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Spot Spraying of Citrus Tree Canopies for Controlling Psyllids

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Since the Asian citrus psyllid *Diaphorina citri*, vector of the Huanglongbing (HLB) disease, feeds primarily on young leaf flushes, it was hypothesized that applying pesticides on only new leaves could mitigate the impact of pesticide loading on citrus trees. An automated technique capable of recognizing new leaves and spraying the pesticide only on those targets would be of great interest to growers by making the spray applications economical and environmentally sustainable. A sensing system was developed that could differentiate new (immature) from old (mature) leaves on citrus tree canopies, based on spectral reflectance characteristic of the leaves. Based on preliminary results, a laboratory test stand was built consisting of a four-band active optic sensor, control box and spray system components. Using the spectral reflectance data, various vegetative indices were calculated and the utility of each index for differentiating young and old leaves was investigated. The control box and its algorithm, managed different tasks, e.g., communication with the sensor, computation of the vegetation indices and operation of the solenoid-controlled spray nozzles. Series of tests were carried out to evaluate the performance of the system under various static and dynamic conditions. Six of the eleven different vegetation indices used for the test were able to differentiate new from old leaves. Normalized Difference Vegetation Index (NDVI-870) gave the best results in both static and dynamic tests. The orientation of the sensor also provided a significant effect on target identification of the leaves but mounting it perpendicular to the tree detected a higher number of new leaves than mounting it at an angle. This paper reports on the development of the system and shows the performance of the system under various operating conditions.

Psyllids not only cause direct plant damage to citrus trees through their feeding (Harbert and Manjunath, 2004) but also serve as an efficient vector of huanglongbing (HLB) disease. These insects feed on new leaves (immature flush) and their females lay their eggs on the tips of a growing leaf (Grafton-Cardwell et al., 2005). Citrus growers normally remove the trees found infected by HLB and routinely control the insects by frequent foliar pesticide applications. Potential problems associated with the frequent pesticide applications, e.g., the effect of pesticides on beneficial insects, can be minimized by applying pesticides only to the new leaves. This can also make the production more economical and environmentally sustainable. However, visually identifying the new leaves and selectively spraying them is laborious and slow, if not impossible.

NTech Industries (Ukiah, CA; <http://www.ntechindustries.com/weedseeker-home.html>) has developed a commercial ground based weed detection system, known as the WeedSeeker® that uses the reflection of a special light source to determine if a weed is present. The system is being used to control weeds in vineyards and orchards, however, the success of this technology is highly dependent on its sensing system that can accurately locate weeds in a dynamic environment.

Using the reflection of a special light source to determine a particular target such as vegetation, has been used for different applications such as identifying a natural gas leakage by using the spectral responses of the plants from the affected soil (Smith et al., 2004). Spectral reflection can predict crop canopy measurements, e.g., green area index, shoot dry matter, total nitrogen in the shoot (Muller et al., 2008) and the nutritional value of the high moisture grain corn (Fassio et al., 2009). The vegetation indices most commonly used for this purpose were based on red and near infrared (NIR) regions as vegetation produces a unique reflectance in these bands (Broge et al., 2000). For instance, a normalized difference vegetation index (NDVI), computed from the spectral reflectance measurements in the red and near infrared regions, was used to analyze if the object being observed contains green vegetation. This was primarily used in remote sensing applications to detect green plant canopies (Myneni et al., 1995). A preliminary study on the reflectance characteristics of citrus leaves showed that there was a difference between new and old leaves which was consistent with the work of Ye et al. (2008). The combination of this information and a localized "spot" sprayer system would be of great interest to citrus growers.

The objective of this study was to develop a spray system for spot treatment of young citrus leaf flushes for the economic control of psyllids (*Diaphorina citri* K.) in HLB management. The specific objectives were to 1) study the performance of different vegetation indices under static and dynamic conditions; 2) determine the effect of the angle and direction of the optical sensor; and 3) develop a spraying control system that could spray when the sensor identifies a young flush.

