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Distribution of Black Point Infection on Wheat in Relation to Precipitation and Topographic Features Using Geographic Information Systems

Coğrafi Bilgi Sistemleri Kullanılarak Buğdayda Embriyo Kararması Enfeksiyonunun Yağış ve Topoğrafik Özelliklere Göre Dağılımı

Ömer Faruk KARACA[1], Ali ENDES[2], Bekir AKTAŞ[3]

[1]Yozgat Bozok University, Faculty of Engineering and Architecture, Department of Biosystem Engineering, Yozgat, Türkiye
· omerf.karaca@yobu.edu.tr · ORCID > 0000-0002-6302-9738

[2]Yozgat Bozok University, Faculty of Agriculture, Department of Plant Protection, Yozgat, Türkiye
· ali.endes@yobu.edu.tr · ORCID > 0000-0003-4815-5864

[3]Yozgat Bozok University, Faculty of Agriculture, Department of Field Crops, Yozgat, Türkiye
· bekir.aktas@yobu.edu.tr · ORCID > 0000-0002-8431-4554

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Sorumlu Yazar/Corresponding Author: Ömer Faruk KARACA

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DISTRIBUTION OF BLACK POINT INFECTION ON WHEAT IN RELATION TO PRECIPITATION AND TOPOGRAPHIC FEATURES USING GEOGRAPHIC INFORMATION SYSTEMS

ABSTRACT

Environmental factors and geographical features are of great importance in the disease incidence and severity of black point. Geographic Information System (GIS), Expert System and Artificial Neural Network are among the techniques recently used to guide producers in preventing wheat diseases and harmful insects. In this study, it was aimed to determine the effect of precipitation and topographic features such as aspect, slope, digital elevation model (DEM), lithology classes and soil groups on the black point incidence formation in wheat production areas in Yerköy (Yozgat) and Çiçekdağı (Kırşehir) districts with the help of GIS. It was defined that there were statistically significant differences between aspect, soil groups, lithology, precipitation and black point. In contrast, no significant difference was found in DEM and slope degree. A statistically significant difference was found between lithosol type soils and black point among soil groups, and an increase in the incidence of infection occurred in these types of soils. In terms of precipitation amount, 201-300 mm and 301-400 mm precipitation ranges had a statistically significant difference from the 401-500 mm precipitation range. Regarding the black point incidence, it was found that the north, east, and west directions from the major directions differed statistically significantly from the south directions. More attention should be paid to cultivation techniques against black point in wheat cultivation, especially in areas with such geographical features.

Keywords: Digital Elevation Model, Environmental, Conditions, GIS, Precipitation, *Triticum Aestivum*.

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COĞRAFİ BİLGİ SİSTEMLERİ KULLANILARAK BUĞDAYDA EMBRİYO KARARMASI ENFEKSİYONUNUN YAĞIŞ VE TOPOĞRAFİK ÖZELLİKLERE GÖRE DAĞILIMI

ÖZ

Çevresel faktörler ve coğrafi özellikler, embriyo kararması hastalığının görülme sıklığı ve şiddetinde büyük öneme sahiptir. Coğrafi Bilgi Sistemi (CBS), Uzman Sistem ve Yapay Sinir Ağı, son zamanlarda üreticilere buğday hastalıkları ve zararlı böcekleri önlemede rehberlik etmek için kullanılan teknikler arasındadır.

Bu çalışmada, Yerköy (Yozgat) ve Çiçekdağı (Kırşehir) ilçelerindeki buğday üretim alanlarında kara nokta görülme sıklığı oluşumu üzerine yağış ve bakı, eğim, sayısal yükseklik modeli (DEM), litoloji sınıfları ve toprak grupları gibi topoğrafik özelliklerin etkisinin CBS yardımıyla belirlenmesi amaçlanmıştır. Bakı, toprak grupları, litoloji, yağış ve embriyo kararması arasında istatistiksel olarak anlamlı farklılıklar olduğu belirlenmiştir. Buna karşılık, DEM ve eğim derecesinde anlamlı bir fark bulunamamıştır. Litosol tipi topraklar ile toprak grupları arasında embriyo kararması arasında istatistiksel olarak anlamlı bir fark bulunmuş ve bu tip topraklarda enfeksiyon görülme sıklığında artış meydana gelmiştir. Yağış miktarı açısından, 201-300 mm ve 301-400 mm yağış aralıkları, 401-500 mm yağış aralığından istatistiksel olarak anlamlı bir fark göstermiştir. Embriyo kararması görülme sıklığı açısından ise, ana yönlerden kuzey, doğu ve batı yönlerinin güney yönlerinden istatistiksel olarak anlamlı bir şekilde farklı olduğu bulunmuştur. Özellikle bu tür coğrafi özelliklere sahip alanlarda buğday yetiştiriciliğinde embriyo kararmasına karşı yetiştirme tekniklerine daha fazla dikkat edilmelidir.

Anahtar Kelimeler: CBS, Çevresel Koşullar, Sayısal Yükseklik Modeli, *Triticum Aestivum*, Yağış.

1. INTRODUCTION

Global wheat production is constrained by various biotic stress factors particularly diseases. Although more than 200 diseases affect wheat, approximately 50 are both widespread and economically significant. Annual yield losses due to diseases can approach -20% each year (Wiese, 1987; Lalic et al., 2017).

Geographic Information System (GIS), Expert System (ES), and Artificial Neural Network (ANN) have recently been employed to help producers prevent wheat diseases. GIS is a computer-based framework designed to collect spatially referenced data, store them in databases, analyze them, and display results visually. GIS and remote sensing (RS) are seen as a new and innovative alternative, especially for the conventional diagnosis, detection and management of diseases with spectral symptoms. Agricultural production and post-harvest management can greatly benefit from such contemporary technologies. Using the data obtained, diseased plants can be identified based on the differences in reflection spectra when compared to healthy plants (Fitzpatrick et al., 2000; Shen et al., 2005; Demirci, 2008; Haggag et al., 2023).

Knowing the spatial variability of soil properties is necessary for agricultural productivity, food safety and environmental modelling. Especially in the management of spatial and temporal information, GIS plays an important role in applications that require complex analysis such as the management and planning of economic, political, social and cultural resources. The most common agricultural uses of GIS are soil classification, yield estimation, soil surveys, soil conservation, watershed planning and disease detection (Yomralıoğlu, 2000; Başayiğit and Şenol, 2008; Bhunia et al., 2018).

The susceptibility of wheat varieties, changes in water and fertilizer use to achieve high yields and the effects of climate change during the grain filling stage of wheat have led to an increase in the incidence and severity of black point in recent years (El-Gremi et al., 2017; Li et al., 2020; Masiello et al., 2020; Aktaş and Endes, 2025).

