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Evaluating Sorghum Senescence Patterns Using Small Unmanned Aerial Vehicles and Multispectral Imaging

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Abstract

Grain sorghum is an important crop in cropping systems worldwide. Many different genetic lines are tolerant to post-flowering heat and drought stress because they express the “stay-green” trait which causes a delay in senescence patterns. Traditional methods of senescence identification are labor-intensive and time consuming. However, remote sensing is a proposed method of identifying sorghum senescence. A study using small unmanned aircraft systems (sUAS) as a remote sensing platform was conducted in Concordia, KS. Twenty sorghum varieties with 3 replications were sown in a randomized block design. The aircraft used was a DJI S-1000 equipped with a MicaSense RedEdge 3 multispectral camera. Two successful flights were completed after the flowering period (September 13 and October 4, 2018). Subsequent ground-truthed senescence ratings were taken on both days, with each leaf of 4 sample plants being assigned a senescence score between 100 and 0 (100 indicating no visible leaf senescence and 0 indicating complete leaf senescence). Data processing was done using Agisoft Photoscan Pro to generate an orthomosaic image and ArcGIS Pro for vegetation index generation and data extraction. Three vegetation indexes (VI) were generated: the normalized difference vegetation index (NDVI), normalized difference red edge (NDRE), and soil adjusted vegetation index (SAVI). The NDRE was the only significant VI of the three found to predict whole plant senescence. It also had the strongest correlation coefficient when analyzed with ground-truthed senescence scores. When comparing NDVI, NDRE, and SAVI data, the NDRE index is the best indicator of grain sorghum senescence.

Keywords

unmanned aircraft, grain sorghum. multispectral indices, remote sensing, NDVI, NDRE, SAVI

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Evaluating Sorghum Senescence Patterns Using Small Unmanned Aerial Vehicles and Multispectral Imaging

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Summary

Grain sorghum is an important crop in cropping systems worldwide. Many different genetic lines are tolerant to post-flowering heat and drought stress because they express the "stay-green" trait which causes a delay in senescence patterns. Traditional methods of senescence identification are labor-intensive and time consuming. However, remote sensing is a proposed method of identifying sorghum senescence. A study using small unmanned aircraft systems (sUAS) as a remote sensing platform was conducted in Concordia, KS. Twenty sorghum varieties with 3 replications were sown in a randomized block design. The aircraft used was a DJI S-1000 equipped with a MicaSense RedEdge 3 multispectral camera. Two successful flights were completed after the flowering period (September 13 and October 4, 2018). Subsequent ground-truthed senescence ratings were taken on both days, with each leaf of 4 sample plants being assigned a senescence score between 100 and 0 (100 indicating no visible leaf senescence and 0 indicating complete leaf senescence). Data processing was done using Agisoft Photoscan Pro to generate an orthomosaic image and ArcGIS Pro for vegetation index generation and data extraction. Three vegetation indexes (VI) were generated: the normalized difference vegetation index (NDVI), normalized difference red edge (NDRE), and soil adjusted vegetation index (SAVI). The NDRE was the only significant VI of the three found to predict whole plant senescence. It also had the strongest correlation coefficient when analyzed with ground-truthed senescence scores. When comparing NDVI, NDRE, and SAVI data, the NDRE index is the best indicator of grain sorghum senescence.

Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is an important crop in cropping systems around the world. It is well adapted to semi-arid regions around the world and is mostly grown where water stress is expected. One of the most damaging forms of stressors to crops is post-flowering drought stress or "terminal drought," which can greatly reduce grain yields. Several genetic lines of sorghum have a form of tolerance to this late-stage stressor known as the non-senescence or "stay-green" (SG) trait. This trait is characterized by the ability to maintain green leaf color and resist leaf death for longer periods of time under post-flowering drought stress. When compared to their non-SG counterparts, SG lines of grain sorghum have been shown to produce higher grain yields when subjected to yield-limiting conditions such as heat and drought stress. In addition, they also show increased tolerance to stem rots and lodging under these same conditions and do not show yield penalties when exposed to ideal growing conditions.

