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DETECTION OF *SOLENOPSIS INVICTA* (HYMENOPTERA: FORMICIDAE) NESTS USING SPECTRAL DATA

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Abstract

Rapid detection of red imported fire ant (*Solenopsis invicta* Buren; Hymenoptera: Formicidae) nests is important in assessing the control efforts and for monitoring dispersal of this pest. In this study, spectroscopic techniques were employed to characterize the reflectance spectra of fire ant nest soil and the areas surrounding the nests. The results showed significant differences between nest soil, grass, and bare soil not disturbed by fire ant at the 680 nm wavelength of the electromagnetic spectrum. The reflectance of nest soil was 10% to 15% lower than that of the surrounding non-nest bare soil at wavelengths of 780 to 1000 nm. Furthermore, the reflectance of nest soil was significantly correlated with soil water content (R^2 = 0.962).

Key Words: control, dispersal monitoring, red imported fire ant, reflectance spectra, soil moisture

Resumen

La detección rápida de los nidos de la hormiga de fuego roja importada (*Solenopsis invicta* Buren; Hymenoptera: Formicidae) es importante en el monitoreo del control y dispersión de esta plaga. En este estudio, se utilizó la técnica espectroscópica en los nidos de la hormiga de fuego para detectar el espectro del reflejo enl suelo de los nidos y su alrededor. Los resultados mostraron diferencias significativas entre el suelo de los nidos, la grama, y de los nidos de otras especies de hormigas en suelo estéril a los 680 nm de longitud de onda del espectro electromagnético. El reflejo del suelo de los nidos fue del 10% a 15% menor que el suelo estéril alrededor del nido a longitudes de onda de 780-1000 nm. Además, el reflejo del suelo del nido fue significativamente correlacionado con el contenido de agua del suelo (R^2 = 0.962).

Palabras Clave: control, monitoreo de dispersión, hormiga de fuego roja importada, espectro de reflejo, humedad del suelo

The red imported fire ant (RIFA), *Solenopsis invicta* Buren (Hymenoptera: Formicidae), is native to South America, and is a common agricultural and medical pest across the world and was accidentally introduced in Guangdong, China (Zeng et al. 2005). This fire ant, with its painful sting, is more aggressive than most native ant species. Its invasion poses a serious danger to human health, public safety, agricultural and forestry production, and the environment. Moreover, it was listed as one of the 100 most dangerous invasive species in the world (Adams 1986; Lofgren 1986; Allen et al. 1994). Thus, prompt control measures are necessary to counteract the hazards posed by fire ants, and utilization of rapid detection methodologies would assist fire ant management.

For large-scale investigations, satellite, or aerial imagery, or both, were previously used to provide area-wide images of large RIFA mound distributions (Vogt 2004a,b). However, the inspection and counting of RIFA mounds by ground surveys is still one of the most important methods for investigating the degree of occurrence of this pest. Dogs have been trained and used to detect and identify fire ant mounds (Lin et al. 2011). Also, to determine whether a RIFA nest exists and is active, the color and shape of the nest surface and the nearby undisturbed soil can be visually compared, while the mound may be poked with a stick to observe if ants would come pouring out. However, this traditional method is labor intensive. Importantly the rapid and accurate detection of RIFA nests is the key to large-area control since it facilitates the targeted application of precise insecticide treatments, which reduce both the environmental and economic costs of chemical control (Lin et al. 2011). The purpose of this study was to evaluate our hypothesis that the RIFA nests and the areas surrounding them have differences in surface light reflection characteristics, and that these differences are adequate to locate RIFA nests.

Methods and Materials

Study Site

The current study was performed in the summer of 2011 on a RIFA-infested lawn (approx. 30,000 m^2) at the South China Agricultural University, Guangzhou. The lawn was predominantly covered with bermudagrass, *Cynodon dactylon* L. (Poales: Poaceae). The mean density of the active RIFA nests was 5/100 m^2. The fire ant was suspected to have invaded to the lawn when it was newly planted in 2009. The surface soil of the RIFA mounds and the surrounding bare soil and grass were studied.

Description of Soil and Fire Ant Mound Aggregates

The soil texture at our investigation site was a sandy loam with 50% sand (2-0.05 mm). Specific information concerning the texture of the fire ant mound soil aggregates and of the soil surrounding the mounds is shown in Table 1.

