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A decision support system for rainfed agricultural areas of Mexico

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ABSTRACT

Rural inhabitants of arid lands constantly face a lack of sufficient water to fulfill their agricultural and household needs. In this situation they have to take quick and precise decisions about how to cope with the situation. Moreover, there is not readily available technical information to support their decisions regarding the course of action they should follow to handle the agro-climatic risk. In this paper a computer model (soil water balance model) is described to assess the impact on crops yields of rainfall shortages in dry lands in Mexico. The model is linked to a knowledge based database where a farmer may find readily available information to support cropping decisions. The knowledge base activates when the computed average crop yield is less than the 50% of the expected crop yield. The knowledge base provides information on risk, potential crops, and the geographical location (counties) where the crop may succeed. Also, it provides a technology to increase water productivity under limited availability situations. Further, the model can evaluate the impact of a climate change scenario (IPCC B2). Other inputs to the model being equal, the user may shift the model to run the climate change scenario and to compare the outputs of the model to assess the climate change impact on future crops yields.

1. Introduction

Developed countries are characterized by a large population that has exited the rural sector. Mexico, despite public policies to increase the annual GDP, still has about 28% of the total population linked directly or indirectly to the rural sector. Also, land tenure for most of these dryland farmers is characterized by high climate uncertainty and the lack of support to prevent or to cope with this risk (Sanchez Cohen et al., 2011).

Capacity constraints are often coupled with weak harmonization and coordination of policy, legal and regulatory frameworks between the sectors competing for land and natural resources. Also, there are often weak institutions in charge of coordinating land issues, including those tasked with implementing National Action. There is a need for synergies among these strategies, including agriculture strategies and action plans (FAO, 2013).

Mexico, like many other countries in the world, faces great water challenges. In fact, water is the most important impact of climate change that should be addressed in its relation to the water cycle, water pollution, water scarcity, poor water administration, lack of resources for research and technological development, and lack of environmental planning (Arreguin Cortes et al., 2011).

Rainfed areas in Mexico account for 14 million hectares where around 23 million people live and are located in places where there is little climatic information or are ungagged at all. The severe drought that has impacted northern Mexico in the past several years as well as other parts of the country, has forced decision makers to look for improved tools and procedures to prevent and to cope with this natural hazard. Computer models that simulate

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crop growth and estimate crop yields are a powerful tool for decision taking and planning when properly used. Achieving potential crop yields under irrigated conditions depends on following agronomical recommendations regarding planting dates, use of suitable seeds, and pests and diseases control; on the other hand, for estimating crop yields under rainfed conditions one must to add rainfall uncertainty to the above constraints. This uncertainty may be accounted for using stochastically driven water balance models where rainfall patterns are estimated based on statistics that define the behavior of the rainfall historical data (Sanchez-Cohen et al., 2014).

Dryland farmers face uncertainty every year about what to do or lack of knowledge regarding what alternatives they have to prevent or to adapt to the imposed risk by climate uncertainty or variability.

The objective of this paper is to present a stochastic decision model (water balance model) for dry lands in Mexico whose outputs are linked to readily available technology to cope with climate risk aiming to support farmers decision taking at farm level. Besides farmers, technicians, agronomy professionals and decision takers at different levels of decision are also the aim of this research work.

2. Research approach

2.1. Soil water balance description

Soil water balance assesses the soil water content at a given time and it may be defined as the amount of water held in the soil at that time. The soil water balance relies on the soil water storage capacity in the root zone which, for the purpose of modeling, is determined by soil texture and plant growth stage. In rainfed agriculture planning and analysis, it is desirable that this balance be done on a daily basis as a way to identify dry or wet spells that impact crop yields.

A crop growth simulation model must therefore keep track of the soil moisture potential to determine when, and to what degree, a crop is exposed to water stress. This is commonly done with the aid of a water balance equation, which compares incoming water in the rooted soil with outgoing water for a given period of time, and quantifies the difference between the two as a change in the amount of soil moisture stored. The purpose of soil water balance calculations is to estimate the daily value of the actual soil moisture content, which influences soil moisture uptake and crop transpiration and then, based on this balance, to compute the effect on crop yield.

A computer program was written for the simulation model in Fortran 90 and then it was migrated to a Delphi platform to facilitate building a user-friendly interface. For the purpose of this paper, the water balance is defined as:

$$\Delta S_i = \Delta S_{i-1} + [Pp + Q + \delta]_i - [\mathrm{Eta} + \mathrm{Qo} + Z]_i \quad (1)$$

where ΔS_i is the current soil water content (L), Pp is the daily precipitation (L), Q is runoff to the cropped area expressed as water depth (L), δ is the soil capillarity, Eta is the crop maximum evapotranspiration (L T^{-1}), Qo is the runoff out of the cropped area (L), and Z is deep percolation (L). The subscript "i" refers to the timing, (i.e. t_{i-1} is the previous day).

In most dry lands it is difficult to find the water table near the soil surface and also in shallow soils that characterizes drylands in Mexico, it is not common to have deep soils; so based on this, δ is dropped from Eq. (1).

2.2. Rainfall computation under actual climate scenario

The main characteristic of the water balance method in this paper is the stochastic process used to compute rainfall amounts and occurrence under both actual and climate change scenarios (Scenario B2 of the Intergovernmental Panel on Climate Change, IPCC). Within the model, daily rainfall is simulated using a Markov chain-exponential model in which precipitation occurrence is described by a first-order Markov chain and the amount of rainfall for those days on which rainfall occurs is based on an exponential distribution of daily rainfall amounts (Sanchez-Cohen et al., 1997, 2014):

$$F_{x1}(x) = P(x_1 \le x) = 1 - e^{-\lambda x} \quad (2)$$

where parameter λ = inverse of daily precipitation (Hanson et al., 1975). The first-order Markov chain utilizes two states defined by the transition probabilities:

$$p_{ij}(n) = P(X_n = jIX_{n-1} = i); \quad i,j = 0,1;\ n = 1,2,\ldots 120 \quad (3)$$

where state 0 signifies a dry day and state 1 signifies a wet day and:

$$p_{i1}(n) = 1 - p_{i0}(n); \quad i = 0,1 \quad (4)$$

Thus these transition probabilities define four possible states as follows: P_{00} – the probability of a day being dry given that the previous day was dry; P_{01} – the probability of a day being dry given that the previous day was wet; P_{10} – the probability of a day being wet given that the previous day was dry; and P_{11} – the probability of a day being wet given that the previous day was wet (Sanchez-Cohen et al., 1997). Both Markov chain and exponential distribution parameters may be computed for selected periods from daily rainfall data using methods described by Woolhiser and Roldan (1986) and by Wilks (1995).

Once the distribution parameters have been defined, the simulation procedure consists of generating a random number between 0 and 1 to determine whether or not precipitation occurs on any given day utilizing Eqs. (3) and (4). If rainfall does occur, another independent random number is generated and transformed to compute the amount of precipitation according to Eq. (2) (Sanchez-Cohen et al., 1997).

