Seasonal Soil Cracking and Dynamic Nitrate Concentrations Control Deep Percolation and Leaching in an Irrigated System

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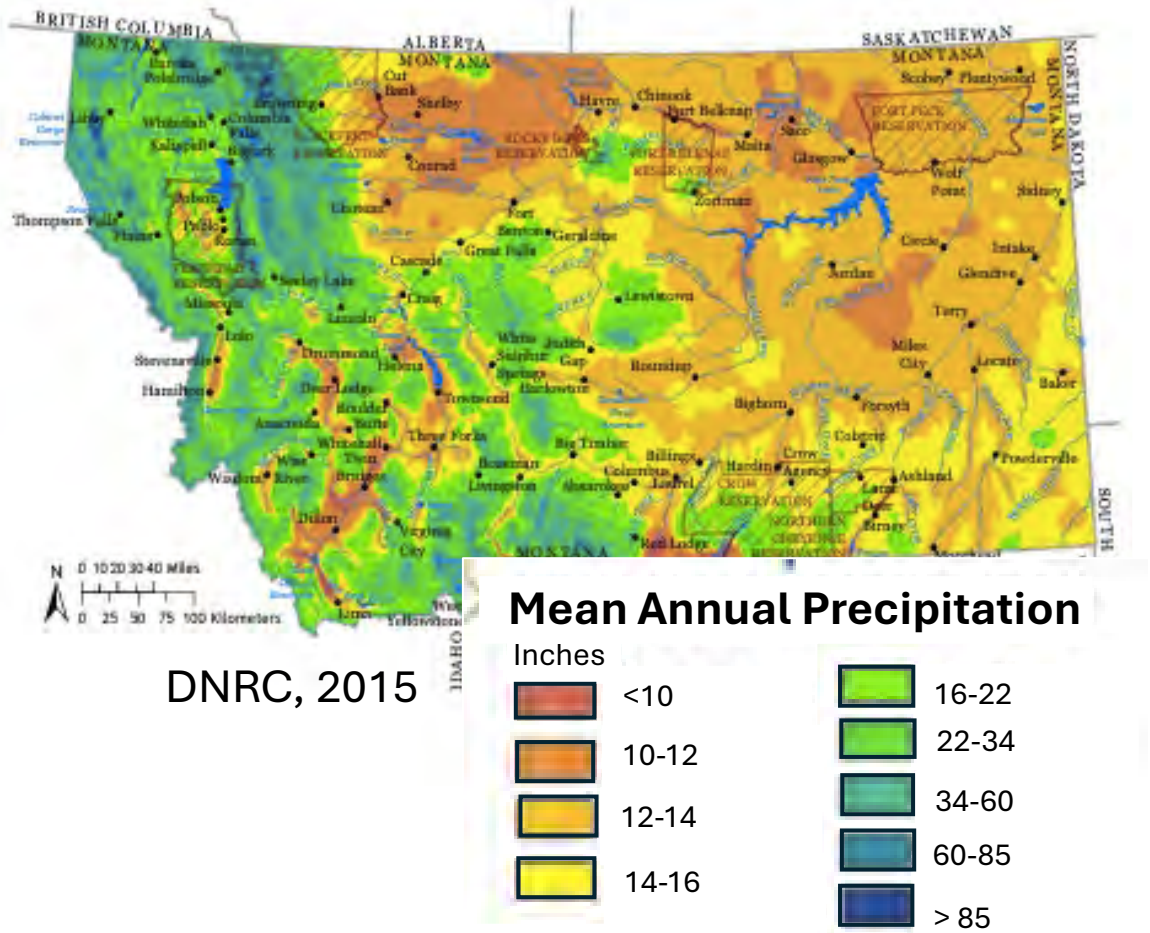
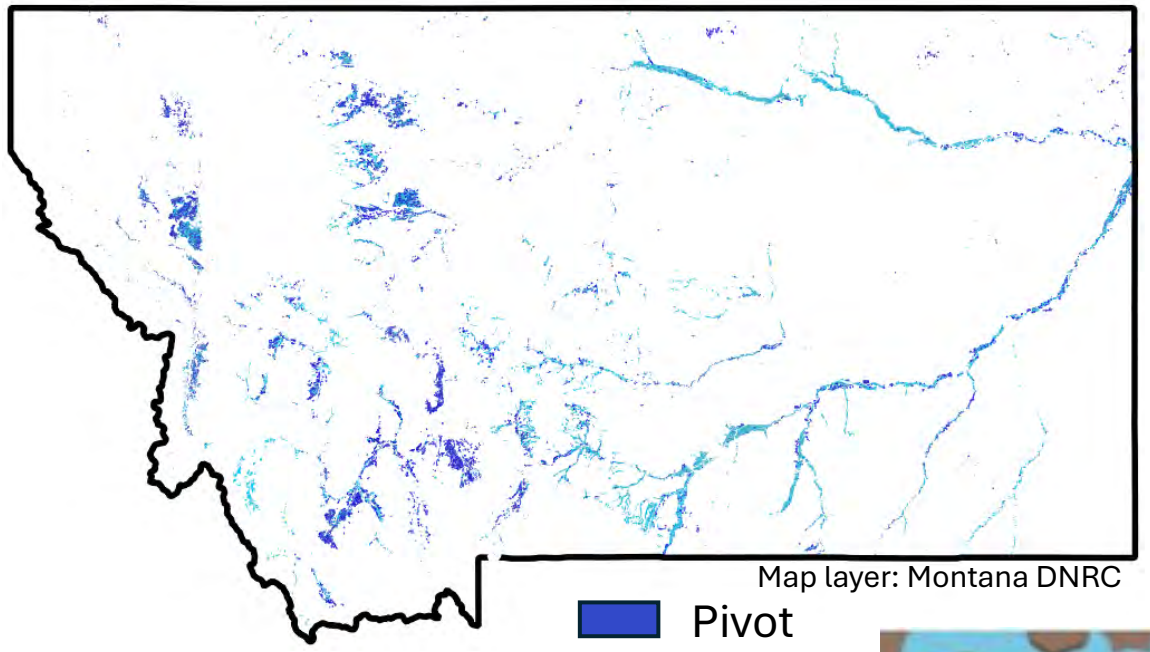
October 10th, 2025

