GROUND-BASED TECHNOLOGIES FOR COTTON ROOT ROT CONTROL

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Abstract

Phymatotrichum, or cotton root rot (CRR), is a fungus currently affecting broadleaf crops including cotton in the southwestern U.S. and northern Mexico. The ability of CRR to lie dormant in the soil for several years tends to negate the effects of crop rotation, and it remains a problem for cotton because there are currently no genetically resistant cotton strains, and chemical solutions to date have not been cost-effective. The overall goal of this research is to develop ground-based technologies for early detection and site-specific management of CRR. Early detection could facilitate a more economical solution than those that might be used after plant infection had become more severe and widespread. Three cotton fields were chosen for field data collection. Freshly picked cotton leaves from healthy, disease-stressed, and dead plants were scanned with an ASD VisNIR spectroradiometer. Surface soil moisture, temperature, and electrical conductivity were measured in each field with a Delta-T WET sensor. A thermal infrared camera was used to capture leaf canopy images of healthy and disease-stressed plants. A complete soil apparent electrical conductivity survey will be conducted for each field using an EM-38 sensor. Plant status was visually inspected and recorded to form a series of disease progression maps in each field. These data will be analyzed to (1) identify promising means for early detection of CRR, (2) relate disease occurrence to soil data, and (3) develop sound strategies for site-specific management of CRR.

Introduction

Phymatotrichopsis omnivora, otherwise known as cotton root rot (CRR), is a highly destructive fungus affecting dicotyledonous plants in the southwestern United States and northern Mexico (Uppalapati et al., 2010). CRR penetrates the roots of broadleaf plants and blocks the flow of water from the roots to the leaves for transpiration, causing the leaves to wilt (Yang et al., 2005). In general the fungus will not infect entire fields (Lyda, 1978); instead it will begin from different locations throughout the field and spread in a circular pattern from those foci (Uppalapati et al., 2010). Due to the added stress the fungus puts on the plant, infected plants usually produce a lower lint yield and lower quality cotton than healthy plants from the same field (Yang et al., 2005). Yield and quality are the principal determiners of profitability in cotton production, so CRR can have serious effects on profitability.

Much work has been done concerning the life cycle, treatment methods, and remote sensing identification of CRR. The life cycle of CRR begins and ends with sclerotia (Uppalapati et al., 2010), which are the food-storage bodies of the fungus that allow it to lie dormant in the soil. In the next phase of the life cycle, thin strands called hyphae branch out from the sclerotia in search of an additional nutrient source or host (Uppalapati et al., 2010). As more and more hyphae branch out of the sclerotia they begin to form thicker bundles called mycelium. Upon contact with

a host root the mycelial strands unbind and allow the individual hyphae to engulf and penetrate the root (Uppalapati et al., 2010). Once the plant has been infected, the hyphal stands on the root's surface begin to form new sclerotia in order to complete the life cycle (Uppalapati et al., 2010).

The widespread effects of CRR have brought about several treatment methods with limited success. Due to the fungus's ability to deplete the starch on the host's roots, high nitrogen fertilizers have been used to increase the amount of starch deposited in the roots (Lyda, 1978). It is also believed that carbon dioxide in the soil facilitates the growth of CRR while simultaneously suppressing the growth of competing saprophytes (Lyda, 1978). As a result, many have used deep plowing to aerate the soil and minimize the occurrence of CRR (Lyda, 1978). Several chemical compounds have also been examined for their influence on disease spread. It was found that sodium chloride was effective in lowering the disease incidence in soils known to be infested with the fungus. Furthermore, four to ten times less exchangeable sodium existed in infested soils than in soils producing healthy plants (Lyda, 1978). Overall, current practices have limited ability to prevent the spread of CRR in production fields.

In an effort to increase the economic feasibility of some current treatment methods, an attempt has been made to identify problem areas in specific fields with remote sensing. Aerial images of a cotton field's canopy in three different color bands (near infrared, red, and green) were classified into areas of healthy or diseased plants (Yang et al., 2005). The resulting disease maps were modified to remove healthy areas surrounded by disease that were too small for farm equipment to practically avoid (Yang et al., 2005). The data were further analyzed to add a buffer around the infected areas to account for disease spread (Yang et al., 2005). The final images served as maps of the cotton fields displaying treatment areas (Yang et al., 2005). These maps were completed with the assumption that the main stress present was CRR (Yang et al., 2005).

