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ORIGINAL RESEARCH

UAV-based plant height estimation of maize cultivated using different varieties and sowing spacing

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Abstract

This study aimed at estimating plant height of maize using low-cost unmanned aerial vehicle (UAV) based imagery. The experiment was laid out in a factorial arrangement in randomized complete block design. The factors were maize varieties (*honampa, ahooden, ahoofe and abontem*) and intra-row sowing spacing (20 cm, 30 cm and 40 cm). A constant inter-row spacing of 80 cm was used for all sub-plots. Data (both UAV-based imagery and manual data) were taken 21 days after sowing (DAS) - seedling/establishment stage-, 42 DAS (vegetative stage), 63 DAS (tasseling stage), and 84 DAS (physiological maturity stage). The results showed a high correlation between the UAV-based plant height and manual measurement with R^2 (adjust) > 0.92 in all cases. For the intra-row sowing spacing, the 20 cm plant spacing was found to have had the best overall R^2 (adjust) of 0.949, showing the strongest regression of UAV with the manual data among the treatments. Also, it was found that the best stage to estimate maize plant height is dependent on the variety being used since the honampa gave the best correlation coefficient (R = 0.85) at the tasseling stage while the ahooden, ahoofe and abontem gave optimum correlation coefficients (R) of 0.70, 0.90 and 0.69 respectively at the vegetative stage. Overall, the study shows potency of using UAV-based imagery for estimating plant height of maize. The findings of the study could be useful to agronomists and smallholder farmers in Ghana and other developing countries regarding the usefulness of the technology for in-field data collection and advisory services.

Keywords: Variety, Intra-row Spacing, Unmanned Aerial Vehicle, Plant Height

Introduction

Maize (*Zea mays* L) is an important grain crop that contributes significantly to ensuring global food security (Shiferaw *et al.*, 2011; Langner *et al.*, 2019). However, its demand is expected to triple by 2050 in sub-Sharan Africa due to estimated rapid population growth, thus making it crucial to put in place measures for its sustainable production (Acevedo-Siaca and Goldsmith, 2020). Economically, almost every part of the crop is significant, including the stalk, leaves, tassel, cob and grain. Despite the economic benefits of maize production, yield in Ghana's maize farms is one of the lowest worldwide (Wongnaa *et al.*, 2019). In Ghana, maize is considered a food security crop and if low yields persist, it may affect the country's strive to achieve the Sustainable Development Goals 1(no poverty) and 2 (zero hunger).

Among the key crop performance indicators of maize is its plant height, which is often linked to growth and yield (Munialo *et al.*, 2020). Studies have reported strong correlation between plant height and biomass or grain yield and its usefulness in estimating biomass (Han *et al.*, 2019) and grain yield (Geipel *et al*., 2014). However, the manual measurement of plant height tends to be laborious and time-consuming. Moreso, as the plant develops broader leaves over time, it becomes more difficult to take such manual measurements due to the fact that the leaves scratch the skins of the field workers, causing itching and also, where the plants grow much taller than the people taking the measurements, it becomes a challenge in ensuring the accuracy and reliability of the data.

The physiological traits of crops including plant height varieties based on the stage and state of the plant are very useful in predicting yield. Thus, in an attempt to come up with other innovative and efficient approaches to in-field data collection, others have come up with different methods/tools including the use of ultrasonic devices as well as the unmanned aerial vehicle (UAV) for such purposes (Turner, 2008; Adão *et al.*, 2017; Chang *et al.*, 2017). The UAV has in recent times been recognized and is receiving rapid attention as a useful tool for plant height estimations (Anthony *et al.*, 2014; Han *et al.*, 2018; Feng *et al.*, 2019; Kawamura *et al.*, 2020). The other advantage UAV offers is the fact that it is possible to incorporate normal red green blue (RGB) camera into its system which are familiar to many smallholder farmers in Africa who use mobile phones with RGB cameras to take photographs of their crops from time to time.

Additionally, Abera *et al.* (2017) reported that different varieties of maize could have different physiological growth patterns and features, especially with respect to its height. Also, Hasan *et al.* (2018) noted that maize variety and spacing play key roles in influencing the crop's environment and growth. Hence this study aimed at using UAV-based imagery data to estimate the plant height of different maize varieties cultivated under varying intra-row sowing spacing and at different stages of growth.

