

Research Article



Distribution of Fusarium Wilt in Banana Plants: An Epidemiological Study Based on Land Unit Modeling in Malang Regency

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ABSTRACT

Fusarium wilt caused by *Fusarium oxysporum* f. sp. *cubense* (Foc) is a destructive soil-borne disease threatening banana production in Indonesia, particularly in Malang Regency, East Java. This study aimed to determine the occurrence and spatial distribution of Foc and assess disease dynamics in relation to environmental factors using spatial analysis and epidemiological modeling. Field surveys and laboratory analyses were conducted from October 2024 to January 2025 in six sub-districts of Malang Regency. Foc isolates were obtained from symptomatic banana plants and identified through macroscopic and microscopic observations and pathogenicity tests. Spatial distribution was analyzed using Geographic Information System (GIS)-based land unit modeling integrating land use, slope, soil type, and rainfall data. Disease development was evaluated using the Susceptible–Infected–Recovered (SIR) model. The results confirmed Fusarium wilt occurrence, characterized by leaf chlorosis, vascular discoloration, and fungal structures typical of Foc. Disease intensity varied among locations, with the highest severity recorded in Tajinan and Pakis sub-districts (score = 2), while the overall mean disease intensity was 0.83. Spatial analysis indicated that areas with gentle slopes, typic dystrodepts soils, and moderate-to-high rainfall were more prone to disease occurrence. Epidemiological simulations showed that the infected population peaked around day 40, whereas the recovered population increased to approximately 900 plants by day 80. Among the 32 banana cultivars evaluated, Cavendish was the most susceptible, whereas BRS Platina showed higher resistance. Integrating spatial environmental analysis and SIR modeling provides a practical approach for predicting disease distribution and supporting sustainable Fusarium wilt management in banana production.



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1. Introduction

Banana (*Musa* spp.) is one of the important horticultural commodities in Indonesia. According to data from the BPS (2023) shows that banana production in East Java reached 2.8 million tons and

Malang Regency as the main producer managed to contribute 13.7 thousand tons. Despite having quite high production, banana cultivation is greatly influenced by disease attacks. In recent years, East Java Province, particularly Malang and Lumajang Regencies has shown an average incidence of fusarium wilt disease of 17.28% (Hermanto *et al.* 2011). Foc is a soil-borne pathogen that can attack the plant's vascular system by

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infecting the roots and spreading to the xylem vessels, thereby inhibiting the flow of water and plant nutrients. In addition, Foc can persist in the soil environment and spread rapidly under favorable environmental conditions, making this pathogen a major challenge for banana farmers in Indonesia. At low population levels, Foc may survive as a saprophyte and act as a decomposer of organic matter, but in the presence of susceptible banana plants its population increases and becomes pathogenic, infecting the root system and vascular tissues. Although Foc does not directly damage the soil, soil properties such as organic matter content, pH levels, and cation exchange capacity play an important role in developing effective soil management strategies to control Fusarium wilt, as has been demonstrated in banana plantations in Colombia (Rodríguez-Yzquierdo *et al.* 2023).

The common approach taken by farmers in Indonesia is the use of chemical pesticides. Although this method can provide temporary control of the disease, the use of chemical pesticides is still less effective because Foc is a soil-borne pathogen that can survive for long periods in the soil as chlamydospores, making eradication difficult. Moreover, excessive pesticide use may negatively impact soil health, increase production costs, and contribute to environmental pollution, highlighting the need for more sustainable management strategies.

This is due to the lack of attention to the development factors of Foc that encourage pathogens to be more resistant, one of which is environmental factors. So, it is necessary to understand the epidemiology of Foc, including soil types, rainfall patterns, land use practices, and so on. This study aims to relate to environmental factors by integrating epidemiological data with spatial and environmental analysis. This study is also expected to contribute to the development of sustainable management practices and support the resistance of banana production to fusarium wilt.