2.2.1. Intergovernmental Panel on Climate Change Scenario (IPCC)

As a result of the need for regional projections to evaluate the integrated impacts of climate change to a regional scale, downscaling dynamic and statistical techniques have been developed which reduce some of the bias in General Circulation Models (GCM) as well as their spatial limitations. The term scale reduction or transformation is a relatively recent one aiming to describe a series of techniques that correlate atmospheric variables with local or regional variables (Hewitson and Crane, 1996). This is widely used in climate modeling due to its relatively rapid application and reduced computational need compared to the dynamic rescaling approach of the GCM. Essentially, the regional climate is considered to be conditioned by the global scale climate as $Y = F(X)$, where Y is the predictand or local variable being rescaled (i.e. temperature or rainfall), X is a series of predictive atmospheric variables of global scale (sea level pressure, relative humidity, etc.) and F is a linear or non-linear transfer function.

Within the proposed model under climate change scenario, downscaled variables (temperature, maximum and minimum) are used to rescale transition matrix probabilities for computing time and amounts of rainfall according Eqs. (2)–(4) and to recalculate the soil water balance and to compute crop evapotranspiration. Table 1 shows a comparison between transition probabilities for a given climate station under both a current and future scenario (IPCC B2).

Figs. 2 and 3 show the general steps to rescale local climate databases expanding the method highlighted by the dark gray rectangle shown in the second row of the left hand side of Fig. 1 (IPCC). The chosen IPCC scenario for computing climate variables

Table 1
Transition probabilities for a climate station under both actual and climate change scenario. PWD = probability of having a wet day following a dry day; PWW = probability of having a wet day following a wet day. Climate station Canelas Durango, Mexico (25°6′ north latitude and 106°34′ west latitude).

Month	Actual scenario					Climate change scenario B2				
	PWD	PWW	PP mean (mm)	TMAX (°C)	TMIN (°C)	PWD	PWW	PP mean (mm)	TMAX (°C)	TMIN (°C)
J	0.08	0.55	62	23.2	8.5	0.07	0.53	46	24.6	9.5
F	0.05	0.48	29	24.2	8.5	0.06	0.37	37	25.6	9.9
M	0.03	0.38	24	25.6	9.7	0.04	0.27	19	26.6	10.8
A	0.03	0.36	9	27.9	12	0.03	0.34	12	28.9	12.8
M	0.05	0.46	24	29.9	14.2	0.06	0.44	40	31.1	15.5
J	0.19	0.69	160	30.3	16	0.18	0.71	157	30.8	16.9
J	0.61	0.86	329	28.2	16.5	0.63	0.81	311	29.1	17.2
A	0.58	0.81	289	28.1	16.3	0.48	0.79	267	29.2	17.7
S	0.4	0.72	199	28.1	16.1	0.31	0.7	205	29.7	17.4
O	0.13	0.45	87	27.7	14.5	0.12	0.46	78	29.3	15.6
N	0.06	0.5	42	26.1	12	0.06	0.39	51	26.9	12.8
D	0.1	0.46	79	23.5	9.1	0.14	0.41	95	24.8	10.4

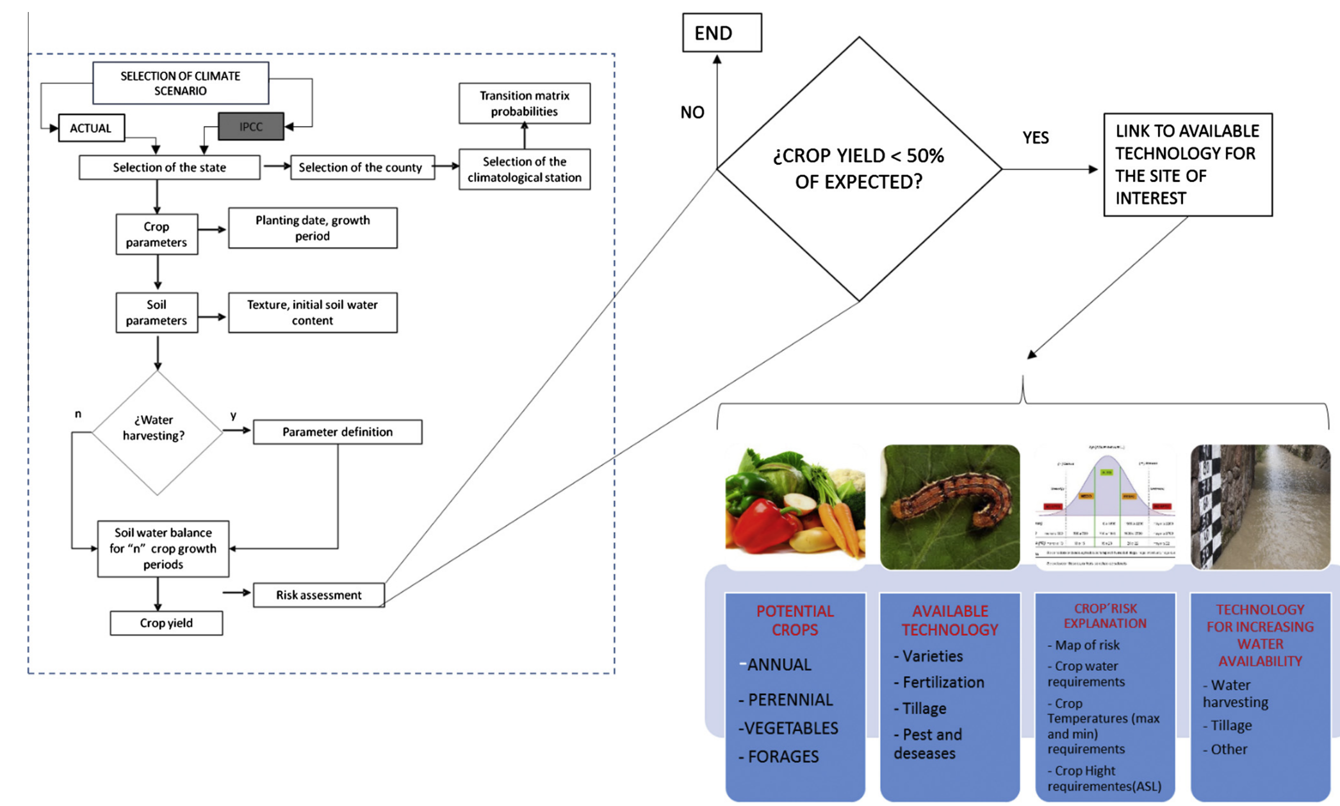

Fig. 1. General conceptual diagram of the water balance model and the decision support database.

is B2, given that that scenario better fits the economical and management conditions projected for drylands in Mexico. According to the IPCC (2000) the B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2 (continuously increasing global population), intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 (with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies). While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

The LARS-WG (a stochastic weather generator for use in climate impact studies) model was used for the purpose of rescaling regional data. A description of this model may be found in Semenov and Barrow (2002). LARS-WG can be used for the simulation of weather data at a single site under both current and future climate conditions. These data are in the form of daily time-series for a suite of climate variables, namely, precipitation (mm), maximum and minimum temperature (°C) and solar radiation (MJ m^{-2} day^{-1}).

The procedure for using downscaled climatic data consisted in determining the transition probabilities out of the rescaled data provided by the model; that is, to obtain the matrix that originated the daily data bases within the LARS-WG model.