Many breeders consider these traits of much agronomic importance. Stay-green measurements involve characterizing leaf senescence patterns using traditional methods such as visual leaf scoring and taking chlorophyll readings. However, these methods can be labor-intensive and time-consuming. With the rise of remote sensing use in agriculture, a proposed method of improving sorghum senescence identification includes using small unmanned aircraft systems (sUAS) to collect multispectral data. Therefore, the objective of this experiment was to identify sorghum senescence patterns using sUAS multispectral imagery.

Procedures

Twenty hybrids with three replications were sown in a randomized block design in a field near Concordia, KS (97° 34' 12" N, 39° 36' 36" W). The field's soil type was a Muir silt loam. Plot size was 17.5-ft long × 5-ft wide.

The sUAS used was a DJI S-1000 multi-rotor aircraft. The sensor attached to the aircraft was a MicaSense RedEdge 3 multispectral camera, which captures 5 separate bands per image: Blue (465-485 nm bandwidth), green (550-570 nm), red (663-673 nm), red edge (712-722 nm), and near infrared (820-860 nm). The sensor is capable of collecting data at a spatial resolution of 8 cm/pixel at an altitude of 120 m above ground level (AGL). The sensor also has a field of view of 47.2°.

Two successful flights were flown on September 13 and October 4, 2018. The camera was calibrated immediately before and after each flight to ensure image quality. The flight path was planned before flight using a mobile ground station and the software 'DJI Ground Station Pro.' Each flight was conducted at an altitude of 30 m AGL, was flown with an 80% front and side overlap, and traveled at a speed of 2 m/s. To ensure uniform lighting distribution, the flights were conducted ±2 hours of solar noon. The MicaSense camera was set to an 'overlap' mode for image capturing, which is the recommended setting for image capturing. Images were stored in a micro SD card as GEOTIFF images.

Subsequental ground-truth measurements were taken to measure plant senescence. Four consecutive plants were designated as sample plants to measure for senescence. Each sorghum leaf was scored based on a visual score of 100 (no visible senescence) to 0 (complete senescence). The leaves were scored starting from the flag leaf to the first leaf such that every leaf afterwards was completely senesced. The leaf scores were averaged, with the resulting score assigned to the plot as a senescence score.

Data processing was completed in two phases: orthomosaic generation and data extraction (Figure 1). During the first phase, individual GEOTIFF images taken during flight were stitched together to form a multi-band orthomosaic using Agisoft Photoscan Professional. This process involves generating a sparse point cloud, dense point cloud, digital elevation model (DEM), and then an orthomosaic photograph. In the second phase, the orthomosaic was uploaded into ArcGIS Pro, where three vegetation indices (VI) were generated: the normalized difference vegetation index (NDVI), the normalized difference red edge (NDRE), and the soil adjusted vegetation index (SAVI). Prior to this, plot boundaries were established using the 'fishnet' tool in ArcGIS Pro. To mask reflectance values of features such as soil, the image was classified using a supervised Maximum Likelihood Classification (MLC) approach (Figure 2). Five image classes were generated: leaves, soil, shadows, dead plants, and grain heads. Through a conditional tool in ArcGIS Pro, the vegetation index was then combined with the 'leaves' class. Data were then extracted, characterized by plot location, and exported to a results table for statistical analysis. Statistical analysis included correlation analysis using Pearson's Correlation Coefficient.

Results

To test the ability of each VI to determine whole plant senescence, correlation between the VIs and the ground-truthed senescence scores was performed (Figure 3). The difference in scores (both ground-truthed and VI scores) between September 13 and October 4 were taken and plotted in a correlational analysis. There was a significant relationship found between the whole-plant senescence ground-truthed scores and the NDRE index (Table 1). An intermediate correlation coefficient was found with the NDRE, with the NDVI and SAVI indexes both demonstrating weak correlation coefficients.