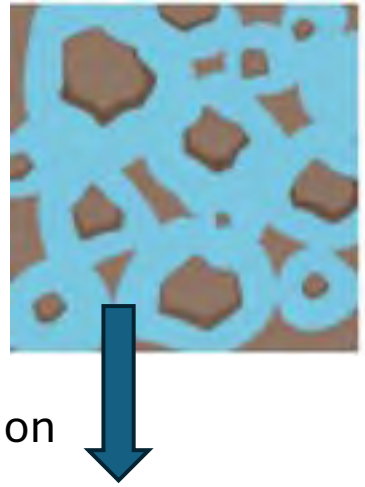
Montana Water in Agriculture



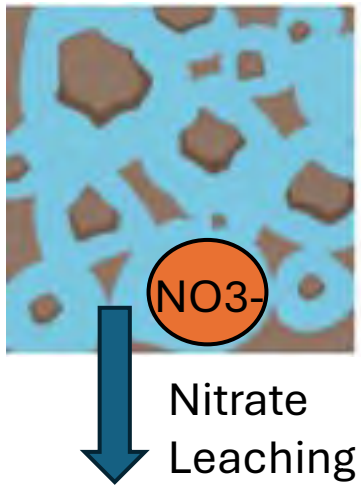
DNRC, 2015



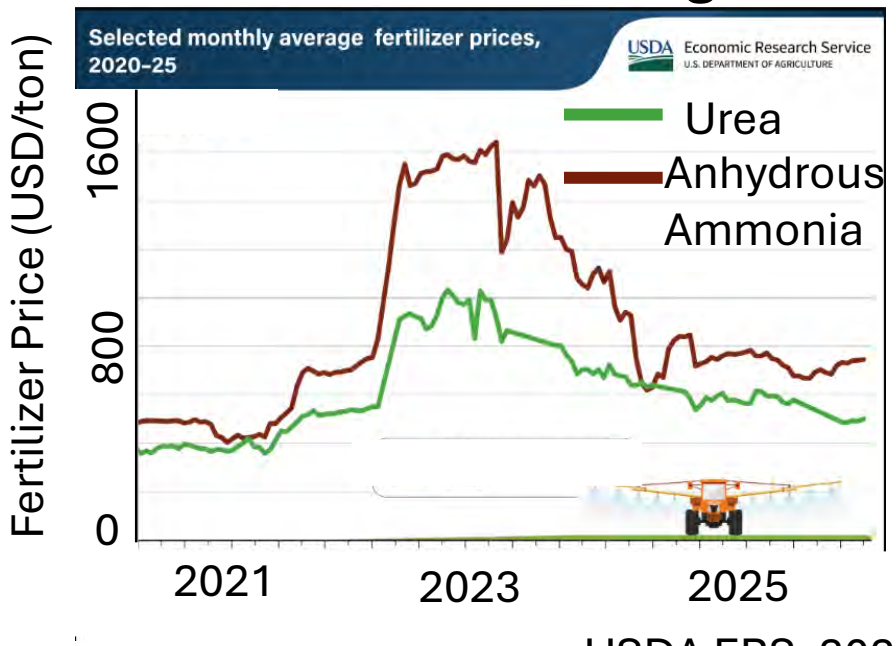
2 million acres of irrigation, accounting for 70% of consumptive water use in the state (DNRC, 2015)



