Project Name: Quantifying Nitrogen Leaching in Irrigated Fields

Principal Investigator and Cooperators: Dr. Adam Sigler; Dr. Clain Jones; Meghan Robinson, Mitch Konen; Bill Lee; Travis Stuber

Time Period: July 1, 2024 - June 30, 2025

Project Results:

Field instrumentation and sampling: In 2024, we instrumented two additional soil pits (for a total of 6) in cooperator Mitch Konen's field near Fairfield (Figure 1). We had four additional sites in the Gallatin under seed potatoes, in fields farmed by Bill Lee (two instrumented pits) and Travis Stuber (two instrumented pits). Each soil pit included soil moisture sensors at three depths (6", 12", 36") and lysimeters (soil water samplers) at two depths (12" and 24"). The two new sensors in Mitch's field were METER sensors that relayed data to the web to be viewed in real time. We installed instruments in Creston at the Northwestern Agricultural Research Center (NWARC) with funding under a companion project. We also started partnership on a new project with Bruce Thomas and the MT Dept. of Natural Resources Conservation (DNRC) at Gold Creek.

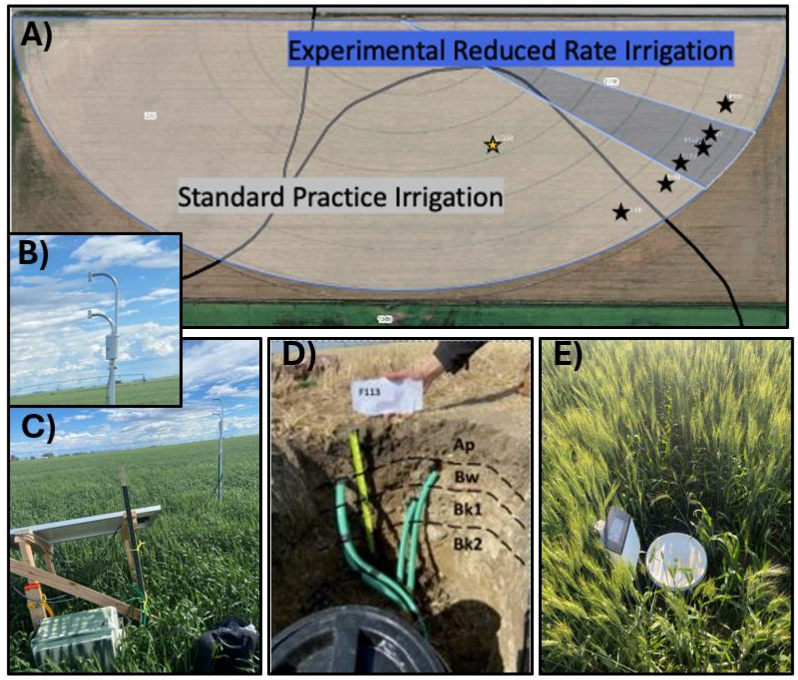


Figure 1. A) Fairfield study site map farmed by cooperator Mitch Konen and planted to spring wheat in 2024; black stars are soil pit instrumentation sites; yellow star LI-COR ET sensor; pie shape covering three stars is reduced irrigation rate selected and applied by Mitch. B) LI-COR zoomed in. C) LI-COR full setup. D) Soil pit during install. E) Soil pit instrument access during growing season.

Graduate student Meghan Robinson and a field technician visited each instrumented pit every two weeks to download soil moisture data and place the lysimeters under vacuum to collect soil water samples over a 24-hour period. Soil samples were collected before fertilizer application and at harvest, as well as during biweekly field visits and were analyzed for nitrate concentrations and soil texture. Observations of rooting depth were collected during each field visit.