Equipment

To describe the spectral characteristics of the various land-surface features, the HyperSIS hyperspectral imager (Zolix, Beijing, China) was employed. This imager has a spectral range of 400 to 1000 nm with a spectral resolution of 3 to 10 nm.

Sampling and Test Treatment

The spectral-information-based detection system collected spectral information including images for spectral data analysis and image processing to determine if spectral signatures of RIFA nests could be defined in order to distinguish them from other features around the mound. If this separation could be accomplished, then a scientific basis for developing appropriate photoelectric sensors that quickly detect RIFAs mounds would lead to additional procedures to eliminate their nests and prevent the further spread of the RIFA.

We used the following 3 approaches:

(1) The fire ant nest soil, surrounding non-nest soil, sand, and grass were separately placed into the HyperSIS hyperspectral imager to obtain the spectral data of each feature from samples. Then the reflectances of the fire ant nest soil and surrounding soil were compared in the field. The test data were simultaneously acquired from 5 test groups in 5 different test areas of the same lawn.

(2) To determine the relationship between the fire ant nest soil reflectance and soil moisture content, the following steps were performed. First, the fire ant nest soil was sampled and weighed. Then, the reflectance was measured using the hyperspectral imager. Second, the sample was placed into an oven and dried at 105 °C for 8 h. After the sample had cooled it was weighed and tested again using the hyperspectral imager. Third, the soil moisture was altered by uniformly spraying the sample 17 times with water, and the spectral reflectance and weight of each sample were measured after each sample was permeated completely by water. Six replicates were conducted.

(3) To characterize the differences between lumpy and granular soils, their spectral reflectances were tested several times using the hyperspectral imager. Six sub-samples of each soil feature type were conducted.

Statistical Analysis

The variations in the reflectance values of the different samples were analyzed using the General Linear Model. When ANOVA results were significant, multiple comparisons of means were performed by Tukey HSD post-hoc analysis. Linear regression was used to analyze the correlation between the reflectance value and soil water content. All statistical analyses were conducted using the SPSS 13.0 software package.

Table 1. Properties of the fire ant mound soil aggregates and of the soil surrounding the mounds on a lawn on the of South China Agricultural University, Guangzhou.

	Soil texture			
Source	% sand (2.0-0.05 mm)	% silt (0.05-0.002mm)	% clay (< 0.002 mm)	Soil type
Soil surrounding the mounds	50.00 ± 1.15	45.67 ± 2.08	4.33 ± 0.58	Sandy loam
Fire ant mound soil aggregates	63.67 ± 4.51	30.33 ± 3.51	6.00 ± 1.00	Sandy loam

Results and Discussion

Reflectance Comparison between RIFA Nests and the Surrounding Objects

Rapid detection technologies have been used in managing some pest species (Lan et al. 2009; Zhang et al. 2011). To detect RIFA nests, the spectral reflectances of 4 kinds of soil samples, namely, RIFA nest soil, ordinary soil surrounding RIFA mounds, nearby grass, and bare sand in the same environment were compared using spectral technology. Then, their differences in the visible and near-infrared were detected. The spectral data (signal-to-noise ratios) were low in the 325 to 400 nm wavelength; hence, these bands were excluded from the analysis. By comparing the waveform trends, the reflectance spectrum of the RIFA nest soil was found to be similar to that of the ordinary soil, although their reflectance values were different in some wave ranges. The spectral reflectances of sand and grass differed significantly within the range of 500 to 700 nm, and the reflectances of these 2 substrates were evidently different from those of the RIFA nest and ordinary soil ($p < 0.05$; Fig. 1).

The results show significant differences ($p < 0.05$, Fig. 1) in the reflectance spectra of both the surface samples in the visible (590 to 630) nm and near-infrared (750 to 780) nm bands. The percent reflectance in the visible range (590 to 630nm) for non-nest soil was higher than the fire ant nest soil and the grass ($p < 0.05$, Fig. 1). In the 750 to 780 nm near-infrared band, the percent spectral reflectance of the grass was higher than that of the surrounding non-nest soil, sand, and the fire ant nest soil ($p < 0.05$, Fig. 1).

