# 2D Orthomosaic and 3D Modeling Applications in Winter Wheat High-Throughput Phenotyping

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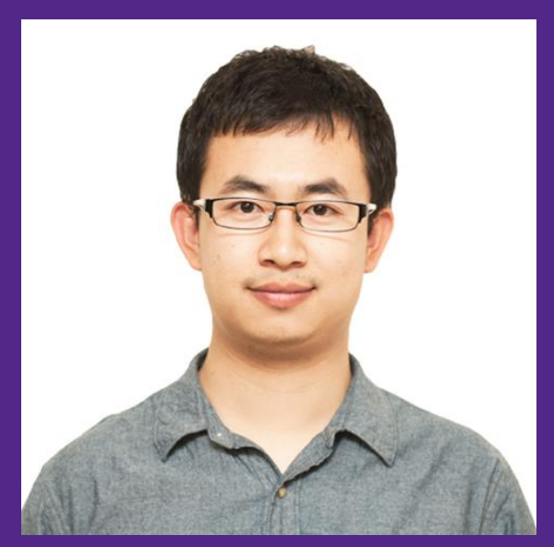


## Introduction

Perhaps the greatest challenge of plant science and crop improvement in the 21st century is predicting how a plant's appearance (phenotype) is dictated by its genetic make-up (genotype). Advances in "next generation" DNA sequencing are rapidly reducing the costs of genotyping. In contrast, most of the plant phenotypic traits are still extracted using destructive sampling methods and manual measurement, which can be time-consuming, labor-intensive and costly. Recognition of the phenotyping constraint has stimulated huge development of high-throughput phenotyping that seeks to accurately characterize large numbers of individuals or populations using a fraction of time and labor of manual phenotyping methods. An increasing number of scientists are turning to the use of remote sensing for characterizing plant phenotypes such as plant height.

## Objectives

- Construct 2D orthomosaic and digital elevation model (DEM) using high resolution color infrared (CIR) images.
- Develop the workflow of data processing to extract reliable Normalized Difference Vegetation Index (NDVI) values and crop canopy height.

## Materials and Methods

**Study location:**

- Ashland Bottoms research station (Department of Agronomy, KSU) near Manhattan, KS.

**Experimental Design:**

Randomized Complete Block Design w/ Split-plot.

**Treatments:**

- Main plot factor: 4 rates of N application (0, 50, 100, and 150 lb/ac).
- Sub plot factor: 4 hybrids of winter wheat (Everest, Jagger, Karl 92, and 1863)

**Data collection:**

- Image data was collected using a Canon T4i modified camera (R/G/NIR) (Figure 1.a.) with a Canon EFS 18-55 mm lens (Figure 1.b.) mounted on a DJI S800 evo hexacopter (Figure 1.c.). All UAS operations were performed under certificate of authorization (COA).
- Biomass data was collected from 12 50cm x 50cm PVC pipe quadrats (Figure 1.d.) across the biomass gradient after the image data collection.
- Both image and biomass data were collected at Feekes growth stages: F3, F4, F6, F7, F10, F10.2, F10.5, F10.5.2, F10.5.4, F11.1 and F11.3.
- 36 Ground Control Points (GCPs) were evenly distributed in the wheat field and tagged with Topcon Hiper Lite+ RTK GPS unit.

