Assessing CO2 Exchange, Water Use, and Yield of Maize Crops under Full and Deficit Irrigation Using UAV and Satellite Imagery

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Introduction

- Agricultural water supplies in the US are experiencing a significant decline due to climate change, increasing population, and competition for water use. As a result, there is an increasing need for accurate estimation of crop water use (evapotranspiration, ET) to improve precision irrigation decisions.
- There is also increasing interest in understanding crop water use and carbon dioxide (CO2) exchange in agricultural ecosystems. Various methods have been developed to monitor these processes at different spatial and temporal scales.
- With the rapid advance and availability of low-cost unmanned aerial systems (UAS), they are now being used to acquire spatial information within fields and inform irrigation decision-making.
- The research aims to integrate UAV and satellite remote sensing for assessing maize crop growth, water stress, CO2 exchange, and yield.

Methods

Experimental design

- The maize crop was planted in May 2022 at USDA-ARS Limited Irrigation Research Farm (LIRF) in Greeley, Colorado. Two experimental fields at different scales were set up (Figures on the right side).
  - The north field (Fig.1) was designed with 16 plots (18x29 m^2) managed with various irrigation scheduling methods at full and deficit levels. Deficit irrigation was applied during the late vegetative stage (LV, Jun 28–Jul 25) and maturation stage (Mat, Aug 17 to harvest). All plots were fully irrigated during the reproductive stage (Rep, Jul 26–Aug 16). Irrigated by a linear sprinkler irrigation system (Fig.2)
  - The south field was designed as two plots (Fig.3). The left plot was fully irrigated, and the right plot was deficit irrigation.

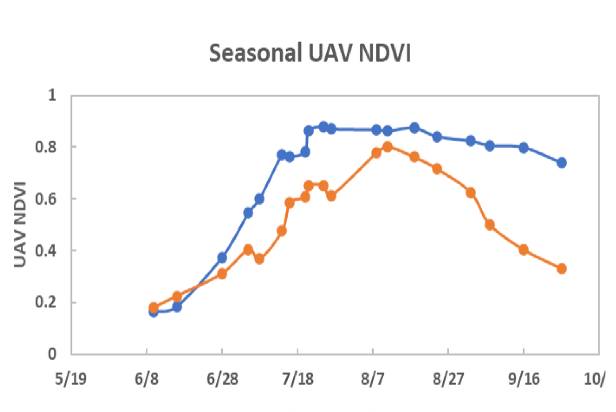
Data collection

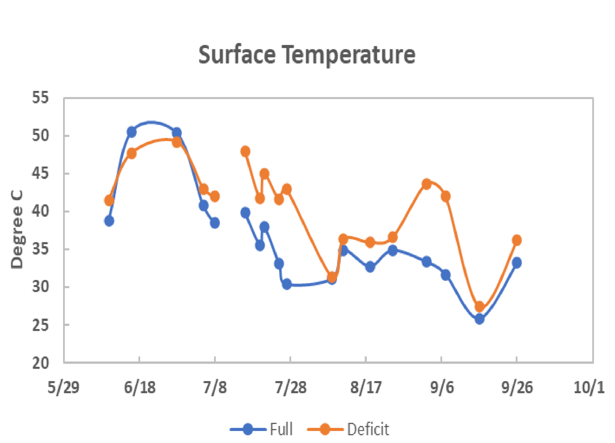
- **UAV**: Weekly high-resolution RGB, multispectral and thermal imagery. (Fig.4)
- **Eddy covariance system**: Set up at the border between full and deficit irrigation plots, and measured ET, CO2, and energy balance components. (Fig.5)
- **T-SWIFT**: Tower Spectrometer on Wheel for Investigations with Frequent Timeseries (Fig.6). It provides high spectral and temporal vegetation reflectance (400-1000nm) and solar-induced fluorescence (SIF) data at 31 minutes return time. (Francis Ulep's poster)
- **Satellite imagery**: Planet, Sentinel 2A/B, Landsat, etc.
- **Onsite CoAgMET micrometeorological station**: Weather data and reference ET
- **Ground measurements**:
  - Canopy temperature, infrared thermometers, 5-minute interval, 18 plots
  - Plant transpiration, sap flow sensors, hourly,12 plots
  - Soil moisture (NP, TDR), twice a week, 18 plots
  - Leaf area index, LAI-2200, weekly, 12 plots
  - Leaf fluorescence, Fluorescence meter, weekly, 18 plots
  - Biomass (twice) and final grain yield