2.3. Runoff (Q)

The soil water balance model offers the option of adding amounts of water to the cropped area by means of runoff; if

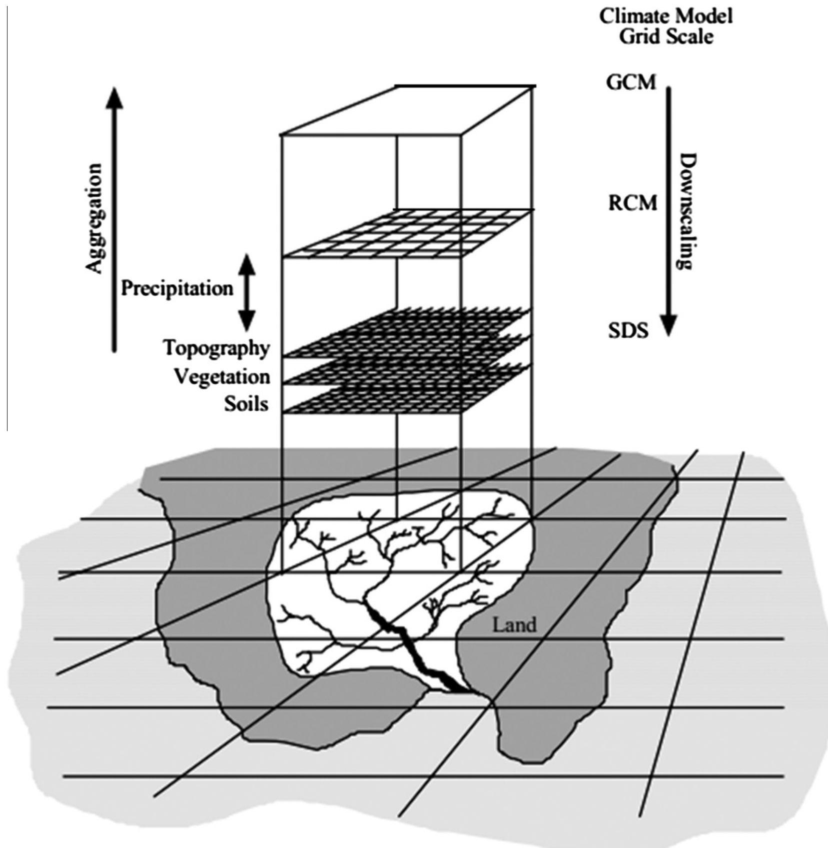

Fig. 2. Scale Reduction approach for a General Circulation Model (GCM). Local climate information is transferred correlating surface climatic variables (predictands) with those of global scale (predictors).

selected, this option computes runoff using the Soil Conservation Service Curve Number (CN) method (Schwab et al., 1993). This method figures the portion of rainfall that becomes runoff considering the hydrologic soil group, soil cover and condition of the cover from where a curve number is selected that reflects the integrated impact of these variables on runoff. The complete description of the method may be found elsewhere i.e. Hawkins, 1986, 1975, 1990; Rawls and Brakensiek, 1986; Aron et al., 1977.

Within the simulation model, once the soil depth defined at the beginning of the run is saturated according to its water holding capacity dictated by the soil texture, the remaining water is considered either runoff (Qo) the cropped area or infiltrated below the root depth (Z). No further consideration is kept for these variables.

2.4. Evapotranspiration (Eto)

For practical purposes the model computes actual evapotranspiration Eta out of reference evapotranspiration from the Blaney and Criddle method (Blaney and Criddle, 1962).

The Blaney–Criddle equation was developed to estimate Eto losses in the western United States by the SCS (SCS, 1967). It should be noted that this method is not very accurate; it provides a rough estimate or "order of magnitude" only. Nevertheless, for ungaged areas as many drylands in Mexico are, the method is suitable to fulfill the Eto data requirements.

This method provides evapotranspiration data on a monthly basis, so in some areas it may underestimate the Eto values and in others overestimate them (Jensen et al., 1990). The Blaney–Criddle method is simple, using only measured data on temperature

$$\mathrm{Eto} = p * (0.46\mathrm{Tm} + 8.13) \tag{5}$$

where Eto = reference crop evapotranspiration (mm day^{-1}) as an average for a period of 1 month.Tm = mean daily temperature (°C). p = mean daily percentage of annual daytime hours.

A full description of Blaney and Criddle use may be found in Brouwer and Heibloem (1986).

Actual evapotranspiration (Eta) is computed under nonstandard conditions following the method of FAO. Where the conditions encountered in the field differ from the standard conditions (irrigated), a correction of Eta is required. Soil water shortage and soil salinity may reduce soil water uptake and limit crop evapotranspiration (Allen et al., 1998). In dry soils, the water has a low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, and is less easily extracted by the crop. When the potential energy of the soil water drops below a threshold value, the crop is said to be water stressed. Within the model Eta is computed as:

$$\mathrm{Eta} = \mathrm{ks} \cdot \mathrm{kc} \cdot \mathrm{Eto} \tag{6}$$

where ks = describes the effect of water stress on crop transpiration, kc = crop coefficient and Eto is the Blaney and Criddle potential evapotranspiration computed with Eq. (5).

The source code of the simulation model includes the "default" kc values (Allen et al., 1998) for the crops considered; nevertheless, the user may provide his own kc values that reflect more precisely the crop growth characteristics. The model considers only three values of kc for the initial, middle, and late crop stages of crop development. The computer program keeps track of the percentage of development of the crop based on the length of growing period (input by the user depending on the type of variety used: early

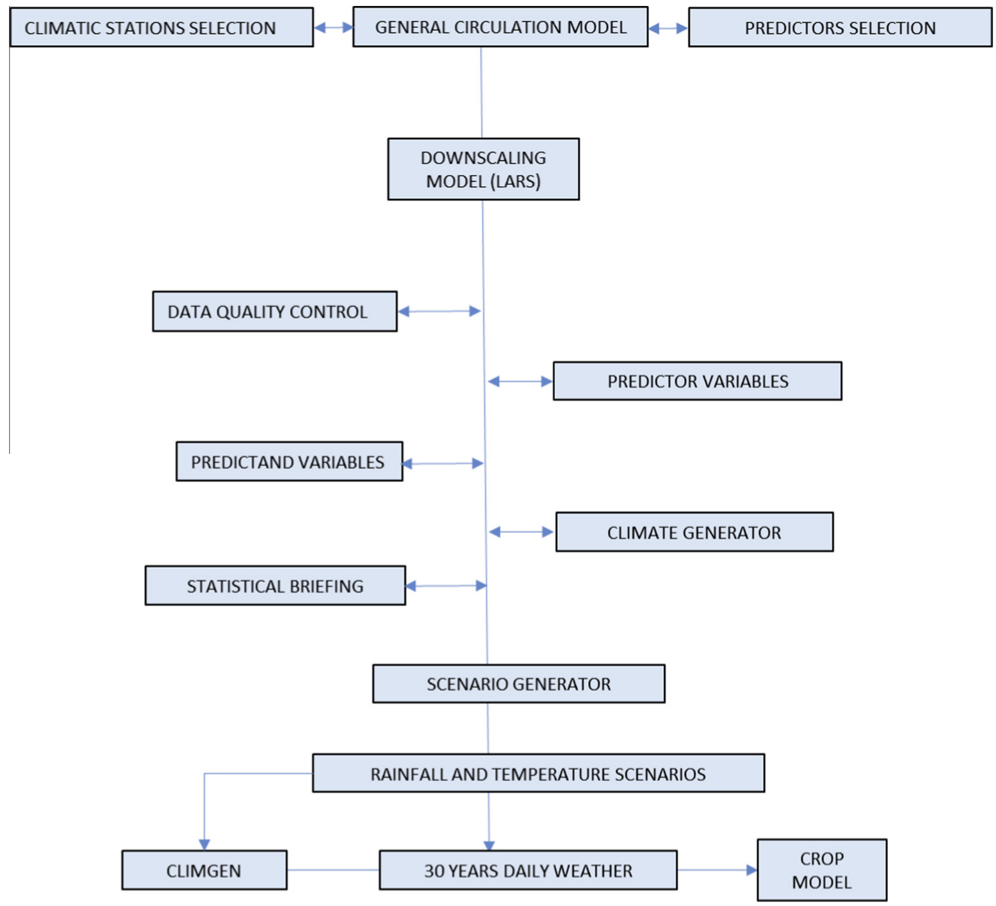

Fig. 3. Flow diagram for the generation of downscaled variables for computing the soil water balance under a climate change scenario.

