VALIDATION OF UNMANNED AERIAL SYSTEM (UAS) DATA FOR COTTON RESEARCH

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Abstract

Interest in Unmanned Aerial System (UAS) for agriculture research, plant breeding, and precision farming is quickly growing; however, there is a need to validate, contrast, and compare plant trait estimates derived from UAS data. New platform and sensor technology now enable the collection of high resolution crop data over the entire growing season, creating new opportunities for agriculture research. In 2017, a field trial consisting of five different genotypes was established at the Texas A&M AgriLife Research and Extension Center (Corpus Christi, TX). Plots were one or two rows planted in skip or solid pattern, respectively. Objectives of this research were to improve UAS platforms for high throughput data collection, validate plant height estimates derived from UAS data, as well as contrast and compare multi-source canopy cover estimates. Plant height data extracted from red-green-blue (RGB) imagery showed good correlation with manual ground measurements r^2 0.89 and 0.94 for 13 and 10 dates, respectively. On average and over time, there is a tendency of UAV-based measurements to underestimate plant heights at the plot level. Preliminary assessment of correlation between RGB and Normalized Difference Vegetation Index (NDVI) canopy cover measurements showed low r^2 (0.37) over the season. As soon as crop senescence starts RGB-based estimates of canopy cover tend to drop, which affected comparison. Removing dates past initiation of crop senescence revealed a very high correlation between canopy cover estimates (r^2 0.99), also indicating that NDVI represents a measure of canopy cover, with an added appreciation for the surface coloration.

Introduction

Recent advances in Unmanned Aerial System (UAS) and sensor technology are now making it possible to accurately assess overall crop growth and health status with fine spatial and high temporal resolutions previously unobtainable from traditional remote sensing platforms, at a relatively low cost. When UAS is properly equipped with sensors, these platforms enable fast and accurate data collection throughout the growing season. Combined with state-of-the-art image processing algorithms, visualization techniques, and geospatial data analysis, UAS offers an innovative opportunity for the development of high throughput phenotyping system and precision agriculture applications including plant-level phenotyping and crop precision management for field-level production. Additionally, UAS and remote sensing technology will soon be an important tool for plant breeding scientists, since it provides the capability to efficiently evaluate a large number of genotypes for specific traits of interest.

Objectives

1. Improve our Unmanned Aerial System (UAS) platforms for high throughput phenotyping data collection
2. Validate plant height estimates derived from UAS data and compare multi-source canopy cover estimates

Materials and Methods

Field Location and Experimental Setup

A field experiment was established at the Texas A&M AgriLife Research and Extension Center in Corpus Christi, TX. The trial consisted of 5 cotton genotypes from the Texas A&M AgriLife Cotton Breeding Program. Genotypes were planted March 22nd, 2017, in skip and solid row patterns (i.e. one- or two-row plots, respectively), each replicated four times.

Platforms and Sensors

Rotorcraft UASs were used as mapping platforms. These platforms can perform low altitude flights with slow ground speeds, which results in finer spatial resolution measurements, and consequently, better quality data products. A DJI Phantom 4 Pro and DJI Matrice 100 platforms were used for Red-Green-Blue (RGB) and Multispectral (MS) data collection, respectively. The RGB sensor used was the standard 20MP gimbal-stabilized DJI sensor, while a SlantRange 3p multispectral sensor was integrated and used with the Matrice 100 platform. Data collection occurred 19 and 14 times for RGB and MS, respectively, from March 25th through August 1st, 2017.

Image Acquisition and Spatial Referencing

Geo-referencing, spatial aligning, and ortho-rectification of the raw images acquired is a critical task in utilizing UAS-based platforms for agriculture research applications. To address this, ground control targets were installed around the test field and their precise position surveyed using a Post Processed Kinematic GPS (PPK-GPS) device that can provide sub-centimeter location accuracy. The 3D (longitude, latitude, and elevation above sea level) coordinates of the ground control targets were integrated into the data processing workflow to ensure that the final geospatial data products (ortho-mosaic image and 3D point cloud) were well aligned throughout the growing season for comparisons over time.

