Modeling of Plant Disease

EN250 Midterm & Final Report

"I pledge my honor that I have abided by the Stevens Honor System."

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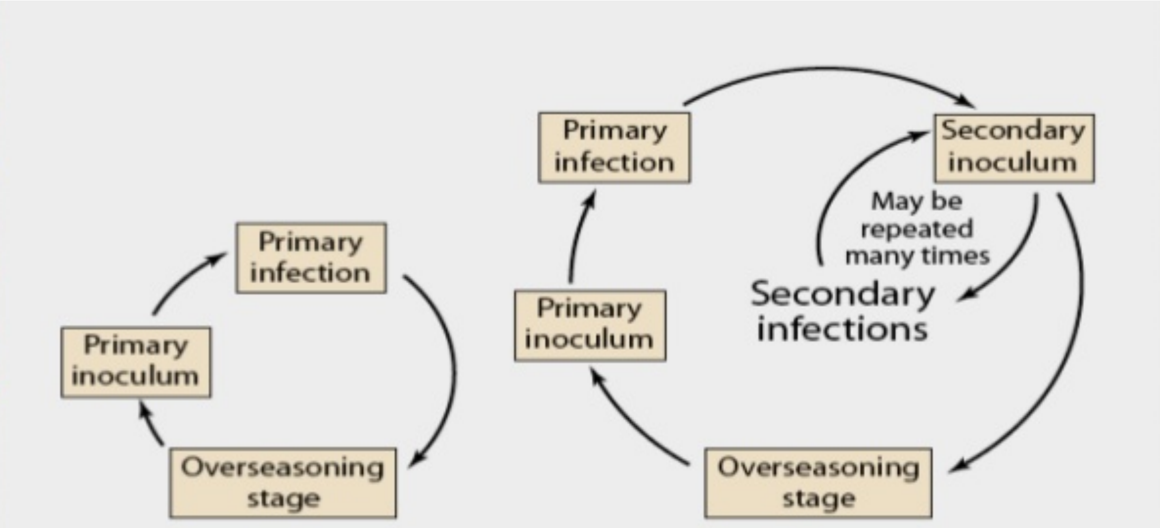
History of Modeling Plant Disease

Modeling plant disease is an approach taken to better understand the interactions between a host plant, the environment and the pathogen. This is done so in order to simplify and determine the potential growth of the disease and find solutions to prevent it from spreading as an epidemic over time. The study of plants dates back to before the Middle Ages and the information discovered was credited greatly to philosopher Theophrastus, considered the "father of botany." Theophrastus' research laid grounds for further plant research, taking large strides with the invention of the microscope in the 19th century. This invention allowed for the examination of plant cells and their interactions with foreign substances like a pathogen [5].

Throughout time, plants have been afflicted by plant diseases that can kill the host plant and spread to surrounding ones. When crops contract a disease, it can spread throughout an area over time, killing a majority of the crops in that area. Plant disease epidemics have caused humans to face horrific famines in the past with no understanding of a solution to stop the disease [6]. The notable Irish Potato Famine of 1845-1952 was caused by the spreading of a fungus *Phytophthora infestans,* or a potato blight. This epidemic spread throughout Ireland, killing half of the country's crops the first year, and three quarters of the following years' yield. Relying heavily on the potato for food, Ireland's people starved, killing roughly one million and forcing another million to leave Ireland. However, with advances in plant disease modeling following shortly after, plant pathologists are able to study and analyze the spread and growth of plant diseases to protect plant growth and prevent another catastrophic famine from occurring [5].

Types of Plant Diseases

There are thousands of different pathogens that can infect a plant, all of which are categorized as either a Fungus, Fungus-like Organisms, Bacteria, Viruses/Viroids, Virus-like Organisms, Nematodes, Protozoa & Algae, or Parasitic Plants. Plant diseases do not include plant eating pests, insects or other ectoparasites. Each pathogen reacts differently in different environments and in different host plants, making it important to have a general formula for understand-



Diagrams of (left) monocyclic and (right) polycyclic plant diseases. Monocyclic diseases lack secondary inoculum and secondary infections during the same year.

Figure 1.

ing and predicting a disease's growth [2].

