CITRUS TREE COUNTING USING VERY HIGH RESOLUTION SPACEBORNE IMAGERY

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ABSTRACT

There is strong interest within the citrus community for developing methods to accurately detect and count citrus trees, as well as, assess citrus tree vigor using very high-resolution (VHR) spaceborne imagery. In 2003, the USDA's National Agricultural Statistics Service (NASS) along with the Florida Agricultural Statistics Service (FASS) conducted a pilot study funded by the Florida Department of Citrus, using DigitalGlobe's QuickBird imagery to detect citrus trees over several test sites in Florida. A computer assisted method developed within NASS and an automated tree counting algorithm developed by the University of Singapore's CRISP group were tested to determine the feasibility and reliability of automated citrus tree counting. The pilot study demonstrated that citrus trees could indeed be counted with VHR imagery, however, with various degrees of consistent downward bias.

This follow-up investigation evaluated techniques to refine the original methodology to reduce the downward bias and improve accuracy. This report describes specific procedural changes to the CRISP program variables, as well as, the results derived from supplemental testing of the CRISP software. Statistical analysis of the results determined that changing the CRISP Maximum Scale Level (MSL) variable had a positive effect, reducing the overall downward bias from 18 percent in the initial study to 14 percent in this follow-up. In addition, a first step in the development of techniques using the Normalized Difference Vegetation Index (NDVI) and an image differencing procedure were conducted to assess the condition and health of citrus trees.

BACKGROUND

The USDA/NASS remote sensing program has been classifying and estimating the spatial extent of agriculturally intensive cropland areas, throughout the United Sates, since the early 1970's. Additionally, NASS has performed cost benefit analysis (Craig, 2001; Hanuschak and Mueller, 2002) and created a publicly available cropland data layer on an annual basis (Mueller and Ozga 2002). NASS has also been involved in several cooperative agreement efforts to count orchard trees in New York State (Gordon and Philipson 1986; Gordon et al., 1986; and Taberner et al., 1987). Initial efforts attempted to separate orchards from mixed forest stands, fruit trees by species and estimate total acreage. Project results were accomplished using a variety of image enhancement techniques including several vegetation indices, classification, filtering, smoothing, ratioing and principal component analysis. The results showed promise for isolating orchard acreage to estimate total acreage.

The original pilot study funded by the Florida Department of Citrus in cooperation with the Florida Agricultural Statistics Service (FASS), utilized two DigitalGlobe QuickBird acquisitions over Florida. Several methods for counting citrus trees were evaluated in the initial investigation. The most effective was a computer assisted technique developed by NASS and was 92 percent accurate. However, this method cannot be used for larger scale applications due to the extensive expert analyst time required. Additionally, this method was subject to analyst bias and has proven unsuccessful for counting citrus blocks dominated by reset (immature) trees. The second, completely automated algorithm, called CRISP from the University of Singapore's CRISP group had a significant but also very consistent (20 percent) downward bias (Hanuschak et al., 2003).

The CRISP group adopted a tree counting technique from Brandtberg and Walter (1998) that provided excellent results for counting palm oil trees. The counting technique was based on the concepts of edge and curvature using differential geometry, where pixel based image analysis techniques were previously unsuccessful. Image processing and analysis algorithms utilizing the textual, contextual, and geometrical properties were required to exploit the trees. These algorithms made use of the relationship between neighboring pixels for information extraction (Hui et.al., 2000). To fully exploit the palm oil tree imagery, the CRISP group developed an application based on this concept and was able to detect palm oil tree counts to within 93-99 percent accuracy on 4 sample sites when compared to visual counts. The CRISP algorithm, however, had a 9 to 15 percent error rate resulting from the incorrect placement of tree centroids and an 8 to 22 percent error rate resulting from tree omission.

The methods currently used by the FASS, based largely upon an aerial tree census and sound statistically designed ground surveys, are the best in the world for fruit crop forecasting and estimation. The pilot investigation was designed to determine if a tree inventory could be conducted, with reliability, using little or no ground information except for the purpose of verification. Any efficiency gains identified through the pilot study or in the future will be examined for usefulness and operational feasibility in Florida.

INTRODUCTION

A pilot investigation using very high resolution (VHR) QuickBird imagery to detect and count citrus trees, over identified sites in Florida was conducted by NASS and the FASS (Hanuschak et al., 2003). The study compared the effectiveness of a NASS computer assisted method developed by Hanuschak and Mueller and an automated tree counting algorithm developed by the University of Singapore's CRISP group for performing citrus tree counting. The initial study demonstrated that VHR imagery could be used to count citrus trees. However, results from the original study identified a consistent downward bias using CRISP.

