Revista Mexicana de Ciencias Agrícolas
DOI: https://doi.org/10.29312/remexca.v16i5.3760
Article

GIS for the management of phytosanitary problems of coffee in Sultepec

Alfredo Ruiz-Orta[1]
José Francisco Ramírez-Dávila[1,§]
Juan Campos-Alanís[2]
Francisco Gutiérrez-Rodríguez[1]
1 Facultad de Ciencias Agrícolas-Universidad Autónoma del Estado de México. Carretera Toluca-Ixtlahuaca km 15, El Cerrillo Piedras Blancas S/N, entronque a El Cerrillo, Toluca, Estado de México, México. CP. 50200. Tel. 722 2965518. (aruizo@uaemex.mx; fgrfca@hotmail.com).

2 Facultad de Geografía-Universidad Autónoma del Estado de México. Cerro de Coatepec s/n, Ciudad Universitaria, Toluca, Estado de México. CP. 50110. Tel. 722 2150255. (jcamposa@uaemex.mx).

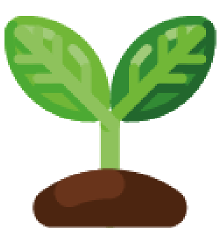
Autor para correspondencia: jframirezd@uaemex.mx.

Abstract

Geographic information systems, as well as thematic maps, are used in precision agriculture for the collection, analysis and representation of data of interest; to enable crop efficiency and minimize the costs and resources used for different activities, such as pest and disease monitoring. The research aimed to design a geographic information system for the sustainable management of phytosanitary problems of coffee in the municipality of Sultepec, State of Mexico. Databases were created and the QGIS 3.24 Tisler program was used to make 108 thematic maps that represent a monthly average of the incidence of rooster's eye, rust and iron spot in three sampled plots, in which the progress of each of the problems is observed during a year of sampling. These maps allowed us to identify well-marked sources of infection, as well as the months with the highest incidence, September to December for rooster's eye and iron spot, with an infected area of up to 86%, and for rust, the months with the highest incidence were from January to April, reaching an infected area of up to 82%. The thematic maps allow the dissemination of the usefulness of technologies and the development of the most timely and effective decision-making in the management and control of coffee pests and diseases, with the challenge of sustainable crop management.

Keywords:

agronomic potential, sustainable management, thematic maps.



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Introduction

Agriculture is a task that has accompanied man for thousands of years and its processes have evolved over time. Recently, private and public companies in the agricultural and industrial sectors have joined forces to design precision agriculture (PA) solutions, whose purpose is to improve crop yields, optimize the use of resources, reduce environmental impact, and facilitate strategic and economic decision-making (Silva *et al*., 2011; Orozco and Ramírez, 2016).

Geographic information systems (GIS) are used in PA for the collection, management, manipulation, analysis and representation of data and information of interest to achieve an understanding of the observed variation of soils, the possible association between plants and plantations, crop yield mapping, monitoring the appearance of pests or diseases, and the use of fertilizers. This makes it possible to increase crop efficiency and minimize the costs and resources used for these activities (Jiménez-Moya *et al*., 2016; Cantos *et al*., 2024).

Coffee is a traditional, basic, export and strategic crop; it is a source of jobs and foreign exchange for the country, as well as for the conservation of biodiversity; at the national level, it reaches a production of around 1 056 388.39 tonnes and a production value of $5 210 614.06 MXN. Its importance in the country's economy is a determining factor for the development of programs and support for the coffee-producing sector (CEDRSSA, 2019; SIAP, 2023).

Currently, coffee production faces phytosanitary threats, such as Iron spot (*Mycosphaerella coffeicola*), Rooster's eye (*Mycena citricolor*), and rust (*Hemileia vastatrix*), which affect the profitability of the crop and require the application of control measures. Coffee rust in particular is the main phytosanitary problem with a high impact on coffee farming; the economic impact of the disease is not only reflected in the reduction of the quantity and quality of production, but also in the need to implement costly control measures (CEDRSSA, 2019).

Therefore, this research aimed to design a GIS for the sustainable management of phytosanitary problems of coffee crops in the municipality of Sultepec in the State of Mexico, under the assumption that the integration of data in the environment of a GIS can favor timely decision-making in the management and control of such phytosanitary problems in the state.

Materials and methods

Study region

The research was conducted in the municipality of Sultepec, State of Mexico, located at 18°52' 00" north latitude and 99° 57' 00" west longitude south of the state, at an altitude of 2 290 masl for 12 months (September 2022-August 2023).

Sampling

Twenty-four samplings were carried out every fifteen days for three phytosanitary problems, Iron Spot (*Mycosphaerella coffeicola*), Rooster's Eye (*Mycena citricolor*) and Rust (*Hemileia vastatrix*), in three half-hectare plots, which were divided into 10 x 10 m quadrants, resulting in a total of 50 quadrants that were marked with ribbons and georeferenced with a differential global positioning system (DGPS) (model Trimble® SPS361, Trimble, Dayton, United States of America), selecting 4 plants per quadrant, resulting in a total of 200 plants per plot.

Each plant was divided by stratum (low, medium, and high), in which 12 leaves per stratum were counted, having a total of 36 leaves per plant, recording the number of leaves with the presence of each disease based on the guide of symptoms and damage of coffee from the phytosanitary epidemiological surveillance program of SENASICA (2024).