Conclusions

When compared to other indexes that can be generated with multispectral imagery, the NDRE index is the most successful in identifying whole-plant sorghum senescence patterns throughout the post-flowering crop stages. Further research should be conducted comparing multiple VIs with a greater number of flights following the flowering stage.

Table 1. Vegetation scores for each index computed for the 2018 experiment; the only significant index was the NDRE ($\alpha = 0.05$), which also had a higher correlation coefficient value (0.38)

Vegetation index	Degree of freedom	*P*-value	r
NDVI	47	0.06	0.26
NDRE	47	0.006	0.38
SAVI	47	0.07	0.26

NDVI = normalized difference vegetation index. NDRE = normalized difference red edge. SAVI = soil adjusted vegetation index. r = correlation coefficient value.

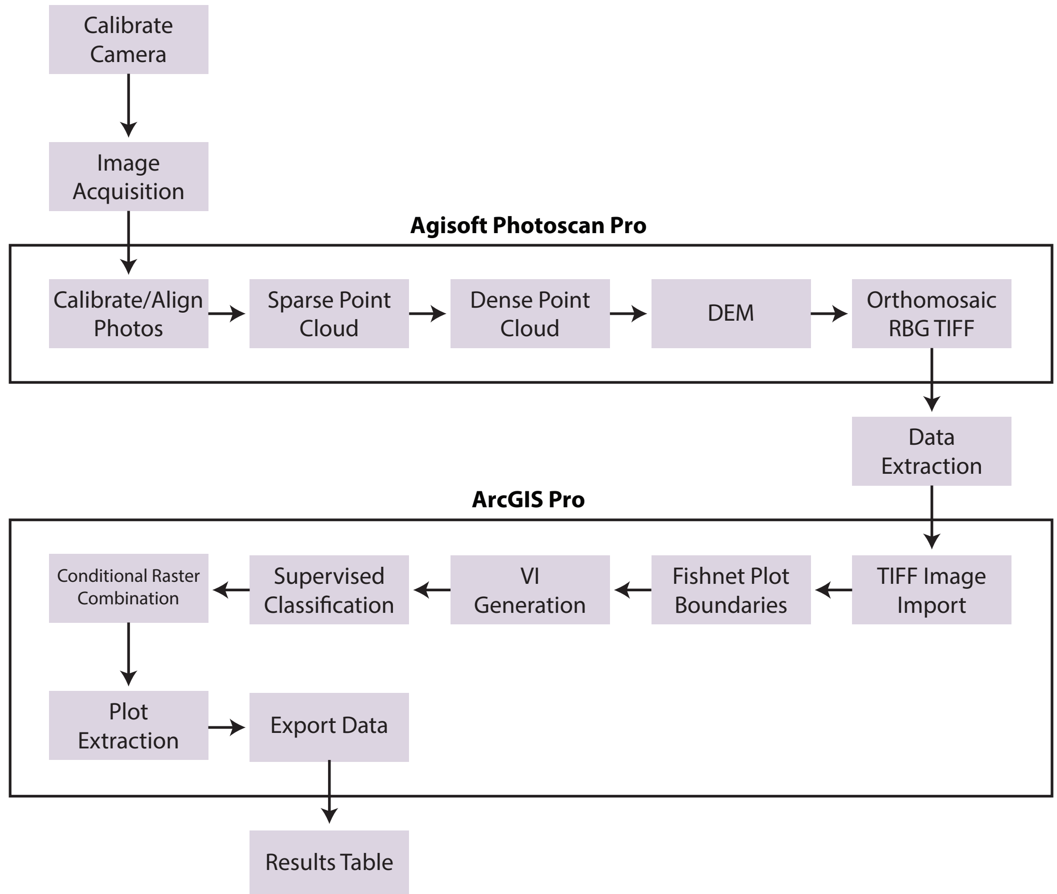

Figure 1. Framework for image processing and data extraction steps.