A major separating factor for disease classification is whether or not the pathogen is monocyclic or polycyclic; the pathogen has a single infection cycle per year or the pathogen has multiple infection cycles per year. This is seen in Figure 1 above.

Disease Forecasting Systems

Disease Forecasting Systems use multiple parameters to predict growth and change of plant diseases. They are used to determine whether action must be taken to control a disease, including the use of a pesticide, rotating crops, or adjusting watering levels.

The first ever Disease Forecasting System was developed at the end of the 19th century, when botanist F.C. Stewart observed a bacterial wilt in his field of sweet corn and observed the corns' condition. Isolating and inoculating the bacteria with sweetcorn, he was able to reproduce the same condition of the wilted sweet corn and able to conclude low winter temperature would

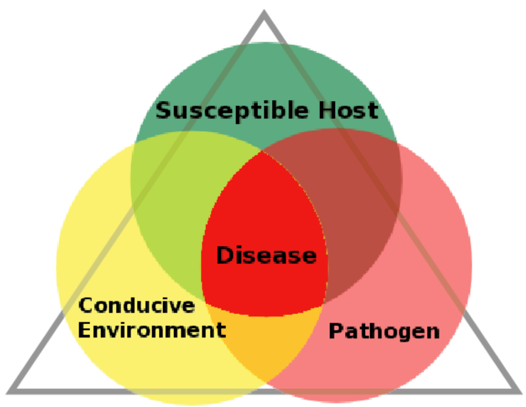


Figure 2. Plant Disease Triangle

kill the disease and prevent an epidemic [1].

Disease Forecasting Systems are assumption-based, meaning they rely on the observations of the plant's condition and environment's condition [4]. With correct analyzing, a prediction of when the pathogen, host plant, and environment interacting in a particular way that causes a disease can be made. These assumptions are based on the Plant Disease Triangle [4], seen above in Figure 2.

The assumptions are made on modeling factors necessary to accurately predict the outcome of a plant disease. The main factors (seen in Figure 2) include a susceptible host plant, a pathogen, and a conducive environment but can also include the factors both humans and time. A Pathogen is an infectious disease and can include information on growth factors including if it is monocyclic or polycyclic. A host is a susceptible plant, including details on its stage of growth and current condition. The environment should include details on temperature, moisture, rainfall, wind speed and other factors. In addition to these assumption factors, in order to accurately predict with a Disease Forecasting System, a person must have prior knowledge or data on the disease to correctly pick parameters.

