Geotechnologies applied in the monitoring of mealybug in the black pepper cultivation in the South of Bahia

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Abstract:
The behavior of insect pests within the agricultural system represents a strategy for integrated pest management. The objective of this study was to evaluate the pattern of spatial and temporal distribution of mealybugs in black pepper crop with the use of applied geotechnologies. The study was conducted in an area of 26 hectares with black pepper cultivation, using a grid samples with 96 points. Notes were assigned according to the infestation of the mealybugs, with the presence, formation of colonies and/or dispersion in the plant. The data were grouped by season and submitted to the Lilliefors test at 5%. The ordinary kriging method was used for phytotechnical and orbital variables, and indicator kriging for infestation data. Drone images were used to calculate the aerial indexes and to obtain the leaf area of each plant. With satellite images, the vegetation index and surface temperature were obtained. Climatic data were associated with phytotechnical, spectral and monitoring variables, using principal component analysis, when it was found that cochineal infestation levels are directly associated with the summer season and with NDVI and GLI index with a correlation above of 0.90. It was observed that the insect presents random distribution. The spatial-temporal distribution of GLI and the maximum indices occur in the winter and spring seasons. From the probability of occurrence map, the spring and summer seasons presented more favorable conditions for the occurrence of mealybugs in the planting of black pepper.
Keywords: Spatial distribution, Pipericulture, Kriging, Vegetation index, *Piper nigrum*.

Geotecnologias aplicadas no monitoramento da cochonilha na cultura da pimenta-do-reino no Sul da Bahia

Resumo:
O comportamento de insetos-praga dentro do sistema agrícola representa uma estratégia para o manejo integrado de pragas. O objetivo deste trabalho foi avaliar o padrão de distribuição espacial e temporal de cochonilhas na cultura da pimenta-do-reino com o uso de geotecnologias aplicadas. O estudo foi conduzido em cultivo de pimenta-do-reino, em uma área de 26 hectares, utilizado um grid amostras com 96 pontos. Foram atribuídas notas de acordo com a infestação das cochonilhas, com a presença, formação de colônias e/ou dispersão na planta. Os dados foram agrupados por estação do ano e submetidos ao teste de Lilliefors a 5%. Utilizou-se o método de krigagem ordinária, para as variáveis fitotecnicas e orbitais, e krigagem indicadora para dados de infestação. Foram utilizadas imagens de drone para cálculos dos índices aéreo e para obtenção da área foliar de cada planta. Com as imagens de satélite, foram obtidos o índice de vegetação e a temperatura de superfície. Os dados climáticos foram associados com as variáveis fitotécnicas, espectrais e do monitoramento, utilizando análise de componentes principais, quando se verificou que os níveis de infestação da cochonilha estão diretamente associados com a estação do verão e com os índices NDVI e GLI com correlação acima de 0,90. Observou-se que o inseto apresenta distribuição aleatória. A distribuição espacial-temporal do GLI e as máximas dos índices ocorrem nas estações de inverno e primavera. A partir do mapa de probabilidade de ocorrência, as estações de primavera e verão apresentaram condições mais favoráveis para a ocorrência de cochonilhas no plantio de pimenta-do-reino.
Palavras-chave: Distribuição espacial, Pipericultura, Krigagem, Índice de vegetação, *Piper nigrum*.

Geotecnologías aplicadas en el seguimiento de la cochinilla en el cultivo de la pimienta negra en el Sul de Bahia

Resumen:
El comportamiento de las plagas de insectos dentro del sistema agrícola representa una estrategia para el manejo integrado de plagas. El objetivo de este trabajo fue evaluar el patrón de distribución espacial y temporal de cochinillas en el cultivo de pimienta negra con el uso de geotecnologías aplicadas. El estudio se realizó en cultivo de pimienta negra, en un área de 26 hectáreas, utilizando muestras de cuadrícula con 96 puntos. Las notas fueron asignadas de acuerdo con la infestación de las cochinillas, con la presencia, formación de colonias y/o dispersión en la planta. Los datos fueron agrupados por temporada y sometidos a la prueba de Lilliefors al 5%. Se utilizó el método de kriging ordinario para variables fitotécnicas y orbitales, y kriging indicador para datos de infestación. Se utilizaron imágenes de drones para calcular los índices aéreos y para obtener el área foliar de cada planta. Con imágenes satelitales se obtuvo el índice de vegetación y la temperatura superficial. Los datos climáticos se asociaron con variables fitotécnicas, espectrales y de monitoreo, utilizando análisis de componentes principales, cuando se encontró que los niveles de infestación de cochinilla están directamente asociados con la temporada de verano y con el índice NDVI y GLI con una correlación superior a 0,90. Se observó que el insecto presenta distribución aleatoria. La distribución espacio-temporal de GLI y los índices máximos ocurren en las estaciones de invierno y primavera. Del mapa de probabilidad de ocurrencia, las temporadas de primavera y verano presentaron condiciones más favorables para la aparición de cochinillas en la siembra de pimienta negra.
Palabras clave: Distribución especial, Pipericultura, Kriging, Índice de vegetación, *Piper nigrum*.

INTRODUCTION

The population behavior of insect pests within the agricultural system represents an important strategy in the development of integrated pest management (MIP) that aims to employ a set of techniques that aim to keep the population below the level of economic damage (GALLO *et al*., 2002). Through population monitoring, it is possible to identify the fluctuation and behavioral aspects of the insect, in view of the development of crops and the environment (GAZOLA *et al*., 2019), and determine the levels of damage and control.

