Colegio de Postgraduados

Productive potential and typology of the bean agroecosystem in the Papaloapan basin, Mexico

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ABSTRACT

Objective: analyze the municipal level production potential using simulation methods and typification of the bean agroecosystem based on the edaphoclimatic, socioeconomic, and technological characteristics present in the basin.

Design/methodology/approach: the potential yield of beans was mapped, the SWAT model set a total of 8423 HRU'S within the basin surface. Based on this, three clusters were generated for high (1-65-2.75 t ha^{-1}), medium (0.87-1.64 t ha^{-1}), and low (0-01-0.86 t ha^{-1}) yield.

Results: regarding the variables used to analyze the typology of clusters of the bean agroecosystem, Natural Resources (RN) had a P=6.842e-08 value; Technological Development (DT) a P=1.01e-06 value and Infrastructure Development (DI) a P=8.284e-06 value, while the Economic Development (DE) variable obtained a value of P=0.3564 and the Social Development variable (SD) a P=0.04867 value, therefore, in these last two, there were no significant differences among the three clusters.

According to the P values, the high cluster agroecosystem presents the ideal conditions to produce comapa black beans, while the medium cluster can be improved to optimize it. For its part, the low cluster must be addressed in the RN, DT, and DI variables to improve its potential and sustainability.

Findings/conclusions: high cluster areas, despite containing fewer municipalities, present a higher production biophysical potential (RN). The agroecosystem of the high and medium-yield clusters has a surface with edaphoclimatic, socioeconomic, and technological characteristics suitable for the productive development of the bean agroecosystem.

Keywords: agroecosystem, bean, SWAT model, typology, Papaloapan.

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INTRODUCTION

In Mexico, beans rank second in importance in the national agri-food sector, due to their socioeconomic importance, the extension of land for its cultivation, and *per capita* consumption (San German-Jarquín, 2010).

Beans are produced in two seasons: spring-summer and autumn-winter. Due to their high availability, low cost, and cultural tradition, at a national and regional level, about 70 varieties of beans distributed in seven groups are cultivated: black, yellow, white, purple, bay, pinto, and speckled (Lara, 2015).

The demand for black beans (*Phaseolus vulgaris* L.) concentrates in the central and southern areas of the country, with consumption close to 300,000 t per year. The main black beans-producing states in the humid tropical region are Chiapas and Veracruz states, in the dry tropical region Nayarit and Sinaloa states, and in the semi-arid highlands, Zacatecas, Durango, and Guanajuato states (Acosta-Gallegos *et al.*, 2000; López -Salinas *et al.*, 2011).

In Veracruz state, mainly black and opaque grain varieties are cultivated. In 2010, the Bean Program of the National Institute of Forestry, Agriculture and Livestock Research (INIFAP), through the Cotaxtla Experimental Field, registered the improved Comapa black variety, whose grains are opaque black in color and small, characteristics demanded by the local producers and consumers (López-Salinas *et al.*, 2011b). This variety has high yield potential, disease tolerance, and a high adaptation rate to tropical agro-environmental conditions.

In terms of biodiversity, culture, and water resources the Papaloapan Basin is a rich area. In this region, the land use is mainly for agricultural activities, representing approximately 85%. Due to its location and topography, the Papaloapan basin has different climates: 47% of the area is extremely hot, with average temperatures of 25 °C, 47% is temperate and 6% corresponds to cold conditions (Moreno *et al.*, 2003).

According to the diversity of bean grains the Papaloapan basin reports and the crop's importance, this research objective was to analyze the production potential, at the municipal level, using simulation methods and typification of the bean agroecosystem based on the edaphoclimatic, socioeconomic, and technological functions present in the basin.

MATERIALS AND METHODS

Study area

The Papaloapan basin is located on the southern slope of the Gulf of Mexico; its surface covers territories of the states of Puebla, Oaxaca, and Veracruz, totaling an area of 46,263 km^2 that represents 2.36% of the Mexican territory (Murillo and López, 2005).

Sub-basins Delineation

The SWAT software (Neitsch *et al.*, 2005) works at the basin and sub-basin levels. The model subdivides the basin into sub-basins, based on the topography of the study area (Narasimhan *et al.*, 2005; Garg *et al.*, 2011; Du *et al.*, 2006; Akhavan *et al.*, 2010; Guzmán *et al.*, 2004). For the present work, the total area of the Papaloapan Basin was taken. Using a Digital Elevation Model (DEM) with a 90×90 pixel acquired from (INEGI) we proceeded to generate sub-basins. At the end of the process, 168 sub-basins were generated for the entire study area.

Generation of Hydrological Response Units (HRU)

Once the sub-basins were created, the model subdivided them into hydrologic response units (HRUs) based on a single soil type, land use, and slope range (Narasimhan *et al.*, 2005; Garg *et al.*, 2011; Du *et al.*, 2006; Akhavan *et al.*, 2010; Guzmán *et al.*, 2004). For the HRU generation within the surface of the basin, a vector format series III soil map from the INEGI scale (1:250,000) was used. This database came from the spatial distribution of 4,418 soil profiles classified WRB (Paz-Pellat, 2018). The slope ranges were divided into 5 categories (0-3, 3-8, 8-15, 15-30, and >30%). By the end of the process, the model generated 8, 423 HRU'S.