Irrigation and Nitrate Leaching Risk

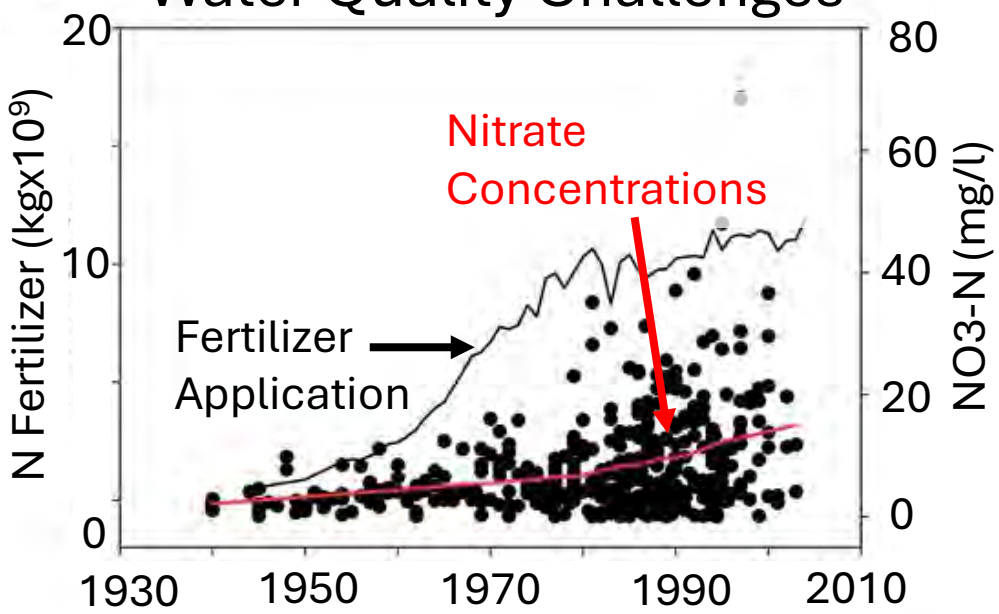


Economic Challenges



USDA ERS, 2025

Water Quality Challenges



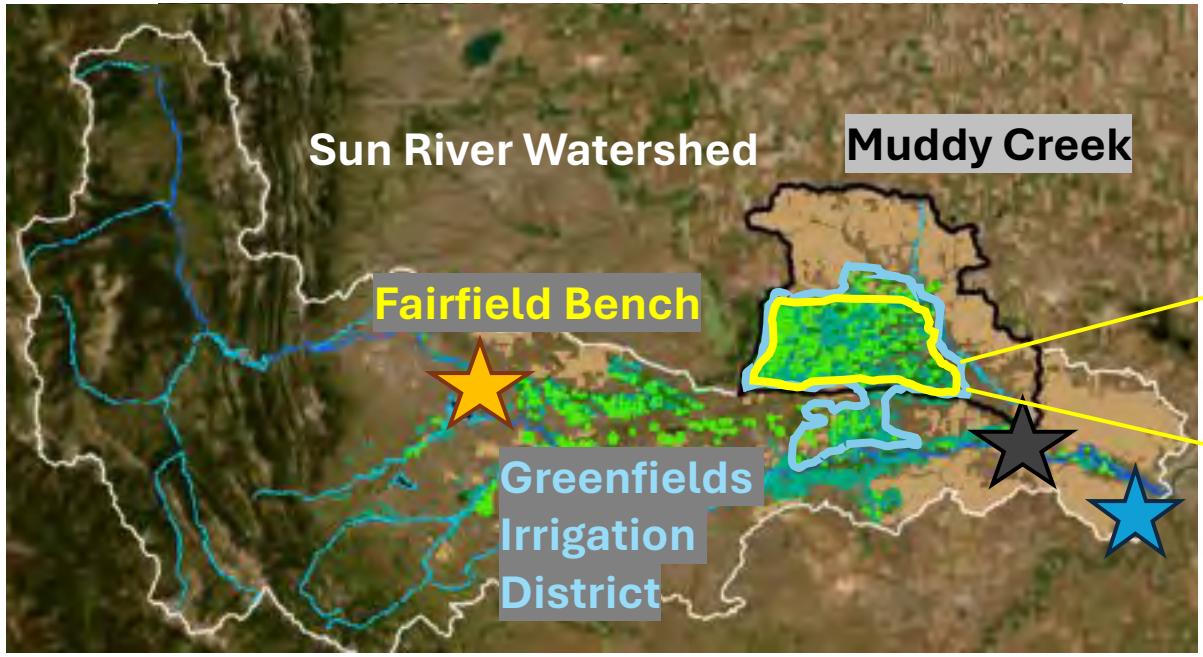
Puckett et al., 2011

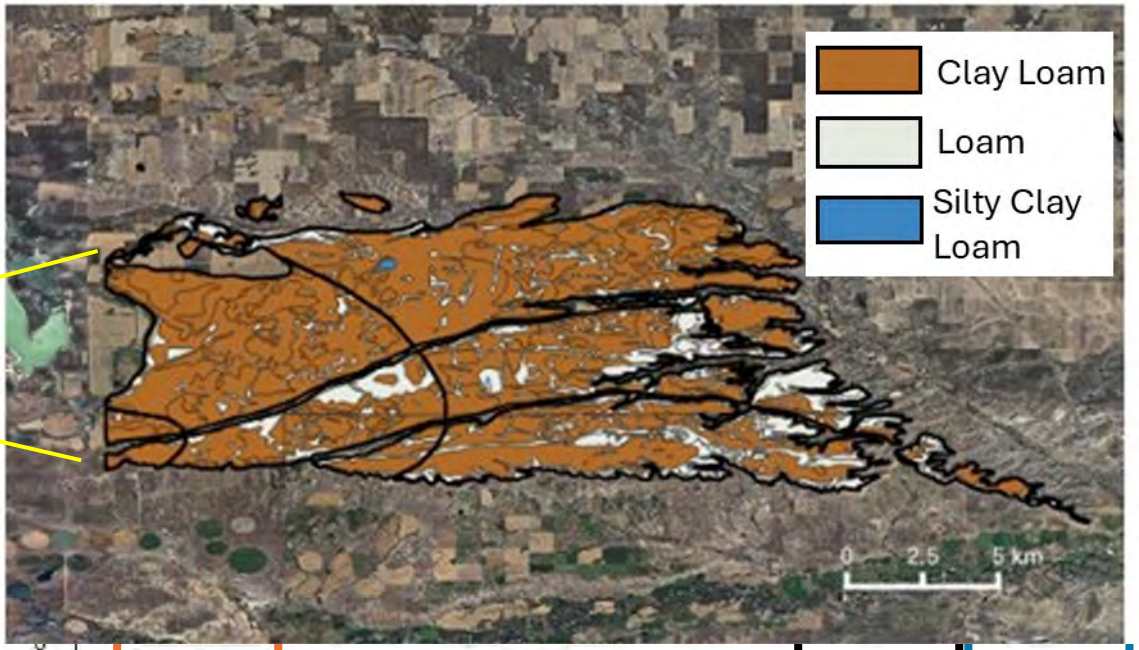