The objectives of this project are first to understand the progression of CRR in a field both temporally and spatially, and second to develop a method and sensor for early detection of plant infection. While this paper will focus only on objective 1, it is important to keep in mind that work towards objective 2 will expand on the results of objective 1.

Materials and Methods

The objectives will be achieved through the analysis of several data sets collected over multiple growing seasons. In the first year (2010), disease maps of plots were made on multiple visits during the growing season so that disease progression between each trip could be shown. A Delta-T WET (Water content, Electrical conductivity, and Temperature) sensor (Delta-T Devices Ltd., Burwell, Cambridge, United Kingdom) was used to measure soil water content (WC) or volumetric soil moisture at predetermined points within individual plots in order to form WC maps. Plant leaves throughout the plots were also collected and scanned with an ASD VisNIR spectroradiometer to determine specific wavelength ranges useful in identifying early onset of CRR. A PalmIR thermal infrared camera (SPI Infrared, SPI CORP, Las Vegas, NV) was used to capture images of the crop canopy and indentify stressed plants. On a larger scale aerial images were taken of the entire fields where the research plots were located. These aerial images were used to guide where in the fields that soil apparent electrical conductivity (ECa) data should be collected. All the data taken within each research plot are to be examined for correlations with disease maps. Similarly, the ECa data will be compared to the aerial images to examine possible relationships between ECa and infected cotton plants on a larger scale.

Three plot locations were chosen for the collection of data during the 2010 growing season. The first plot was located on the Stiles Farm & Texas A&M Research Center at Thrall, in the Northern Blackland Prairie of Texas. The plot measured twenty-four rows wide by approximately forty-five yards (forty-five paces) long. The second plot, located near Sinton, TX falls in the Southern Subhumid Gulf Coastal Prairies of Texas. The plot at Sinton measured fifteen rows wide by approximately thirty yards (thirty paces) long. The third plot was located in the Red

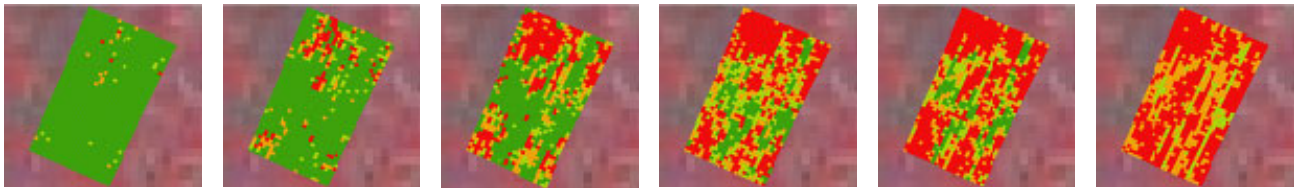
Prairies of Texas near San Angleo, and measured twenty-four rows by approximately forty-five yards (forty-five paces). Data collection for the Thrall location was based on a weekly schedule, whereas that for the Sinton and San Angelo locations was based on a bi-weekly schedule.

Several types of data were collected at each plot. Disease maps were created by visually evaluating the plants in each pace of each row and rating them on a scale of one to four, from healthy to dead. Data points for measuring WC were established every five paces in every third row of the plots. The WET sensor used to measure WC was inserted three times at the soil surface and once in a hole 10 to 15 cm (4 to 6 in.) deep at each data point in the plot. By averaging the three surface measurements, the data for the exposed soil were more repeatable. On each visit leaf samples were taken at the same points where WC was measured, every fifth pace of every third row. Reference leaves were also collected to provide examples of each disease stage one through four. Leaves were collected at the plot and stored in plastic zipper bags which were placed inside a cooler on ice. Once all samples were collected, the cooler was taken back to the lab where the leaves were analyzed. The leaf collection procedure was based on a study done by Thomasson and Sui (2009) that proved this method to have minimal effects on leaf reflectance spectra within 6 hours of picking. Each leaf was then scanned twice with the ASD VisNIR spectroradiometer to give the reflectance signature that could be used to classify the leaves. The PalmIR thermal infrared camera was used to examine the canopy of the plot in an attempt to identify plant stresses that might be invisible to the naked eye. Different angles between the crop canopy and the camera were attempted in order to obtain the most contrasting images between healthy and infected plants. Aerial images were collected on each plot to show the spread of CRR on a larger scale. Four cameras with optical filters were used to obtain the aerial images in near-infrared (NIR) (810-850nm), red (630-670nm), green (530-570nm), and blue (430-470nm) bands (Yang, 2010). The images were taken from an aircraft at approximately 2600 m altitude during clear conditions to limit atmospheric interference (Yang, 2010). The ECa measurements were collected with an EM-38 sensor (Geonics Limited, Mississauga, Ontario, Canada) over a large area of the field. The areas of measurement were selected based on information obtained from the aerial images. The EM-38 sensor (Geonics Limited, Mississauga, Ontario, Canada) was pulled through every sixth row of the sample areas to obtain a uniform distribution of data. Vertical measurements with the EM-38 were taken straight down into the soil whereas horizontal measurements were taken at a more shallow depth in the soil going out from the EM-38.

