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LEAF WETNESS DURATION AS A CRITICAL AGROMETEOROLOGICAL VARIABLE FOR FORECASTING FUNGAL DISEASES IN CROPS

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Abstract

Leaf wetness duration (LWD) is one of the most influential agrometeorological variables governing the initiation and progression of fungal diseases in agricultural crops. It represents the cumulative period during which free water persists on leaf surfaces as a result of rainfall, dew, fog, irrigation, or guttation. Because many fungal pathogens require liquid water for spore germination, penetration and colonization, LWD serves as a direct environmental indicator of infection risk. Compared with other meteorological variables such as temperature, rainfall and relative humidity, LWD more accurately reflects the immediate microclimatic conditions experienced by pathogens at the host surface. This review synthesizes current knowledge on the biological significance of LWD, its interactions with temperature, methods of measurement and estimation and its application in disease forecasting systems. Classical studies established the mechanistic importance of leaf wetness in disease epidemiology, while more recent research has demonstrated that machine learning and artificial intelligence can improve LWD estimation and disease prediction. Evidence from wheat, grapevine, coffee, sorghum and other cropping systems confirms that accurate representation of wetness periods substantially enhances forecasting performance. Despite challenges in standardization and sensor deployment, advances in weather monitoring, neural networks and real-time analytics are enabling robust and scalable disease warning systems. Leaf wetness duration remains a cornerstone variable for climate-smart crop disease management and offers considerable opportunities for precision agriculture and sustainable plant protection.

Keywords: leaf wetness duration, fungal disease forecasting, agricultural meteorology, plant pathology, machine learning, crop protection

Introduction

Fungal and fungus-like pathogens cause major losses in crop production and remain a significant threat to global food security. Disease development depends on interactions among the host, pathogen and environment, with weather often being the most dynamic factor. Although temperature, rainfall, humidity and wind influence pathogen survival and spread, many foliar pathogens respond directly to the presence of free water on leaf surfaces. Leaf wetness duration (LWD), defined as the time leaves remain covered with water from dew, rainfall, fog, or irrigation, is therefore one of the most important variables in plant disease epidemiology.

LWD is biologically significant because many fungal spores require continuous moisture to germinate and penetrate host tissues. If wet periods are too short, infection does not occur; if they persist under favorable temperatures, disease risk increases rapidly. Huber and Gillespie (1992) established the theoretical basis for incorporating LWD into disease forecasting by showing that it integrates multiple atmospheric processes affecting pathogen infection.

Unlike standard weather variables, LWD is a microclimatic parameter influenced by canopy structure, leaf orientation, radiation balance and local topography. As a result, fields experiencing similar atmospheric conditions may differ substantially in wetness duration and disease risk. Studies across diverse crop–pathogen systems confirm its importance. Makowski *et al.* (2011) quantified wetness thresholds for *Mycosphaerella nawae*, while Carisse *et al.* (2020) showed that longer wet periods significantly increased grape anthracnose infection, especially at moderate temperatures.

Advances in agricultural meteorology have improved the estimation of LWD using sensors, empirical models and machine learning. Dalla Marta *et al.* (2005) demonstrated that artificial neural networks accurately estimated wetness duration for grape downy mildew forecasting. More recently, Bijlwan *et al.* (2025) and de Oliveira Aparecido *et al.* (2024) showed that machine learning models using weather variables, including moisture-related indicators, substantially improved prediction of crop disease severity.

Climate change has further increased the relevance of LWD-based forecasting. Altered rainfall patterns, rising temperatures and shifts in dew formation may change infection opportunities and disease distribution (Misra *et al.*, 2020). This review examines the biological significance, measurement and application of leaf wetness duration in fungal disease forecasting and highlights its continuing importance in precision crop protection and climate-resilient agriculture.

Biological and Epidemiological Significance of Leaf Wetness Duration

Leaf wetness duration (LWD) plays a central role in the infection cycle of many fungal pathogens because free water on leaf surfaces is often essential for spore germination and host penetration. Spores deposited on dry leaves generally remain dormant, whereas rainfall, dew, fog, or irrigation provides the moisture needed for germination and infection. The probability of successful infection increases as wetness persists under favorable temperatures.

Pathogens differ in their wetness requirements. Some infect after only a few hours, while others require more than 12–24 hours of continuous moisture. Makowski *et al.* (2011) showed that infection probability of *Mycosphaerella nawae* increased progressively with wetness duration, demonstrating the value of quantitative thresholds in forecasting models. Temperature strongly modifies this response, as shorter wet periods may be sufficient under optimal thermal conditions. Carisse *et al.* (2020) confirmed this interaction by showing that grape anthracnose infection increased significantly when prolonged wetness coincided with moderate temperatures.

Beyond primary infection, extended wet periods promote sporulation, inoculum release and dispersal, accelerating epidemic development. Nocturnal dew events can sustain infections even without rainfall. El Jarroudi *et al.* (2010) reported that night-time moisture conditions improved forecasting of wheat leaf rust, highlighting the importance of dew-induced wetness. In polycyclic diseases such as Septoria leaf blotch, rice blast and downy mildews, each wetness event can trigger a new infection cycle. El Jarroudi *et al.* (2017) further showed that hourly variations in wetness and humidity significantly improved disease prediction in winter wheat.