A follow-up investigation was conducted by NASS, in 2004, to improve the accuracy of the original methodology by reducing the downward bias. The same 33 samples, used in the initial investigation, were retested with QuickBird, by modifying the CRISP Maximum Scale Level (MSL) variable, against bands 1 and 4. The variable was changed from 8.5, 7.5, 6.5, 5.5, 4.5, to 4.0 (Figure 1) to determine the optimum MSL. Additionally, 7 large area reset blocks were evaluated to determine if results indicated a comparable downward bias. The Hanuschak and Mueller counting method proved unsuccessful in counting reset trees and these blocks were not used in the initial study. In addition, a first step was taken in the development of a technique, using the Normalized Difference Vegetation Index (NDVI) to assess citrus tree health and condition. This report describes specific procedural changes to the CRISP program variables, as well as, the results derived from supplemental testing of the CRISP software. Changes in citrus condition over a 3.5 year period, as identified using the NDVI, were also evaluated.

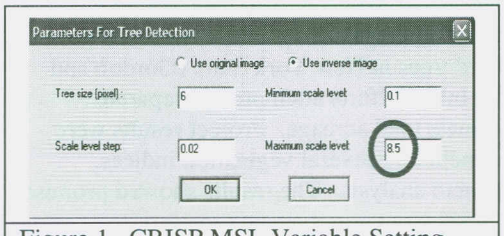


Figure 1. CRISP MSL Variable Setting.

METHODS

Site Condition

The 40 study sites selected for evaluation were planted in tightly packed rows for optimum spacing and production. The initial 33 sites contained blocks of citrus trees with a combination of mature and mature/reset trees. The additional 7 sites contained large variable sized blocks of citrus trees combined together based on a differencing procedure to identify reset areas. The spacing between rows averaged from 20-25 feet with an average planting distance of 12 to 16 feet on center within a row. The citrus block sizes were generally in the 12-acre range. In many cases, when older trees were pushed (removed), two young trees were reset within the same area that was previously occupied by a single older tree. This process allowed for greater production until the trees reached maturity, at which time the hardiest tree was retained and the weaker tree pushed. Once the trees reached maturity or containment size, the canopies closed together and were actively groomed on the sides and tops to give the appearance of a 'hedge row'. The individual citrus trees lost their natural crown during this process.

Data Processing

DigitalGlobe's QuickBird VHR imagery was selected for use in both the pilot and follow-up study for a variety of reasons. The pilot investigators wanted to evaluate the utility of the highest resolution imagery commercially available. Additionally, one of the FDOC contract stipulations was that the data used for the pilot study originate from a spaceborne rather than aerial platform. This left two commercial players in the 2002 marketplace, Ikonos and QuickBird. QuickBird was selected because of its higher resolution, given the spatial characteristics of the citrus groves.

The QuickBird images were processed using ERDAS Imagine software. The resolution merge function using a principal components transform and nearest neighbor resampling was performed on the QuickBird data to sharpen the spatial resolution of the imagery. This function fuses the PAN (0.61) meter with the multi-spectral (2.44) meter data to produce a multi-spectral 4 band image with a 0.61 meter ground resolution.

The tree counting software developed by CRISP was originally designed for palm oil tree counting and was modified for citrus tree counting. Both NASS and the University of Singapore were performing software testing to optimize the CRISP software for citrus tree counting. For the citrus pilot, the tree and tree shadows appeared darkest in the image, while the bedding around the trees was the brightest. The CRISP tree counting software permitted the inversion of pixel values to highlight the spectral contrast. The tree detection procedure does not use a simple intensity threshold for tree detection, because of the different intensity levels and variations between individual trees. Instead, the software uses intensity gradients to locate tree crowns. "It makes use of the concept of curvature in differential geometry to detect the edge pixels of each tree crown, and forms a model of intensity profile for each crown." (Center for Remote Imaging, Sensing and Processing, 2003). A local maximum filter was applied to determine the tree crown location and tree locations were identified on the original image with a red marker.

The CRISP system requirements called for a single band 8-bit tiff image for input. In the pilot investigation, the blue channel spatially enhanced using a high pass filter with a 3x3 kernel was recognized as the optimum input for tree counting (Hanuschak et al., 2003). Many of the same test sites were again evaluated, in an attempt to identify an optimum band. In addition, several of the CRISP default settings were changed. It was determined that changing the MSL (Figure 1) had a positive impact on the counts. According to the CRISP group, "Tree detection is done at a series of spatial scale levels, starting from the minimum scale level specified, incremented by the scale level step, up to the maximum scale level. So the number of scale levels to be processed is (Maximum scale level - Minimum scale level)/Scale level step + 1." (Center for Remote Imaging, Sensing and Processing, 2003).

The FASS provided ground truth information for the 40 test sites. The results derived from the Hanuschak and Mueller computer assisted method and CRISP software were compared. Test sites one, two and three were revisited and inventory counts were computed by the investigators. All 4 bands and MSL variables were tested to determine the optimum band(s) to test against the other samples. These sites were used for additional testing to determine the optimum band for adjusting the MSL. The test site images were clipped in ERDAS Imagine so that surrounding tree blocks and neighboring tree stands were not included.

