Analysis of vegetation indices derived from aerial multispectral and ground hyperspectral data

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Abstract: Aerial multispectral images are a good source of crop, soil, and ground coverage information. Spectral reflectance indices provide a useful tool for monitoring crop growing status. A series of aerial images were obtained by an airborne MS4100 multispectral imaging system on the cotton and soybean field. Ground hyperspectral data were acquired with a ground-based integration system at the same time. The Normalized Difference Vegetative Index (NDVI), Simple Ratio (SR), and Soil Adjusted Vegetation Index (SAVI) calculated from both systems were analyzed and compared. The information derived from aerial multispectral images has shown the potential to monitor the general growth status of crop field. The vegetation indices derived from both systems were significantly different (p-value was 0.073 at α= 0.1 level) at the early growing stage of crops. The correlation coefficients of the image NDVI and ground NDVI were 0.3029 for soybean field and 0.338 for cotton field. SAVI and SR were not correlated.

Keywords: airborne multispectral image, hyperspectral reflectance, vegetation index, remote sensing, crop growth condition

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1 Introduction

Multispectral techniques provide a good source of crop, soil, or ground cover information in agricultural research and applications. Airborne multispectral systems are much less expensive and data intensive compared to space or hyperspectral systems. Multispectral images and the information derived from them can be used to evaluate biomass, crop health, biotypes, and pest infestations in agricultural fields. Airborne remote sensing technology has been employed for detecting crop disease and assessing its impact on productivity[1-4]. Lan et al. indicated that the airborne MS4100 multispectral imaging system has a great potential for use in area wide pest management systems[5]. Some studies used multispectral image senor system to measure crop canopy characteristics. Jones et al. estimated biomass based on multispectral images taken by a Duncan® Tech MS3100 multispectral camera[6].

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For ground truth study, easiness of availability and cost-effective, ground-based methods are also widely used in precision agriculture. Field spectroscopy can provide applications of airborne or spaceborne remote sensing with data support and pertinent correction reference. Spectroradiometers can be used to quickly measure light energy over a range of wavelengths and identify crop stress. Crop conditions can be closely monitored by using reflectance spectral signature. Thenkabail et al. used a hand held spectroradiometer to obtain the correlation between spectral observations with crop parameters of cotton[7]. Darvishzadeh et al. examined the utility of hyperspectral remote sensing in predicting canopy characteristics by using a spectroradiometer[8]. Ren et al. had used handheld hyperspectroradiometer to monitor vegetation stress and concluded that hyperspectral remote sensing is a potential and promising technology for monitoring environmental stresses on agricultural vegetation[9]. Reyniers et al. compared an aerial image with a ground platform measuring device to predict yield of winter wheat[10].

Spectral reflectance in the visible and near infrared region (400-2500 nm) has been identified as a popular tool to assess crop growth status. Spectral reflectance indices were developed based on the simple mathematical formula, such as ratios or differences between the reflectance at given wavelengths. The Normalized Difference Vegetative Index (NDVI) is a commonly used measurement of crop health in agricultural applications. NDVI is calculated by equation: (1):

$$NDVI = \frac{\mathrm{NIR - Red}}{\mathrm{NIR + Red}} \qquad (1)$$

where Red and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. Huete found that NDVI was sensitive to canopy background variations and exhibited saturated signals for high biomass conditions[11]. Healthier crop canopy will absorb more red and reflect more near infrared light, and consequently has a higher NDVI value. NDVI values vary between −1.0 and +1.0. The negative NDVI values indicate the presence of cloud, snow, or water, and the positive NDVI values are positively correlated to green vegetation. Other vegetation indices (VI), such as Simple Ratio (SR) and Soil Adjusted Vegetation Index (SAVI) were developed to reduce or eliminate soil influence on solar reflectance values[11-13]. The simple ratio is calculated by equation (2):

$$SR = \frac{NIR}{\mathrm{Red}} \qquad (2)$$

The Soil Adjusted Vegetation Index is a superior vegetation index for low cover environments[11]. *SAVI* is calculated by equation (3):

$$SAVI = \frac{NIR - \mathrm{Red}}{NIR + \mathrm{Red} + L} \times (1 + L) \qquad (3)$$

where L is a constant that is empirically determined to minimize the vegetation index sensitive to soil background reflectance variation. If L is zero, *SAVI* is as same as NDVI. For intermediate vegetation cover ranges, L is typically around 0.5.