Materials and Methods

Study area

The experiment was conducted at the A.G Carson Technology Centre of the University of Cape Coast, Cape Coast, Ghana (between 5° 07' 48" N, 1° 17' 26" W and 5° 07' 50" N, 1° 16 ' 57"W) as shown in Fig 1. The experimental plot (marked in orange rectangle in Figure 1C) was used for the study. The soil in the area of the experimental plot is predominantly sandy loam. The mean temperature for period of May, June, July and August were 27.3 °C, 24.8 °C, 25.0 °C and 24.3 °C respectively. The mean rainfall for the period were also recorded to be 241.6 mm, 83.6 mm, 30.6 mm and 24.7 mm for the months of May, June, July and August respectively.

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Figure 1 Study area map showing the experimental site and plot: (A) Map of Ghana (B) Map of Southern Ghana showing the Central Region and the location of the University of Cape Coast in Cape Coast, (C) Map of the location on the University of Cape Coast campus where the experimental field is located – with an extension of the actual field.

Experimental design and plan

The field was initially ploughed with a tractor-mount disc plough and subsequently harrowed with a disc harrow to obtain a fine tilth. The field was laid out using factorial arrangement in randomised complete block design with three replicate blocks and two factors (variety and planting spacing). Four maize varieties (*abontem*, *ahooden, ahoofe* and *honampa*) developed by scientists at the Council for Scientific and Industrial Research – Crops Research Institute, Fumesua, near Kumasi in Ghana- were used for sowing. Two seeds per hole were sown on 2nd May, 2019. Three different plantings intra-row plating spacing treatment of 20 cm, 30 cm and 40 cm – were used. However, a constant inter-row spacing of 80 cm was used for all plots. In all, there were 36 plots with each block measuring 4 m long x 2 m wide. The alleys between blocks measured 1 m while that between blocks were 2 m apart. Two (2) weeks after sowing, the plants were thinned to one plant per stand. Each plot consisted of five rows. Weeding was done at an interval of three weeks from the date of sowing till harvesting. Four (4) developmental stages -seedling/establishment, vegetative/jointing, tasselling and physiological maturity stages- were used for the data collection since they show different plant characteristics as pointed out by Wang *et al.* (2019) and Udom and Kamalu (2019) . Specifically, data was collected on the 21st, 42nd, 63rd and 84th days after sowing which fall within the above-mentioned developmental stages.

Manual plant height measurements

Manual measurements of the plant height of six (6) tagged plants per plot were done using a tape measure on the same day of flying the UAV on the experimental field by placing the instrument on the soil surface close at the base up to the apex of the plant. The distance between the soil surface and the apex of the plant was thus recorded as plant height.

UAV data collection, image processing and plant height data extraction

In this study, the quad-copter DJI Phantom 3 Professional UAV system with an onboard RGB camera, equipped with a 1/2.3 inch sensor and 12 megapixels was used to collect a set of aerial images of the field in five flights for the whole period (with the aid of the Map Pilot v2.7 software) at an altitude of 50 m above ground level (AGL). The Map Pilot v2.7 software was used to plan the flight paths with a frontal and side overlap of 80%. The resolution of the aerial images captured was 0.86 cm. Each flight followed the same flight plan. Black and white Ground Control Points (GCP) targets were placed at the four edges of the field and their geographical locations measured using a dual-frequency global positioning system with an accuracy of 2 cm. The images were collected every three weeks from the date of planting between daytime hours of 10 am to 12 pm on days with clear sky conditions (30 May, 20 June, 12 July and 02 August). On May 1, 2019, the first flight was carried out before the seeds were sown the following day to obtain the Digital Terrain Model (DTM). Table 1 shows the details of the flights in correspondence with the growth stages of the plants.