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GIS development

In the research, a GIS is created using Quantum GIS or QGIS version 3.24 Tisler (QGIS, 2023) as the main data processing tool, available for various operating systems and it enables the management of a wide variety of files from different sources. It also has connection support with the most internationally renowned geospatial databases and in turn allows the configuration of web services, maps of thematic information, and metadata in general (Shekhar and Xiong, 2017; Pérez-García *et al*., 2019). The databases were created and standardized in Excel format; they are introduced into QGIS and then the thematic maps are generated.

Results and discussion

Thirty-six thematic maps were created with monthly averages, which represent the incidence of rust, iron spot, and rooster's eye, obtaining 108 maps in total of the three plots sampled, which allowed visualizing the presence of disease infection. The maps obtained show that the problem populations are focused, with an increasing growth in infection.

Specifically for *H. vastatrix*, an increase in populations can be observed from January to April for the three plots sampled with notable infection points (Figures 1, 2 and 3). The aggregates can occur randomly within the experimental unit, as mentioned by Pérez-Constantino *et al*. (2024), in addition to the fact that this may be the result of the dissemination of the fungal spores by environmental factors, such as wind and rain, or human factors.

Figure 1. Monthly maps of rust (*Hemileia vastatrix*) incidence in plot 1 in Sultepec, State of Mexico.

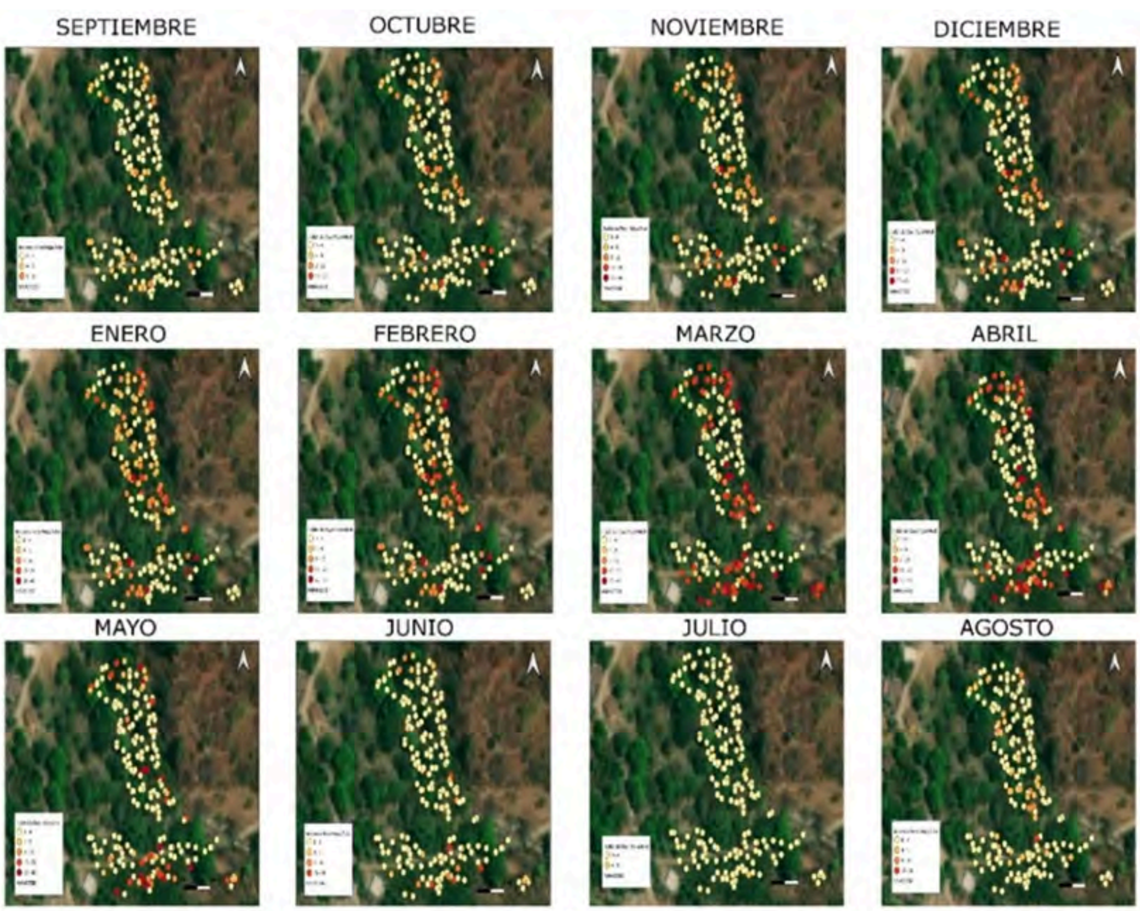

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Figure 2. Monthly maps of rust (*Hemileia vastatrix*) incidence for plot 2 in Sultepec, State of Mexico.

