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Simulation of blueberry production in Lambayeque, Peru: An agent-based approach

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Abstract: This study presents an agent-based simulation to analyze and optimize blueberry production in Lambayeque, Peru. Using data [1]and various academic sources, a model was developed on the NetLogo platform. This model simulates the interactions between climatic, agronomic and logistical factors that affect the production and export of blueberries. The results suggest that the implementation of advanced technologies and optimized agricultural practices can significantly improve the efficiency and competitiveness of Peruvian producers in the global market. Simulation offers a valuable tool for making informed decisions in the agro-export sector.

Keywords: *Agent-based simulation, Agricultural technology, Agroexport, Blueberry production, Lambayeque.*

1. Introduction

The blueberry supply chain in Peru is at a crucial stage of development, where the incorporation of good management and production practices is essential to increase the competitiveness of companies. Various studies have highlighted the importance of improving these practices to boost the long-term growth of small businesses in the sector. (Ramos, Espichan, Rodriguez, Lo, & Wu, 2018)emphasize the need to integrate and efficiently execute the blueberry supply chain in Peru to improve its competitiveness in the global market. In addition, (Escalante Yaulilahua, Olivera Recuay, Miranda Galván, & Venegas Rodríguez,, Sector Agroexportador Peruano: un Estudio de Competitividad de sus Principales Productos en el Período 2010-2019, 2023)they highlight that Peruvian agro-export products, such as blueberries, have shown a high level of specialization and competitiveness compared to other Latin American countries, particularly in the period before the pandemic and the energy crisis.

(Viera, Huanca, Trujillo, & Fernández, 2023)analyze the impact of green logistics as a strategy for agro-export companies in the Lambayeque region, Peru, concluding that the implementation of sustainable practices not only improves customer perception and the company's image, but also optimizes costs and increases profits. earnings. (Chaman-Cortez, Palomino-Encarnación, Perez-Paredes, Alvarez, & Raymundo-Ibañez, 2019)present a precision agriculture model that incorporates advanced technologies and management tools to improve the production of exportable blueberries, emphasizing the importance of adaptation to change and risk assessment in agricultural companies in the coastal regions of Peru.

Regarding blueberry production in the northern region of Peru, particularly in Lambayeque, it has experienced significant growth due to high international demand and favorable climatic conditions. According to the National Institute of Statistics and Informatics (INEI), blueberry production in 2022 reached 42,040 tons, with 59% of exports directed to the United States (Parraga-Arotinco, Cárdenas-Martinez, & Vilchez-Baca, 2023). This growth in blueberry production and export highlights the importance of implementing advanced technologies to improve efficiency and quality in post-harvest processing.

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One of the most relevant technological innovations in this context is the development of automated systems for the classification of blueberries. (Parraga-Arotinco, Cárdenas-Martinez, & Vilchez-Baca, 2023)have designed an automated system that classifies blueberries by size and degree of maturity, using tools such as Factory IO and TIA PORTAL connected to an S7-1200 PLC. This system not only allows for accurate sorting, but also improves operational efficiency, demonstrating the potential of automation in agribusiness.

Technological innovations, the dynamics of the international blueberry market have been the subject of detailed studies. (Soto-Caro, Wu, Xia, & Guan, 2023)investigated the impact of increasing blueberry imports on the US market, concluding that a significant increase in imports from Mexico could negatively affect domestic production in the United States. This analysis highlights the importance of understanding global market interactions to maintain the competitiveness of Peruvian producers.

Pollination is another critical factor for optimal blueberry production. (Ramírez-Mejía, y otros, 2024)identified optimal pollination thresholds that maximize fruit diameter, demonstrating that both deficiency and excess of pollination can affect fruit quality. These findings provide a basis for more precise pollination management, which can translate into significant improvements in blueberry yields and quality.

