ISSN 2007-9737

Simulation of Corn Production in Chicontepec Veracruz with Agent-Based Modeling

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Abstract. The objective of this research focused on the simulation of corn production in Chicontepec Veracruz, Mexico, over a period of 5 years, using Agent-Based Modeling with the high-level programming language NetLogo, which allows representing complex interactions between key factors such as: indigenous producers, government institutions at different levels. The complex systems research method made it possible to analyze and simulate the interactions of the parameters or variables: area planted, price per ton of corn, rainfall, fertilizer, government support, indigenous producers. The results found is that corn production in the indigenous municipality of Chicontepec Veracruz, Mexico is highly influenced by the availability of fertilizer inputs, seasonal rains for a more favorable yield, the implementation of crop rotation and adoption of sustainable technologies is indispensable. The findings: it is one of the important economic activities, although production is carried out in a rudimentary way, there is a lack of organization for a collective production that guarantees the recovery of the investment, the crop is rooted in their culture. The limitations encountered in the process of applying the field study are that the indigenous producers did not want to provide data due to the distrust generated by political campaigns.

Keywords. Simulation, corn production, agents.

1 Introduction

The Agent-Based Models (MBA) are cellular models that simulate a certain phenomenon through the behavior of autonomous agents, it is a branch of study of the theory of complexity that nowadays is gradually gaining importance to be used in the solution of social problems in the field of scientific research; to analyze problems and/or social entities from a complex point of view, is to decompose the parts from the smallest part, like a button up, to later analyze the larger parts or the result of the interaction of elements with diffuse behavior, but which form an essential part of the conglomerate for the occurrence of an event.

Under this conception a complex system "has elements that relate to each other and in doing so produce a collective behavior that is not evident to the traditional observer but with the use of information systems and simulators that allow the identification of non-linear emergent behaviors that arise from interactions and that no single element can explain by itself" (Rivas, 2015, p. 5).

A model has the characteristic of simplifying reality by describing or representing the different components, processes and interactions that are an important part of a given system under study, so the design and development of the model allows to identify, select, order the information that integrates it and that is likely to be analyzed to establish that the system works, the evaluation can be through the simulation of both internal or external behavior of the problem (Cardoso et al., 2011).

As technology is developed to solve economic, social or any other kind of problems, new scientific methodologies are being discovered, one of them is the Agent-Based Modeling (ABM), which will be explained in the following.

Through agent-based simulation it is possible to recognize complex social systems, the way in which they interact, the way in which the first abstraction of the real environment is designed and, consequently, the formal model; in formal models modeled through agent-based simulation, the basic components of the real system are a result of individual behaviors (Izquierdo, Galán, Santos, & del Olmo, 2008 pp. 98).

The interactions of the agents or basic components of an MBA are represented in the model individually; each agent pursues its own goals and objectives, as happens in social networks, which are influenced by a diversification of factors within the space that are not ordered or structured (De la Barrera, Urdiales, & Mendoza, 2008).

Ortega & Gómez (2014), state that the agents define their relationships and interaction rules and determine the actions in the model sequentially, this can be physical or virtual with autonomous decision making, can represent; "atoms, cells, animals, people or organizations depending on their application, the agents have their own resources such as land or capital, also objectives such as maximizing their income, or decreasing risk and sensory capabilities, that is, they have information about attributes and state of other agents and the environment" (Ortega & Gómez , 2014 pp.19).

The MBA has potential advantages that make it possible to discover and explain behaviors that emerge from complex systems, as well as to incorporate agents with new characteristics of interference, heterogeneity, and hierarchies, such as financial, economic, social, personality, structural, and location characteristics, in different environmental contexts (Cardoso et al., 2011).

Agent-based modeling is currently being taken into consideration in the study of complex systems more frequently in different aspects of social sciences for decision making, autonomous entities interacting in a social environment can be modeled as autonomous agents in a simulation to analyze their behavior in different scenarios (López & Galán, 2012 pp. 13).

Agents methodology have the following main characteristics:

— Ability to integrate the behavior of agents,
— Interaction of a group of agents,
— System on which they act,
— Rules of behavior.

Models under a simulation of complex urban phenomena created from spatial patterns because of individual behaviors to generate different scenarios (De Carvalho, 2011 pp. 29).

The ABM offers a different approach to the rest of the methodologies or conventional methodologies in this one, the rules that govern the system are applied to each individual or agent so that it is explained that group behavior is nothing more than the sum of individual behaviors (Goñi & García, 2006 pp. 6).

It has been found that MBAs offer the social sciences authentic virtual laboratories where it is possible to analyze, experiment and study interactions of the behavior of individuals in a heterogeneous environment, subject to eventual hierarchical organizations, in addition, MBAs (like other models) contribute to quantify, formalize information, knowledge, can be complementary to sociological methodologies and studies, and offer a great opportunity to integrate knowledge from different disciplines (Cardoso et al., 2011).

Agent-based modeling as mentioned above in this paper has become an important technique for the solution of social problems, therefore, the problem of the decrease or stagnation of corn production in Mexico becomes a social problem since it is a basic food product in the great majority of social sectors, in this way it is important to mention the importance of the use of agent-based modeling.

Agent-based modeling has been used in some areas other than corn production, such is the case of the model of Quezada & Canessa (2010), which analyzes the time required to find care for the sick depending on the treatment, home or hospital, to verify whether or not the staff can share information on the location of the sick and whether or not they reside in urban areas, Based on the results obtained, it was found that sharing information significantly reduces the time required only for hospital treatment and that density has no impact. It is concluded that the MBA has great advantages for the design of social research and is the basis for decision making in professional contexts.

Within the same approach, an exploratory work was carried out in Cuba with the purpose of determining whether a group of students and teachers agreed with the use of agent-based modeling (MBA) as a tool in their learning process, the experience was carried out with 2 groups of 35 fifth year medical students, 5 work teams were formed and each of them simulated the spread of the HIV AIDS virus with different social behaviors in a small community, they worked with the Netlogo software program, specifically with the “AIDS” model, a survey was conducted with the participants after the experience and it was found as a result that both students and teachers agree that this type of model could be included as a learning tool (Baetancourt, 2014).