Environmental factors-including number of rainy days, total precipitation, high relative humidity, extreme temperatures and daily sunshine duration during the grain filling stage, as well as agricultural practices such as irrigation, fertilization levels, and tillage systems are among the main factors affecting disease formation. Seed moisture content exceeding 20%, relative humidity exceeding 90%, and relatively low temperatures (<30°C) significantly increase the incidence and severity of the disease. In addition, late-season irrigation, excessive nitrogen fertilizer use and lodging of plants can increase the impact of black point damage (Cromey and Mulholland 1988; Conner et al., 1992; Sisterna and Sarandon, 2005; Moschini et al., 2006; Toklu et al., 2008; Li et al., 2008; Fernandez et al., 2000; Fernandez and Conner, 2011).

By integrating GIS and RS tools, Lorestani et al., (2013) investigated the diversity of pathogenic fungi in wheat fields in the Karasu basin of Golestan province, Iran. They found that precipitation and soil factors were the most important components in determining pathogenic fungal diversity. In a study on the application of GIS to determine the overwintering regions of Blumeria graminis f. sp. tritici in China, the relationship between 10 day mean temperature and the development of powdery mildew was used to calculate the probability of overwintering using weather data from 743 regions across China in two different methods (Li et al., 2013). In a study on wheat rust fungal disease and the desert locust, a serious insect pest, multiple data sources including UAV hyperspectral and multi-temporal images, RS imagery, and meteorological observations and multi-temporal UAV images were used to estimate damaged areas and levels at environmental and regional scales related to the distribution of vegetation ecological data set, rust and locust (Dong et al., 2019).

To date, no research has examined the influence of topographic features such as aspect, slope degree, digital elevation model (DEM), lithology, soil groups and precipitation-on black point. There are more studies on climatic and meteorological characteristics. For this reason, it is extremely important to know how effective these topographic characteristics and environmental factors are on the disease in the cultivated lands with this original study. In this study, samples were taken from 581 wheat production fields in Yerköy (Yozgat) and Çiçekdağı (Kırşehir) districts, and the disease incidence of black point was specified in the laboratory. This study aims to quantify changes in black point incidence-derived using GIS-relative to aspect, slope, DEM, lithology classes, soil groups and total precipitation amounts.

2. MATERIAL AND METHODS

2.1. Material

2.1.1. Study Area

Central Anatolia is one of Türkiye's principal agro-ecological regions for wheat cultivation because of its favorable ecological conditions. Yozgat and Kırşehir provinces are located in the center of Anatolia and are two important cities in wheat production. Yerköy and Çiçekdağı are two important agricultural production districts that are adjacent to each other and even their settlement centers are merged. The sampling sites within the study area are shown in Figure 1.

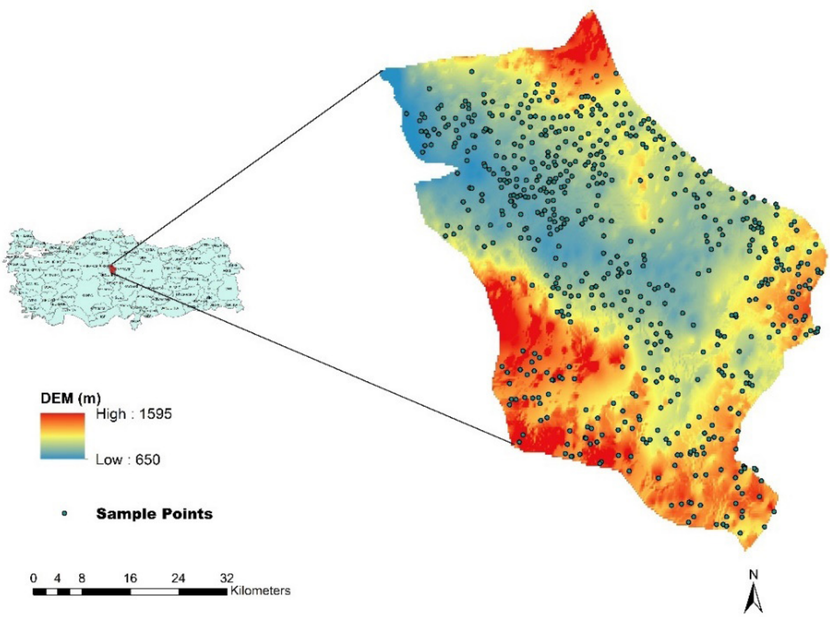

***Figure 1**. Location of the study area*

2.1.2. Soil and Rock Properties

The most common soil groups in the study area are lithosol and xerosols. Lithosol comes from the Greek word lithos (stone) and refers to soils with hard rock at a very shallow depth. In USDA soil taxonomy, they are defined as entisols, which are soils lacking horizon development due to steep slopes or parent materials that do not contain permanently weatherable minerals (such as ironstone). Typically, they are extremely shallow soils and are frequently referred to as skeletal soils or lithosols in the FAO soil classification (FAO/UNESCO, 1974; Yoshino et al., 2015; Lithosols, 2025).

Calcic xerosols are xerosols that have a calcic horizon at a depth of 125 cm from the surface, without an argillic B horizon above the calcic horizon. Luvic xerosols are xerosols with an argillic B horizon; they have a calcic or gypsiferous horizon below the B horizon. These are the main soils of the vast desert steppes of Central Asia and characterize the outer regions of large deserts. Since water is scarce in the regions where these soils are found, cultivation is concentrated along river valleys (FAO/UNESCO, 1974).

Sedimentary rocks are composed of pre-existing rocks or pieces of organisms that once lived. They mostly occur through the sedimentation of material that accumulates on the Earth's surface and in water bodies. They usually have distinct stratification or bedding. Limestone, sandstone, siltstone, shale, conglomerate and breccia are the most well-known. These rocks generally begin to form as sediments carried by rivers and deposited in lakes and oceans. They contain tuffaceous sandstones and volcanic ash. Clastic sedimentary rocks, on the other hand, are composed of fragments (clasts) of pre-existing rocks. Rock fragments loosen by weathering and are then transported to a basin or depression where the sediment compacts. If the sediment is buried deep, it is compacted, cemented, and eventually forms sedimentary rock. They can have particles ranging in size from microscopic clay to massive rocks. Their names vary according to the grain sizes of these particles. The smallest particles are named clay, then silt, and then sand (USGS, 2025).

Sediments are formed by weathering and erosion in a source area before deposition and are then transported to the deposition site by water, wind, mass movement, or glaciers. Unlike magmatic and metamorphic rocks, sedimentary rocks usually contain very few different main minerals and have lower strength and higher porosity. Sedimentary rocks containing clay minerals are particularly sensitive to pressure and water. For this reason, water can cause a major problem in the stability of a tunnel or underground structure surrounded by sedimentary rocks containing certain clay minerals (Zhang, 2016).

2.1.3. Precipitation Characteristics

In the study area, which has a dry-summer continental climate (Köppen-Geiger: DSB) characteristics are observed, the mean precipitation is 40.1 mm and the mean relative humidity is 53.4%. While precipitation generally occurs between January and May, while precipitation is minimal from June to August. On the other hand, when looking at the number of rainy days, similarly to the amount of precipitation, it rains on at least a mean of 7 different days a month between January and May (Anonymous, 2025).