Only 32 sites were used to test the Hanuschak and Mueller method. The CRISP MSL variables of 8.5, 7.5, 6.5, 5.5, 4.5 and 4.0 were tested using the first 33 sites. The CRISP MSL variables: 8.5 and 4.0 were tested on the remaining 7 sites. These 7 sites contained only reset trees and were large and variable in size. The Hanuschak and Mueller method was unsuccessful at counting citrus blocks dominated by reset trees. A weighting procedure was used to account for inconsistency within the blocks.

The 7 samples sites were weighted, by the number of blocks in each sample calculation, to make the 7 sites comparable to the original 33 sites. To prepare the 7 sites for analysis, areas of major change were identified using a TM NDVI change detection method and the blocks were digitized onto the QuickBird image. The perimeters of the reset areas were digitized, ensuring that no additional tree areas were included. The interior blocks were split along the visible roads on centerline to define the blocks. Additionally the non-citrus areas, such as forest stands and man-made objects were also digitized so they would be eliminated and not be potentially counted. A buffering operation of 6 meters was performed on the centerlines to eliminate roads and other shrubbery from interfering in the counting process. The QuickBird image was now clipped for the 7 previously identified study sites to perform CRISP counts on.

RESULTS AND DISCUSSION

Site Testing

Initially, three test sites were evaluated with CRISP, using all QuickBird bands, to determine the optimum bands to use in the assessment of the MSL variable. Bands 1 and 4 provided the most accurate CRISP results and were, subsequently, used as inputs in a comparison of the two methods over the remaining 37 sites. The sites were split into three categories (mature, mixed, and reset) based on the majority tree composition within a block.

Test site one was a fully mature block, with reset trees occurring in only a few places (Figure 2). Test site one had a FASS tree count of 1498, while the Hanuschak and Mueller method counted 1443, a four percent undercount. Using the CRISP software, band 1, high pass filter (Figure 3), and a MSL of 8.5, produced a 9.5 percent undercount (Figure 4). Using a MSL of 4 produced a count of 1502 (Figure 5), a .2 percent overcount. Both bands 1 and 4, using the high pass filter and a MSL of 4 resulted in a .2 percent undercount.

Test site two was characterized by a mix of mature and reset trees (Figure 6). The high pass filter image of this site is presented in Figure 7. This site was selected to determine if CRISP could accurately discriminate between trees of different ages. Site two's FASS count was 1495, along with a Hanuschak and Mueller count of 1269, which was a 15 percent undercount. Bands 1 and 4 performed the best again, with band 1 performing the best at a MSL of 8.5 with 1278 trees (Figure 8). Band 4 had the highest accuracy at 7 percent undercount at MSL 4 (Figure 9).

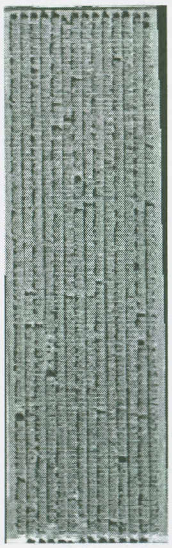
Test site three had only three full rows of mature trees, with some mature trees scattered throughout the image, while the remainder were recently reset trees (Figure 10). The high pass is shown in Figure 11. The official FASS count was 1374; the Hanuschak and Mueller count was 937, a 32 percent undercount. Band 1 performed the best of the other bands at MSL 8.5 (Figure 12) deriving 1170 trees or a 15 percent undercount. Bands 1 and 2 performed the best on this site as band 1 counted 1282 trees at four MSL (Figure 13); a 7 percent and band 2, 1135 trees a 9 percent undercount respectively. Band 4 did not perform as expected, perhaps due to the lack of vegetation present.

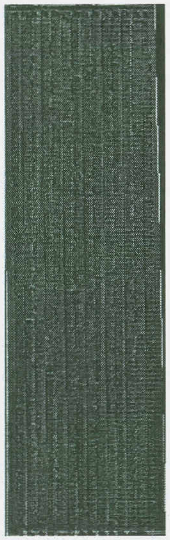
For every decrease in whole number MSL, an increase of 1-2 percent in counting accuracy was achieved. Figure 14 illustrates the trend of more accurate counts as the MSL was decreased. Bands 2 (Green) and 3 (Red) however, were consistently lower at each MSL level. Bands 2 and 3 were not chosen for further analysis based on the results from the first 3 test sites.