Results: The depth that rain and irrigation water reach in the study fields was highly variable based on soil texture. We would expect water to move down most readily in the sandiest soils, intermediate for silt, and the least movement through clay, but that is not what the data show. In Figure 2, we see the least movement of water to depth in silt soils (water does not reach 12 inches), the greatest water movement to depth in clay soils (water reaches 36 inches), with the sandiest soils falling in the middle (water reaches 12 but not 36 inches). Sandy soils at Creston and silty soils in Gallatin saw essentially no leaching risk in 2024 with the irrigation rates applied because water did not make it to 36 inches. Irrigation water reached 36 inches in the clay-rich Fairfield soils during June and July irrigation events. Higher clay content in soils at the Fairfield study site that resulted in soil cracking and macropores is the likely reason that water moved to depth more readily at the Fairfield site (Jarvis, 2007).

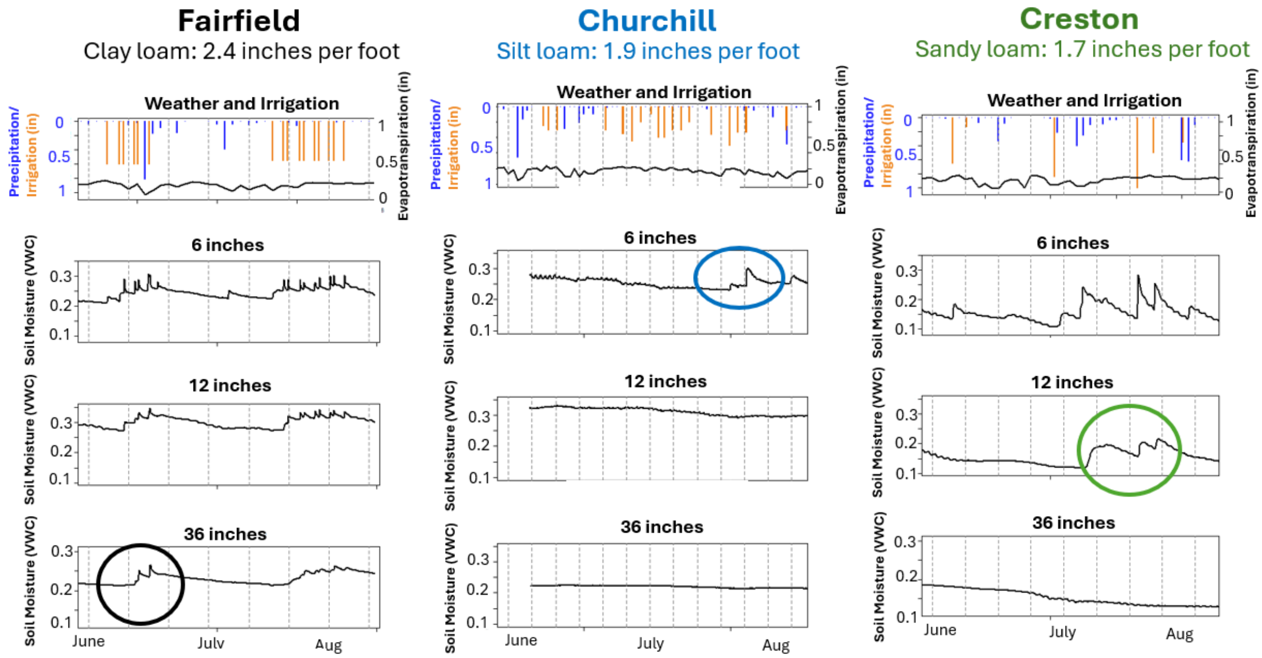
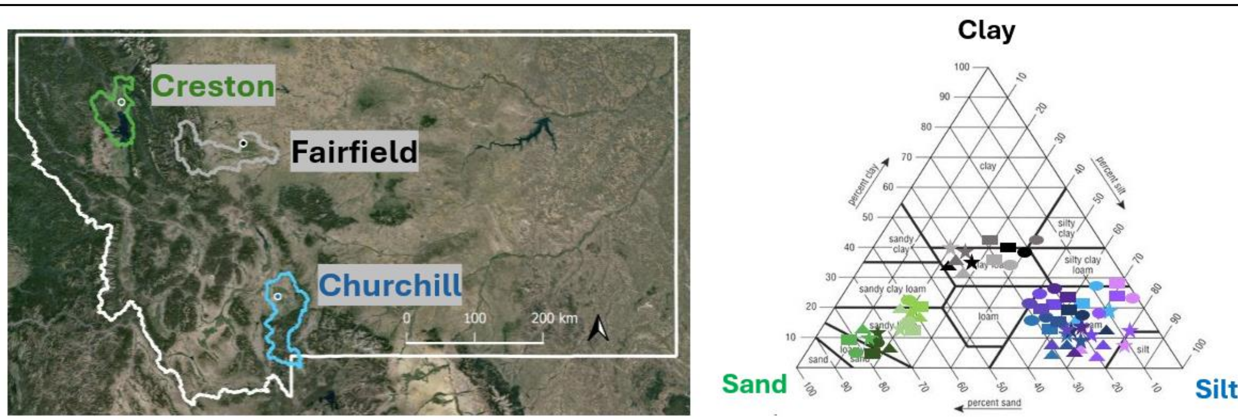


