

Grant Code: AW7063

Title: Aerial imaging-based wheat evapotranspiration (ET) mapping for precision irrigation 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 scheduling systems. Evapotranspiration (ET) is a process of evaporation from the soil and transpiration from plants, describing the movement of water vapor from the land to the atmosphere. Accurately estimating ET in agricultural systems is of high importance for efficient use of water resources and precise irrigation scheduling operations, leading to improved water use efficiency. Spatially distributed estimates of ET are critical for farmers to know plant water use to evaluate irrigation requirements, respond to drought or precipitation events, and forecast year-end yields (Kresovic, 2013). Using high-resolution spatiotemporal crop ET mapping that can estimate crop water consumption throughout the season is critical for site-specific and precision irrigation management considering the subfield heterogeneity induced by cropping system agronomic operations, such as soil texture, soil organic matter, water availability, topography, and more (Molaei, 2022, Zipper 2014, Schepers, 2004). The current satellite image-based ET mapping (30-1000m) could not meet the needs for subfield drought-stress region identification. Low-altitude high-resolution aerial multispectral and thermal imaging provide us opportunities to combine the local meteorology, crop surface temperature, and remote sensing crop characteristics for real-time and high-resolution ET mapping. Therefore, applying the multimodal aerial imaging and data fusion can be used for developing real-time site-specific high-resolution ET mapping for precision water management.

Objectives: This project will address these needs through four objectives: (1) Develop a multimodal aerial imaging (multispectral and thermal) system and standardize the protocol for measuring crop surface temperature and crop characteristics (such as enhanced vegetation index (EVI), leaf area index (LAI), and plant height); (2) Develop an aerial image based ET mapping tool to combine the local meteorological data, spatially variable remotely sensed land surface temperature, and canopy characteristics derived in Objective 1 for well-watered and drought-stressed conditions with ground observations; (3) Characterize relationships between water use and water availability of different crops (e.g., wheat, pea) using aerial image based ET maps in Objective 2 ; (4) Evaluate potential precision irrigation benefits based on the aerial image based ET tool developed in Objective 3.

Methods/Plan of work: This project will leverage a USDA NIFA funded wheat intercropping field trial in Aberdeen Research & Extension Center, University of Idaho, with wheat and pea planted in alternate rows at

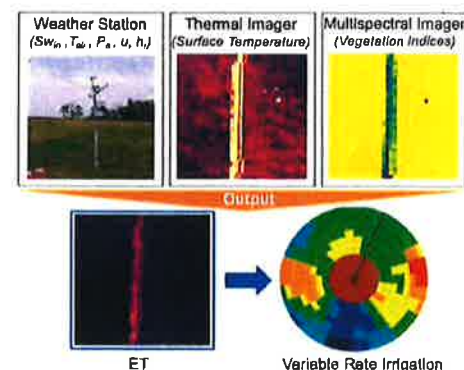


Fig.1 Aerial Imaging-based ET Mapping

different seeding rates. This ongoing wheat intercropping field experiment provides us with a unique and complex wheat cropping system for this new proposal to conduct the aerial image-based ET mapping and quantify the water use efficiency in wheat-pea intercropping systems for Southern Idaho growers. The experiment follows a split-plot design with four replicates and will be repeated for three years. Two water regime treatments will be utilized to evaluate aerial imaging-based ET mapping for precision water management and spatially explicit crop yield and quality estimation.

The main plot will be water regime and the subplot will be cropping system treatment. Two water regimes will consist of well-watered and drought-stressed conditions. The dimension of each plot will be 10×20 ft with 14 plant rows with 7-inch between rows. 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_0 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 an 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 40 ft, 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 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 the field experiment for irrigation scheduling, in-season measurements, and sample analysis for yield components and quality, as well as the on-farm trials. Co-PI Kayler will conduct the leaf sample analysis at the end of the experiment to estimate intrinsic water use efficiency ($iWUE$) 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 (Werner et al., 2012). Estimates of the isotope based $iWUE$ assimilated with the plant responding to the treatment will be calculated to assessing plant water use efficiency over the entire experiment.