In the paper “Cultural Algorithms” by (Ochoa Zezzatti, 2008) it is mentioned that a number of algorithms motivated in social groups have been used to solve complex optimization problems in the same way three algorithms are used in a population based model as the basis of the algorithm and solve problems by sharing information via social interaction between agents in the population, the basic cultural algorithm allows individuals to communicate via shared belief space.

In the doctoral thesis entitled: Modelling Trust into an Agent-Based Simulation Tool to Support the Formation and Configuration of Work Teams developed by Pavon & Martinez (2010), presents a new agent-based simulation model for the configuration and formation of work teams, the model represents real candidates that form the team through software agents, Each candidate is modeled from a set of cognitive, social, emotional and personality traits to simulate the behavior and performance of a work team in relation to the tasks assigned to them.

Garcia & Valdecasas (2011), argue that agent-based simulation is a new way of exploring social phenomena, with multiple advantages of combining laboratory experiments, network analysis to design doubly empirical models: laboratory experiments provide data on the behavior of agents and network analysis that gives information about the structure of interaction between agents on which to build such models; which can explore more complex social situations than those carried out in the laboratory or by network analysis; moreover, the results of such models can be tested, such models open the juncture to study and analyze the relationships between the actions of individuals and the dynamics of the networks where they are immersed from new perspectives.

In the paper System and Agent Dynamics for modeling the diffusion of two competing innovations compares the equation-based modeling methodology and the agent-based modeling methodology in terms of advantages, disadvantages, scope and limitations in modeling and simulation of complex phenomena, the authors develop a system dynamics simulation model and an agent-based model that represent the diffusion of two innovations in a competing market considering elements of bounded rationality; It is concluded that agent-based modeling can capture the dynamics of equation-based models, but equation-based models leave out the analysis that could be addressed with agent-based models (Cadavid & Franco, 2012).

The use of ABM in solving current social problems are set out below (Li, Sun, Zhu, & Li, 2015), in the study of agent-based modeling in the organizational dynamics of the terrorist network mentions that in order to undertake actions to combat terrorism, the first thing to do is to analyze and understand the way they are organized, for this organizational dynamics are investigated, using a computational experiment through agent-based modeling in the organizational dynamics of the terrorist network, The changes in the operational environments affect the development of the terrorist organization in terms of its recovery and ability to perform future tasks, and the possible strategies that can be implemented to restrict or attack the activities of criminals are also discussed.

The Department of Geography of the University of Munich, Germany, conducted a simulation of water consumption in the tourism sector under climate change conditions using agent-based models, examines the impact of climate change on tourism, through a model which incorporates hydraulic, climatic, demographic and economic processes and simulates the development of various sectors in the Upper Danube River Basin in Central Europe in a multi-agent approach, considering the interaction of man-environment systems and environmental changes that influence human life as well as climate and societal scenarios to investigate the operational ability of tourism establishments in relation to supply and demand and the reactions that arise in this way to calculate the water demand of tourism which is not recorded in official statistics, the results give room to search for economically reasonable investment strategies, give scope for further research on the issue of tourism demand as it relates to climate change (Soboll & Schmude, 2011).

In the Department of Irrigation and Drainage, China Agricultural University, Beijing in North China Plain; they conducted the study named: Modeling soil water regime and maize yields; it was considered, climatic uncertainty; the simulation model has the ability to estimate and predict real-time soil water storage and maize yield response to soil moisture was developed by combining two existing models: Soil water storage was estimated through the soil water balance equation considering the uncertainty of evapotranspiration and combing with the Kalman technique (Kalman filter application). Crop dry matter and grain yield were simulated using a functional relationship between yield and soil moisture, the data used were collected for 4 years to calibrate the model the results indicate that the estimated and predicted soil moisture storage agree with the measured data and the relative yield prediction error is around 10%, which means that the combined model and the applied methodology are able to predict crop Yield and soil water storage dynamics (Huang, 2004).

Also (Oppong, Onumah, & Asuming-Brempong, 2014) at the Department of Agricultural Economics and Agribusiness, University of Ghana, in the Republic of Ghana conducted a stochastic frontier modeling of maize production in the Brong-Ahafo region (Stochastic Frontiers are topics of applied econometrics, production efficiency and Technological Change Models), maize is one of the main crops for food security and marketing, the model analyzes the technical efficiency of maize farms, using cross-sectional data from 232 production areas, with input variables per hectare: seeds, herbicides, labor, and cost of intermediate inputs positively influence production, further concludes that corn producers obtain an average of 83% of the frontier product and there is the potential to increase corn production by 17% to technology and input levels in the short term by adopting best farming practices, concludes that producer specific factors impede the full potential of farmers and the effects of inefficiency can be mitigated by focusing on policies that enhance the use of best practices.

In the case of (Dyer & Taylor, 2011), they applied in the study Corn Price Increase: Impact on Rural Mexico an agent-based general equilibrium model that explores the impact of rising world corn prices on arable land use and incomes in rural areas, the results suggest that subsistence activities allow agriculture to absorb the impact, limit the benefits of higher prices for the population, the expansion of corn area is estimated at 5.7% in 2008 and the wide variation between regions.

In the research on the development of a typology for water conservation in the U.S. corn belt, the different practices for good practices to reduce rainfall runoff and thus nutrient depletion are analyzed through the ABM (Daloğlu et al. 2014).

The ABM model of Gan et al (2014) is applicable to many bioenergy production systems, which allows imitating the decisions of the raw material producers, in the generation of biofuel from corn stover, this model obtains variable positive results with respect to the type of soil, price and harvesting cost.

In the research, the impacts of alternative crop market scenarios on land use change with an agent-based model simulates producers' decisions on the type of crop to implement with parameters; fertilizer application, crop price and expectation of forecasting the profit of corn stubble producers (Ding et al 2015).

