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# REMOTE SENSING FOR DETECTION OF SPIDER MITE AND COTTON APHID IN SAN JOAQUIN VALLEY COTTON

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## Abstract

Multispectral and hyperspectral analysis from remote sensing, a precision tool in development, can detect differences in crop health. This information should be coupled with observations on the ground for ground-truthing of arthropod populations and other plant stress factors. This allows the information seen in the image to be associated with biological factors in the field. Field experiments were conducted in 2003 and 2004 investigating the potential for remote sensing to detect early infestations of cotton aphid (*Aphis gossypii* Koch) and spider mites (*Tetranychus* spp.) in the San Joaquin Valley, CA. Differential populations of aphids and mites were established in field plots using selective and disruptive pesticides. Hyperspectral and multispectral airplane imagery were collected in 2003; hyperspectral imagery using a portable spectrometer and multispectral satellite imagery was collected in 2004 in the plots. Treatments with mite damage were found to have lower average reflectance, with mite infestations above treatment threshold levels in 2003, using the green band in the multispectral imagery, although the actual numbers of mites in the field were quite low. In the narrow band at ~579nm, uninfested cotton was found to have higher average reflectance levels than mite-infested and aphid-infested cotton using the hyperspectral imagery in 2003. Additionally, the treatment with the highest mite number was found to have lower average reflectance than the other treatments at ~579nm, using the hyperspectral imagery in 2003. Using the portable spectrometer in 2004, it was found that average reflectance levels tended to decrease as aphid numbers increased. Additionally, using the multispectral satellite image in 2004, it was found that aphids at economic threshold levels could be detected using a canopy index and near infrared images.

## Introduction

Arthropod management practices in California cotton production involve the use of insecticides and acaricides for protection of yield and quality. Cotton aphid control relies mainly on the neonicotinoid insecticides, but organophosphate and carbamate insecticides are also used, and are important for resistance management considerations due to their modes of action. Restriction of these and other pesticides under the Food Quality Protection Act and other regulatory actions will hinder integrated pest management in California cotton.

Precision agricultural methods have the potential to positively impact San Joaquin Valley (SJV) grown cotton. If the area where pests are located within fields can be known, pesticide applications can potentially be greatly reduced both in frequency and in amount. Spider mite and cotton aphid infestations in the SJV tend to be heterogeneous, with some areas of high infestation and some areas of negligible infestations in fields. However, the currently available ground sampling methods make it impossible to detect all infestations within the large fields of the SJV-typically 80 to 190 acres. Arthropod management decisions are currently made on an inter-field basis rather than an intra-field basis.

Remote sensing is a precision tool with its roots in the aerospace and defense industries that collects spatial information of land-masses with large datasets. Several wavelengths can be recorded to provide a wealth of information including plant coverage versus soil coverage, plant health, soil type, etc. To provide relative information on plant vigor, this information can be converted into a vegetation index, on an intra-field basis, up to one to several meters in resolution. The wavelengths used and reflectance detected are also precise enough to detect plant response to different types of plant injury caused by different arthropod pest damage and other factors. Thus, this technology is precise enough to provide information on an intra-field basis for use in agricultural situations and this information can be used to provide information to reduce pesticide application to micro-units within the field for individual arthropod pests.

Work has been done in the southern US to develop a vegetation index for insect pests, with success in combining remote sensing from the air and a ground approach using a drop cloth in a line-intercept pattern in cotton fields to sample for tarnished plant bug (*Lygus lineolaris* Palisot De Beauvois). It has been demonstrated that this pest preferentially infests areas of vigorously growing cotton over more sparsely growing areas. It has been shown that it is possible to combine remote sensing methods with less time consuming ground sampling methods, while maintaining the sensitivity of sampling necessary for economic control this pest (Willers et.al. 1999). As, a result, in Mississippi, spraying for tarnished plant bug can be limited to infested areas in vigorously growing cotton and has been shown to be successful in limiting insecticide application with no negative impacts on yield (Seal et al. 2001). This work is also being continued currently in other states.