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Material and Methods

System hardware and software. A system was developed that scans a tree and computes the vegetation index of the scan area to determine if the area has young leaves. If young leaves were present, the system sends a signal to open the solenoid valve to spray. The system consists of a control box, a sensor, a pump, and the solenoid-controlled spray. The control box includes a microcontroller (Tern Inc., Davis, CA) and four Single Pole Double Throw (SPDT) relays. A preliminary study was conducted to characterize the spectral reflectance characteristics of the new and old leaves. Based on the results of the preliminary study, four bands were selected that could be used for differentiating the new and old leaves. The identified wavelengths were 554, 676, 870, and 960 nm. Since sensors with those wavelengths were not commercially available, a small portable four band active optic sensor (hereafter, referred to as a four-band sensor), was custom built (Applied Technologies LLC, Stillwater, OK). The four-band sensor (Fig. 1) consisted of four light sources that closely represented the identified wavelengths. Two of the light sources were in the visible region (570 and 670 nm) and two in the near infrared (NIR) region (870 and 970 nm). After activation, the reflected wavelengths from the four light sources were captured by a Charge-Coupled Device (CCD) array sensor receiver located at the center of the four light sensors. The CCD automatically generated four reflectance values as shown in Table 1. These reflectance values were then sent to the serial port where a handheld Personal Digital Assistant (PDA) or a laptop computer can be connected to record the readings. The same serial port of the four-band sensor was connected to the control box for communication between the controller and the sensor.

A pump (Shurflo LLC, Cypress, CA) was used to generate the required pressure of 345 kPa (50 psi) for operating spray nozzles that were connected to solenoid valves (Teejet Technologies, Wheaton, IL). A microcontroller was a C/C++ programmable controller based on the 32-bit 133 MHz Advance Micro Devices (AMD) Elan SC520. This single board computer consisted of four RS232 ports, a compact flash interface, and a four channel 16-bit analog to digital converter (ADC). The opening and closing of the solenoid valves was controlled based on the results of the vegetation index computation. Figure 2 shows the basic modules of the sensor system. In the initialization phase, valves are closed and all four light sources and the pump are turned on. In the next phase, a four-band sensor scans for the young leaves. The reflectance data is sent to the controller to generate a vegetation index for each scan. If the computed index falls within the pre-established (calibrated) values for new leaves, then the controller records the global positioning systems (GPS) data (Garmin International Inc., Olthe, KS) and opens the solenoid valve to release spray. The sensor system will repeat the entire process until it is turned off. The total processing time of the controller including the computation of vegetation indices and control of the valve was about 200 ms.

A text-based user interface program was developed in C++ (Paradigm Systems, Endwell, NY) to control the system, acquire measurements, and to update the system configuration. The system configuration was stored in the erasable programmable read-only memory (EPROM) chip of the controller, which can be updated through a personal computer using a hyper-terminal program.

The algorithm included formulas for computing eleven different vegetation indices. The interface program allowed changing the range of values which could be used to trigger the solenoid valves and controlling the sensor and the pump. It could also be