2.2. Methods

2.2.1. Obtaining Black Point Incidence Data

In order to determine the incidence of black point in Yerköy and Çiçekdağı districts, samples were taken from a total of 581 fields. From each field, wheat heads were collected from multiple interior points (avoid field edges), threshed, and cleaned to obtain 100 g grain samples. Three replicate subsamples of 10 g were drawn from each composite sample and grains infected with black point were discovered and weighed. The obtained data were converted to % by weight.

2.2.2. Data Statistics

Data were organized in Microsoft Excel. Then, descriptive statistics, correlation, normality test and ANOVA were applied on these data through SPSS v25 software. The basic rule in Shapiro-Wilk or Kolmogorov-Smirnov test statistics, which are used for normality test, is to look at the Kolmogorov-Smirnov test results if the sample size is <30, and the Shapiro-Wilk test results if the sample size is > 30. If the data show a normal distribution, parametric tests are applied; if they do not show a normal distribution, non-parametric tests are applied. The main reason for insisting so much on parametric tests is that they use the entire data set in the calculations and are therefore superior to non-parametric tests (Eymen, 2007).

All obtained data were first subjected to a normality test. As a result of the test, Normality was assessed to determine the suitability of the data for parametric analyses and to identify potential correlations. Games-Howell post-hoc tests for non-normal data and LSD tests for normally distributed data. However, a skewness value test between ±1.0 is considered excellent for most psychometric purposes, but in most cases a value between ±2.0 can be used depending on the specific applications. For this purpose, in addition to the normality test results, the change in skewness and kurtosis values in the data was also checked (George and Mallery, 2010).

2.2.3. Deriving Sampled Areas and Topographic Maps

While sampling from 581 farmer fields, the geographical coordinates of the lands were recorded. The ".shp" extension data in vector format, which shows the land boundary used as a base, was obtained from HGM web pages (HGM, 2025). The widely used ArcGIS 10.8 package software was preferred for topographic and numerical operations. The data in excel were transferred into the software with the ArcGIS join (merge) operation. According to the base workspace boundary map obtained from, spatial density maps of each analysis value were created with inverse distance weighting (IDW) in the Geostatistical Analyst-Interpolation sub-toolbar in the system tool box within the software.

The Coordination of Information on the Environment (CORINE) project covers the production of land cover maps at a scale of 1/100,000 using computer-aided visual interpretation method via satellite images in line with the land cover classification defined by the European Environment Agency (EEA) throughout the European continent. CORINE is a program launched in 1985 that aims to collect information for the European Union on priority environmental issues (air, water, soil, land cover, coastal erosion, biotopes). From 1994, the EEA included CORINE in its program. The EEA is responsible for collecting impartial, timely and targeted information on the environment throughout Europe. The project is carried out in 39 countries, including Türkiye, in an area of approximately 5.8 million km^2. To date, land use and land cover (LULC) data for the years 1990, 2000, 2006, 2012 and 2018 and data sets showing the changes between these years have been created for the European Union member countries and Türkiye (RTMAF, 2025).

The LULC base map (CORINE, 2025), soil groups (FAO/UNESCO, 2025), DEM maps (EarthExplorer, 2025), lithology map (GLIM, 2025) with 30 m resolution and long-term mean precipitation data (MEVBIS 2025) were obtained. The DEM map of the study area was obtained by clipping according to the boundary of the study area with the spatial analyst-extraction-extract by mask tool bar in ArcGIS software (Figure 1). The slope map was obtained by applying the slope command in degrees from the spatial analyst, surface sub-command in ArcGIS software of the DEM map. The aspect map was obtained by applying the aspect command from the spatial analyst, surface sub-command in ArcGIS software of the DEM map. In the aspect analysis method, direction assignment was made automatically according to angle degrees.

There are many surface interpolation methods in GIS raster data analysis such as Thiessen polygon (nearest neighbour, NN); local mean (fixed radius); IDW; kriging and spline. Each method has its own advantages and disadvantages, and it has not been proven that one method is the best. In this study, the inverse distance weighted (IDW) method in the interpolation sub-heading of the geostatistical analyst tab, which is frequently used in the creation of point density maps, was preferred (Bolstad, 2005).

Finally, with the processing of base maps in raster and vector format in ArcGIS software, the spatial distribution map of precipitation and 5 different topographic criteria (DEM, slope degree, aspect, soil groups and lithological) in digital format was obtained. By overlapping these derived maps with the black point analysis results, it was examined which analysis value spatially changes depending on which topography type. For this, the intersection command under the ArcGIS geoprocessing tab was used in the topographic maps and black point analysis results maps. Thus, the two maps were overlapped and new intersection maps were obtained with the data in the background. The data obtained in .txt format from the intersection maps were transferred to SPSS software and the factors associated with the black point incidence were revealed.

3. RESULTS

3.1. Evaluating of Density Maps

The black point density map is shown in Figure 2. Accordingly, relatively lower black point incidence was generally found in the northern parts of the area. Higher incidence values were detected in the district centers than in the northern areas. As one goes south, an increase in the black point incidence was observed in wheat samples.

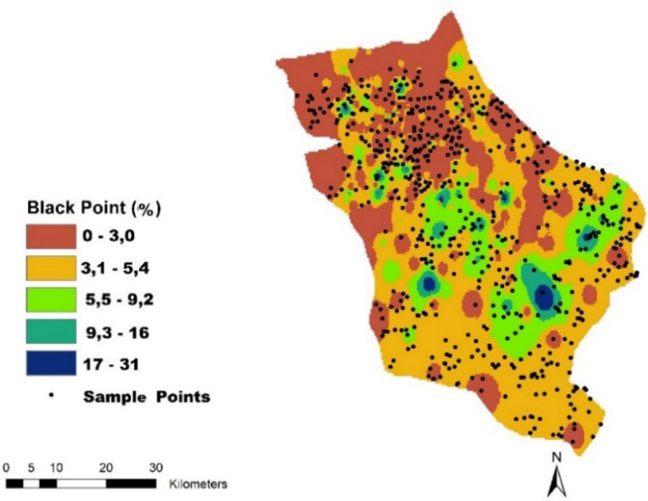

Figure 2. *Density map of black point incidence1*

Topographic maps of the study area processed in ArcGIS, and the resulting density map after the digitization is presented in Figure 3. The areas and proportional distributions of the rock groups in the lithology map are shown in Table 1. It was determined that the most common rock types in the study area are mixed sedimentary rocks with 30.49%, siliciclastic sedimentary rocks with 23.19%, and carbonate sedimentary rocks with 20.47%, respectively. Sedimentary rock types in the region cover approximately 74.05% of the total area.