2. Materials and Methods

2.1. Time and Place

This research was conducted for three months, starting from October 2024 to January 2025 at the Microbiology Laboratory, Agrotechnology Study Program, University of Muhammadiyah Malang. The survey period was chosen because it coincides with the rainy season in Malang Regency, when high soil moisture and humidity favor the development and observation of Fusarium wilt symptoms in banana plants. Field sampling was carried out across several sub-districts in Malang Regency, and

the collected samples were then isolated and identified in the laboratory.

2.2. Distribution of Fusarium Wilt Disease Attack Levels on Banana Plants in Malang Regency

The results of mapping the distribution of fusarium wilt disease intensity on banana plants in Malang Regency refer to the research results of Lestarini *et al.* (2015). Survey locations were determined using purposive sampling to represent major banana-producing areas and different agroecological conditions in Malang Regency, including variations in land use, slope, soil type, and rainfall distribution. Site selection was also supported by previous reports of banana cultivar distribution and Fusarium wilt occurrence in the region. Field surveys were carried out in six sub-districts, namely Sumberpucung, Kalipare, Wajak, Dampit, Tajinan, and Pakis (Table 1; Figure 1). At each location, symptomatic banana plants were randomly selected within the observation area for disease scoring and pathogen isolation. The results of the intensity of fusarium wilt disease were carried out using a scoring method for disease symptoms in each surveyed location.

2.3. Tools and Materials

The tools used in this study were petri dishes, micropipettes, measuring pipettes, LAF, beaker glasses, erlenmeyer flasks, microscopes, scalpel blades, and autoclaves. The materials used were banana plant stems infected with the disease, 70% alcohol, 5% NaOCl, Potato Dextrose Agar (PDA) media, tissue, and sterile distilled water.

Table 1. Scoring results of fusarium wilt symptom mapping on banana plants in Malang Regency

Survey locations		Total of Fusarium wilt
District	Regency	
Karangates - Sumberpucung	Malang	0
Arjowilangun - Kalipare	Malang	1
Tambakrejo - Wajak	Malang	0
Pamotan - Dampit	Malang	0
Ngawonggo - Tajinan	Malang	2
Asrikaton - Pakis	Malang	2
Average		0.833

0: Healthy plants, no visible disease symptoms on plants (0%); 1: Plants infected with mild disease, visible disease symptoms 1-25%; 2: Plants infected with moderate disease, visible disease symptoms 26-50%; 3: Plants infected with severe disease, visible disease symptoms \geq 51%