**Statistical analysis:**

- SAS 9.3 GLIMMIX procedure, alpha=0.05

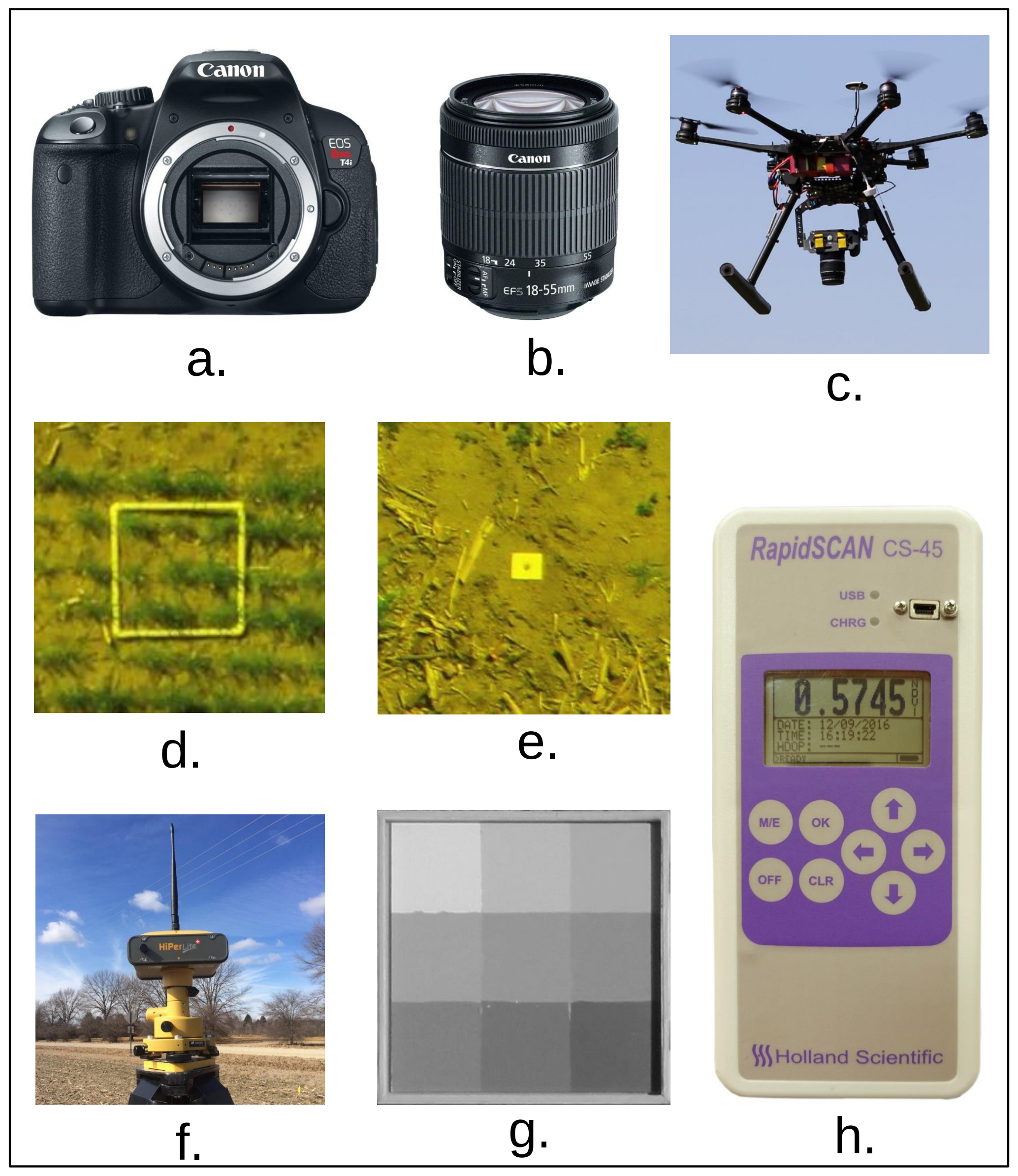
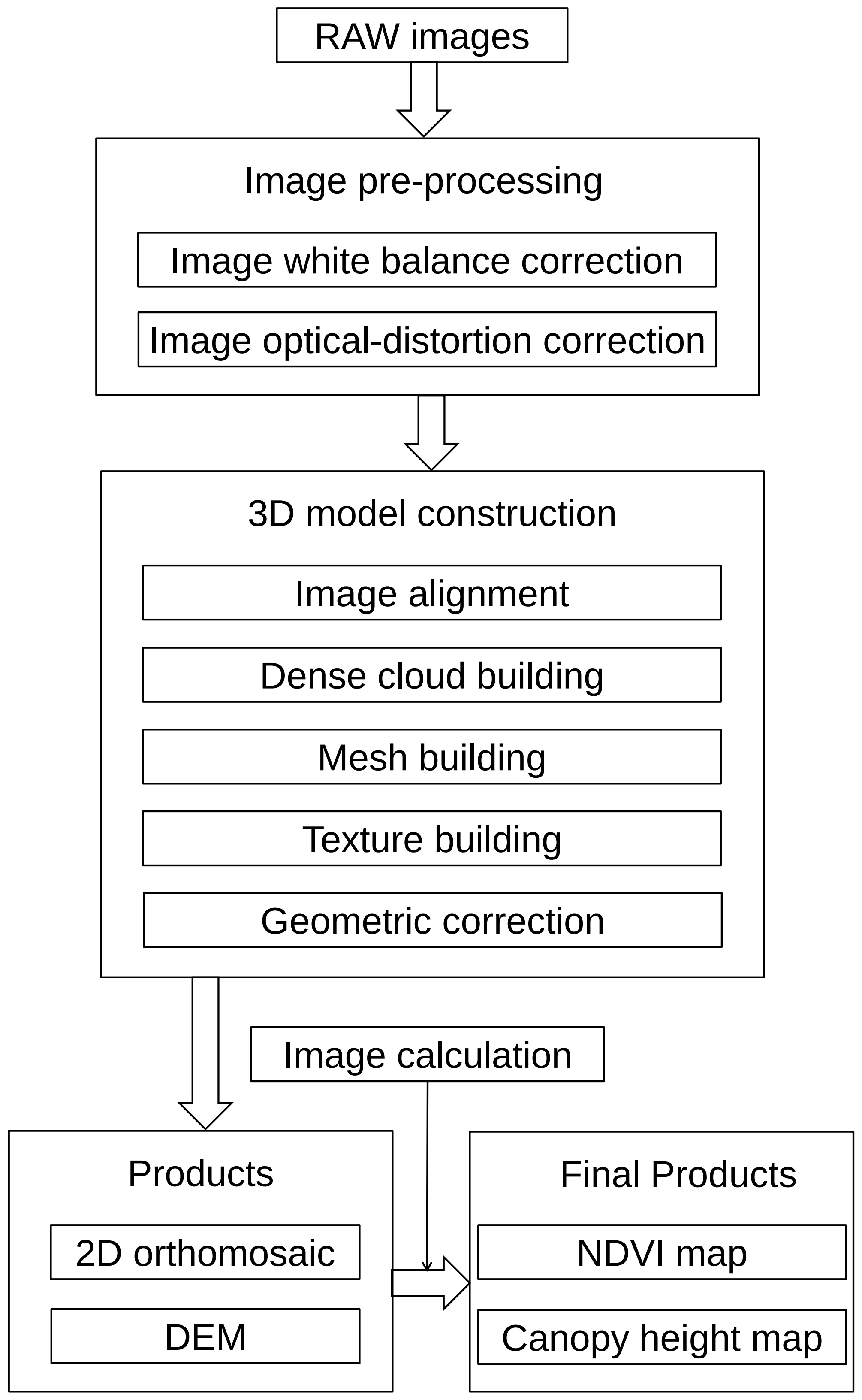