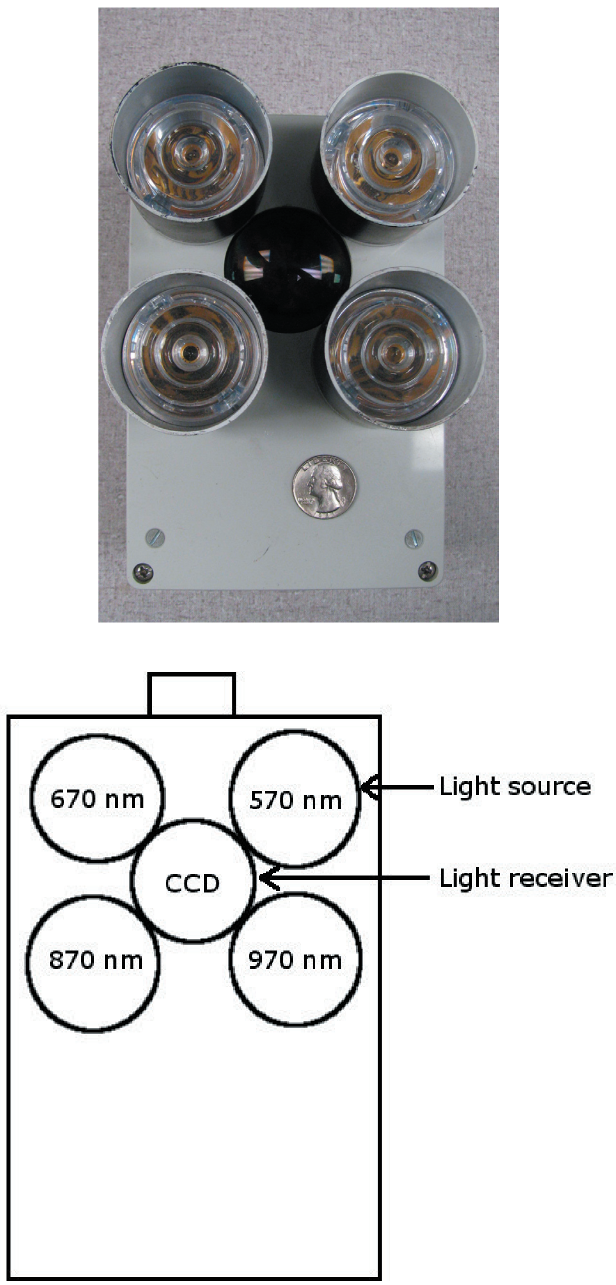

Fig. 1. Picture and schematic of the four-band sensor used on the spot sprayer test setup.

Table 1. Typical data collected from the sensor module.

Sample	Sensor wavelengths (nm) 570	670	870	970	Temp[z]
1	0.282	0.134	0.458	0.472	23.2
2	0.749	0.215	1.210	1.264	23.2
3	0.752	0.213	1.212	1.264	23.2
4	0.742	0.212	1.211	1.266	24.1
5	0.766	0.211	1.208	1.264	24.9
6	0.761	0.21	1.210	1.263	24.1
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[z]Temperature of the sensor.

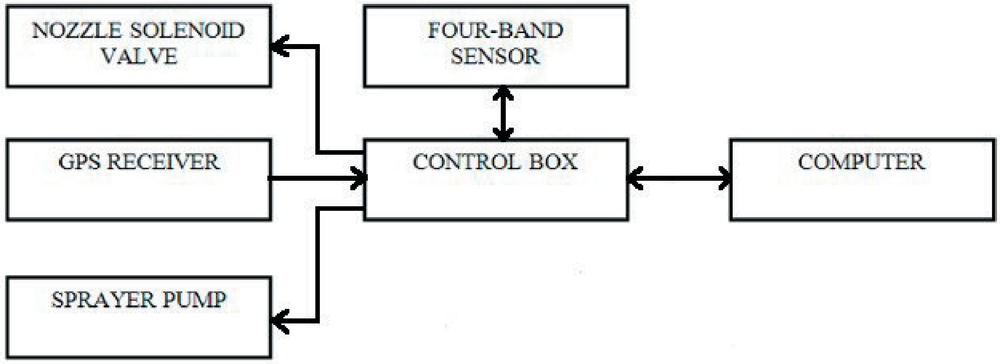

Fig. 2. Schematic of the complete system.

configured to acquire raw reflectance data from each of the four bands of the sensor for offline calculation or post-processing.

Vegetation indices. Two experiments were carried out to determine which vegetation index could provide the most useful information both in static and dynamic conditions. Using the reflectance value of the four-band sensor, various vegetative indices such as: NDVI, simple ratio index (SR), modified triangular vegetation index ($MTVI_1$ and $MTVI_2$), renormalized difference vegetation index (RDVI), greenness index (G), triangular vegetation endex (TVI), modified chlorophyll absorption in reflectance index ($MCARI_1$) and structure intensive pigment index (SIPI), were evaluated to find which of the different indices can be used to differentiate between new and old leaves. The formulae for computing these indices are listed elsewhere (Zarco-Tejada et al., 2005). To calculate NDVI and SR indices, both wavelengths in NIR region, i.e., 870 nm and 970 nm were used. For instance, NDVI-870 and NDVI-970 used the reflectance values at 870 nm and 970 nm, respectively.

It should be noted that Zarco-Tejada et al. (2005) have used specific bands to compute $MTVI_1$, $MTVI_2$, RDVI, G, TVI, $MCARI_1$, and SIPI indices. Since the sensor used in this study was custom built with four specific bands, the nearest available band was used to compute those indices. For instance, Haboudane et al. (2004) used the following equation to compute the $MTVI_1$:

$$MTVI_1 = 1.2 \times [1.2 \times (R_{800} - R_{550}) - 2.5 \times (R_{670} - R_{550})] \quad \text{(Eq. 1)}$$

where R_{800}, R_{550}, and R_{670} are reflectance values at 800, 550, and 670 nm, respectively.

