

Grant Code: New

Title: Aerial imaging-based wheat evapotranspiration (ET) mapping for precision water management in Southern Idaho

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Justification/Rationale:

Precision irrigation is an agricultural practice to optimize the spatiotemporal application of water to maximize yield and minimize environmental impacts (e.g. Nitrogen leaching), and can reduce water use by up to 50% compared to traditional irrigation systems (Sadler 2005).

Evapotranspiration, is a process of evaporation from the soil and that of transpiration from plants, describing the movement of water vapor from the land to the atmosphere. Accurately estimating evapotranspiration in agricultural systems is of high importance for efficient use of water resources and precise irrigation scheduling operations that will lead to improved water use efficiency (Ghiat, 2021). Using high-resolution spatiotemporal crop ET mapping and models that can estimate crop water consumption throughout the season is critical for site-specific and precision irrigation management considering the subfield variety such as soil texture, soil organic matter, water availability, topography, and more (Molaei 2022, Zipper 2014, Schepers 2004). Spatially distributed estimates of evapotranspiration (ET) are critical

for farmers, agronomists, and water resource managers to know plant water use to evaluate irrigation requirements, respond to drought or precipitation events, and forecast year-end yields (Kresovic 2013). The current satellite image-based ET mapping(30-1000m) could not meet high spatial resolution requirement for subfield water-stress region identification. Low-altitude high-resolution multispectral and thermal aerial imaging provide opportunities to combine the local meteorology, surface temperature and remote sensing crop characteristic for real-time and high-resolution ET mapping. Surface energy balance models relying on remotely sensed data typically require surface reflectance data in one or more wave- lengths and surface temperature data, all of which are available on common drone platforms. Therefore, it is innovative to apply the high resolution multimodal aerial imaging and the High-Resolution Mapping of EvapoTranspiration Model for real-time site-specific subfield ET mapping for precision water management in Southern Idaho and Northern Idaho dryland farming.

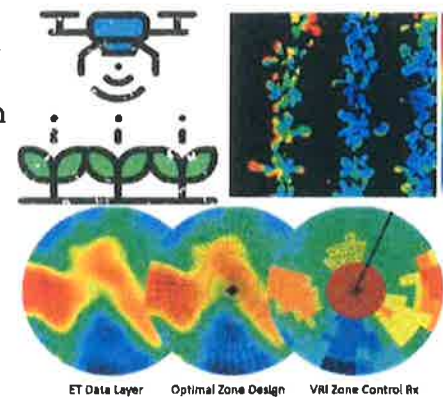


Fig.1 Aerial Imaging-based ET Mapping

Objectives:

This project will address these needs through four objectives: (1) Develop multimodal aerial imaging (multispectral and thermal) system and its standardize protocol for crop surface temperature and crop characterization (such as NDVI, LAI and crop height); (2) Develop aerial image based ET mapping tool coupled with High-Resolution Mapping of EvapoTranspiration (HRMET) model to combine the local meteorological data, spatially variable remotely sensed land surface temperature and canopy characteristics derived above for well-watered and drought-stressed field trials with ground observations; (3) Characterize relationships between water use and availability across crop rotations within the same fields and across different crop types (e.g., wheat, pea, barley) using aerial image based ET maps; (4) Evaluate potential precision irrigation benefits from both field and crop variety basis in Southern and Northern Idaho dryland.