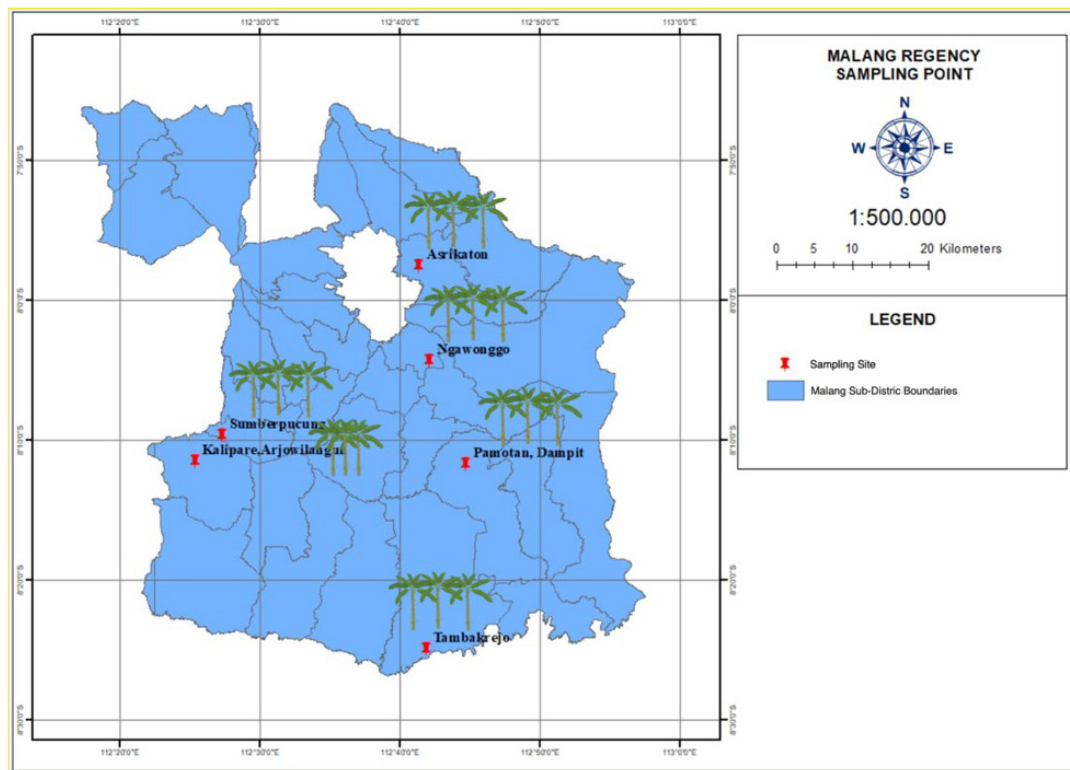


Figure 1. Distribution map of survey locations for *Fusarium* wilt disease in banana plants across Malang Regency. The map displays district and sub-district names as well as the number of samples collected from each site

Fungus isolation was obtained from the stem part that showed symptoms of being attacked by the disease. The stem sample was cut with a size of 2 x 2 cm and soaked in 5% NaOCl for 1 minute, then rinsed using sterile distilled water for three times. Dry on sterile tissue and inoculate on PDA media. Media incubation was carried out for 72 hours, after the isolate was obtained, purification was carried out into new media (Zainudin *et al.* 2025). Microscopic observation of pure isolates was carried out by making slide cultures, then observed under a microscope with magnification of 400x (Figure 2).

2.4. Pathogenicity Assay of *Foc* in Banana Plants

The pathogenicity test was observed to verify whether the isolated *Foc* could cause disease in banana plants. The *Foc* isolates were cultured in Potato Dextrose Broth (PDB) medium for 7 days at 37°C to allow sufficient fungal growth. The inoculation method followed the procedure described by Zhang *et al.* (2021), in which banana roots were deliberately wounded using a sterile scalpel blade to facilitate infection. The wounded roots were then immersed in 30 mL of *Foc* spore suspension for 30 minutes. Disease symptoms were observed and recorded 14 days post-inoculation to assess the pathogenic potential of the fungus.

2.5. GIS-Based Spatial Analysis

The method for maps used is the Citra Interpretation, DEM Derivatives, Point Interpolation. To collect the spatial data needed in the observation parameters, a DEM (Digital Elevation Model) is a visualization of topography or ground elevation based on deterministic interpolation containing position coordinate information (x, y) and elevation (z) for each pixel is needed for land use, land slope, soil type and isohyet (rainfall pattern) (Iswari & Anggraini 2018). In ArcGIS software, the Slope tool is used to produce a slope map which can then be classified into relevant categories (Darmawan *et al.* 2024).

The method of classified land use is by extracting data from satellite citra, specifically Landsat Citra. Landsat Citra data input process is carried out by determining the coordinate system to be used. Then, raster and vector data are added to the Landsat Citra data working layer. Next, coordinate system projection is performed using Composite Bands and Project Raster is performed to see whether the coordinate system correction is successful or not yet. Next, perform Area of Interest (Clip), which then uses the Landsat Citra that has been composited and its coordinate system corrected, and take the Malang city area. The results of the Landsat Citra data clipping will