Tree Placement

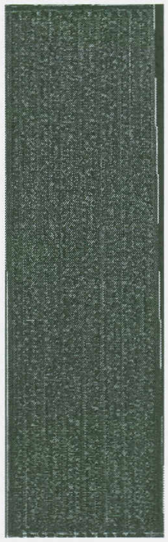
The CRISP algorithm placed an oversized red pixel in the processed image, on the tree centroid's predicted location. It was apparent that decreasing the MSL had a positive impact on the accuracy, bringing the first three test sites to within ranges of .2 to 7 percent undercounting. This was a noted improvement from the initial pilot report of a consistent 15-20 percent undercount. Figure 15 is site one; high pass filter, with the tree rows drawn off in green, and the red dots indicating tree placement. Note there were no actual breaks in the tree rows. However, the CRISP algorithm did not detect trees in certain instances and the tree placement could lie on either side of the actual tree row. Additionally, in a few cases a tree was counted more than once.

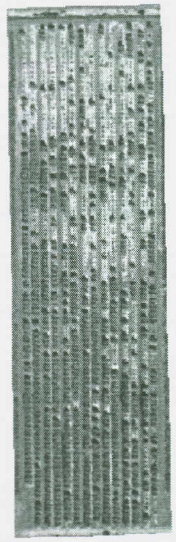
The reliability of the citrus tree inventory was influenced by a variety of factors. These include: variations in the age composition of trees (mature versus resets) within blocks and inaccuracies resulting from tree shadows. Also, spectral confusion caused by soil reflectivity, weeds, swales, and grower grooming practices, including; mechanical pruning on all sides, canopy closure altering the natural tree crown, grounds maintenance between rows, planting density and planting orientation north/south versus east/west. Additional factors affecting accuracy include: the angle of image acquisition (nadir versus off-nadir) and seasonal issues affecting data acquisition, specifically fall/winter image acquisition in near tropical environments because of cloud coverage.

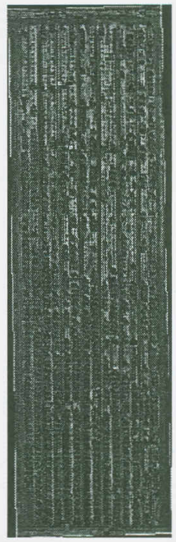

Site 1
Bands 4,2,1
Figure 2

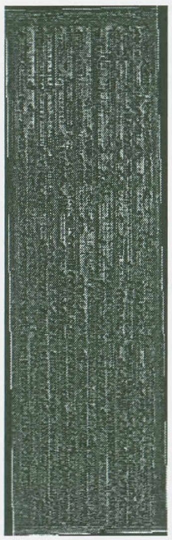

Band 1
High Pass
Figure 3

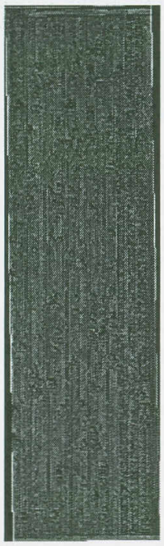

Crisp Max Scale
8.5
Figure 4

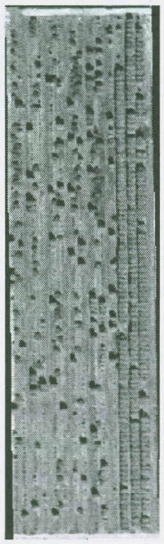

Crisp Max Scale
4.0
Figure 5

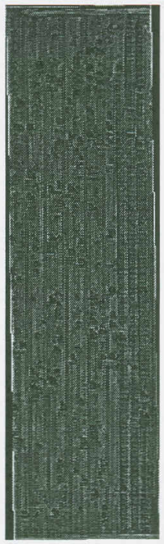

Site 2
Bands 4,2,1
Figure 6


Band 1
High Pass
Figure 7

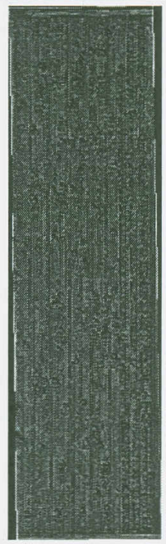

Crisp Max Scale
8.5
Figure 8


Crisp Max Scale
4.0
Figure 9


Site 3
Bands 4, 2,1
Figure 10


Band 1
High Pass
Figure 11


Crisp Max Scale
8.5
Figure 12


Crisp Max Scale
4.0
Figure 13

CRISP Statistical Analysis

Two separate tree counting methods were tested; the Hanuschak and Mueller computer assisted method and CRISP. Table 1 shows bias, absolute deviation, root mean squared error, and error measurement results comparing the computer assisted and the automated methods to the FASS methods as 'truth'. The 40 testing sites were all run through the CRISP algorithm using QuickBird bands 1 and 4. Both bands were passed through a high pass filter before testing. The Hanuschak and Mueller method was only tested on 32 sites. The CRISP MSL variables of 8.5, 7.5, 6.5, 5.5, 4.5 and 4.0 were tested using the first 33 sites. The CRISP MSL variables: 8.5 and 4.0 were tested on the remaining 7 sites. These 7 sample sites, contained only reset trees, were large and variable in size where the Hanuschak and Mueller counting method was ineffective. To account for the variability, a weighting procedure was conducted. The 7 samples sites were weighted, by the number of blocks in each sample calculation, to make the 7 sites comparable to the original 33 sites.