As in Fig. 1, local meteorological data including solar radiation, wind speed, relative humidity, air temperature, and precipitation will be retrieved every 15 min from AgriMet (Cooperative Agricultural Weather Network). The aerial thermal imager will be able to capture ~ 17 cm per pixel high-resolution surface temperature data at a subfield scale in conjunction with 1.2 cm resolution multispectral imagery (RedEdge 3, MicaSense, Inc.) from a DJI M210 drone platform. The multimodal aerial thermal and multispectral imaging will be performed at different growth stages. The ground control points (GCP) will be used for high accuracy georectification (cm level) and image mosaic to compute enhanced vegetation index, and then LAI and canopy height will be derived from the geo-rectified remote sensing data. A plant canopy analyzer (LI-COR LAI-2200 LI-COR Inc., Lincoln, NE, USA) will be used to collect LAI and h values from each flight mission. Thus, High-Resolution Mapping of EvapoTranspiration (HRMET) model (Zipper 2014) is able to estimate the latent heat flux (AET) at subfield scale based on the three primary inputs: daily meteorological data, spatially variable remotely sensed land surface temperature, and a remotely sensed model of canopy characteristics. AET can be directly converted to crop ET rate by partitioning of relative magnitudes of the sensible heat flux (H) from the total available energy (A) through surface energy balance. The error from all model inputs on ET estimates will be assessed using a Monte Carlo approach (Serbin 2014). The water balance and crop ET will be

mapped based on the above approach for precision irrigation management.

Water use efficiency will be calculated as crop yield (i.e., aboveground biomass and grain 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 precision water management and variable rate irrigation at subfield scale for Southern Idaho in the future. In-field trials will be conducted in irrigated and dryland environments to determine the overall economic benefits of aerial image-based ET mapping and precision water management of water intercropping systems. The development and evaluation of the aerial-imaging based ET mapping and precision water management decision support tools will be synergized with the ongoing wheat intercropping system and expand to the multistate wheat variety trials and commercial farms to maximize grower's profit.

Duration: 3 years: 2023-2026. The proposal is intended to produce promising preliminary data for pursuing federal funds, particularly, developing innovative aerial imaging-based ET mapping and decision support tools for precision water management and involving growers in on-farm trials to evaluate the economic benefit.

Cooperation/Complementation: This new proposal will leverage the wheat-pea intercropping experiment well-managed by Co-PIs Liang and Kayler to validate the proposed aerial image-based ET mapping tool. The ongoing intercropping project creates two water regimes to evaluate the crop yield under different water availability but does not include soil moisture monitoring (up to 3 feet) and ET mapping, or isotope-based water use efficiency from plant tissues as proposed. Grain in the field trials will be harvested by growers and associated with the plant samples collected by the research crew. After carefully validating the proposed aerial image-based ET mapping tool in this dedicated intercropping experiment, we will expand our efforts to multiple wheat variety trials in southern and northern Idaho with cooperation with Dr. Kurt Schroeder. It will be very promising for publishing this innovative research and applying for federal grants.

Anticipated Benefits/Expected Outcomes: Results of this work are critical in providing farmers with near real-time information on crop growth for irrigation scheduling or variable-rate application. This new proposal is to develop an aerial image-based ET mapping tool for southern Idaho's precision irrigation management and future wheat germplasm field phenotyping. It is aiming to help growers with different water rights improve their field ET monitoring and irrigation management with IWC support. The project will 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 drivers (e.g., stress sensitivity or moisture sensitivity) and conduct climate-smart and efficient irrigation operations in southern Idaho and northern Idaho dryland region.

Transfer of Information/Technology: Results will be made available to stakeholders (including growers, crop consultants, and seed companies) through presentations at Extension events (e.g., field days, grower meetings, workshops, etc.) and Extension publications (2024-2025). Results and ET tools can be used for on-farm irrigation management zone creation and crop yield prediction. Results will also be communicated to peers in scientific meetings and through refereed journal publications (2025-2026).