There is, however, no vegetation index or techniques available for cotton grown in the SJV, where spider mites and cotton aphids have been recent problem pests. Spider mite damage can be detected with the use of remote sensing (Fitzgerald et al. 1999, Fitzgerald et al. 2000, Fitzgerald et al. 2004). They were able to detect the damage using wavelengths in the near infrared (NIR) and developed a supervised classification scheme that could distinguish between healthy cotton, soil, and mite-damaged cotton. However, threshold levels important to using remote sensing as a management tool have not been established. Although economic damage does not occur until 80% of the leaves are infested (8th mainstem node leaf from the top), the treatment threshold is set at 30-50% infested leaves (5$^{th}$ mainstem node leaf from the top) to allow time for the acaricide to control the infestation before economic loss (Godfrey, et. al. 2004). The economic threshold for aphids is 50-75 aphids per leaf for at least 7-10 days (5$^{th}$ mainstem node leaf from the top) (Godfrey, et. al. 2004). The potential exists to establish a system in the SJV similar to that of the tarnished plant bug system in the South for spider mites and aphids. This would decrease the cost involved in detecting heterogeneous populations of arthropod infestations on an intra-field basis and has the potential to decrease the amount and frequency of pesticide applications.

## Materials and Methods

### Field Experiments

Acala cotton, variety Maxxa and Acala cotton, variety NemX, was planted on May 5, 2003 and April 26, 2004, respectively, at the Shafter Research and Extension Center near Shafter, CA. Field plots were infested with natural populations of cotton aphids (*Aphis gossypii* Glover) and spider mites (*Tetranychus* spp.). Differential populations were established in plots using selective and disruptive pesticides on August 11, 2003 (Assail 70WP at 1.1 oz./A, Zephyr 0.15E at 12 fl. oz./A, Capture 2EC at 3.8 fl. oz./A, and Orthene 75S at 11 oz./A). Differential populations were also established in plots using selective and disruptive pesticides on July 25, 2004 (Assail 70WP at 1.1 oz./A, Zephyr 0.15E at 12 fl. oz./A, Warrior at 3.84 fl. oz./A, and Orthene 75S at 11 oz./A). Warrior was substituted for Capture in 2004 in an attempt to flare aphid populations to a greater level than the previous year, although aphid populations were much higher overall in 2004 than 2003. Additionally, all the plots were treated with a Courier application (0.38 lbs./A) on July 25, 2004 to eliminate whitefly populations that were present in the field in 2004. The intent was to have plots that had both cotton aphids and spider mites (untreated), neither pest (Assail+Zephyr), an intermediate number of mites and a high number of aphids (Capture in 2003 or Warrior in 2004), spider mites individually (Assail+Orthene), and aphids individually (Zephyr).

Spider mites are a perennial pest of cotton in the SJV and populations normally develop by July. However, due to an unseasonably wet spring in 2003, the cotton was planted later than usual and, consequently, aphid populations did not develop until early August, 2003. Aphids were extremely abundant in 2004. Cotton aphids have been a severe pest of the SJV during the last ten years. Because aphid populations are favored by high nitrogen levels (Cisneros and Godfrey. 2001), all plots were fertilized with 225 lbs. N/acre to favor population development (this amount is on the upper end used by growers) in 2003. Because there were abundant aphids in 2004, a more realistic fertilizer regiment was employed. Two applications of Nitrogen Un32 were applied in 2004 at 80 lbs./A. No plant growth regulators were used on the tests in either year. Two rows were harvested per treatment and weighed for yield analysis on November, 18, 2003 and on November 3, 2004. All treatments were established in a completely randomized block design in ~55ft x 8 row (~27ft) plots with four replicates.