Figure 1:
a. Canon T4i modified camera (R/G/NIR);
b. Canon EFS 18-55mm lens;
c. DJI S800 evo hexacopter carring a. and b.;
d. 50cm x 50cm PVC pipe quadrat;
e. Ground control point; f. Topcon Hiper Lite+ RTK GPS unit;
g. Calibration panel for cross-time and space calibration;
h. Holland Scientific RapidScan CS-45 Active Optical Sensor (R/G/NIR), used for cross-sensor calibration in this study.

**Image processing (workflow chart):**



RAW images

Image pre-processing
- Image white balance correction
- Image optical-distortion correction

3D model construction
- Image alignment
- Dense cloud building
- Mesh building
- Texture building
- Geometric correction

Image calculation

Products
- 2D orthomosaic
- DEM

Final Products
- NDVI map
- Canopy height map

**Image reflectance calibration:**

- Before extracting NDVI values for analysis from the NDVI maps, image reflectance calibration needs to be performed. A two-step reflectance calibration method was developed.

**Step 1:**

- A calibration panel with nine shades of gray (Figure 1.g.) was used to take out the effect of different light conditions on reflectance values so the data collected from different dates and locations can be compared.

**Step 2:**

- Image data collected from different sensors can vary resulting in dramatically different NDVI values that are either too condensed or too stretched. An active optical sensor (Figure 1.h.) was used to collect ground truth reflectance data to build a calibration function so that NDVI values can be compared with other sensors.