The ability of farmers to adapt to climate change and the livelihood strategies they employ are essential for the sustainability of agricultural production. (Lan, Song, Li, & Liu, 2023)investigated how different livelihood strategies affect farmers' sensitivity to climate change, highlighting that diversification, commercialization and ecological sustainability are key to mitigating associated risks.

(Montoya, María, Llatas, & del Pilar Pintado Damian, 2023)analyzes the survival of agro-export companies in the department of Lambayeque, Peru, during the period 2013-2022. The main objective is to understand the challenges that companies face when entering the international market. The findings reveal a high business mortality rate. Around 50% of companies leave the market during their first year, and only 4% manage to survive after 10 years and even more so at this time of the pandemic that affects many express producers .

This study proposes an agent-based simulation to analyze and optimize blueberry production in Lambayeque. Through this simulation, we seek to better understand the interactions between various factors that affect production and export, providing valuable information for farmers, exporters and policy makers. The implementation of these technologies and strategies can improve the competitiveness of Peruvian producers in the global market.

2. Method

2.1. Research Design

The research design was based on a quantitative approach (Dugheri, y otros, 2022), using data obtained (Moore Morey & Rogger O. , 2023)and other relevant academic articles. The methodology followed a structure that included data collection, analysis of this data, development of an agent-based simulation model, and model validation (Yakimenk, Zhertovskaja, Gorelova, & Pshenichnykh, 2018).

2.2. Investigation Procedure

2.2.1. Data Collection

2.2.1.1. Data Sources:

Lambayeque Export Statistical Bulletin (January-February 2023): Provided data on exported value, exported quantity, destination markets and companies exporting blueberries and other agricultural products.

Promperú and Infotrade: Provided additional data on foreign trade and export statistics.

Scientific Articles: Data on agricultural practices, climatic and logistical effects on the production and export of blueberries.

2.3. Specifications of the Data Collected

Climate: Temperature, precipitation and relative humidity.
Soil: Composition, water and nutrient retention capacity.

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Agronomic : Blueberry varieties, agricultural practices (irrigation, fertilization) and historical yields.
Logistics: Storage capacity, transportation routes, shipping times and costs.

2.4. Data Analysis

The analysis of the collected data involved the use of statistical and simulation tools to identify patterns and trends in the production and export of blueberries in Lambayeque (Flores, Aranibar-Molina, Palomino-Peralta, & Soto-Palomino, 2023).

2.5. Analysis Method

Descriptive Analysis: Identification of trends and patterns.
Regression and Correlation Analysis: To understand the relationships between climatic, agronomic and logistical variables.
Time Series Analysis: To predict future trends in production and export.

2.6. Modeling and Simulation

2.6.1. Definition of Agents

- **Blueberry Plants:** They represent individual production units that grow and develop depending on climatic conditions and agricultural practices.
- **Climate:** Daily variables that affect the growth and development of plants.
- **Soil: Dynamic** characteristics that influence water and nutrient retention.
- **Farmers:** Implement specific agricultural practices .
- **Climate:** Daily variables that affect the growth and development of plants.
- **Logistics:** Storage, transportation and export processes.

2.6.2. Daily Simulation

- **Climatic Conditions:** Update on temperature, precipitation and relative humidity.
  Formula for Evapotranspiration (ETc):

$$ET_c = ET_0 x\ K_c$$

Where:

- ET_c = *Crop evapotranspiration.*
- ET_0 = *Reference evapotranspiration.*
- K_c = *Crop coefficient.*

Formula for Soil Water Balance:

$$\Delta W = P - ET_c - D - R$$

Where:

- ΔW = *Change in soil water content.*
- P = *Precipitation*
- ET_c = *Crop evapotranspiration.*
- D = *Deep drainage.*
- R = *Surface runoff.*

- **Plant growth:** Evaluation of vegetative growth and fruit development based on climatic conditions and agricultural practices.