A ground-based integration sensor and instrumentation system for monitoring crop conditions is under construction now[14]. The objectives of the present study were to analyze aerial multispectral images taken during the growing season and compare vegetation indices derived from both aerial and ground-based measurements taken by the integration system.

2 Materials and methods

2.1 Study area

The study field was located in College Station, Texas (30°31'17N, 96°23'56W). Soybean and cotton were planted with row spacing of 1 m (Figure 1). Aerial imagery was taken over the field in June, July and August, 2008. Two ground-based field experiments were conducted in the meantime under cloud free conditions.

2.2 Image acquisition

2.2.1 Airborne multispectral imaging system

The imaging system used to acquire multispectral image is TerraHawk® Aerial Imaging System. A MS4100 multi-spectral camera (Geospatial Systems, Inc., Rochester, NY) is the central component of the airborne multi-spectral imaging system (Figure 2). The camera supports three standard models for RGB, CIR and RGB/CIR with blue band in between 437 and 483 nm, green band in between 520 and 560 nm, red band in between 640 and 680 nm, and NIR band in between 767 and 833 nm. They approximate Landsat satellite (NASA, Washington DC and USGS, Reston, VA) bands.

Figure 1 Raw CIR image of concerned cotton and soybean fields obtained on July 10, 2008

Figure 2 TerraHawk aerial imaging system and MS4100 multispectral camera

Based on the requirement of the research, the body of the MS4100 camera was equipped with a 14 mm Sigma lens with a 58.1 degree field of view. A single-engine airplane, Cessna 206 (Wichita, KS), owned by the SPARC USDA ARS was assigned to fly over the concerned field with the assembled imaging system.

2.2.2 Image processing

To be used for any quantitative evaluation or temporal analysis, acquired raw images must be corrected and converted into reflectance images. TerraVerde® provides an irradiance radiometer and Image Correction software with the imaging system for this purpose. The ground based radiometer is used to record solar data at a preset rate throughout the day in which imagery is being acquired. The data then is used for image calibration. The Image Correction software is the interface for uploading irradiance radiometer data and processing raw images to reflectance images.

Image-to-image registration was done in the Environment for Visualizing Images (ENVI) software package (Version 4.5, ITT Visual Information Solution, www.ittvis.com). The base image was the standard DOQQ (Digital Ortho Quarter Quads) aerial photograph provided by TNRIS (Texas Natural Resources Information System) in Austin, Texas. At least fifteen ground control points (GCPs) were selected within the reflectance images to perform warping with the 1st degree polynomial function. For the best results, the RMS error was minimized. Nearest neighbor was used for resampling. The resampled pixel size changed to the resolution of the DOQQ image (1 m). Warped images then were examined and compared to the DOQQ image by using Dynamic Overlays.

Two types Region of Interest (ROI) were selected for image analysis. To record the temporal profile of the study area, polygon ROI was randomly selected. To compare the measurements from ground, polyline ROI was used. NDVI, SR, and SAVI of the ROIs were calculated using Band math function in ENVI. Summary statistics of ROIs including minimum, maximum, mean and standard deviation were conducted and compared with ground measurements.

2.3 Ground measurements

The ground-based integration sensor and instrumentation system was configured with different sensors[14]. FieldSpec® (Analytical Spectral Devices, Inc., Boulder, CO), a portable field spectroradiometer, was one of them and used for collecting spectral reflectance data. The instrument can detect reflected light from canopy ranging from 325 nm to 1075 nm wavelengths with a sampling interval of 1.4 nm of the spectrum. It was mounted on a tractor at a height of about 2 m above the ground. With an angular field-of-view of 25°, it scanned an approximately 0.62 m^2

of ground area. According to Castro-Esau et al.[15], instrument optimization and white reflectance measurements were performed prior to field test. It was adjusted to 10 scans per dark current and the integration time was set at 217 ms. Spectral reflectance data which were uncorrected for sun angle or atmospheric effects were used to calculate the vegetation indices using equation (1), (2) and (3), respectively. The reflectance values at the 680 nm wavelength in the red region and the 800 nm wavelength in the NIR region were chosen[15]. Reflectance measurements were taken while the tractor was driven along the rows. The GPS coordinates of the beginning and end sampling points were recorded.