Figure 2. Soil moisture response to rain and irrigation by depth for sites across the three study areas with different soil textures. Subtitles indicate texture and inches of water that can be stored by that texture per foot of soil. Circles indicate data at the deepest depth where a clear moisture response was observed.



Fairfield:
- Sun Watershed, north-central MT
- Clay loam soils; 35-45% clay
- Barley and spring wheat
- 1 cooperating producer
- 70% lysimeter sample success rate, 119 total samples

Churchill:
- Gallatin Watershed, southwest MT
- Silt loam soils; 50-80% silt
- Potatoes
- 2 cooperating producers
- 25% lysimeter sample success rate, 23 total samples

Creston:
- Flathead Watershed, northwest MT
- Sandy loam soils; 55-85% sand
- Spring wheat
- MSU Northwestern Agricultural Research Center
- 40% lysimeter sample success rate

Figure 3. Map of sample locations and soil texture triangle with samples from each site for four depths. Fairfield samples (grey) have the highest clay content, Gallatin samples (blue) are primarily silt, and Creston samples (green) are dominated by sand.

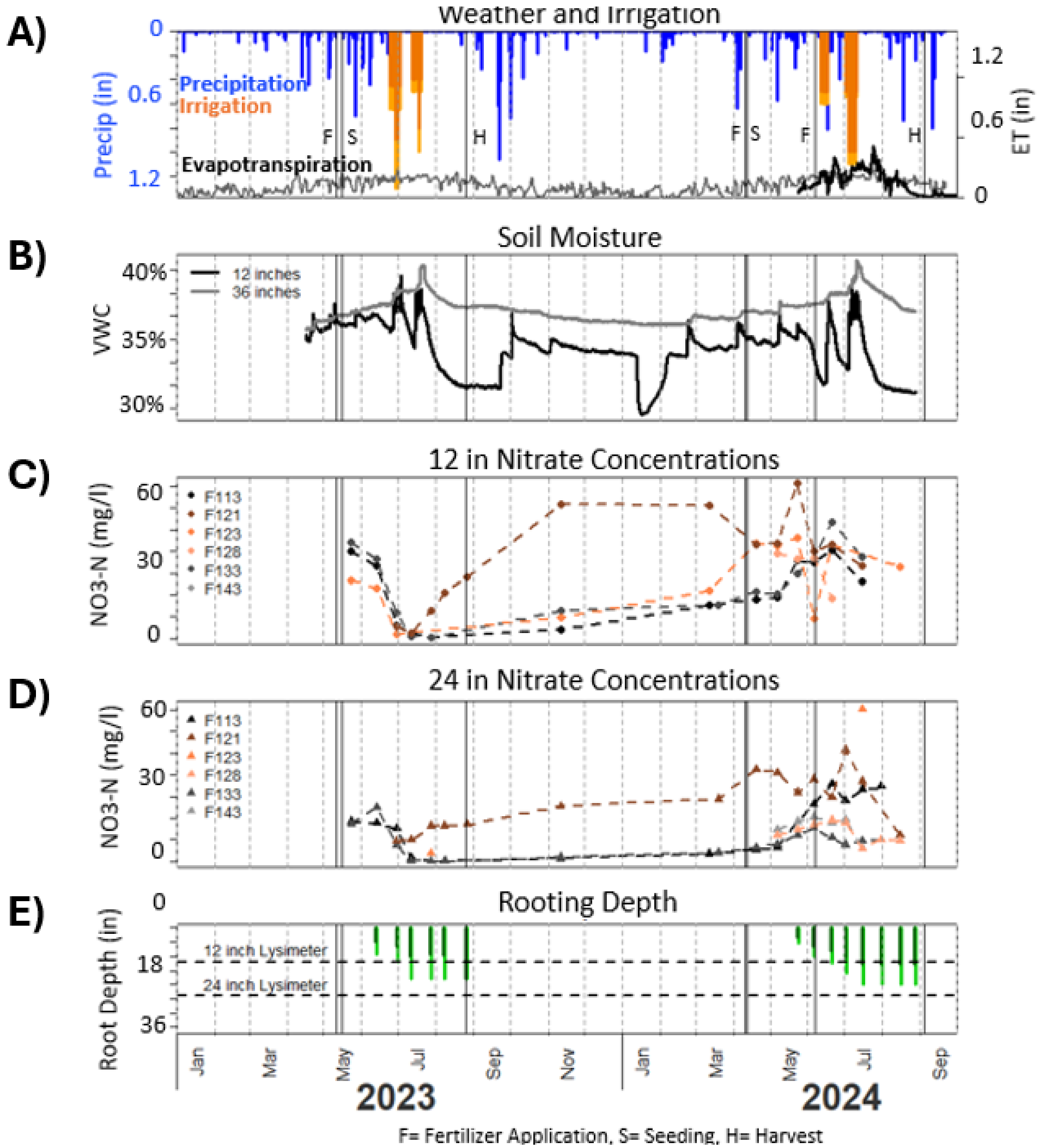


Figure 4. Fairfield data, which has been shared in many presentations to producer and other audiences and continues to spark a lot of curiosity and engagement. A) Water input as precipitation (blue) and irrigation (orange), potential ET from Mesonet (gray), and actual ET from LI-COR on the field (black). Fertilizer, seeding, and harvest dates are indicated with vertical lines. B) Soil moisture at 12 inches (black) and 36 inches (gray). C) Nitrate concentration from 12 inch lysimeter samples. D) Nitrate concentration from 24 inch lysimeter samples. E) Root depth observed over the growing season, with lysimeter depths as dashed lines for reference. Note: irrigation water for Fairfield is from the headwaters of the Sun River with nitrate-N concentration less than 0.1 mg/L.

A total of 82 lysimeter samples were collected at the Gallatin and Fairfield sites in 2024 for a total of 142 across the 2023-24 seasons. With minimal water moving to depth in Gallatin soils, leaching risk is low, so we focus here on the Fairfield site where water and nitrogen move more readily to depth. The lysimeter nitrate concentrations for Fairfield in 2023 were consistent across soil pits and showed a clear pattern, indicating some nitrate leaching did occur from the 24 inch soil depth (Figure 4). In 2024, the lysimeter nitrate concentrations were more variable than in 2023. Addition of a slow release N fertilizer during the growing season is likely the primary explanation for more variable soil nitrate concentrations in 2024. Soil moisture moving below 24 inches (and below rooting depth) at the same time that soil nitrate concentrations were elevated, indicates some nitrate was lost to leaching again in 2024. Additional nitrate sampling was conducted in 2024 on soil samples collected with a hand auger. The changes in N pool (lb N/ac) by depth over time (Figure 5) indicate nitrate was moving down below the roots at Fairfield, and provides additional evidence of nitrogen moving beyond the reach of roots in 2024.