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$$P(t) = \frac{K}{1 + (\frac{k - P_o}{P_o})e^{-rt}}$$

Where:

- *P(t) = Blueberry production at time t.*
- *K = Load capacity (maximum possible production).*
- P_o *= Initial production.*
- *r = Growth rate.*
- *t = Time.*

- **Agricultural Practices :** Application of irrigation, fertilization and pest control according to the established calendar.

Formula for Soil Water Balance:

$$N(t) = N_o - (N_{aplicado} x\, F)$$

Where:

- $N(t)$ *= Level of nutrients in the soil at time t.*
- N_o *= Initial level of nutrients.*
- $N_{aplicado}$ *= Amount of nutrients applied.*
- F *= Fertilization efficiency.*

- **Production Monitoring:** Recording of daily fruit production and updating of soil resources.

Crop Yield Formula

$$Y = PxA$$

Where:

- Y *= Total crop yield.*
- P *= Production per unit area.*
- A *= Total cultivated area.*

-

Formula for harvest index

$$HI = \frac{W_f}{W_t}$$

Where:

- HI= Harvest index.
- Wf= Weight of harvested fruits.
- Wt= Total weight *of the plant biomass.*

2.6.3. Harvest and Logistics

- Harvesting blueberries on harvest days.
- Preparation for export, including storage and transportation.
- Evaluation of logistics times and costs, and registration of export data.

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2.6.4. Implementation in Netlogo

NetLogo platform , an agent-based simulation model was developed that represents the components and dynamics of the blueberry production system in Lambayeque (Walker & Johnson, 2019). This approach allows us to simulate interactions between different agents of complex agricultural systems (Aqib & Ukil, 2020), such as blueberry plants, climatic conditions, soil and management practices.

Initialization: Configuration of climatic agents, soils and plants with historical data and predictions.

Daily Cycle: Update of climatic variables, plant growth, application of agricultural practices, and logistics management.

Validation: Comparison of simulated results with real data, parameter adjustment, and evaluation under different scenarios.

2.7. Model Validation

The validation of the model was carried out by comparing the simulation results with data collected from 2023 on blueberry production and export in Lambayeque. Statistical techniques were used to verify the accuracy of the model and necessary adjustments were made to improve its reliability (González, Campano, & López, 2018). Comparisons were made between the results of the simulation model and the actual production data obtained from the region. Cross-validation techniques were used to ensure the robustness of the model (Echávarri, y otros, 2018).

Model calibration was carried out by adjusting the parameters until the model predictions agreed with the empirical observations. (Albayrak & Özdemir, 2018)

2.7.1. Soil Data

Data were collected on soil quality, composition and water retention capacity.

2.7.1.1. Agricultural Practices

Local agricultural practices, including irrigation, fertilization, and pest management, were documented through interviews with local producers and literature review.

2.7.1.2. Production Data

Recent blueberry production and export statistics were obtained (Moore Morey & Rogger O. , 2023).

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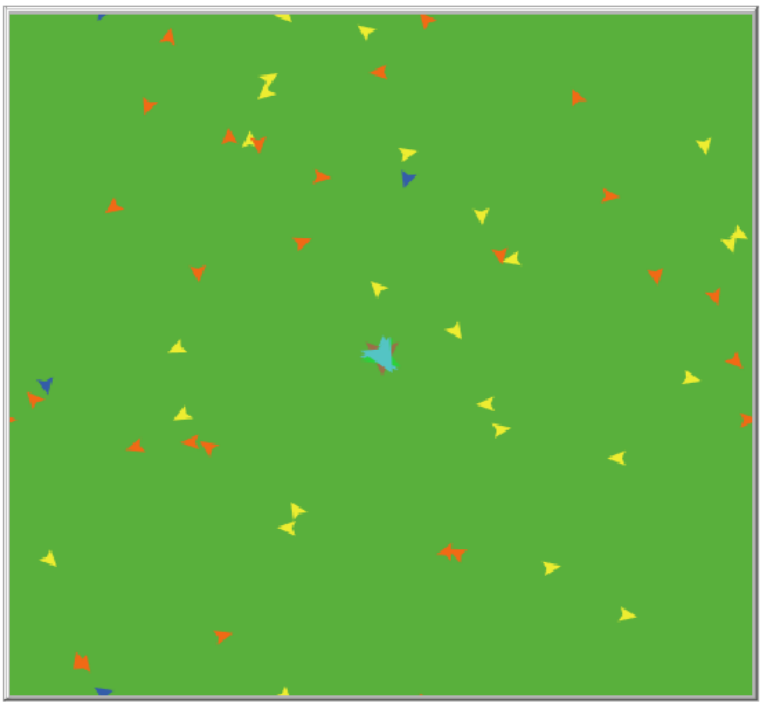