Among the species of insect pests in agricultural production systems, mealybugs are characterized as pests of economic importance in several agricultural crops, such as pipericulture, as an example of the species of the genera *Dysmoccus* and *Pseudococcus*)(COCCO *et al*., 2020; FINCH *et al*., 2020). These insects, through sap sucking, toxin injection, as well as association with fungi (NEDUNCHEZHIYAN *et al*., 2011; OLIVEIRA *et al*., 2014), threaten the health of plants. In this sense, the knowledge of population trends, in the temporal and environmental aspects of this group of insects, helps in the successful management and reduction of losses (TELLI and YIĞIT, 2019), as it has been studied in grape crop (EL-GAYED *et al*., 2020), citrus (YAVUZ *et al*., 2021) and cassava (GAZOLA *et al*., 2019).

Efficiency in pest management requires timely identification and intervention that, through sampling, through traditional methods, assist in decision making, however, these resources are time-consuming and can present low accuracy (RANJAN and VINAYAK, 2020). The Geographic Information System (GIS) brought a new dimension to the IPM, seeking to optimize and aggregate the decision (RANO *et al*., 2022). Precision agriculture (PA) allows to know the spatial-temporal variability of several parameters that influence the productivity and health of crops, from the collection of data by sensors and platforms (PEDERSEN and LIND, 2017).

Precision agriculture techniques involve the collection and management of data and information, obtained by remote sensing, satellites or drones, and processed by information technologies (HUANG *et al*., 2018) that, in turn, support the implementation of precise and sustainable actions (RAJMIS *et al*., 2022). The management zones represent, in precision agriculture, subareas that require different practices in crop management based on the needs of insums, such as application of nutrients or insecticides (FULTON and PORT, 2018; FILHO *et al*., 2020). The precision agriculture has been applied to the IPM for several pests and crops, through artificial intelligence (TOSCANO-MIRANDA *et al*., 2022), studies on spatial distribution by interpolation methods, such as kriging (DUARTE *et al*., 2015) and spectral sensing (PRABHAKAR *et al*., 2013).

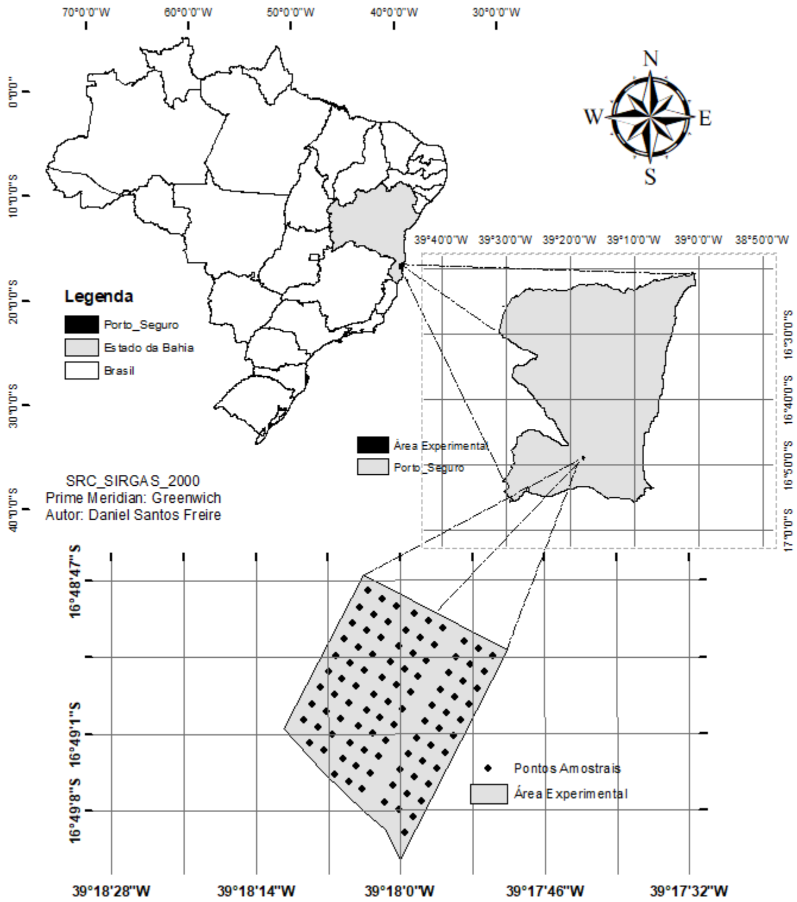
Agricultural technologies are still little widespread in the crop of black pepper (*Piper nigrum* L.), despite playing an important socioeconomic role in the world and in Brazil, because they have a consumer market demanding quality standards for bioproducts (DALAZEN *et al*., 2022). Studies on technologies and management of mealybugs in black pepper culture are scarce. Thus, this work aimed to evaluate the spatial and temporal distribution pattern of mealybugs and phytotechnical characteristics in black pepper culture with the use of applied geotechnologies.

MATERIALS AND METHODS

The study was conducted during the period from January 2021 to January 2022, in commercial cultivation of black pepper (*P. nigrum*), cv. Bragantina, , in the municipality of Porto Seguro, BA, extreme South of Bahia (16°49'7.52"S and 39°18'0.27"W, with 68 meters a.s.l.). The study area was 26 hectares, with climatic typology Köppen Af' of the Tropical type rainy forest without dry season and sandy soilconducted in drip irrigation system, in a spacing of 3.40 m x 1.80 m.