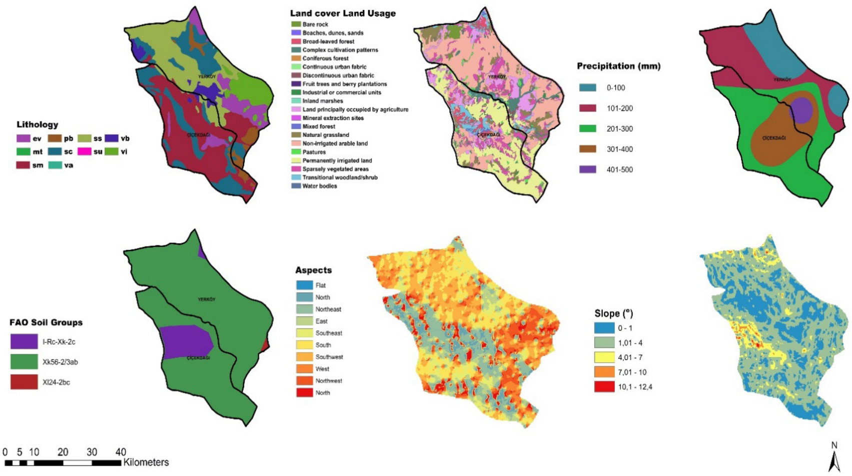

Figure 3. *Lithology map of the study area*

Table 1. *Areas and proportional distributions of rock groups in the lithology map*

Rock Groups	Description	Area (km²)	Proportional Distribution (%)
EV	Evaporites	315.69	9.07
MT	Metamorphic rocks	2.04	0.06
PB	Basic plutonic rocks	164.96	4.74
SC	Carbonate sedimentary rocks	712.37	20.47
SM	Mixed sedimentary rocks	1060.96	30.49
SS	Siliciclastic sedimentary rocks	807.14	23.19
SU	Unconsolidated sediments	2.18	0.06
VA	Acid volcanic rocks	4.39	0.13
VB	Basic volcanic rocks	130.89	3.76
VI	Intermediate volcanic rocks	279.45	8.03

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The land-use/land-cover (LULC) density map was generated in ArcGIS. The derived map is given in Figure 3, and the table showing the amount of area it covers is given in Table 2. 34.60% of the study area consists of non-irrigated arable lands and 21.22% consists of permanently irrigated lands. 10.07% of the study area consists of land principally occupied by agriculture.

Table 2. *Area amounts and proportional distributions of land cover and land use classes in the map*

LULC Code	Description	Area (km²)	Proportional Distribution (%)
111	Continuous urban fabric	0.83	0.02
112	Discontinuous urban fabric	43.88	1.26
121	Industrial or commercial units	6.41	0.18
131	Mineral extraction sites	6.74	0.19
211	Non-irrigated arable land	1203.94	34.60
212	Permanently irrigated land	738.31	21.22
222	Fruit trees and berry plantations	0.42	0.01
231	Pastures	59.73	1.72
242	Complex cultivation patterns	153.22	4.40
243	Land principally occupied by agriculture	350.61	10.07
311	Broad-leaved forest	85.33	2.45
312	Coniferous forest	2.69	0.08
313	Mixed forest	13.91	0.40
321	Natural grassland	244.55	7.03
324	Transitional woodland/shrub	138.01	3.97
331	Beaches, dunes, sands	3.56	0.10
332	Bare rock	57.17	1.64
333	Sparsely vegetated areas	366.08	10.52
411	Inland marshes	2.82	0.08
512	Water bodies	1.84	0.05

Spatial density maps of precipitation values were created with ArcGIS IDW in the long-term precipitation data of Yerköy and Çiçekdağı districts obtained from MEVBIS (MEVBIS, 2025). The derived precipitation map is given in Figure 3, and the data showing the area covered by the precipitation range groups are given in Table 3.

Spatial analysis of long-term precipitation showed that 35.28% of the area received 201-300 mm annually, whereas only 3.26% received 401-500 mm. Approximately 80% of the precipitation in the region is in the range of 0-300 mm.

Table 3. *Precipitation density map area amounts and proportional distribution*

Precipitation Range (mm)	Area (km²)	Proportional Distribution (%)
0-100	553.43	16.00
101-200	924.03	26.71
201-300	1220.48	35.28
301-400	648.82	18.75
401-500	112.80	3.26

The soil groups map of the study area obtained from (FAO/UNESCO, 2025) was digitized with ArcGIS and given in Figure 3. It was discovered that there are three general soil groups in the study area. In addition, the area and proportional distributions of the soil classes within the region are given in Table 4. Accordingly, the regions with the most proportional area are calcic xerosols with the code xk56-2/3ab with 89.22%, and the lowest is luvic xerosols with the code xl24-2bc with 0.69%.

Table 4. *Area amounts and proportional distribution of soil groups in the study area*

FAOSOIL	DOMSOI	Description	Area (km²)	Proportional Distribution (%)
I-Rc-Xk-2c	I	Lithosols	351.21	10.09
Xl24-2bc	Xl	Calcic xerosols	24.07	0.69
Xk56-2/3ab	Xk	Luvic xerosols	3104.79	89.22

The DEM map is given in Figure 1 and the area amounts and proportional distributions according to elevation values are given in Table 5. A large part of the study area (52.34%) consists of areas with an elevation in the range of 751-1000 m. The elevation of the areas with the least percentage varies between 1501-1626 m.

Table 5. *DEM density map area amounts and proportional distributions*

DEM Range (m)	Area (km²)	Proportional Distribution (%)
0-750	257.22	7.39
751-1000	1821.46	52.34
1001-1250	1058.84	30.43
1251-1500	329.81	9.48
1501-1626	12.52	0.36

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The derived aspect degree map is given in Figure 3 and the area values and proportional distributions it covers are given in Table 6. Southwest ranks first with 17.75% in terms of area covered, south ranks second with 16.17% and west ranks third with 10.73%. Only the southern directions cover 42.83% of the total study area, while the northern directions cover 39.48%.

Table 6. *Area and proportional distribution of the study area in terms of aspect direction*

Number	Aspect (direction)	Aspect (angle)	Area (km²)	Proportional Distribution (%)
1	Flat	-1.00	0.07	0.00
2	North	0-22.5	308.02	9.07
3	Northeast	22.51-67.50	475.71	14.01
4	East	67.51-112.50	236.35	6.96
5	Southeast	112.51-157.50	302.41	8.91
6	South	157.51-202.50	548.94	16.17
7	Southwest	202.51-247.50	602.81	17.75
8	West	247.51-292.50	364.28	10.73
9	Northwest	292.51-337.50	327.51	9.64
10	North	337.51-360.00	229.7	6.76

Degree was used as the output unit in the ArcGIS software during the acquisition of the slope degree. The derived map is given in Figure 3 and the area values and proportional distributions it covers are given in Table 7. Areas between 1.01°-4.00° in terms of slope degrees constitute 61.14% of the total area. Areas with a slope degree of 10.1°-12.40°, which has the lowest percentage, cover 0.08% of the total area. In general, regions with a slope of 0°-4° cover a very large part of the total area, approximately 91.30%. It has been determined that areas with a slope degree of 4° and greater cover a very small area.