Several commercial and non-commercial software packages have been developed to process UAV image data. In this study, Pix4D Mapper software version 4.1 was used to process all the acquired images to generate Digital Surface Model

Table 1 UAV flights at different growth stages of maize

Date	Flight	Days after sowing	Growth stage
2nd May 2019	1	-	(Bare ground)
30th May, 2019	2	21	Seedling/establishment stage
20th June, 2019	3	42	Vegetative/jointing stage
12 July 2019	4	63	Tasselling stage
02 August 2019	5	84	Physiological maturity stage

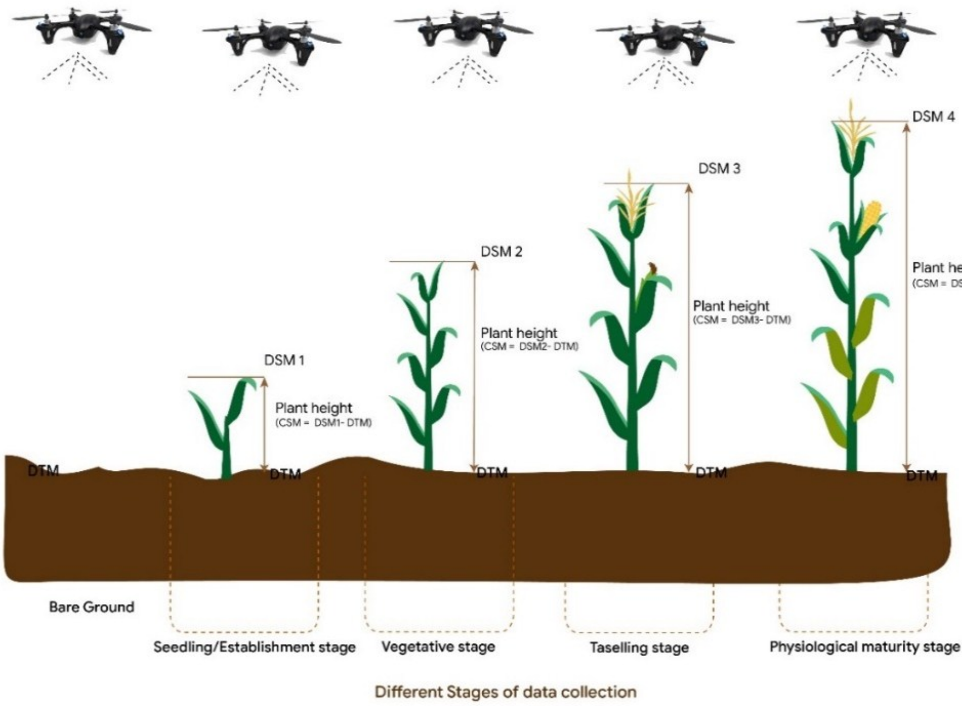

Figure 2 Visualization of the extraction of the crop surface model/ plant height at different growth stages

(DSM) and Ortho-mosaicked images. The software performs calibration of the camera, extraction and matching key points from individual images and densification of the point cloud, which enables the generation of ortho-mosaicked images and DSM. The digital terrain model (DTM) was obtained prior to planting when the land was bare, as indicated in Fig. 2.

As demonstrated by Bendig *et al.* (2014), the crop plant height referred to as the Crop Surface Model (CSM) was estimated by subtracting the DSM from the DTM (see figure 2). The CSM was clipped using the polygon shapefile of the experimental plots. Zonal statistics tool in ArcMap (version 10.5, Esri Inc., Redlands, California, USA) was used to estimate the average elevation (z-value) to obtain the value for the CSM of each flight date. The mean height per plot on each CSM was compared to the manual measurement in the field.

Statistical analyses

Data collected were subjected to the analyses of variance at a confidence level of 95 % using the general linear model to assess the main and interactive effects of the variety and sowing spacing treatments. Where a significant difference existed, the Tukey post-hoc comparison test was carried out. Pearson's correlation coefficient(R) was also used to evaluate the correlations between image-based data and that of manually measured data. Linear regression models for specific flights (different dates) for different varieties and plant spacings were carried out. All the statistical analyses were performed using Minitab statistical software version 17.