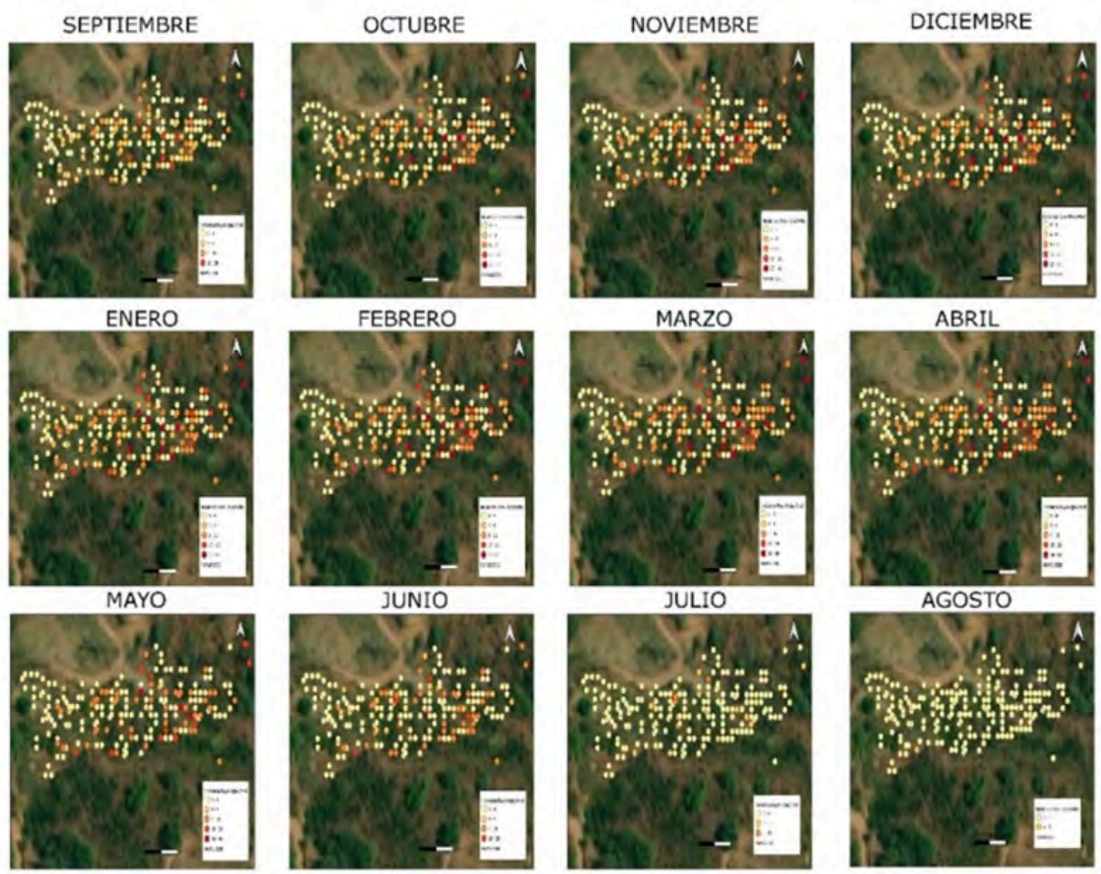

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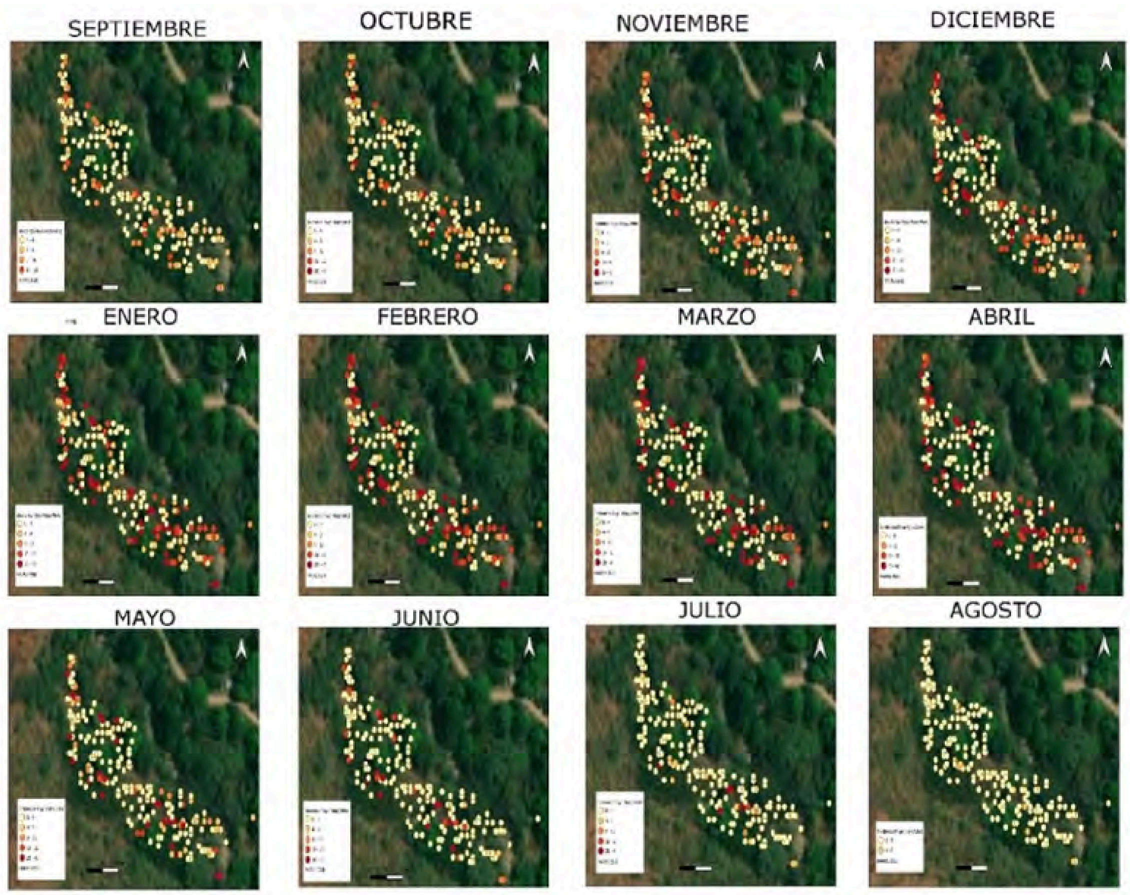
Figure 3. Monthly maps of rust (*Hemileia vastatrix*) incidence for plot 3 in Sultepec, State of Mexico.



