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Multitemporal field-based plant height estimation using 3D point clouds generated from small unmanned aerial systems high-resolution imagery

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ABSTRACT

Plant breeders and agronomists are increasingly interested in repeated plant height measurements over large experimental fields to study critical aspects of plant physiology, genetics and environmental conditions during plant growth. However, collecting such measurements using commonly used manual field measurements is inefficient. 3D point clouds generated from unmanned aerial systems (UAS) images using Structure from Motion (SfM) techniques offer a new option for efficiently deriving in-field crop height data. This study evaluated UAS/SfM for multitemporal 3D crop modelling and developed and assessed a methodology for estimating plant height data from point clouds generated using SfM. High-resolution images in visible spectrum were collected weekly across 12 dates from April (planting) to July (harvest) 2016 over 288 maize (*Zea mays* L.) and 460 sorghum (*Sorghum bicolor* L.) plots using a DJI Phantom 3 Professional UAS. The study compared SfM point clouds with terrestrial lidar (TLS) at two dates to evaluate the ability of SfM point clouds to accurately capture ground surfaces and crop canopies, both of which are critical for plant height estimation. Extended plant height comparisons were carried out between SfM plant height (the 90th, 95th, 99th percentiles and maximum height) per plot and field plant height measurements at six dates throughout the growing season to test the repeatability and consistency of SfM estimates. High correlations were observed between SfM and TLS data (R^2 = 0.88–0.97, RMSE = 0.01–0.02 m and R^2 = 0.60–0.77 RMSE = 0.12–0.16 m for the ground surface and canopy comparison, respectively). Extended height comparisons also showed strong correlations (R^2 = 0.42–0.91, RMSE = 0.11–0.19 m for maize and R^2 = 0.61–0.85, RMSE = 0.12–0.24 m for sorghum). In general, the 90th, 95th and 99th percentile height metrics had higher correlations to field measurements than the maximum metric though differences among them were not statistically significant. The accuracy of SfM plant height estimates fluctuated over the growing period, likely impacted by the changing reflectance regime due to plant development. Overall, these results show a potential path to reducing laborious manual height measurement and enhancing plant research programs through UAS and SfM.

1. Introduction

Small unmanned aerial systems (UAS) have emerged as a promising platform to capture detailed imagery over large crop fields for precision agriculture and plant breeding research. Detailed and timely information on crops can be collected efficiently due to UAS ability to fly lower and their ease of deployment compared to traditional satellite and manned aerial remote sensing platforms (Zhang and Kovacs, 2012). The significant improvement in spatial and temporal resolution characteristic of UAS has opened new opportunities. Plant breeders and agronomist can more affordably generate in-depth site-specific information on field and plant conditions including crop yield estimation (Yu et al., 2016), biomass estimation (Bendig et al., 2014), plant population (Castillo et al., 2016) and weed mapping (Peña et al., 2013). Through SfM techniques, high-density point clouds of crop canopies are also obtainable allowing the 3D modelling of crops (Zhang and Kovacs, 2012), which was unprecedented decades ago.