Generation and Assignment of Climate and agronomic management

For the introduction of the climatic data required by the model, the historical data of 1074 climatic stations of the national meteorological service was used, and the EPIC climatic generator (Sharply and Williams, 1990) produced the climatic statistics required by the model for each station.

Table 1 shows the considered management in the simulation of the Comapa Black beans variety within the total basin area.

Development of the municipal typology of the bean agroecosystem

The analyzed variables for the entire study area were: 1. Economic Development (DE); 2. Technological development (DT); 3. Social development (DS); 4 Infrastructure Development (DI); and 5. Natural resources (RN), following the synthetic statistics methodology by Uresti *et al.* (2016).

RESULTS AND DISCUSSION

The analysis of variance (ANOVA - R®) of the data generated by the SWAT model for the 2016-2020 period, indicates that there is a significant difference ($F_{1,\ 42110}=197.25$, p=2.2e-16) among the simulated years. By fitting the data model generated in R studio (R core team, 2021) for the five years (command: negrocomapa<- lm(YLDth~Year, data = csvsimne9) and the emmeans function (CI=95) an average of the data was generated. The spatially explicit results are shown in Figure 1.

Based on the results of the simulated yields map in Figure 1 and the division of ranges by breaking natural breaks method (Lee *et al.*, 2019), the municipalities (280 municipalities) of the Papaloapan Basin were divided into three clusters (High: 1.65-2.75 t ha^{-1}; Medium: 0.87-1.65 t ha^{-1}; Low: 0.01-0.86 t ha^{-1}). Table 2 shows field data and simulated average yield at the municipal level for different regions of the basin.

Through a correlation analysis of the data assessed in the field, and those simulated by the SWAT model under the Pearson method in the R® studio, a value of P=0.05, IC 95=−0.026 to 0.99, and a weighted correlation coefficient of 0.9, which indicates that the model simulated with notable precision.

Table 1. Bean management introduced to the model.

Activity	Year	Operation	Input	Date
Soil Preparation	1	Cleaning	Rotary Hoe	September 1st
	1	Fallow	Disk Plow Ge 23 ft	September 15th
	1	Tillage	Tandem Disk Plw 14-18 ft	September 29th
	1	Tillage	Tandem Disk Plw 14-18 ft	September 30th
Crop establishment	1	Planting	COMAPA BLACK BEANS	October 1st
Fertilization	1	1st Fertilization	23-00-00 NPK (Kg ha^{-1})	October 1st
	1	2nd Fertilization	18-46-00 NPK (Kg ha^{-1})	October 1st
	1	1st Cultivator	Row cultivator	October 20th
Cultivator	1	1st Furrower	Furrow diker	November 5th
Harvest	1		Harvest and kill operation	December 9th

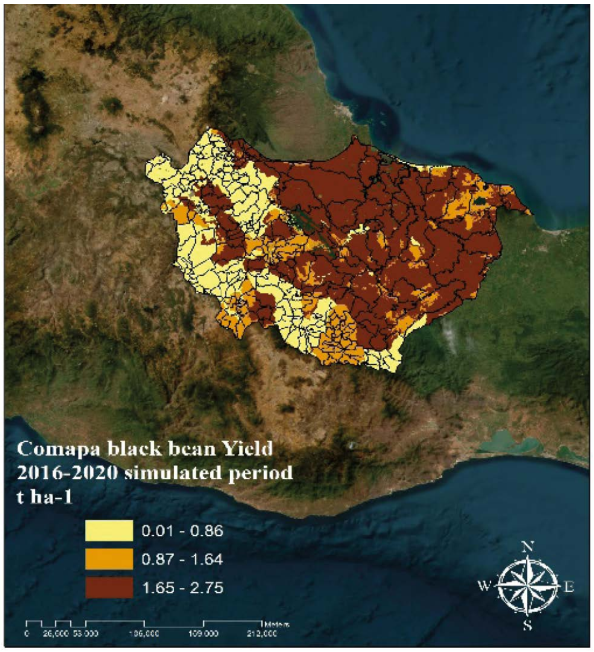

Figure 1. Simulation of the productive potential of Comapa black beans with the SWAT model in the Papaloapan Basin.

According to Figure 2, the analysis of variance of the RN variable showed a significant difference ($F_{1,\ 537}$=17.01; P=6.842e-08) in the three clusters.

In Figure 3, the analysis of the DE variable did not show a significant difference ($F_{1,\ 537}$=1.03; P=0.3564). For its part, Figure 4 shows that the DS variable showed a significant difference between clusters ($F_{1,\ 537}$=3.0397; P=0.04867).

The analysis of the variance of the DT variable showed a significant difference ($F_{1,\ 537}$=14.167; P=1.01e-06) in the three clusters. The behavior of the variable is shown in Figure 5. Finally, the DI variable showed values of F1, 537 = 11.96, and P = 8.284e-06, for which there was a significant difference between clusters. Figure 6 shows their analysis of variance.