In the northern plain of China, main cultivation area of corn and wheat is urbanizing rapidly, the behavior pattern of producers by crop cereals is decreasing rapidly, the MBA simulates the decision-making of in relation to the problematic, in that research found a decrease of 89.71% compared to 2019, the above could cause a threat to food security and must implement appropriate policies to control it (Yao et al., 2018).

In Agent-based simulation to analyse the potential of a biogas-based power plant in Schwarzwald-Baar district, Germany: A step towards better economics analyses the economic distribution of power plants for the location and installation of new processing centres and to facilitate the supply logistics of biomass or corn for silage (Imran et al., 2017).

In a social science perspective regarding the MBA simulating the mitigation of the insect resistance Bacillus Thurringiensis that attacks the corn crop, it evaluates multiple policies implemented for its control as well as the resistance of the variety for the adoption of farmers (Saikai et al., 2021).

In the agent-based model to identify risks in the supply chain and sales of corn types with three agents; farmers, PTPN VIII company and buyers where everyone faces risks, under the parameters; corn seeds, planting and crop management, harvesting and drying corn, with the simulation with NetLogo it was shown that the most latent risk is quality (Hidayat & Suliandar, 2020).

2 Method

To simulate corn production in Chicontepec Veracruz, the corresponding literature was reviewed so that the variables of this research are based on the contextual framework of corn production, as well as on the theoretical framework and state of the art, in such a way that it can describe and simulate the conditions under which this agricultural activity is carried out.

Using data collection techniques: interviews with focus groups, in-depth interviews and a data collection instrument on the Likert scale.

Studies were carried out in several communities of the municipality of Chicontepec in the Nahuatl language since it is the mother tongue of the population under study with the greatest number of speakers. The results obtained were validated using the Cronbach Alpha statistical test in the SPSS (Statistical Package for the Social Sciences) statistical software version 25, obtaining a result of .857, which means that the measurement instrument is reliable because it has a Cronbach alpha greater than 0.7.

Based on the validation in the statistical software of the 324 tests answered by the corn producers of Chicontepe Veracruz, the confirmatory factor analysis is carried out. It is a necessary step for modeling with structural equations or structural equation modeling (SEM). According to (Littlewood & Bernal, 2014), it is a statistical technique that allows testing theoretical models, establishes causal relationships between independent and dependent variables based on theoretical review, measurement of relationships with the SEM, modeling is carried out using the items of the dimensions and indicators proposed in the evaluation instrument.

Structural equation modeling was carried out with LISREL, a scientific software that allows researchers in social sciences, management sciences, behavioral sciences and other fields to evaluate their theories.

The sample selected from two strata of this research corresponds to women and men who are dedicated to corn production in the municipality of Chicontepec:

Stratum 1 = 516 women.

Stratum 2 = 1,554 men.

Total, N = 2,070

The sample size when n is finite (known) using maximum variance:

$$n = \frac{Z^2 Npq}{(N-1)E^2 + Z^2 pq},$$

where:

Z.- Level of confidence, 95% → z = 1.96

N.- Population

p.- Proportion of individuals who present the characteristic of interest

q.- Proportion of individuals who do not present the characteristic of interest

E.- Maximum permissible error.

$$n = \frac{(1.96)^2(2{,}070)(0.5)(0.5)}{(2{,}070-1)(0.05^2)+(1.96^2)(0.5)(0.5)},$$

$$n = \frac{(3.8416)(2{,}070)(0.5)(0.5)}{(2{,}069)(0.0025)+(3.8416)(0.5)(0.5)},$$

$$n = \frac{1{,}988.028}{5.1725+0.9604},$$

$$n = \frac{1,988.028}{6.1329},$$

$$n = 324.16.$$

Stratum	Population	Proportion	Sample
1	N_1 = 516 Women	25 %	N_1 = 81 Women
2	N_2 = 1,554 Men	75 %	N_2 = 243 Men
Total	N = 2,070	100 %	N = 324

The parameters or variables used for the simulation are the following: planted surface, price per ton of corn, rainfall, fertilizer, government support, producers.

For Calvo (2006), a model is an explanatory synthesis that is adequate according to its deductive capacity, its skill with which it can derive the equations or description of the data under observation for which an explanation is sought.

In this way, it is conceived that a model shows unique characteristics that highlight an idea, this idea may or may not be followed by those who perceive it; a model represents the ingenuity and work of a person or of nature itself, creating a range of characteristics that are imitated by others.

Agent-based complex system modeling involves the expert performing an abstraction to build a non-formal model, then the modeler intervenes who performs the design and coding of the formal model, the formal model is then developed in NetLogo based on the development of computer systems, the results obtained are then analyzed by the modeler who determines the validity of the model and writes a formal document with the results supporting the deployment of the application as seen in Figure 1.

According to the results of the analysis with structural equations, the latent variables obtained from the confirmatory factor analysis are the independent variable yield with a strong relationship with the indicator use of fertilizers and the dependent variable production, with their respective indicators reflected in the items, rainfall (within this indicator are immersed, the growth of the plant, natural disasters) harvest or ton per hectare indicators that have a strong relationship with the variable yield, the sown area, the above are latent variables validated by the SEM, it also has weak relationships with the use of insecticides, herbicides and fungicides in the crop development process.

Based on the modeling of complex systems through agent-based simulation and system dynamics (Luis R. Izquierdo et.al., 2008) shown in Figure 1, the model for simulating the competitiveness of corn producers in Chicontepec was designed.

Figure 1 represents the visual part of the model, where the modules necessary to establish the environment and simulation core are specified. The expert module has the capacity to receive different types of data and process them in the design and coding module of the formal model, also called the modeler. In the computer interface module, the high-level language intervenes, in this case the NetLogo language, which, under a set of grammatical and syntax rules, translates the instructions into machine language to execute and obtain the desired results, under an interpretation and analysis that is finally generated as a numerical report or through graphics.

