

Impact of Climatic Factors on Coffee Growth

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Abstract: Nowadays, technology is evolving, in various sectors which have seen the need to adopt technologies that help them make decisions and streamline processes by developing tools that are capable of analyzing data for decision making. Therefore, the research had the purpose of developing software that allows predicting the growth of coffee plants taking into account environmental factors such as temperature, height, humidity and wind, and in this way be able to determine if any of these factors affected in any way the development of the plant. The system used data collected through weather stations and sensors strategically placed on the plantations, the data was processed using data analytics techniques, such as machine learning and data mining, to identify patterns, trends and correlations. The system provided producers with an interactive tool to explore and understand environmental data that can affect crop growth. By implementing this analytics system, coffee producers will be able to make informed, data-driven decisions to better optimize plantations and adjust cultivation practices based on observed environmental conditions, implement risk mitigation measures, and maximize crop productivity, to improve the sustainability and profitability of coffee plantations.

Keywords: Machine Learning, Innovation, Innovation, Prediction, Profitability, Sustainability.

1. Introduction

Coffee producers around the world face various challenges in efficiently managing plantations, coping with climate risks (Koutouleas *et al.*, 2022; Jawo *et al.*, 2023), natural resource use, competitiveness in global markets, and sustainability of coffee production. Addressing this issue is critical to promote more sustainable agricultural practices, adapt to climate change, and improve the profitability and competitiveness of the global coffee industry.

At first glance the growth of a coffee plant is something simple, but it can be somewhat complicated since some plants tend to suffer some delay or some type of problem after different factors. It is not taken into account what influence can have the height, humidity and temperature in the growth of coffee plants, particularly in Ecuador, climatic changes can be a great disadvantage, therefore, this can make it difficult to make decisions for crop management, so it is necessary to frequently measure climatic parameters such as temperature, humidity, evaporation and precipitation (Hameed *et al.*, 2020; Blen *et al.*, 2022).

The analysis of the aforementioned parameters is key, given that environmental conditions

such as temperature and humidity affect coffee quality (Kath *et al.*, 2021; Leal and Tobon, 2021). Therefore, data analysis systems allow managers to monitor and analyze these factors to understand how they affect the quality of coffee produced. This allows the introduction of cultivation practices and processing technologies that improve the quality of the final product and the resulting market value.

In recent years, there have been significant advances in the use of information technology in all fields, including agriculture, education and health care. Data analytics has become one of the most important topics in any field because it allows studying all the necessary information represented as historical or real-time data, structured or unstructured, qualitative or quantitative (Saiz and Rovira, 2020; Sarker, 2021), can identify patterns and derive relevant insights to support informed decision making and, in some cases, even automate processes.

In addition, the results of the data analysis can be coupled with a web-based environmental data analysis system for decision making (Zhong *et al.*, 2021; Liu, 2023), where detailed information on environmental conditions in coffee plantations can be collected and analyzed. This will help farmers better understand the factors that affect the growth, health, and productivity of coffee plants. Access to this data allows them to make more accurate and strategic decisions to optimize crop yields and better organize plantations.

The data analysis system allows farmers to closely monitor and evaluate relevant environmental conditions to identify potential threats and take timely preventive measures, thus reducing costs and ensuring the long-term sustainability of coffee farms (Santana *et al.*, 2021; Dinh *et al.*, 2022), in addition to increasing profits for producers, consolidating the economies of the regions that revolve around coffee production, which historically has been one of the most important crops in Ecuador.

Therefore, we propose the implementation of a system that through the data previously collected can be useful to predict the growth of coffee plants. In order to improve the management of plantations, increase profitability and production, and also adopt a sustainable practice in coffee cultivation, which will be evaluated in a pilot farm in the canton of La Mana and that can be used as an example for its massification, to be used by local producers.

2. Materials and Methods

Description of the Software Used to Predict Coffee Plant Growth

The Scrum methodology has made it possible to address complex projects developed in dynamic and changing environments in a flexible way. It is based on partial and regular deliveries of the final product based on the value offered to customers. In other words: Scrum serves to improve collaborative work between teams, which is an ideal management option to undertake projects developed in complex environments that demand fast results and where flexibility is a prerequisite. Scrum offers agility and, as a result, always value. It is a methodology that helps teams to learn and organize themselves based on experiences while addressing problems and inviting reflection on successes and failures. All this under a series of tools and resources that allow teams to organize themselves with greater agility.