At the 560 nm visible wavelength, a significant reflectance difference was observed between any 2 samples, except for the surrounding non-nest soil and sand ($p > 0.05$, Fig. 1). At the 680 nm wavelength a significant reflectance difference was also observed between any 2 surfaces ($p < 0.05$, Fig. 1) with the fire ant nest soil reflectance ranging from 20% to 25%. These results distinguished the fire ant nest from the other surfaces. At the 760 nm wavelength, a significant reflectance difference was observed between any 2 samples, except for the surrounding non-nest soil and sand ($p > 0.05$, Fig. 1). For the 900 nm wavelength, only the reflectance difference between the sand and surrounding non-nest soil was observed to be insignificant ($p > 0.05$, Fig. 1).

Therefore, the spectral data of the 4 substrates were similar in trend and relatively smooth in the 700-1100 nm band. Also, near-infrared photoelectric sensors are readily available on the photoelectric sensor market. So, based on this research, a main band defined to be from 700 nm to 1100nm was selected to potentially distinguish fire ant nests from surrounding substrates.

Relationship between Reflectance and Soil Water Content of the RIFA Nest

The spectral reflectance of soils is determined by an assemblage of physical factors of which moisture content is deemed the most important, as it has the greatest overall impact on soil reflectance (Baumgardner et al. 1985). Thus, it has been suggested that mower-mounted spectral devices designed to recognize and map imported fire ant infestations need to record data from 3-5, user-selected wavebands (VIS, NIR, and SWIR) to optimize ant mound detection across seasons (DeFauw et al. 2009). In this study, wetness of soil was also found to affect the RIFA nest soil reflectance (Fig. 2), as assayed by the hyperspectral imager.

The results show that the effect of soil water content on the reflectance of the RIFA nest soil was insignificant ($p > 0.05$) in the 400 to 420 nm band, but was evident in the visible band. In particular, the reflectance percentages of the dry RIFA nest soil were approximately 10% and 15% higher than those of the wet samples in the 410

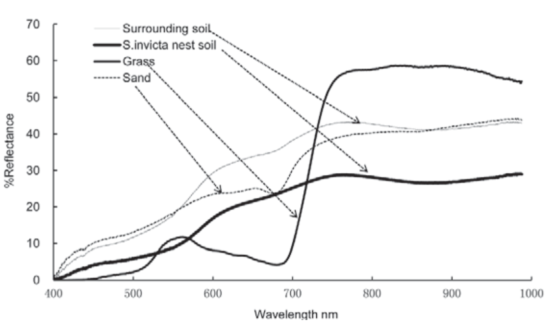

Fig. 1. Reflectance spectra of the soil of a red imported fire ant nest and surrounding or nearby surfaces consisting of grass, soil and sand.

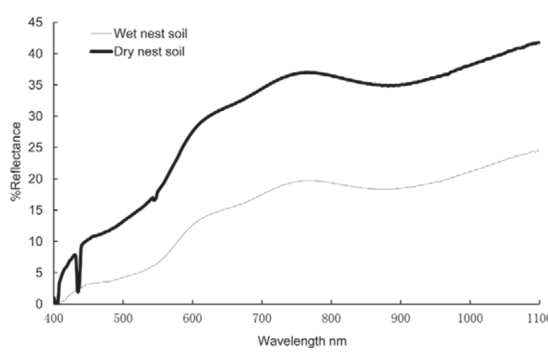

Fig. 2. Influence of soil wetness on the percent reflectance of various wavelengths from red imported fire ant nests.

to 600 nm and 700 to 900 nm bands, respectively (Fig. 2). Fig. 2 also shows that in the 900 to 1100 nm band the reflectance of the dry RIFA nest soil was approximately 15% higher than that of the corresponding wet soil.

The results indicated a strong linear correlation between the soil water content and reflectance (Fig. 3). With the RIFA nest soil reflectance and moisture at the 900 nm wavelength as an example, the following linear equation can be obtained:

$$Y = -0.761 \cdot X + 0.435 \ (R^2 = 0.962)$$

In the above model, X and Y denote the water content and reflectance of the fire ant nest soil, respectively, and also indicate the significantly negative linear regression relationship between the water content of the reflectance of the fire ant nest soil ($p < 0.01$).

Comparison of Soil Aggregates of RIFA Nest Soil and Aggregates of Nearby Ordinary Soil

After a series of samplings to obtain measurements outdoors, the RIFA nest soil was found to have smaller, smoother, and more uniform particles than the surrounding soil. The most common soil found throughout the study was lumpy soil, and aggregates of soil were observed on the fire ant nest surfaces.