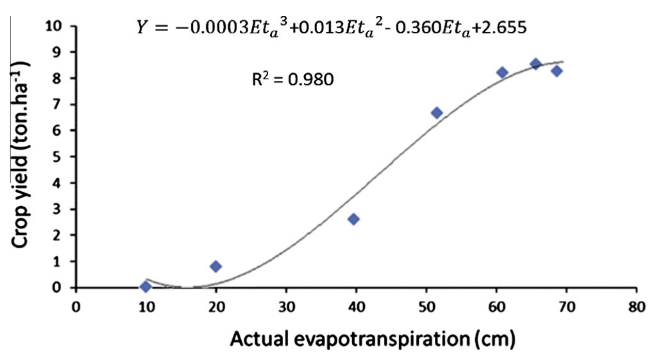

Fig. 4. Example of a water function production (WFP) for corn. Et_a is actual evapotranspiration of the crop.

plantations ≈ 90 days, intermediate plantations ≈ 120 days or late plantations, more than 120 days) and then assigns the corresponding kc according to the stage of crop development as: if crop development ⩽20%, then use kc1; if crop development >20% and ⩽47%, then use kc2; else if crop development is >47% and ⩽100%, then use kc3. This procedure allows the kc distribution to adjust to the length of the growing period in an "elastic" type of adjustment.

The ks value is computed as:

$$ks = \frac{\mathrm{TAW} - \mathrm{Dr}}{(1 - p) \cdot \mathrm{TAW}} \tag{7}$$

where ks is a dimensionless transpiration reduction factor dependent on available soil water, Dr = root zone depletion (mm), TAW = total available soil water in the root zone (mm), p is a fraction of TAW that a crop can extract from the root zone without suffering water stress.

TAW is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth: usually the range is between field capacity and wilting point. According to the FAO, when the soil water content drops below a threshold value, soil water can no longer be transported quickly enough toward the roots to respond to the transpiration demand and the crop begins to experience stress. The fraction of TAW that a crop can extract from the root zone without suffering water stress is the readily available soil water RAW = p·TAW.

Within the source code p is computed according Brouwer and Heibloem (1986) as (0.55 + (0.04 ∗ (5 − Eta))). In addition, when the user chooses the soil texture, the program reads the default values of the physical properties of that soil to compute the posterior model parameters. Physical properties for thirteen soil textures are included within the program.

The model has been validated in its capability of producing reliable rainfall data and its capacity of estimating crop yield. For the calibration of the rainfall generator, two contrasting climatological stations were selected: Nazas in the state of Durango within the Chihuahuan Desert (25°14′ north latitude and 104°7′ west latitude) and the station of Comitan Dominguez in the state of Chiapas in the south the country (16°15′ north latitude and 92°7′ west latitude). Correlation coefficients of 0.96 and 0.97 were obtained between observed and computed rainfall probabilities (PWD and PWW) respectively.

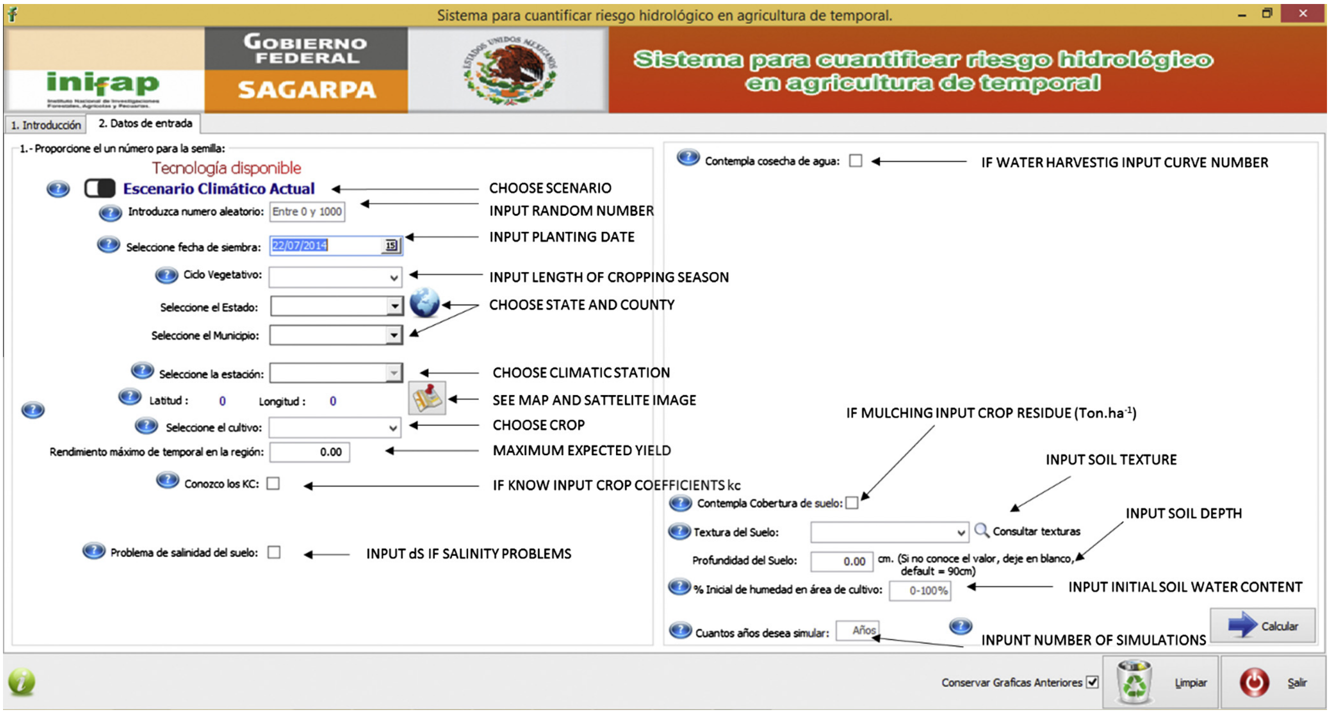

Fig. 5. Inputs to the simulation model within the interface to the user.