Geospatial Data Product Generation

Images acquired from the UAS platform were processed using the Structure from Motion (SfM) algorithm to generate geospatial data products such as 3D point cloud and ortho-mosaic images. The ortho-mosaic images were radiometrically calibrated using spectral targets with known reflectance (i.e. reflectance tarps).

Crop Height Model Generation

A Digital Surface Model (DSM), which represents the surface elevation of objects on the ground was generated from the 3D point cloud data at the same spatial resolution as the orthomosaic image (0.5 and 1 cm for RGB and MS, respectively). The Crop Height Model (CHM) was generated by subtracting the Digital Elevation Model (DEM) from the DSM for each flight date to estimate plant height.

Manual Plant Height

Manual plant height measurements were taken in the field using a meter-stick. To approximate measurements obtained from image-processing technology, plant heights were measured from the ground surface to the top of the plants' terminal. Five measurements were taken per plot for comparison with UAS estimates.

Canopy Cover

A classification algorithm to delineate crop canopy from other non-canopy objects (background) was used to calculate canopy cover from the ortho-mosaic images. Four spectral bands (Blue, Green, Red, and Near Infrared) of ortho-mosaic images, were used to estimate canopy cover. The same grid structure designed for the crop growth pattern analysis was used to calculate canopy cover from the binary classification maps. Canopy cover was calculated using RGB (CC_{RGB}) and MS (CC_{NDVI}) sensors for comparison purposes. Equations used are shown below. As seen on the equation for canopy cover calculation from MS data, Normalized Difference Vegetation Index (NDVI) values higher than higher than 0.6 were 'considered as canopy'.

$$CC_{RGB} = \frac{[(\sum pixel\ size^2), if\ canopy]}{\sum(pixel\ size^2)} * 100$$

$$CC_{NDVI} = \frac{[(\sum(pixel\ size^2), if\ NDVI > 0.6]}{\sum(pixel\ size^2)} * 100$$

Results and Discussion

Plant Height

Time series UAS plant height data extracted from RGB imagery over the growing season showed a good correlation with manual ground measurements r^2 0.89 and 0.94 for 13 and 10 dates, respectively (Figs. 1 and 2). Early to mid-season, UAV plant height estimates were very well correlated to manual measurements, as evidenced by their proximity to the 1 to 1 line shown in figures 1 and 2. It was also apparent that sometime late in the season, UAV measurements seem to lose their ability to pinpoint maximum plant height. According to manual measurements, maximum plant height was achieved by June 9th (at 80 days after planting). When comparing manual and UAV measurements throughout the growing season, crop height average at four dates were statistically different at the 5% probability level. For two of those comparisons, manual and UAV measurements were collected at different dates, two days apart (see Fig. 2).

On average and over time, however, there is a clear tendency of UAV-based measurements to underestimate plant heights at the plot level, when compared to ground measurements. This trend seems to be accentuated late in the season (after plants reach maximum height) and could be attributed to current UAV image processing technology inability to accurately resolve the plants' terminal after leaf senescence, despite high-resolution data products. Other factors such as windy conditions during data collection may also be confounding. This may not be a problem after maximum plant height has been achieved since for most practical purposes plant height would be of interest during the crops' vegetative and early reproductive stages. For uses such as crop phenotyping and management of plant growth regulator application, the current accuracy may be adequate. Correlations between ground/manual and UAV estimates found this year are consistent with results obtained in the past few years of testing. Overall, r^2 values are usually around 0.90 or so.