Nevertheless, from June to August, it is observed that the incidence of the fungus decreased considerably in the three plots sampled possibly due to the fact that the precipitation washed away the rust spores and in turn transports the inoculum to the surrounding leaves and plants, as mentioned by Mora *et al*. (2015), who describe the development of the fungus in foci of infestation.

The combination of geospatial techniques and the creation of thematic maps revealed the progress of the incidence of *H. vastatrix* during the sampling period (Figures 1, 2 and 3), coinciding with what was mentioned by Bautista *et al*. (2018), who, by using thematic maps, were able to distinguish certain elements, such as forests, accurately to identify areas with agricultural coffee production potential in Veracruz. In addition, due to the cyclical nature of the pathogen, the intensity of damage may vary between plots within the same control region (Coria-Contreras *et al*., 2014; Pérez-Constantino *et al*., 2024).

These technologies have been developed and applied as a strategy for crop management and timely decision-making that helps determine the type of behavior and distribution of phytosanitary problems in crops (Lokers *et al*., 2016; Martínez-Martínez *et al*., 2023).

Figures 4, 5 and 6 show the incidence of rooster's eye (*Mycena citricolor*) for the sampled plots, with a percentage of infected area of 86% at the beginning of the study (September), decreasing during the following months, which indicates the decrease in rainfall and humidity; in turn, it was observed that, from January and February, it decreased to 70%, indicating the beginning of the drought season in the area, causing a decrease in the aggregation points of the disease in each of the plots (Pino *et al*., 2023).

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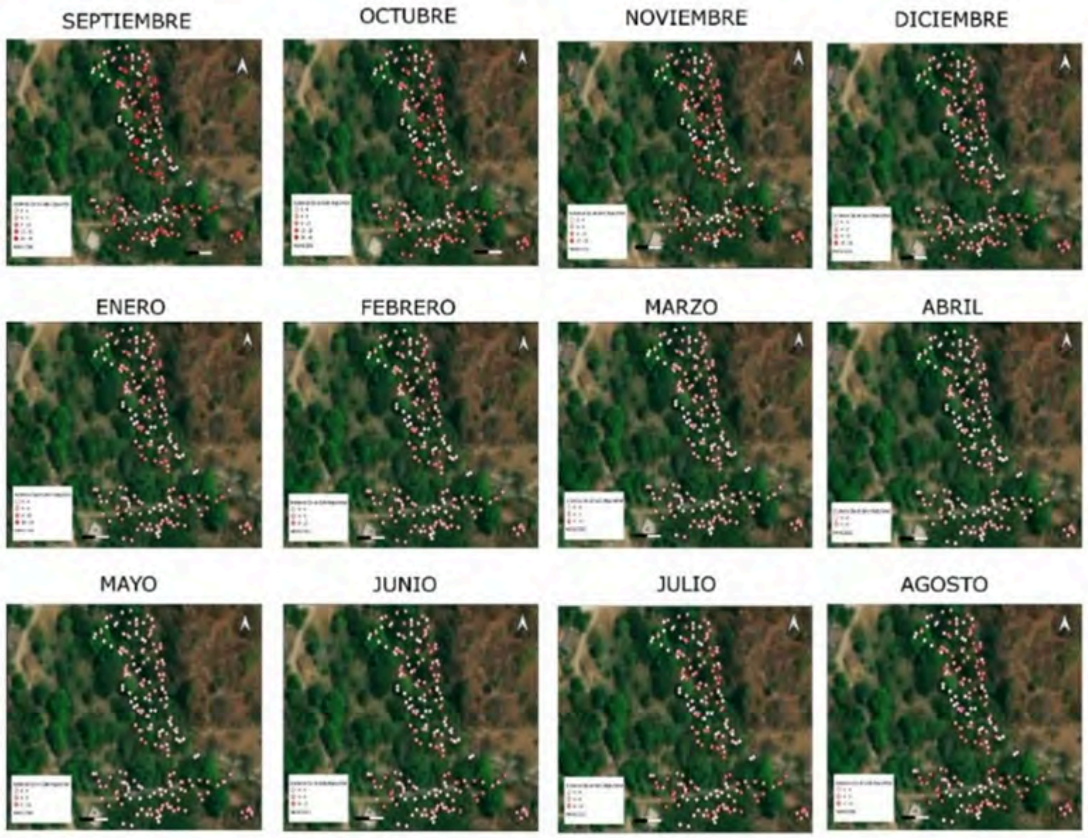
Figure 4. Monthly maps of rooster's eye (*Mycena citricolor*) incidence for plot 1 in Sultepec, State of Mexico.