These outdoor findings, meant an analysis of the relationship between soil aggregate size and spectral reflectance was also necessary. After bare ordinary soil samples were collected from the same place, the soil types were distinguished by sizes of the aggregates and obtaining the spectral reflectance using the HyperSIS hyperspectral imager. The reflectance spectra of the lumpy or cloddy soil and of coarse sandy soil are shown in Fig. 4; and the data presented are the averages of measurements of 3 samples. Further, Fig. 4 shows that the reflectance in the 750 to 1000 nm band of the cloddy soil was 5% to 10% higher than that of the granular soil under the same conditions ($p < 0.05$). Fig. 5 compares the reflectance of the granular fire ant nest soil to that of the surrounding cloddy ordinary soil, and shows that the reflectance of the cloddy soil is 5% to 10% higher than that of the nest soil ($p < 0.05$). These results agree with those of Fig. 4. Thus, we concluded that granular nest soil can be reliably distinguished from cloddy ordinary soil by the lower percent reflectance of nest soil compared to cloddy ordinary soil.

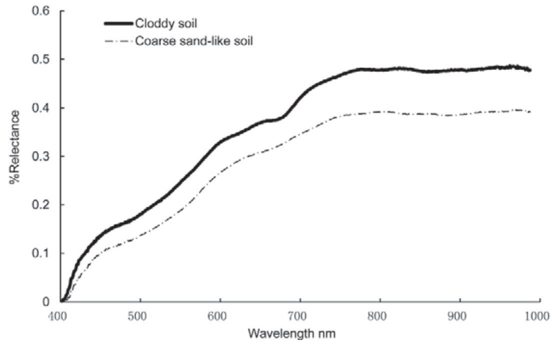

Fig. 4. Relationship between soil texture (lumpy, cloddy or block-shaped soil versus coarse sandy soil) and the reflectance spectrum.

Conclusions

In the current study, we used a hyperspectral imager to identify the wavelength characteristics of red imported fire ant (RIFA) mounds and surrounding surfaces to provide a scientific basis for further work to develop appropriate photoelectric sensors to quickly identify RIFA mounds. The results of the current study can be significant for the control and prevention of RIFA infestations. Fu-

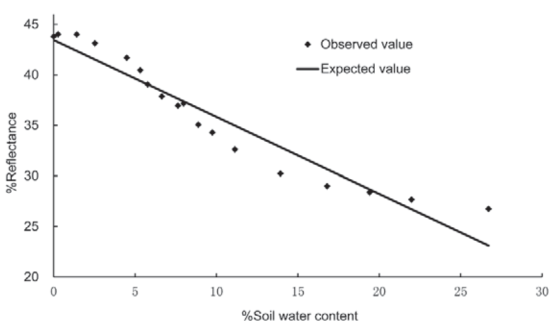

Fig. 3. Linearity of the fit of the 400 to 420 nm band reflectance and the percent soil moisture content of red imported fire ant nest soil.

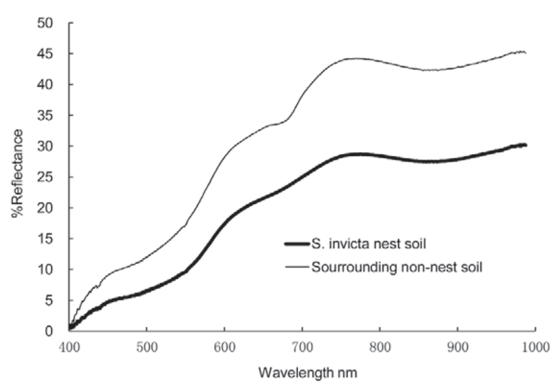

Fig. 5. Comparison of the percent reflectance of various wavelengths of light by the granular red imported fire ant nest soil and by the surrounding cloddy ordinary soil.

ture studies are recommended to integrate and optimize the data analysis, as well as to discover not only different spectral characteristics, but also the effect of the angle of incidence of either sunlight, or emitted light by an active sensor, on recognition thresholds between RIFA nests and other objects. A real-time, highly accurate spectral-information-based RIFA mound detection system can be built by merging spectral information of specific wavelengths, and by creating spatial contrasts from other image information obtained from a near-to-mid, remotely sensed field of view.

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