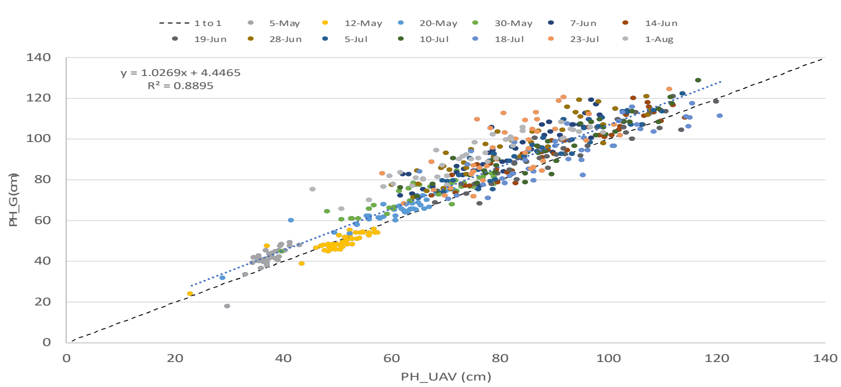

Figure 1. Correlation between UAV-based plant height (PH_UAV) and manual ground measurements (PH_G). Each point represents an average of 5 manual measurements and 6 UAV measurements per plot. A total of 13 dates are plotted.

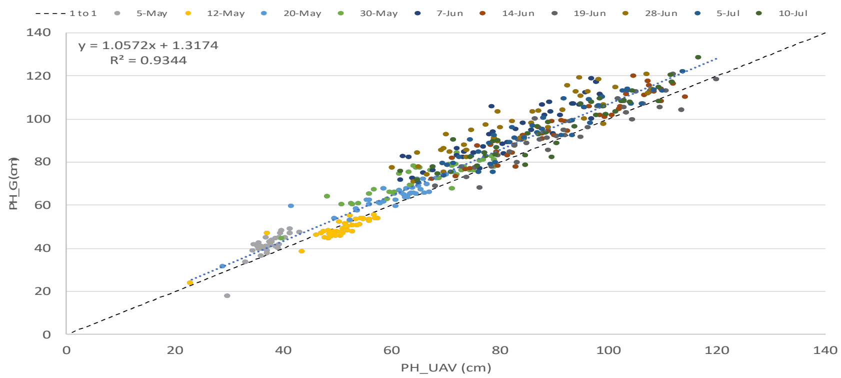

Figure 2. Correlation between UAV-based plant height (PH_UAV) and manual ground measurements (PH_G). Each point represents an average of 5 manual measurements and 6 UAV measurements per plot. A total of 10 dates are plotted (i.e. last three dates of the season were removed).

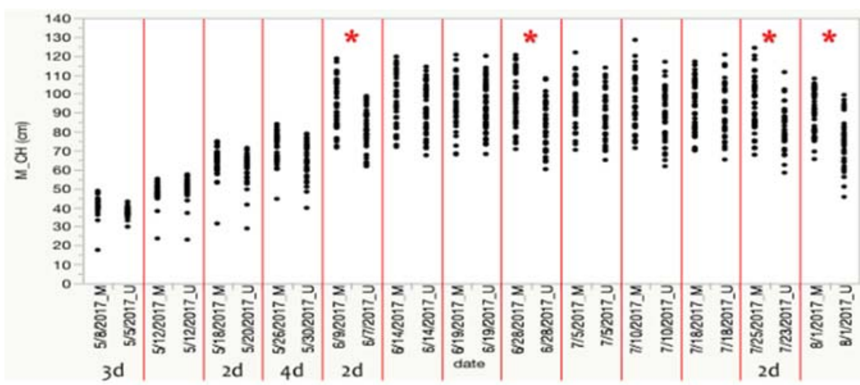

Figure 3. Average plant height values collected during the growing season. Manual (_M) measurements and UAV (_U) estimates are plotted side-by-side for comparison. Red stars indicate statistical difference at the 5% level of probability. Note that not all dates compared match; number below dates indicate how many days apart measurements were taken.