Table 2. Yield of the Comapa black beans variety in municipalities of the Papaloapan Basin.

Municipalities of the Papaloapan basin	Cycle / year	Municipal average yield (kg ha^{-1}) field trial	average municipal yield (kg ha^{-1}) SWAT simulation	Field trial references
Isla, Veracruz	O-W 2009-10	2000	2200	López Salinas *et al.*, 2010 López Salinas *et al.*, 2012 López Salinas *et al.*, 2015 Tosquy Valle *et al.*, 2020
San Andrés Tuxtla, Ver.	O-W 2009-10 O-W/2011-12 O-W/2012-13	1649	1810	
Acayucan, Ver.	O-W/2011-12	1567	1810	Tosquy Valle *et al.*, 2020
Orizaba, Ver.	O-W/2011-12	1272	1255	Tosquy Valle *et al.*, 2020
Medellín, Ver.	O-W 2008-09	1292	1727	López Salinas *et al.*, 2010

O-I: Autumn-winter.

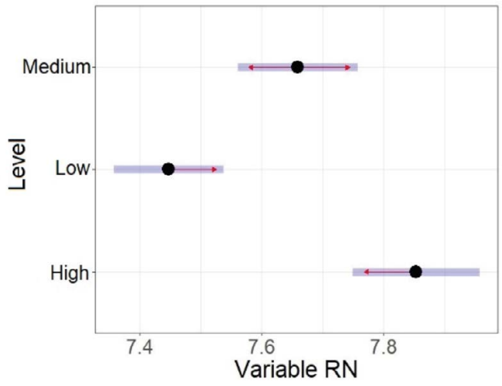

Figure 2. Behavior of the RN variable at the three cluster levels.

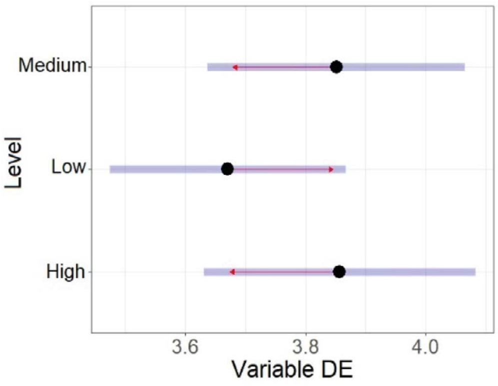

Figure 3. Behavior of the DE variable at the three cluster levels.

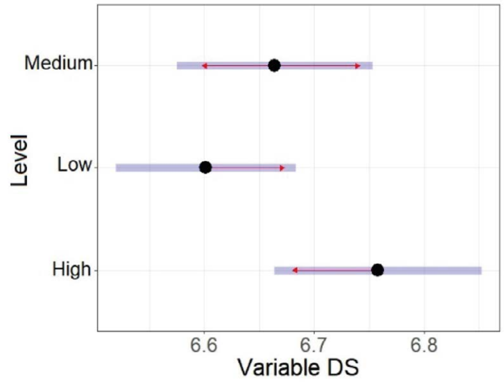

Figure 4. Behavior of the DS variable at the three cluster levels.

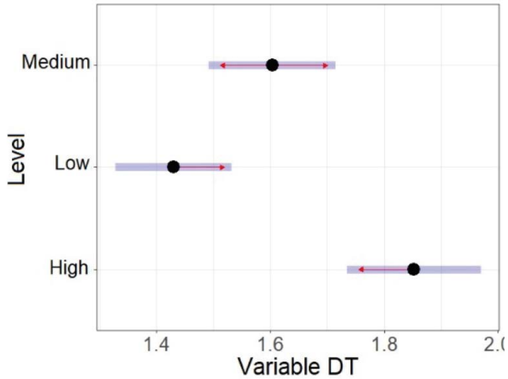

Figure 5. Behavior of the DT variable at the three cluster levels.

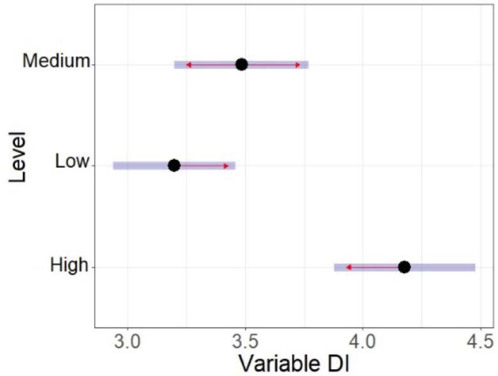

Figure 6. Behavior of the DI variable at the three cluster levels

CONCLUSIONS

The main differences between clusters lie in the DT and DI variables indicators since the DE and DS variables show no significant differences. The high and medium-yield clusters have an ideal suitability for the productive development of the bean crop. Regarding the level that makes up the low cluster, it is important to attend to the context of the indicators that the variables RN, DT, and DI entail.

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