In the model, the expert is the agricultural technician who advises corn producers. He has the knowledge to increase competitiveness in corn production. However, he may not have the knowledge to create formal models, and that is why the result is a non-formal model that can be written in fluid language.

The modeler is a professional person with knowledge of modeling complex systems using symbolic calculus, propositional logic, or a programming language.

The computer is responsible for executing or solving the formal model; the computer deduces the logical implications that derive from the premises that define the model and the initial conditions.

The model executed on a computing platform produces results that must be analyzed by the modeler to provide an interpretation of the analysis of the results and validate the model. If the model is correct, then the application is deployed to help corn producers in the Chicontepec region to increase their competitiveness

Figure 2 shows the flowchart for the implementation of the formal model in Netlogo, the diagram corresponds to the formal algorithm expressed in a pseudo or algorithm.

ISSN 2007-9737

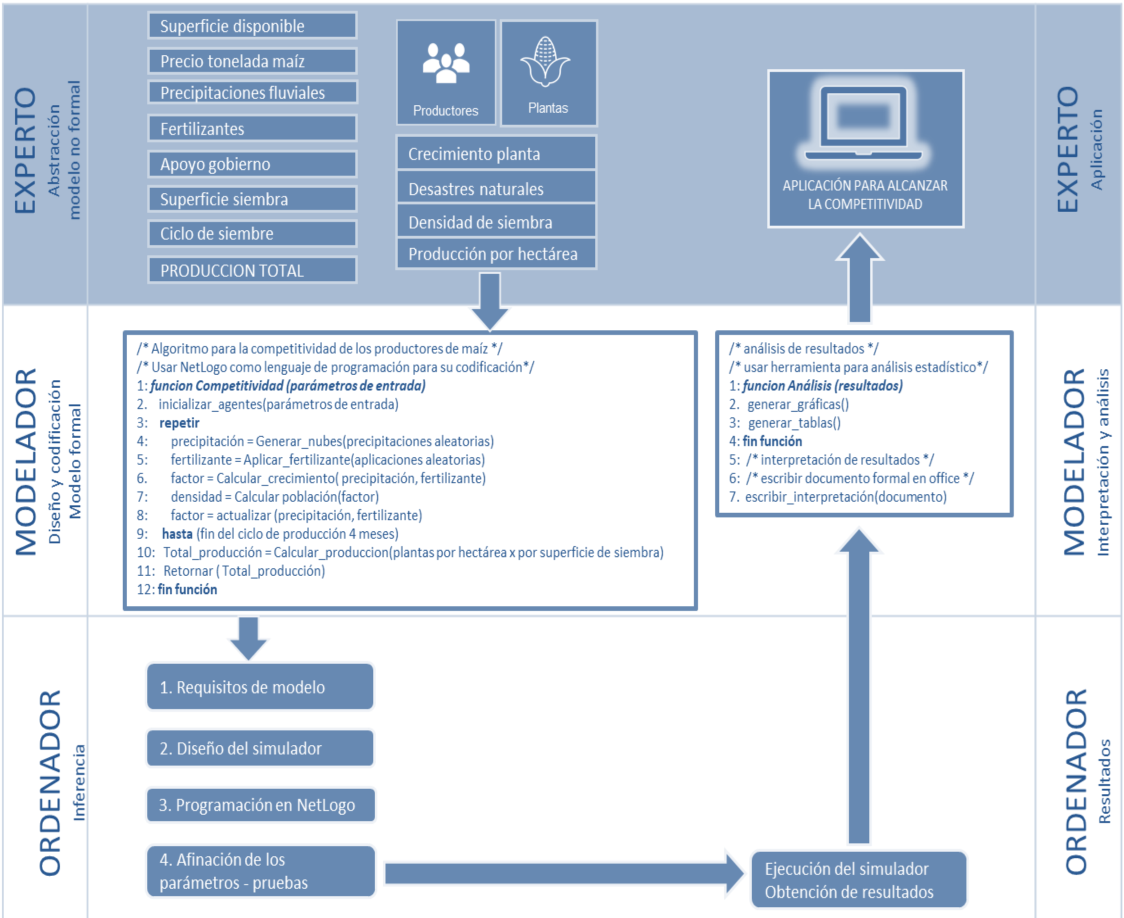

Fig. 1. Corn production simulation model in Chicontepec Veracruz Source: Own elaboration based on the results of the piloting

It also shows the model programming process, which must be established before starting to code the instructions in NetLogo language.

The simulation model written in NetLogo uses several parameters as input described in Table 1, the parameters use maximum and minimum values that are set before starting the simulation to establish a range [minimum, maximum] for random generation of values during the simulation process, the parameters are described below.

Available surface area (S). Represents the total surface selected to be planted by producers. This surface changes at each planting based on the conditions that each producer has before planting.

Price per ton of corn (P). The price per ton of corn is set in a maximum and minimum range that is determined by the price and conditions during the previous planting.

Rainfall (PF). Represents the amount of rain in river precipitation given in millimeters. During the simulation process, rain is generated randomly.

Fertilizer application (F). Represents the amount of fertilizer used per hectare. During the simulation process, fertilizer will be applied in randomly generated quantities based on government support to acquire them and sporadically by the producer.