Canopy Cover

Plant canopy cover is another trait of interest as it relates to crop growth, development, water use, and sunlight energy capture. RGB-based canopy cover estimates are very stable over time and seem to remain relatively unaffected by changes in environmental conditions (e.g. sunlight angle, cloud cover, etc.) throughout the crop growing season. As such, and as interest in MS sensors for use with UAV platforms grows, it was pertinent to compare, and contrast canopy cover estimates derived from RGB and MS sensors. One of the potential benefits of such approach would be to use a single sensor (e.g. multispectral) and platform, in cases where only canopy cover and vegetation indices such as NDVI are of interest. This could lead to reductions in cost of equipment (i.e. no need for RGB platform/sensor), equipment maintenance, and operation (i.e. less flights needed). Preliminary assessment of correlation between RGB and MS measurements showed low r^2 (0.37) between the two estimates over a growing season (Fig. 4.a.). However, it became evident that correlation was in fact good up to June 7th, 2017, after which point measurements shifted away from the 1 to 1 line (Fig. 4.b.). Upon closer inspection of test plots, it was clear that the plants' canopies were starting to senesce (Fig. 4.b. insert images). Since RGB-based estimates, as calculated here, are directly dependent upon the 'green' color, as soon as senescence starts and leaves transition to a more 'yellow/brown' coloration, RGB-based estimates of canopy cover tend to drop. This does not necessarily mean plants are losing leaves but may simply indicate a change in leaf coloration. The NDVI-based canopy cover estimates, on the other hand, proved to be slightly more stable over the season, since it relies on the red and near infrared bands, rather than on the green color. A very high correlation between RGB- and NDVI-based canopy cover estimates was found for a combination of 5 different dates (r^2 0.99), from April 24th to June 7th, 2017 (Fig. 5).

Although not the focus here, it is important to mention not only that NDVI has been correlated to many important plant/crop traits, including plant biomass, leaf area index (LAI), nutrient and water status, and yield, but also that these relationships are often misinterpreted. One needs to be aware of the limitations of NDVI (and other vegetation indices), and carefully examine its relationship with traits of interest. Our results (shown on figure 5) seem to indicate that NDVI actually represents a measure of canopy cover, with an added appreciation for the surface coloration. Interestingly, an unrelated study by Sudbrink et al. (2003) investigating NDVI values for plant canopies damaged by cabbage looper larvae, *Trichoplusia ni* (Hubner), found that although percent light penetration into the canopy of damaged plots was higher than in plots where the larvae was controlled with insecticide, NDVI values were not. This finding seems logical since overall crop leaf area is decreasing (due to defoliation), thus increasing percent light penetration into the canopy; however, with no detectable impact on leaf color. This further supports the notion that NDVI may, in fact, represent canopy cover with an added appreciation for leaf color.

When comparing average canopy cover collected using RGB and MS sensors during the growing season, no differences were found between estimates generated from the different sensors up to June 7th, 2017 (78 days after planting). The difference in average plot canopy cover estimates derived from RGB and MS sensors became statistically significant on June 19, 2017 (90 days after planting), where the beginning of crop canopy senescence is easily discernable by the naked eye (Fig. 6).

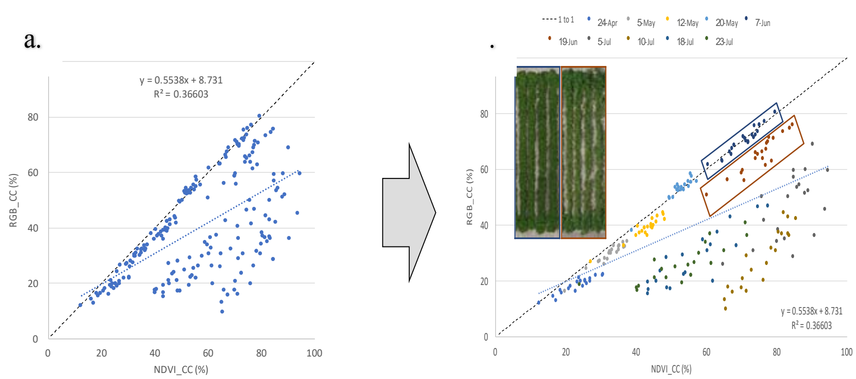

Figure 4. Correlation between plant canopy cover as estimated using Red-Green-Blue (RGB_CC) and normalized difference vegetation index (NDVI_CC) for ten dates between April 24 to July 23, 2017. (a.) Data for all dates combined. (b.) Data plotted by date. Dashed line represents the 1 to 1 line on both graphs, $r^2 = 0.366$. Blue and brown inserts/images represent June 7 and June 19, respectively (b.).