Literature Review: Surface energy balance models relying on remotely sensed data typically require surface reflectance data in one or more wavelengths and surface temperature data, all of which are available on drone platforms. Many techniques have been used to estimate spatially distributed ET rates using remotely sensed data. One class of ET models is surface energy balance models, which attempts 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 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. 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 wet and dry pixels. Using spatial explicit drone aerial imagery for high resolution ET mapping coupled with HRMET model under different water regimes has the potential to improve variable rate irrigation and water use efficiency at the 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.
- 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/GENSRI301261K>.
- 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.
- 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
- Werner, C., Schnyder, H., Cuntz, M., Keitel, C., Zeeman, M.J., Dawson, T.E., Badeck, F.W., Brugnoli, E., Ghashghaie, J., Grams, T.E. and Kayler, Z.E., 2012. Progress and challenges in using stable isotopes to trace plant carbon and water relations across scales. *Biogeosciences*, 9(8), pp.3083–3111.
- 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. 10.1016/j.agrformet.2014.06.009

FY2025
COMMODITY COMMISSION BUDGET
Principal Investigator: Johnny Li, Xi Liang, Zachary Kayler

Allocated by <u>Idaho</u> Wheat Commission	during FY2023	\$	39,819
(Commission/Organization)			
Allocated by <u>Idaho</u> Wheat Commission	during FY2024	\$	39,930
(Commission/Organization)			

REQUESTED SUPPORT	<u>Awarded for FY2024</u>	<u>Requested for FY2025</u>
Budget Categories		
(10) Salary (staff, post-docs, et NOTE: Faculty salary/fringe NOT allowed)	\$ 16,250	\$ 15,600
(12) Temporary Help/IH	\$ 873	\$ 8,000
(11) Fringe Benefits	\$ 3,300	\$ 1,054
(20) Travel	\$ 4,200	\$ 5,606
(30) Other Expenses	\$ 3,801	\$ 4,300
(40) Capital Outlay >\$5k	\$ -	\$ -
(45) Capital Outlay <\$5k	\$ 3,500	\$ -
(70) Graduate Student Tuition/Fees	\$ 7,896	\$ 8,260
TOTALS	\$ 39,820	\$ 42,820

TOTAL BUDGET REQUESTED FOR FY2025:	\$ 42,820
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BREAKDOWN FOR MULTIPLE INDEXES:						
Budget Categories	<i>Li</i>	<i>Liang</i>	<i>Kayler</i>	<i>(Insert Co-PI Name)</i>		
(10) Salary (staff, post-docs, et	\$ 15,600	\$ -	\$ -	\$ -	\$ -	\$ -
(12) Temporary Help	\$ 3,200	\$ 3,200	\$ 1,600	\$ -	\$ -	\$ -
(11) Fringe Benefits	\$ 656	\$ 265	\$ 133	\$ -	\$ -	\$ -
(20) Travel	\$ 5,606	\$ -	\$ -	\$ -	\$ -	\$ -
(30) Other Expenses	\$ 2,500	\$ -	\$ 1,800	\$ -	\$ -	\$ -
(40) Capital Outlay >\$5k	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
(45) Capital Outlay <\$5k	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
(70) Graduate Student Tuition/Fees	\$ 8,260	\$ -	\$ -	\$ -	\$ -	\$ -
TOTALS	\$ 35,822	\$ 3,465	\$ 3,533			
				Total Sub-budgets		
				\$ 42,820		

Annual Report

Grant Code: AW7063

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

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ABSTRACT:

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 scheduling systems. Accurately estimating evapotranspiration (ET) in agricultural cropping systems is critical for efficient use of water resources and precise irrigation scheduling operations. In-field mapping of heterogeneity, such as soil texture, soil organic matter, water availability, topography, etc. are important for farmers to know plant water use to evaluate irrigation requirements, respond to drought or precipitation events, and forecast year-end yields. The current satellite-image-based ET mapping (30-1000m) and point-based soil moisture sensing could not meet the subfield drought-stress region identification needs. The project aims to apply low-altitude drone-imagery and combine the local meteorology, remote sensing crop characteristics and surface temperature for high-resolution ET mapping. The project acquired time-series drone imagery in a wheat-barley-pea intercropping field trial at different water regimes in Aberdeen, Idaho during this reporting year. The crop surface temperature and crop characteristics (including enhanced vegetation index (EVI), leaf area index (LAI), and plant height) were derived from the drone imagery and fed into the High-Resolution Mapping of Evapotranspiration model to compute the actual ET and water use efficiency at subfield scale. Among the 11 different cropping system at grain filling growth stage, the results shows that monocropping wheat has lowest biomass and water use efficiency, while the 75% barley+75% pea has highest biomass and water use efficiency in 100% ET (well-watered) condition. 75% Wheat+25% pea has highest biomass yield and water use efficiency at 50% ET (drought-stressed) conditions. Therefore, it confirms that our drone remote sensing imaging and ET modeling can provide insights for growers to better understand subfield plant water use and optimize the irrigation scheduling for different cropping system.