Government support (AG). Government support given in pesos per hectare to each

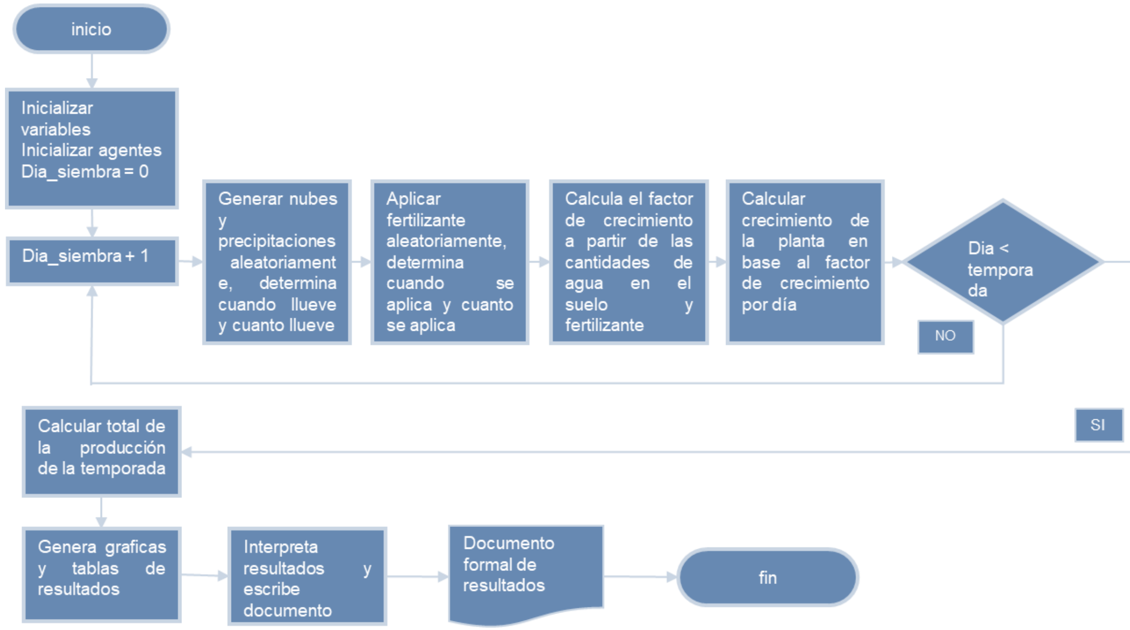

Fig. 2. Flowchart of model implementation. Source: own elaboration

Table 1. Input parameters

Parámetro	Minimum value	Maximum value
Available surface	3084	3084
Price per ton of corn	3600	3654
River precipitation	10	300
Fertilizer	30	40
Government support	1600	2000
Producers	2070	2100

producer is considered. The support is generated randomly based on a maximum and a minimum determined by previous programs.

Number of producers (NP). It represents the number of producers who will plant corn for the current season. This amount is generated randomly based on the maximum and minimum number of producers from past plantings.

Other parameters to be considered by the model are the total surface area available for planting and the number of days that the planting season lasts.

Planting area (ST). Represents the total surface area in the municipality of Chicontepec that has been sown by producers.

Sowing density (DP). It is the number of seeds or plants sown in one hectare. At the end of sowing, the surviving plants and their accumulated growth power from rain (PF) and fertilizer (F) are calculated, which allows calculating the tons of production per hectare.

Sowing cycle (CS). A total of 4 months is considered which lasts the sowing season from when the seed is placed on the ground until it is harvested. The model simulates 120 days and studies the behavior of the parameters during that time.

The simulation process focuses on the sowing, growth, development and harvesting of corn plants. From birth, the development of the plant is