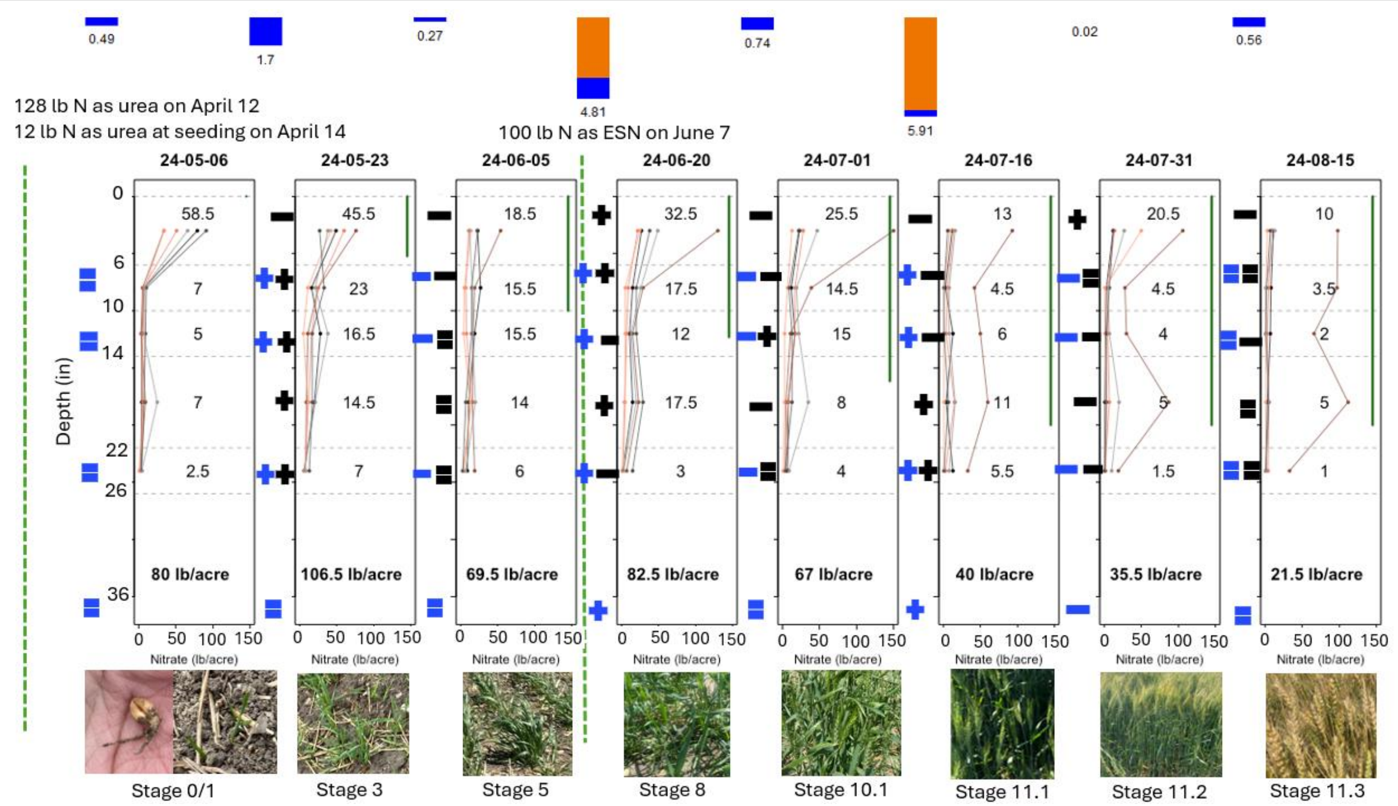


Figure 5. Soil nitrate concentrations from soil samples collected at 6 location (different line colors), from 5 hand auger depths, 8 times over the season. Blue and orange bars at the top indicate inches of rain and irrigation input between sample dates. Fertilizer dates are indicated with vertical green dashed lines. Plots have depth on the Y axis and soil nitrate concentration on the X axis with horizontal dashed lines indicating soil sampling depth increments (designed to have intervals aligned with lysimeter depths). The symbols (+, -, =) between plots indicate whether soil moisture (blue) and soil nitrate (black) increased (+), decreased (-), or stayed consistent (=) between sample events for each depth. Feekes growth stage and accompanying pictures are included below the plot for each sample date.