Figure 1.

3. Results and Discussion

- The blue dots represent blueberry plants in the initial stage of growth. This is the stage in which the plants are planted or transplanted and have not yet begun their significant vegetative development.
- The purple dots represent blueberry plants in the vegetative stage. At this stage, the plants are undergoing active growth of stems, leaves and roots, but have not yet reached the flowering stage.
- White dots represent blueberry plants in the flowering stage. At this stage, the plants have produced flowers and are ready for pollination and fruit development.
- The red dots represent blueberry plants in the fruiting stage. At this stage, the plants have been successfully pollinated and are producing fruit (blueberries).
- The yellow dots represent blueberry plants with low health. This can be caused by various factors, such as adverse environmental conditions (inappropriate temperature or precipitation), presence of pests or diseases, or lack of nutrients in the soil.
- The orange dots represent blueberry plants in critical or near-death health. These plants are experiencing significant decline and are likely to die if conditions do not improve.

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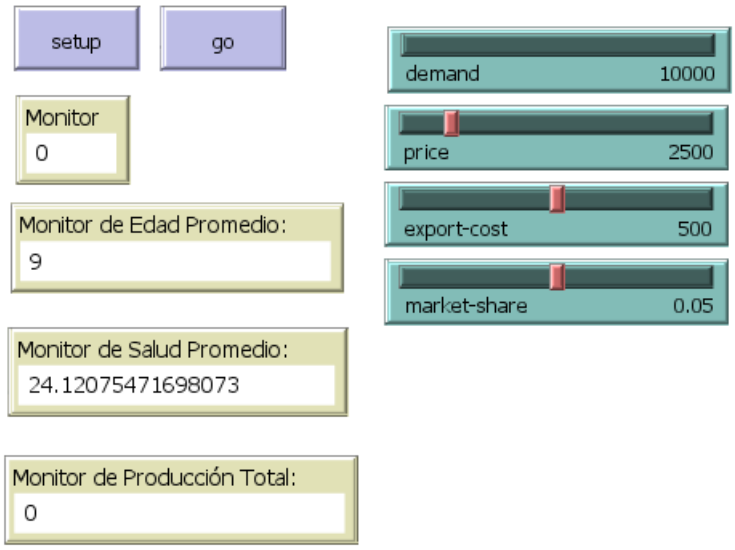

Figure 2.

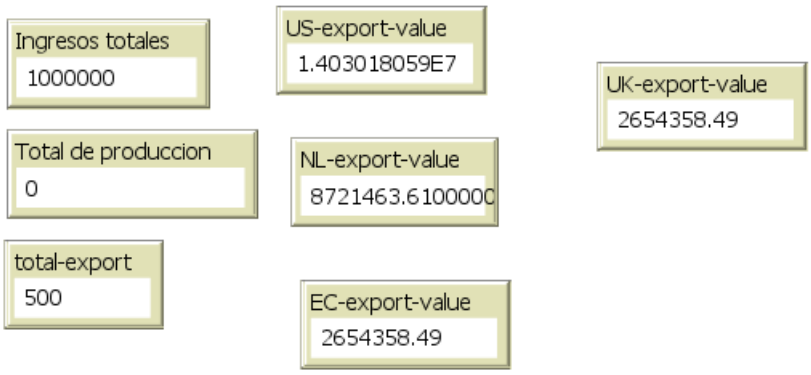

Figure 3.