BACKGROUND/OBJECTIVES:

Our program goal is applying high-resolution multispectral/thermal drone imagery and ET model computing for high resolution mapping of evapotranspiration and assessing subfield crop water use efficiency in different irrigation regimes cross different agronomic cropping systems. Our project objectives includes (1) Develop a multimodal aerial imaging (multispectral and thermal) system and standardize the protocol for measuring crop surface temperature and crop characteristics (such as enhanced vegetation index (EVI), leaf area index (LAI), and plant height); (2) Develop an aerial image based ET mapping tool to combine the local meteorological data, spatially variable remotely sensed land surface temperature, and canopy characteristics derived in Objective 1 for well-watered and drought-stressed conditions with ground observations; (3) Characterize relationships between water use and water availability of different crops (e.g., wheat,

pea) using aerial image based ET maps in Objective 2 ; (4) Evaluate potential precision irrigation benefits based on the aerial image based ET tool developed in Objective 3.

RESULTS/ACCOMPLISHMENTS:

Cropping system design for drone-based ET mapping: This project leveraged a USDA NIFA funded wheat intercropping field trial in Aberdeen Research & Extension Center, University of Idaho, with wheat and pea planted in alternate rows at different seeding rates. This ongoing wheat intercropping field experiment provides us with a unique and complex wheat cropping system for our project to conduct the aerial image-based ET mapping and quantify the water use efficiency in wheat-pea intercropping systems for Southern Idaho growers. As shown in Figure 1a, the experiment follows a split-plot design with four replicates and will be repeated for three years. 11 cropping system was planted in plot of 10 × 20 ft with 14 plant rows with 7-inch between rows and 40 ft between main plots (in the split-plot design). Two water regime treatments will be utilized to evaluate aerial imaging-based ET mapping for precision water management and spatially explicit crop yield and quality estimation. Fig.1 (b) shows the drone thermal imaging with plot map. The in-situ soil moisture sensor was installed for sampling soil moisture at different cropping system under different water regimes. A weekly time-series multispectral imaging was conducted from June 1st to August 15th. The crop and soil characteristic will be used to compute the ET mapping correspondingly.

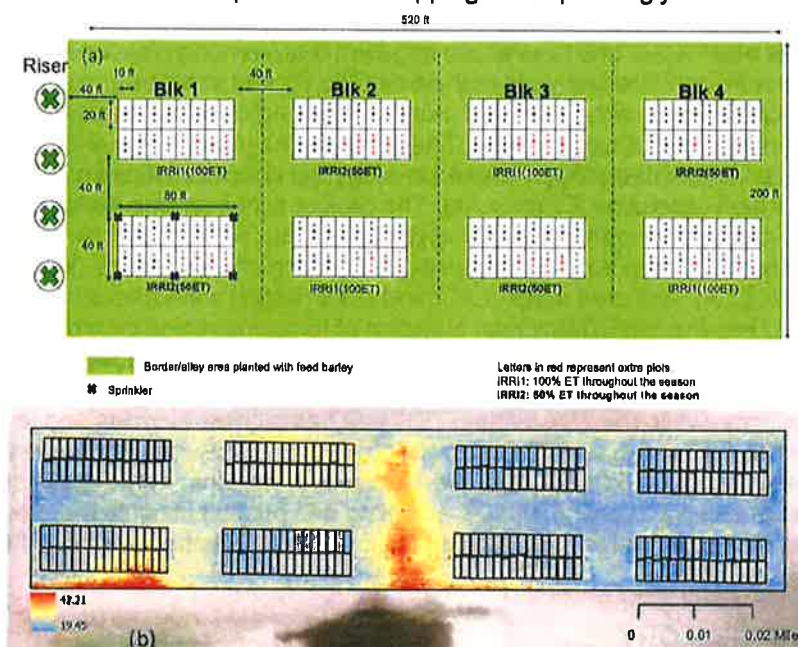


Figure 1: Experiment design of different 11 cropping system for drone multispectral imaging and high-resolution evapotranspiration mapping

