

1. Project Name: Developing a Dynamic Crop Coefficient (Kc) To Improve Irrigation Efficiency
2. Investigators:
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3. Justification:

There are approximately 2 million acres of irrigated land in the state of Montana (NASS, 2013). Nearly two-thirds are gravity fed with water diverted from rivers such as the Sun, Yellowstone, Milk, Missouri, Jefferson, and Flathead, all of which are tributaries to either the Missouri or Columbia drainage systems. Conservation and protection of these water networks are of regional, state, and national concern. Additionally in the Flathead for example, there are water right concerns due to existing or developing water compacts between water users and the tribal community which could begin to restrict water availability. Strategic use of water that provides irrigators the highest economic gain is a research priority. Sustainable agricultural production within the lands managed under irrigation begins with efficient water management. In order to properly manage water resources, critical information such as crop water use is needed, but field-scale crop water use has not been measured across different crops in Montana.

The world-wide standard for irrigation scheduling uses the ASCE Standardized reference evapotranspiration equation (Allen et al., 2005). This equation was developed in concert with ARS scientists at Kimberly, ID during the 1990's and was adopted by the Food and Agriculture Organization in 1998 as a guideline to determine crop water requirements (Allen et al., 1998). The ASCE standard provides an approximation of crop water use that is **rarely tested against measurements** despite the widespread application of this approach.

Evapotranspiration (ET) is largely driven by ambient air temperature, atmospheric vapor pressure deficit, solar radiation, and wind speed. Regional weather stations routinely measure these parameters and the data are freely available for use. For irrigation scheduling, additional processing of this data is necessary; reference ET (ET_o) must be calculated. Locally applicable crop coefficients (K_c) can then be used to convert the ET_o into actual crop water use. Currently the K_c values used in Montana have been estimated using the documentation for the ASCE models, but have not been tested, which leads to inaccuracies. Independent regional verification is needed.

The eddy covariance method of measuring evapotranspiration (latent heat flux) from a surface can be used to derive crop coefficient values and improve ASCE approximations by dividing the daily ETo from a nearby weather station with the daily latent heat flux (Suyker and Verma, 2009; Harris and Stoy, 2015). Here, we use eddy covariance measurements to improve our understanding of crop water use across different irrigated crops in Montana.

4. Objectives:

- Measure crop water use of malt barley (near Huntley, MT) and spring wheat and canola (near Kalispell, MT) in non-stressed irrigated environments in proximity to local weather stations using eddy covariance.
- Calculate Kc on half-hourly time step by dividing measured ET of the crop from flux towers by ETo of the weather stations.
- Determine the relationship between calculated Kc and ancillary data such as growing degree days (GDD), heat units, duration from date of planting to physiological maturity and harvest, and canopy ground coverage.

5. Methods:

Eddy covariance systems with CSAT-3 triaxial sonic anemometers and LI-7200 closed path infrared gas analyzers were mounted at 2-m height from the ground and placed in a flood irrigated malt barley (Southcentral MT) and center-pivot irrigated spring wheat and canola fields (Northwest, MT). The fetch (distance between tower and the closest edge of the field) was approximately 200 m for the field in Huntley and 250 m for the fields in Kalispell.

Three-dimensional wind speed, carbon dioxide concentration, and water vapor concentration were measured at 10 Hz. Half hour wind speed, sensible heat flux (thermals), and water vapor flux (evapotranspiration) were quantified using EddyPro freeware (LiCor, Lincoln, NE).

Crop growth scores, ground cover, biomass, and yield data were gathered. Average ground canopy coverage of the fields will be estimated using available satellite data from the U.S. Geological Survey.

The study site in Huntley in 2015 was a 14 acre flood irrigated malt barley field on a Ft. Collins clay loam. Tillage was conventional inversion tillage with the field leveled and fertilized with 100-50-30 lbs NPK in the fall. Malt barley (Moravian 115) was planted on March 23 at 82 lbs/a on 6 in rows. The field was irrigated to a full profile on May 27-28, and June 17-18. The crop was harvested on July 20 with an average yield of 110 bu/a. Ancillary measures included biomass accumulation, height, and growth stage on a weekly basis at locations approximately 150 ft distal from the tower.