Results and Discussion

Figure 3 shows the linear regression between the UAV-based data and that of the plant heights obtained by manual measurements for the whole growth period. The results show high overall R^2 (adjust) values of more than 0.92 for all the four varieties under consideration. In all cases, p-values < 0.001 were obtained for both the plant height correlation coefficient and the linear model's intercept. Also, it was observed that apart from *ahooden*, the lowest correlation coefficients were all recorded at the establishment stage (see Table 2). However, the correlation generally improved at different developmental stages which confirms the findings of Li *et al*. (2018) and Tirado *et al.* (2020). This could be attributed to the differences in the gene or varietal characteristics of the plants at different stages of development. In essence, the findings of this study for the *abontem, ahooden* and *honampa* varieties generally confirm the works of Sharma *et al.* (2016) who posited that estimating maize plant height using sensor-based plant height tends to correlates better at the vegetative stage of the plant's growth. However, for the *ahoofe* variety, the best correlation coefficient(R) of 0.854 was obtained at the tasselling stage which agrees with the findings of Varela *et al.* (2017), who used UAV to predict the plant height of maize in Ashland Bottoms Farm, Manhattan, Kansas in the United States of America. A similar pattern was observed for the intra-row spacing treatments. This indicates that knowledge of the best stage of determining plant height with UAV is dependent on the variety and plant spacing used. Therefore, from this study, it could be noted that among the four varieties, the best period of estimation of predicting the plant height of maize could be between the vegetative and tasselling stages of its development as shown in Table 2.

As shown in Fig. 4, although the prediction based on the plant height using UAV is generally strong (R^2 (adjust)> 0.92), it is superior in the case of 20 cm intra-row spacing to 30 cm and 40 cm when considering the whole growth period. This result can be explained based on the fact that the higher the plant density per sub-plot, the less likely it is to lose more water from the soil through evaporation because its leaves tend to cover the entire plot over time and reduce the direct impact of the sun on the bare soil and thus enhance growth in terms of height. Besides, there is a high level of suppression of weeds under such circumstances compared to areas where the plants' wider spacing leads to available free spaces uncovered with plant leaves. The results agree with the findings of Zhang *et al.* (2018) and Akukah (2020) who carried out similar studies using maize as test crop and observed similar pattern under different planting spacing.

However, the analysis of variance on the UAV- based crop surface model showed no significant differences among the