## Results

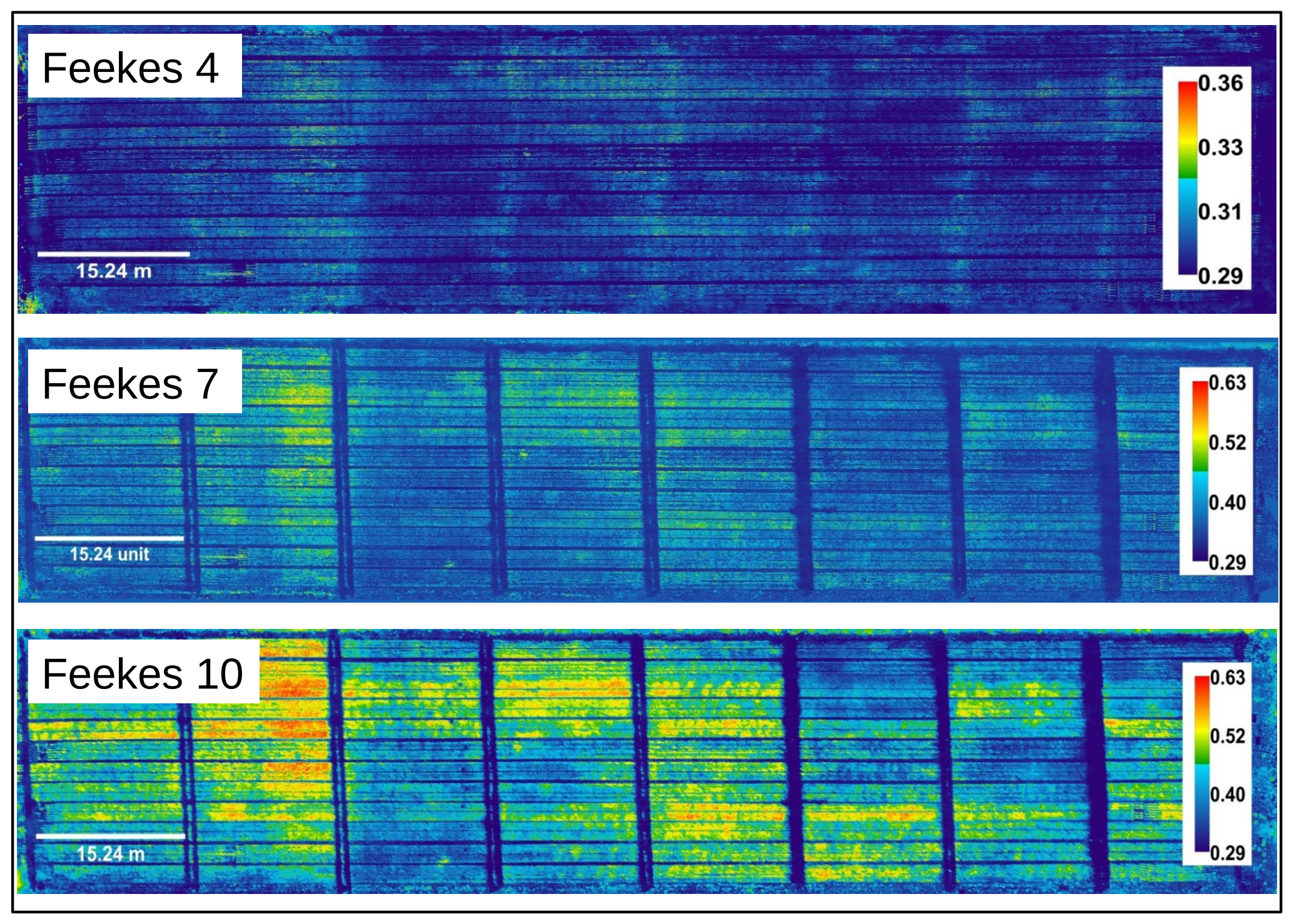


Figure 2: Winter wheat NDVI maps generated using high resolution CIR images at Feeks 4, 7 and 10.