Table 7. *Area and proportional distribution of the study area according to slope degree*

Slope (°)	Area (km²)	Proportional Distribution (%)
0-1	1024.02	30.16
1.01-4.00	2075.63	61.14
4.01-7.00	260.45	7.67
7.01-10.00	32.18	0.95
10.1-12.40	2.84	0.08

3.2. Determination of the Effect of Precipitation and Topography on Black Point Disease

Homogeneity test results for precipitation and all topographic criteria are given in Table 8. The normal distribution condition was met for aspect, slope and soil criteria, but the normal distribution condition was not met for DEM, lithology and precipitation criteria. Therefore, Games-Howell tests were selected for non-normal distribution in ANOVA Post-Hoc tests, and LSD tests were selected for those that meet the normal distribution condition. Since the class intervals discovered for each criterion are different, the number of degrees of freedom (df) was taken differently in the study (Tables 3,4,5,6,7).

Table 8. *Homogeneity test results for precipitation and topographic criteria*

Test of homogeneity		Levene statistic	df_1	df_2	Sig.
Aspect	Based on mean	1.724	8	573	0.090
DEM	Based on mean	12.260	3	578	0.000
Lithology	Based on mean	3.294	7	574	0.002
Soil	Based on mean	1.661	2	579	0.191
Precipitation	Based on mean	7.089	4	577	0.000
Slope	Based on mean	1.995	4	577	0.094

The results of the variance analysis conducted to define the effect of precipitation and topographic features on the disease incidence of black point are given in Table 9. A significant relationship ($p<0.01$) was found between aspect, lithology, soil and precipitation criteria and the disease incidence of black point. However, no significant relationship was detected between slope degree and DEM criteria and the black point incidence. In this case, the criteria were evaluated separately within themselves and the relationships between the levels of the criteria and the black point incidence were focused on. Separate multiple comparison matrices were used for this purpose.

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Table 9. *ANOVA test results for precipitation and topographic criteria*

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Aspect	Between Groups	46.038	8	5.755	9.420	0.000
	Within Groups	350.038	573	0.611		
	Total	396.076	581			
DEM	Between Groups	4.154	3	1.385	2.042	0.107
	Within Groups	391.922	578	0.678		
	Total	396.076	581			
Lithology	Between Groups	52.023	7	7.432	12.399	0.000
	Within Groups	344.053	574	0.599		
	Total	396.076	581			
Soil	Between Groups	8.598	2	4.299	6.424	0.002
	Within Groups	387.477	579	0.669		
	Total	396.076	581			
Precipitation	Between Groups	40.548	4	10.137	16.452	0.000
	Within Groups	355.527	577	0.616		
	Total	396.076	581			
Slope	Between Groups	2.054	4	0.513	0.752	0.557
	Within Groups	394.022	577	0.683		
	Total	396,076	581			

Aspect map and black point incidence data were transferred to the ArcGIS software and the values obtained as a result of overlaying the maps were subjected to a homogeneity test and variance analysis in the SPSS package program. The multiple comparison matrix values obtained are given in Table 10. Only values for which a significant relationship was specified are included in the table.

Table 10. *Multiple comparison results of aspect values*

Multiple Comparisons (LSD) - Dependent Variable						
Aspect (I)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
North	Southeast	0.351*	0.169	0.038	0.02	0.68
	South	0.609*	0.153	0.000	0.31	0.91
	Southwest	0.572*	0.152	0.000	0.27	0.87
Northeast	Southeast	0.318*	0.135	0.019	0.05	0.58
	South	0.576*	0.115	0.000	0.35	0.80
	Southwest	0.539*	0.113	0.000	0.32	0.76
Northwest	Southeast	0.500*	0.148	0.001	0.21	0.79
	South	0.758*	0.129	0.000	0.50	1.01
	Southwest	0.721*	0.128	0.000	0.47	0.97
East	South	0.578*	0.152	0.000	0.28	0.88
	Southwest	0.541*	0.151	0.000	0.25	0.84
Southeast	South	0.259*	0.131	0.049	0.00	0.52
West	Southeast	0.297*	0.143	0.038	0.02	0.58
	South	0.556*	0.124	0.000	0.31	0.80
	Southwest	0.519*	0.122	0.000	0.28	0.76

* The mean difference is significant at the 0.05 level.

Variance analysis was applied to the DEM and black point incidence data in the SPSS package program and the resulting multiple comparison matrix results are given in Table 11. There was no statistically significant relationship between altitude and black point incidence. It is thought that this result may have resulted from the fact that most of the sampled agricultural lands have similar altitudes.

Table 11. *DEM multiple comparison matrix test results*

Multiple Comparisons (Games-Howell) - Dependent Variable						
DEM (I)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0-750 m	751-1000 m	-0.188	0.133	0.492	-0.54	0.16
	1001-1250 m	-0.264	0.134	0.211	-0.62	0.09
	1251-1500 m	0.031	0.169	0.998	-0.41	0.47
751-1000 m	0-750 m	0.188	0.133	0.492	-0.16	0.54
	1001-1250 m	-0.075	0.072	0.718	-0.26	0.11
	1251-1500 m	0.219	0.125	0.310	-0.12	0.55
1001-1250 m	0-750 m	0.264	0.134	0.211	-0.09	0.62
	751-1000 m	0.075	0.072	0.718	-0.11	0.26
	1251-1500 m	0.295	0.127	0.107	-0.04	0.63
1251-1500 m	0-750 m	-0.031	0.169	0.998	-0.47	0.41
	751-1000 m	-0.219	0.125	0.310	-0.55	0.12
	1001-1250 m	-0.295	0.127	0.107	-0.63	0.04

Variance analysis was applied to the data obtained by intersecting the lithology and black point incidence maps and the resulting multiple comparison matrix results are given in Table 12. Only values for which a significant relationship was defined are included here. The rock types with predominantly sedimentary and volcanic characteristics are dominant in the land where the study was carried out. The relationship between volcanic (VA), mixed sedimentary (SM) and evaporites (EV) rocks and black point incidence was found to be statistically significant compared to almost all rock types. The sedimentary rocks have the highest value in terms of the area they cover in the study area (Table 1). More attention should be paid to black point infection in wheat cultivation in areas where these types of rocks are present.

