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Spatial-Temporal Evaluation of Plant Phenotypic Traits via Imagery Collected by Unmanned Aerial Systems (UAS)

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Abstract

Unmanned aerial systems (UAS) and a stereovision approach were implemented to generate a 3D reconstruction of the top of the canopy. The 3D reconstruction or CSM (crop surface model) was utilized to evaluate biophysical parameters for both spatial- and temporal-scales. The main goal of the project was to evaluate sUAVs technology to assist plant height and biomass estimation. The main outcome of this process was to utilize CSMs to gain insights in the spatial-temporal dynamic of plants within the experiment. Four experiments were carried out during 2015 corn growing season and utilized for ground-truth validation. The experiments were located at Ashland Bottoms Research Farm, Kansas State University (Manhattan, KS). Flight missions and ground-truthing were accomplished at two critical stages of biomass accumulation. At known locations individual plant height and biomass were measured and correlated to plant height estimation at the same locations in the CSMs. Same samples plants were then compared to a stem volume estimation by mixing estimated plant height from the CSM and ground stalk diameter from the same plants and locations. Plant height correlation was stronger at flowering stage than 2 weeks –prior flowering. Plant biomass estimation became stronger by adding ancillary field data. Per-plant basis results suggested that the CSMs could assist prediction of biophysical variables. Outcomes from this study confirmed that UASs could assist predicting "key" traits ("on-farm rapid phenotyping").

Keywords: *remote sensing, unmanned aerial systems, site-specific, corn, plant phenotyping.*

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Introduction

Current challenges in crop production relates to sustainability and productivity. Detailed spatial and temporal data becomes critical to enhance efficiency in farm production. Moreover, conventional methods for estimating plant growth and field survey by farmers are labor-intensive and are relatively at small-scale. Recent incursion of unmanned aerial systems (UAS), low cost remote sensing, and enhanced computer power allow to introduce novel approaches to gain insights in cropping systems over large areas.

During the crop season some limitations in the data collection were faced. These limitations relate to a lack of RGB coverage early in the season, and lack of reliable remote spectral sensor along the season. Consequently, missing early RGB coverage did not allowed including plant population patterns in the process. In the same direction, un-reliable spectral and non-available thermal data constrained the potential analysis over functional patterns within the experiment. In addition to that, RTK survey was not possible early in the season. Consequently, we only could estimate plant height by using those accurate Crop surface models (CSMs) generated 2-weeks before- and at-flowering stage. Absolute plant height was defined as the difference between the surrounding clear bare soil areas closer to each plant height measured.

Materials and Methods

During the growing season, four experiments of corn were established in 2.8 acres at Ashland Bottoms Farm, Manhattan, KS. The experimental design utilized was a completely randomized block (CRD) with 5 replications in all studies.

Two critical stages in corn were identified related to a high rate of change in biomass accumulation during the season. The goal of this step was to finely overlap UAS mission and ground-truthing that enable to capture high height plant change within that period. Hence, we identified 2 weeks prior flowering and flowering stage as critical stages for biomass accumulation. Field ground-truthing included per-plant measurement of absolute height. The procedure defines absolute plant height as the top central stem region of the plant where leaves reach maximum height without holding external intervention (N=129 and 334), stalk diameter (N=231) and biomass samples (N= 231).

UAS surveys. Equipment used in the study includes: cameras Canon 110 and Sony A5100, platform X8-M, RTK Topcon GR-5, software Argis10.3.1 and Photoscan-Agisoft. At each crop stage a sUAVs mission was accomplished. At 2 weeks prior flowering mission, flight altitude was set at 65 meters, 254 images were collected during the survey and combined with 10 ground control points (GCP) from the RTK survey to improve geometry quality. At flowering stage, a second flight was carried out over the experiment, same altitude as previous flight, 348 images were collected and combined with 18 (GCP) from the RTK survey for further analysis.

Results and discussion

Temporal and spatial changes in plant height can be estimated via imagery collected by UAS. Plant height patterns could assist in the rapid phenotyping process for proper characterization of plant growth.

In terms of geometrical quality, the first CSM reconstruction obtained a spatial resolution of 0.023 m/pixel, a GCP accumulative error of 0.10 m or 1.95 pixels. Second CSM generated at flowering stage obtained a spatial resolution of 0.024 m/pixel and an accumulative error of 0.04 m or 0.33 pixels.

Results showed a stronger correlation between CSM and ground truth data when corn plants were at flowering stage (R^2= 0.83, RMSE= 0.09 m) than to the two weeks prior flowering (R^2=0.51, RMSE= 0.15 m) (Fig. 1A). Prior flowering, CSM generation was 5 days before ground-truthing survey, which could explain a higher RMSE and lower correlation in the results (Fig. 1A). The CSM at flowering stage present more homogeneous height reconstruction compared to CSM from two-week prior flowering. It follows the same pattern that the plant heights sampled at the field. Clearly, before flowering greater plant height variability was explored (Fig 1.A) as compared to when the plant trait reached flowering (Fig 1.B). The latter can explain why the CSM two weeks prior flowering obtained lower coefficient of determination.

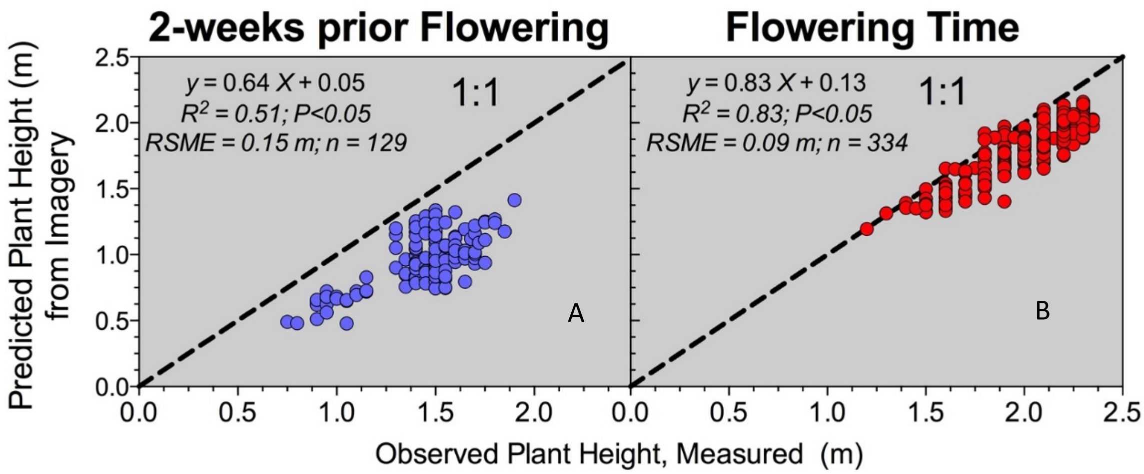

Figure 1. Plant height prediction via UAS imagery collection – 2 weeks prior- and at-flowering relative to observed plant height (determined from the ground base to the top of the canopy).

Conclusion

Spatial-temporal correlation between CSM for plant height trait versus ground-truthing suggested that the CSM integration could assist in the prediction of plant traits for rapid phenotyping. There are clear evidences that other specific plant traits and/or phenological stages should be targeted for increasing biomass and yield predictions. However, this approach validates relevant data for future scale-integration (multi-scales analysis). Future steps should look further integration of UAS and spectral remote data into ultra-high spatial resolution analysis for crop growth modeling.

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