In 2016 the study site in Huntley was a 38-acre flood irrigated malt barley field on a Toluca and Wanetta clay loam previously in sugar beets. The field was disked in the fall of 2015, fertilized

with 125-20-30 NPK with 30 units of N as ESN, and disked a second time. Malt barley (Moravian 115) was planted on March 16 at 85 lbs/a on 6 in rows. The field was irrigated to a full profile on May 27, and a second time around June 25. The crop was harvested on July 26 with an average yield of 122 bu/a. Ancillary measures included biomass accumulation, crop height, and growth stage on a weekly basis at 4 locations approximately 150 ft distal from the tower.

The study site in 2015 in Creston was a 140-acre center pivot irrigated spring wheat field on a fine sandy loam soil. The ground was tilled conventionally, leveled, and minimally irrigated prior to planting for better seed germination. Spring wheat (Solano) was planted on May 12 at target population of 35 plants /ft² with 8 inches row-spacing. From emergence to physiological maturity, only 1.8 inches of rain was received. Irrigation was applied to maintain 50% plant available water in the top 2-feet from emergence to the first awn visible, and top 3 ft from first awn through milk stage. A total of 7 inches supplemental irrigation was applied. Yield averaged to 116 bu/a. In 2016, an irrigated 70-Acre (half pivot) was planted April 27, 2016 with Solano spring wheat. This site received approximately 6 inches of rain. Yield was 106 bu/A.

In 2016 an additional Eddy Covariance tower was installed at an irrigated 140-Acre spring canola field on a gravelly-loam soil. This site was planted on April 13, 2016 with 4.8 lbs/A seeding rate of HyCLASS variety. This site achieved 49 bu/A canola yield.

6. Results:

We now have 5 complete datasets (2015 and 2016) for measured and predicted ET along with ancillary data for each crop year. This includes 2 site years of irrigated malt barley at Huntley, 2 site years of irrigated spring wheat at Creston, and 1 site year of irrigated canola at Creston. Data analysis by Dr. Stoy continues and we are currently on-track to finish half-hourly data sets for all 5 site years within the next few months. At that time we can begin the analysis of how to use ancillary data to predict the Kc curve for each crop. Preliminary data for one site year has been completed; consider the following chart that represents data from Huntley, 2015.