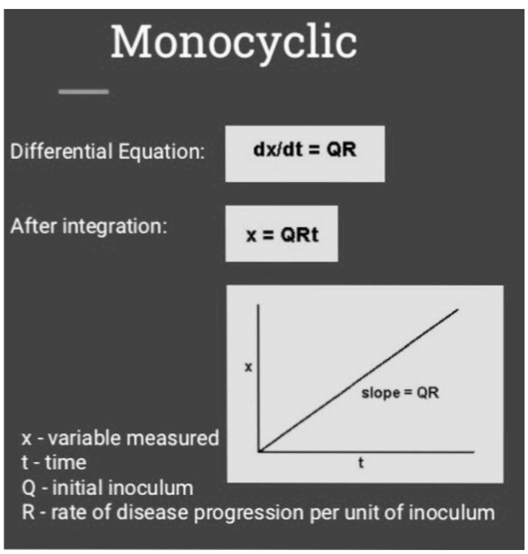


Figure 3a. Monocyclic

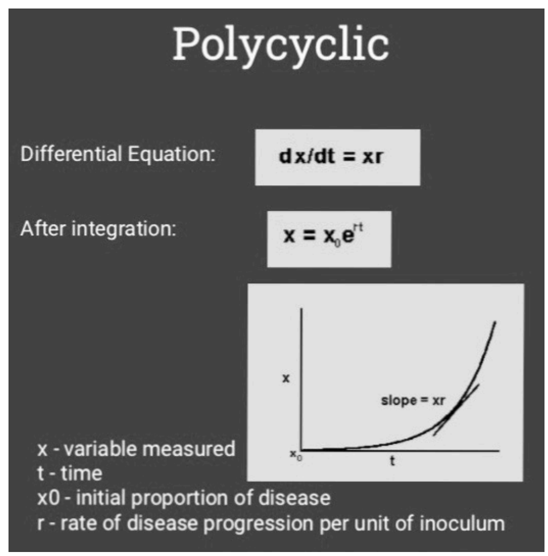


Figure 3b. Polycyclic

The data collected from these systems can be used to create Disease Progress Curves. Depending on the pathogen in question and the factors taken into consideration for a period of time, different disease progress curves can be used to compare effects of variables on the disease development [6]. Monomolecular curves are used for single-cycle, monocyclic diseases (seen in Figure 3a). Exponential can be used for understanding the scenario of an infected plant infecting another plant. Logistics curves are commonly used for polycyclic pathogens to model plant disease epidemics spreading (seen in Figure 3b). Using these curves and the area under them, can help to accurately predict optimal conditions a disease can thrive in, thus providing insight on how to control the disease.[3]

Applications and Importance

Disease is estimated to decrease plant yield 10%-20% each year, causing farmers to face major economic losses [6]. Without the modeling of plant diseases, this percentage of crops killed could greatly increase. The application of modeling diseases can help provide valuable data that can then be turned into solutions. Pertaining to the individual disease and its host, disease management solutions can accurately be made in order to protect plant growth, provide reliability for farmers and prevent loss of income. However, disease management solutions made from the models of plant disease are the most important application, preventing catastrophic famines similar to the potato blight epidemic of Ireland from occurring again.

<u>Final Report</u> - Statistical Analysis of Real Data:

<u>Report:</u> "Xylem cavitation susceptibility and refilling mechanisms in olive trees infected by *Xylella fastidiosa" [7]*

Olive orchards, during autumn of 2013 in Apulia south Italy, were severely affected by a disease denoted olive quick decline syndrome (OQDS). The presence of *Xylella fastidiosa*, was detected in the olive stands in the area off the Ionian coast of the Salento peninsula. The disease incidence increased rapidly through the heavily olive-grown countryside of the peninsula. *Xylella fastidiosa*, a gram-negative bacterium that colonizes xylem vessels, is transmitted to new host plants during sap feeding by insect vectors such as sharpshooter leafhoppers (Hemiptera, Cicadellidae) or spittlebugs (Hemiptera, Cercopidae) and spreads from the site of infection to the plant's network of xylem vessels. The problem occurring in olive trees is the colonization of xylem vessels by *Xylella fastidiosa* that compromises water transport causing the olive quick decline syndrome (OQDS). The plant's responses (tyloses, gums, sap, etc.) and the bacteria biofilm create vessel occlusions, causing the loss of hydraulic conductivity that triggers embolism. The ability of the infected plants to detect embolism and to respond, by activating mechanisms to restore the hydraulic conductivity, can influence the severity of the disease symptomatology.

In Apulia, however, olive trees appear to be the host of major economic relevance, reacting to infection with scattered desiccations of twigs and small branches that show first on the upper part of the crown, then extend to the rest of the canopy, which acquires a blighted aspect. OQDS attacks lead to the death of the trees within a few years from the onset of the symptoms.

The conductive environment was the area of the Ionian coast of the Salento peninsula (Apulia, southern Italy). In the coastal areas of the Mediterranean, the climate is temperate and the winters are wild. Favorable conditions for bacterial growth and the alarming scenario of hosting colonization. A study recently detailed the olive orchards wide distribution in Apulia and the abundance of a bacterial vector (philaenus Spumarius L.) Populations are the factors that contribute the most to the entrenchment of *X. fastidiosa* in the territory and to the emergence of the associated disease. The bacteria origins are of South America.

Xylella fastidiosa, a phytopathogenic bacterium that can infect all Citrus cultivating plants. The endophytic bacterial communities of healthy, resistant, can be studied using cultivation as well as cultivation-independent techniques. Xylella fastidiosa, a xylem-limited Gram-negative bacterium. Xllella fastidiosa growth factor results were observed in Pierce's disease of grapevine a high proportion of colonized vessels in infected leaves were not blocked and instead had small colonies or solitary cells, suggesting that vessel blockage is not a colonization strategy employed by the pathogen but, rather, a by-product of endophytic colonization. The conclusion in olive orchards "olive quick decline syndrome (OQDS)" in olive trees; OQDS causes the die-back of the leaves, twigs and branches causing fruiting to stop. The lack of spread within orchards and limited persistence in the leaves from year to year were a limited occurrence and distribution of the disease. Under these conditions the xylella fastidiosa caused olive quick decline syndrome is considered to be a monocyclic disease. Not only found to be recognized to be the causing agents of leaf scorch (PD) X. fastidiosa is the agent in phony peach disease (PPD) in peach (Prunus persica), citrus variegated chlorosis (CVC) citrus X disease, almond leaf scorch (ALS), Prunus amygdalus and plum leaf scald (PLS) in Prunus domestica, coffee leaf scorch (CLS), Coffea arabica and the oleander leaf scorch (OLS).

