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DETECTION AND POPULATION ESTIMATION OF THE RENIFORM NEMATODE ON COTTON USING HYPERSPECTRAL REMOTELY SENSED DATA

Amber T. Kelley, Gary W. Lawrence, John Vickery, Roger King, and Hee-kyung Lee
Department of Entomology and Plant Pathology
Mississippi State University
Mississippi State, MS

Abstract

The reniform nematode (*Rotylenchulus reniformis*, Linford and Oliveira 1940) is one of the most prevalent nematodes on cotton (*Gossypium hirsutum* L.). This nematode inhibits cotton plant development resulting in reduced plant growth and sometimes plant death; cotton crop yield loss up to 40-60% has been due to reniform nematode infestations. In 2001 and 2002, controlled field microplots were used to study the correlation between reniform nematode population thresholds and reflectance properties exhibited by infected cotton plants. Reflectance properties, measured by a hand-held hyperspectral spectroradiometer, were used to develop self-organized maps (SOMs). SOMs were used to determine relationships between cotton plant stress and nematode population thresholds. Using a Matlab based hyperspectral toolkit (MHTK) operating with SOM analysis, classification accuracies of 94.7-100% (2001) and 80-100% (2002) were found using a spectral range of 451-949 nm.

Introduction

Cotton (Gossypium hirsutum L.) is an important cash crop in 14 states in the US including the state of Mississippi. To ensure high crop yields, cotton producers must reduce weeds and pests such as insects that abate cotton plant development. Oftentimes, plant-parasitic nematodes are the primary pests responsible for cotton plant stress resulting in reduced cotton yields, thus decreasing producer economic returns (Birchfield 1962.)

In Mississippi, the reniform nematode was identified on cotton in 1980. Since identification in Mississippi, the reniform nematode has become a great economic pest of cotton and has been found in 51 different counties (Lawrence et al. 1990). Due to the lack of nematode resistance in midsouth varieties and because transgenic cotton varieties do not reduce nematode infestations, cotton producers must depend on crop rotation and nematicides to manage nematode populations. To determine the reniform nematode as the primary contributor to yield loss, and to determine the necessary nematicide management program to be used, cotton producers must first collect numerous soil samples from the cotton field(s) in question. The samples are sent to a laboratory where nematode extraction and identification can take place. This is an extensive and sometimes costly process that can take several weeks to complete possibly causing the producers to miss the window of opportunity to initiate the necessary nematode management program. However, by using hyperspectral imagery, this process may be eliminated saving cotton producers both time and money.

Using a remote sensing device, such as an Analytical Spectral Device (ASD), we can collect spectral information about objects in areas of the spectrum that we cannot observe with our eyes alone. The FieldSpec Pro Spectroradiometer (an ASD) gathers data from 350-2500 nm in the electromagnetic spectrum (EMS). To date, spectral reflectance analyses have been useful in agricultural related research including weed area estimation (on a limited basis), plant and crop disease detection, and vegetation map development. (Everitt et al. 1999).

In 1975, Gausman et al studied the reniform nematode to determine if differences of cotton leaf reflectance due to varying reniform nematode population numbers were detectable. Reflectance levels of cotton leaves of plants inoculated with the reniform nematode and leaves of plants not inoculated with the nematode were measured. Gausman et al. found that nematode stressed leaves have lower reflectance values than non-stressed leaves suggesting a potential for distinguishing nematode infested cotton plants from non-infested cotton plants by analyzing the leaves' spectral reflectance values.

Therefore, spectral imagery may be a useful remote sensing tool in correlating cotton plant stress and nematode population thresholds enabling cotton producers to test for nematode presence while avoiding the time consuming and sometimes-costly soil sampling process presently used today.

Self-Organized Maps

To analyze the hyperspectral data, self-organized maps (SOMs) were explored. The self-organizing map (SOM), introduced in 1981, is an artificial neural network (ANN) software tool that allows visualization of high-dimensional data (Kohonen, 1990). ANNs are information processing systems modeled after the human nervous system. These networks may be described as libraries of mathematical models that are analogous to neurons bound to one another by synapses. ANNs are capable of pattern recognition in complex data systems, including spectral systems. SOMs use pattern recognition to identify similar features. Once those features are recognized, SOMs then group those similar features by implementing the Euclidian

distance formula (King, et al. 2002, Kohonen et al. 1996). This formula determines the similarity of the data through "an iterative process of selecting a neuron and determining whether other neurons in a 'neighborhood ' should move closer or further away (Null, 2002)." SOMs organize high-dimensional data by compressing the data into a two-dimensional plot according to similarities of the data samples. By implementing the SOM, the hyperspectral data is more easily visualized for human analysis than the original three-dimensional cube. Null, using somtoolbox2, developed SOMs to determine if various weed species could be identified from one another and from the crop, soybeans, using spectral data. Results of this study showed separation classification accuracies of 70-85 % of various weeds species in soybeans (Null, 2002).

With the encouraging results from the 2001 weed study, MATLAB was used as the computational engine in this research. Application of SOMs utilizing a MATLAB based hyperspectral toolkit (MHTK) was the analysis function of interest. The purpose of the MHTK was to perform spectral dimension analysis by manipulating input hyperspectral data employing built-in data analysis techniques. The MTHK with SOM development was used in this research to examine the correlation between hyperspectral remotely sensed data to cotton plant stress by known levels of *R. reniformis*. Microplot tests were conducted.