The experimental site was previously georeferenced and the data processed in GIS software, Quantum GIS 3.16, and a sample mesh was generated in a regular grid, with spacing between the sampling points of 50 meters, based on the planting line, totaling 96 points (Figure 1).

Figure 1. Location map of the experimental area and sampling mesh with distribution of georeferenced points.



Source: Authors.

The sampling protocol of mealybug species is nonexistent in the literature and, for this study, was developed based on qualitative evaluation, with attribution of notes, according to the pest infestation, observing the presence and formation of colonies or dispersion of mealybugs in the plant, being carried out monthly monitoring of three plants per sample point, totaling 288 plants, which were collected for subsequent taxonomic identification in the laboratory how *Protuvinaria longivalvata* and *Dysmicoccus gracilis.*

The assigned notes were based on the methodology of Nagrare *et al.* (2011) and adapted for pepper culture: 0 – Absence of mealybug; 1 - Dispersed mealybugs without colony formation; 2 - Grouped mealybugs with beginning of colony formation; 3 - Grouped mealybugs with colony formation less than 2 cm; 4 - Mealybugs grouped with colony formation greater than 2 cm and/or beginning of formation in the bunches; 5 – Infestation with distributed colonies and formation of colonies greater than 2 cm in the clusters and presence of fumagina.

The spatial-temporal distribution by season (summer 21, autumn 21, winter 21, spring 21 and summer 22) was obtained by studying the semivariogram and adjusted by the theoretical models, allowing estimating the coefficients of the semivariogram: nugget effect (C0); landing (C0+C); partial level (C); and range (a). After adjustment, data were interpolated using the ordinary kriging method for the attributes: GLI (Green Leaf Index), DPM (Dry Pepper Mass) and LF (Leaf area). For the probability of occurrence map, the indicator kriging was performed, based on the infestation data. The spatial dependence index was also calculated according to the evaluator proposed by Dalchiavon *et al*. (2012): C/(C0+C) x 100, in which a 20% ≤ ADE is considered, indicating spatial attribute with very low dependence; 20% < ADE ≤ 40%, attribute with low dependence; 40% < ADE ≤ 60%, attribute with medium dependency; 60% < ADE ≤ 80%, high dependency attribute; and ADE ≥ 80%, attribute with very high spatial dependence.

For remote aerial sensing, four flights were performed in the area, according to the seasons: summer 21, autumn 21, winter 21 and spring 21. The drone, model Phantom 4 Pro, equipped with RGB camera (Red, Green and Blue), obtained a GSD (Ground Sampling Distance) of 5 cm. The acquired images were processed in Pix4D software, and orthomosaics were generated.

To verify the spectral responses of plants under stress of cochineal attack, the maximum, average and minimum values of GLI (Green Leaf Index) indices were calculated for aerial and orbital images through the equation (2.Band Green – Band Red – Band Blue / .Band Green – Band Red – Band Blue); NDVI (Normalized Difference Vegetation Index) through the equation (Band NIR – Band Red / Band NIR + Band Red) and LST (Land Surface Temperature) on the Google Earth Engine platform, using landsat 8 satellite images. The leaf area attribute (LA) was acquired through orthomosaic processing and delimitation of the area of each plant in square meters (m^2).

The black pepper harvest was carried out in July 2021 and January 2022, when the fruits of three plants were harvested at each sampling point. The harvested grains were dried in a greenhouse for 7 days, at 70ºC, to obtain the parameters of dry mass of pepper in kg^{-1}.

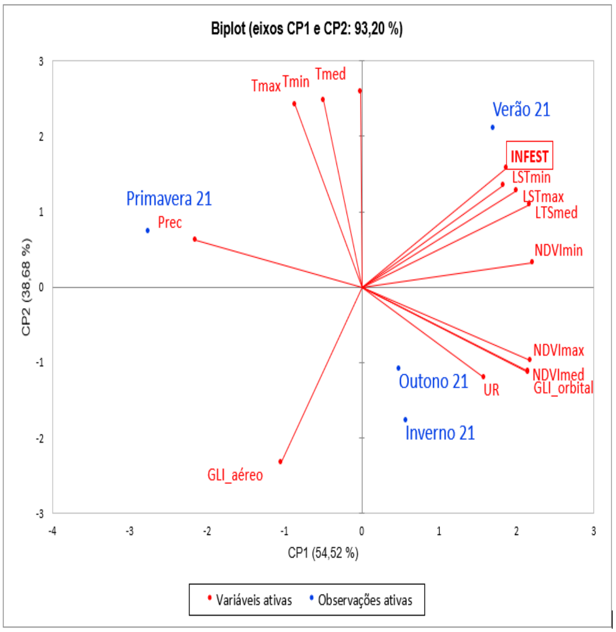
Climatic data of temperature (maximum, average and minimum) in degrees Celsius (ºC), relative humidity (%) and precipitation (mm) of the experimental area were obtained monthly through a weather station, model Davis Vantage Pro 2, installed in the property. Multivariate analysis of main components was performed, seeking to associate the climatic, phytotechnical, spectral and mealybug monitoring variables in XLSTAT software.