Measuring plant phenotypic attributes such plant height is of great

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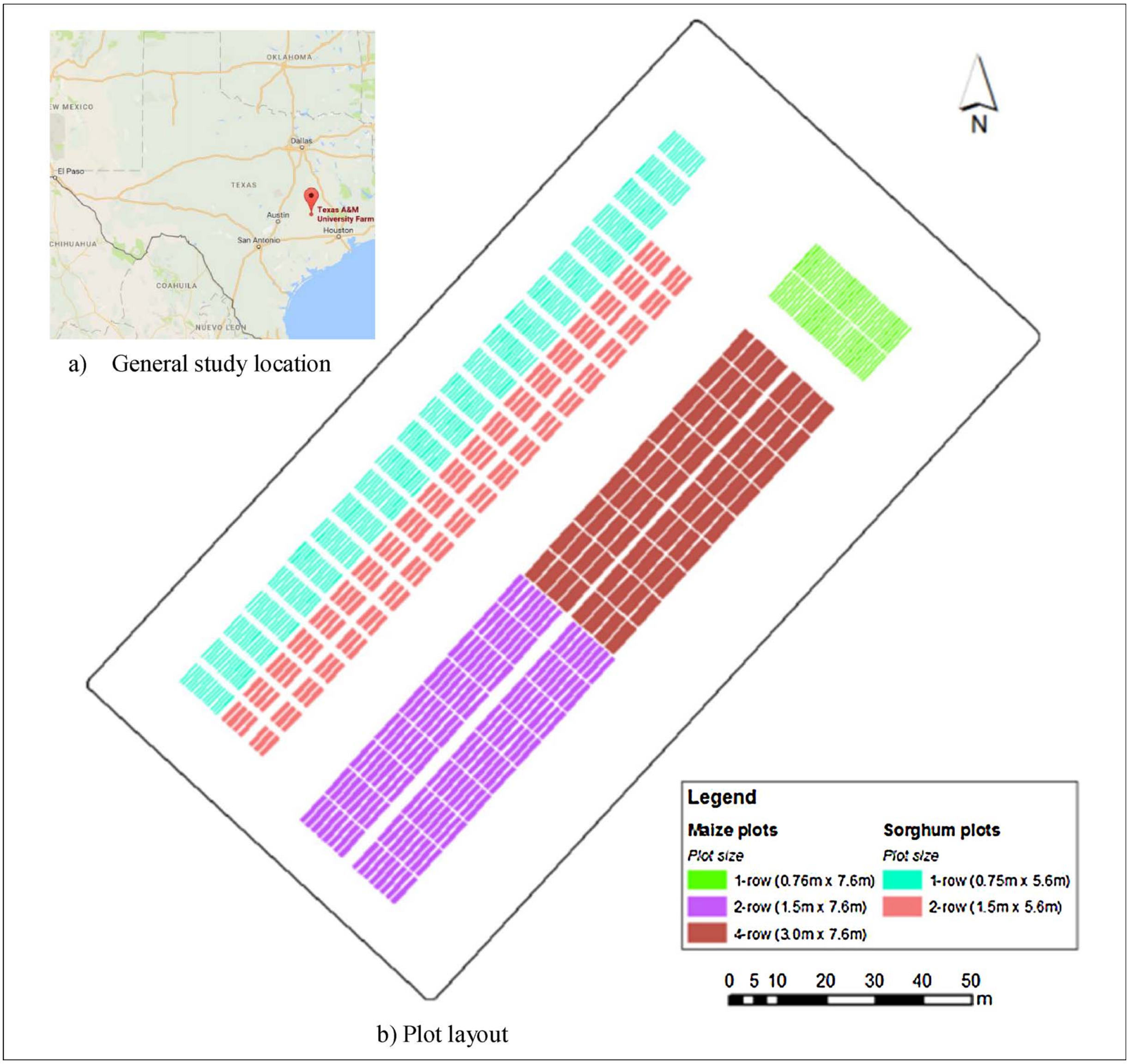

Fig. 1. Study area. a) Google Maps® inset showing the general location of the study site, b) Maize and sorghum plots symbolized by plot size.

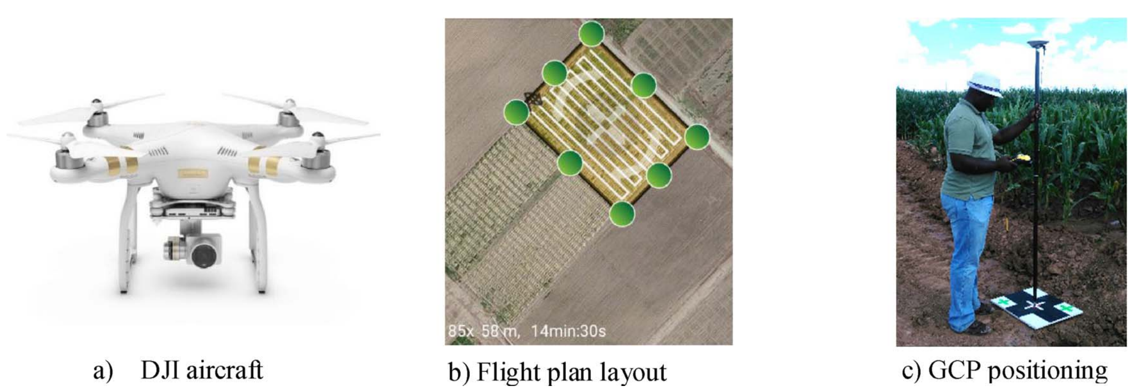

Fig. 2. UAS equipment and field procedures: a) DJI Phantom 3 Professional UAS aircraft with camera, b) Flight path layout as generated by Pix4Dcapture and c) Ground control point (GCP) measurement using GPS.

interest to plant breeders and agronomists. Plant height is a good indicator of plant growth and grain yield (Farfan et al., 2013). Measured over time, plant height and other phenotypic attributes enable the assessment of critical genetic traits, fundamental plant physiology and the influence of environmental conditions on plant performance (Araus and Cairns, 2014; Ghanem et al., 2015). As plant breeders strive to develop better hybrids to meet current and future food demand, repeated measurements over large fields are increasingly needed (Araus and Cairns, 2014). However, commonly used plant height measurement methods including manual field measurement and ground vehicles are