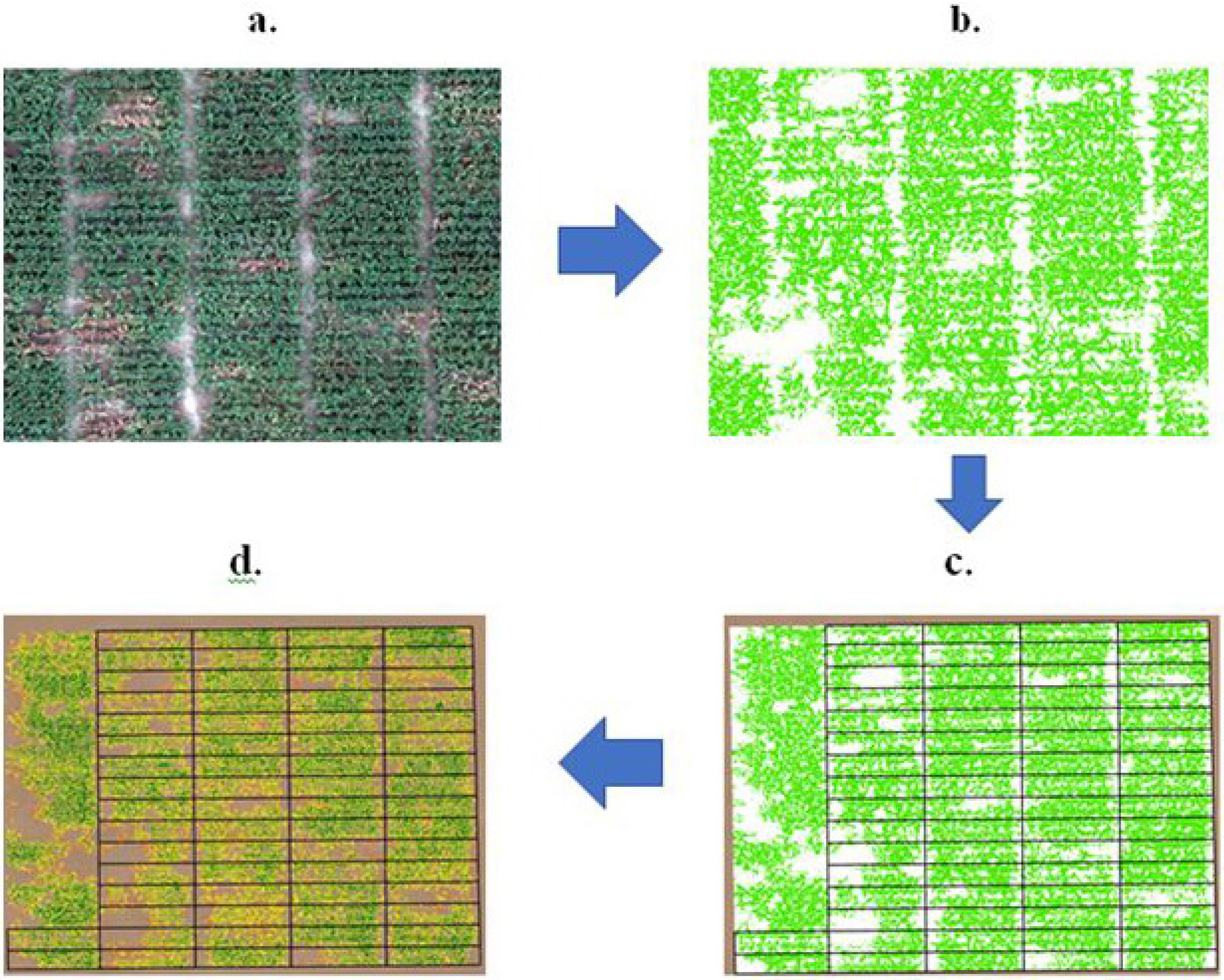

Figure 2. (a) Orthomosaic after processing with Agisoft Photoscan Pro; (b) through a process of supervised maximum likelihood classification, classes for soil, shadows, grain heads, dead plants, and leaves were created; all classes other than leaves were set to a white color to mask out of data extraction; (c) plot boundaries were established using ArcGIS Pro fishnet tool; (d) vegetation indexes were computed and combined with the leaves class using the ArcGIS Pro 'con' tool, allowing for data extraction only from the leaves.