Characteristics of SCRUM Teams

Autonomous Teams: Scrum teams are intended to operate on the fly, with a unique order and dynamic that lacks hierarchy. These teams are considered self-organizing, exhibit autonomy, continuous growth and collaboration.

Overlapping development phases: Individuals on a Scrum team must work to synchronize their paces to meet deadlines. At some point in development, each individual's pace begins to overlap and synchronize with that of the others, and eventually a collective pace forms within the team.

Multiple learning: Scrum is a framework that relies heavily on trial and error. Scrum team members also aim to keep up with changing market conditions. That is why learning is fluid and rotates among different members of the organization.

Tracking without control: As mentioned, Scrum teams are self-organizing and operate like a small startup, but that doesn't mean there is no structure. By creating checkpoints throughout the project to analyze team interactions and progress, Scrum teams maintain control without hindering creativity.

Definition of Team Roles

The first step of the Scrum methodology is the definition of roles of the development team for which a format was established in order to detail the names, role, responsible and description below is detailed and in the second step according to the Scrum methodology, the user stories are established order to detail the needs of the beneficiaries where the story number, actor, description and importance are described.

Developer: Creates an accessible and well-structured database for storing and retrieving climate and plant growth data.

Farmer: who enters the daily climatic data to obtain predictions on the growth of my coffee plants and the most important of the system.

Researcher: analyzes historical and current climate and plant growth data to improve predictive models.

Plant manager: receives weekly reports on growth forecasts and recommendations to optimize farming practices.

Data analyst: visualizes trends and patterns in climate and growth data to identify critical factors affecting the performance of coffee plants.

Collection of data obtained from the software application

Through this research it was possible to collect data through the proposed survey, to later tabulate and analyze the needs of the Sacha Wiwa coffee plantation located in the parish of Guasaganda. Through field research, a visit to the Sacha Wiwa coffee plantations located in the parish under study was carried out to gather the requirements of the system to be implemented.

In addition, documentary research was used as a method to prepare the scientific-technical foundation, since it allows the selection of content from journals, books and reliable sources, thus guaranteeing adequate consultation of information related to the research project.

Analysis of the Collected Information

The use of the deductive method facilitated the understanding of the information management in the Sacha Wiwa coffee plantation, which allowed observing the need of having a web system of environmental data analytics for decision making, likewise the hypothetical deductive method was used, whose approach, the visit to the coffee plantation was achieved in order to eliminate any uncertainty related to the development of the web system of environmental data analytics for decision making.

Data Collection Techniques

The creation of a web-based environmental data analytics system for decision making in coffee plantations was proposed. In order to achieve a proper implementation, it is necessary

to obtain information to gather all the necessary requirements, through interviews with the people in charge of the coffee plantations. In this sense, we have the privilege to meet with the coffee plantation manager Sacha Wiwa and conduct an interview.

The interview was conducted with the director of the agronomy program of the La Maná extension, who was able to state that they are currently making agreements and strategic alliances with agricultural sectors and governmental entities to offer our students opportunities for professional practices in the field, as in the case of the Guasaganda parish, which is a coffee sector, where the development of a web system for the prediction of coffee growth is proposed, taking into account the impact that climatic factors can have on coffee plantations.

Survey

Information was obtained through the use of the survey technique, which consisted of the creation of a set of questions directed specifically to the inhabitants of the Guasaganda parish, who are dedicated to coffee production, whose results were compared through descriptive statistics, taking as a reference the average values of each of the items considered in the survey.

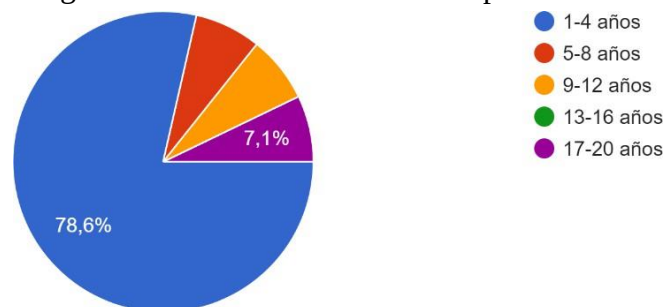
Data analysis

The data obtained from the surveys were tabulated and graphed, using Excel software, and average values were calculated to compare the opinion of the different respondents in order to evaluate the experience of the users in relation to the use of software to predict the growth of coffee plants.