Workflow of High-resolution Evapotranspiration Mapping: In order to combine the local meteorological data, spatially variable remotely sensed land surface temperature, and canopy characteristics, the below workflow was established to compute measuring crop surface temperature and crop characteristics (such as enhanced vegetation index (EVI), leaf area index (LAI), and plant height). The proposed aerial image-based ET modeling is one-dimensional (vertical), two-source (both soil and vegetation), process-based energy balance model. The intercropping system field trial was able to use 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 wet and dry pixels. It aims to investigate the biomass yield and water use efficiency of different cropping system under different water regimes for improving irrigation scheduling and water use efficiency at the subfield scale.

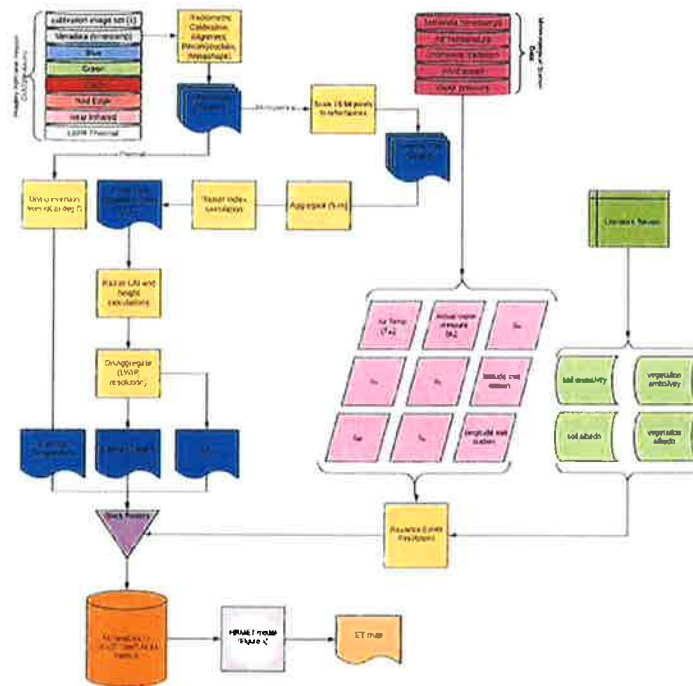


Figure 2: workflow of High-resolution Evapotranspiration Mapping

Different irrigation treatment (50% ET and 100% ET) on ET mapping

Varying irrigation treatments (50% ET and 100% ET) on Evapotranspiration (ET) mapping were investigated. The violin plots in Figure 3a vividly depict the variation in Relative ET, with blue and orange representing 50% ET and 100% ET, respectively. The Relative ET values ranges from 0.2 to 1.0 (Figure 3a), with the 100%ET irrigated level (in blue) demonstrating minimum values of >0.4 and maximum values of 1.0 and the 50%ET irrigated level showing values from 0.2 to 0.98. The observations suggest notable differences in Relative ET between the two irrigation levels. Figure 3b highlights the distribution of Actual ET across the different irrigation levels. Overall, the 100%ET experienced higher evapotranspiration with values ranging from 0.29 to 0.451 while 50%ET treatment was from 0.24 to 0.44. The results show distinct patterns in Actual ET between the two irrigation treatments, suggesting that the level of irrigation significantly influences the overall water consumption by crops. These insights into the actual water consumption patterns contribute to our understanding of crop water requirements under different irrigation scenarios.