### Coefficient of determination ($r^2$) values for Canon NDVI and wheat biomass

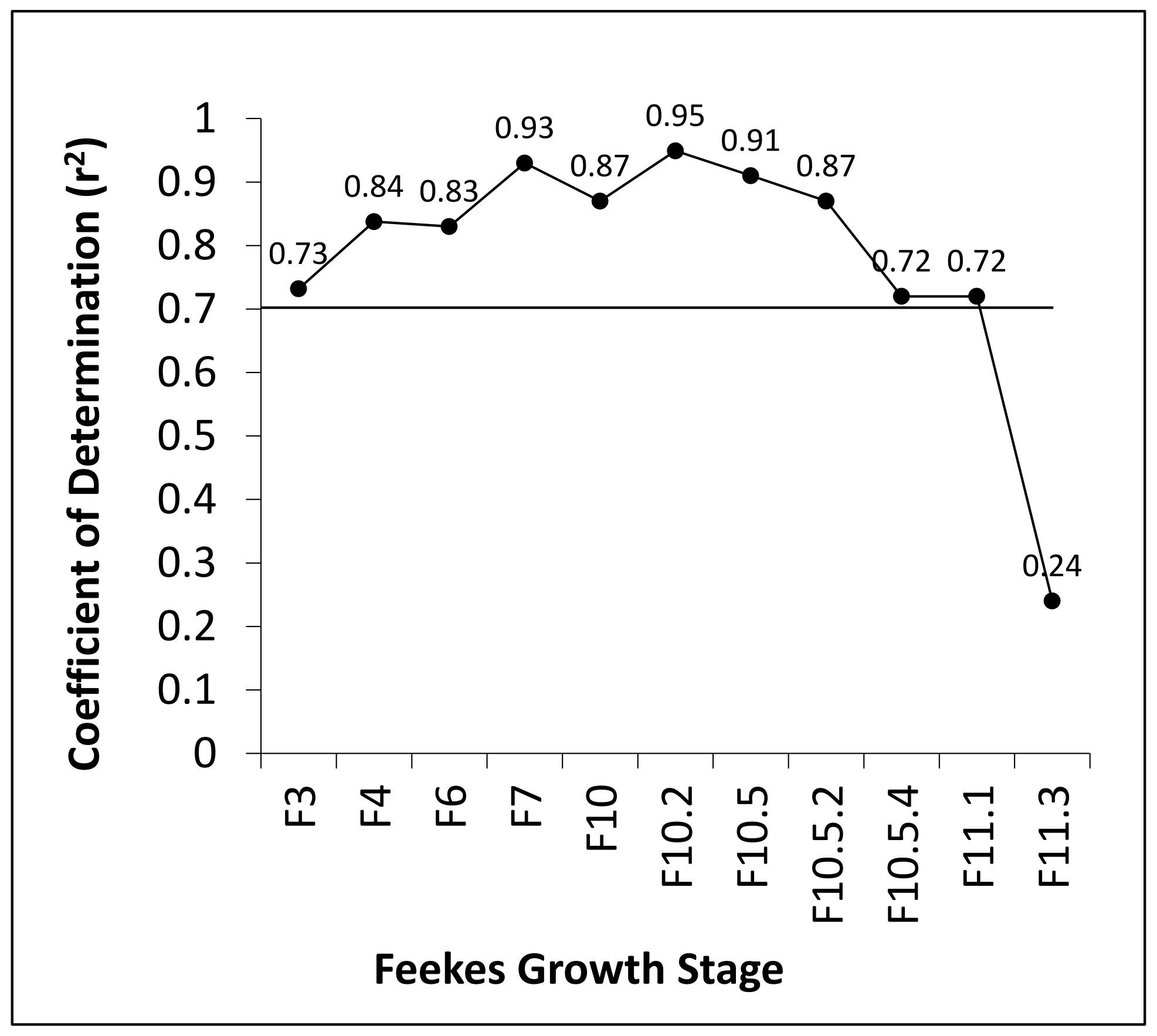


Figure 3: Coefficient of determination ($r^2$) values for Canon NDVI and wheat biomass at different growth stage from F3 to F11.3.