Leaf wetness duration is therefore a mechanistic link between atmospheric conditions and pathogen biology. By directly representing the moisture conditions required for infection, LWD consistently emerges as one of the most powerful predictors in plant disease forecasting and remains indispensable for understanding and managing fungal epidemics in crops.

Measurement and Estimation of Leaf Wetness Duration

Accurate measurement of leaf wetness duration (LWD) is essential for disease forecasting, but it remains difficult because wetness depends on dew, rainfall, fog, irrigation, canopy structure and radiation conditions. Unlike standard meteorological variables, LWD varies considerably within crop canopies and is strongly influenced by sensor placement and crop architecture.

Electronic leaf wetness sensors are commonly used to detect changes in electrical resistance or capacitance when water accumulates on an artificial leaf surface. These sensors provide detailed records of wet and dry periods, although their readings can differ depending on orientation, height and exposure to wind and solar radiation. Huber and Gillespie (1992) noted that this variability complicates the standardization of LWD measurements.

To overcome limited direct observations, LWD is often estimated from conventional weather data. Simple empirical models use relative humidity thresholds, while more advanced physical models simulate dew formation and evaporation using heat and moisture balance. Machine learning has further improved estimation accuracy. Dalla Marta *et al.* (2005) demonstrated that artificial neural networks effectively predicted LWD for grape downy mildew forecasting by capturing nonlinear relationships among temperature, humidity, rain.

High-frequency weather data also enhance LWD estimation. El Jarroudi *et al.* (2017) showed that hourly meteorological observations better represented short wet periods critical for fungal infection than daily averages. Recent developments in automated weather stations, wireless sensors and Internet of Things platforms now enable near real-time monitoring of canopy moisture conditions and support operational forecasting over large areas.

Although uncertainties remain due to differences in crop structure and local conditions, modern approaches combining physical models and machine learning have greatly improved LWD estimation. Accurate representation of wetness periods is therefore a key requirement for robust disease forecasting and precision crop protection.

Leaf Wetness Duration in Disease Forecasting Models and Future Perspectives

Leaf wetness duration (LWD) is a core component of plant disease forecasting systems because it directly reflects the moisture conditions required for pathogen infection. Most models combine LWD with temperature to identify infection periods and guide fungicide applications based on actual disease risk rather than fixed schedules, thereby improving efficiency and reducing unnecessary chemical use.

The value of LWD-based forecasting has been demonstrated in many crop–pathogen systems. El Jarroudi *et al.* (2017) showed that hourly variations in wetness significantly improved prediction of Septoria leaf blotch in winter wheat, while El Jarroudi *et al.* (2010) found that night-time moisture conditions enhanced forecasting of wheat leaf rust. Bhardwaj *et al.* (2021) similarly reported that moisture-related variables improved prediction of zonate leaf spot in sorghum.

In perennial crops, Carisse *et al.* (2020) established temperature–wetness thresholds for grape anthracnose and Dalla Marta *et al.* (2005) demonstrated that neural network-based LWD estimates enhanced forecasting of grape downy mildew. In coffee, de Oliveira Aparecido *et al.* (2024) successfully used machine learning and weather variables associated with wetness to predict Phoma leaf spot.

Recent advances in machine learning have further strengthened the role of LWD in disease prediction. Algorithms such as random forests and gradient boosting can analyze complex interactions among wetness duration, temperature, rainfall and disease history. Bijlwan *et al.* (2025) showed that real-time weather variability substantially improved prediction of crop disease severity, with LWD often emerging as one of the most influential predictors.

Climate change is expected to increase the importance of LWD-based forecasting by altering rainfall, humidity and dew formation patterns. Misra *et al.* (2020) noted that these changes may shift disease distribution and epidemic timing. Although challenges remain in measurement standardization and regional calibration, advances in sensor networks, remote sensing and precision agriculture are improving operational applications. By linking atmospheric conditions directly to pathogen infection, LWD will remain a key variable in intelligent and climate-resilient disease warning systems.

Conclusion

Leaf wetness duration is a pivotal agrometeorological variable that directly governs the infection and spread of many fungal pathogens. Unlike broad atmospheric indicators such as rainfall or relative humidity, LWD captures the actual presence of free water on leaf surfaces, making it a biologically precise measure of infection opportunity.

Research across wheat, grapevine, coffee, sorghum and other crops has consistently demonstrated that combining LWD with temperature substantially improves prediction of disease outbreaks. Advances in sensor technology, mechanistic modeling and machine learning have enhanced the accuracy and operational applicability of wetness-based forecasting systems. In the context of climate change and increasing demand for sustainable agriculture, LWD offers a powerful tool for optimizing fungicide applications, reducing production risks and strengthening climate-smart crop protection strategies.

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