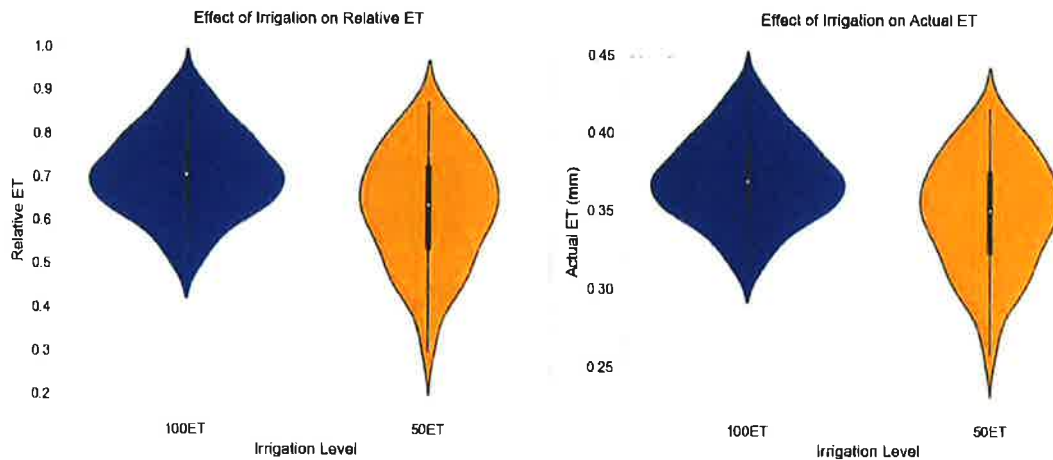


Figure 3: Impact of Irrigation Treatments on Relative and Actual evapotranspiration (ET)

Effect of different cropping system on ET mapping

After we segmented the drone multispectral /thermal imaging into individual plots (5' by 20'), the Normalized Difference Vegetation Index (NDVI), and Leaf Area Index (LAI), plant height was computed for ET estimation. The influence of different cropping systems on Evapotranspiration (ET) mapping was analyzed. The effect of cropping systems on Actual ET and its variability of water consumption patterns is depicted in the box plots of Figure 4. The box plots showcase the distribution of Actual ET across various cropping systems. Each box plot represents a distinct cropping system, providing insights into the variability of water consumption patterns. The values for 100% ET tend to have higher evapotranspiration values. Extreme higher evapotranspiration outlier value was evident in pea cropping system. On the other hand, feed barley cropping system for 100% ET treatment displayed the lowest value of evapotranspiration of 0.31. For the 50% ET treatment, the evapotranspiration value was from 0.3 to 0.4 with barley cropping system showing outlier evapotranspiration values of 0.26. The analysis indicates significant differences in Actual ET among different cropping systems, highlighting the impact of agricultural practices on water usage.

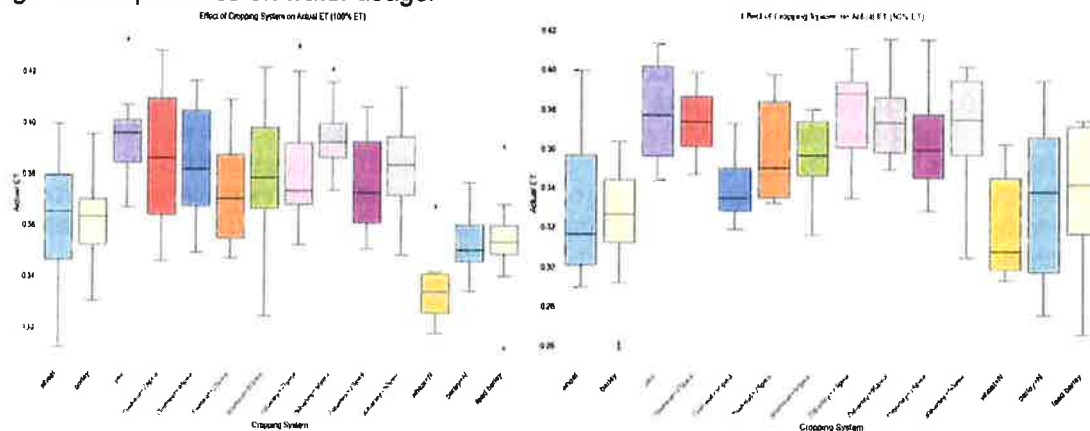


Figure 4: Impact of Irrigation Treatments on Relative and Actual evapotranspiration (ET)

Effect of different cropping growth stage on ET mapping and biomass development

To assess the biomass yield performance across diverse cropping systems and irrigation schemes, we conducted a comprehensive analysis utilizing data obtained from multiple

experimental treatments. The following sections present the findings for different growth stages and irrigation levels. We selected the July 8th multispectral imaging which is close to grain filling growth stage and the actual ET and biomass development of each cropping system are indicated in Figure 5. The biomass of barley was the lowest, with values 80 grams respectively. However, pea and 75%Barley+75%Pea had the highest evapotranspiration value of 0.38, while wheat had a value of 0.32 under the 50% ET treatment.