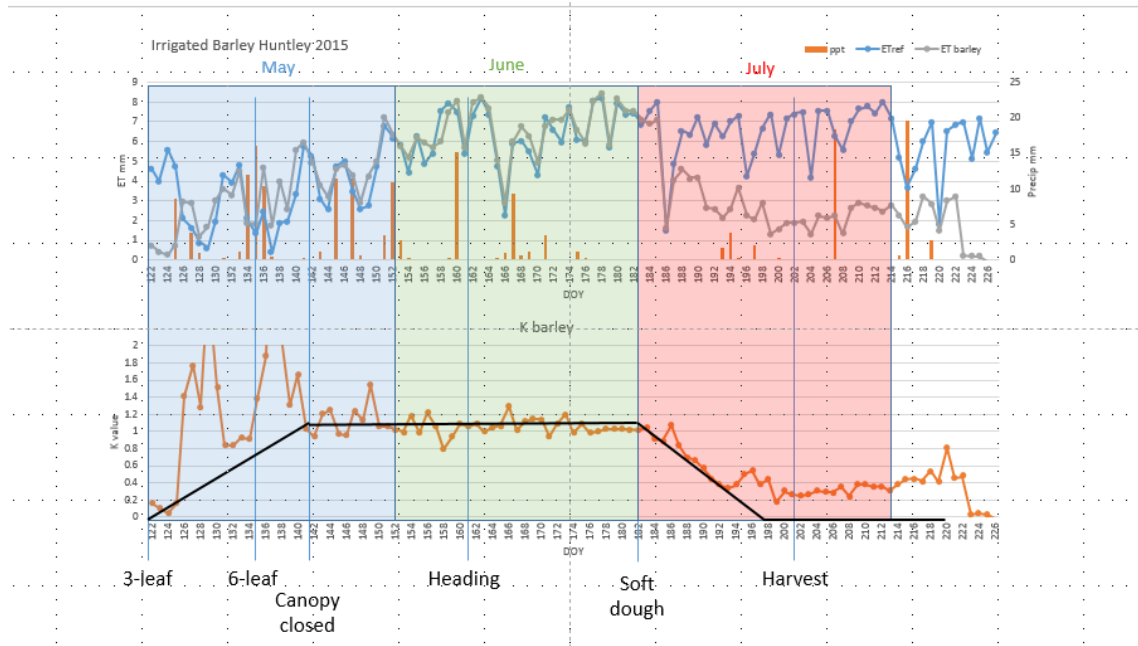


Figure 1. The top half of this chart shows measured evapotranspiration (ETbarley), and estimated ETo (from the weather station) on a daily basis for the 2015 growing season. Overlaid are bars representing rainfall or irrigation events. The bottom half of the chart is the daily estimate of Kc as calculated by ETcrop divided by ETo. The black line shows the expected Kc value according to Allen et al. (ASCE 2005).

The estimate of Kc once the canopy closes is very close to the expected value of approximately 1.05 to 1.1 for malt barley in this region. The decline in the Kc value as soft dough stage develops is also as expected from ASCE documentation. At this stage, plants have already achieved maximum yield for the season and plant-tissue senescence begins. The rising Kc curve from early 3-leaf to canopy closure is poorly estimated by our technique. Notice though that many of the peaks in ETbarley coincide with precipitation events. This behavior is best explained by understanding that our single term model used for Kc estimation does not separately account for evaporation from the soil surface when it is wet and exposed. Once the canopy closes, Kc appears to do well in correcting the weather station estimate of ETo to actual ETcrop, but Kc models must improve during the period prior to canopy closure to improve water resource planning.

Figure 2 below shows a similar trend for malt barley in 2016. The data fits less well as in 2015, but does indicate a Kcrop value of 1.05 to 1.1 during the maximum water usage period (crop canopy closure to soft dough).