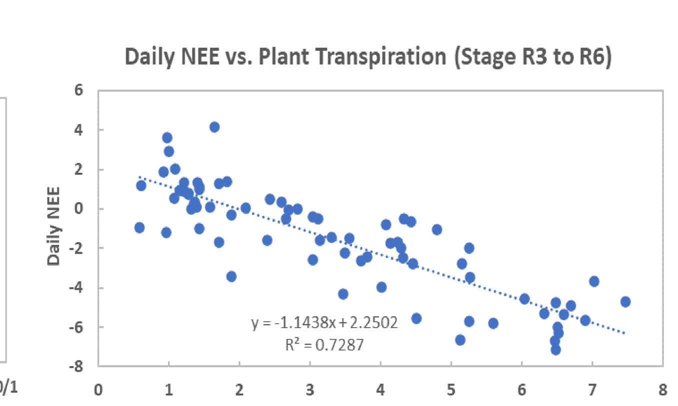
Fig. 4. UAV system with an RGB, thermal, and multispectral camera.

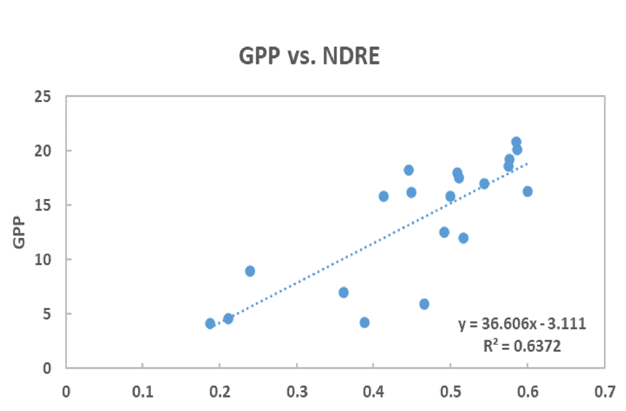
Results

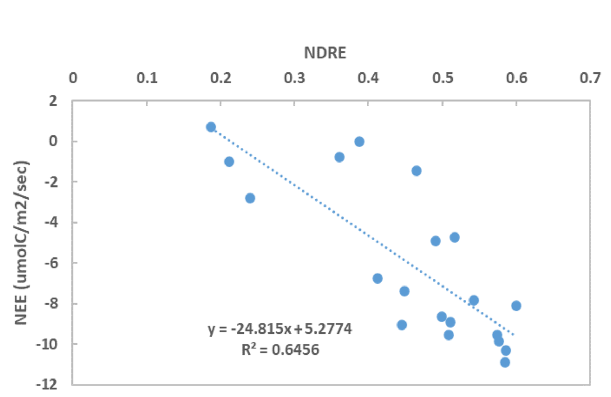
- A significant negative correlation was found between daily net ecosystem CO2 exchange (NEE) and transpiration rate from late July to the end growing season, although the significance and slope of the correlations were different at different growth stages.
- Several common vegetation indices were calculated from UAV and Planet multispectral bands. Normalized Difference Red Edge Index (NDRE) had the highest correlation with daily and mid-day NEE and gross primary productivity (GPP).
- Both UAV and satellite-derived vegetation indices were positively correlated to biomass, leaf area index, and yield.