Almost all of the data collected in this work are spatially variable, and so analyses were initiated by mapping the data with their GPS coordinates in ArcGIS. The plots were then broken down into a grid based on the row-by-pace dimensions, and the collected data were stored at the appropriate locations on the map. Disease level, WC, and ECa maps as well as aerial images were linked in ArcGIS. Thermal infrared images and the spectral scans of the leaves are spatially variable but in a less defined manner; therefore they have not been entered into ArcGIS and must be handled on more of a case-by-case basis. Spectral scans were classified according to their relationship to the reference leaf scans from the same plot on the same date.

Results and Discussion

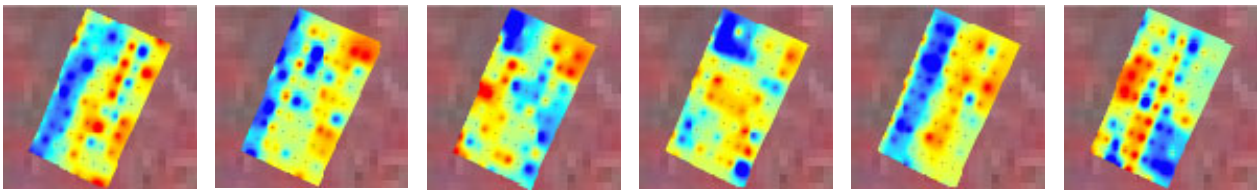
ArcGIS maps, aerial images, leaf spectra, and thermal infra red images are the major sources of data used to develop an understanding of how CRR spreads within a field. The ArcGIS maps from the San Angelo plot provide a visual example of the data produced at each plot. Figure 1 demonstrates the disease spread from one visit to the next.



7/20/2010 8/3/2010 8/17/2010 8/24/2010 9/2/2010 9/23/2010

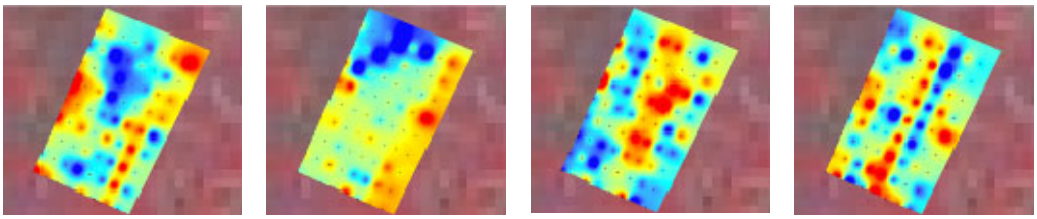
Figure 1, The disease map from each visit at the San Angelo plot (1: healthy = green, 2: disease stage 1 = yellow-green, 3: disease stage 2 = orange, 4: dead = red).

From Figure 1 we can see that the fungus begins infecting plants in a small area, and as it spreads it fills in the gaps between infected plants and spreads radially from that location. Similarly, WC measurements were used to make volumetric soil moisture maps of the plot at each visit as shown in Figures 2 and 3. These maps were interpolated with the inverse-distance ratio of the twelve closest measured points. In the future, kriging may be implemented for interpolation if the data warrant it, but for now trends are evident with this more simplistic method.