Ground-truthing data were collected by sampling the arthropods of interest at approximately weekly intervals. Both cotton aphids and spider mites were sampled in 2003 by collecting 10-leaf samples per plot and counting the individuals in the laboratory under 50x magnification. To increase the power of detecting true differences in arthropod populations among the treatments, 20-leaf samples were collected in 2004. Leaves were washed onto a fine mesh sieve and the retained material back-washed onto filter paper for storage and later quantification of spider mite number. From the aphid and mite numbers, accumulated aphid days and accumulated mite days were calculated (Ruppel. 1983).

Flight data, provided by OKSI through the USDA-ARS Western Integrated Cropping Systems Research Unit, were collected from an airplane with both multispectral, Shafter Airborne Multispectral Remote Sensing System (SAMRSS), and hyperspectral, Airborne Visible Near Infrared (AVNIR), camera systems on August, 20, 2003. Flight data were also collected on August 26, 2004 from the QuickBird satellite system, provided by DigitalGlobe, Inc. through AgriDataSensing, Inc. Using the hyperspectral flight data from 2003, a Normalized Density Vegetation Index (NDVI) (Rouse et al. 1974), Normalized Near Infrared Index (NNIR), Normalized Red Index (NR), a modified version of Optimized Soil Adjusted Index (OSAVI) (Rondeaux et. al. 1998 and Ojala, unpublished), Modified Chlorophyll Absorption in Reflectance Index (MCARI) (Daughtrey et. al 2004), the Green Differential Vegetation Index (GDVI), the Photochemical Reflectance Index (PRI) (Gamon et. al. 1992), two ratio vegetation indices (RVI), sometimes referred to as simple ratio indices (SR) (Jordan. 1969), the Green Normalized Differential Vegetation Index (GNDVI) (Gitelson and Merzlyak. 1998), the Difference Vegetation Index (DVI) (Tucker. 1979), a Visible Atmospherically Resistant Index ($VARI_{GREEN}$) (Gitelson et. al. 2002), the Half Max (HM), Photochemical Reflectance Index (Gamon et. al. 1992), and the Yellowness Index (Adams et. al. 1999), narrow bands (green peak reflectance value (~550 nm), 579 nm, and 880 nm, and several of my own indices were then calculated from the resulting reflectance values. The software ENVI was used for visualization and Excel for calculations. Because the multispectral system only had 3 bands, the number of indices that could be calculated was more limited. As in the procedure for the hyperspectral information, a NDVI, NNIR, GDVI, GNDVI, and RVI were calculated using ENVI software for visualization and Excel for calculations. Narrow bands (green peak reflectance value (550 nm) and 850 nm) were also used. This information was also correlated with weekly measurements using a backpack hyperspectral spectrometer with a hand held contact probe (Analytical Spectral Devices, Inc., FieldSpec® Pro) in 2004. Five measurements of reflectance were made on random leaves in each plot and the information was subjected to the same analysis in Excel as the aerial data. These indices and interesting reflectance values calculated from the ground, in 2004, and aerially, in 2003, were each, individually, analyzed using two-way ANOVA. Tukey's test, at $\alpha=0.05$, was used to separate means when significant differences were detected ($P<0.05$) by two-way analysis of variance (ANOVA). Data that violated the assumptions of ANOVA were transformed to fit the assumptions or, in the cases that this failed to satisfy the assumption of homogeneity of variances, were subjected to a weighted ANOVA. The accumulated aphid and mite days for each treatment from the ground data, were compared to the index and reflectance values from both the spectrometer and the airplane data using regression analysis and it was attempted to determine at what point plant stresses from aphids and/or spider mites could be detected, if at all with the index and reflectance values. The QuickBird satellite is equipped with a multispectral system that detects 3 bands, at a spatial resolution of 2.8m, and a panchromatic sensor with a spatial resolution of 0.6m. The images provided were calibrated to a reflectance factor at the earth's surface. The images that were received were representative of information in the red, green, blue, and infrared (IR) bands, and of the panchromatic range. Canopy closure, a green vegetation index (GVI) (Kauth and Thomas. 1976), an adjusted vegetation index and a vegetation adjusted soil index were obtained by data that were directly processed by DigitalGlobe through a vegetation index-type algorithm, which is an advanced derivative of the TSAVI model (Baret et al. 1989 and Baret and Guyot. 1991). Some images included 3 bands of information, except for the panchromatic image (ReisigBlack). Using ENVI to distinguish the field treatments, every band from each image was subjected to a separate two-way ANOVA, in an attempt to distinguish treatments from one another. These values from each image and each band were compared to the accumulated aphid and mite days for each treatment by regression analysis.