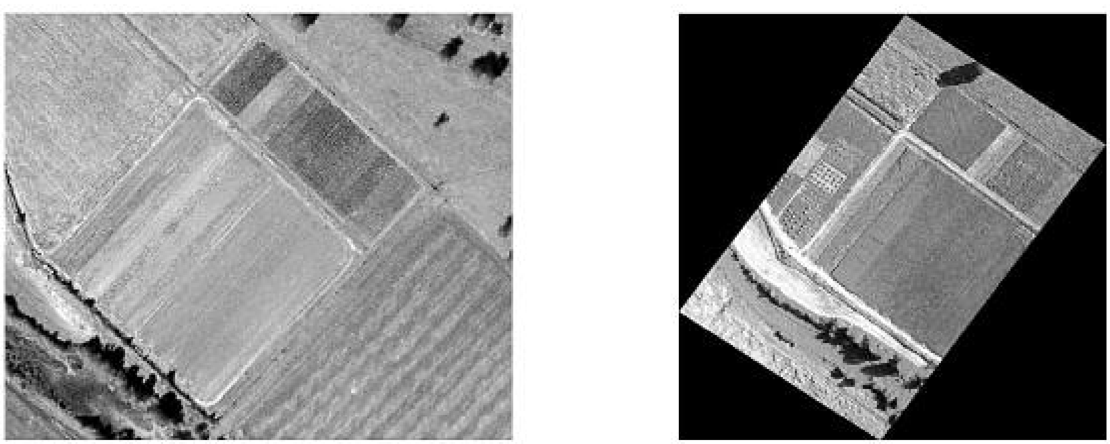
3 Results and discussion

3.1 Image analysis

Figure 3 shows the corresponding reflectance image of the image in Figure 1. It was converted in the Image Correction software with the measurement of the irradiance radiometer on the same day. The reflectance image was brightened since the original reflectance image was too dark. The reflectance image obtained on July 10, 2008 was registered to the standard DOQQ image and was shown in Figure 4.

NDVI, SAVI and SR subset images were generated from reflectance images and shown in Figure 5.

Figure 3 Corresponding brightened reflectance image of the raw image (Fig 1)



a. Standard DOQQ image of the study area obtained on 2005 (Projection NAD83-UTM-14N) b. Registered and rectified aerial image obtained on July 10, 2008