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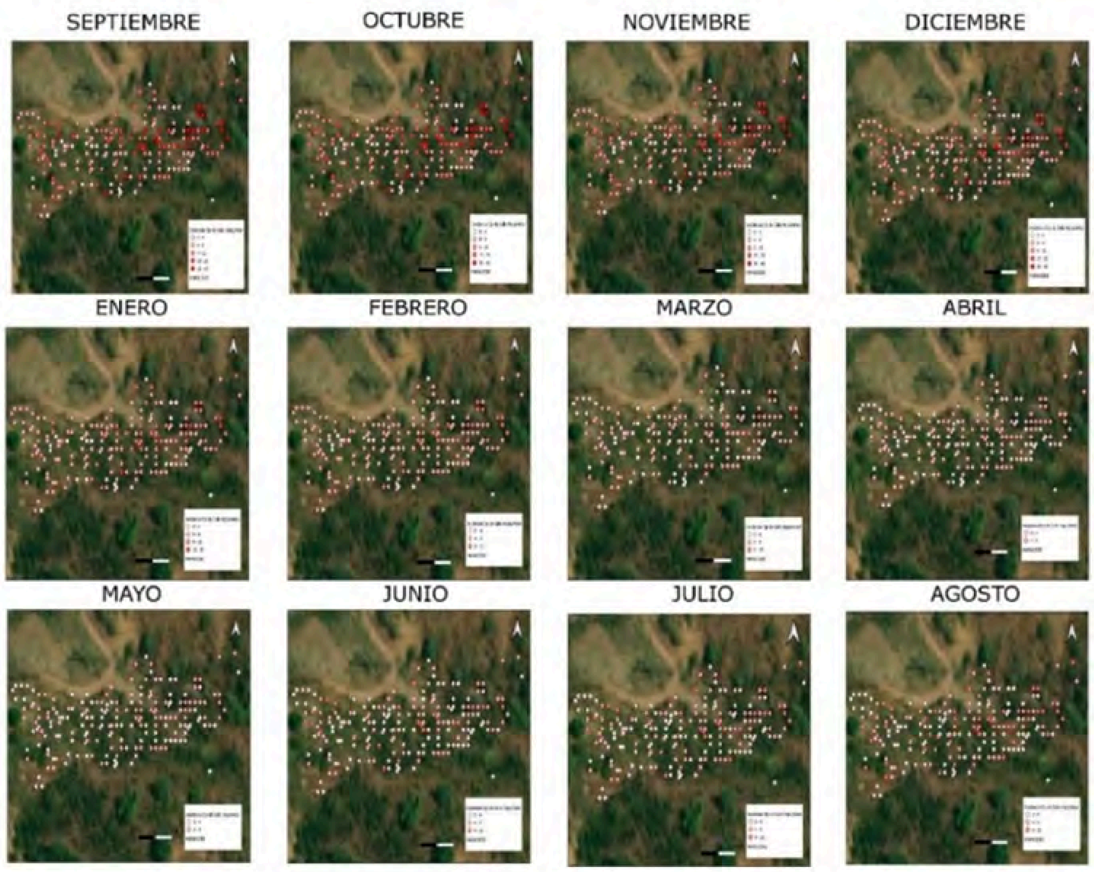
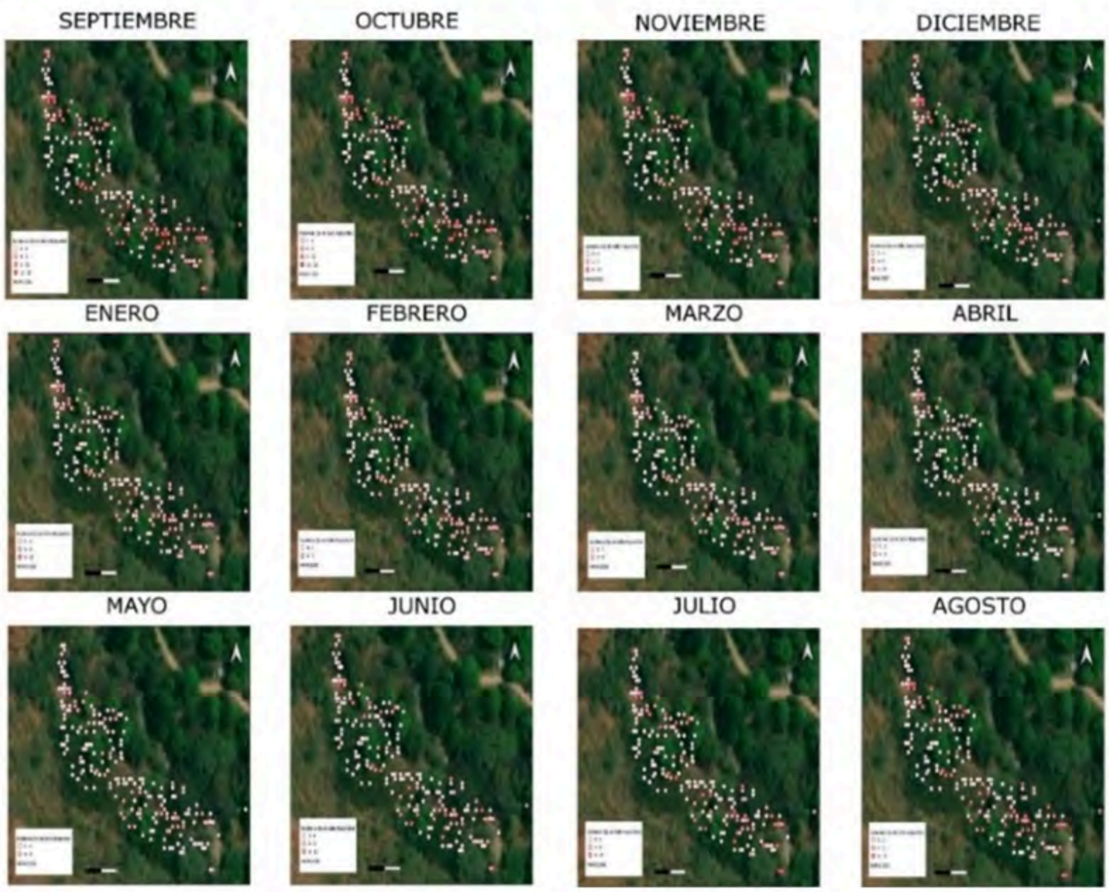
DOI: https://doi.org/10.29312/remexca.v16i5.3760