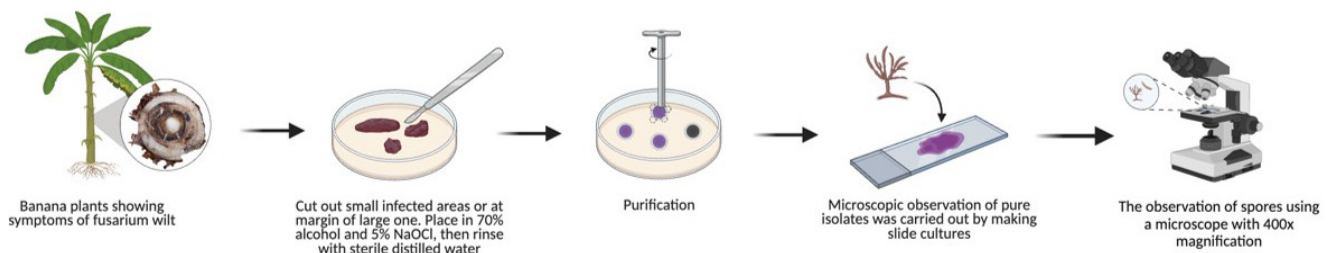


Figure 2. Isolation and purification of Fusarium wilt disease symptoms banana stem on PDA medium

later be used for land change analysis. The next step is to sharpen the Landsat Citra used sharpening to make the Landsat Citra data sharper and more detailed, thereby facilitating land cover identification. The next step is to identify land cover using the supervised classification method, which is used for classification based on samples created for land cover types.

Land slope: This data preparation activity collects DEM data and administrative boundaries in shapefile (shp) format. Data processing includes combining DEM data (mosaic) and then creating slope data using the Slope tool. After that, it is also clipped to match the administrative boundaries.

Isohyet Map: Prepare rainfall data and base map of administrative boundaries., Input data into ArcGIS software, convert Excel tables to shapefiles, and ensure that the coordinate system matches the selected area, Interpolate rainfall using Spatial Analyst Tools Interpolation, then select IDW (Inverse Distance Weighted) interpolation to produce a raster, Create contours with the interpolated raster data using Spatial Analyst surface analyst contour, then determine the interval according to requirements, Symbolize the isohyet map and finally overlay it with the base map

Soil Type: Preparation of soil type data (shape file) from FAO, Prepare base map: administrative boundaries, rivers, roads from Geoservice.BIG.go.id, Enter data into ArGIS, Checking the projection/coordinate system, Processing soil type data by ensuring that the soil type layer has soil type attributes, Symbolization, Overlay with a support layer by adding administrative boundaries above the soil type layer. Soil type data were then entered and reclassified. After all data layers were prepared, the Intersect tool was used to combine land use, slope, soil type, and rainfall into unique land units. Finally, the land unit map was visualized and exported for further analysis (Hariyanto *et al.* 2024).

Land unit maps are zones with significant environmental homogeneity created by overlaying well-structured vectors from remote sensing images,

topographic maps, geology, morphology, pedology, and land cover maps. The process of overlapping maps is carried out using Intersection tools on vector data and adjusting the Datum selection area. This method is used to combine maps and produce new data.

2.6. Epidemiological Modeling of Fusarium Wilt in Banana Plants

This epidemiological modeling was carried out using the SIR (Susceptible, Infected, Recovered/Removed) epidemiological model. The aim is to reflect the dynamics of the spread of fusarium wilt in banana plants. Furthermore, statistical analysis was also carried out to determine the influence of key parameters such as the level of pathogen transmission (β) and the rate of elimination or control of the disease (γ) on the development of the disease.

2.7. Intensity of Fusarium Wilt Disease Attacks on Several Banana Cultivars in Malang Regency

The analysis was conducted to determine which cultivars are more resistant or susceptible to Fusarium attacks by identifying 32 different cultivars referring to Lestarini *et al.* (2015). Each cultivar was tested separately, and the results were averaged to obtain the intensity value of the attack. The data obtained were then visualized in the form of a bar chart with gradient coloring using Python with the Matplotlib and Seaborn libraries to show the differences in intensity between cultivars (Cao *et al.* 2021; Sial *et al.* 2021). Seaborn was used to create a bar chart where the x-axis represents banana cultivars, and the y-axis indicates the intensity of Fusarium wilt attacks (Kumar *et al.* 2019).

2.8. Statistical Analysis

All statistical analyses and graphical visualizations were performed using Python version 3.11 with the Pandas, SciPy, Matplotlib, and Seaborn libraries. Spatial data processing and land unit modeling were conducted using ArcGIS software version 10.8. Spatial and non-

spatial datasets were integrated through overlay analysis by combining disease intensity data from field surveys with environmental thematic maps, including land use, slope, soil type, and rainfall distribution. The resulting integrated spatial layers were subsequently used to evaluate the environmental factors associated with Fusarium wilt distribution patterns in banana plantations.