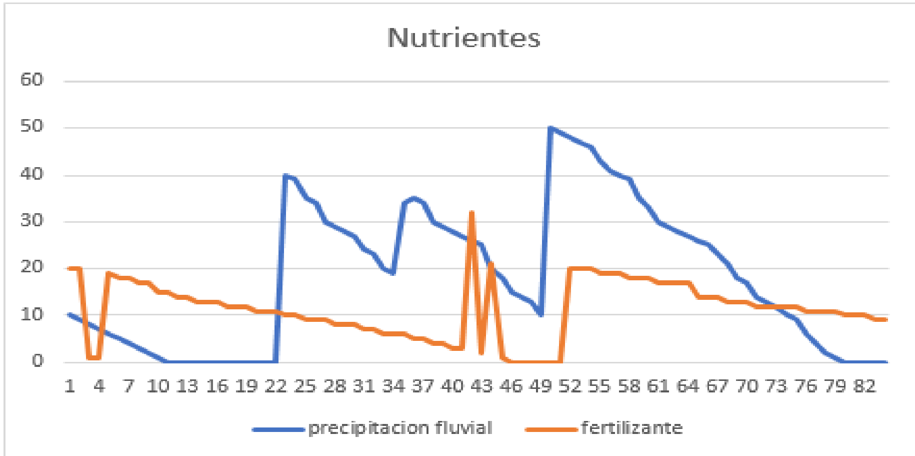

Fig. 4. Plant nutrients through growing days. Source: Own elaboration

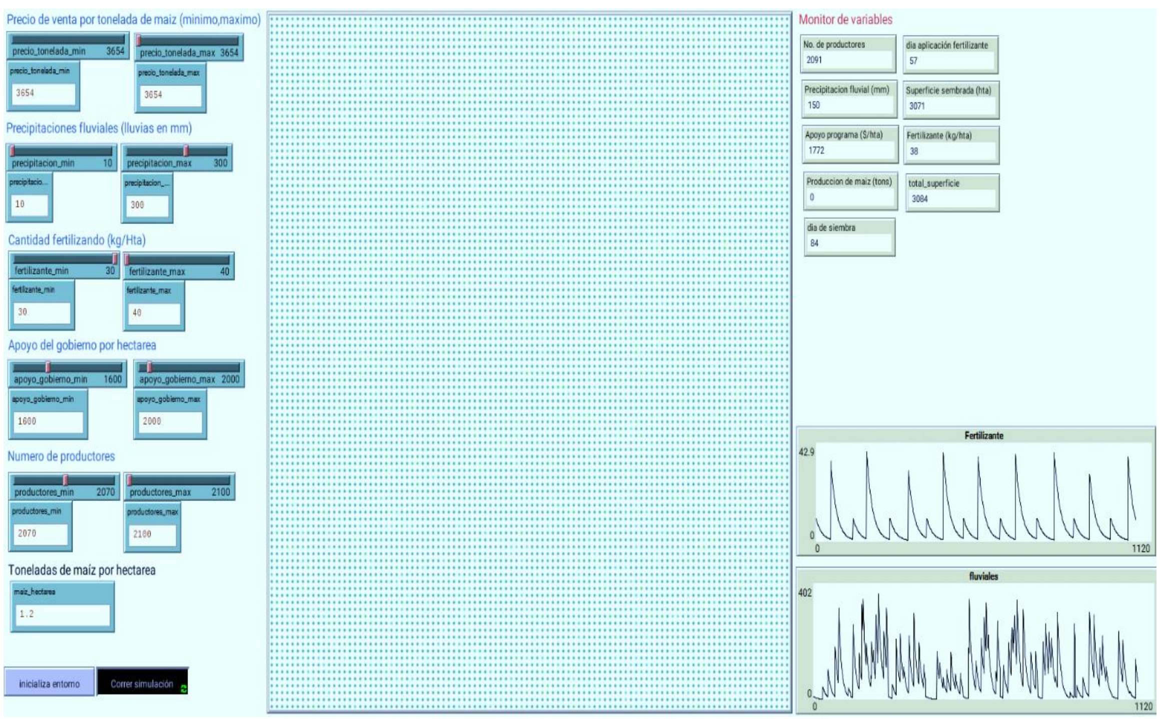

Fig. 5. Model interface. Source: Own elaboration based on research results

subject to rainfall and fertilization conditions. These conditions determine the number of plants that are harvested and the number of plants that die during the season.

The model considers corn growth only by these two factors; other conditions such as pests, amount of sun, water evaporation rate, natural disasters and other factors are ignored because they are too complex to simulate.

120 days of simulation are considered for a harvest; during this period, rain and its fluvial precipitation are generated randomly, as well as the number of fertilizations and the amount in kilograms. These two parameters condition the

growth and development of corn plants as shown in Figure 3.

Plant growth is constant every day and is conditioned by the factors of river precipitation (PF) and the amount of fertilizer (F), these quantities tend to decrease day by day, therefore, plant growth is different throughout the days, when the water and fertilizer conditions are ideal the plants grow steadily, but when the conditions are not adequate the plants grow more slowly or may even die.

The rainfall reduction factor (DPF) and the plant available fertilizer reduction factor (DF) are introduced into the model. These two factors reduce the amount of rainfall and fertilizer available for plant growth on a daily basis.

The amount of fertilizer available on a given day is given by equation 1:

$$PF = PF \times DF, \tag{1}$$

The amount of water available in the soil is also calculated for a specific day using equation 2:

$$F = F \times DF, \tag{2}$$

The fertilizer and rainfall reduction factors are set in a range between zero and one, so that the number of resources for the plant decreases every day until it rains or more fertilizer is applied.

Figure 4 shows how rainfall decreases every day until it rains, and the levels become high. On the other hand, the fertilizer levels increase with each application and from that moment on it decreases day by day. Both factors directly impact the growth of the plant over time, which grows at a constant rate based on the amount of nutrients it has.

The plant growth factor (FC) is introduced between zero and one, when the FC is at a high level calculated from the amounts of river precipitation (PF) and the amount of fertilizer (F) the plant has a constant growth equal to 1, when the levels drop the plant has a growth less than 1 the plants do not have enough water and fertilizer, then the FC tends to zero and the plants can die.

Thus, at the end of the 120 days the plants will have a cumulative growth rate (CGR) from which corn production can be calculated. Corn production is calculated from the CGR and the number of surviving plants (SP) after planting a total of plants (DP) per hectare.

The corn production rate is determined by equation 3:

$$Tons = CGR \times SP \times ST. \tag{3}$$

The amount of accumulated growth FCA is directly proportional to the grams that a plant can produce corn at harvest. The tons of harvest for a season is the total corn produced per hectare multiplied by the total number of hectares that were planted (ST).

The Chicontepec, Veracruz corn production simulation, using Agent-Based Modeling, describes the environment and conditions of how corn is produced based on latent variables validated in structural equation modeling in the LISREL statistical scientific software.

The program allows you to specify the input parameters: price per ton of corn, rainfall in mm, amount of fertilizer to be applied, number of producers and the historical production per hectare of Chicontepec as shown in Figure 6.

The grid presents a total of 10,000 corn plants evenly distributed over one hectare of surface shown in figure 7, the simulation begins on the day adjusting the parameters of rainfall and initial fertilizer, sowing coincides with the rains so that the seeds naturally hatch, therefore, the levels of humidity or fluvial precipitation of the soil are adjusted to the minimum value specified in the initial parameters and the natural fertilizer to 10kg.

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The execution of the model allows for a simulation that advances one day at a time. On each day, the dissipation of fertilizer and humidity associated with the quantity of fertilizer in the plant and the river rainfall is calculated. The values that allow these two parameters to be reduced are shown in Table 2.

Fertilizer and humidity decrease, affecting its growth, so that when it reaches minimum values, its growth stops, and it can die. On the other hand, when it is randomly determined that fertilizer is applied, the plant increases its levels and allows normal growth. Figure 8 shows the day of application of fertilizer and how it decreases each day. Equation 1 shows how this factor is applied.

On the other hand, the fertilizer values are combined with the humidity values, in such a way that when it rains, these values increase and with this the growth of the plant accelerates, when it drops to minimum levels its growth decreases and it can die, in figure 9, it is shown how randomly rains are created on the basis of the river precipitations established in the input parameters, we can observe the days that it rains the humidity levels in the soil increase and subsequently day by day they decrease, equation 2 shows how this factor is applied.

The growth is carried out for each of the 10,000 plants, each plant has associated amounts of fertilizer and humidity available for its growth, only one application is established for the fertilizer, so the day it is applied is determined randomly. In the case of rain, each day it is determined randomly whether it will rain or not and in what quantity.

Every day the growth of each plant is calculated based on fertilizer and moisture. This growth is contained in the accumulated growth factor (AGF), which is the amount of energy that is accumulated during the 120 days of growth. At the end, each plant will have an energy factor that is equivalent to its growth and development, with which it is possible to calculate the size of the corn cobs and therefore their production.