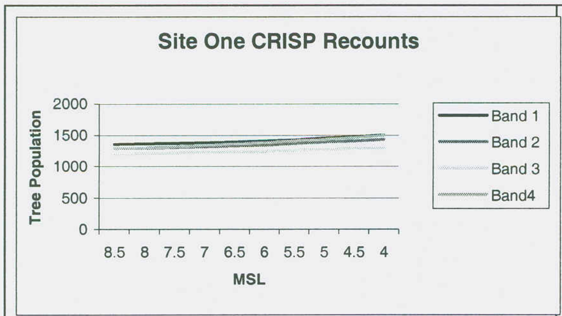


Figure 14. Site one FASS count 1498. Note how accurate bands 1 & 4 become as the MSL is decreased, .2 percent over and .2 percent under respectfully.

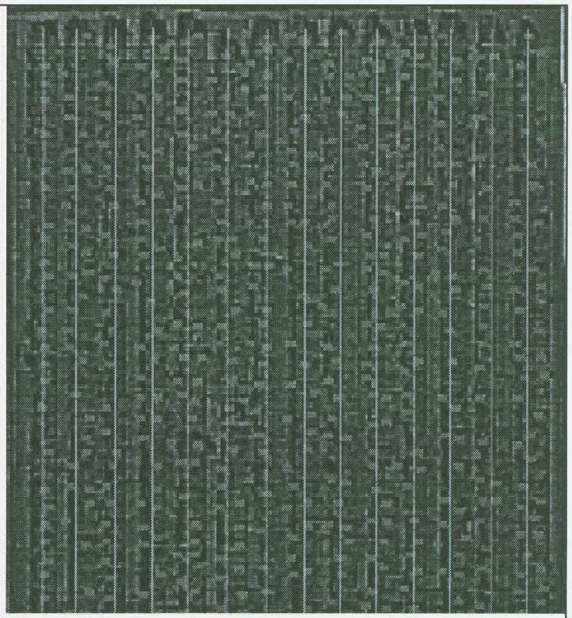


Figure 15. Test site one, tree rows delineated in green, and CRISP tree placements in red

The results achieved comparing QuickBird bands 1 and 4, using the CRISP 4.0 MSL, were statistically insignificant on the initial 33 test sites. The CRISP algorithm was able to deliver a - 9 percent (Table 1) downward bias with band 4 and a -10 percent downward bias with band 1 on the initial 33 test sites. A CRISP MSL value of 4.0 delivers a nearly identical percent root mean squared error (RMSE) of just over 13 percent for both bands 1 and 4 across all sample sites. All of the bias estimates were negative indicating a consistent underestimation of the tree count using the CRISP method.

When the 7 weighted samples were added to the original 33, the relative bias increased to 14 percent at MSL 4.0 for both bands 1 and 4. Other statistical measures including; relative absolute deviation (ABD), bias, and mean were correlated to the bands. These statistical measures indicated that a lower degree of accuracy was achieved at the higher MSL values. However, the relative RMSE percentage drops to just over 2 percent for both bands 1 and 4, indicating that the weighting of the large sample size and the initial 33 sites provided a good indicator of an overall bias of 14 percent.

The computer assisted method performed best with an average bias of -7.6 percent (Table 1). However, the RMSE of nearly 20 percent was among the highest of all counting methods. A regression analysis was conducted to determine the accuracy of the method when compared to the official FASS counts. The regression analysis indicated that the computer assisted method was inconsistent (Figure 16). Results indicate a high number of undercounts, several correct estimates, and several over counts providing for an inconsistent outcome. It was apparent that analyst bias and planting patterns (close proximity of tree plantings along with reset trees) make the computer assisted method an inconsistent predictor of tree population. However, in an investigation with no available ground truth, this method has the potential to serve as the dependant (Y) variable, while an automated method such as CRISP would serve as the independent (X) variable in a regression estimation approach.

The results of the regression analysis, using the optimum MSL setting of 4.0 with an average bias of – 14 percent, are presented in Figures 17 and 18. The initial 33 sites were evaluated followed by an assessment of the 7 large acreage sites. The regressions supported the negative bias, while the additional weighted samples decreased total error and improved the r-squares. One sampling issue presented itself at the end of the study, which was the small variation in FASS reported tree counts that resulted in a flat regression line.