The acquired data were grouped according to the season (autumn, winter, spring, summer) and submitted to the Lilliefors normality test at 5% in SPSS Statistics software. Then, they were integrated into GIS environments, in ArcGis 10.6 software, and submitted to descriptive data analysis.

RESULTS AND DISCUSSION

In the principal component analysis, the first two CP1 and CP2 components were extracted, which are responsible for explaining 93.20% of the variability contained in the set of the 14 original variables, with individual contributions of 54.52% and 38.68% for the first (CP1) and second (CP2) components, respectively (Figure 2).

Figure 2. Analysis of main components in Black Pepper, according to the seasons.



Source: Authors.

Visualizing the projections represented by the variables and the position of the seasons in the quadrants, in the CP1 and CP2 axes, in the two-dimensional graph (Figure 2), it is evident that the levels of mealybug infestation are directly associated with the summer season. Rainfall, on the other hand, is directly correlated with the spring season in 2021, when it provided a reduction in infestation. The favorable environmental conditions in the summer with high temperatures and humidity favor the bioecological aspects of the mealybugs, however, when there are rainy periods and due to their low lomocation in the environment, the mealybugs are susceptible to mechanical damage from rainfall in their colonies.

Analyzing the two-dimensional plane, referring to the positive correlation of the variables and the main component - CP1, in order of importance and by the highest correlation coefficients (r-pearson), it is observed that the variables: minimum vegetation index - NDVImin (0.92), maximum vegetation index - NDVImax (0.91), average surface temperatures - LSTmed (0.91), orbital green leaf index- GLI_orbital (0.90), average vegetation index - NDVImed (0.90), maximum surface temperatures - LSTmax (0.84), cochineal infestation level-INFEST (0.78), minimum surface temperatures - LSTmin (0.77) and Relative Humidity (RH) (0.66) are directly associated (Table 1). On the other hand, rainfall and infestation index showed a negative correlation (-0.90), indicating that rainfall has a direct effect on the control of the cochineal population (Table 1).

Table 1 - Linear correlation coefficients (r-pearson) between the variables and the first two main components (CP1 and CP2) related to the seasons

Variables	Correlation coefficients - Pearson	
	CP1 (54,52%)*	CP2 (38,68%)
Minimum air temperature (Tmin)	-0,21	**0,95**
Maximum air temperature (Tmax)	-0,36	**0,93**
Average air temperature (Tmed)	-0,01	**0,99**
Relative Humidity (RH))	**0,66**	-0,46
Rainfall (Prec))	**-0,90**	0,24
Minimum Surface Temperature (LSTmin)	**0,77**	0,52
Maximum Surface Temperature (LSTmax)	**0,84**	0,49
Average Surface Temperature (LSTmed)	**0,91**	0,42
Minimum Vegetation Index (LSTmin)	**0,92**	0,13
Maximum Vegetation Index (LSTmax)	**0,91**	-0,37
Average Vegetation Index (LSTmed)	**0,90**	-0,43
Green Leaf Index - Orbital (GLI_orbital)	**0,90**	-0,44
Green Leaf - Aerial Index (GLI_aéreo)	-0,44	**-0,89**
Infestation Level (Infest)	**0,78**	**0,61**

Value referring to the percentage of variability of the original set of data retained by the respective main components. Bold correlations (>0.60 in absolute value) were considered in the interpretation of the main component.
Source: Authors.

The increase in surface temperature favors the development of the species, as well as the increase in LST can also promote, with a migration of mealybugs from the soil surface to the aerial part of the plant, as there is a strong correlation between infestation levels and vegetation (NDVI) and green leaf index (GLI-orbital). The increase of these indicators of vegetation vigor may be providing a microclimate effect and, consequently, the mealybugs migrate more easily to the area part of the plant.

Kumar *et al*. (2013), when studying the effects of temperature and relative humidity in the Phenacoccus solenopsis life table, found that the temperature of 35 ± 1 °C and 65% RH is the most favorable combination for optimal population growth. Chong *et al*. (2008), studying Maconellicoccus hirsutus, observed that the increase in temperature accelerated the development of females of *M. hirsutus* up to a maximum rate of 29°C. For the second main component, the temperatures: minimum - Tmin (0.95), maximum - Tmax (0.93) and mean (0.99), and infestation level (0.61) showed positive correlations (Table 1), with air temperatures (Tmin, Tmax and Tmed) associated with the level of infestation of the mealybug, in the spring and summer seasons, due to the location of the variables at the top of CP2 (Figure 2). The Green Leaf Index (GLI_aéreo) showed a negative correlation (-0.89) with CP2.

In the geostatistical analysis (Table 2), for each attribute a semivariogram was generated, and the best model that fit for most variables was Gaussian, except for infestation in the autumn season whose best model was exponential. According to Seidel and Oliveira (2014), the Gaussian model of semivariogram is the one with the greatest force of spatial dependence, evidencing that the data have a strong spatial dependence. The range of spatial dependence of the samples is an important information to assist in the definition of sampling. The maximum distance found between the attributes of remote sensing, GLI between stations, ranged from 168.16 to 266.64 meters. For the phytotechnical variables, leaf area (LA) and dry mass of black pepper (DPM), the maximum range was 143.38 meters. For infestation variables, a range variation of 86.31 to 352.87 meters is observed between seasons, suggesting that this insect may present different spatial arrangements of its distribution in the field, depending on the season and environmental conditions.