Thus, instead of R_{800} and R_{550}, the reflectance values of 870 nm and 570 nm were used.

Measurements of reflectance were made at a horizontal distance of about 78 cm (30.7 inches) between the sensor and a potted tree with new and old leaves as depicted in Fig 3a (below left). The test was conducted in the laboratory at room temperature under fluorescent lighting fixtures. The sensor was positioned perpendicular to the tree at 128 cm (50.4 inches) above the ground.

In a static test, 10 readings were taken for each type of leaves (new and old) and the vegetation indices were computed based on those readings. The data were used to identify the band of minimum-maximum values of each index. These bands were used to differentiate between new and old leaves. The values of each index for new and old leaves were compared by a *t*-test using statistical software (SAS Institute Inc., Cary, NC). The confidence interval used was 99% ($\alpha = 0.01$).

In a dynamic test, the sensor was mounted on a moving frame (Fig. 3b, below right). New leaves were positioned on the tree across from the sensor field of view. The sensor was moved at nominal speed of about 30.0 $cm{\cdot}s^{-1}$ (0.67 mph) in one direction, and all vegetative indices were recorded. In post processing of the collected data, the number of indices that identified new leaves (based on the given band) was determined. The test was repeated 10 times.

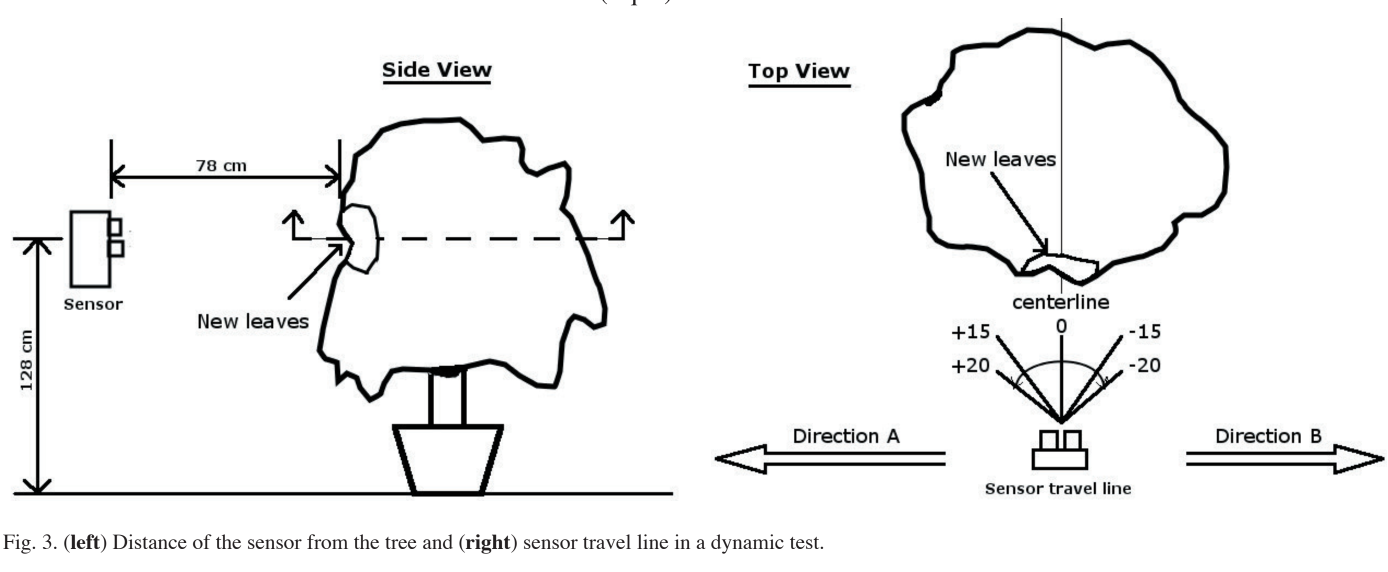

Fig. 3. (**left**) Distance of the sensor from the tree and (**right**) sensor travel line in a dynamic test.