The Fairfield site was in barley in 2023, so nitrogen availability was most important early in the growing season and was provided by a single application of urea before planting. In 2023, the soil water nitrate concentration dropped off around the time that water from irrigation started moving past the root zone. In this scenario there was a relatively short period of time when irrigation scheduling was most critical to avoiding nitrate leaching. In 2024, the field was in spring wheat, for which nitrogen availability is important early for yield and later in the season to get high protein. Slow-release fertilizer added in June of 2024 extended the period of time where soil water nitrate was high. In this scenario there is a longer period when irrigation scheduling to avoid nitrogen loss is important. More detailed quantification of nitrate leaching is forthcoming, but these results motivated Mitch and our team to propose a focused irrigation experiment in 2025 to identify an irrigation scheduling approach that can reduce movement of water and nitrogen below 12 inches.

Measurement of actual evapotranspiration (ET) at the Fairfield site in 2024 provided useful insights about periods when Mesonet station based potential ET is and is not well aligned with ET of the producer's crop. During June and July, actual ET (AET) for the field generally ranged between 0.25 and 0.4 in. of water consumed per day. During this peak period, actual ET was about 1.2 times the potential ET estimated by the nearby Mesonet site. Actual ET on the field started exceeding Potential ET around June 12th, about 60 days after seeding. AET started falling below potential ET again on August 13th, about 120 days after seeding and 24 days before harvest. Post harvest AET was approximately 6% of potential ET, primarily evaporation.

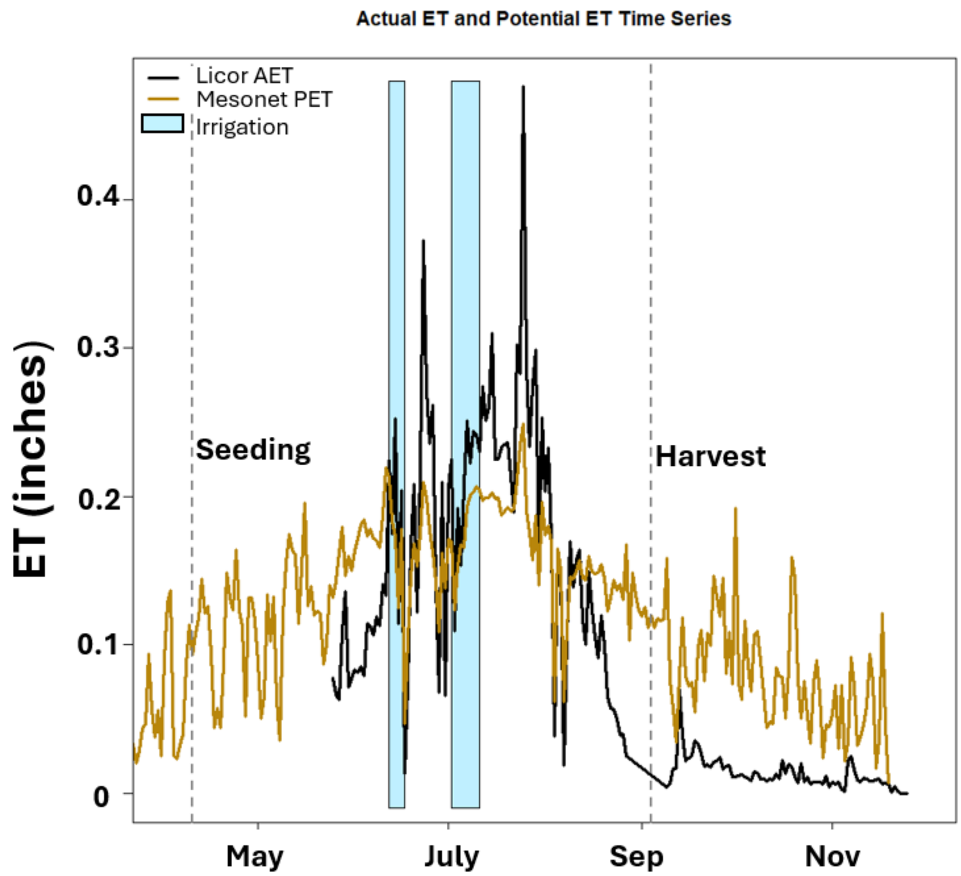


Figure 6. Measured actual evapotranspiration (ET) with the new LI-COR 710 and potential ET from the local Mesonet station. The LI-COR started collecting data on 24 May, 2024.