	Maxscale (MSL)	**n**	**Mean FASS**	**Mean Measure**	**Bias**	**Relative Bias (%)**	**Relative RMSE (%)**	**Relative ABD (%)**
CompAsst	n/a	32	1475	1363	-112	-7.59	19.59	11.53
Band 1	4	33	1475	1326	-150	-10.17	13.47	10.44
	4.5	33	1475	1303	-172	-11.66	14.42	11.86
	5.5	33	1475	1266	-210	-14.24	16.43	14.24
	6.5	33	1475	1241	-234	-15.86	17.73	15.86
	7.5	33	1475	1212	-263	-17.83	19.52	17.83
	8.5	33	1475	1194	-281	-19.05	20.63	19.05
Band 4	4	33	1475	1340	-136	-9.22	13.18	10.1
	4.5	33	1475	1318	-157	-10.64	14.12	11.12
	5.5	33	1475	1277	-199	-13.49	16.12	13.49
	6.5	33	1475	1244	-232	-15.73	17.77	15.73
	7.5	33	1475	1217	-259	-17.56	19.31	17.56
	8.5	33	1475	1197	-278	-18.85	20.41	18.85
Band 1**	4	40	1366	1174	-192	-14.06	2.27	14.13
	8.5	40	1366	1087	-279	-20.42	3.29	20.42
Band 4 **	4	40	1366	1170	-196	-14.35	2.34	14.49
	8.5	40	1366	1081	-285	-20.86	3.37	20.86

** = seven variable sized observations were weighted by their number of plots in calculations

Table 1 Bias, Deviation, and Error Measurement.

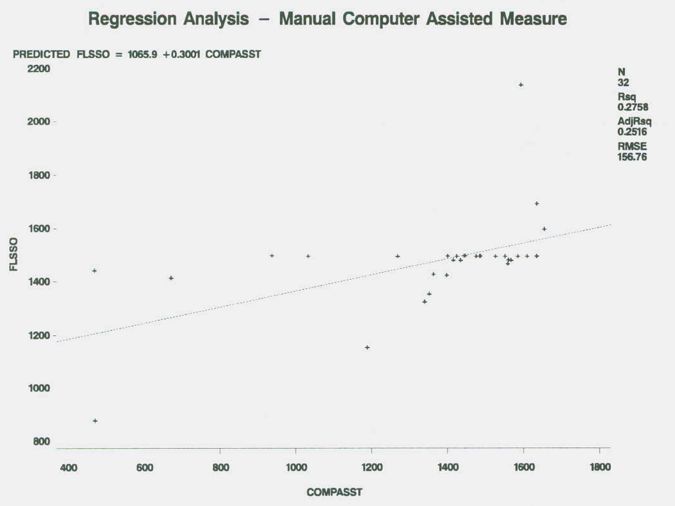


Figure 16. Computer assisted manual counting method, note the inconsistency between the counts, and a low R-squared of .28.

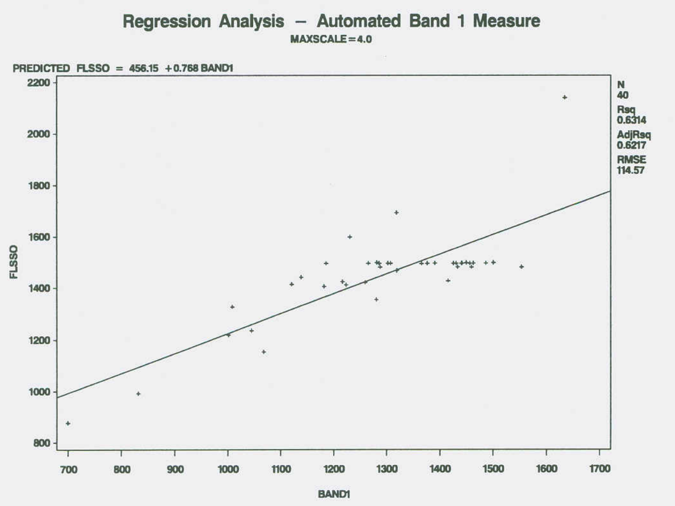


Figure 17. QuickBird band 1, CRISP algorithm Maximum Scale Level 4.0.

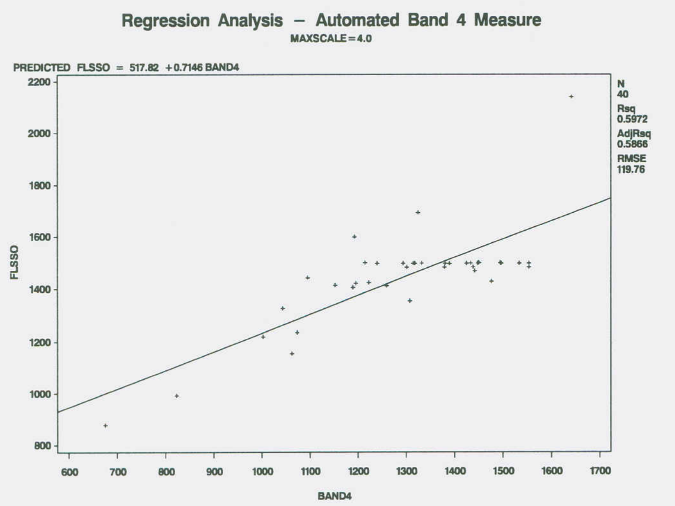


Figure 18. QuickBird band 4, CRISP algorithm Maximum Scale Level 4.0.