3. Results

3.1. Symptoms and Characterization of Foc

To identify the causal agent and symptom characteristics of fusarium wilt in banana plants, a series of observations were conducted both in the field and in the laboratory. The study demonstrated that fusarium wilt disease in banana plants displayed both external and internal symptoms. External symptoms included yellowing of older leaves, progressing to wilting and drying (Figure 3A). Internal symptoms appeared as discoloration in the vascular tissues of the pseudostem from white to brown or brownish black (Figure 3B). Macroscopic observations of the isolates (Figure 3C) showed white colonies with a purplish underside and cotton-like texture. Microscopic characteristics (Figure 3D-F) revealed colorless microconidia with oval or oblong shapes, macroconidia, and round chlamydo spores.

3.2. Pathogenicity Assay in Banana Plants

The pathogenicity test confirmed the ability of Foc to cause disease in banana plants. Inoculated plants displayed significant symptoms of Fusarium wilt (Figure 4). Control plants, both prior to and 14 days after inoculation, remained healthy, with no signs of necrosis or disease symptoms. These suggested that mechanical root injury alone does not induce disease in banana plants. Conversely, plants inoculated with Foc exhibited characteristic symptoms of Fusarium

wilt, including leaf chlorosis, necrosis, and complete wilting. These observations confirm the virulence of the Foc isolate used in this study.

3.3. Land Unit Modeling and Epidemiology of Fusarium Wilt Disease

Based on spatial analysis, environmental factors influencing the distribution of Fusarium wilt disease in banana plantations across Malang Regency were examined using several thematic maps, including land use, land slope, soil type, and isohyet (Figure 5A-D). Land use patterns (Figure 5A) showed that banana plantations were classified as dense vegetation. Areas dominated by dense vegetation may consist of secondary forests, mixed gardens, or agricultural lands with perennial crops such as banana plants. Land slope characteristics (Figure 5B) varied from flat to very steep across the region. Tajinan and Pakis exhibited flatter topography, making them agriculturally suitable for banana cultivation but also more vulnerable to Foc infection due to water accumulation.

In contrast, steeper areas like Wajak and Dampit had better natural drainage, potentially reducing the risk of infection. Soil types (Figure 5C) also played a significant role. Wajak, characterized by fertile andic dystrudepts soil with good drainage, was favorable for banana growth and relatively lower Foc risk. Meanwhile, typical dystrudepts soils found in Pakis, Tajinan, and Kalipare, although fertile, were more prone to erosion and Foc incidence. Rainfall intensity (Figure 5D), derived from the isohyet map, ranged from light to heavy. Dampit District, with light daily rainfall (0.5-20 mm/day), offered favorable conditions that limited Foc spread. In contrast, Kalipare and Sumberpucung experienced higher rainfall, which may enhance the dissemination and proliferation of the pathogen.

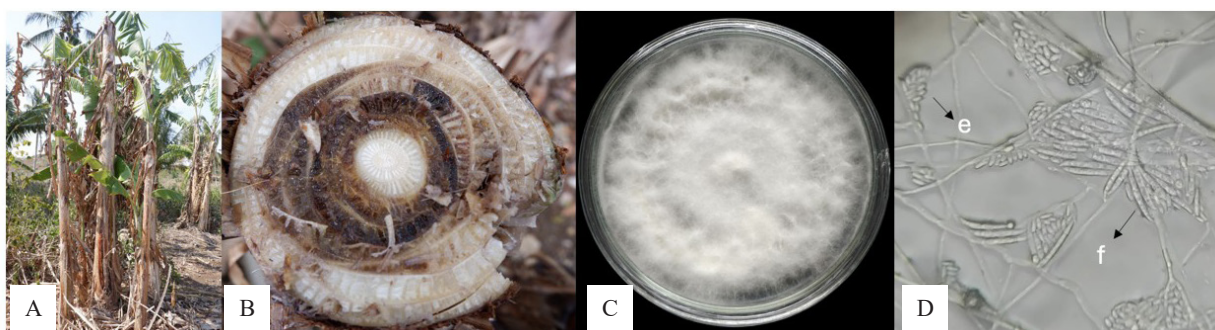


Figure 3. Observation of fusarium wilt disease symptoms and characterization of foc (A). External symptoms of fusarium wilt, (B). Internal symptoms of fusarium wilt, (C). Macroscopic characteristics of Foc, (D). Microscopic characteristics of Foc, (E). microconidia, (f). macroconidia