3. Results

In order to know the opinion of the inhabitants of the Guarangada parish, we first asked how long the producers have been working in the coffee sector, to which 77% responded that they have less than 4 years and only 7.1% have been managing these systems for more than 17 years (Figure 1), which demonstrates their lack of experience in the management of this crop.

Figure 1. Time dedicated to coffee production.



Regarding the typology of producers, it can be observed that the majority of respondents 66.73% (Figure 2) have a high level of familiarity and comfort with the use of technology and online systems. This indicates that they are familiar and comfortable using technology and Internet-based systems in daily activities.

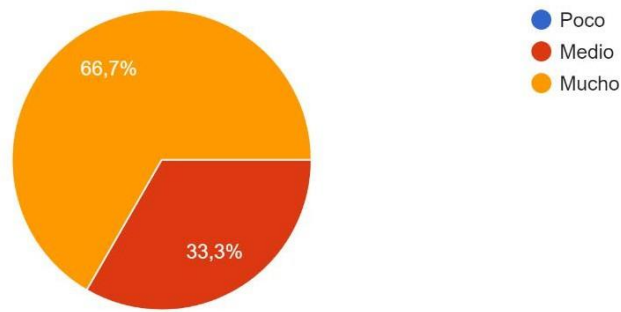
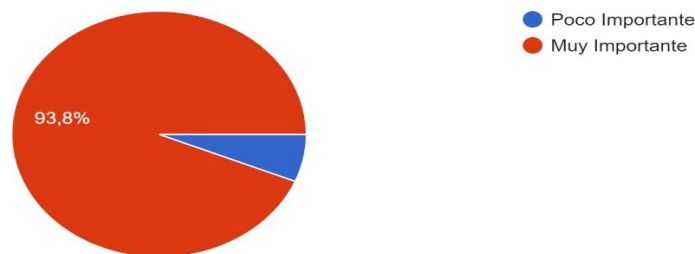


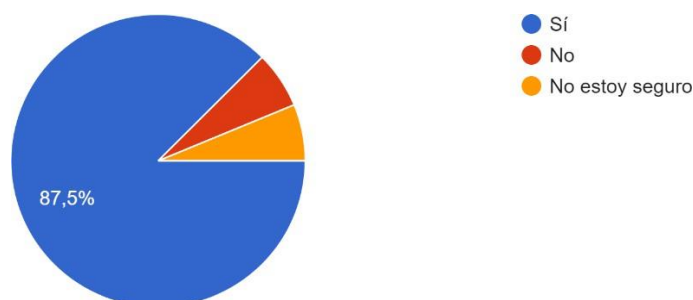
Figure 2. Familiarity with the use of technology in coffee production systems.

Another key factor is in relation to the importance that farmers attach to the use of technology in coffee production systems, the results shown in Figure 3 show that 93.6% consider the use of accurate data for coffee cultivation to be important, and this is understandable since most farmers are young and prefer to innovate.



Importance of the use of technology in coffee production systems.

The use of technology in coffee production systems as a key factor in decision making, according to 87.5% (Figure 4), is based on the fact that they consider that it is a good tactic to use the information that can be provided on climatic factors for the coffee sector and the benefits of the farmers themselves, for which access to the data that feeds the system is required.



Importance of access to data for predicting changes in climatic factors in coffee production systems.

The importance of knowing the changes in climatic factors is that according to 93.8% (Figure 5) believe that it is a good strategy to use precise information on climatic factors to improve production in the coffee sector, given that these elements are those that in a greater proportion condition the yields of this item,

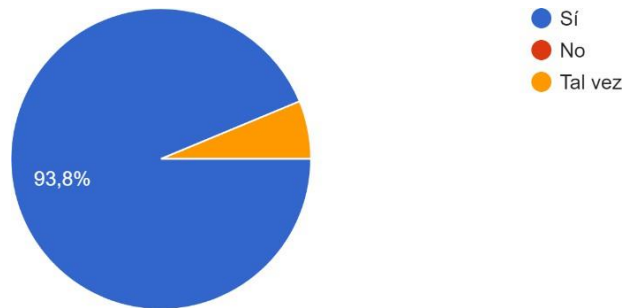


Figure 5 Importance of the prediction of changes in climatic factors in coffee production systems.