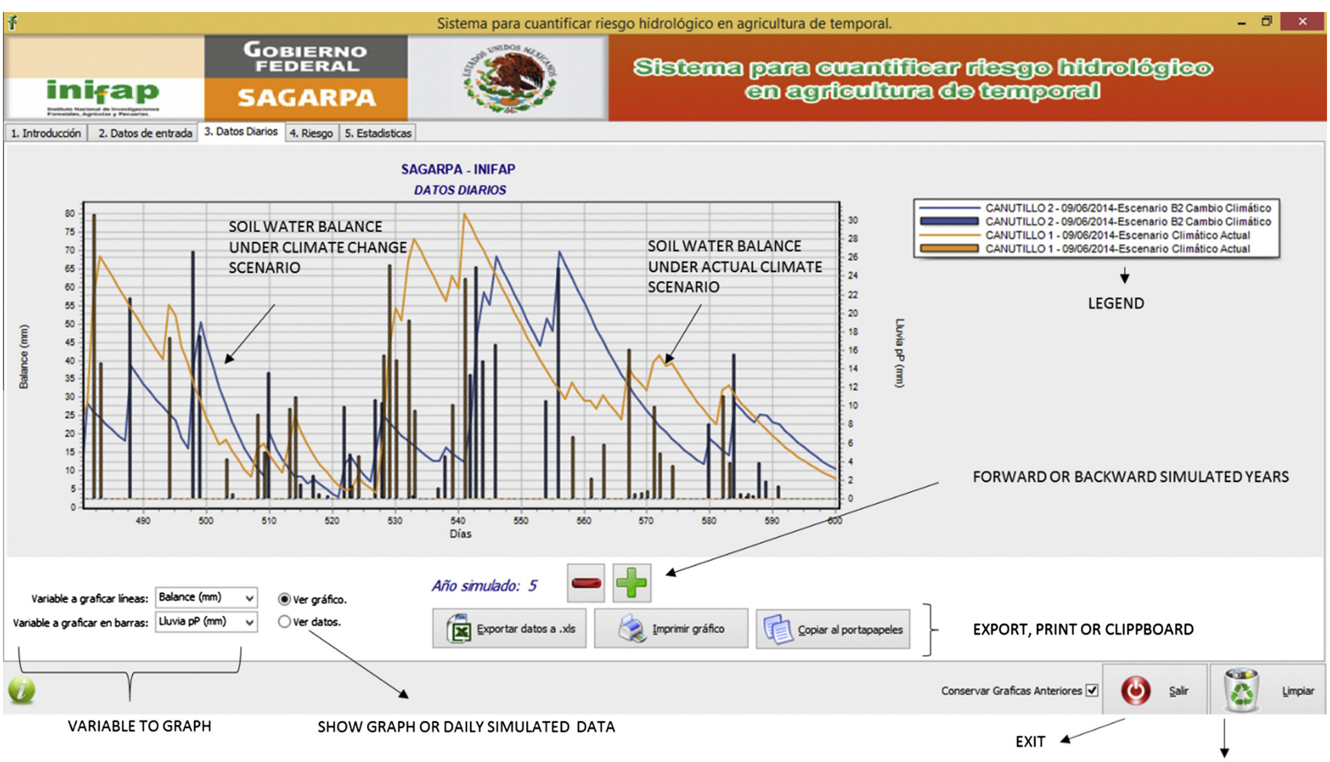

Fig. 6. Primary output from the simulation model. For each simulated year a graph of the soil water balance may be displayed moving forward or backwards with the "+" or "–" sign respectively.

2.4.1. Crop yield model

The crop yield computation procedure assesses yield using crop's water function productions. This approach for computing crop yield computes and accumulates actual evapotranspiration (Eta) in a daily basis taking into account rainfall occurrence and soil water depletion by Eta. Then the water function production of the crop being analyzed is used to compute actual yield.

General water function productions were obtained under irrigated and controlled conditions in four different experimental stations of INIFAP in the states of Chiapas (16°14′ north latitude and

Fig. 7. Secondary output from the simulation model. Statistics of the simulated variables and pup up window linking to the knowledge based system for supporting decision taking if the average computed yield by the model is <50% of the expected yield.

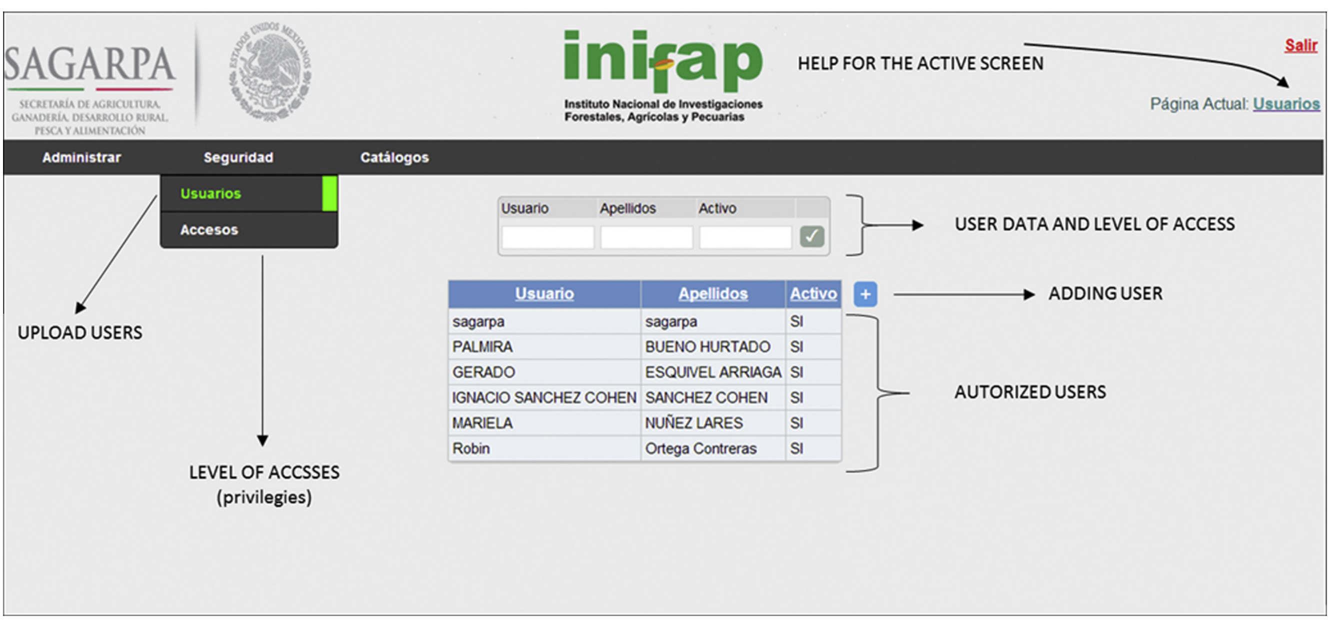

Fig. 8. Knowledge database administration within the server.

93°16′ west longitude), Jalisco (20°33′ north latitude and 104°3′ west latitude), Durango (25°35′ north latitude and 103°27′ west latitude) and Tamaulipas (22°55′ north latitude and 98°4′ west latitude), representing most of the climatic gradient of Mexico, following standard experimental procedures. Random blocks with randomized treatments of irrigations during the crop stage of development were undergone. Within this procedure, water function productions depicts the yield that it may be expected for a given location according the amount of rainfall falling during the crop development from where Eta is computed (Bootsma et al., 1994). For all locations summer plantations where only considered (Fig. 4).

For crop yield calibration, a correlation coefficient of 0.76 and 0.80 between observed (from SIAP) and computed crop yield was obtained for beans and corn with root mean square error (RMSE) of 0.27 and 1.37 respectively.