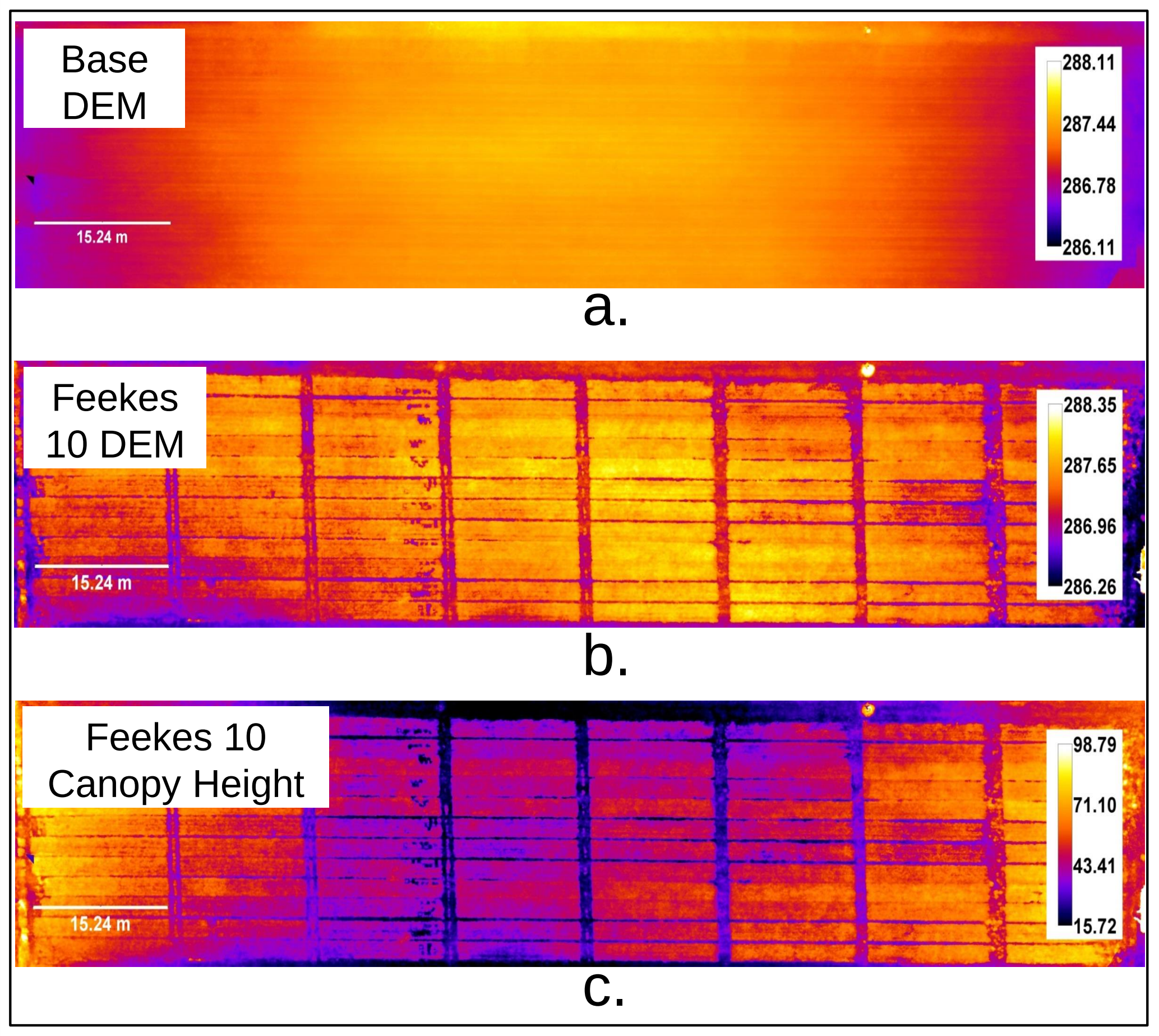


Figure 4:
a. Base DEM of a winter wheat field;
b. DEM of a winter wheat field at growth stage of Feekes 10;
c. Winter wheat canopy height map generated by subtracting base DEM from Feekes 10 DEM.