Table 2 - Estimated parameters for experimental semivariogram for spectral, phytotechnical and mealybug infestation variables in the culture of black pepper

Variable	Model	C0	C	C0+C	ADE	a (m)	Error mean
			Variable spectral				
GLI Autumn	Gaussiano	0,000	9,700	9,700	37,259	171,470	0,000
GLI Winter	Gaussiano	0,000	1,825	1,825	99,998	202,705	0,000
GLI Spring	Gaussiano	0,0003	0,0002	0,001	99,995	168,16	-0,00002
GLI Summer	Gaussiano	0,0002	0,0001	0,0003	33,33	266,64	0,0002
			Variable phytotecnic				
AF Autumn	Gaussiano	0,049	0,041	0,090	45,556	127,200	0,004
AF Winter	Gaussiano	0,059	0,072	0,131	55,172	108,840	-0,002
AF Spring	Gaussiano	0,026	0,068	0,094	72,340	90,520	-0,001
AF Verão	Gaussiano	0,052	0,053	0,105	50,429	112,010	-0,001
Summer	Gaussiano	0,1623	0,1617	0,324	49,907	143,38	0,0108
			Variable of infestation				
Infestation Autumn	Exponencial	0,250	0,001	0,251	0,398	86,306	-0,003
Infestation Winter	Gaussiano	0,242	0,010	0,252	3,968	352,870	-0,010
Infestation Spring	Gaussiano	0,218	0,022	0,240	9,167	97,105	-0,010
Infestation Summer	Gaussiano	0,240	0,011	0,251	4,382	104,850	-0,010

C0 - nugget, C - partial sill, C0+C - partial, a - range, ADE - Spatial dependence index
Source: Authors.

From the application of geostatistical methods, it is possible to reduce the number of samples due to the knowledge of maximum distance between attributes. In this study, the sampling grid was 50 meters between the points, allowing a detection of the spatial distribution of mealybug in black pepper, however, it can be optimized for a grid of up to 90 meters. According to Valeriano and Prado (2001), sampling can be performed with spacings lower than the maximum range found, without loss in sample representativeness, thus reducing costs and optimizing the monitoring operation.

Another important evaluation is the spatial dependence index, which represents the relationship of how much spatial dependence is, quantified by the semivariogram model, and contributes to data variability (PAZINI *et al.*, 2015). The variables of stational GLI presented an ADE from low to high spatial dependence by the methodology of Dalchiavon *et al.* (2012). The phytotechnical attributes of leaf area and dry mass pepper showed moderate spatial dependence. The mealybug infestation showed very low spatial dependence. In summary, the attributes GLI autumn and GLI summer and cochineal infestation did not present spatial dependence.

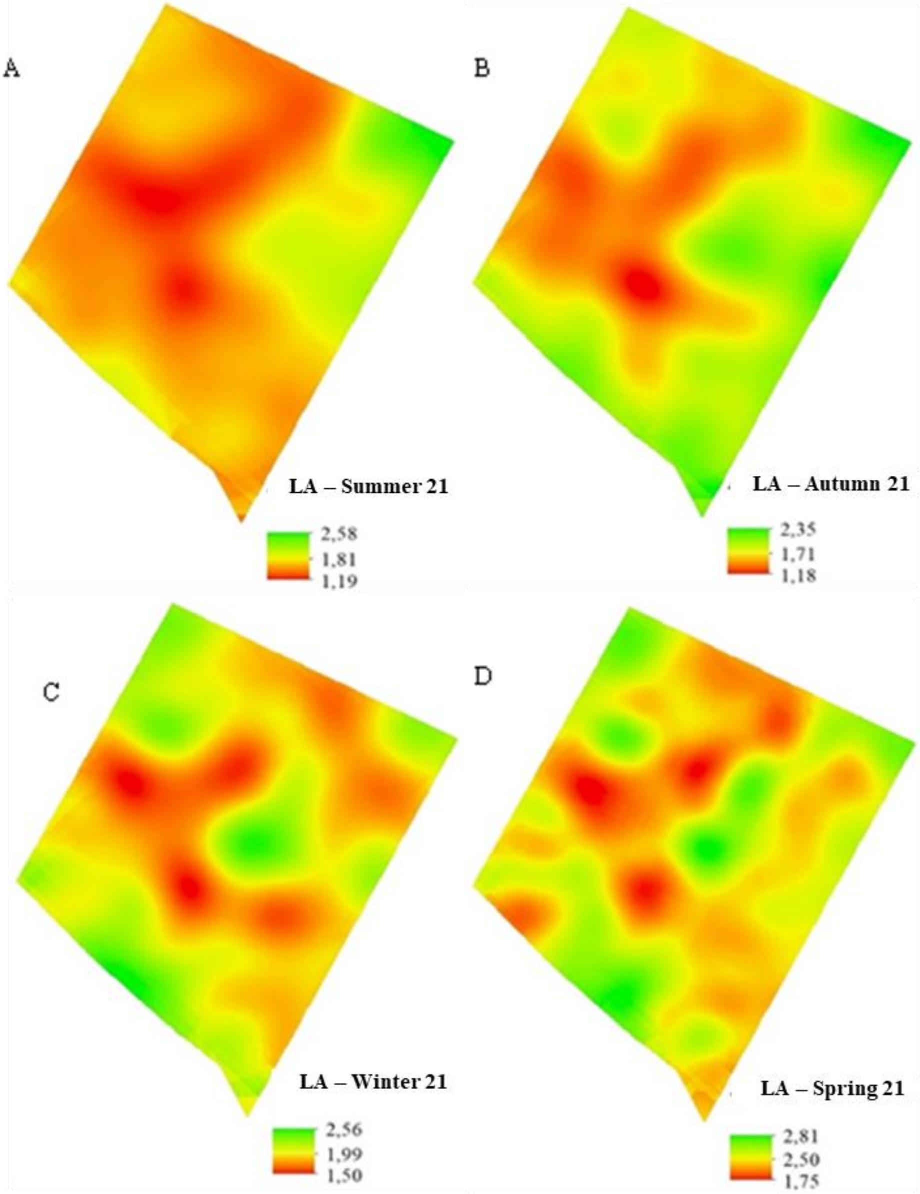
In the case of infestation of mealybugs *D. gracilis* and *P. longivalvata*, the low spatial dependence obtained by geostatistics indicates that the behavior of these insects may be random. In other studies with mealybugs, the spatial distribution pattern varied according to the insect species and host. Góngora-canul *et al.* (2018), when studying the spatial distribution of Paracoccus marginatus in jatropha, also identified a random dispersion pattern, however, Chellappan *et al.* (2013), when they also studied *P. marginatus*, observed that this species presented spatial distribution behaviors uniformly, aggregated and randomly, depending on the host and environment. Other studies conducted for other species of mealybugs, such as *Praelongorthezia praelonga* in citrus (GOUVEIA *et al.*, 2020) and *Pseudococcus viburni* in cotton (CANÁRIO *et al.*, 2016), showed an aggregate distribution.