Methods/Plan of work:

Field experiment will be conducted at the Aberdeen Research & Extension Center, University of Idaho (42°57'20.9"N 112°49'36.1"W, altitude 1,342 m). Two water regimes will consist of well-watered and drought-stressed conditions and there are three type of trial plots of monoculture and intercropping spring wheat (cultivar 'Ryan'), spring barley (cultivar 'GemCraft'), and spring pea (cultivar 'Hampton') under these two water regimes. The experiment follows a two-factor split-plot design with four replicates and will be repeated for three years. The main plot will be water regime and the subplot will be cropping system treatment in order to evaluate the aerial imaging-based ET mapping and decision support tool for actual crop water use and its precision water management benefits on its crop yield and quality cross different crop type and rotations. The on-farm trials will be conducted with producer collaborators in irrigated and dryland environments and determine the overall economic benefits of aerial image-based ET mapping and precision water management at various wheat-barley-pea cropping systems under well-watered and drought-stressed conditions. The aerial-imaging based ET mapping and precision water management decision support tool development and evaluation will be synergized with the Profitable Cereal-Pea Intercropping Systems field trials led by Co-PI Drs. Kayler and Liang. Two water regime treatments will be applied to the various crop rations and utilized to evaluate aerial imaging-based ET mapping for precision water management and spatially explicit crop yield and quality estimation. The dimension of each plot will be 3 × 6 m with 14 plant rows with a distance of 18 cm between rows. The seeding rates are adopted based on recommendation under high water availabilities (e.g., irrigated and rainfed conditions) and under dryland conditions (Kandel and Endres 2019). All crops will be planted in mid to late April and harvested in August. To create the two water regimes, irrigation will be applied at 100 (well-watered) and 50% (drought-stressed) of crop evapotranspiration (ET_c). Daily ET_o will be retrieved from a meteorological station located within 1 km of the experimental site (AgriMet Cooperative Agricultural Weather Network). The Actual irrigation will be applied by converting ET_c with irrigation application efficiency of 85% for the sprinkler irrigation system, which is prevalent in eastern and southern Idaho. The distance between main plots (in the split-plot design) is 12 m, which is also the irrigation radius of nozzles in the sprinkler irrigation system, thus irrigation water will not drift to other main plots. Soil moisture will be monitored in one of the four blocks using soil moisture probes (e.g., Delta- T PR2 Multi-Depth Soil Moisture Probe, up to 3 feet) to quantify soil moisture dynamics throughout each growing season and variograms of soil water content estimation will be compared to study the soil property heterogeneity and precipitation and irrigation factors. Co-PI Liang will lead to conduct sample analysis for yield

components and quality in the field experiment and on-farm trials. Co-PI Kayler will conduct the leaf sample analysis at the end of the experiment to estimate intrinsic water use efficiency (*i*WUE) and leaf nitrogen and isotope content with carbon isotope-based method in order to integrate water use efficiency of the plant as it responds to changes in environmental conditions (Li et al., 2017). Estimates of the isotope based *i*WUE assimilated with the plant responding to the treatment will be calculated to assessing plant water use efficiency over the entire experiment (Nitzsche, 2016). The multimodal aerial imaging will be performed on a weekly basis on the different crop rotations and physiological stages within two water regime treatments. The long-wave thermal infrared imager at 14,000 nm with a 13 mm lens (Duo Pro R, FLIR Systems, OR, USA), and a multispectral imaging sensor (RedEdge 3, MicaSense, Inc., Seattle, WA, USA) with five bands (Blue, 475 ± 10 nm; Green, 560 ± 10 nm; Red, 668 ± 5 nm; Red Edge, 717 ± 5 nm; and Near Infrared, 840 ± 20 nm) will be configured on the DJI M210 drone platform. Real-time solar irradiance data from onboard incident light sensor (DSL, MicaSense, Inc., Seattle, WA, USA) and ground calibrated reflectance panel (CRP, MicaSense, Inc., Seattle, WA, USA) will be used for radiometric calibration. The ground control points (GCP) will be used for high accuracy georectification (cm level) and image mosaic. The aerial thermal imagery will be used to estimate the canopy temperature to estimate the surface energy balance in different crops and irrigation/nitrogen plots at subfield scale.