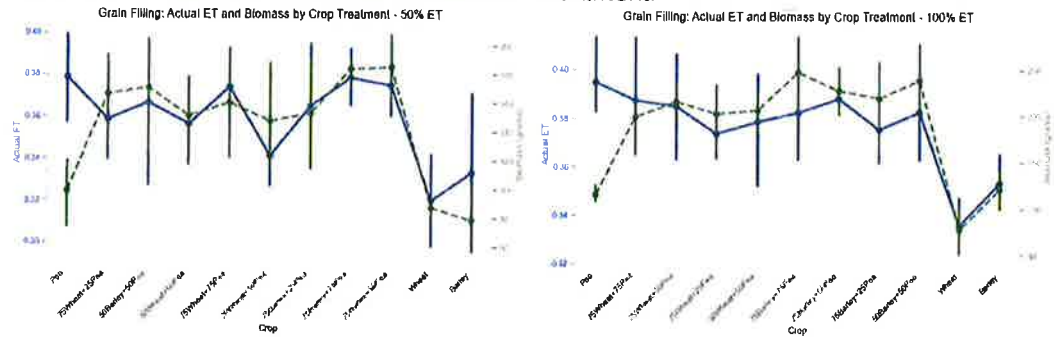


Figure 5: Relationship between Biomass and Actual Evapotranspiration (ET) under 50% and 100% Evapotranspiration (ET) conditions at the grain filling phase.

Water Use Efficiency Comparison among Different Cropping Systems

To further assess the plant water use efficiency and its contribution to the crop development and yield outcome, we investigate the water use efficiency and biomass yield cross different cropping system. Water use efficiency (WUE) is expressed as the ratio of dry matter production in kilograms per hectare by the corresponding evapotranspiration measured in millimeters. Figure 6 offers insights into the WUE and Biomass dynamics under 50% and 100% ET scenarios. At 100% ET treatment in Figure 3.25, Barley with >18000 had the highest water use efficiency while wheat with <14000 water use efficiency was the lowest. At 50% ET treatment, 75%Wheat+25%Pea and Wheat with about 15,000 water use efficiency kg/ha/mm was the highest and 50%Wheat+50%Pea with <12,000 kg/ha/mm water use efficiency was the minimum value observed.

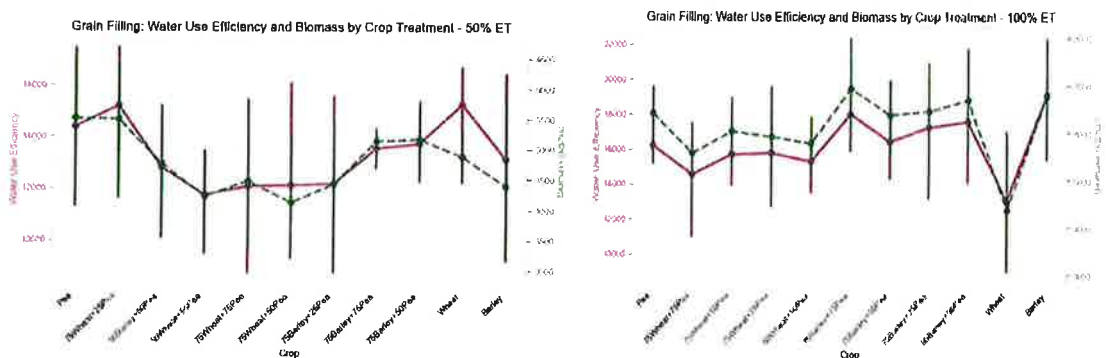


Figure 6: Comparative analysis of Water Use Efficiency and Biomass production among different crops under 50% and 100% ET conditions during the grain filling stage

OUTREACH/APPLICATIONS/ADOPTION:

The project has developed a multimodal drone image based high resolution ET mapping for the diverse cropping system, which can provide insights and provide guidance on irrigation scheduling and climate-smart agriculture practices. Our remote sensing and ET modeling was invited to present to the Idaho water resource seminar series, which is *open to all interested*

professionals, legislators, water supply managers, local government representatives, attorneys, students and interested public. We also convey our research findings to the 2023 ASA, CSSA, SSSA International annual meeting and 2023 Hermiston Farm Fair on Nov 29-30, 2023, by Oregon State University. We will present our comprehensive research result in the upcoming 2024 ASABE Annual International Meeting, July 28 - 31, 2024 in Anaheim, California so that it might be adopted by the agriculture community widely.