Figure 4 Image-to-image registration

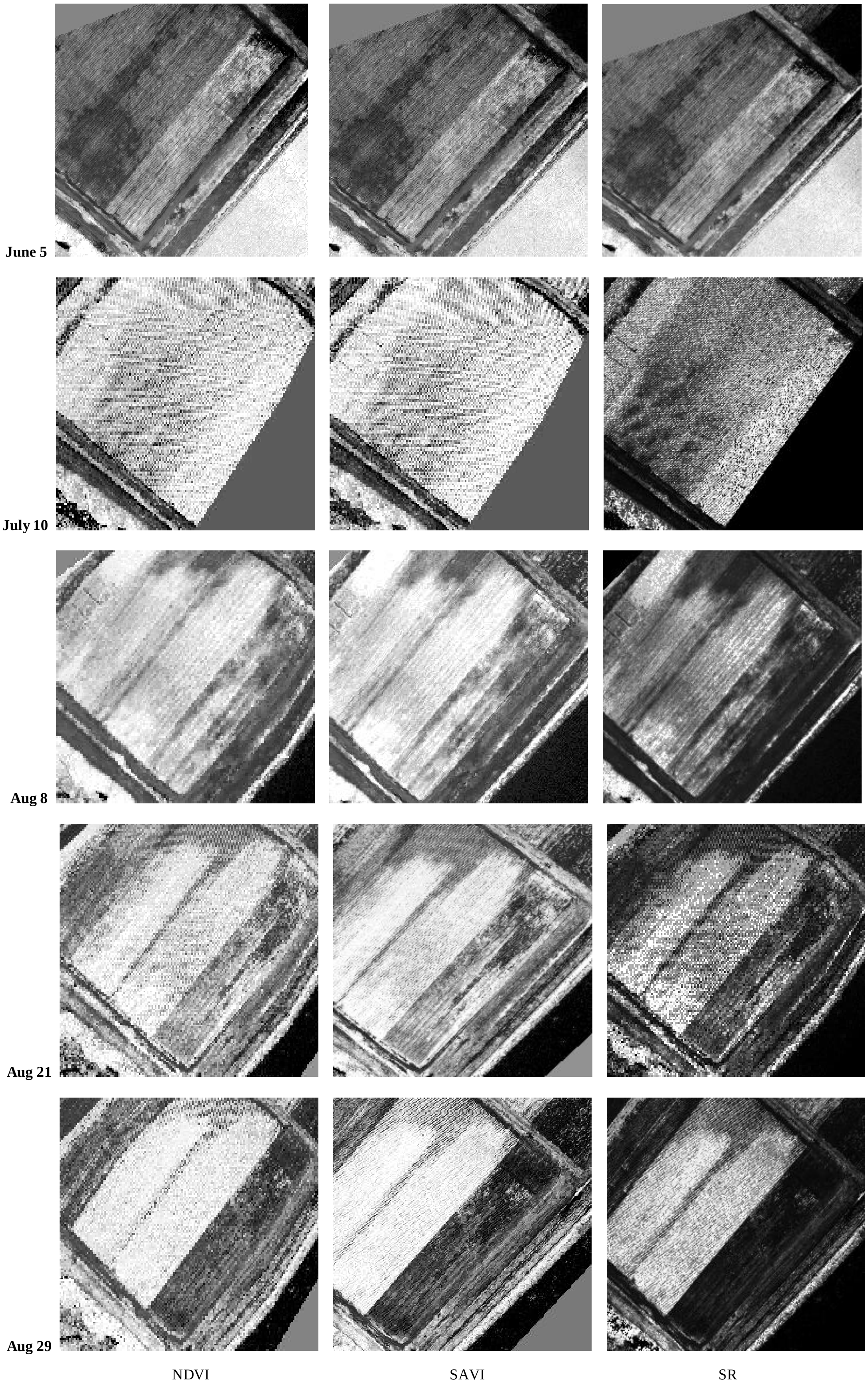


Figure 5 NDVI, SAVI and SR image series obtained on June 5, July10, Aug 8, Aug 21, and Aug 29, 2008

A total of 3537 and 3656 pixels of ROIs were selected within the soybean and cotton fields, respectively (Figure 6). The coordinates of four polygon corners for both ROIs were indicated. ROIs were selected from other four images according to these coordinates.

With Cursor locator tool in ENVI, the beginning and end sampling points of ground measurements were located on the image. Transect was drawn by connecting the beginning and end points (Figure 7). Each transect consisted of 173 pixels.

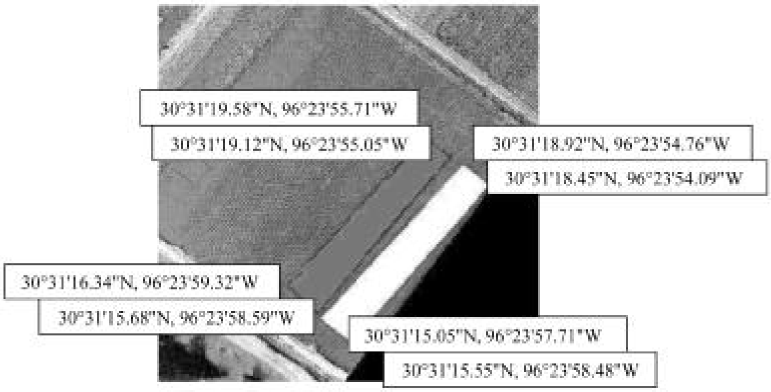


Figure 6 Selected polygon ROIs of the soybean and cotton field on the reflectance image obtained on July 10, 2008.

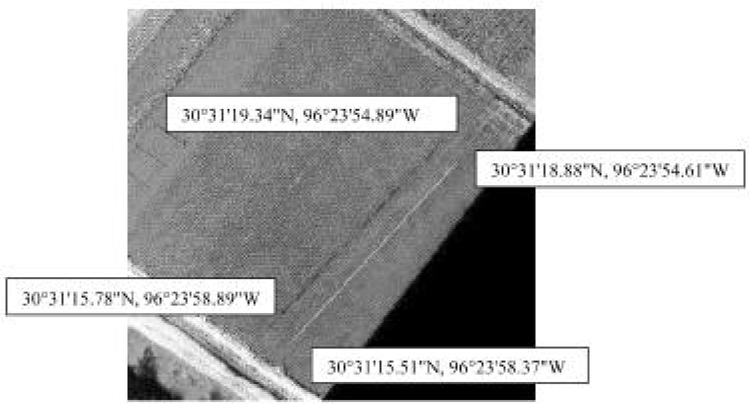


Figure 7 Selected transects of the soybean and cotton field on the reflectance image obtained on July 10, 2008.

Quick statistics were conducted on those ROIs and the tendencies of NDVI, SAVI and SR changing over time were plotted in Figure 8. For the soybean field, three VIs reached maximum in July. For the cotton field, the VIs reached maximum in July, and then dropped off, and increased again in late August.