To eliminate the hot and cold pixel requirement and its uncertainties, in this project we applied the one-dimensional (vertical), two-source (both soil and vegetation), process-based energy balance model called High-Resolution Mapping of EvapoTranspiration (HRMET) model (Zipper 2014) to estimate ET using three primary inputs including basic meteorological data, spatially variable remotely sensed land surface temperature, and a remotely sensed model of canopy characteristics. Local meteorological data including solar radiation (R_s , Wm^2), wind speed (ms^{-1}), relative humidity (RH, %), air temperature ($^{\circ}C$) and precipitation (mm) will be retrieving every 15min in real-time or historically from the Aberdeen, Idaho Weather station (ABEI). The multispectral imaging time window and altitudes/perspectives/overlaps and the calibration protocols will be optimized to calculate the NDVI, LAI and canopy height as well as the Digital Elevation Map (DEM) for the canopy characterization. Thus, HRMET is able to estimate the latent heat flux (λET) at subfield scale which is directly related to the ET rate by partitioning of relative magnitudes of the sensible heat flux (H) from the total available energy (A), by employing high-resolution surface temperature data at a subfield scale in conjunction with 4cm resolution aerial multispectral imagery and local meteorological data to estimate the surface energy balance. The error from all model inputs on ET estimates will be assessed using a Monte Carlo approach (Serbin 2014). The mean and standard deviation of all spatial, meteorological, and empirical inputs were ensembled based on the standard normal distribution and randomly selected for permutations and ET estimation stability insurance. The water balance and crop evapotranspiration will be mapped based on the above approach and the latent heat flux (λET) as the residual of the energy balance, which then be converted to ET with validation of in-situ measurements from the soil moisture probes and weather station and irrigation schemes. Water use efficiency will be calculated as crop yield divided by seasonal water use that is estimated by aerial imaging ET mapping and water balance. The accuracy and efficiency of the proposed aerial imagery-based ET mapping of subfield precision water management and crop yield and quality will be established. The proposed near-real-time high resolution ET mapping is critically beneficial to fill the gap of satellite-based ET mapping (30-1000m) for the precision water

management and variable rate irrigation at subfield scale for the Southern Idaho and Northern dryland farming and commercial production in the future.

Duration: 3 years: 2023-2026. The proposal is intended to produce preliminary data for pursuing federal funds, particularly, develop aerial imaging-based ET mapping and decision support tool for precision water management in Field experiment at Aberdeen R&E Center, involve growers and their on-farm trials in South Idaho for the economic benefit evaluation.

Cooperation/Complementation:

Kurt Schroeder, Associate Professor & Cropping Systems Agronomist.

Anticipated Benefits/ Expected Outcomes and Transfer of Information: Results of this work has been critical in providing farmers and agronomist with near real time information on crop health and crop water stress for irrigation scheduling or variable-rate application. The project will also provide a powerful spatially explicit aerial image-based ET mapping tool for identifying stressed regions on a subfield scale and the persistence of these patterns between dates can be used to help guide future management decisions and identify sensitive regions' ET patterns and its drivers (such as stress sensitive or moisture sensitive) in southern Idaho and northern Idaho dryland region (2023-2024). Results will be made available to growers through on-farm trial and presentations and through extension publications (2024-2025). Results will also be shared with wheat-barley-pea intercropping system developers/seed/drone companies and be communicated to peers in scientific meetings and through refereed journal publications (2025-2026).

Literature Review:

Many techniques have been used to estimate spatially distributed ET rates using remotely sensed data (Maes 2012, Ghia 2021). One class of ET models are surface energy balance models, which attempt to estimate the partitioning of latent heat flux from the available energy (A) at the land surface and the relative magnitudes of the sensible heat flux (H). Commonly used models include SEBAL (Bastiaanssen et al., 1998), METRIC (Allen et al., 2007), and SEBI (Roerink et al., 2000). These models rely on the presence of a 'dry' (also referred to as 'hot') and 'wet' ('cool') pixel within the image to define the extremes of surface temperature, where all available energy is apportioned to sensible heat or latent heat fluxes, respectively. The major drawback is that many agricultural landscapes are fairly homogeneous, making it difficult or impossible to identify dry and wet pixels within the same image. Other energy balance models, such as ALARM (Suleiman & Crago, 2004) that doesn't require of dry and wet pixels but assume a closed canopy to simplify canopy transport physics, which could not estimate the ET transient dynamics as completely closed canopies are rarely available during the early growing season, and dry or fallow open canopies are rarely available late in the growing season. High Resolution Mapping of EvapoTranspiration (HRMET) is a one-dimensional (vertical), two-source (both soil and vegetation), process-based energy balance model (Zipper 2014) to estimate ET using three primary inputs including basic meteorological data, spatially variable remotely sensed land surface temperature, and a remotely sensed model of canopy characteristics to estimate ET without does not require wet and dry pixels. Utilization of spatial explicit drone aerial imagery for high resolution ET mapping coupled with HRMET model under different water regime treatments has the potential to improve variable rate irrigation and water use efficiency at subfield scale.

References

- Allen, R.G., Tasumi, M., Morse, A., Trezza, R., Wright, J.L., Bastiaanssen, W., Kramber, W., Lorite, I., Robison, C.W., 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC) –applications. *J. Irrig. Drain. E.* 133, 395–406.
- Bastiaanssen, W.G.M., Menenti, M., Feddes, R.A., Holtslag, A.A.M., 1998. A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. *J. Hydrol.* 212–213, 198–212, [http://dx.doi.org/10.1016/S0022-1694\(98\)00253-4](http://dx.doi.org/10.1016/S0022-1694(98)00253-4).
- Ghiat, I.; Mackey, H.R.; Al-Ansari, T. A Review of Evapotranspiration Measurement Models, Techniques and Methods for Open and Closed Agricultural Field Applications. *Water* 2021, 13, 2523. <https://doi.org/10.3390/w13182523>
- Kresovic, B., Dragicevic, V., Gajic, B., Tapanarova, A., Pejic, B., 2013. The dependence of maize (*Zea mays*) hybrids yielding potential on the water amounts reaching the soil surface. *Genetika* 45 (1), 261–272, <http://dx.doi.org/10.2298/GENSR1301261K>.
- Kandel, H.J. and G.J. Endres. Soybean production field guide for North Dakota. NDSU Extension publication A1172. Revised April 2019.
- Li D, Fang K, Li Y, Chen D, Liu X, Dong Z, Zhou F, Guo G, Shi F, Xu C, Li Y. Climate, intrinsic water-use efficiency and tree growth over the past 150 years in humid subtropical China. *PLoS One*. 2017 Feb 9;12(2):e0172045. doi: 10.1371/journal.pone.0172045. PMID: 28182751; PMCID: PMC5300276.
- Maes, W.H., Steppe, K., 2012. Estimating evapotranspiration and drought stress with ground-based thermal remote sensing in agriculture: a review. *J. Exp. Bot.* 63 (13), 4671–4712, <http://dx.doi.org/10.1093/jxb/err313>.
- Molaei, B.; Peters, R.T.; Khot, L.R.; Stöckle, C.O. Assessing Suitability of Auto-Selection of Hot and Cold Anchor Pixels of the UAS-METRIC Model for Developing Crop Water Use Maps. *Remote Sens.* 2022,14,4454. <https://doi.org/10.3390/rs14184454>
- Roerink, G.J., Su, Z., Menenti, M., 2000. S-SEBI: a simple remote sensing algorithm to estimate the surface energy balance. *Phys. Chem. Earth B* 25 (2), 147–157, [http://dx.doi.org/10.1016/S1464-1909\(99\)00128-8](http://dx.doi.org/10.1016/S1464-1909(99)00128-8).
- Schepers, A.R., Shanahan, J.F., Liebig, M.A., Schepers, J.S., Johnson, S.H., Luchiari, A., 2004. Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. *Agron. J.* 96 (1), 195–203.
- Suleiman, A., Crago, R., 2004. Hourly and daytime evapotranspiration from grassland using radiometric surface temperatures. *Agron. J.* 96 (2), 384–390.
- Serbin, S.P.; Singh, A.; McNeil, B.E.; Kingdon, C.C.; Townsend, P.A. Spectroscopic determination of leaf morphological and biochemical traits for northern temperate and boreal tree species. *Ecol. Appl.* 2014, 24, 1651–1669
- Zipper, S.C.; Loheide, S.P., II. Using evapotranspiration to assess drought sensitivity on a subfield scale with HRMET, a high resolution surface energy balance model. *Agric. For. Meteorol.* 2014, 197, 91–102.