The spatial distribution of insects is dependent on the quality of habitat and environmental conditions that influence the behavior of the insect (SILVA *et al.*, 2017), corroborating the correlations found for the species *D. gracilis* and *P. longivalvata* in black pepper.

Among the phytotechnical attributes, the leaf area represents an important evaluation parameter, since plants with greater leaf area have a larger surface of light interception, which may result in a higher photosynthetic rate (TAIZ *et al.*, 2017).

Some nondestructive methods have been validated in pipericulture to estimate leaf area for monitoring the development of varieties (PARTELLI *et al.*, 2007). From the geoprocessing of aerial images, it was possible to isolate the leaf area of each plant and understand the spatial-temporal dynamics (Figure 3). It was observed that the black pepper plants have different leaf area development for each season of the year, and in the autumn season, it observed a variation between 1.18 m² and 2.35 m²; in winter, a variation of 1.50 m² and a maximum of 2.56 m², reaching, in spring, the maximum of 2.81m². In the summer, there was a decrease in the leaf area of black pepper, with a variation of 1.19 m² to 2.58m², which may have been influenced by the reduction of rainfall and temperature increase, impacting the vigor of the plants.

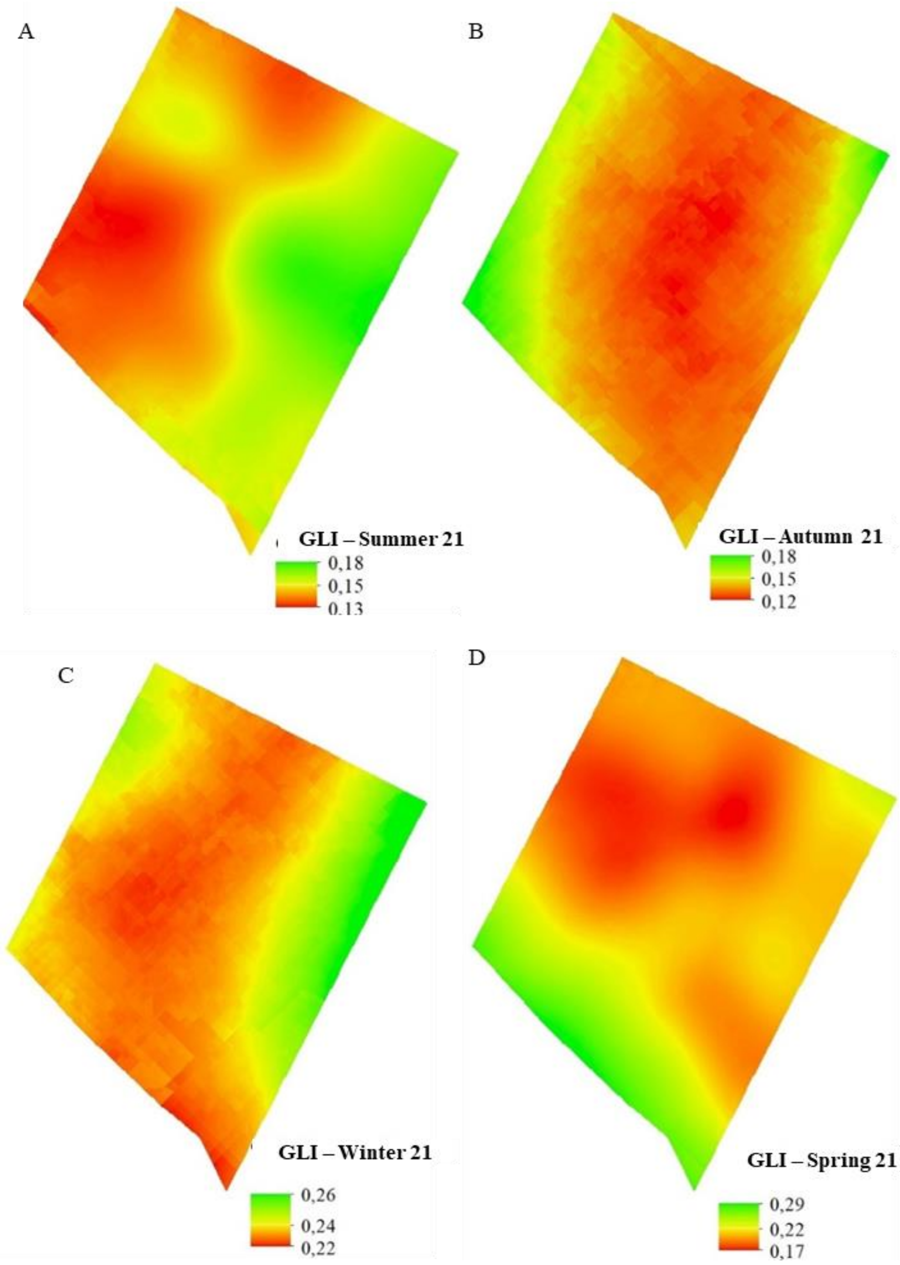
Figure 3. Thematic map of the spatial distribution of the leaf area of black pepper in different seasons