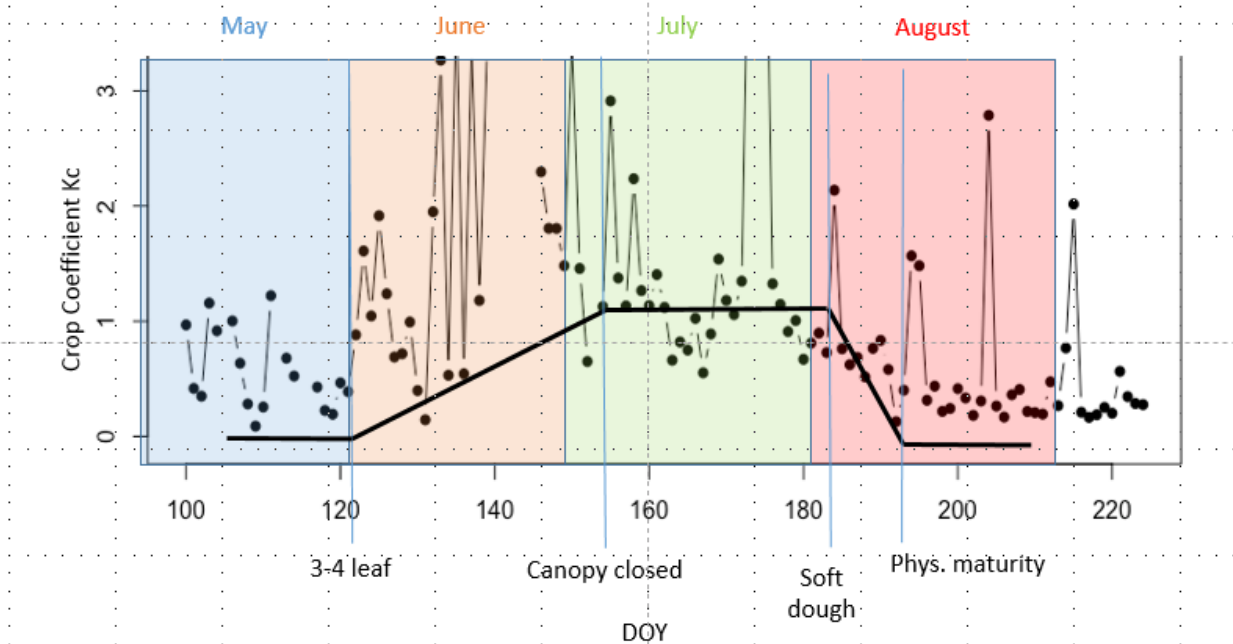


Figure 2. Estimate of K_c for Huntley irrigated malt barley, 2016. The black trapezoid indicates the expected K_c from ASCE 2005. Like the 2015 data, the estimate wildly misses on the rising limb of the K curve, but with the exception of a few peaks, fits fairly well after canopy closure, and drops off following soft dough stage. Evaporation from the soil surface continues after physiological maturity while the expected K value arbitrarily drops to 0 as the crop is mature/harvested.

Further analysis of the data will help determine if these trends are repeated in the other site years and will help us determine a correct approach to use this information to better schedule irrigation on crops. Currently a stop-gap approach that could work would be to recommend scouting and soil monitoring of water status especially through the open canopy period of early crop production and schedule irrigation appropriately to avoid stress. But then rely more heavily on our ET estimates and K_c values for each crop once canopies close and water use is dominated by transpiration rather than being split with soil surface evaporation. Another approach would be to utilize a 2-term model for K_c , considering evaporation separate from transpiration so that each mechanism is modeled independently. This approach has been successfully used by other scientists working in this field.

7. Budget: Expenditure information can be provided by OSP
8. References:
 - Allen, R.G., L.S. Pereira, D. Raes, M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Food and Agriculture Organization (FAO)-United Nations. Rome. Italy.
 - Allen, R.G., I.A. Walter, R. Elliott, R. Howell, D. Itenfisu, M. Jensen. 2005. The ASCE Standardized reference evapotranspiration equation / prepared by Task Committee on Standardization of

Reference Evapotranspiration of the Environmental and Water Resources Institute of the American Society of Civil Engineers. Reston, VA.

- Harris ESK & Stoy PC (2015) Are there any hydrologic benefits to fallow? Quantifying water use in Montana wheat fields and designing strategies for avoiding fallow when unnecessary. Montana Wheat and Barley Committee Meeting, Bozeman, MT, Feb. 18, 2015.
- NASS. 2013. United States Department of Agriculture National Agricultural Statistics Service. www.nass.usda.gov.
- Suyker, A, and S. Verma. 2009. Evapotranspiration of irrigated and rainfed maize-soybean cropping system. [Agricultural and Forest Meteorology](#) vol. 149 (3): 443-452.
- Torrion, J.A., T.R Setiyono, K.G Cassman, S. Irmak and J.Specht. 2011. Soybean growth and developmental stage-driven crop coefficient simulation. Presented to ASA-CSSSA-SSSA International Meetings. <https://scisoc.confex.com/crops/2011am/webprogram/Paper65854.html>. San Antonio TX. Oct 16-19, 2011.
- Vick ESK, Stoy PC. 2016. The surface-atmosphere exchange of carbon dioxide, water, and sensible heat across a dryland wheat-fallow rotation. *Agriculture, Ecosystems & Environment*, Vol 232:129-140.