Ecosystems

Human Health

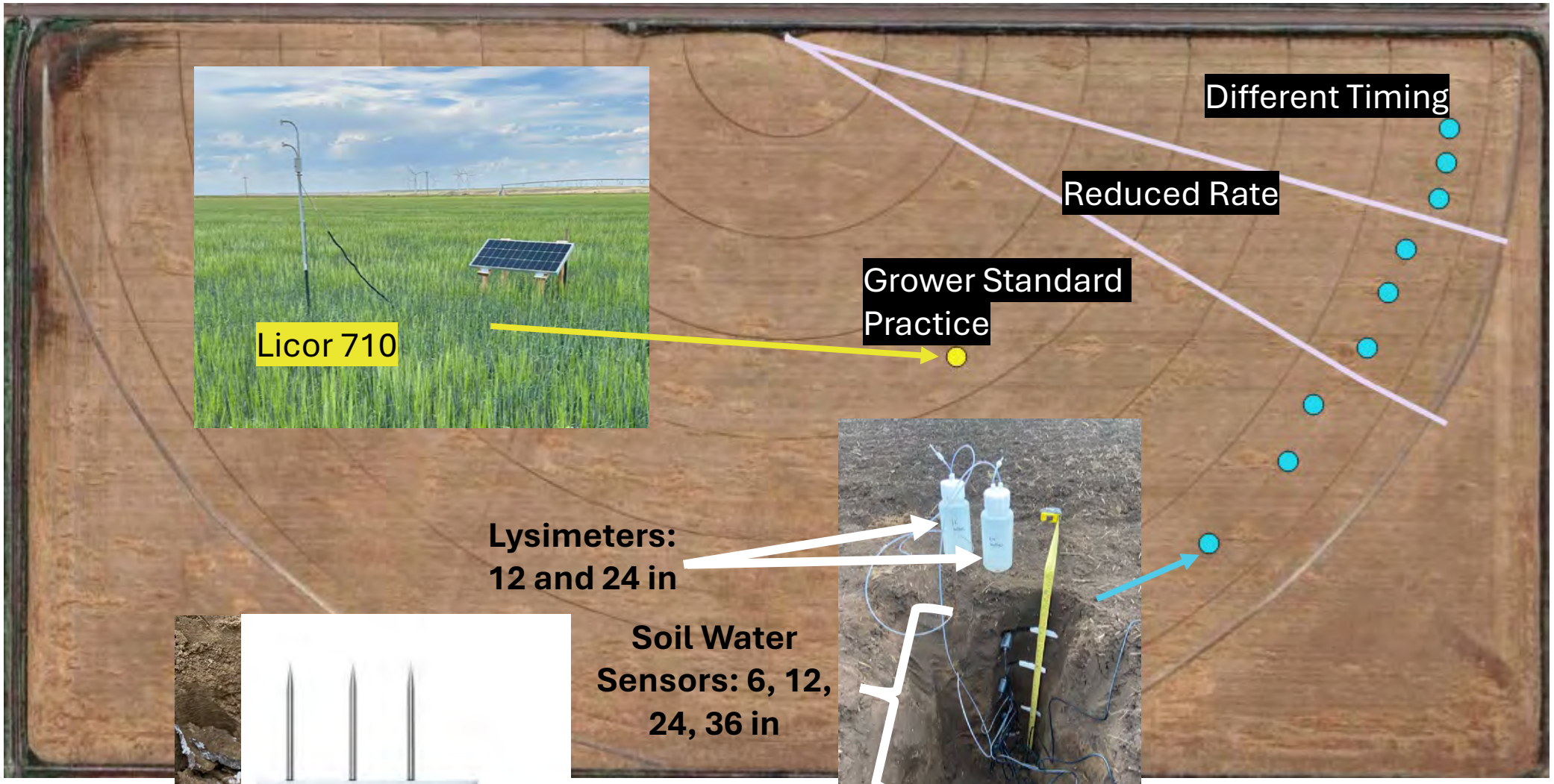
How does temporal variability in soil structure and nitrate concentration control deep percolation and leaching risk through the growing season?