<u>Outcomes</u>:

Since our project report last year, we have presented our results at five producer meetings, including the MSU Northwestern Agricultural Research Center field day and four stops (Fairmont, Missoula, Thompson Falls, and Kalispell) on the MSU Extension pesticide education tour in fall 2024. We also presented to a broader audience on the Montana Watershed Coordination Council and Sun River Watershed Group fall watershed tour. We have met with Mitch Konen to discuss the 2024 data and have forthcoming meetings with the two Gallatin cooperating producers. The results were presented in the last year at three Montana specific science meetings, one national meeting, and two science meetings internal to MSU. We have a workshop planned in February 2025 in Fairfield to share results with irrigators and to have Mitch, our cooperating farmer, share his experience and the implications he sees from the research for his water and nitrogen management.

Funding under this MFAC project has been a springboard to facilitate three other projects in the last year (Flathead, Gold Creek, and a sensor evaluation study). This work is providing valuable insights about additional projects and is helping set the stage for a proposal to USDA for a larger project planned for submission in Fall of 2025.

Meghan Robinson is approaching the end of her Master's program and has made incredible progress toward completion of her thesis, which she will finish in 2025 along with a peer reviewed journal article. One MontGuide is underway and we anticipate the potential to write at least one or two more MontGuides based on findings from this research and the accompanying work.

Impacts:

The data that we have collected so far has been very interesting to both the agricultural producer and scientific audiences that we have presented it to. At every meeting we have presented, producers have asked several questions and then approached us afterwards to ask follow-up questions. We are excited to have a full workshop focused on these results in Fairfield in February 2025 where we will present research results, but more importantly, where cooperating producer Mitch Konen will talk about his experience with the data, the implications for his operation and what he is excited to learn about with continued research in 2025. A common question producers ask us, is what can be done to avoid risk of nitrogen loss. We can say with confidence that using soil moisture sensors is a great approach, but the irrigation scheduling experiment proposed for 2025 would provide very useful insights to help answer these questions.

The strong interest from producers outside of our cooperators is particularly interesting given the estimate that only 5% of Montana producers currently use soil moisture data in their irrigation decision making (USDA, 2018). A review of past nitrate leaching research identified more precise water management in irrigated systems as a beneficial method for limiting nitrate leaching losses without compromising crop yields, as opposed to reduced fertilizer rates which could be detrimental to yields (Quemada et al. 2013). For this reason, we are optimistic that the interest we have received from producers may translate into action as we continue our research and refine our understanding of irrigation management opportunities to improve water and nitrogen use efficiency.

References:

Jarvis, N.D. (2007). A review of non-equilibrium water flow and solute transport in soil macropores: principles, controlling factors and consequences for water quality. *European Journal of Soil Science, 58,* 523-546. http://10.1111/j.1365-2389.2007.00915.x

Quemada, M., Baranski, M., Nobel-de Lange, M. N. J., Vallejo, A., & Cooper, J. M. (2013). Meta- analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield. *Agriculture, Ecosystems & Environment*, *174*, 1–10. https://doi.org/10.1016/j.agee.2013.04.018

Sigler, W. A., Ewing, S. A., Jones, C. A., Payn, R. A., Miller, P., & Maneta, M. (2020). Water and nitrate loss from dryland agricultural soils is controlled by management, soils, and weather. *Agriculture, Ecosystems & Environment*, *304*, 107158. https://doi.org/10.1016/j.agee.2020.107158

USDA NASS. (2019). 2018 Irrigation and Water Management Survey. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris.pdf