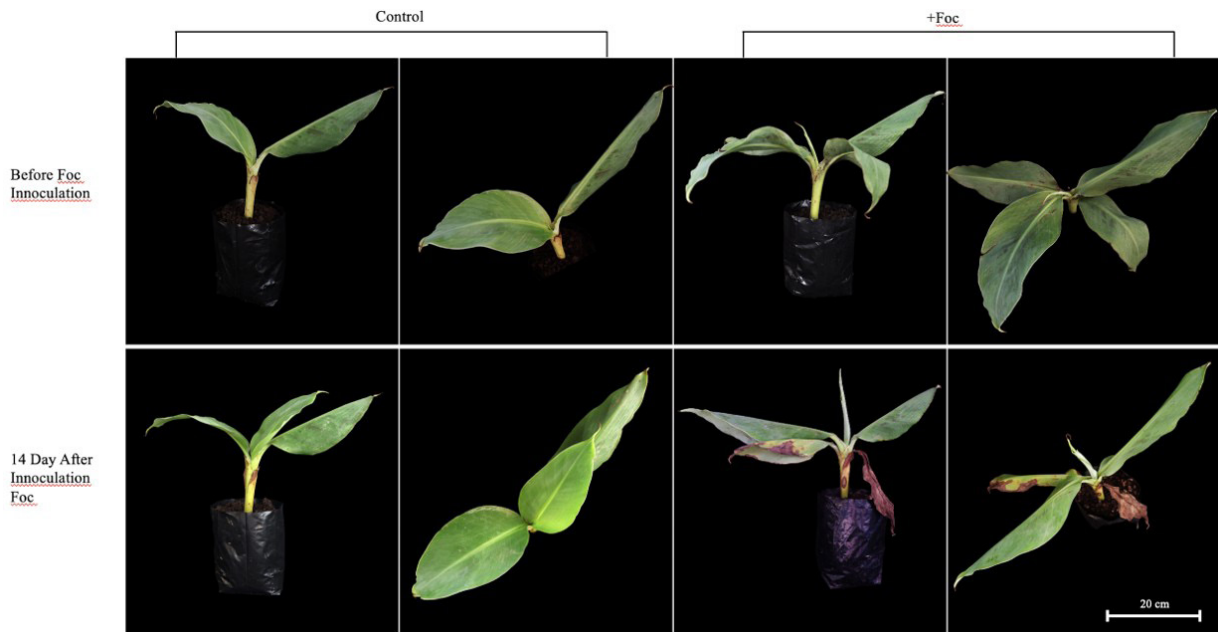


Figure 4. Pathogenicity assay in banana plants 14 days after inoculation foc

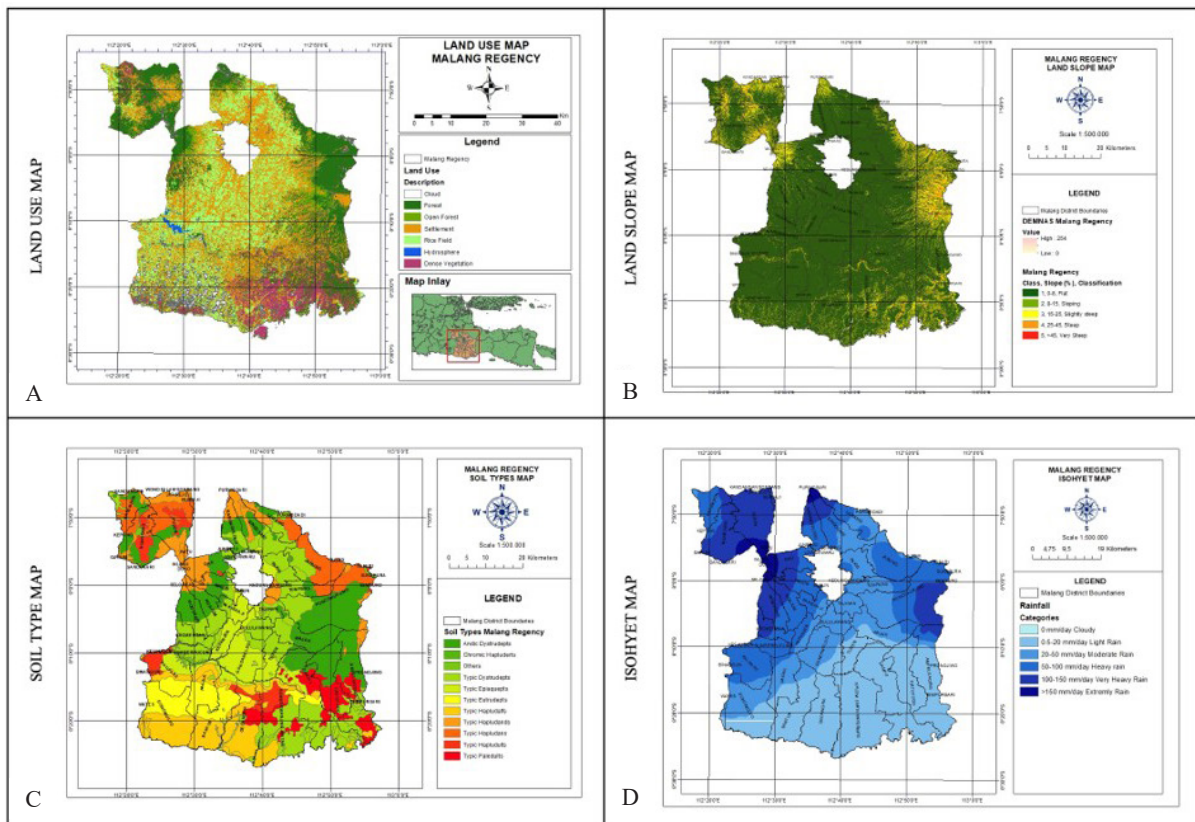


Figure 5. Land unit modeling and epidemiology of fusarium wilt disease in Malang regency. (A). Land use map; (B). Land slope map; (C). Soil type map; (D). Isohyet map

3.4. Epidemiological Modeling of Fusarium Wilt in Banana Plants

To further understand the dynamics of Fusarium wilt disease in banana plantations, an epidemiological model was applied using the classical Susceptible–Infected–Recovered (SIR) framework, which has been widely used in plant disease epidemiology. In this model, susceptible plants (S) become infected (I) at a transmission rate (β), while infected plants can move to the recovered state (R) at a recovery rate (γ). The dynamics are expressed as:

$$\frac{dS}{dT} = -\beta SI \quad \frac{dI}{dt} = \beta SI - \gamma I \quad \frac{dR}{dt} = \gamma I$$

Over a 160-day simulation period (Figure 6), the number of infected plants increased rapidly and peaked on day 40, reflecting the high transmission potential of the pathogen under favorable conditions. Subsequently, the infected population declined as the recovered class increased, with recovery peaking on day 80. This pattern indicates that disease management and host responses can reduce disease prevalence and support recovery, highlighting the usefulness of the SIR model in illustrating the epidemic progression of Fusarium wilt in Malang Regency.

3.5. Intensity of Fusarium Wilt Disease Attack on Several Banana Cultivars in Malang Regency

In this study, to assess the impact of Fusarium wilt across different banana cultivars, disease intensity was measured among 32 cultivars (Figure 7). The findings revealed variability in susceptibility, with 12 of the 32 cultivars showing a higher level of vulnerability to the disease. Among these, the Cavendish cultivar was notably more susceptible, while the BRS Platina cultivar demonstrated better resistance, particularly in the early stages of infection.