Location- Fairfield Bench



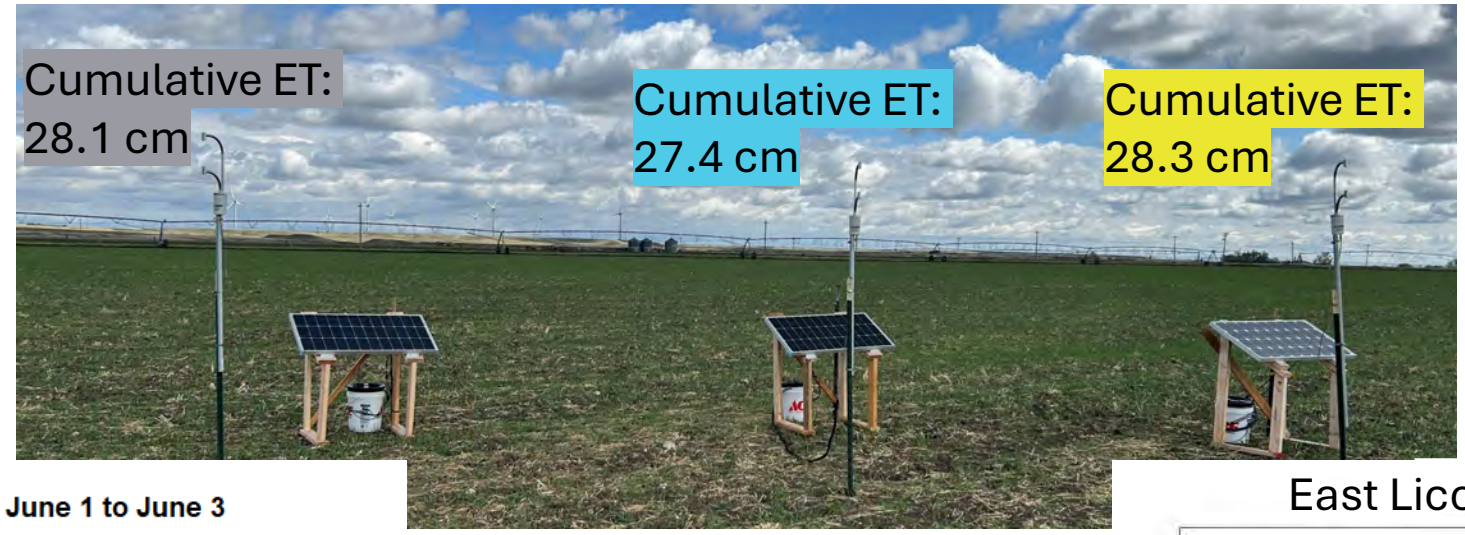


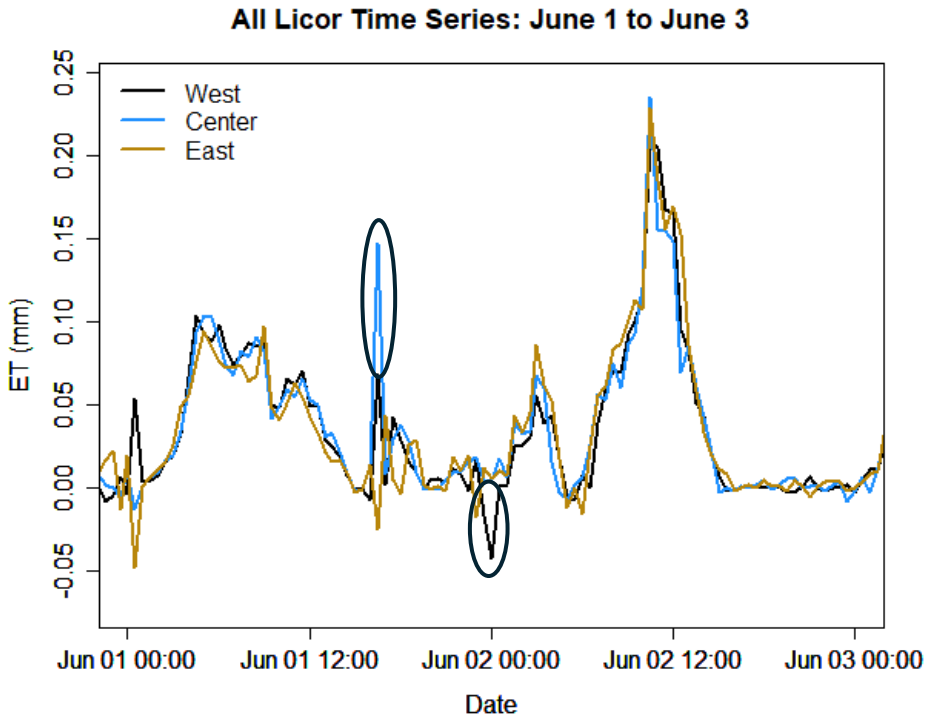
Methods- Field



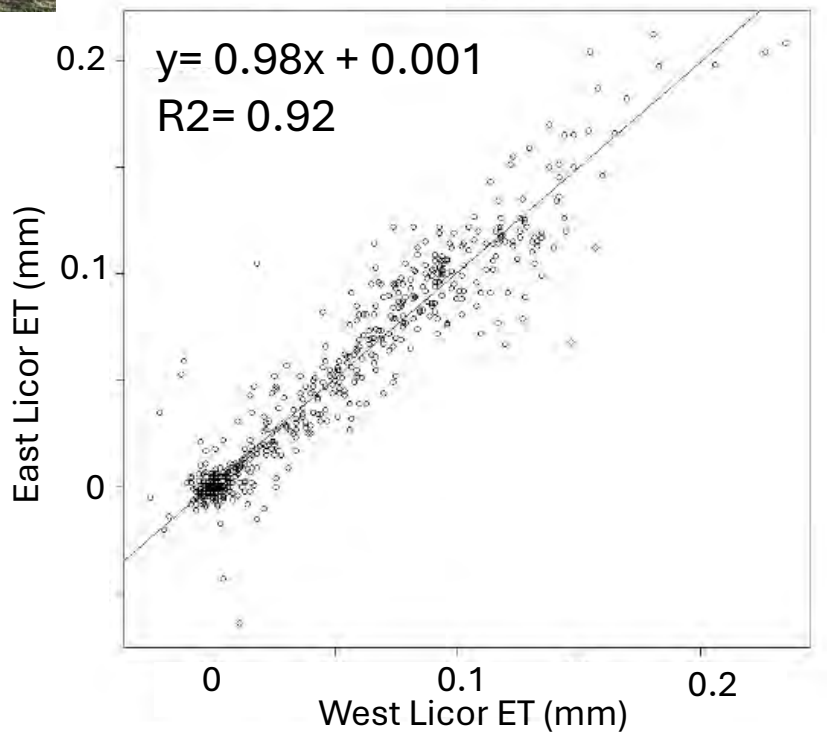
Licor-710: ET Uncertainty

Average daily variability of 0.3 cm, daily total of 2 cm

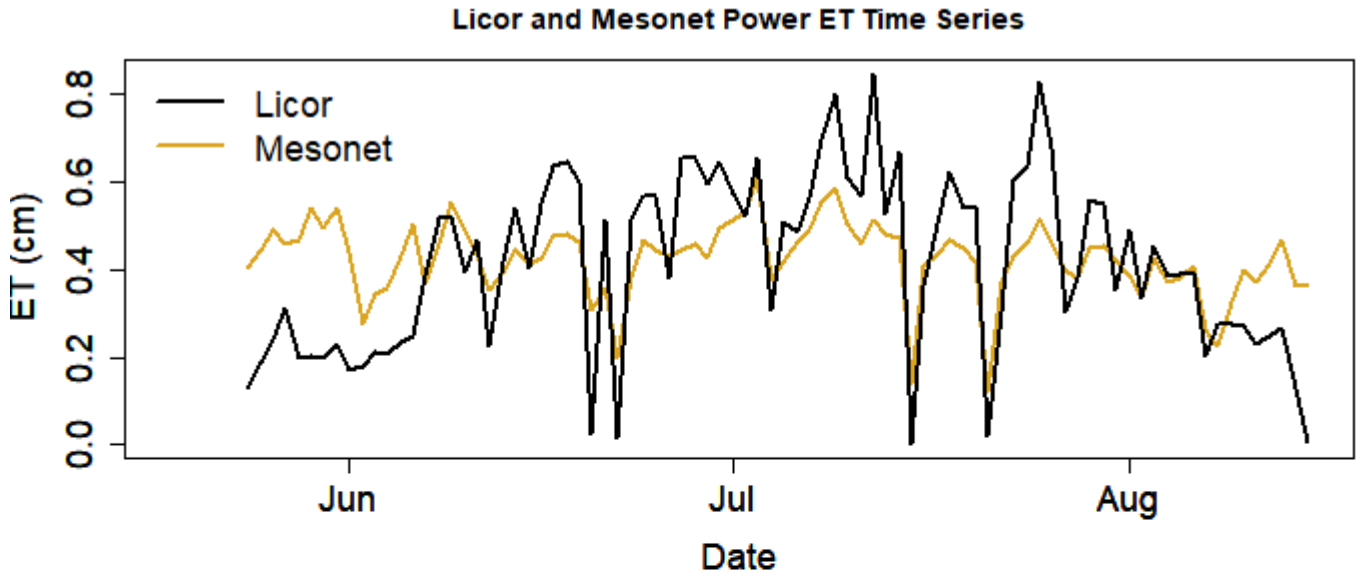