## Results

### Field Experiments-2003

### Pesticide Treatments

The results of the pesticide treatments are detailed in Reisig, et. al. 2004. All the treatments were above the treatment threshold level (30-50% leaves infested); however, mite numbers were extremely low, regardless, and were still in the early infestation stage. Aphid numbers were also extremely low and were well below treatment threshold levels in all the treatments.

### Multispectral- Airborne (SAMRSS)

Treatments differed significantly in the green band (~550nm) (Fig. 1), although there were no significant differences among treatments for any of the vegetation indices or bands tested. The average reflectance values in the green band for the Assail + Zephyr treatment were significantly higher than the Capture treatment and the Assail + Orthene treatments. Both the Capture treatment and the Assail + Orthene treatment had higher accumulated mite days. The untreated plots, Capture treatment, and Zephyr treatment had higher accumulated aphid numbers than the Assail + Zephyr treatment. However, the untreated plots and the Zephyr treatment had reflectance values that were significantly the same as the Assail + Zephyr treatment. Thus, it is possible that the mite damage was easier to detect in the green band than aphid damage, in this case.

**Hyperspectral- Airborne (AVNIR)**
Treatments differed significantly in one of the green wavelengths tested (~579nm) (Fig. 1), although there were no significant differences among treatments for any of the vegetation indices or bands tested, including the narrow band values at the Green Peak (~550nm). This is not surprising, as the green band in the multispectral data is an average across the range of values in the wavelengths in the green area.

The average reflectance values at ~579nm for the Assail + Zephyr treatment were significantly higher than all the other treatments. In addition, the Capture treatment, the Assail + Orthene treatment, and the Zephyr treatment had significantly higher reflectance values than the Assail + Orthene treatment. This is similar to the findings in the green band, using the multispectral data as the Assail + Zephyr treatment had lower accumulated mite and aphid days than any other treatment (the Assail + Orthene treatment had marginally fewer accumulated aphid days but many more accumulated mite days). Thus, it is conceivable that the cotton in the Assail + Zephyr treatment had a higher reflectance values at ~579nm because it had lower mite and aphid pressure than the other plots.

The Capture treatment, Assail + Orthene treatment, and Zephyr treatment had comparable accumulated mite and aphid days. The Assail + Orthene treatment had much lower accumulated aphid days than any of these treatments, but higher accumulated mite days than these treatments. Because the accumulated aphid days in the Assail + Orthene treatment were similar to those in the Assail + Zephyr treatment, it is conceivable that the cause of its significantly lower reflectance values was due to the presence of more mites than any of the other treatments. This is similar to the findings in the green band of the multispectral data.

