t ha^{-1}) in agricultural areas: a) rice; b) broccoli (6 months); c) onion (3 months); d) onion (6 months); e) beans (2 months); f) beans (9 months); g) habanero pepper; h) corn; i) potato (3 months); j) potato (5 months); k) cucumber; l) sorghum; m) soy; n) tomato; o) grapefruit; p) wheat.

In the case of grapefruit, it would increase to 35 t ha^{-1} if the information generated in this study were used in the north and northeast areas of the state (Agualeguas, Salinas Victoria and China, to mention a few municipalities). In the case of basic grains for the 2018 cycle, the planted area covered 13% of the agricultural area in the municipalities of: China, Doctor Arroyo, Linares, General Teran and Galeana, (SEDGRO, 2018; SIAP, 2018). However, the predictions made place the northern and central zones with the best yields to name some municipalities: Anáhuac, Cadereyta Jiménez and General Bravo, together with isolated areas in the southeast zone (General Zaragoza).

The estimated potential yield in percent of state agricultural areas for basic grain crops were: a) rice with yields of 1, 2, 4, 5 and 7 t ha^{-1} in areas of 0.01%, 27%, 31%, 24 % and 18% respectively; b) beans (2 months) with 0.5, 1, 1.3 and 2 t ha^{-1} in 27%, 0.02%, 22% and 51% respectively; c) beans (9 months) with 2 and 4 t ha^{-1} in 49% and 51% respectively; d) corn with 2, 3, 6 and 9 t ha^{-1} in 0.03%, 43%, 27% and 30% respectively; e) sorghum with 1, 3 and 4 t ha^{-1} in 17%, 14% and 69% respectively; f) soybeans from 1 to 5 t ha^{-1} from 0.3% to 39%; g) wheat with 2, 4 and 6 t ha^{-1} in 29%, 49% and 22% respectively.

On the other hand, vegetables and fruit trees were estimated in: a) broccoli with yields of 4, 5, 9, 10, 12, 14 and 17 t ha^{-1} in an area of 33%, 16%, 33%, 12%, 6%, 0.01% and 0.2% respectively; b) onion (3 months) with 5, 6, 10, 11, 14, 16 and 20 t ha^{-1} in 14%, 13%, 0.002%, 18%, 3%, 45% and 6% respectively; c) onion (6 months) with 16, 39, 41, 55 and 57 t ha^{-1} in areas of 46%, 46%, 3%, 0.6% and 4% respectively; d) habanero pepper with 9, 21, 23 and 32 t ha^{-1} in 29%, 63%, 8% and 0.2% respectively; e) potato (3 months) with 6, 8, 16, 19, 22 and 26 t ha^{-1} in 27%, 16%, 38%, 4%, 10% and 5% respectively; f) cucumber with 8, 10, 20, 24, 25 and 33 t ha^{-1} in 33%, 16% 46%, 1%, 4% and 0.02% respectively; g) tomato with 5, 6, 14, 18 and 20 t ha^{-1} in 22%, 26%, 27%, 21%, 3% and 1% respectively; and h) grapefruit with 10, 11, 25, 28 and 35 t ha^{-1} in 16%, 16%, 22%, 5% and 41% respectively (Figure 5).

Conclusions

The combination of climate databases and edaphic thematic maps can reduce uncertainty in locating areas with high crop yields and proposing potentially agricultural areas. Likewise, planting dates can be established at a monthly level, which lead to maximum climatic capacity and recommend crop rotations that allow generating intensive and diversified agriculture taking advantage of commercial windows.

In crops of early varieties such as three-month onion, two-month bean and three-month potato despite low yields compared to late cycles, they may be more efficient. Frost periods also limit the production of tropical crops such as grapefruit; however, the prediction increases the areas with the lowest risk of frost in the north and northeast of the state.

The state has a greater capacity to produce basic grains since it has a greater surface area and efficiency in its yield; however, there are crops with areas less than 10% of the agricultural area with high yields.

Cited literature

Ball, B. C.; Bingham, I.; Rees, R. M.; Watson, C. A. and Litterick, A. 2005. The role of crop rotations in determining soil structure and crop growth conditions. Canadian Journal of Soil Science. 85(5):557-577. https://doi.org/10.4141/S04-078.

Cai, R.; Feng, S.; Oppenheimer, M. and Pytlikova, M. 2016. Climate variability and international migration: The importance of the agricultural linkage. Journal of Environmental Economics and Management. 79:135-151. ISSN: 0095-0696. https://doi.org/10.1016/j.jeem.2016.06.005.

de Wit, C. T. 1965. Photosynthesis of Leaf Canopies. Agricultural Research Report. 663(2):1-64. PUDOC, Wageningen University. https://edepot.wur.nl/187115.

Duman, J. G., and Wisniewski, M. J. 2014. The use of antifreeze proteins for frost protection in sensitive crop plants. Environmental and Experimental Botany. 106:60-69. ISSN 0098-8472. https://doi.org/10.1016/j.envexpbot.2014.01.001.

ECOCROP. 2007. Food and Agriculture Organization of the United Nations (FAO), http://ecocrop.fao.org/ecocrop/srv/en/home.

FAO. 2015. Food and Agriculture Organization of the United Nations. Base referencial mundial del recurso suelo: Sistema internacional de clasificación de suelos para nomenclatura de suelos y la creación de leyendas de mapas de suelos. Informe sobre recursos mundiales de suelos.