Figure 5. Monthly maps of rooster's eye (*Mycena citricolor*) incidence for plot 2 in Sultepec, State of Mexico.



DOI: https://doi.org/10.29312/remexca.v16i5.3760

Figure 6. Monthly maps of rooster's eye (*Mycena citricolor*) incidence for plot 3 in Sultepec, State of Mexico.



In their study, Figueroa-Figueroa *et al*. (2020) mentioned that the use of remote sensing systems is a viable option to identify the potential of agricultural crops with an economic impact in the State of Mexico, such as avocados and coffee.

In El Salvador, Choriego *et al*. (2023) detail that their 'AgroSIG' project in coffee and sugarcane made it possible to identify, through thematic maps, land use, slopes, vegetation, among others; that is, by knowing more accurately what customers have, it allows them to be trained in specific areas that have a more effective impact on their farms, which coincides with what was observed in the maps of this research. In addition, GISs allow creating models and predictions that help in risk assessment and management, which provides the opportunity to plan the management of plots and available resources (Figueroa *et al*., 2024).

For the maps of plots 2 and 3 (Figures 5 and 6), foci of infection of the disease were identified, which decreased from January and remained constant until June; this could allow producers to carry out a control aimed at areas of the plot where the focus of infection is located, coinciding with what was mentioned by Sosa-Escalona *et al*. (2017) in a province of Cuba, who created a GIS for the digital field identification, where the areas with the greatest threat of drought are forecast, so that farmers can plan their plantings around the driest periods of the year.

Figures 7, 8 and 9 show the thematic maps of the distribution and incidence of *Mycosphaerella coffeicola* in the three sampled plots; as in the previous phytosanitary problems, it is possible to observe the foci of infection of the disease well identified during the months of sampling. From September to December, there is a higher incidence with a percentage of 81% for plot 1, 57% for plot 2 and 64% for plot 3.