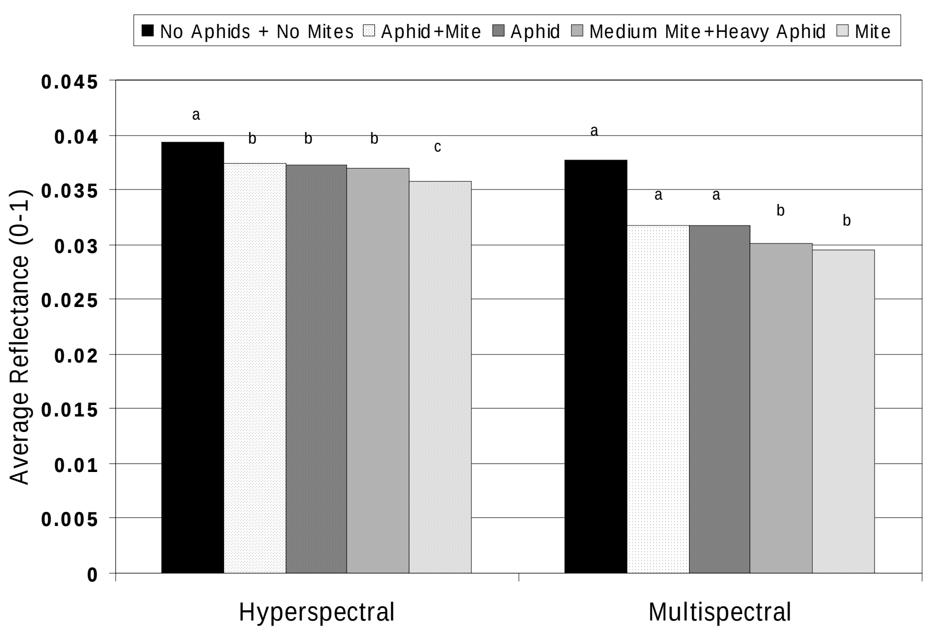


Fig. 1- Average reflectance values of hyperspectral (AVNIR, ~579nm) and multispectral Images (SAMRSS, green band, ~550nm), August, 20, 2003.

**Field Experiment- 2004**
The Assail + Zephyr treatment was consistent with the expected result of relatively arthropod clean cotton, for a heavy aphid year. An average 28% of the leaves were mite infested, which was below the treatment threshold and

below the economic threshold level. This treatment was well below economic threshold levels for aphids. The untreated treatment was not as consistent with mite + aphid infested cotton, as was hoped for, as the mite pressure was relatively low, due to late infestation. This was considered a separate treatment, as in 2003. An average 36% of the leaves were mite infested, which was in the range of the treatment threshold and below the economic threshold level. This treatment was below economic threshold levels for aphids. The Assail + Orthene treatment was more consistent with an infestation of mites and an infestation of aphids, rather than a mite only treatment. An average 69% of the leaves were infested with mites, which was above the treatment threshold of 30-50% infested mite leaves, but below the economic threshold level. However, the actual number of mites in the field was still relatively low. This treatment was below economic threshold levels for aphids. The Warrior treatment was consistent with the medium infestation of mites and heavy infestation of aphids that was hoped for. The aphid infestation had just passed the treatment threshold (>30 aphids/leaf) when the remote sensing data were taken. An average 78% of the leaves were infested with mites, which was above the treatment threshold of 30-50% infested mite leaves and close the economic threshold level. This treatment had just reached economic threshold levels for aphids. The Zephyr treatment was not was consistent with the expected result of a light infestation of aphids, but was more similar to clean cotton. It was considered a separate treatment, however. An average 25% of the leaves were mite infested, which was below the treatment threshold and below the economic threshold level. This treatment was well below economic threshold levels for aphids.

Fig. 2- Accumulated mite days over time, 2004. Arrow denotes when the remote sensing data were taken.