FAO. 1978. Food and Agriculture Organization of the United Nations. Report on the Agro-ecological Zones Project: Results for Southwest Asia.

Fraisse, C. W.; Breuer, N. E.; Zierden, D.; Bellow, J. G.; Paz, J.; Cabrera, V. E. and O'Brien, J. J. 2006. AgClimate: A climate forecast information system for agricultural risk management in the southeastern USA. Computers and Electronics in Agriculture. 53(1):13-27.

GAEZ (ver 3.0). 2016. Global Agro-ecological Zones. Food and Agriculture Organization of the United Nations (FAO). 37-47 pp. www.fao.org.

Grassini, P., van Bussel, L. G. J., Van Wart, J., Wolf, J., Claessens, L., Yang, H., Cassman, K. G. 2015. How good is good enough? Data requirements for reliable crop yield simulations and yield-gap analysis. Field Crops Research. 177:49-63. https://doi.org/10.1016/j.fcr.2015.03.004.

Hansen, J. 2004. Linking dynamic seasonal climate forecasts with crop simulation for maize yield prediction in semi-arid Kenya. Agricultural and Forest Meteorology. 125(1-2):143-157. https://doi.org/10.1016/j.agrformet.2004.02.006, ISSN: 0168-1923.

INEGI. 2005. Instituto Nacional de Estadística Geografía e Informática. Base de datos geográficos, Diccionario de datos edafológicos escala 1: 1000 000 (Vectorial). 1-7.

Intergovernmental Panel on Climate Change. 2014. Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Johnson, M. D.; Hsieh, W. W.; Cannon, A. J.; Davidson, A. & Bédard, F. 2016. Crop yield forecasting on the Canadian Prairies by remotely sensed vegetation indices and machine learning methods. Agricultural and Forest Meteorology. 74-84. pp.

Neild, R. E. and Boshell, F. 1976. An agroclimatic procedure and survey of the pineapple production potential of Colombia. Agricultural Meteorology. 81-92 pp.

Ortiz, S. C. A. y de la Cerda, H. E. C. 1978. Metodología del levantamiento fisiográfico: un sistema de clasificación de tierras. Posgrado de Edafología. Colegio de Postgraduados. 85 pp.

Ortiz, S. C. A. y Pájaro, H. D. 1988. Estimación del período libre de heladas para la República Mexicana. Revista de Geografía Agrícola. 17:109-118.

Ortiz, S. C. A. 2011. Elementos de agrometeorología cuantitativa con aplicaciones en la república mexicana. Texcoco, Estado de México. 70-79 pp.

Ortiz, S. C.; Gutiérrez, C. Ma. C y Gutiérrez, C. E. 2014. Claves para la Taxonomía de Suelos. (12° Ed. Traducción al español). USDA-NRCS. 31-33 pp.

Sánchez-Guzmán, P.; Gutiérrez-Castorena, E. V.; Ortiz-Solorio, C. A. y Gutiérrez-Castorena, Ma. C. 2009. Soil moisture regimes of Mexico using Newhall model, Soil Geography: New Horizons. 38 p.

SEDAGRO (Secretaría de Desarrollo Agropecuario). 2018. Boletín agropecuario.

SEMARNAT (Secretaría de Medio Ambiente y Recursos Naturales), CP (Colegio de Postgraduados). 2001-2002. Evaluación de la Degradación del Suelo Causada por el Hombre en la República Mexicana escala 1:250 00, Memoria Nacional. 76 p.

SIAP. 2018. Servicio de Información Agroalimentaria y Pesquera. https://nube.siap.gob.mx/gobmx_publicaciones_siap/pag/2018/Nuevo-Leon-InfografiaAgroalimentaria-2018.

SMN. 2018. Servicio Meteorológico Nacional de México (Normales Climatológicas por Estado.

Tilman, D.; Balzer, C.; Hill, J. and Befort, B. L. 2011. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences of the United States of America. 108(50):20260-20264.

Turner, N. C. 2004. Sustainable production of crops and pastures under drought in a Mediterranean environment. Annals of Applied Biology. 144(2):139-147.

Valin, H.; Sands, R. D.; van der Mensbrugghe, D.; Nelson, G. C.; Ahammad, H.; Blanc, E. and Willenbockel, D. 2014. The future of food demand: understanding differences in global economic models. Agricultural Economics. 45(1):51-67.

Van Ittersum, M. K.; Cassman, K. G.; Grassini, P.; Wolf, J.; Tittonell, P. and Hochman, Z. 2013. Yield gap analysis with local to global relevance. Field Crops Research. 143:4-17.

Van Wart, J.; Grassini, P.; Yang, H.; Claessens, L.; Jarvis, A. and Cassman, K. G. 2015. Creating long-term weather data from thin air for crop simulation modeling. Agricultural and Forest Meteorology. 209-210 49-58. https://doi.org/10.1016/J.AGRFORMET.2015.02.020.

WRB. 2015. IUSS Working Group. Base referencial mundial del recurso suelo 2014. Actualización 2015. Sistema internacional de clasificación de suelos para la nomenclatura de suelos y la creación de leyendas de mapas de suelos. Informes sobre recursos mundiales de suelos 106. FAO, Roma.