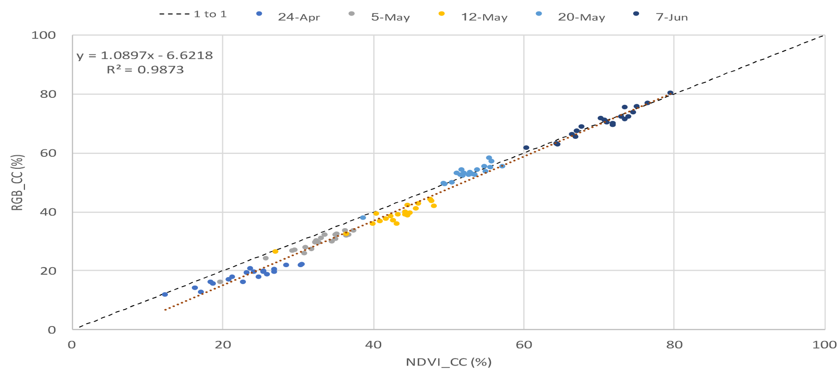

Figure 5. Correlation between average plant canopy cover as estimated using Red-Green-Blue (RGB_CC) and normalized difference vegetation index (NDVI_CC) for five dates between April 24 to June 7, 2017.

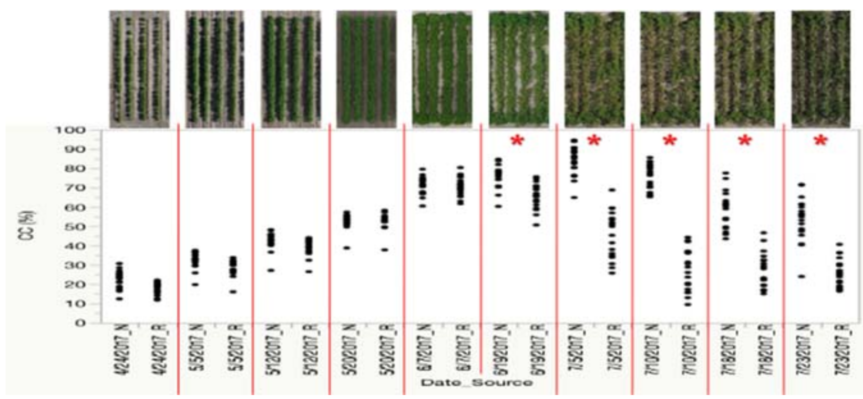

Figure 6. Average canopy cover estimates collected using Red-Green-Blue (RGB) and multispectral sensors during the growing season. RGB (_R) and Normalized Difference Vegetation Index (_N)-derived estimates are plotted side-by-side for comparison. Images on top of each date pair depicts an 'average' plot and are shown for visual reference purpose. Red stars indicate statistical difference at the 5% level of probability.

Conclusions

Rotorcraft-type small UAS may be used to collect high resolution RGB and MS imagery from which plant parameters such as canopy height and canopy cover may be extracted. Plant height estimates derived from RGB imagery have good correlation with manual ground measurements over the growing season (r^2 0.89 and 0.94 for 13 and 10 dates, respectively). Comparison of RGB- and NDVI-derived canopy cover estimates showed high correlation between the two different sources (r^2 0.99), until the beginning of crop senescence. The high correlation and proximity of canopy cover measurements derived from the multispectral sensor to the 1 to 1 line also indicate that NDVI is a measure of canopy cover with an added appreciation for leaf coloration.

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