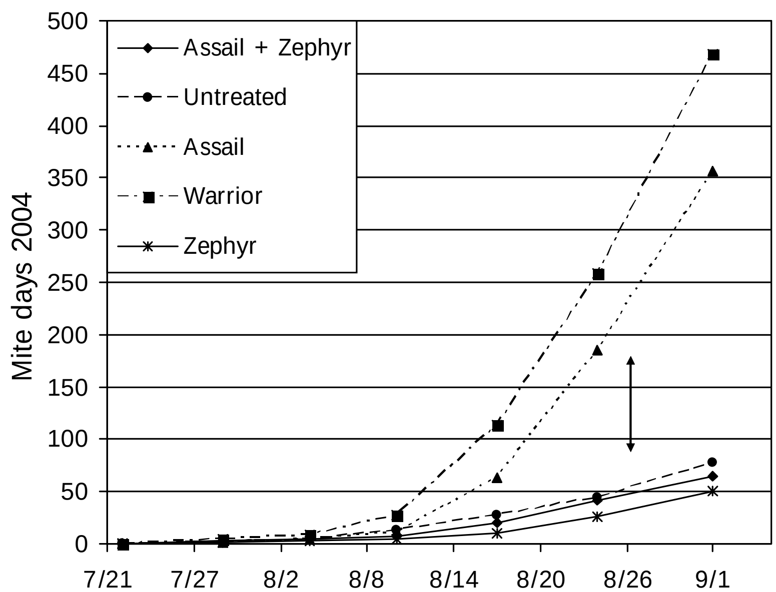
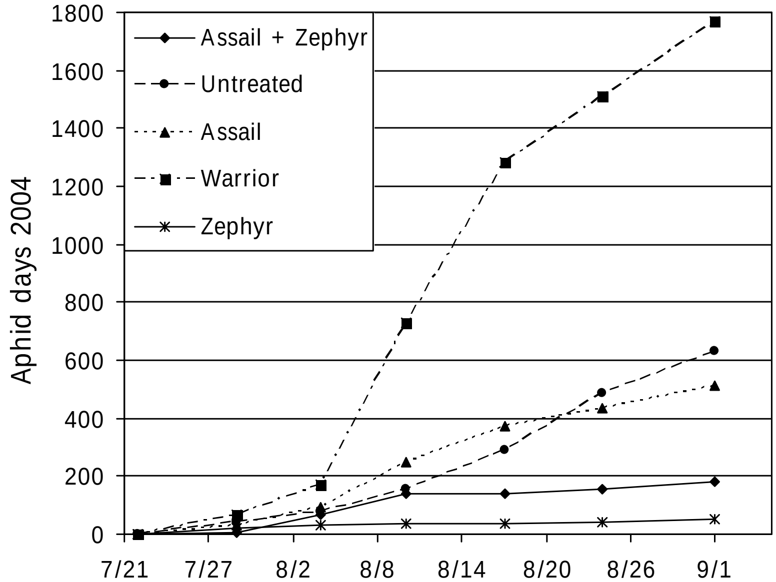


Fig. 3- Accumulated aphid days over time, 2004. Arrow denotes when the remote sensing data were taken.




**Multispectral- Airborne (QuickBird)**

The Warrior treatment was significantly different from the other treatments in the color infrared images, the canopy image, and both the vegetation images obtained from DigitalGlobe, Inc. The canopy image was the best at differentiating this treatment from the others, followed by three of the four color infrared images, the false color image, and one of the vegetation images (Table 1). The panchromatic image, one of the color infrared images, the soil/vegetation image, and the GVI image were not able to significantly distinguish any of the treatments from each other. Additionally, although the false color image and one the vegetation images had significance in ANOVA, the Tukey groupings failed to differentiate any of the treatments from one another. Subsequently, the significant in the original ANOVA of the false color and vegetation index may represent a Type I error. Also, although the Assail + Orthene treatment had more accumulated mite and aphid days, and the untreated plots had more accumulated aphid days than the Assail + Zephyr treatment and the Zephyr treatment, they were not significantly different from each other.

Table 1- Images provided by DigitalGlobe, Inc. that were able to significantly distinguish aphid infested cotton (Warrior treatment) from other cotton.

| Image type analyzed | Image name | F value | P value |
|---|---|---|---|
| Canopy | ReisigCanopy | 7.4 | 0.0030 |
| Color Infrared 1 | ColorInfrared | 6.72 | 0.0045 |
| Color Infrared 2 | ColorIR-0-0 | 6.61 | 0.0048 |
| Color Infrared 3 | ReisigCIR | 6.71 | 0.0045 |
| False Color | ReisigTrueColor | 3.41 | 0.0439 |
| Vegetation Index 1 | ReisigVegetation | 3.38 | 0.0452 |

**Hyperspectral- Ground (Spectrometer)**

There were no significant differences among any of the vegetation indices or narrow bands tested. There were correlations between various vegetation indices and narrow bands and accumulated aphid days. As the number of accumulated aphid days increased, the average reflectance values tended to decrease. These correlations had $R^2$ values ranging from 0.67 for reflectance values at ~880nm and accumulated aphid days, to 0.07 for the NNIR and accumulated aphid days. The best correlation was in the NIR at ~880nm ($R^2$=0.67) and a representative of this correlation and the narrow bands at ~550nm and ~579nm is shown in Fig. 4.