Effects of the angle and direction of the sensor. Another set of tests was conducted to determine the effect of the sensor angle and travel direction on the efficiency of new leaf detection in both the static and dynamic conditions. The objective of the dynamic test was to determine if the sensor could differentiate new leaves at five different yaw angles or two moving directions, using NDVI-870 as the vegetation index.

In static test, a completely randomized block design was used with two factors of sensor angle (–20°, –15°, 0°, +15°, +20°) and two leaf types (new, old). The spray target was a potted 'Hamlin' orange tree, about 118 cm (46.4 inches) in height and 63 cm (24.8 inches) in width. The test was repeated 10 times. In the dynamic test, both angle and direction (A and B) were the factors and there were five replications in each direction. The angle "0°" means that the sensor was facing perpendicular to the tree, at "–15°" and "–20°", the sensor were rotated to the right and "+15°" and "+20°" were rotated to the left (Fig. 3b). The average measured travel speed of the sensor was 30.5 $cm \cdot s^{-1}$ (0.68 mph) with a standard deviation of 3.2 $cm \cdot s^{-1}$ (0.07 mph). In addition to the reflectance data, speed of the sensor movement and light intensity (Lutron Electronics Enterprise Co., Ltd., Taipei, Taiwan) during the test were also recorded.

Results and Discussion

Vegetation indices. Table 2 lists the results of the *t*-test for comparing various vegetative indices of new and old leaves in static test. The indices NDVI-870, NDVI-970, SR-870, SR-970, $MTVI_2$, and G were the only ones that could separate new from old leaves. Thus, the test showed not all vegetative indices are useful in differentiating old and new leaves.

In the dynamic test, using NDVI-870 detected the highest number of new leaves followed by RDVI (Fig. 4). However, the minimum-maximum bands of RDVI for new and old leaves overlapped to some extent (Fig. 5, left) and therefore, could not be used as a separation index. For the same reason, vegetative indices SR-870, SR-970, $MTVI_2$, and G were not useful in the dynamic test. There was a significant separation of new and old leaves in the dynamic test for NDVI-870 (Fig. 5, right).

Sensor angles and direction. There was a significant difference in the number of detected new leaves among sensor angles and travel directions ($P < 0.0001$, Fig 6). Angles of +20°, +15°, 0°, and –20° gave significantly better new leaf detection than the –15° and +20° in Direction A. In Direction B, angles –20°, 0°, and –15° gave significantly better results. This implies that placing the sensor in the leading direction of the equipment gives a better chance for detecting new leaves. In both directions, orienting the sensor perpendicular to the tree (0°) gave the best results.

Conclusions

Although vegetation indices NDVI-870, NDVI-970, SR-870, SR-970, $MTVI_2$, and G were able to distinguish old and new leaves in the static tests, only NDVI-870 was useful in the dynamic tests.

Table 2. Mean values of different computed vegetative indices based on reflectance of new and old leaves in the static test.

NDVI-870	NDVI-970	SR-870	SR-970	$MTVI_2$	G	$MTVI_1$	$MCARI_1$	RDVI	SIPI	TVI
New leaves										
0.759 (a)[z]	0.743 (a)	11.275 (a)	7.084 (a)	0.812 (a)	2.494 (a)	0.91 (a)	0.914 (a)	0.674 (a)	0.714 (a)	36.158 (a)
Old leaves										
0.879 (b)	0.818 (b)	16.120 (b)	10.403(b)	0.963 (b)	4.247 (b)	1.06 (a)	1.066 (a)	0.726 (a)	0.694 (a)	41.260 (a)

[z]Within a column, means followed by the same letter are not significantly different ($\alpha = 0.01$).