ASSESSING THE CONDITION AND HEALTH OF CITRUS TREES

Citrus Disease

The citrus community has expressed interest in developing techniques using remote sensing imagery to aid in the early identification of diseased trees. Citrus diseases such as citrus canker and the tristeza virus cost the citrus industry millions of dollars annually. Symptoms of citrus canker disease include: raised circular lesions surrounded by yellowish halos on leaves and/or brown to blackish circular lesions (scab like) on the citrus fruit (University of Florida, 2004). Symptoms of the citrus tristeza virus include: stem pitting of trunk and limbs or in the presence of aggressive strains; the rapid decline or death of infected trees (Mooney and Harty, 2004). Current treatment measures for citrus canker require the removal of all trees within a 1,900-foot radius of a canker-infected tree. Trees infected with the tristeza virus are removed, once they have been identified as diseased. Both measures result in a significant loss in production for the citrus industry. Scientists are examining the spatial and temporal patterns of disease spread in the hopes of developing improved methods of prevention, eradication and disease control (Gottwald et al., 2001; Gottwald., et al., 1996; Hughes and Gottwald, 1999). Satellite imagery could be an excellent early warning tool to assess the condition and health of citrus trees.

Multi-Resolution Assessment

A multi-resolution approach is necessary to locate and map the spatial extent of citrus groves. A larger scale application, such as a growing region, could be evaluated using a multiple resolution approach. A wall-to-wall inventory conducted over major citrus regions using QuickBird data alone was estimated to cost nearly $1,000,000. As a cost saving measure, an initial inventory of the citrus growing area could be conducted using a moderate resolution satellite such as Landsat (30 meter) data followed by a targeted sampling using QuickBird data. Additional efforts can be made to determine the spatial extent of recently cleared land, along with diseased or reset groves. Sampling could focus on areas suspected of disease progression, abandonment, new planting or be statistically designed to derive the average number of trees per acre or hectare.

Landsat TM data was previously acquired over the test site before the QuickBird capture of November 23, 2002, with observation dates of February 26, 1999 and June 2, 2002. Both Landsat TM observation dates were clipped to match the QuickBird scene footprint and co-registered to one another using ERDAS Imagine. This provided an opportunity to test a NDVI change detection technique to determine if it was possible to detect reset trees, and to the follow-up with a targeted high resolution sample. The two Landsat TM observations were almost 3.5 years apart in age and were acquired at different times during the growing season. The Florida citrus harvesting season generally runs from September through June, with different orange varieties spanning the season while grapefruit were available all season long. Additionally two sets of fruit can be on the tree simultaneously, somewhere between flowering and harvesting stages. So there were many variables, including plant phenology, to consider when comparing images across years, but the NDVI appears to be best at detecting canopy health and change (Perry et al., 1984; Pinter et al., 2003; Wade et al., 1994).

NDVI

The NDVI was calculated against the two Landsat TM observations, NDVI = (TM4-TM3) / (TM4 + TM3). An image differencing procedure was run using the NDVI calculations to determine if changes in vegetative condition could be identified and the spatial extent isolated. The NDVI image (Figure 19), dated 02/26/1999, highlights possible areas of citrus disease in red. The NDVI image (Figure 20), dated 06/02/2002, highlights major changes in red, including the linear blocks that were removed since the 1999 Landsat TM observation. Clouds were showing up as low values in the lower left corner of the NDVI image. Masking procedures could be used to eliminate the clouded areas from consideration in the evaluation of vegetative condition. Major changes in vegetative condition could be identified and the spatial extent determined even though the images were non-anniversary date (winter vs. summer).

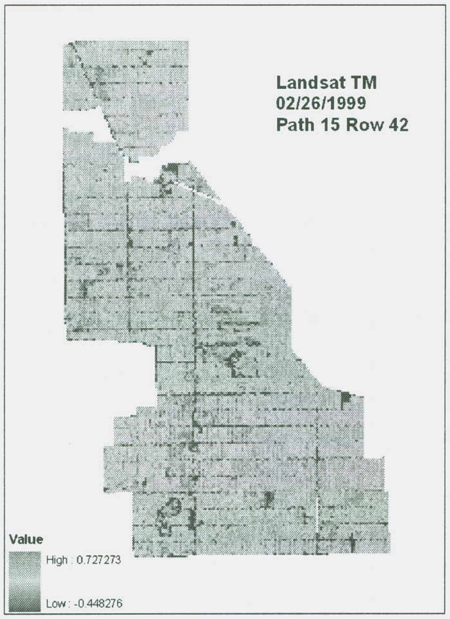


Figure 19 Computed TM NDVI 02/26/99.