Source: Authors.

Compared to the spatial-temporal distribution of the spectral index (Figure 4), it is observed that the highest values occur in the winter and spring seasons (ranging from 0.22 to 0.26; 0.17 to 0.29, respectively), and the lowest values in the autumn and summer seasons (ranging from 0.12 to 0.18 and 0.13 to 0.18, respectively).

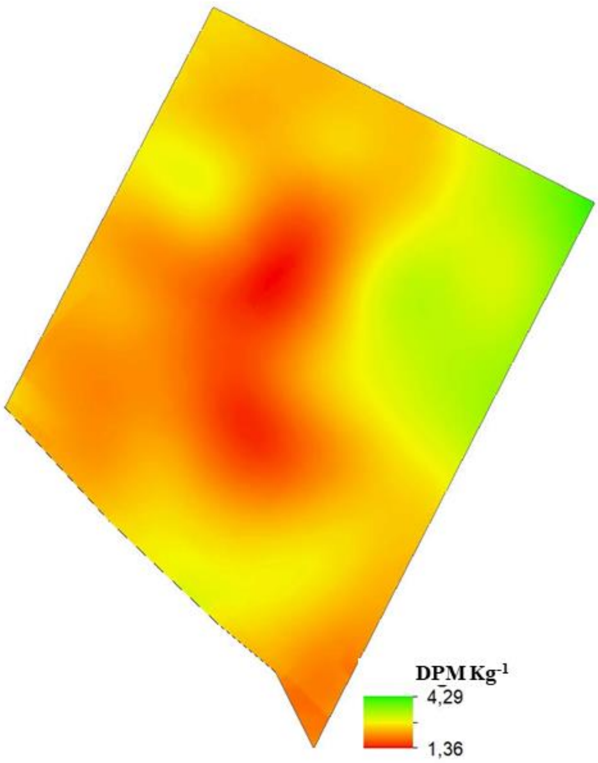
Figure 4. Thematic map of the spatial distribution of the spectral index GLI in black pepper, in different seasons.



Source: Authors.

After harvesting and drying the black pepper, the dry mass attribute of black pepper kg-1 was obtained (Figure 5). It was observed that the maximum dry mass was 4.29 kg and the minimum dry mass was 1.36 kg of dry black pepper/plant. It can be noted that the lowest values found for DPM occur in a zone at the center of the study area, which is the same region with low GLI index (Figure 4) and leaf area (Figure 3). The low productivity at the center may have been influenced by the characteristics of the rugged topography of the terrain, which differs from the marginal areas, evidencing a possible management zone to be introduced.