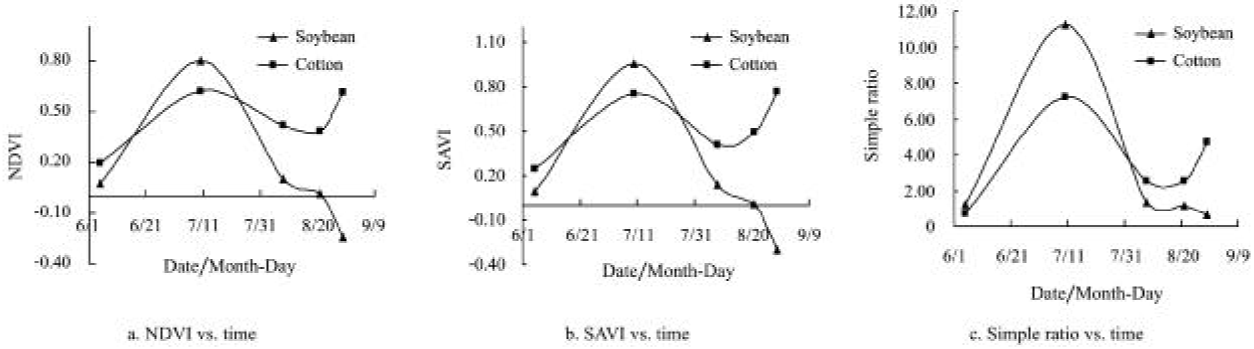


Figure 8 Tendencies of NDVI, SAVI and SR values derived from ROIs of soybean and cotton field over time

3.2 Comparison of aerial and ground data

Spectral reflectance data were processed by ViewSpec™ Pro4.05 which comes with FieldSpec®. There were a total of 96 and 108 measurements within soybean and cotton fields, respectively. The NDVI, SR and SAVI were calculated on the spectral data.

The comparison of the average NDVI, SR and SAVI values from aerial images and ground truth measurements are shown in Table 1.

Table 1 Comparison of Vegetation Indices calculated from aerial images and ground measurements

Date	Crop	Index	Image		Ground	
			Mean	Stdev	Mean	Stdev
June 5, 2008	soybean	NDVI	0.0732	0.1463	0.8500	0.1146
		SR	1.2157	0.3768	3.2057	0.0898
		SAVI	0.0925	0.1852	0.8614	0.0950
	cotton	NDVI	0.1922	0.1359	0.5660	0.0792
		SR	0.7000	0.1988	2.0832	0.0550
		SAVI	0.2484	0.1769	0.6032	0.1401
July 10, 2008	soybean	NDVI	0.7954	0.1442	0.7053	0.0952
		SR	11.2292	7.1922	6.2352	1.6336
		SAVI	0.9535	0.2222	0.5698	0.1143
	cotton	NDVI	0.6235	0.2648	0.7087	0.0787
		SR	7.2682	6.0499	6.3279	1.8090
		SAVI	0.7551	0.3399	0.6248	0.1461

No consistent trend was indicated by the datasets. One-way ANOVA tests indicated that the VIs derived from both systems were significantly different (p-value was 0.073 at α= 0.1 level) on June 5. The plants were at their early growing stages in June 5, and more soil surface exposure than July 10. Bare soils usually generate very small positive NDVI, which is much lower than the NDVI of health vegetation. That could be the reason for lower NDVI values from aerial image than ground measurement on June 5. The area of soil was reduced when crops were starting filling in the rows. Thus, both image NDVI and ground NDVI were similar on July 10. The correlation coefficients of the image NDVI and ground NDVI were 0.3029 for soybean field and 0.338 for cotton field. The image SAVI were higher than image NDVI for both fields. The ground SAVI and NDVI were similar for both field on June 5 and the ground SAVI were lower than ground NDVI for both fields on July 10. The SAVI was more effective on minimizing soil background reflectance variation for analyzing image data; however, the ground SVAI did not have better performance than the ground NDVI. Overall, the standard deviations of ground measurements were smaller than those from aerial images.

4 Conclusions

In this study, the aerial multispectral images and ground spectral reflectance measurements were analyzed and the relationship between them was investigated. The information derived from aerial multispectral images has potential to monitor the overall growth status of crop field. The vegetation indices derived from them followed the expected trend of crop plants growing over time. When crop coverage was low, the VI values from both systems were significantly different. The VI values calculated from the spectroradiometer measurements were much higher than those from aerial images. What caused the difference and how to acquire high quality images and reliable ground measurements will be further investigated in the future study.

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