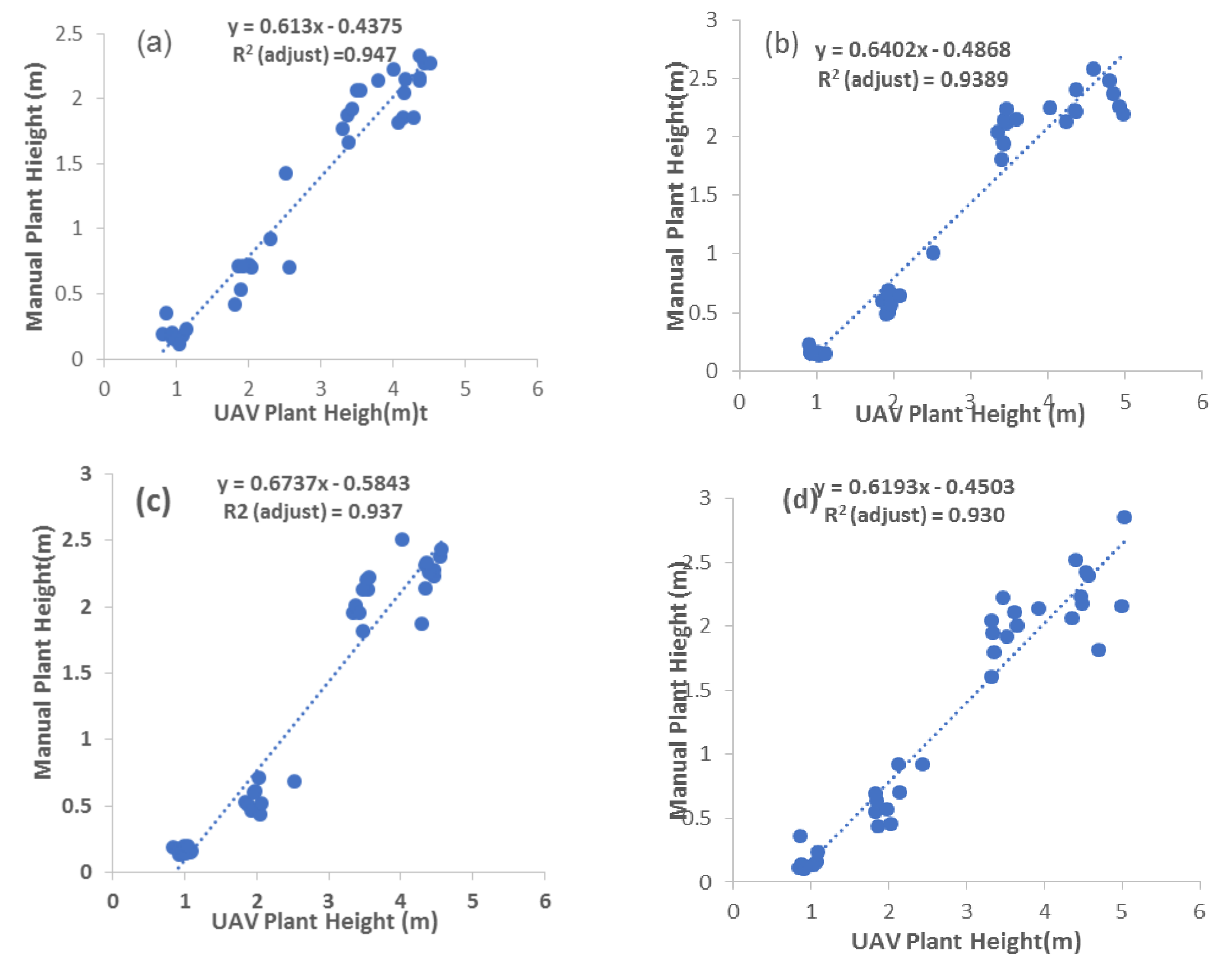

Figure 3 Relationship between the estimated UAV plant height and the manual measurements for variety (a) *abontem*, (b) *ahooden*, (c) *ahoofe,* and (d) *honampa*

Table 2 Correlation coefficients (R) between UAV and manual plant height estimations for the treatments at different growth stages.

Date/ Stage	Variety				Sowing spacing		
	Abontem	*Ahooden*	*Honampa*	*Ahoofe*	20 cm	30 cm	40 cm
30th May, 2019 (seedling/establishment)	0.353	0.611	0.058	0.091	0.170	0.007	0.328
20th June, 2019 (vegetative/jointing)	0.698	0.902	0.693	0.499	0.680	0.923	0.142
12th July, 2019 (tasseling)	0.481	0.568	0.545	0.854	0.507	0.578	0.639
2nd August, 2019 (physiological maturity)	0.688	0.218	0.269	0.730	0.693	0.022	0.720
Overall	**0.974**	**0.970**	**0.966**	**0.969**	**0.975**	**0.962**	**0.969**

varieties as well as the spacing for the first stages of data collection until the physiological maturity time. At the time of the physiological maturity stage, the analysis of variance showed a significant difference among the varieties ($p<0.05$). The mean comparison indicated that the *ahooden* and *honampa* varieties did not show significant differences while the *abontem* and *ahoofe* showed significant differences. However, the plant spacing did not show any significant differences ($p>0.05$) at this stage. The interaction effect between the variety and spacing was also found to be non-significant for the plant height generated from the UAV at the crop's physiological maturity stage. The manual data also did not show any significant differences ($p>0.05$.) for both variety and spacing as well as their interactions at all the targeted growth stages, including the physiological maturity stage.

Conclusions

This study confirms the possibility of using UAV-based RGB imagery for estimating the plant height of maize. It was observed that the best period of predicting plant height is depend-