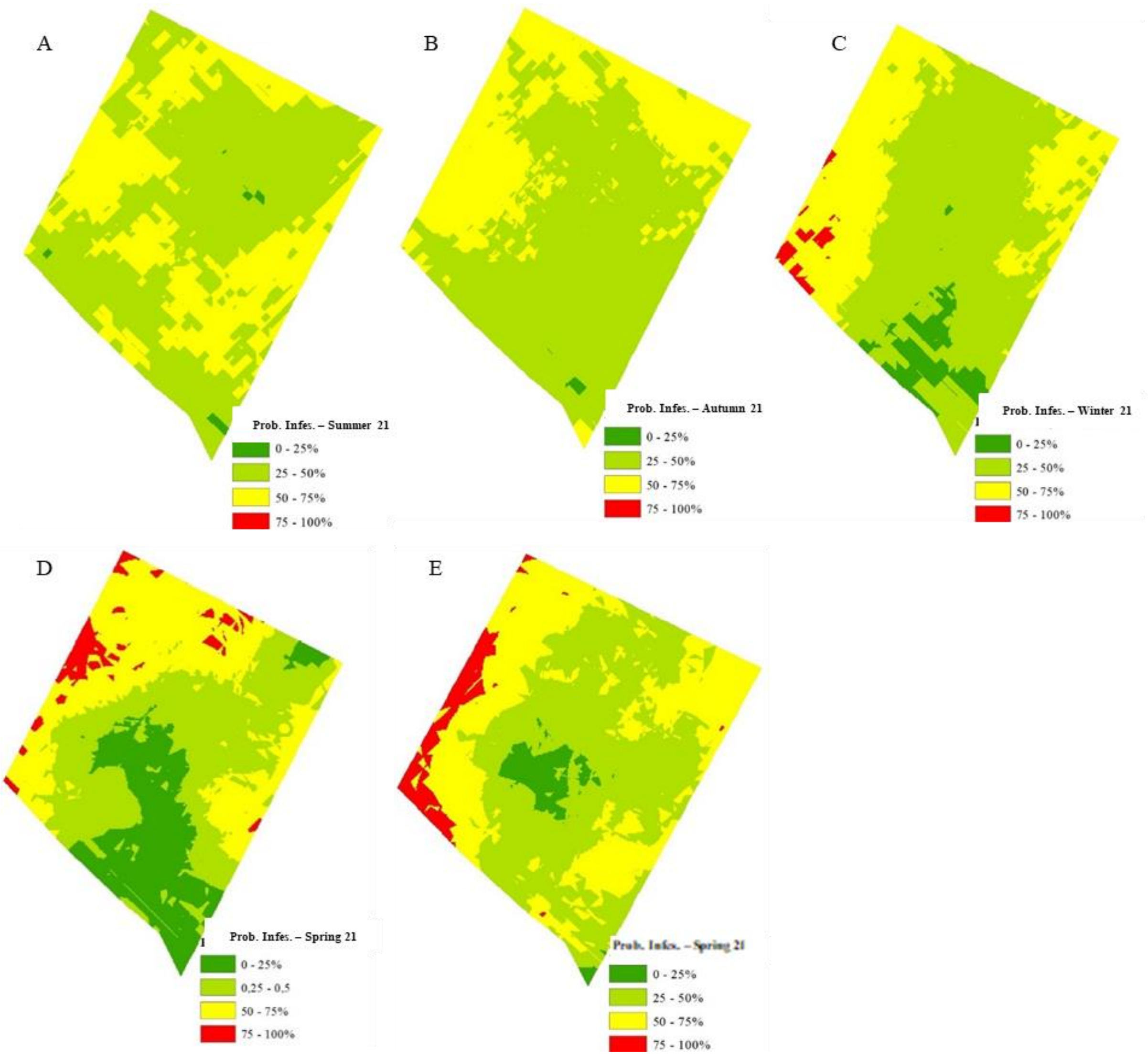
Figure 5 . Thematic map of the spatial distribution of the dry mass of black pepper in different seasons.



Source: Authors.

From the development of predictive distribution through indicator kriging, which allows mapping as a probability of exceeding a predetermined limit, it was observed that it was possible to identify the regions with probability of risks for the occurrence of mealybugs in a given season (Figure 6). In this case, it was found that, despite being likely to occur in different places, the behavior of higher occurrence is marginal in the area of pepper. This behavior may be related to the low movement capacity of female mealybugs, which is the easily visualized genus, because they do not have wings, different from males that are winged insects (ROSS and SHUKER, 2009).

Figure 6. Thematic map of the spatial distribuition of the probability of occurrence of mealybug in black pepper in different seasons.



Source: Authors.

The indicator kriging represents a tool that has been used in integrated pest management (BRENNER *et al*., 1998), making it possible to identify the zones of probabilities of occurrence (Table 3). From the maps modeled by the indicator kriging (Figure 6), it was observed that, during the summer seasons 2021 and autumn 2021, the model estimated that 61.84% and 65.63% of the area under study had low to moderate risk of infestation (<50%) and only 38.11% and 34.37% of the respective areas presented risks above 50%, indicating a possible directed management.

Table 3 - Zones of probability of occurrence of cochineals in the culture of black pepper, modeled by indicator kriging

	Occurrence probability zones (ha)			
	0 - 25%	26 - 50%	51 - 75%	76 - 100%
Summer 21	0,13	16,19	10,07	0,00
Autumn 21	0,06	17,28	9,05	0,00
Winter 21	1,60	16,00	8,42	0,38
Spring 21	5,95	10,19	9,20	1,07
Summer 22	1,23	13,71	10,12	1,35

Source: Authors.

Subsequently, in the winter seasons 21, spring 21 and summer 22, the mealybug gradually increased the presence in the study area, as well as the probability of occurrence, and the spring and summer seasons had the highest probabilities of occurrence in relation to the previous seasons, reaching a moderate to high risk area (>50%) of 38.89%, in the spring; and 43.43% in the summer. By mapping the displacement behavior and gradually increasing the occurrence of the presence of the cochineal, it is possible to define cochineal management strategies in critical seasons that favor the development of the insect.

The spring and summer seasons presented more favorable conditions for the occurrence of mealybugs in the planting of black pepper. In comparison, in summer 21 and summer 22, there was an increase in the risk zone above 50%; in parallel, there was a decrease in areas of low to moderate probability (<50%) that remained similar, indicating a possible adaptation of these recent species of mealybugs in the culture of black pepper over time and environmental factors.

CONCLUSION

The infestation of the species of mealybugs *P. longivalvata* and *D. gracilis* in black pepper indicates to be random and is more likely to occur in the summer and spring seasons;

The phytotechnical characteristics of leaf area, dry mass of black pepper and GLI spectra indicate similar management zones;

Geotechnologies are potential tools for the monitoring of mealybugs in the cultivation of black pepper, determining management zones and monitoring the development of the crop.

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