To determine the corn production per hectare, equation 3 is applied, where the AGF is the accumulated energy of each plant. This amount of energy is multiplied by the total number of surviving plants to give us a total accumulated energy of the entire planting.

Table 3 shows the execution of the simulation model to determine the average FCA.

These quantities will be adjusted to obtain a model that approximates the historical corn production in the Chicontepec region.

Table 4 shows the historical production of the Chicontepec region, it shows an average of 22,241.4 tons of corn production, proportional to an

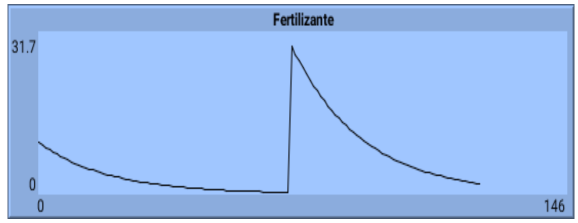

Fig. 8. Adjustment of fertilizer values day by day.Source: Own elaboration based on the ABM model

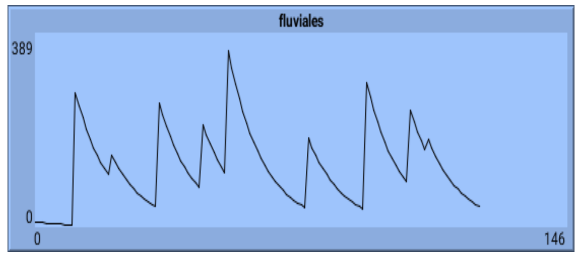

Fig. 9. Adjusting humidity values day by day. Source: Own elaboration based on the MBA model

Table 3. Total average FCA per hectare

Execution No.	FCA accumulated
1	1,077,444.4
2	964,412.1
3	1,122,860.9
4	1,078,348.5
5	1,106,700.6
6	1,108,395.8
7	973,190.6
8	1,090,701.5
9	1,127,345.7
10	1,158,858.7
FCA Media	1,080,825.8

Source: Own elaboration based on the ABM model

Table 4. Historical production per hectare

Year	Hectares	Hectare/ ton	Production tons
2019	20,563	0.629	12,937.5
2018	19,357	1.269	24,574.36
2017	20,460	1.315	26,925.3
2016	20,115	1.152	23,175.0
2015	20,450	1.153	23,597.0
Media	20,189	1.141482	22,241.832

Source: Own elaboration based on the Agri-Food and Fisheries Information System SIAP (2020).

Table 5. Results of the simulator using correlation factor

Year	Hectare/ton	Hectare/ton simulator
2019	0.629	1.17992989120843
2018	1.269	1.07573853452949
2017	1.315	1.11955835742939
2016	1.152	1.04737095995201
2015	1.153	1.05773948920118
T		

Source: Prepared by the authors based on the results of the ABM model.

average of 1,104 tons per hectare and an average planting area of 20,189 hectare, therefore, the simulator adjustment correlation factor corresponds to 1,104.141482 kilos per hectare divided by 1,080,825.80 of the FCA average results in a correlation factor of 0.001021572024676.

With this factor, we launched 10 runs to compare the results in corn production and compare it with the historical ones shown in Figure 10, the results are shown in Table 5. As we can see, the model is adjusted and the production values shown by the simulator are close to real values, except for 2019 when there was a general drought in the region and around the world.

Finally, the results show approximate the scope of Netlogo for simulations.

3 Analysis

Corn production in Chicontepec contributes significantly to state and national production. It is one of the 20 municipalities that have produced corn in the last 20 years. It is an economic activity of great relevance. The farmlands have the characteristic of being productive both in the mountainous area and in the lowland area of the municipality.

Farmers or producers have a culture of planting corn, therefore they have experience in the proper management of the development and harvesting process. However, the implementation of technology and training is needed to increase production levels.

Numerical simulation has been widely used for the areas of science and engineering, this model requires a deep knowledge of mathematics and is suitable for complex systems associated with social and administrative sciences, the agent-based model with NetLogo is capable of representing interactions between individuals and modeling systems closer to reality, providing a work scheme that allows creating simulations of complex systems suitable for this area; This mechanism allows focusing on solving the problem and leaving aside the complexity of traditional simulation programming languages such as C / C ++, Fortran, Python, etc., which have a long learning curve.

Based on the general objective of this research, the simulation was carried out with agent-based modeling (ABM), based on the variables validated in the confirmatory factor analysis and modeling with structural equations.

The information was collected through a measurement instrument which was applied to 324 peasant corn producers in the municipality of Chicontepec. The information obtained was subjected to statistical tests, with the use of the scientific software LISREL the variables were validated, to design the ABM model.

For the simulation, the following parameters were used: available surface, rainfall, fertilizers, planted surface and planting cycle, "support programs" were considered as a complement.

Thus, the agent-based simulation of corn producers in Chicontepec took advantage of the NetLogo language to recreate the growth of corn plants influenced by the variables yield and production with their respective indicators, such as: fertilization, rainfall, support programs, planted area, producers, price per ton, which were necessary to generate with graphics, start parameters, parameter monitor with a reduced code, modeling complex interactions such as the decrease in fertilization levels and soil moisture. This mechanism allows focusing on solving the problem by adjusting the simulation model to corn production. As a first approximation, the variables and indicators analyzed in the ex-ante model were ignored, but for future work it is the starting point for experimentation in the areas of social sciences with the capacity to deal with complex systems.