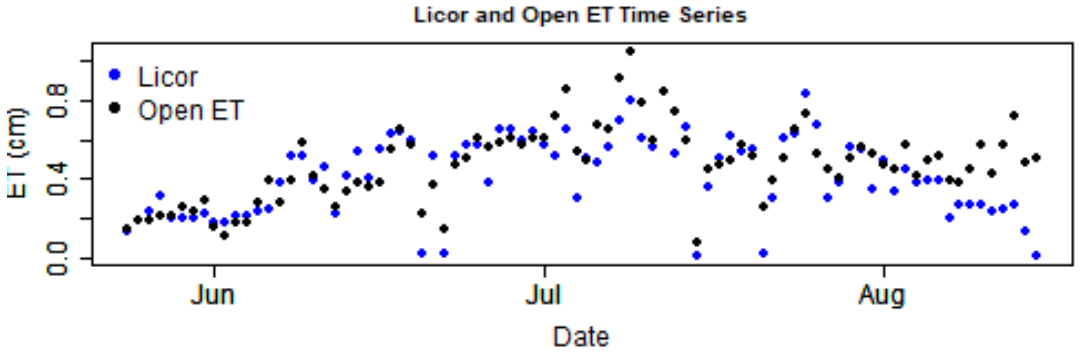


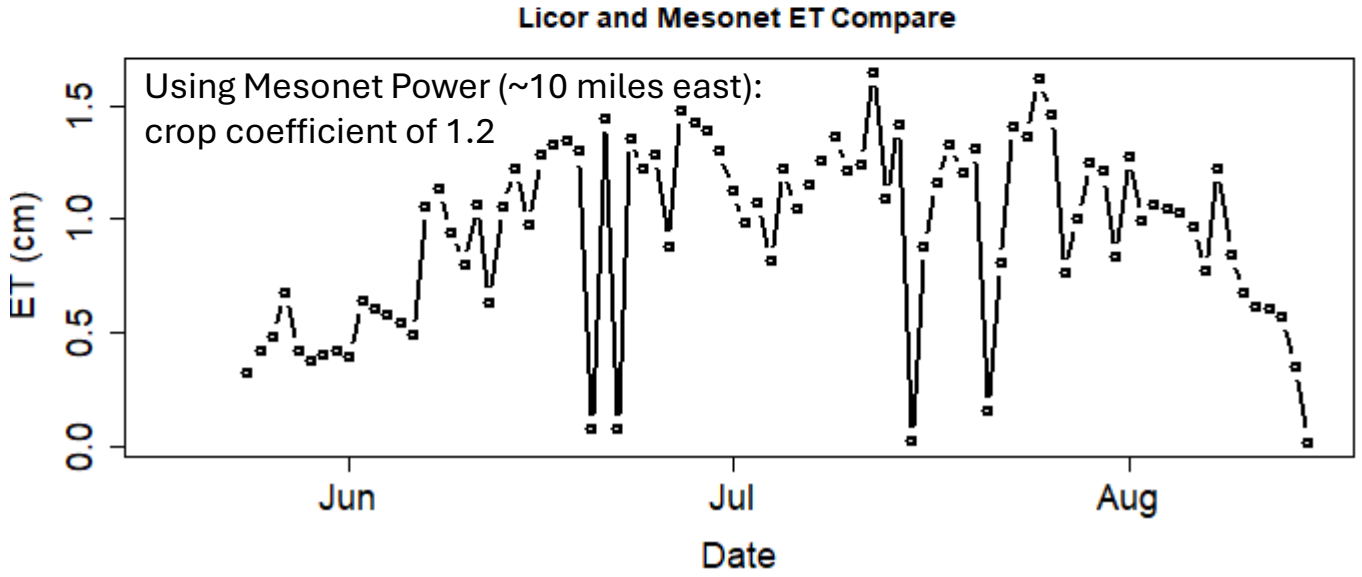
East Licor vs West Licor

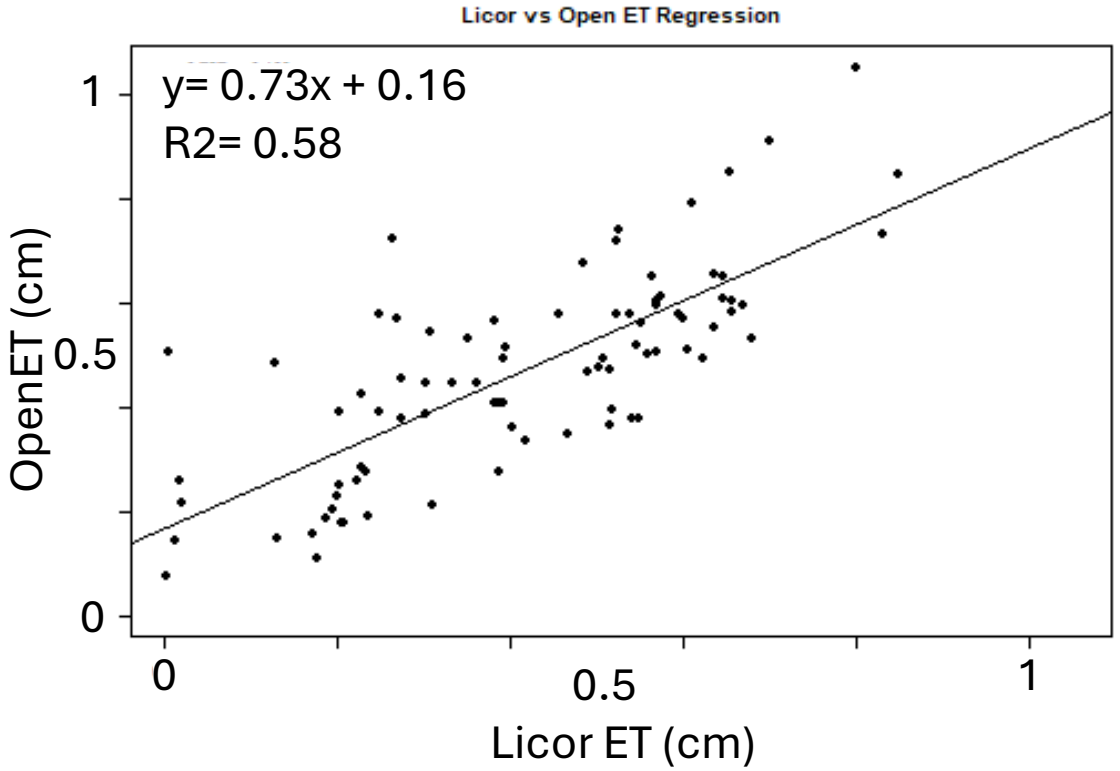


Licors and ET Data Sources

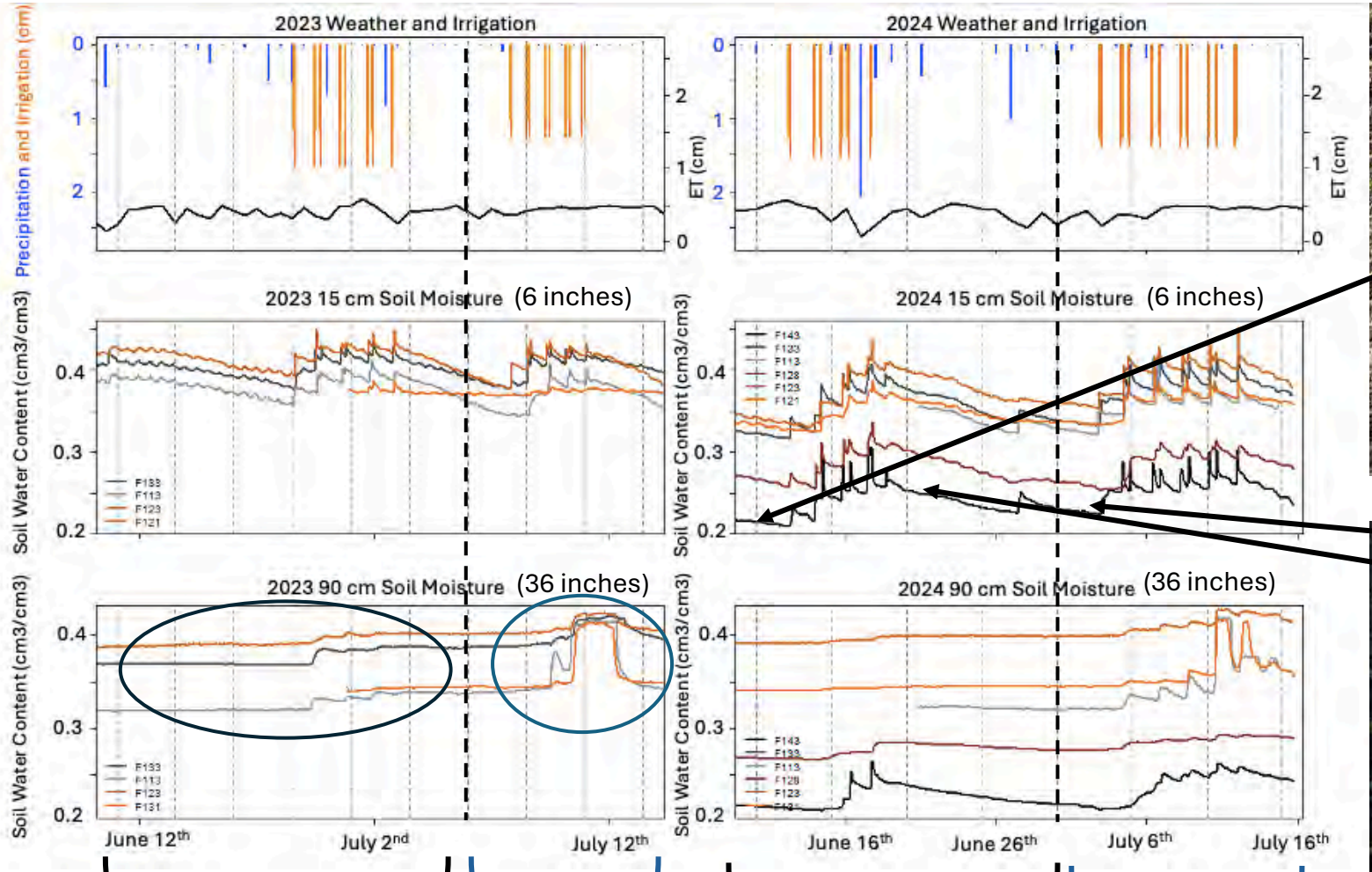








Results- Temporal Variability and Cracking

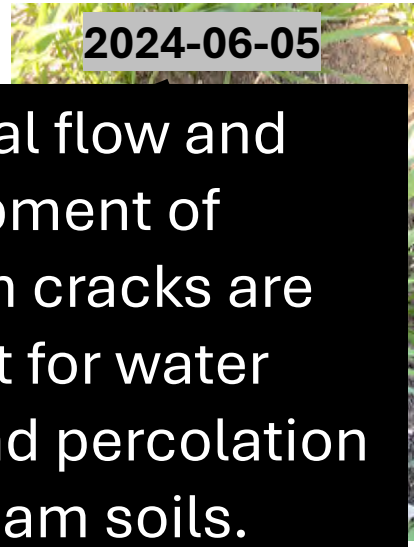