2.5. Decision support

Decision support systems can play an effective role in improving dryland agriculture in the world (Heilman et al., 2004). In this paper we define decision support as a source of primary information for supporting farmers' decisions to reduce climatic risk. It is

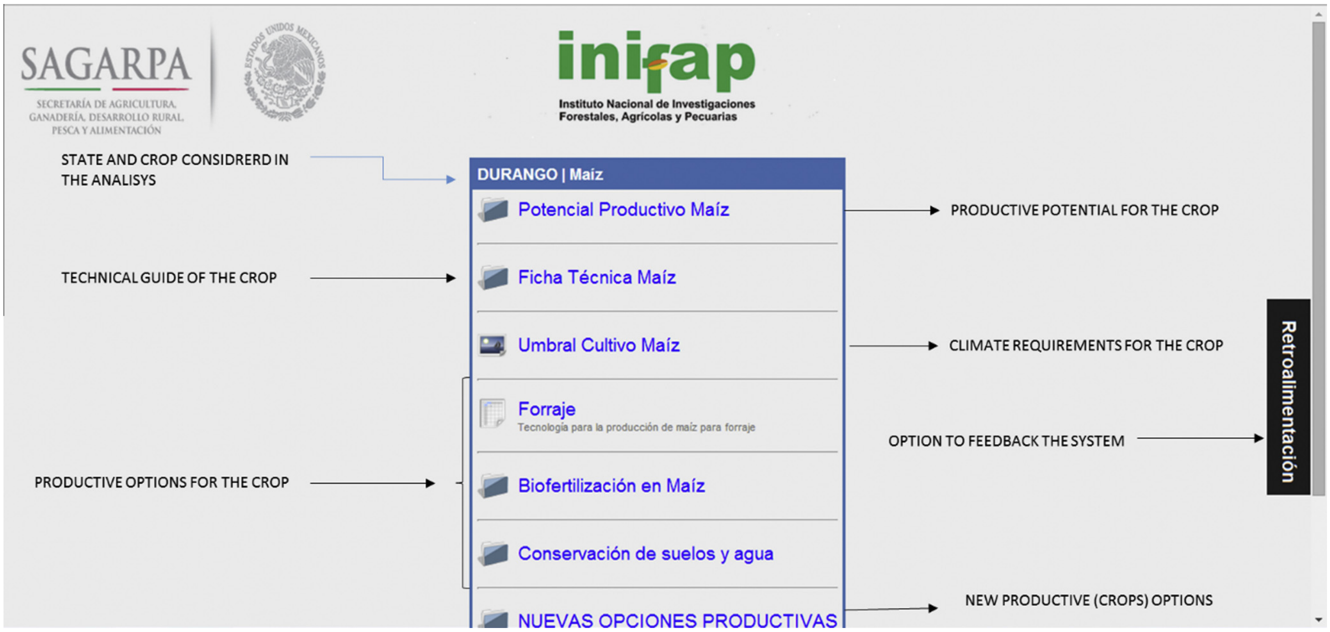

Fig. 9. Knowledge database consulting options. The user may send a notification to the Administrator of the system letting them know about any support (technologies) that may improve the database. This allows the system to increase its potential and widening the impact. Once approved by the Administrator, full credit is given to the person upgrading the technologies.

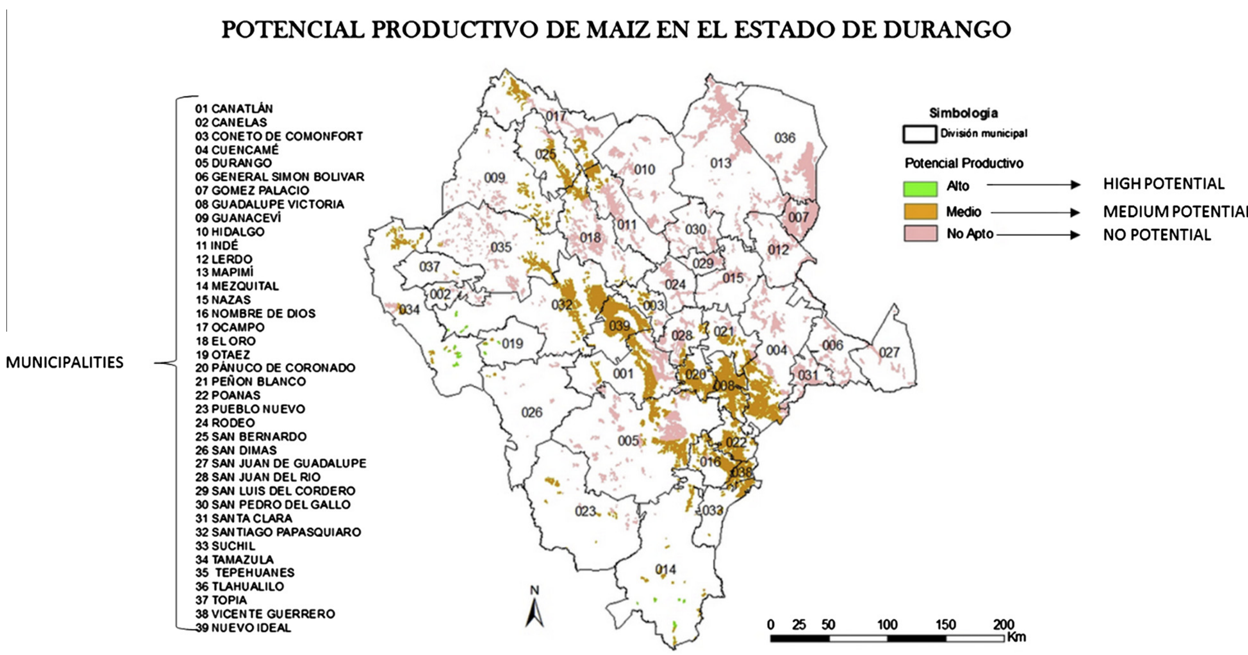

Fig. 10. Information about productive potential of the crop being considered. The maps were obtained by map algebra overlying the climatic requirements of the crop: height above the sea level, precipitation, maximum and minimum temperatures and soil type. Basic information for setting the restrictions to the overlying process was obtained in FAO – ECOCROP (http://ecocrop.fao.org/ecocrop/srv/en/home).

a computer-based information system designed to help Mexican farmers to make better and informed decisions.

Climate uncertainty plays a significant role in dryland agricultural decision making. Decisions affected by climate considerations include both dryland hardware (infrastructure) and software (management, policies, laws) (Barbosa and Lakshmi Kumar, 2012a,b). Nevertheless, there is a lack of information about available technology to face or prevent the impacts of drought linked to rainfall uncertainty. Moreover, is not common to find technical guides to support decisions at the farm level linked to simulation models outputs. These technologies should be already tested and calibrated under different scenarios and to prove its risk-reduction or avoidance effectiveness.

Once the model is run (the user may choose to simulate any number of crop seasons and to have the statistics of the results calculated for: mean precipitation, standard deviation of precipitation, maximum and minimum values for rainfall and runoff, and average, maximum and minimum crop yield throughout the simulations); if the computed average crop yield is less than half the expected yield (data provided by the user at the beginning of the simulations, see Figs. 5–7 below) a window pops up indicating a link to the available technology to overcome the impact of the soil water shortage on crop yield. The right hand side of Fig. 1 shows the general layout of this process.

The knowledge database is resident in a server. The administrator of the database, under request, may give access to users (researchers, technicians, and decision makers) at different levels of privilege: Administrate, Security and Catalogs. The first tag (administrative) contains the states of the country and crops considered. Here one can modify the database adding newly generated technology that applies to a given crop and state. The administrator of the database (knowledge base), after validating the proposed technology, may or may not approve its inclusion in the system. If approved, the technology will appear as available to specific classes of users indicating when and who authorized the addition to the knowledge database; this last piece of information is not visible to the user. Also the system keeps track of any addition to the knowledge base and counts the number of people that have used the system.