Table 12. *Lithological rocks multiple comparison matrix test results*

Multiple Comparisons (Games-Howell) - Dependent Variable						
Lithology (I)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
SM	SC	0.501*	0.089	0.000	0.23	0.77
	SS	0.496*	0.086	0.000	0.23	0.76
EV	SC	0.649*	0.176	0.014	0.09	1.21
	SS	0.644*	0.175	0.014	0.09	1.20
VI	SC	0.657*	0.124	0.000	0.27	1.04
	PB	0.583*	0.171	0.024	0.05	1.12
	SS	0.652*	0.123	0.000	0.27	1.03
VA	SC	2.384*	0.061	0.000	2.20	2.57
	VB	2.118*	0.270	0.000	1.18	3.05
	SM	1.883*	0.064	0.000	1.69	2.08
	PB	2.310*	0.132	0.000	1.88	2.74
	EV	1.735*	0.165	0.000	1.20	2.27
	SS	2.380*	0.057	0.000	2.20	2.55
	VI	1.727*	0.108	0.000	1.39	2.07

*The mean difference is significant at the 0.05 level. EV= Evaporites, PB= Basic plutonic rocks, SC=Carbonate sedimentary rocks, SM=Mixed sedimentary rocks, SS= Siliciclastic sedimentary rocks, VA= Acid volcanic rocks, VB= Basic volcanic rocks, VI= Intermediate volcanic rocks.

In the data obtained by overlapping the soil groups and black point incidence maps, variance analysis was applied in the SPSS package program and multiple comparison matrix results are given in Table 13. A statistically significant relationship was discovered between black point incidence and soil groups. In the study area, more infection was observed in lithosol type soils than xerosol type soils, especially among the three soil groups. If the mean difference value in the table is positive (+), it indicates that the relationship is directly proportional, and if it is negative (-), it indicates that it is inversely proportional.

Table 13. *Multiple comparison matrix test results of soil groups*

Soil (I)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
I	Xk	0.436*	0.123	0.000	0.19	0.68
	Xl	0.604	0.354	0.089	-0.09	1.30
Xk	I	-0.436*	0.123	0.000	-0.68	-0.19
	Xl	0.169	0.336	0.616	-0.49	0.83
Xl	I	-0.604	0.354	0.089	-1.30	0.09
	Xk	-0.169	0.336	0.616	-0.83	0.49

*The mean difference is significant at the 0.05 level.

Variance analysis was applied to the data obtained by overlapping long-term mean precipitation values and disease infection maps in the SPSS package program. Multiple comparison results are given in Table 14. More significant relationships were found especially in the 201-300 mm and 301-400 mm precipitation ranges, rather than 0-100 mm. In this context, it can be said that the disease incidence of black point in these precipitation ranges was higher than others. Otherwise, there are decreases in the incidence of the disease in areas with precipitation amounts above 401 mm.

Table 14. *Multiple comparison test results of precipitation amounts*

Multiple Comparisons (Games-Howell) - Dependent Variable						
Precipitation (I)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0-100 mm	101-200 mm	-0.051	0.095	0.984	-0.31	0.21
	201-300 mm	-0.384*	0.094	0.001	-0.64	-0.13
	301-400 mm	-0.732*	0.111	0.000	-1.04	-0.43
	401-500 mm	-0.634	0.322	0.360	-1.75	0.49
101-200 mm	0-100 mm	0.051	0.095	0.984	-0.21	0.31
	201-300 mm	-0.333*	0.081	0.000	-0.55	-0.11
	301-400 mm	-0.681*	0.100	0.000	-0.96	-0.41
	401-500 mm	-0.583	0.319	0.423	-1.70	0.54
201-300 mm	0-100 mm	0.384*	0.094	0.001	0.13	0.64
	101-200 mm	0.333*	0.081	0.000	0.11	0.55
	301-400 mm	-0.348*	0.099	0.005	-0.62	-0.08
	401-500 mm	-0.250	0.318	0.928	-1.37	0.87
301-400 mm	0-100 mm	0.732*	0.111	0.000	0.43	1.04
	101-200 mm	0.681*	0.100	0.000	0.41	0.96
	201-300 mm	0.348*	0.099	0.005	0.08	0.62
	401-500 mm	0.098	0.324	0.998	-1.02	1.22
401-500 mm	0-100 mm	0.634	0.322	0.360	-0.49	1.75
	101-200 mm	0.583	0.319	0.423	-0.54	1.70
	201-300 mm	0.250	0.318	0.928	-0.87	1.37
	301-400 mm	-0.098	0.324	0.998	-1.22	1.02

* The mean difference is significant at the 0.05 level.

The multiple comparison results with the variance analysis applied to the data obtained as a result of overlapping the black point incidence and the slope degrees in the study area in the ArcGIS software are given in Table 15. According to results, no significant relationship was found between black point incidence and all slope degrees.

Table 15. *Multiple comparison test results of slope degrees*

Multiple Comparisons (LSD) Dependent Variable						
Slope (I)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0-1	1.01-4.00	-0.044	0.073	0.547	-0.19	0.10
	4.01-7.00	0.220	0.162	0.173	-0.10	0.54
	7.01-10.00	-0.063	0.245	0.797	-0.55	0.42
	10.01-12.40	-0.146	0.587	0.803	-1.30	1.01
1.01-4.00	0-1	0.044	0.073	0.547	-0.10	0.19
	4.01-7.00	0.265	0.158	0.094	-0.04	0.57
	7.01-10.00	-0.019	0.243	0.938	-0.50	0.46
	10.01-12.40	-0.102	0.586	0.862	-1.25	1.05
4.01-7.00	0-1	-0.220	0.162	0.173	-0.54	0.10
	1.01-4.00	-0.265	0.158	0.094	-0.57	0.04
	7.01-10.00	-0.283	0.282	0.316	-0.84	0.27
	10.01-12.40	-0.367	0.603	0.544	-1.55	0.82
7.01-10.00	0-1	0.063	0.245	0.797	-0.42	0.55
	1.01-4.00	0.019	0.243	0.938	-0.46	0.50
	4.01-7.00	0.283	0.282	0.316	-0.27	0.84
	10.01-12.40	-0.083	0.631	0.895	-1.32	1.16
10.01-12.40	0-1	0.146	0.587	0.803	-1.01	1.30
	1.01-4.00	0.102	0.586	0.862	-1.05	1.25
	4.01-7.00	0.367	0.603	0.544	-0.82	1.55
	7.01-10.00	0.083	0.631	0.895	-1.16	1.32

4. DISCUSSION

Demand for wheat is projected to rise at a rate of 1.6% annually until 2050 because of increased population and prosperity. As a result, average global wheat yields on a per hectare basis will need to increase to approximately 5 tons per ha from the current 3 tons (WHEAT, 2013). Nearly 200 diseases and pests have been documented, and approximately 50 are considered economically important because of their potential to damage crops and hurt farmer incomes (Weiss 1987). Overall, potential grain yield losses due to disease have been estimated at 18%, and actual losses under current disease control have been estimated at 13% (Oerke, 2006). Although the scale of disease impact can vary from year to year, diseases are always active and can pose a significant challenge even if they attack only certain plant parts. They can occur in any field, depending on environmental conditions and the susceptibility of host cultivars. All disease symptoms draw attention and generate concern because of their effects on grain or straw yield and quality.