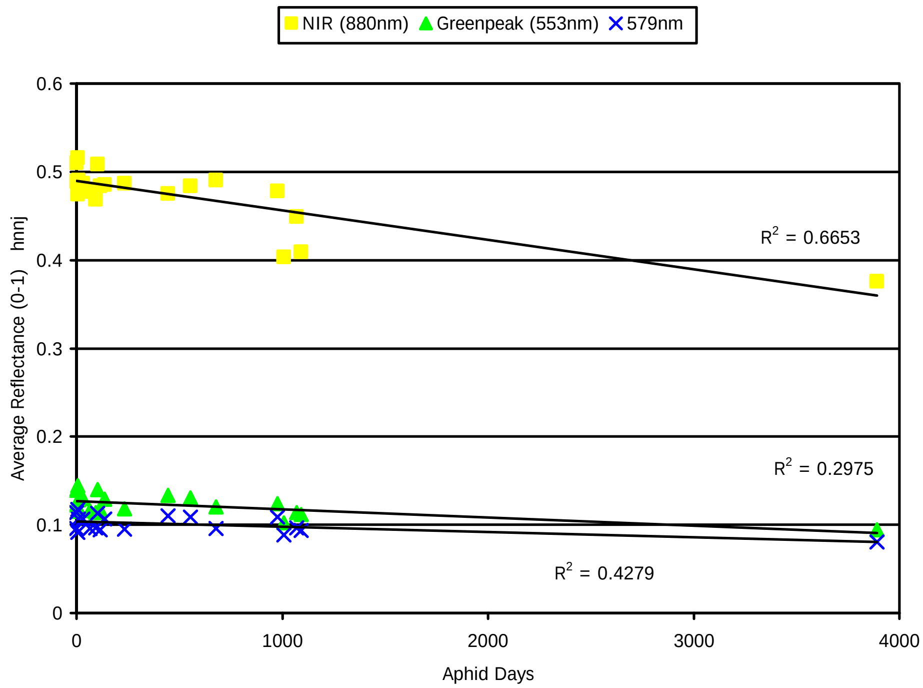



Fig. 4- Sample regressions between narrow ASD spectrometer band values and aphid days, 31 days after treatment.

## Discussion

The field experiment in 2003 showed that early mite damage above treatment threshold levels (although with very low actual mite numbers) was easier to detect than early aphid damage, from airplane imagery. Both the multispectral (SAMRSS) and hyperspectral (AVNIR) systems were comparable in their ability to distinguish mite damage in wavelengths near the green peak (~550nm). The wavelengths in the NIR (~850-880nm) were not able to significantly distinguish arthropod infestations in the cotton.

The field experiment in 2004 was not successful in detecting mite damage above treatment threshold levels, as in 2003, but was successful in detecting aphid levels at the economic threshold (50-75 aphids/leaf for 7-10 days). The images obtained from the QuickBird satellite that sampled the wavelengths in the NIR proved the most useful to distinguish aphid damaged cotton from other cotton.

The potential, thus, exists to detect spider mite and aphid damage at or before treatment thresholds, but work still remains in applying this knowledge to a useful classification scheme. The predictive quality of the indices and reflectance values (Type I and II errors) is being investigated. Also, this work must be applicable at different growth stages of the cotton, with different conditions of the field, in different types of atmospheric conditions, and in different types of soils to be useful on a larger scale.

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