Materials and Methods

The tests were conducted in field microplots located on the North Plant Sciences Research Farm at Mississippi State University. Microplots were fiberglass cylinders, which consisted of 76-cm-d placed 45 cm deep in Sough fine sandy loam soil (68.4% sand, 11.6% clay, 20.0% silt, 0.3% OM, 8.0 CEC, 6.4pH). Microplots were similar to large isolated pots in which we could critically control nematode numbers while subjecting the cotton plants to natural environmental conditions. Microplots were fumigated with methyl bromide (bromomethane, 680.4 gm/30.5 m^2) under 4.5-mil thickness polyethylene for 72 hours and aerated prior to planting. Plots were planted with PayMaster 1218 cotton variety on May 17 in 2001 and with cotton variety Sure Grow 215 on May 15 in 2002. Cotton varieties used were susceptible to the *R. reniformis* and contained the Bt gene for insect resistance.

Microplots were infested with increasing population levels of *R. reniformis* in the top 15 cm^3 of soil at time of planting. Initial population levels (Pi) consisted of Pi= 0, 2,500, 5,000, 7,500, and 10,000 reniform nematodes per 500 cm^3 of soil. Cottonseeds were planted in a single row in each pot. The test was arranged in a randomized complete block design with 10 replications. Cotton plants were allowed to grow and develop throughout the growing season. Plots were watered with a trickle irrigation system. Frequent insecticide applications were necessary in order to obtain spectral imagery due only to the reniform nematode. Nematode population development was followed by sampling each microplot biweekly. Soil samples consisted of six soil cores 2.25-cm-d x 15-cm deep collected from the cotton root zone in each microplot. A 100 cm^3 subsample was processed for *R. reniformis* enumeration. *R. reniformis* was extracted from subsamples using the gravity screening and centrifugal floatation method.

Temporal reflectance readings from the plant canopy alone and canopy and soil were observed biweekly using a FieldSpec Pro hand-held hyperspectral spectroradiometer with a 1.4 m (25° field-of-view) fiber optic cable. A single leaf reading on a black background was measured biweekly using the spectroradiometer with an active light source (tungsten filament) to reduce variability innate with the use of a passive light source (the sun). Plants were tagged for subsequent identification to ensure consistency in spectral sampling. The black background was placed behind the cotton leaf to eliminate background spectral effects. For the single leaf readings, the cotton leaves selected were located 3 nodes posterior from the apical portion of the plants. Four readings per component from each pot were taken in 2001. In 2002, two readings per component from each pot were observed to reduce the enormity of spectral data. The hyperspectral reflectance measurements were collected in the 350-2500 nm spectral range with a total of 2151 individual spectral bands for each hyperspectral curve. A bandwidth of 1.4 nm at 350-1050 nm and a bandwidth of 2 nm at 1000-2500 nm was used. The specific growth stage of the cotton plants was recorded during each data collection date. Hyperspectral data and corresponding *R. reniformis* population data were analyzed with the Matlab based hyperspectral toolkit (MHTK).

Results and Discussion

2001 Test

Canopy with soil, single leaf, and plant canopy spectral measurements and corresponding reniform nematode population levels were analyzed using the MHTK with SOMs. Water bands and bands containing electronic noise were removed prior to SOM analysis. Two batches of SOMs were run for each target. The first batch concentrated on bands 451-949 (visible and NIR regions of the EMS). The second batch ran with not only bands 451-949 but also 1001-1339 (NIR and SWIR). For all three targets, classification accuracies were highest in batch one analysis. Single leaf had a classification accuracy of 94.7%, plant canopy, 100%, and plant canopy with soil 100% (Table 1). Sixteen bands were identified on the spectral curves for all three targets specific to the reniform nematode population levels by the MHTK.

2002 Test

Single Leaf, plant canopy, and canopy with soil spectral measurements and corresponding reniform nematode population levels were analyzed using the MHTK with SOMs. Water bands and bands containing electronic noise were removed prior

to SOM analysis. Two batches of SOMs were run for each target. The first batch concentrated on bands 451-949 (Visible and NIR). The second batch ran with not only bands 451-949 but also 1001-1339 (NIR and SWIR). For single leaf, higher classification accuracy was found using the first batch of bands (491- 949) with a classification accuracy of 80% in batch one and 60% in batch two. Plant canopy had a classification accuracy of 100% for both batch one and 66.7% for batch two. Canopy with soil classification accuracies were 100% for both batch one and two (Table 2). Sixteen spectral bands were identified on the MHTK spectral curves and were identical to those identified in 2001.

Future Research

Further work should follow this study to extract the 16 relevant bands in reniform nematode detection on cotton. Aerial images of reniform infested cotton fields should be analyzed using the MHTK focusing on the 16 relevant bands and the population spectral curves created in this study. With that accomplished, a MHTK software package can be developed relative to reniform nematode detection on cotton.

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Table1. MHTK classification accuracies for reniform nematode population counts and corresponding spectral curves.2001.

Target	Bands Used	Accuracy (%)
Single Leaf	451-949	94.7
	451-949, 1001-1339	83.3
Plant Canopy	451-949	100
	451-949, 1001-1339	66.7
Canopy + Soil	451-949	100
	451-949,1001-1339	83.3

Table 2. MHTK classification accuracies for reniform nematode population counts and corresponding spectral curves. 2002.

Target	Bands Used	Accuracy (%)
Single Leaf	451-949	80
	451-949, 1001-1339	60
Plant Canopy	451-949	100
	451-949, 1001-1339	66.7
Canopy + Soil	451-949	100
	451-949,1001-1339	100