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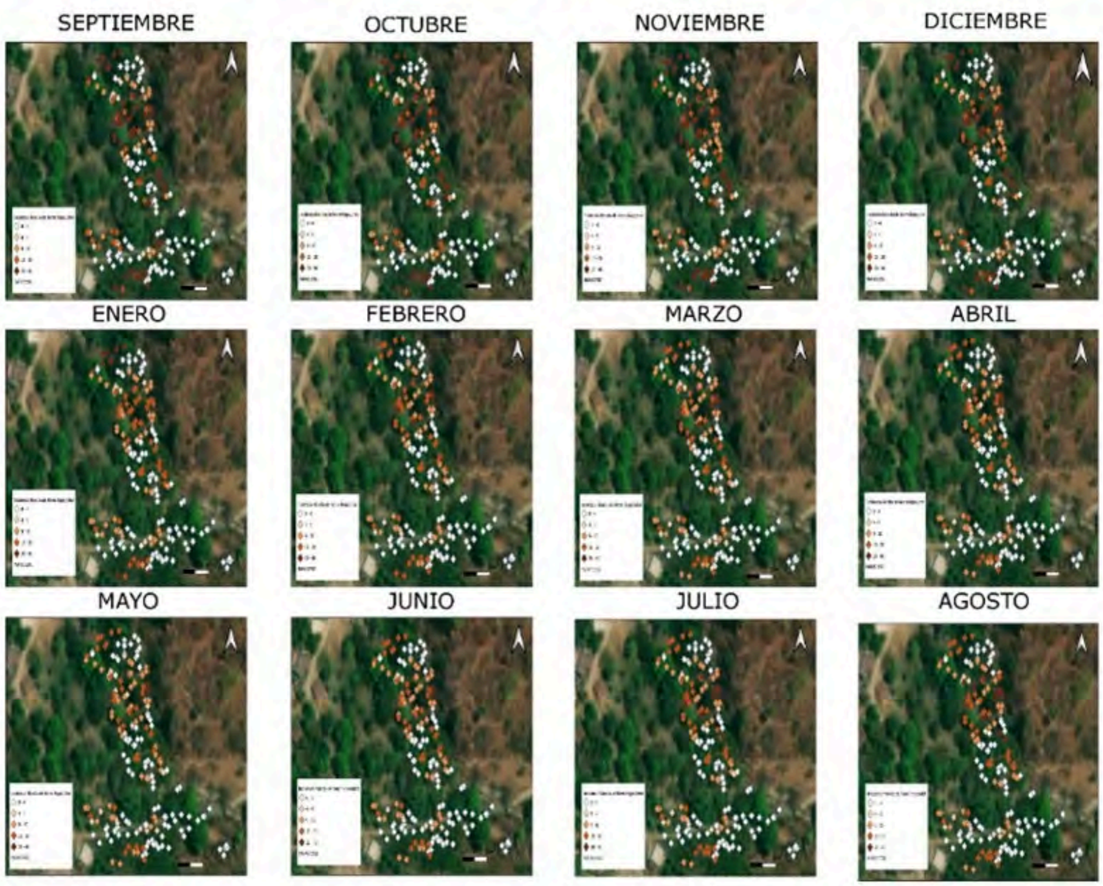
Figure 7. Monthly maps of iron spot (*Mycosphaerella coffeicola*) incidence for plot 1 in Sultepec, State of Mexico.



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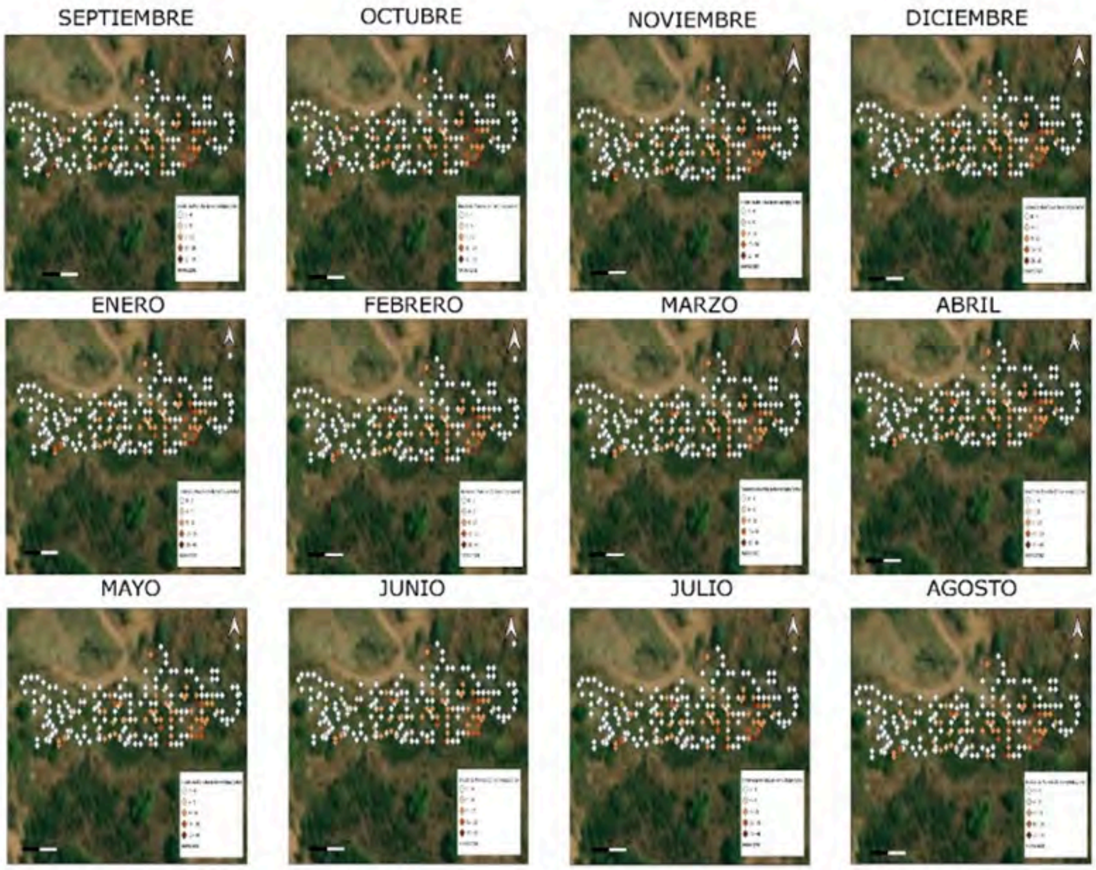
DOI: https://doi.org/10.29312/remexca.v16i5.3760