7/20/2010 8/3/2010 8/17/2010 8/24/2010 9/2/2010 9/23/2010

Figure 2. The volumetric soil-moisture maps interpolated from the Delta-T WET sensor data taken at the soil's surface in the San Angelo plot. Red represents low soil water content and blue represents high soil water content.



8/17/2010 8/24/2010 9/2/2010 9/23/2010

Figure 3. The volumetric soil moisture maps interpolated from the Delta-T WET sensor data taken at 4 to 6 inches below the soil's surface in the San Angelo plot. Red represents low soil water content and blue represents high soil water content.

Cursory observation of the WC data does not yield any profound results. However, further statistical analysis may give a clearer correlation between disease spread and WC. ECa maps taken at the San Angelo plot on Wednesday December 15th, 2010 were mapped, and the map placed side-by-side with the aerial image from August 23rd, 2010 in Figure 4. The vertical and horizontal ECa maps look similar as expected, because they are measuring the same soil properties at the same points, just in different directions from the sensor. In both maps a higher level of ECa is brown, and the ECa value decreases as the color changes to blue. A color-infrared (CIR) composite (NIR, red, and green in lieu of red, green, and blue) of the aerial image shows lighter patches of gray where infected plants are located, and darker red patches denote healthy cotton plants (Yang 2010). By examining the three images in figure 4 it is clear that some relationship between high ECa and infected plants exists in this case.

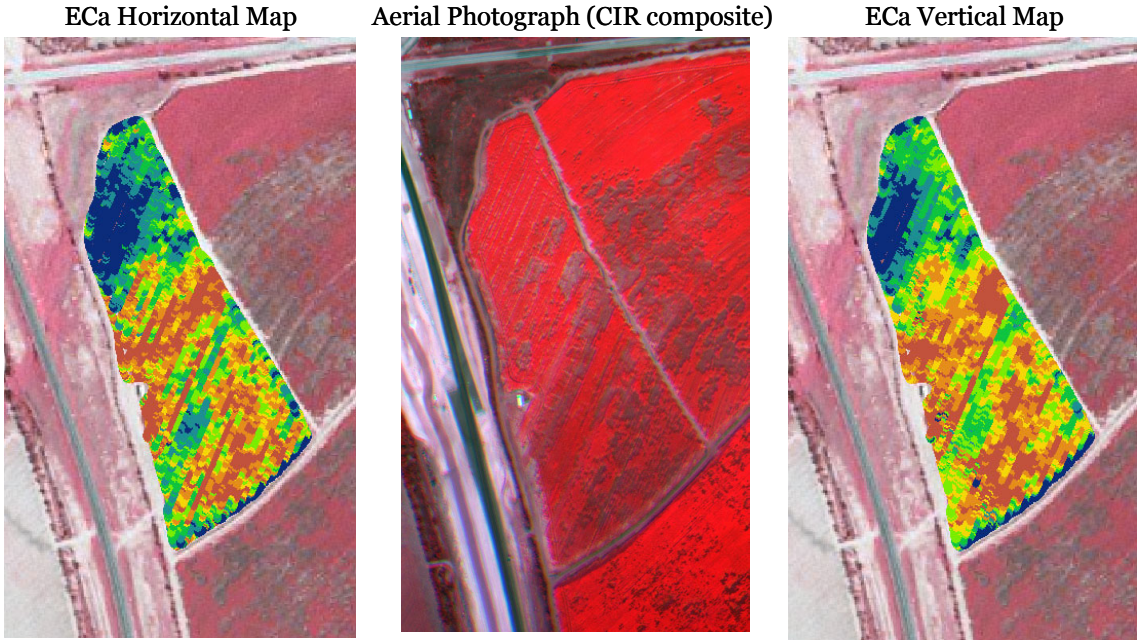


Figure 4. Color-infrared composite of the aerial photo from late August 2010 (gray patches represent infected plants and red patches represent healthy plants) compared against the two ECa maps created in mid December 2010 (brown denotes high ECa and blue denotes low ECa). Vertical and horizontal refer to the direction in which the ECa measurement is taken from the EM-38.

Figure 5. Two sets of digital-color (lower) and thermal-infrared (upper) images. Infected plants are noticeable in digital-color images but become prominent and easy to distinguish in thermal-infrared images. Thermal-infrared images could help distinguish infected plants before symptoms are visible to the naked eye, because they display even slightly warmer temperatures (stressed leaves) as lighter shades, whereas darker shades represent cooler temperatures (healthy leaves).