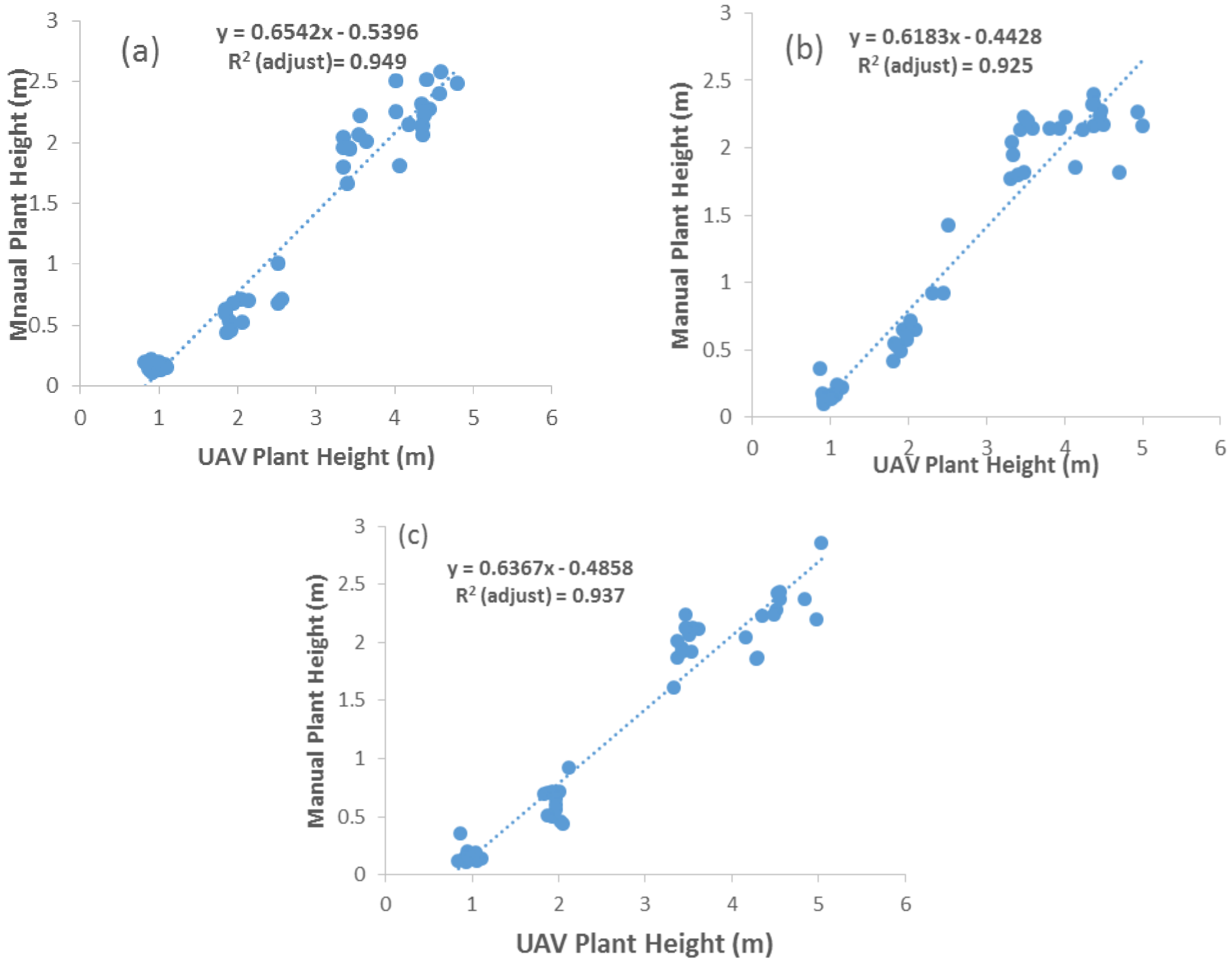

Figure 4 Relationship between the estimated UAV plant height and the manual measurements for different sowing spacing (a) 20 cm, (b) 30 cm, and (c) 40 cm

ent on the type of variety. For *ahoofe*, the superior prediction occurred at the tasseling stage while that of the *abontem*, *hon-ampa* and *ahooden* varieties occurred at the vegetative stage. Similar observations were made for the plant intra-row spacing. Also, in the case of the plant intra-row spacing, the 20 cm plant spacing gave the best overall correlation with the manual data. In this work, the UAV-based data was generated by flying the device at the height of 50 m only but in the future we could look at the possibility of investigating the effect of different flight altitude on the estimation of the plant height of different maize varieties.

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Conflict of Interest Declarations

Authors declare no conflict of interest.

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