This study uses the Student’s t-test to determine the statistical differences between the quantitative continuous data of xylem vessel diameters and the plant's vulnerability to cavitation, Dividing the difference in means by the variance in data. The equation of VI = VD/ VF explains the numerical equation used to explore the differences between the groups of plants, based on the number of vessels per mm2, divided by the average vessel diameter. The increased number of vessels per area would likely increase the risk of possible embolism and/or cavitation due to the increased area of water movement per vessel. The diameter of the vessel posed a different aspect of vulnerability or resistance, meaning the diameter of the vessels also accounts for a change in vulnerability to, or resistance of, possible embolism in the plants. This ultimately means it may have a protective effect if a high VI unit is found due to increased number of vessels, or vice versa. The VI value takes all of these factors into account, and assigns a numerical value to compare groups of plants in whichever category (vessel diameter comparison or differences by species of plant). The Student t-test was used to test the statistical significance of the differences found in the vessel density for different classes of cultivars (Table 2 and 3) It shows that there is a statistically significant difference between groups of Cellina di Nardo and Leccino involving the Anatomical Characters (vessel density) and Vulnerability index (VI) and that vessels frequency was lower in the stem of the cultivar Cellina di Nardò making it more vulnerable at a statistical significance of $P<0.001$.

Table 2

T-test outputs of the vessel diameter classes comparison between the stems of the cvs. Leccino and Cellina di Nardò.

	Vessel diameter classes					
	0–15 µm	15–30 µm	30–45 µm	45–60 µm	60–75 µm	75–90 µm
Cultivar	0.0319*	0.0082**	0.1450	0.0003***	0.0005***	0.1261

*Significance at $P < 0.05$; **Significance at $P < 0.01$; ***Significance at $P < 0.001$.

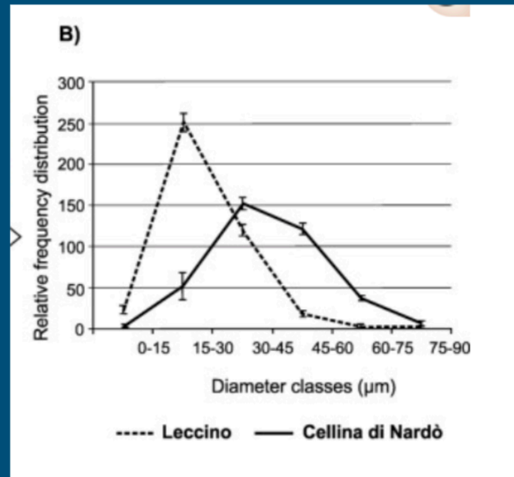
Table 3

Anatomical characters and Vulnerability index (VI) of the olive cultivars Cellina di Nardò and Leccino.

Cultivar	VD (µm)	VF (N/mm^2)	VI
Cellina di Nardò	45.70 ± 11.29***	36.60 ± 2.76***	1.25
Leccino	27.46 ± 9.49***	40.70 ± 2.18***	0.67

VD = Vessel diameter, VF = Vessel frequency (number of vessels per mm^2, N/mm^2), VI = Vulnerability index.

***Significance at $P < 0.001$.



In the report, the measurement of the xylem vessels diameter in the two Olea europaea the Leccino and Cellina Di Nardò could potentially provide an indication of susceptibility to *Xylella fastidiosa*, causing decrease of xylem water-transporting that could cause embolisms. Differences in susceptibility can be determined by the anatomy of the xylem. These findings are major in the sustainability of crop production systems and major constraints on crop production that cause significant losses on a global scale.

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