4. Discussion

Observations of disease symptoms confirmed that Foc induced characteristic manifestations in banana plants, including leaf chlorosis, vascular necrosis, and the formation of microconidia and chlamydo spores within infected tissues (Sukorini *et al.* 2021). Vascular discoloration and tissue degradation disrupted the transport of water and nutrients, ultimately leading to progressive wilting symptoms (Dita *et al.* 2018; Ploetz 2015). These findings are consistent with the reports of Isbatullah *et al.* (2023) and Sari (2023), who identified vascular discoloration as a primary diagnostic indicator of Foc infection. Furthermore, the presence of chlamydo spores reflects the pathogen's ability to survive for prolonged periods in soil environments,

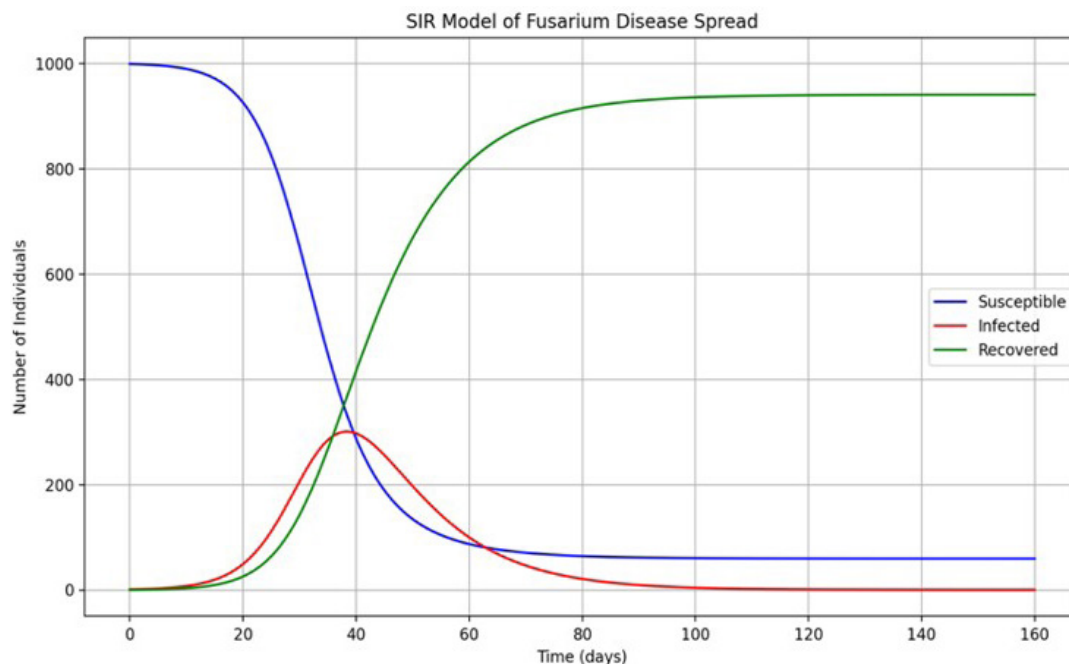


Figure 6. Epidemiological modeling of fusarium wilt using the SIR model

observation, fungal characterization, and pathogenicity assays. Spatial analysis demonstrated that environmental factors, including land use, slope gradient, soil type, and rainfall distribution, significantly influenced disease occurrence and distribution, with Tajinan and Pakis Districts exhibiting the highest disease intensity (score = 2). The SIR epidemiological model revealed that disease infection peaked around day 40, while the recovered plant population increased markedly until day 80, illustrating the temporal dynamics of disease spread and suppression. Among the 32 banana cultivars evaluated, Cavendish exhibited higher susceptibility to Fusarium wilt, whereas BRS Platina showed comparatively greater resistance. These findings highlight the importance of integrating spatial analysis, epidemiological modeling, and resistant cultivar selection to support sustainable Fusarium wilt management in banana production systems. Future studies are recommended to incorporate long-term epidemiological datasets and more detailed environmental analyses to improve predictive accuracy and enhance the effectiveness of disease management strategies against Fusarium wilt.

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