Regarding the most relevant aspects of the information generated by the software for decision making, the users in Figure 6 in order of importance indicate that the access to data in real time, the identification of patterns and trends, the analysis of growth data and the possibility of estimation, in addition to the intuitive visualizations of the data, are the most valued elements of the software.

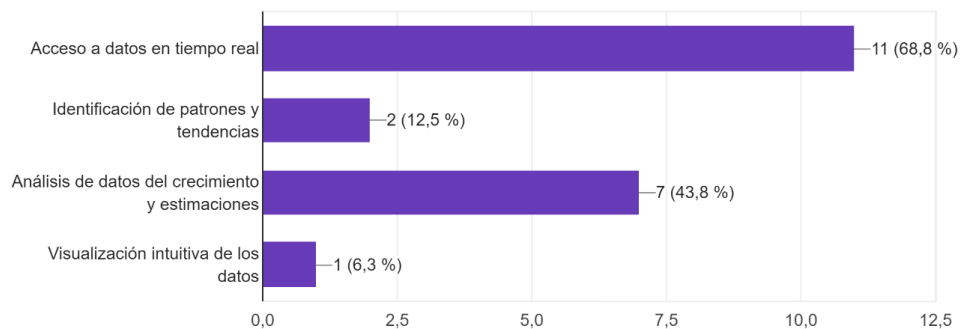


Figure 6. Aspects most valued by users after the implementation of software to predict the growth of coffee plants.

Regarding the challenges of users to optimize the implementation of a software to predict the growth of coffee plants, Figure 7 shows that the most important is to have an adequate technological infrastructure with 62.5%, followed by the privacy and security of the data used with 37.5% and the technical capacity to interpret and use the data generated.

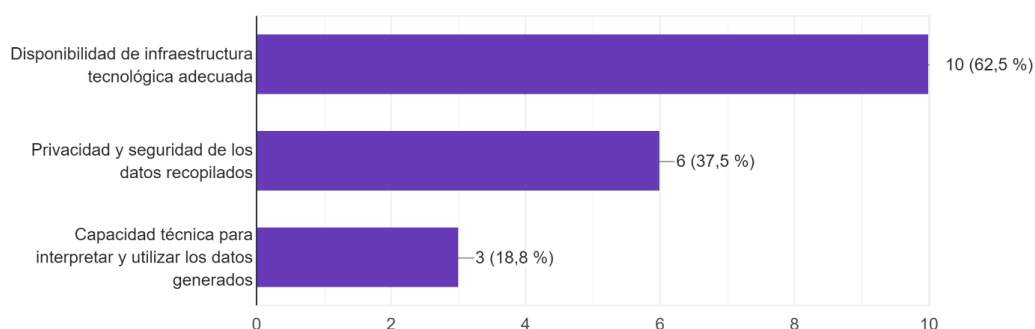
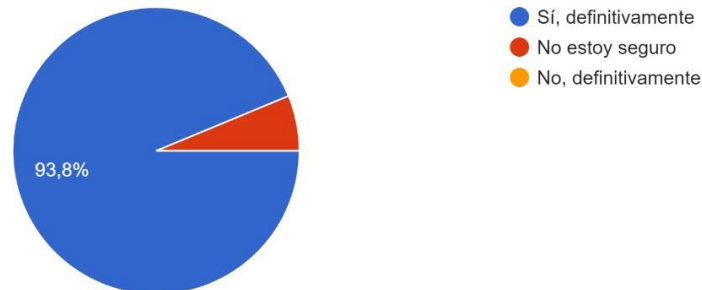


Figure 7. Challenges to optimize the implementation of software to predict the growth of coffee plants.

A very important aspect for the successful implementation of a software to predict the growth

of coffee plants is that 93% of the users are willing to use it through a web system to produce growth in coffee plantations, given that in spite of their little experience in the crop, they have the advantage of being young people who are quite familiar with the use of computer systems, as reflected in the data in Figure 8.

Figure 8. Farmers' willingness to use a software to predict coffee plant growth



The results reveal a positive assessment of the implementation of software to predict the growth of coffee plants that through the data previously collected can be useful to predict the growth of coffee plants. In order to improve plantation management, increase profitability and production, especially in farmers with little experience, but with a willingness to use technological tools that help in decision making, breaking the traditional scheme of conservative farmers with resistance to change.