Unbalanced fertilization and inappropriate water conditions in field soils increase the presence of certain diseases and pests (Walters and Bingham, 2007). Without considering the resistance of wheat varieties, there are two factors that affect the development of black point. One factor is pathogens, including multiple fungal species, such as A. alternata, B. sorokiniana, F. proliferatum, Curvularia spicifera, and Exserohilum rostratum (Xu et al., 2018; Liu et al., 2019). The other factor impacting the incidence of black point is environmental conditions, mainly including cultivation measures, such as irrigation and nitrogen fertilization (Fernandez et al., 2000; Sisterna and Sarandon, 2005), and meteorological factors, such as heavy rain, high humidity, and extreme temperature during the kernel development stage (Moschini et al., 2006; Walker, 2011).

Agricultural fields are highly heterogeneous spatially, regarding pathogen and pest populations and other field properties that impact plant health and growth such as topography, soil type, soil fertility, and soil moisture (Roberts and Kobayashi 2011). These field properties interact with climate, greatly influencing drainage, water and nutrient availability, and pathogen and pest outbreaks and their spatial distribution. For this reason, a new generation of tools based on state-of-the-art knowledge and technologies is needed to allow systems analysis including key processes and their dynamics over appropriate suitable range of environmental variables (Donatelli et al., 2017).

In this context, RS and GIS are effective tools for precision management and optimization for soilborne diseases and nematodes because root damage leads to visible changes in foliage characteristics, infections often cluster in the field, pathogen mobility in soil is slow impeding spatial disease spread in the field, there is scarce introduction of new disease foci in the field, and disease maps from one season can be applicable in future cropping seasons (Oerke, 2020). GIS as the organizing principle for spatial data in combination with big data (defined as a combination of a variety of data, the velocity of data, and/or volume of data) management and analytics now allows us to use data from these varied sensor systems and link information regarding pathogens, pests, crop yield, soil fertility factors, water, etc. with climate factors to develop correlations between disease, crop yield, soil type, and crop and management (Janssen et al., 2017; Delgado et al., 2019; Bestelmeyer et al., 2020). In this way, farmers can maximize disease control, crop productivity, increase profitability and use pesticides more efficiently and other inputs resulting in less loss of these resources from agricultural field and associated harmful environmental impacts (Gebbers and Adamchuk, 2010; Mahlein, 2016).

Many researchers reported that meteorological factors such as rainfall, humidity, and temperature during the kernel development stage are closely related to the incidence of black point (Weiss, 1987; Moschini et al., 2006; Wang, 2006). Waldron (1934) and Moschini et al., (2006) reported that high temperature increased the incidence of black point. Desclaux (2000) and Fernandez et al., (2000) reported that lower temperature in combination with high humidity is needed for black point initiation.

It has been indicated that as temperatures increase many pathogens will spread into new geographic areas, where they will come into contact with new potential hosts (Baker et al., 2000; Etterson and Shaw, 2001). Several aspects of the biology of a pathogen can be directly influenced by environmental factors. Production and germination of propagules and pathogen growth rates are strongly dependent on temperature, relative humidity (RH), and, in the case of foliar pathogens, often leaf wetness (Huber and Gillespie, 1992). Temperature requirements for infection vary widely among pathogen species. In general, prolonged periods of environmental conditions (temperature, precipitation, and humidity) that are close to the optimal for the development of a pathogen lead to more damaging epidemics (Agrios, 2005).

Topography has been reported to be related to yield of many crops in various conditions (Guo et al., 2012). Guo et al., (2012), in their research stated that Mahler et al., (1979) observed high dry pea (Pisum sativum L.) yield and water content at bottom slope positions. (Sinai et al., 1981; Kosmas et al., 1993; Jowkin and Schoenau, 1998) reported higher wheat (*Triticum aestivum L.*) yield at bottom slope or concave landscape positions. Higher corn yields at foot-slope positions were reported by (Stone et al., 1985) and (Kravchenko and Bullock, 2000). Kravchenko and Bullock (2000) reported that topography could explain 40% of soybean and corn yield variability. Consequently, Iqbal et al., (2005) reported that, generally, cotton yielded lower in higher elevation areas compared with lower elevation areas. In a study conducted by Karaca (2024) with the TWI map created, it was tried to determine the saturated and flood-prone areas in Yozgat province. High TWI indicates that there is more moisture in a certain area and the water movement is downward, thus more prone to flood events.

Previous studies have emphasized the effects of latitude and climate factors (temperature, humidity, precipitation etc.) on the disease. In this study, the effects of aspect, DEM, lithology, soil, precipitation and slope on black spot disease were investigated. This is the first study to examine aspect effects on the disease, revealing a stronger relationship between black point incidence and north-, east- and west-facing slopes (Table 10). It was defined that there was a decrease in black point infection in lands with a southern aspect. From these determinations, it was concluded that the disease may be relatively common in colder and wetter regions. It was also concluded that the faster evaporation of precipitation in areas with a southern aspect may have prevented fungi from causing infection.

Elevation decreases soil fungal pathogen richness rather than overall pathogen load of foliar diseases. For this reason, it did not significantly affect foliar fungal diseases, but significantly reduced soil fungal pathogen richness, suggesting that elevation has opposing effects on the increase of aboveground and belowground plant pathogens (Lin et al., 2021). Similarly, as indicated in this study, there was no statistically significant relationship between altitude and black point incidence (Table 11). The growth stages of the plants may be at different stages according to altitude and the fact that the growing season in which the sampling was carried out was hotter and drier than the long-term mean may have eliminated the interaction of disease infection according to altitude. It is thought that this result may have resulted from the fact that most of the sampled agricultural lands have similar altitudes.

In support of this study, in a study conducted by Lin et al., (2025), no direct association was found between elevation and foliar fungal diseases at either the host population or community level. Elevation has been associated with a series of changes in plant communities, soil properties and other environmental factors (Lomolino, 2001). With the result that no association is detected between elevation and foliar fungal diseases.

Another important research topic in the study is to determine whether black spot disease varies according to lithological rocks. As indicated in Table 9, A statistically significant relationship was found between black spot disease and lithology. In Table 12, it is tried to determine which rock type is more effective on the disease. According to the results obtained, more black spot disease was detected especially in areas with SM and VA rock types.

It is commonly known that topography is one of the main factors affecting crop yield. (Godwin and Miller, 2003) said that topography was one of the most obvious causes of variation in field crops from its direct effect on micro-climate-related soil factors such as soil temperature, which influences germination, tiller production and crop growth. Fietz et al., (1994) in their experiments found that in two successive years yield varied by 55 and 35%, respectively, depending upon slope, position and aspect. Soils can serve as a reservoir of plant pathogens capable of causing disease both above and belowground, even when those pathogens are not causing active infections (Delgado-Baquerizo et al., 2020). In the study area, more infection occurred in lithosol type soils than xerosol type soils, especially among the three soil groups. Cultivation in areas with lithosol soil type should be more careful, as the rate of encounter with the disease may increase.