The second level "Security" is for setting the authorized users of the knowledge base and the level of access (privileges). Only the general administrator has full access to all levels within the knowledge base. The general layout for administering the knowledge data base is shown in Fig. 8.

The third level, "Catalogs", is for adding crops or states. The model considers only six crops: maize, beans, sorghum, oat, wheat and barley. This is because according the Agricultural and Livestock Information System (SIAP) from the Ministry of Agriculture of

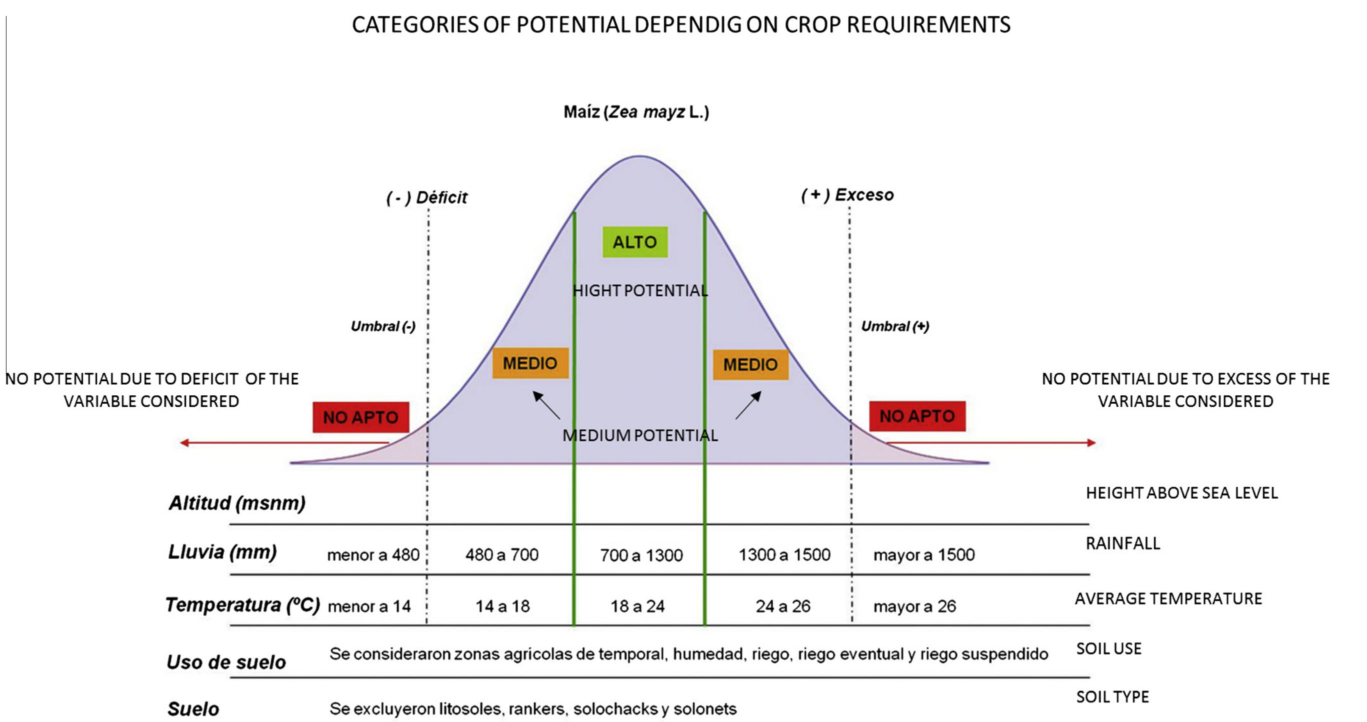

Fig. 11. Crop potentiality according to agro climatic requirements. This explains to the user why the crop may not reach the expected yield. Constructed with FAO ECO CROP information.

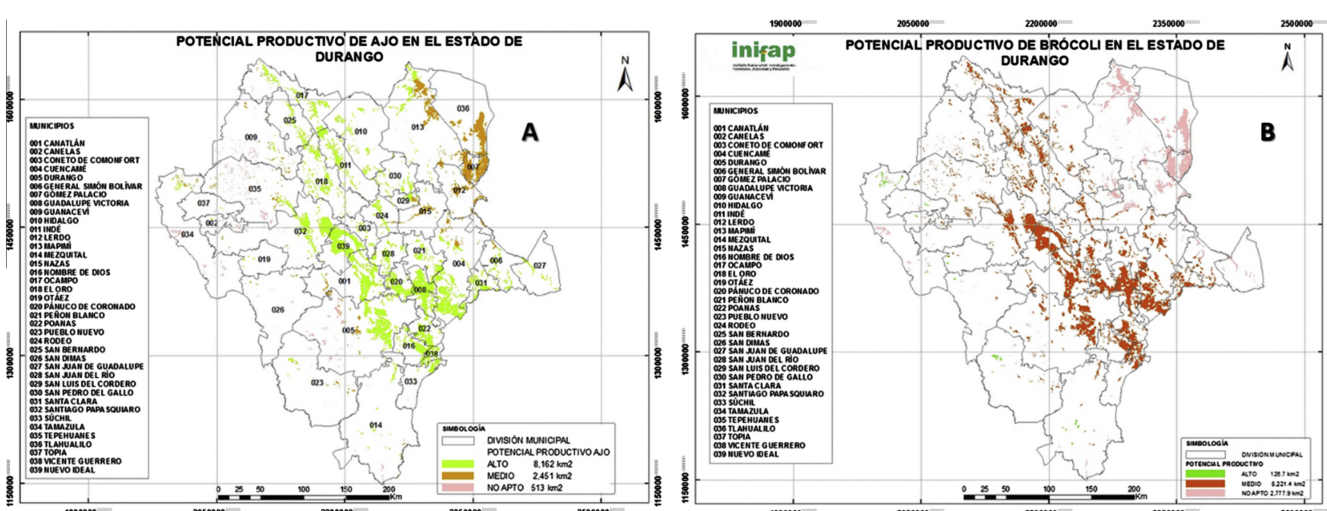

Fig. 12. Production potential for new crops: Garlic (A) and Broccoli (B) for the site under analysis.

Mexico (SAGARPA) these are the most common crops under rainfed conditions within the country and with long historical information regarding yields linked to rainfall patterns. Thus, crop yield is computed out of crop water production function as previously stated.

When the user enters the knowledge database, several pieces of information are available (Fig. 9). First, the user may see a map or the productive potential of the crop being analyzed (Fig. 10). Next, a technical guide for producing the crop under rainfed conditions for the site into consideration may be displayed; also, the agro climatological requirements of the crop may be consulted that explain why the crop is under risk for the conditions imposed. See Fig. 11.

2.6. New crop options

After the user has weighed the risk for the imputed crop into the simulation model, the knowledge database may provide information about other choices (crops) for the site of interest that have potential for producing under the limiting agro climatic variables. As previously noted, this procedure was implemented using Boolean map algebra (See examples in Fig. 12).