FY2024

COMMODITY COMMISSION BUDGET

Principal Investigator: Johnny Li

Allocated by _____	during FY2022	\$ -
(Commission/Organization)		
Allocated by _____	during FY2023	\$ -
(Commission/Organization)		

REQUESTED SUPPORT:	<i>Awarded for FY2023</i>	<i>Requested for FY2024</i>
Budget Categories		
(10) Salary (staff, post-docs, et NOTE: Faculty salary/fringe not allowed)	\$ -	\$ 16,250
(12) Temporary Help/IH	\$ -	\$ 3,300
(11) Fringe Benefits	\$ -	\$ 873
(20) Travel	\$ -	\$ 4,200
(30) Other Expenses	\$ -	\$ 3,800
(40) Capital Outlay >\$5k	\$ -	\$ -
(45) Capital Outlay <\$5k	\$ -	\$ 3,500
(70) Graduate Student Tuition/Fees	\$ -	\$ 7,896
TOTALS	\$ -	\$ 39,819
TOTAL BUDGET REQUESTED FOR FY2024:		\$ 39,819

BREAKDOWN FOR MULTIPLE INDEXES:						
Budget Categories	Johnny Li	Xi Liang	Zachary Kayler	(Insert Co-PI Name)		
(10) Salary (staff, post-docs, et	\$ 16,250	\$ -	\$ -	\$ -		
(12) Temporary Help	\$ -	\$ 1,800	\$ 1,500	\$ -		
(11) Fringe Benefits	\$ 585	\$ 157	\$ 131	\$ -		
(20) Travel	\$ 4,200	\$ -	\$ -	\$ -		
(30) Other Expenses	\$ -	\$ 2,000	\$ 1,800	\$ -		
(40) Capital Outlay >\$5k	\$ -	\$ -	\$ -	\$ -		
(45) Capital Outlay <\$5k	\$ 3,500	\$ -	\$ -	\$ -		
(70) Graduate Student Tuition/Fees	\$ 7,896	\$ -	\$ -	\$ -		
TOTALS	\$ 32,431	\$ 3,957	\$ 3,431	\$ -		
		Total Sub-budgets		\$		39,819

Budget Justification		
\$ 16,250	(10-Graduate Student- 65% of student salary to)	
\$ 3,300	(12-III(Liang) \$15/hr for 120hrs and IH (Kayler) \$15/hr for 100hrs *Fringe rates: Staff = 42%; IH = 8.7%; Student = 3.6%	
\$ 873	(11-Graduate Student @ 3.6%; IH @ 8.7%) Per Diem = \$55/day In-State; Mileage = \$0.625/mi	
\$ 4,200	(20-Travel to field sites and to conduct aerial imaging @ Aberdeen R&E center)	
\$ 3,800	(30-Mositure probe system, lab consumables to measure moisture of soil and conduct leaf analysis for plant water and nutrient use efficiency)	
\$ -	(40-Insert Capital Equipment description)	
\$ 3,500	(45-FLIR Vue Pro 640)	
\$ 7,896	((70- 60% of Graduate Student tuition) \$12,050/YR = Tuition, Fees and SHIP	