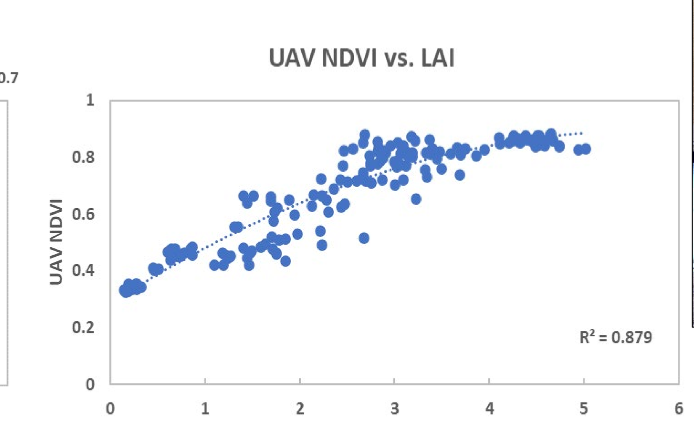


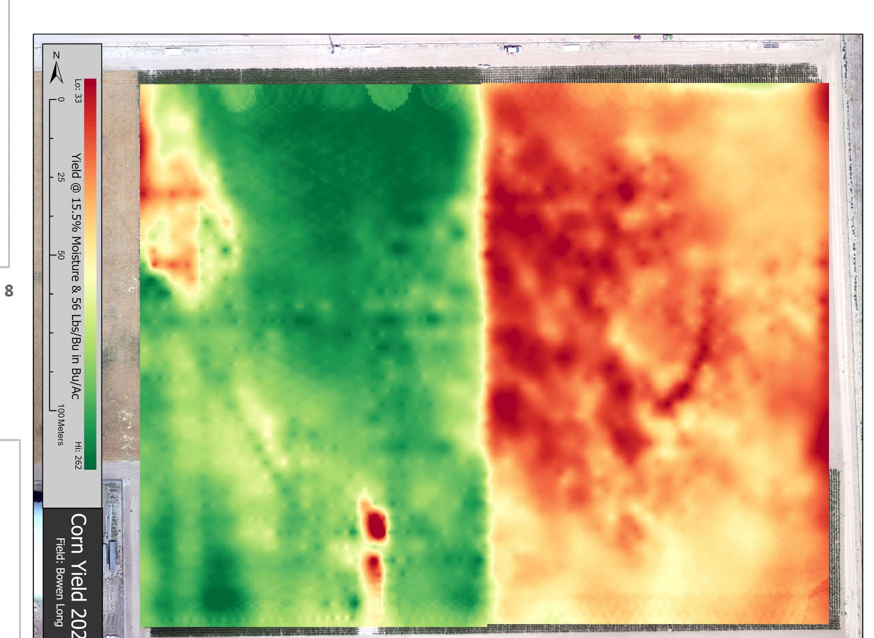