Figure 5 provides examples of thermal images taken at the Thrall plot on August 3rd, 2010. These images provide the opportunity to see the temperature of the plants displayed as shades of gray. The thermal infrared images use lighter shades to denote warmer temperatures and darker shades to denote the cooler ones. It is clear that the

infected plants are warmer than healthy ones as a result of their diminished ability to perform transpiration (Yang et al., 2005). Spectral scans of leaf samples were also studied as a means to define specific wavelengths that could potentially identify infected plants. Figure 6 presents reflectance curves of the four defined disease stages. Wavelengths where the reflectance differs greatly between healthy leaves and disease-stage-one infected leaves would be most beneficial in producing an optical sensor for early detection. By identifying and using these wavelengths, a higher level of accuracy could be designed into a sensor to differentiate between completely healthy plants and plants at an early stage of disease progression. Once developed, a sensor for early detection of CRR might allow producers to manage CRR fungus in their fields by allowing for spot treatments with chemicals to stop the disease spread across the field.

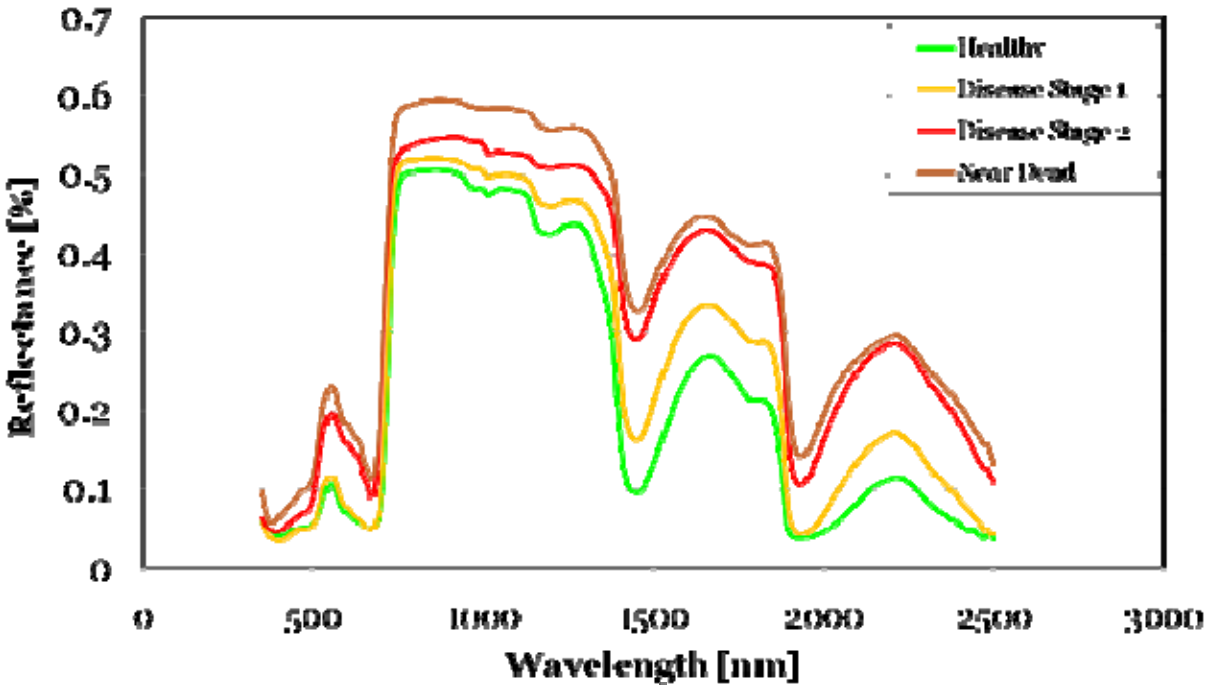


Figure 6. Reflectance of healthy cotton leaves and those at various stages of infection versus wavelength of incident light.

Conclusions

Based on the data that have been collected in the first year of the study, two preliminary conclusions can be drawn:

- Aerial images of a CRR-infested cotton field appeared to have some correlation with ECa maps.
- Thermal infrared images accentuate visible differences between healthy and unhealthy leaves.

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