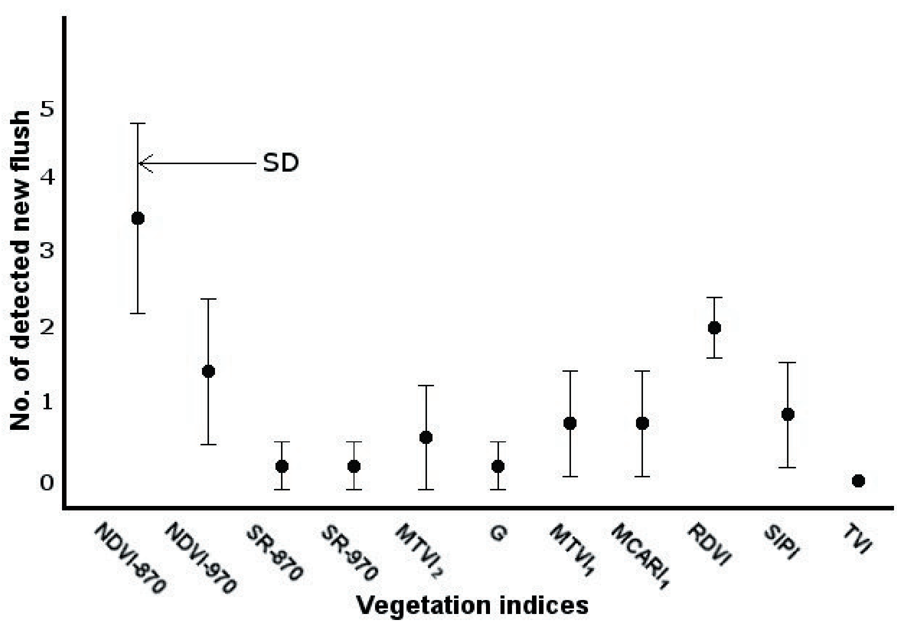

Fig. 4. Performance of different vegetation indices in the dynamic test.

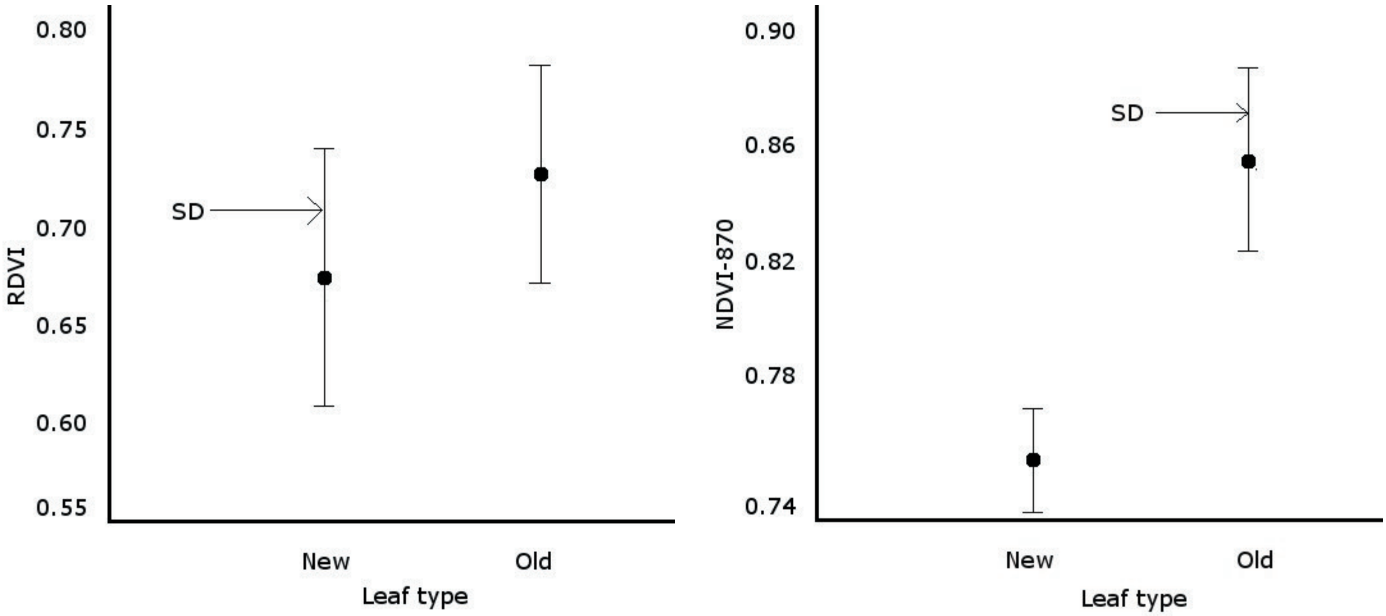

Fig. 5. Reflectance values of old and new leaves by (**left**) RDVI and (**right**) NDVI-870.