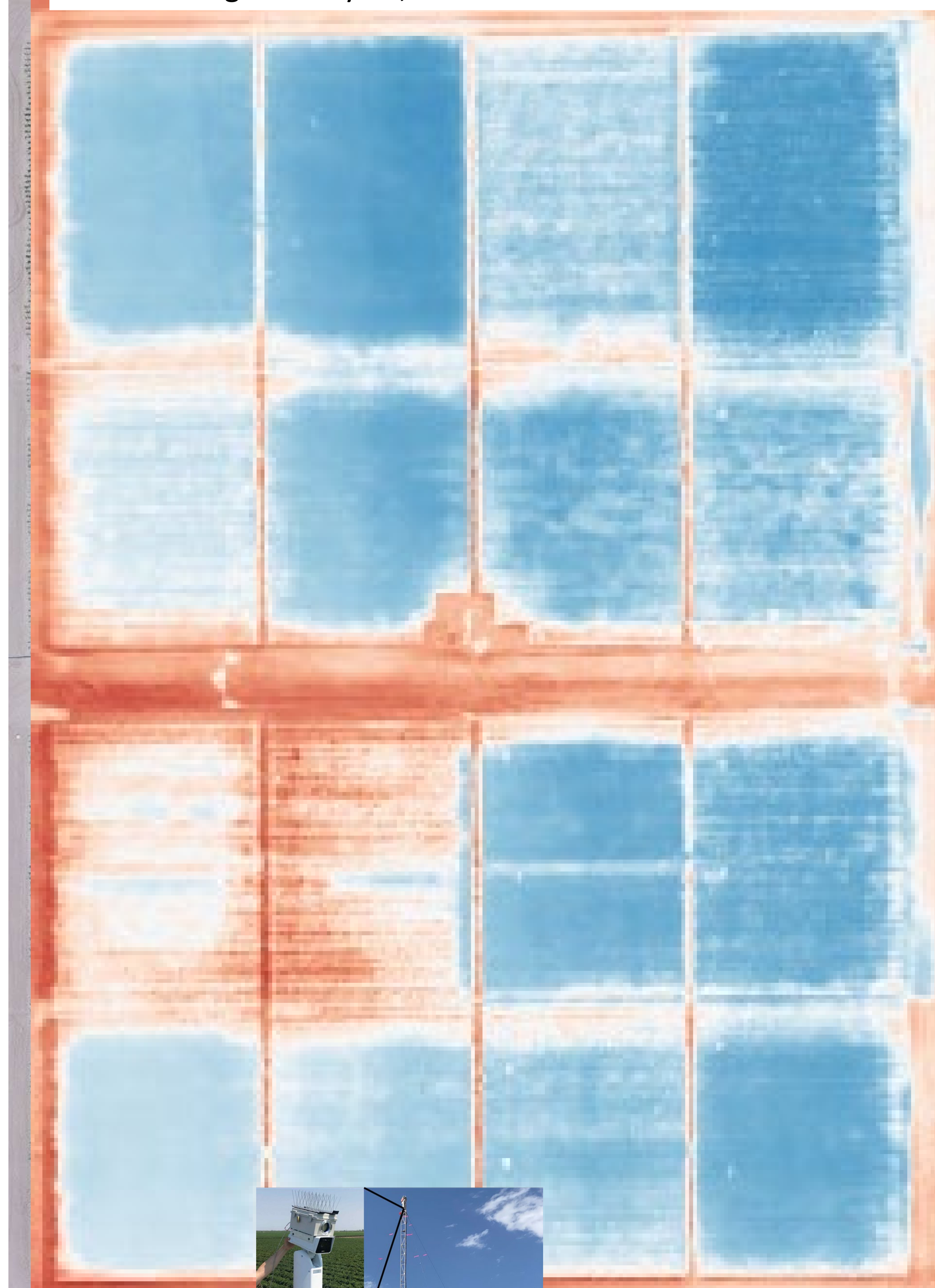


Fig. 1. Irrigation scheduling experiment plots shown as a UAV thermal image on July 25, 2022