NEXT STEPS / PROJECTIONS:

Overall, our multispectral imaging based high resolution ET mapping approach was able to differential the water use efficiency and biomass yield cross 11 different cropping system in grain filling stage. It is indicated that among the 11 different cropping system at grain filling growth stage, the results shows that monocropping wheat has lowest biomass and water use efficiency, while the 75% barley+75% pea has highest biomass and water use efficiency in 100% ET irrigation regime. 75% Wheat+25% pea has highest biomass yield and water use efficiency at 50% ET irrigation regimes. The findings contribute to our understanding of how crops allocate and utilize water resources during the crucial grain filling process, impacting final biomass yield. This pattern/metric serves as a pivotal indicator of how effectively plants convert water into biomass, offering insights into the water utilization dynamics within different cropping systems.

The goal of this project is to provide farmers/growers with novel ET modeling and plant water use assessment through the state-of-the-art drone remote sensing and data analysis algorithm. We have 3 multispectral imaging and thermal imaging on May 25, July 8, July 9 for ET estimation, and 10 multispectral imaging only from June 1st to August 15th. We will continue to analyze the time-series multispectral imaging to derive the NDVI/NDRE growth curve in the two different water regimes for the 11-cropping system. From practical perspective, we will compare the ET calculated by FAO 56 ET calculation method and validate with the in-situ soil moisture sensor data. The grain quality analysis result (including carbon and nitrogen content) will be associated with hyperspectral imaging during growth stage and after harvest. Accurately estimating evapotranspiration (ET) in agricultural cropping systems is critical for efficient use of water resources and precise irrigation scheduling operations, which can optimize the spatiotemporal application of water to maximize yield and minimize environmental impacts (e.g., nitrogen leaching), and reduce water use by up to 50% compared to traditional irrigation scheduling systems. In 2024, we propose to deploy the drone thermal imaging system to the farm crew in Aberdeen Research and Experimental Station so that weekly drone image will be ensured to cover the critical growth stages (Heading, Stem Elongation, Tillering, and Grain Filling, Maturity) and validate our high-resolution ET mapping tools practical for irrigation scheduling and water use efficiency assessment during 2024-2025.

Research findings and ET mapping tool from this research will help growers better estimate their subfield ET level and optimize their irrigation scheduling and maximize the climate-smart practices for different cropping system.

PUBLICATIONS/PRESENTATIONS/POPULAR ARTICLES/NEWS RELEASES/VARIETY RELEASES:

1. Chen, G, Li, L(2023). Aerial Nondestructive Testing and Evaluation (aNDT&E). Materials Evaluation 81 (1): 67–73 <https://doi.org/10.32548/2023.me-04300>
2. Kwaku Opoku-Ware, Carson Sass, Johnny Li. Assessing Plant Health and Soil Moisture with UAV-Derived Vegetation Indices and Evapotranspiration Maps. 2023 ASA, CSSA, SSSA INTERNATIONAL ANNUAL MEETING. ASA Virtual Session # 155603, October 29-November 1, 2023, St Louis, MO.

3. Invited talk "Precision Agriculture Research in Idaho: Assessing Crop Health and Evapotranspiration with Time-series High-resolution UAV Remote Sensing Imagery" for Idaho Water Resources Seminar Series, November 7, 2023,
4. Invited Talk "Advance Robotics Sensing, Control and Computing for Smart Agriculture" by 2023 School of Mechanical and Materials Engineering Seminar Series at Washington State University, September 21, 2023
5. Invited Talk "Drone remote sensing and AI for Precision Agriculture" by 2023 Hermiston Farm Fair on Nov 29-20, 2023, Oregon State University.
6. Kwaku Opoku-Ware, Carson Sass, Johnny Li. Multispectral Imaging and Crop Evapotranspiration Modeling for intercropping System Performance Evaluation in Southerland Idaho. 2024 ASABE Annual International Meeting, July 28 - 31, 2024 in Anaheim, California (To be submitted)