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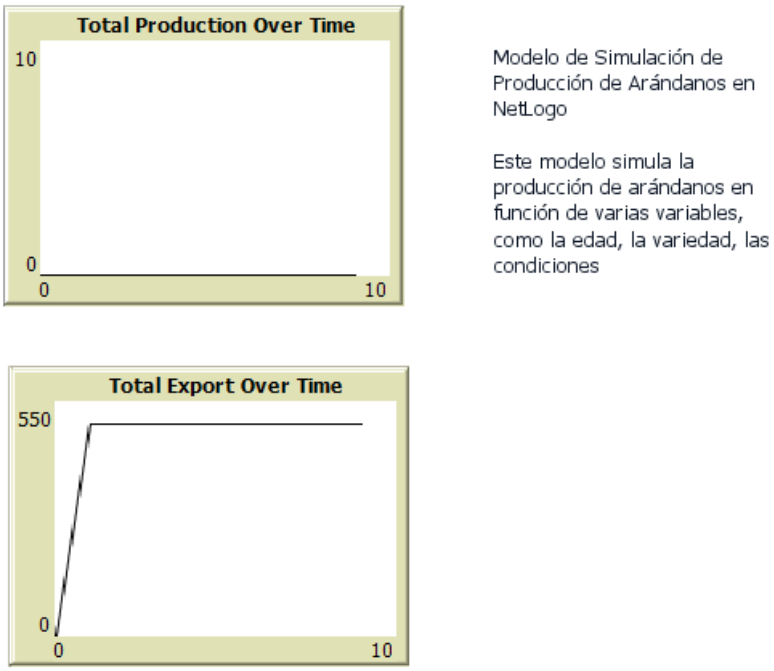

Figure 4.

3.1. Results

Production: The "Total Production Over Time" graph shows that total blueberry production increases over time, which is expected as blueberry plants mature and reach their fruiting stage as time passes.

Total Exports: The "Total Export " graph Over Time" shows a sudden increase in total exports, suggesting that once plants reach the fruiting stage, production goes largely to export. export - value ", "NL- export - value ", "UK- export - value " and "EC- export - value " monitors show the export values for each market according to market shares. established market. These values reflect the distribution of total exports between the different target markets. Plant Health: The "Average Health Monitor" monitor displays a numerical value that represents the average health of blueberry plants. This value can be used to evaluate the impact of environmental factors and pests on plant quality and, therefore, production.

3.2. Discussion

The simulation model captures several important aspects of blueberry cultivation and export, such as plant growth, production, environmental factors and market shares. The results suggest that production and exports increase over time, but also depend on plant health, which in turn is influenced by factors such as temperature, precipitation and pests.

One of the strengths of the model is its ability to simulate different scenarios by varying initial parameters, such as market shares, export prices and costs. This allows researchers and decision makers to explore different strategies and evaluate their impact on production and export earnings.

4. Conclusion

- The blueberry production simulation model in NetLogo provides a useful representation of the key processes involved in growing and exporting blueberries, including plant growth, production, environmental factors and market shares.

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- Model results suggest that blueberry production and exports increase over time, but are influenced by plant health, which in turn depends on factors such as temperature, precipitation and pests.
- The model allows exploring different scenarios by varying the initial parameters, which can be valuable to evaluate strategies and make informed decisions in the blueberry production and export sector.
- While the model provides a useful overview, it is important to note its limitations and consider incorporating additional factors to obtain a more complete and accurate representation of reality.
- The results and conclusions of the model can be used as a basis for future research, policy development or decision-making in the blueberry production and export sector, as long as its limitations are considered and complemented with other approaches and sources of information.

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