Fig. 2. Linear sprinkler irrigation system

Sap flow- Hourly plant transpiration

IRT- Hourly canopy temperature

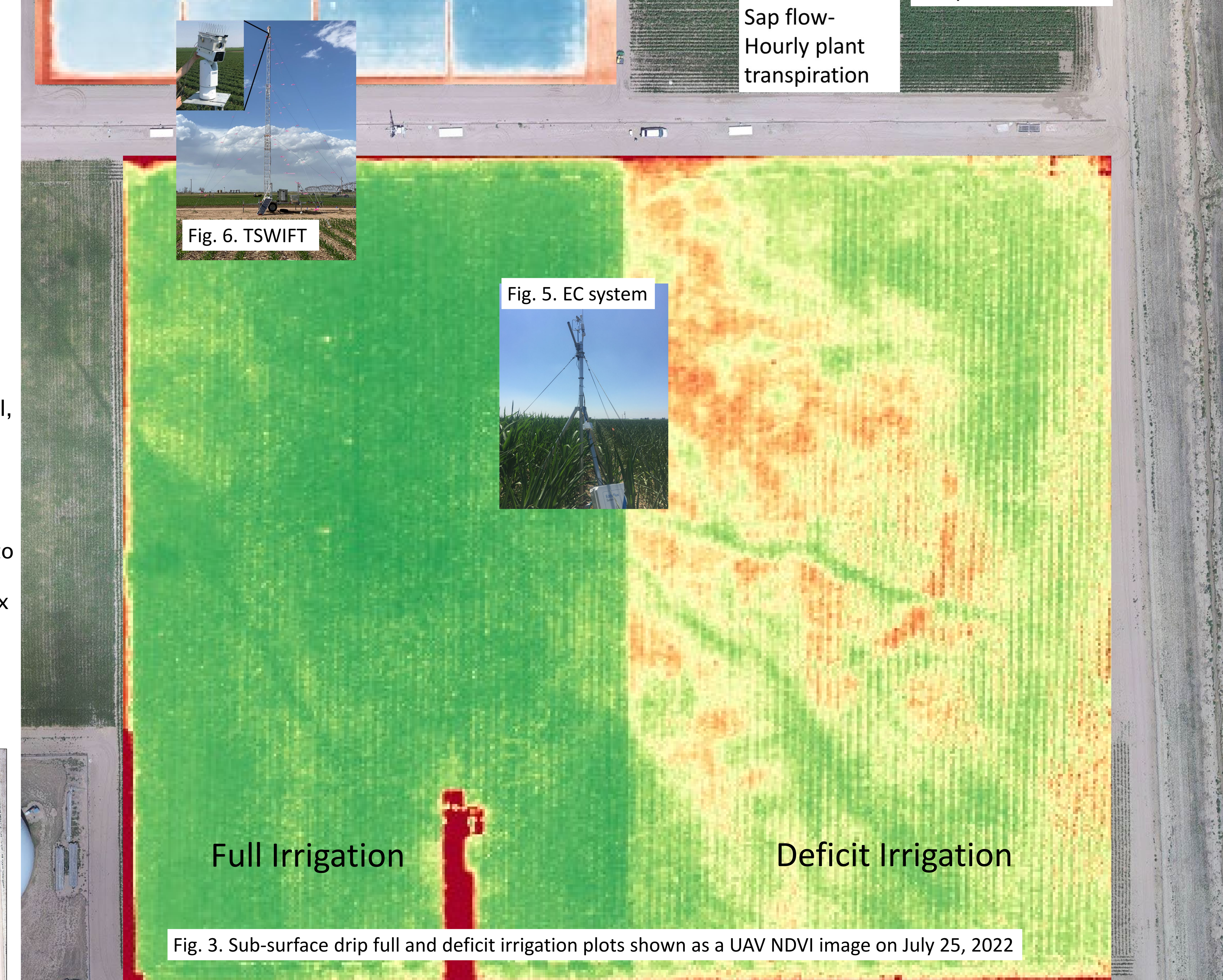


Fig. 6. TSWIFT

Fig. 5. EC system

Fig. 3. Sub-surface drip full and deficit irrigation plots shown as a UAV NDVI image on July 25, 2022

Future Works

- Combining UAV and satellite images for CO2 exchange, SIF, water use, and yield prediction will be evaluated and applied to larger regions.
- Overall, the study aims to provide a valuable tool for monitoring and understanding crop water use and carbon dioxide exchange in agricultural ecosystems. The results can be used to inform and improve management practices, leading to more sustainable and efficient use of water resources in agriculture.

Acknowledgments

We would like to extend special thanks to Katherine Ascough, Chris Brackett, Brian Duenas, John Ellis, and Alex Merklein for help collecting data, and Ross Steward for field operations and management.

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