### Observed Canopy Height vs. Estimated Canopy Height from DEM

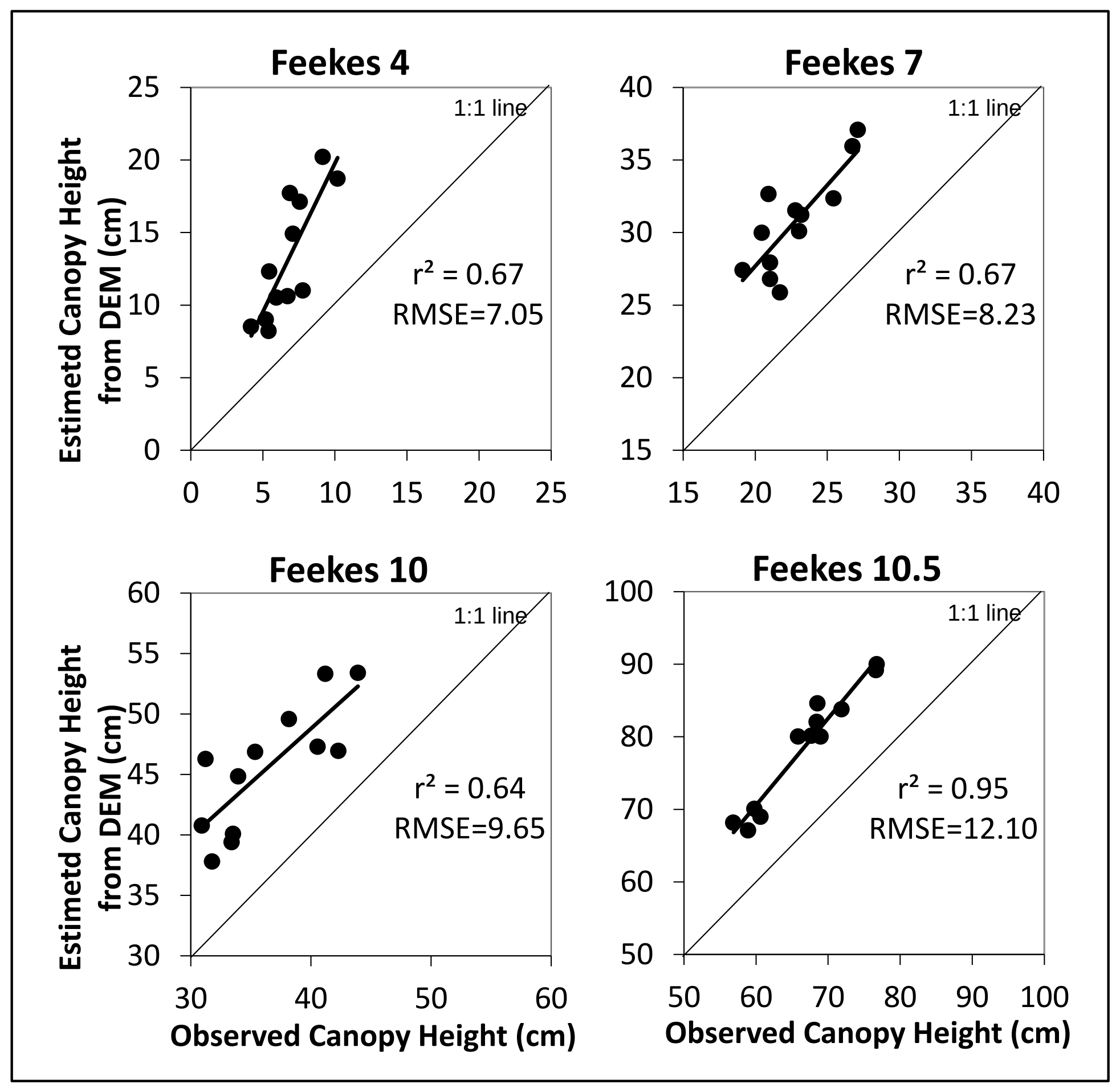


Figure 5: comparisons between observed wheat canopy height and estimated wheat canopy height from DEM at different growth stages: Feekes 4, 7, 10 and 10.5.

## Conclusions

- NDVI maps calculated from 2D orthomosaics can be used to extract reliable NDVI values that can provide a good estimation of wheat biomass during the growing season. ($0.72<r^2<0.95$ between F3 and F11.1.)
- Estimated canopy heights from DEM were highly correlated with the observed canopy heights data (Low $r^2=0.64$ at F4 and high $r^2=0.95$ at F10.5.) but the poor accuracy (Average RMSE=9.26 cm) is unacceptable.
- Future work needs to be done to improve the accuracy of canopy height estimation using DEM. To achieve this goal, the first thing we need to do is improving the accuracy of camera position in the 3D space.