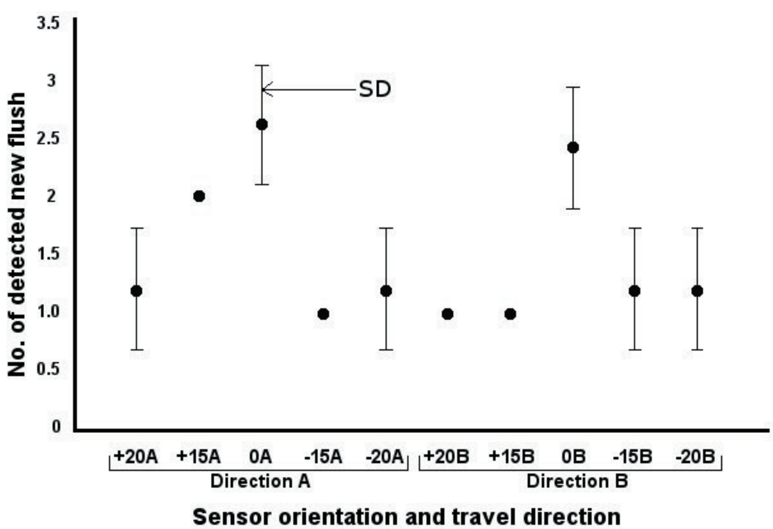

Fig. 6. Effect of sensor angle and travel direction on detection of new leaves in the dynamic test.

Leading orientation of the sensor light beam gave better target identification than the trailing direction and mounting the sensor perpendicular to the tree canopy gave the best results. Future work will focus on optimizing the light sensor performance, developing a new sprayer prototype, and testing the complete system in a citrus orchard environment.

Literature Cited

Broge, N.H. and E. Leblanc. 2000. Comparing prediction power and stability of broadband and hyperspectral vegetation indices for estimation of green leaf area index and canopy chlorophyll density. Remote Sens. Environ. 76:156-172.

Fassio, A., E.G. Fernandez, E.A. Restaino, A. La Manna, and D. Cozzolino. 2009. Predicting the nutritive value of high moisture grain corn by near infrared reflectance spectroscopy, Computers and Electronics in Agriculture.

Grafton-Cardwell, E., K.E. Godfrey, M.E. Rogers, C.C. Childers, and P.A. Stansly. 2006. Asian citrus psyllid. Publ. 8205, Univ. of California, Div. of Agr. and Natural Resources. Accessed 11 May 2009. <http://anrcatalog.ucdavis.edu>.

Haboudane, D., J.R. Miller, E. Pattey, P.J. Zarco-Tejada, and I.B. Strachan. 2004. Hyperspectral vegetation indices and novel algorithms for predicting green LAI of crop canopies: Modeling and validation in the context of precision agriculture. Remote Sens. Environ. 90(3):337– 352.

Halbert, S.E. and K.L. Manjunath. 2004. Asian citrus psyllids (Sternorrhyncha: Psyllidae) and greening disease of citrus: A literature review and assessment of risk in Florida. Florida Entomol. 87(3):330-353.

Muller, K., U. Bottcher, F. Meyer-Schatz, and H. Kage. 2008. Analysis of vegetation indices derived from hyperspectral reflection measurements for estimating crop canopy parameters of oilseed rape (*Brassica napus* L.). Biosystems Eng. 101:172-182.

Myneni, R.B., H.G. Hall, P.J. Sellers and A.L. Marshak. 1995. The interpretation of spectral vegetation indexes. IEEE Trans. Geoscience and Remote Sens. 33(2):481-486.

Smith, K.L., M.D. Steven, and J.J. Colls. 2004. Use of hyperspectral derivative ratios in the red-edge region to identify plant stress responses to gas leaks. Remote Sens. Environ. 92:207–217.

Weedseeker. Automatic spot spray system. Accessed 11 May 2009. <http://www.ntechindustries.com/weedseeker-home.html>.

Ye, X., K. Sakai, H. Okamoto and L. Garciano. 2008. A ground-based hyperspectral imaging system for characterizing vegetation spectral features. Computers and Electronics in Agriculture 63:13-21.

Zarco-Tejada, P. J., A. Berjon, R. Lopez-Lozano, J. R. Miller, P. Martın, V. Cachorro, M. R. Gonzalez and A. de Frutos. 2005. Assessing vineyard condition with hyperspectral indices: Leaf and canopy reflectance simulation in a row-structured discontinuous canopy. Remote Sens. Environ. 99:271-287.