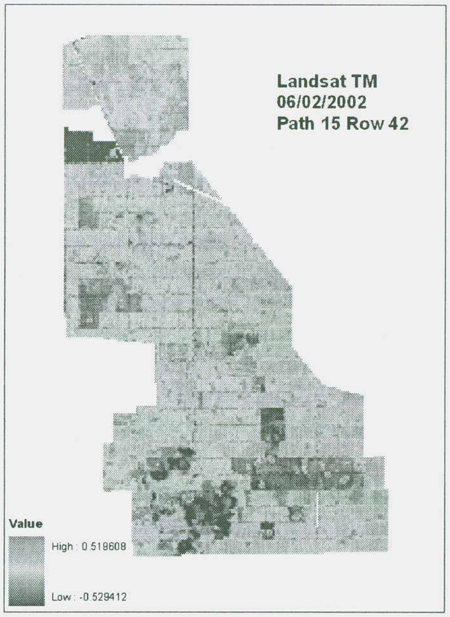


Figure 20 Computed TM NDVI 06/02/02.

The effects of citrus canker and tristeza virus were evident in the 2002 TM NDVI image where large blocks of trees have already been reset. Visual evidence existed in the 1999 TM image indicating that specific areas were in the early stages of citrus disease/decline, where instances of canker and tristeza were apparent. Aggressive eradication efforts were observable in the later image. An image difference procedure was run between the two Landsat TM images, with the results displayed in Figure 21. The difference image was also able to detect NDVI increases in the canopy, shown in green. This can be attributed to a number of factors, including; seasonal variation, increased tree canopy/maturity in the past 3.5 years or better tree health. The areas that contain low biomass were identified by the red or bright orange colors.

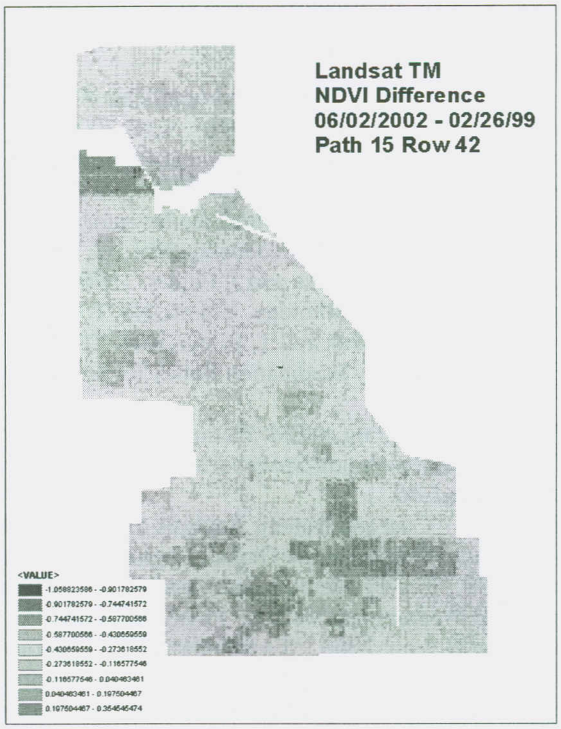


Figure 21. TM Difference Image. NDVI (06/02/2002 minus 02/26/1999).

CONCLUSION

This follow-up investigation proved that the CRISP software is a valuable tool for automating the counting of citrus trees. In the first investigation, band 1 of the pan-sharpened Quick Bird imagery was spatially enhanced using a high pass filter with a 3x3 kernel and was identified as the optimal input for the CRISP software. In this second investigation, the accuracy of the original methodology was improved by altering the CRISP MSL from 8.5, 7.5, 6.5, 5.5, 4.5 to 4.0. Consistent downward bias remains an issue for citrus tree counting. However, the downward bias has been reduced from 18 percent, in the initial investigation, to an overall 14 percent, demonstrating that lowering the MSL improves the accuracy of results.

If the program is to be expanded into large growing regions, a multi-resolution approach is recommended. As a first step, a moderate resolution satellite such as Landsat could be used to identify the major citrus areas and estimate the spatial extent of citrus acreage. In addition change detection techniques such as NDVI and image differencing could be conducted to identify areas of significant change (disease/abandonment/new acreage). Subsequently, a targeted sampling methodology could be carried out using the very high resolution QuickBird data. Targeted sites could be assessed to determine the aerial extent of change previously highlighted using the moderate resolution data. Additionally, the targeted sites could be evaluated further using applications like CRISP to determine tree counts, using statistical analysis to support the findings.

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