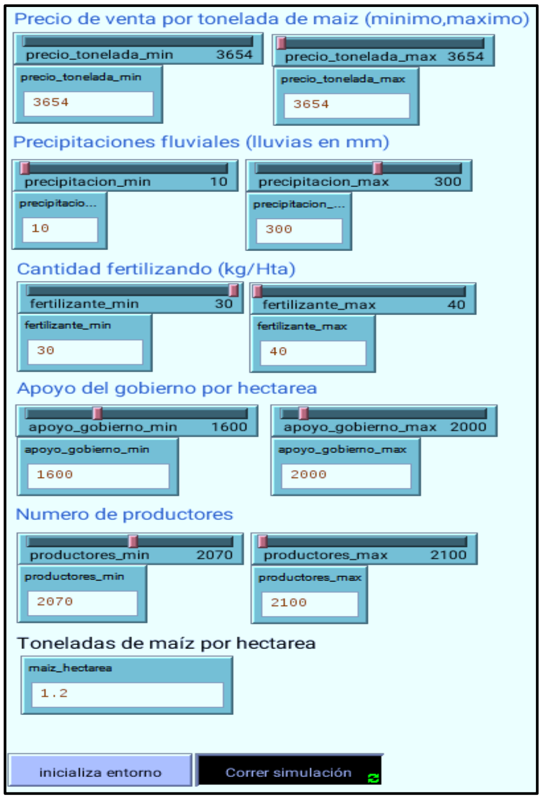

Fig. 6. Adjustment of the simulator input parameters. Source: Own elaboration based on the ABM model

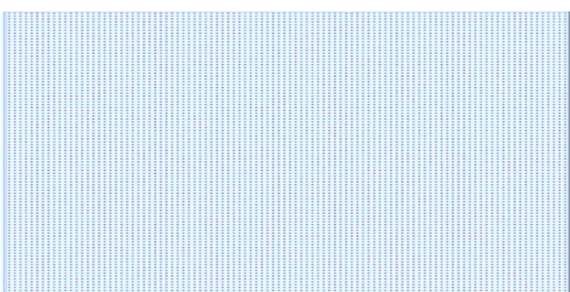

Fig. 7. Simulator grid for 10 thousand plants. Source: Own elaboration based on the MBA model.

Table 2. Control parameters

Plant growth control parameters	Valor inicial
Decrease in river precipitation (DPF	0.95
Decrease in fertilizer in the plant	0.90

Source: Own elaboration based on the development of the model.

In this way, it is concluded that NetLogo allows complex agent-based simulations to be made in a fast and precise way, bringing administrative and social science areas closer to perform experimentation based on simulation and interacting with agents.

4 Discussion

The procedure to carry out the simulation of corn production in Chicontepec Veracruz with agent-based modeling was determined based on independent and dependent variables. The instrument was also validated with Cronbach's Alpha in the SPSS software, the variables with confirmatory factor analysis and structural equations in the Lisrel software.

The indigenous producers of Chicontepec produce corn in a rudimentary way, there is no technology, there are very few government programs that encourage the cultivation, the success of the production process depends greatly on the rainy season, although the geographic location has the necessary conditions, the average yield is only 1.33 tons per hectare, in this area two harvests are generally obtained per year, it would be important for the corresponding authorities to give talks on crop rotation and adoption of sustainable technologies, which is essential.

It is one of the most important economic activities in the area since it allows us to ensure the food of the population in a period of approximately 6 months.

The cultivation has a very marked focus on its culture, its production process is full of ancestral rituals.

It is important to mention that based on the review of the literature there is research on the use of the complex systems method specifically in the use of Agent-Based Models, as stated in the review of the literature they are virtual laboratories to analyze, experience interactions of individual and collective behaviors under this perspective it was found that Quezada & Canessa (2010), which analyzes the time required to find care for patients; (Baetancourt, 2014), in learning models, (Ochoa Zezzatti, 2008) for motivated behaviors in social groups; Pavon & Martínez (2010), for the configuration and formation of work teams; García

& Valdecasas (2011), to explore social phenomena and network analysis; (Cadavid & Franco, 2012), compares an MBA to capture dynamics of equation models; (Li, Sun, Zhu, & Li, 2015), in organizational dynamics of a terrorist network; (Soboll & Schmude, 2011), in a simulation on water consumption in the tourism sector under climate change conditions; (Huang, 2004) to predict crop yield and soil water storage dynamics.

Regarding corn, the use of Agent-Based Modeling (ABM) is reflected in the work of (Dyer & Taylor, 2011), applied in the study of the increase in the price of corn: Impact on the rural environment in Mexico, (Oppong, Onumah, & Asuming-Brempong, 2014) in the modeling of the stochastic frontier of corn production in the Brong-Ahafo region, Ghana; (Daloğlu et al 2014), in policies for good practices with the aim of reducing storm runoff and therefore the wear of nutrients in the corn belt of the United States, in the case of Gan et al (2014), their ABM model imitates the decisions of raw material producers in the generation of biofuel from corn stover; (Yao et al., 2018), simulates the behavior pattern of producers in the North China Plain; (Imran et al., 2017), analyzes the economic distribution of power plants for the location and installation of new corn processing centers for silage, (Saikai et al., 2021). It simulates the mitigation of the resistance of the Bacillus Thurringiensis insects that attack the corn crop; (Hidayat & Suliandar, 2020) the MBA simulates the identification of risks in the supply chain and sales of corn types with three agents; farmers, PTPN VIII company and buyers.

In the case of corn production in Chicontepec, Veracruz, Mexico, it stimulates the production of indigenous corn farmers under conditions of very little technology in terms of irrigation, crop management, harvesting, environmental care and even marketing, although as already mentioned, they produce corn with a focus on food security.

The findings; the MBA models based on the arguments presented are a scientific tool necessary for the visualization of possible solutions to social problems in the case of Chicontepec, Veracruz, corn cultivation is one of the important economic activities that deserves special attention from government levels; although production is carried out in a rudimentary manner, there is a lack of organization for collective production that guarantees the recovery of the investment, it has the conditions to enhance its development as a crop.

It is important to continue researching corn cultivation in the municipality of Chicontepec because, as it is becoming less valuable, producers could choose to change their economic activity to orange cultivation, which would imply contributing to the shortage of grain and continuing to increase its import to satisfy the food consumption demand of the population.

It is recommended to use agent-based modeling (ABM) in research related to corn cultivation in indigenous areas since it is a complex problem.

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Article received on 27/01/2021; accepted on 09/12/2024.
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