4. Discussion

The implementation of a web-based system for the prediction of coffee plant growth in the Sacha Wiwa Guasaganda sector has an important technological impact since it allows the collection and analysis of data in real time (Rodriguez *et al.*, 2021; Silva *et al.*, 2023), informed decision making, resource optimization, early detection of problems and improvement of the productivity and quality of the plantations.

The social impact of the implementation of the web system in the Sacha Wiwa Guasaganda coffee plantations was evidenced, which is important to promote sustainable development (Hidalgo *et al.*, 2023; Rojas *et al.*, 2024), improve the quality of life of farmers, promote the transfer of knowledge and generate benefits for the community in general, which is key in regions where the local economy both at the level of primary production and agro-industry revolves around the production of coffee,

The implementation of a web-based growth prediction system in Sacha Wiwa Guasaganda coffee plantations has a positive environmental impact since it allows data analysis by providing information on climatic factors (Kittichotsawat *et al.*, 2022; Martello *et al.*, 2022). In addition, it helps to reduce waste and overexploitation of resources, which in turn can reduce the environmental impact of coffee plantations. It also allows continuous monitoring of soil quality and continuous analysis of plant growth. This helps to identify early problems and take measures to mitigate them.

Detailed and rigorous planning is critical to project success. This involves clearly defining the objectives, requirements and scope of the system, as well as identifying and mitigating potential risks and challenges from the outset. Proper planning establishes a solid foundation for development and helps to minimize problems and delays during the process, which should consider having an adequate technological infrastructure, ensuring the privacy and security of the data used and the technical capacity to interpret and use the data generated (Hajare *et al.* 2021; Thabit *et al.*, 2021).

To optimize the system and enhance the scope of decision making, the database should be expanded by incorporating data from a longer period to improve the robustness of the models,

through the use of more sophisticated sensors to obtain more detailed information on soil conditions (Hunt *et al.*, 2020), plant and microclimate, and the use of satellite images and drones to obtain large-scale information on crop condition (Souza *et al.*, 2022; Zanella *et al.*, 2024).

On the other hand, the models used for data generation should be refined by exploring deep learning systems to capture nonlinear relationships and more complex patterns in the data (Chang *et al.*, 2021; Tassis *et al.*, 2021), combining different prediction models to improve accuracy and robustness, and performing a more accurate calibration of the models using statistical techniques, using data sets that are at least 10 years old.

Finally, from the use of the software to predict the growth of coffee plants, it should be done in large scale trials for validation in other regions, in order to evaluate the applicability of the models developed in other coffee growing regions with different climatic and agronomic conditions, taking into consideration the cultural and socioeconomic differences of each region to adapt the tool to the specific needs of the farmers.

5. Conclusions

The implementation of this software has proven to be a valuable tool for coffee farmers by providing accurate predictions on plant growth based on climatic data and other relevant factors, optimizing agricultural practices, improving efficiency in the use of resources and increasing productivity. The results obtained in this research show that technology can be a strategic ally to face the challenges of climate change and guarantee the sustainability of the coffee sector in the region.

It is also worth considering the use of Geographic Information Systems (GIS) which offer numerous advantages in coffee production, helping to optimize all stages of coffee cultivation and management, including Land Analysis and Site Selection for more suitable production, Soil and Climate Mapping, Crop Monitoring, Resource Optimization, Harvest Planning, in the coffee production unit could use GIS to create detailed maps of their plots, analyzing factors such as slope and soil type to determine the best cultivation practices. Using drones equipped with multispectral cameras, GIS could provide real-time data on plant health, detecting areas affected by pests or nutritional deficiencies. This data would enable accurate decisions on pesticide and fertilizer use, optimizing resources and increasing productivity.

This study represents a first step towards the implementation of artificial intelligence technologies in precision agriculture. Although promising results were achieved, further research is needed to improve the accuracy of prediction models, incorporate new data and develop more sophisticated analysis tools. In the future, such solutions are expected to help transform the agricultural sector and ensure food security.

Creating a system is an iterative process that requires flexibility and adaptability. It is important to recognize that software development is rarely a linear process, and that changes and new ideas are likely to arise along the way. Through iterative development cycles and user feedback, the system can continually evolve and improve to meet the changing needs of the business and end users.

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