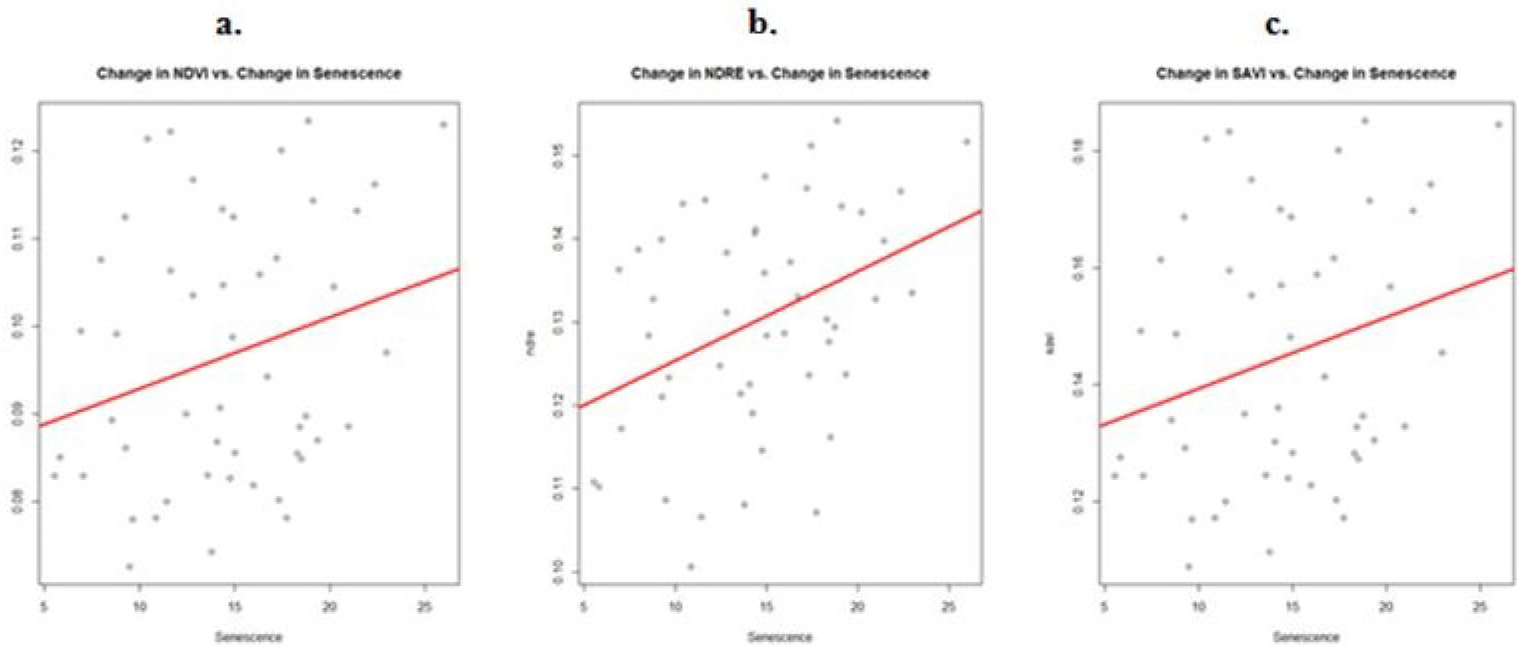

Figure 3. Change in vegetation index values (y-axis) versus the change in ground-truthed senescence values (x-axis) for the (a) NDVI, (b) NDRE, and the (c) SAVI values.