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1. PRODUCCIÓN DE MAÍZ ELOTERO CON UN ENFOQUE DE AGRICULTURA DE CONSERVACIÓN EN LA ZONA MEDIA DE SAN LUIS POTOSÍ

2. INNOVACIÓN TECNOLÓGICA:
Se transfirió la tecnología sobre preparación del suelo con un enfoque de agricultura de conservación. Con esta tecnología no se invierte el perfil del suelo, se mantiene su estructura, lo que facilita el movimiento del aire y agua en la zona de raíces, se facilita el control mecánico de la maleza, se incrementa el rendimiento en un 25% y se reducen los costos de preparación del suelo en un 35%. Se empleó un instrumento conocido como multiarado a una separación entre sí de 0.80 metros. En terrenos con problemas de gramilla o pasto Johnson el suelo no se movió durante dos o tres días para que el suelo perdiera humedad y la maleza se deshidratara. Posteriormente se dio un paso de rastra y se procedió al trazo de riego de presiembra.

3. PROBLEMA A RESOLVER:
El uso del barbecho en la preparación del suelo no solo destruye su estructura sino que también incrementa los costos de producción en un 40%. Al invertir el perfil del suelo con el barbecho y desmenuzar los terrones con la rastra, la estructura y porosidad se destruyen, dejando la superficie expuesta a la acción erosiva de la lluvia y del viento. La competitividad de los productores de maíz elotero en la Zona Media de San Luis Potosí depende en gran parte en la reducción de los costos de producción.

4. RECOMENDACIÓN PARA SU USO:
Después de usar el multiarado, espere de tres a cuatro días para que la maleza perenne, tal como la gramilla y el zacate Jhonson, se deshidraten y mueran. Después de un paso de rastra y en seguida trace los surcos a 0.85 metros de ancho. De el riego de presiembra y espere a que la humedad del suelo permita realizar la siembra. Emplee el híbrido A-7573 en una densidad de 65,000 plantas por hectárea, lo cual se logra al dejar una distancia de 0.18 metros entre cada planta. Para la frecuencia de los riegos, fertilización, control de maleza, plagas y enfermedades siga las recomendaciones del INIFAP para el cultivo de maíz para elote en la Zona Media de San Luis Potosí.

5. ÁMBITO DE APLICACIÓN:
Esta tecnología se recomienda para las áreas de riego de los Distritos de Desarrollo Rural 129 y 130 de San Luis Potosí y zonas agroecológicas similares en las estados de Aguascalientes, Durango, Nuevo León, Tamaulipas y Zacatecas.

6. DISPONIBILIDAD:
En el mercado nacional se pueden encontrar diferentes tipos de multiarados, los cuales no deben ser confundidos con cinceles o subsuelos. El multiarado presenta unas aletas laterales que permiten roturar el suelo en forma horizontal y vertical, a diferencia de cinceles y subsuelos, los cuales solo lo hacen en forma vertical. El INIFAP, en San Luis Potosí, ofrece talleres y cursos diseñados para capacitar a agentes de cambio y productores en el empleo del multiarado como una herramienta para iniciar una agricultura de conservación.

7. COSTO ESTIMADO:
Con la tecnología de agricultura de conservación propuesta, los costos de preparación del suelo se reducen en un 35% en relación con la labranza tradicional con barbecho.

8. RESULTADO OBTENIDO:
La preparación del suelo con el multiarado incrementa la calidad del suelo evitando que se compacte, aumenta la macroporosidad e infiltración del agua, favorece el desarrollo de las raíces, reduce el riesgo de erosión hídrica y eólica, se incrementa el rendimiento en un 25% y se reducen los costos de preparación del suelo en un 35%. Esta tecnología se transfirió a los siguientes productores de maíz elotero: Inés Rojas, Benito Rojas, Jesús Rojas, Feliciano Huerta, Fermín Castillo, Carol Rojas Valdez, Prisciliano Juárez, Benjamín Juárez, Herminio Rodríguez en los ejidos la Reforma, El Refugio y La Loma en los municipios de Rioverde y Ciudad Fernández en la Zona Media de San Luis Potosí.

9. IMPACTO POTENCIAL:
Esta tecnología beneficiará a 10 mil hectáreas en el estado de San Luis Potosí, además de mejorar la calidad del suelo y eficientar el uso del agua y suelo en la producción de maíz elotero.

10. INFORMACIÓN ADICIONAL:
Para el establecimiento y seguimiento del cultivo de maíz para elote, se recomienda aplicar la tecnología disponible, descrita en: El cultivo de maíz para elote en la Zona Media de San Luis Potosí. 2001. Hernández Alatorre, J. A., A. Ramiro Córdova, V. Maya Hernández, C. Jasso Chaverría y M. A. Martínez Gamiño. Folleto para productores numero 26. INIFAP, San Luis Potosí. 14 p.

Para mayor información dirigirse a:
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Fig. 13. Example of technology that depicts the procedure to increase water use efficiency in rainfed areas for corn. The information includes the innovation, the problem to solve, recommendations, scope, availability, costs, impacts and contact for further information.

2.7. Other technology available

Besides offering crop options, the system provides readily available technology to increase rainfall productivity. This information has a unique standard format set by the National Institute for Forestry, Animal Husbandry and Agricultural Research of Mexico (INIFAP). The INIFAP has 38 experimental stations all over the country where agricultural technology is generated for most agro ecological environments. One generated technology should go through an institutional process that includes two steps before being released to the user: (a) Generated: in this step the researcher proposes the new technology (which was generated within a research project) to a national institutional interdisciplinary group which will review it and send feed back to the researcher; (b) Validated: in this step the researcher has soft money to validate the newly generated technology at the farm level; and (c) Transferred: the technology is being released to the users (farmers) and ideally presented in a technical or scientific meeting. After validation, the technologies are published annually. (http://biblioteca.inifap.gob.mx/portal/index.php/2013-09-28-00-33-31) (see Fig. 13).

3. Conclusions

Soil water balance models are a good supporting tool for decision taking. When coupled with external information and databases they increase its usefulness for farmers where there is lack of readily available information regarding courses of action given certain level of agricultural climatic risk. In this paper, a simple soil water balance model is presented that fits the above characteristics. The model has a user-friendly interface with inputs that may be chosen from option tabs (mouse oriented) obviating the need to use the computer keyboard. The knowledge base linked to the model was designed taking into account who the decision makers are, the decisions that are to be made and the information that is needed to make those decisions. We admit that in the design of the knowledge base there may be an unforeseen design flaws that may prevent the system to be used or to reach the planned impact. Nevertheless, the tool has value the ability to speed adoption of practices to adapt to climate change by farmers, technicians and decision takers and was designed to be improved over time. Also, the knowledge base contains technology that it has been generated through research within INIFAP through many years and it is a good way to transferring the technology to primary users. Other institutions that have developed agricultural technology may provide of information through the process described in this paper widening the database and triggering it use. In this fashion, the knowledge base is can be improved indefinitely. The model and the linked knowledge base may be cataloged as a technical computational guide following the outcomes of a stochastic soil water balance for decision support on dry lands in Mexico. While the knowledge base is being completed (32 states with technical recommendations for 6 crops and an undefined number of potential crops), the system is calibrated already for the state of Durango for maize and the knowledge base may be consulted in: https://clientes.bmsolutionsalamedida.com/sagarpa/verelementos.aspx. When consulting the site, choose the state of Durango and maize (maiz) to see the available technology for that crop. The computer model is in its standalone version with a link to the knowledge base as explained within the paper. The executable file of the computer program will be provided upon request to the authors.

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Further reading

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