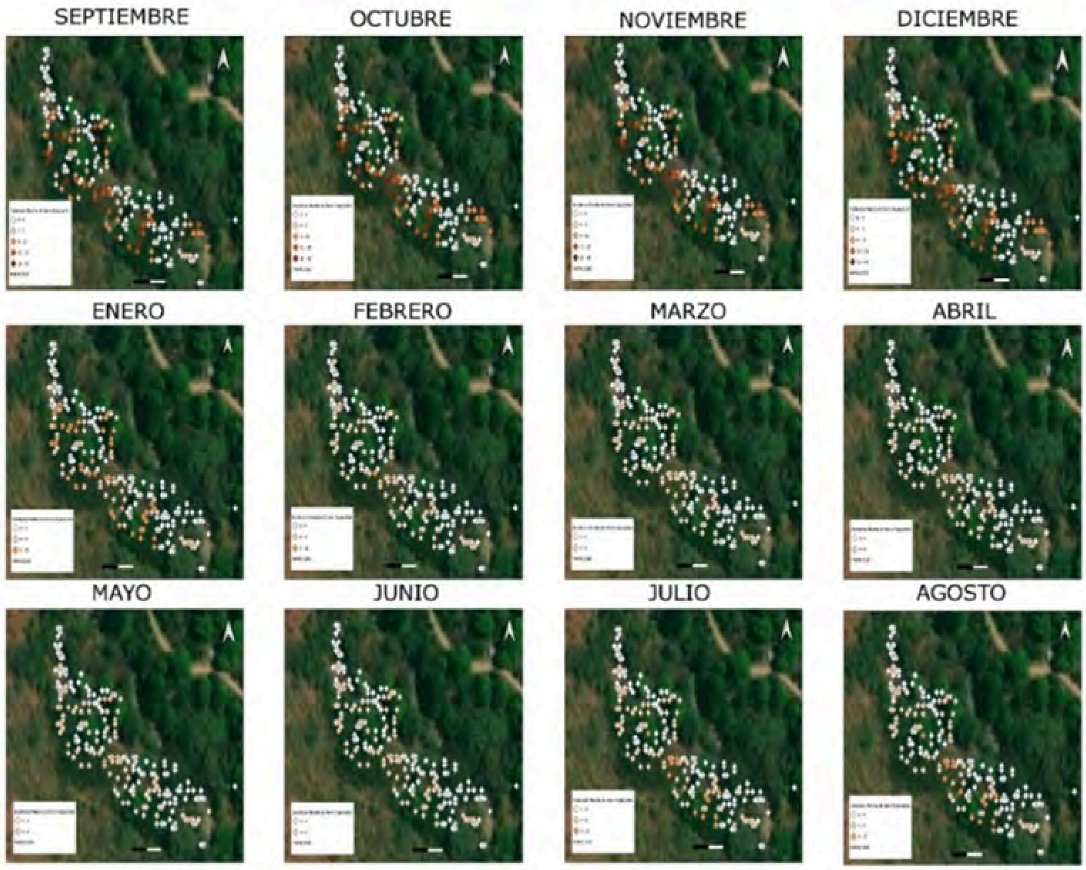
Figure 8. Monthly maps of iron spot (*Mycosphaerella coffeicola*) incidence for plot 2 in Sultepec, State of Mexico.



Revista Mexicana de Ciencias Agrícolas

DOI: https://doi.org/10.29312/remexca.v16i5.3760

Figure 9. Monthly maps of iron spot (*Mycosphaerella coffeicola*) incidence for plot 3 in Sultepec, State of Mexico.



According to Rea-Sánchez *et al*. (2015) in the treatment of aerial images and the generation of thematic maps, detailed areas are identified for real-time decision-making since it minimizes the response time to certain phenomena, such as the application of fertilizers and insecticides, to estimate, evaluate and understand these variations in order to predict crop production more accurately.

Goyes-Chávez *et al*. (2022) evaluated potential areas of coffee distribution centers in Colombia and show as results that geographical tools, such as GIS, multi-criteria methods, and geographical criteria, are adequate for the ideal location of coffee distribution centers; however, it is necessary to have detailed information on the areas to make decisions, such as resolving land use conflicts, interests of coffee-producing associations, among others, and thus improve competitive advantage, not only in coffee but in all agricultural sectors.

Conclusions

Georeferenced data are the primary and basic element to take advantage of a GIS; therefore, the creation of thematic maps of incidence of different pathogens in coffee plots allows the dissemination of the usefulness of technologies to specify the improvement of information exchange between farmers, extensive workers, researchers and to a certain extent, political decision-makers, which allows for more timely, specific and effective decision-making for the control of coffee pests and diseases, achieving sustainable crop management in the area.

DOI: https://doi.org/10.29312/remexca.v16i5.3760

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Journal Information
Journal ID (publisher-id): remexca
Title: Revista mexicana de ciencias agrícolas
Abbreviated Title: Rev. Mex. Cienc. Agríc
ISSN (print): 2007-0934
Publisher: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias

Article/Issue Information
Date received: 01 March 2025
Date accepted: 01 June 2025
Publication date: 12 August 2025
Publication date: Jul-Aug 2025
Volume: 16
Issue: 5
Electronic Location Identifier: e3760
DOI: 10.29312/remexca.v16i5.3760

Categories

Subject: Articles

Keywords:

Keywords:

agronomic potential

sustainable management

thematic maps

Counts

Figures: 9

Tables: 0

Equations: 0

References: 22

Pages: 0