Compared to latitudinal gradients, elevational gradients provide highly variable ecological conditions (abiotic environment, plant community and soils) at a relatively small spatial scale (Rowe 2009), providing an excellent 'natural laboratory' to study how abiotic and biotic factors affect plant pathogens (Halliday et al., 2021). Abiotic factors, such as temperature and precipitation, can affect plant pathogens both directly and indirectly through changes to host plant communities and soil properties (Li et al., 2019). High temperatures often promote both foliar fungal diseases (Roy et al., 2004; Li et al., 2019) and soil pathogens (Delgado-Baquerizo et al., 2020). Warming can benefit pathogen fitness by increasing pathogen survival, growth and transmission (Siebold and Tiedemann, 2013); extending the favourable period for pathogen growth (Roy et al., 2004); and/or reducing pathogen generation time (Bebber, 2015). Additionally, humidity can increase plant diseases by promoting pathogenic spore germination and growth (Romero et al., 2021).

The change in precipitation patterns due to climate change has diverse effects on plant diseases (Garrett et al., 2021). Precipitation stands as a critical environmental factor influencing plant diseases by shaping water and nutrient availability, soil moisture, pH levels, pesticide leaching, runoff, and inoculum formation and dissemination (Chen et al., 2023). In general, heightened precipitation tends to promote the development and spread of plant diseases, particularly those caused by fungi and oomycetes, while simultaneously diminishing the effectiveness of chemical and biological control measures (Lim et al., 2023). This case may enhance the occurrence and severity of soil-borne and foliar diseases, such as root rot, damping-off, leaf spot, and blight (lamichhane et al., 2023). However, the impact of precipitation on plant diseases can vary depending on factors such as timing, frequency, intensity, and form of precipitation, as well as its interaction with other climatic variables like temperature and humidity (Skendzic et al., 2021).

In the current study, it was defined that the disease incidence of black point in these precipitation ranges was higher than others. It has been discovered that there are decreases in the incidence of the disease in areas with precipitation amounts above 401 mm. It has been reported in many studies that the increase in precipitation and relative humidity causes an increase in the incidence and severity of black point. The environmental factors such as the number of rainy days, the amount of precipitation, the stage of development of the plant when the precipitation occurs and high humidity conditions are effective in the emergence of black point disease. Similarly, in this study, relationships were specified between precipitation amount and black point incidence. The incidence of infection was high in areas where precipitation was more common between 201-300 mm and 301-400 mm. In Table 3, it is seen that the share of the study area in the 401-500 mm precipitation range has the lowest value (3.26%) in the total area. For this reason, a relationship between the areas with the highest level of precipitation and infection may not have been discovered. In addition, the characteristics of this 112.8 km^2 area, other than precipitation, suggest that they also affected the incidence of the disease (Conner and Thomas, 1985; Moschini et al., 2006; Toklu et al., 2008; Li et al., 2008; Khani et al., 2018; Cotuna et al., 2020; Li et al., 2020; Sesiz, 2023).

It was concluded that the black point disease develops independently of the degree of slope and that the slope has no positive or negative effect on the disease. However, as can be seen in Table 7, 91.30% of the total area is located within two slope groups. Generally, it is the most appropriate that the vast majority of areas where field crop agriculture is carried out have a slope of less than 2%. For these reasons, no relationship could be established between infection and slope.

In addition to all these results, trend graphs of precipitation and topographic features were created according to the mean black point incidence and are given in Figure 4. The incidence of infected grains in the areas with southern aspect where sampling was carried out is at the lowest level, while it is at a higher level in other aspect areas. No significant relationship was found between DEM and black point, but relatively higher mean black point infection values were found in areas with an altitude of 751-1250 m.

Higher mean disease incidence was found in areas with lithologic rocks siliciclastic sedimentary (SS), intermediate volcanic rocks (VI) and acid volcanic rocks (VA). While the incidence of infection in lithosol soil groups is at its peak, the incidence of disease in other soil groups shows a decreasing trend. In terms of precipitation, the incidence of infection shows an increasing trend up to the range of 301-400 mm, and then it starts to decline. No significant relationship was found between slope and disease, but it was discovered that relatively higher disease values occurred in others except for areas with a mean slope of 4.01°-7.00°.

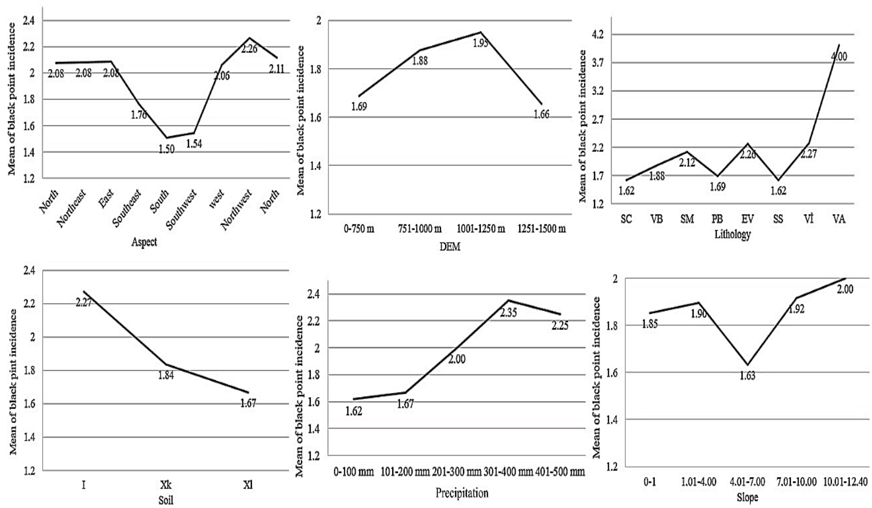

Figure 4. *Trend graphs of precipitation and topographic features related to black point incidence*

5. CONCLUSION

Variety and cultivation techniques are very important for yield and quality in wheat cultivation. Determination of topographical and geographical characteristics helps to analyse yield, quality, diseases and pests. This is because land is an asset that cannot be moved or relocated. The study explores the impact of precipitation and topographic features on black point disease in wheat cultivation. It found a significant relationship between factors like soil groups, lithology, and precipitation values, but no significant relationship between DEM and slope degree. The study also found sedimentary and volcanic rock types dominate areas with higher infection rates. The study suggests using resistant varieties in high-infected areas is an environmentally friendly and economically effective control method.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethics

This study does not require ethics committee approval

Authorship Contribution Statement

Design of Study: ÖFK (%100)

Data Acquisition: ÖFK (%50), AE (%25), BA (%25)

Data Analysis: ÖFK (%100)

Writing Up: ÖFK (%50), AE (%25), BA (%25)

Submission and Revision: ÖFK (%50), AE (%25), BA (%25)

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