Recently Tilled- No Cracks

Cracked– More Preferential Flow

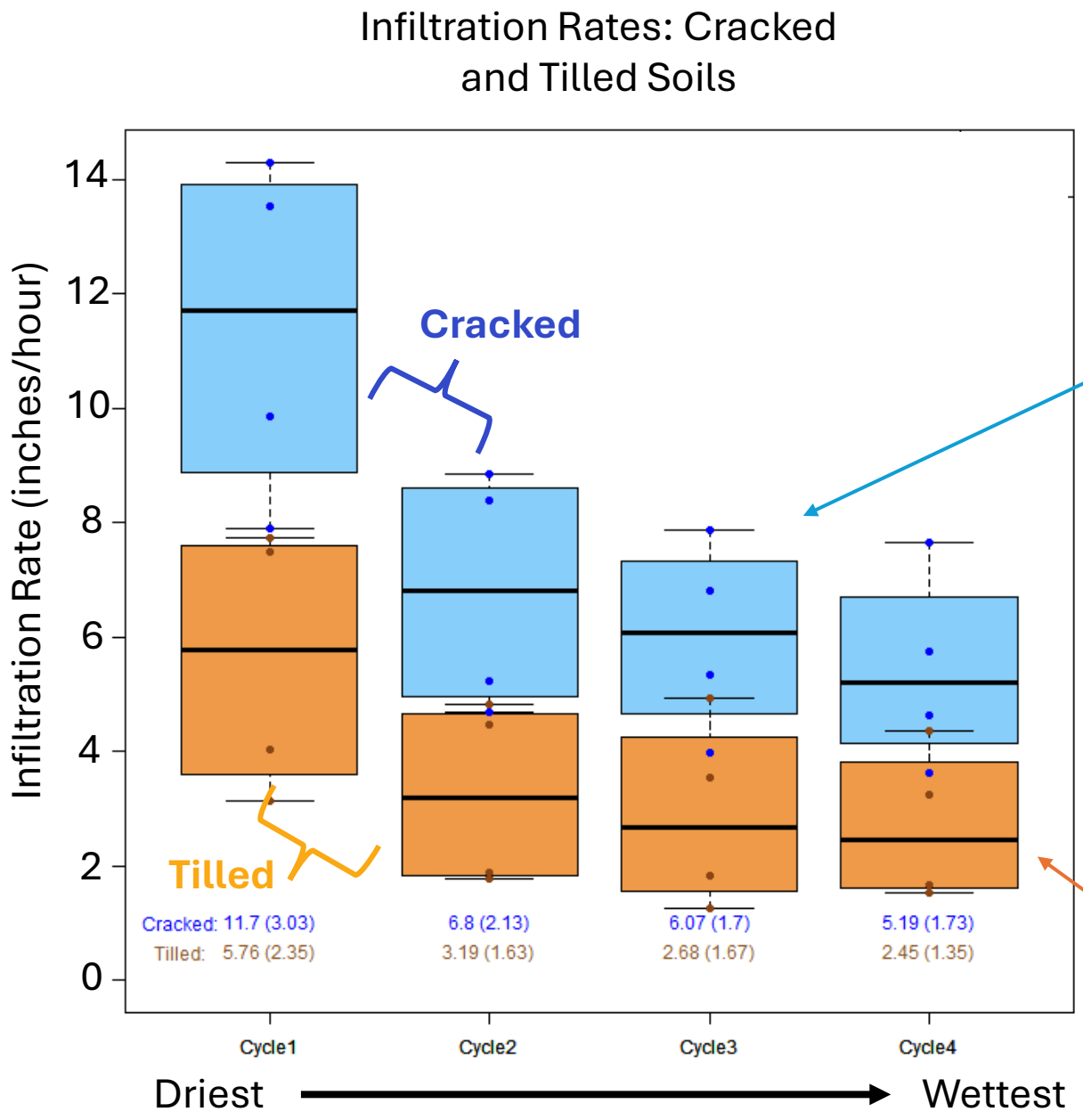
Recently Tilled- No Cracks

Cracked– More Preferential Flow

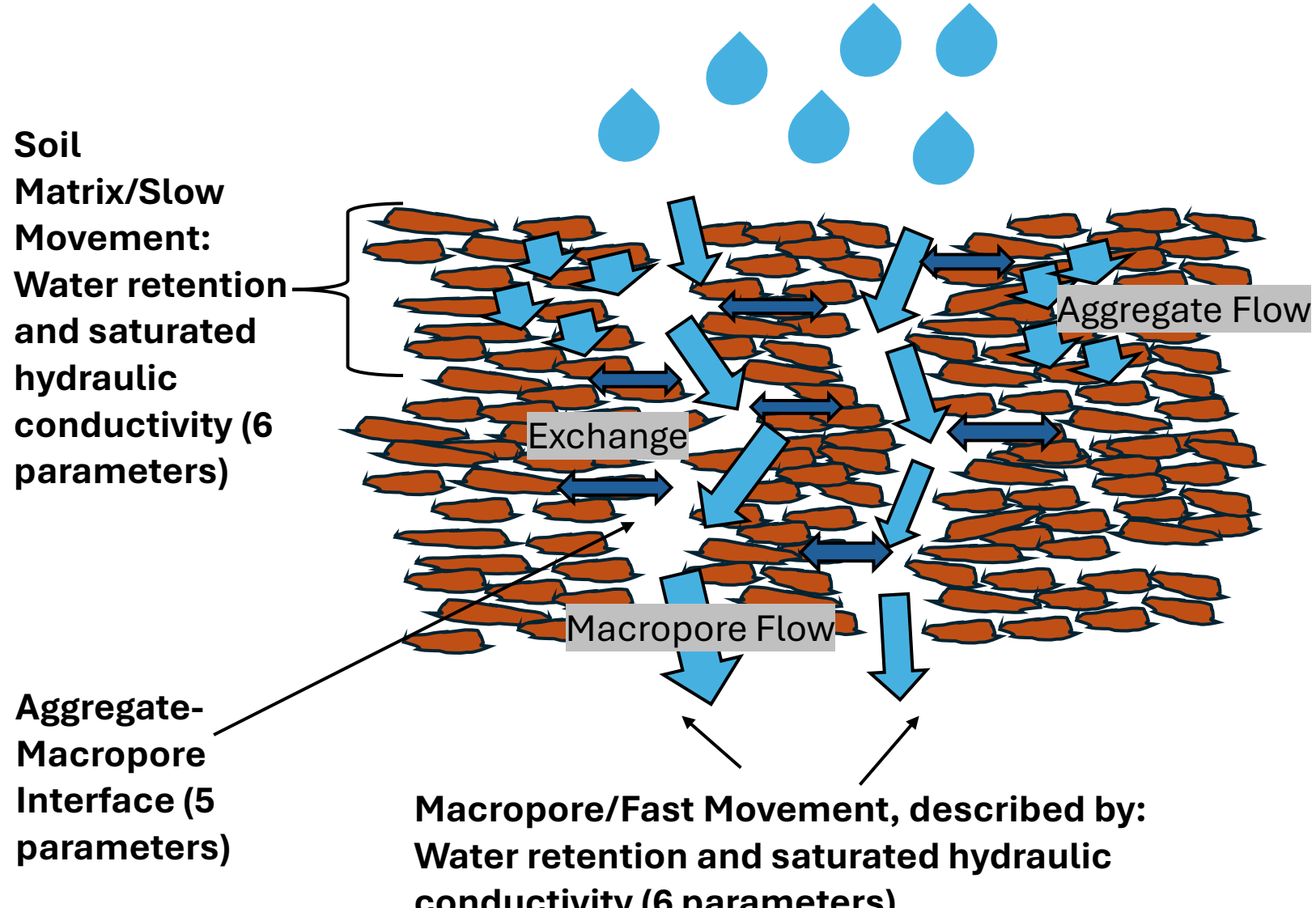


Preferential flow and development of desiccation cracks are important for water infiltration and percolation in clay loam soils.

SATURO


Infiltration Rates: Cracked and Tilled Soils
Infiltration Rate (inches/hour)
14
12
10
8
6
4
2
0
Cracked
Tilled
Cracked: 11.7 (3.03)
Tilled: 5.76 (2.35)
6.8 (2.13)
3.19 (1.63)
6.07 (1.7)
2.68 (1.67)
5.19 (1.73)
2.45 (1.35)
Cycle1
Cycle2
Cycle3
Cycle4
Driest
Wettest

Hydrus 1D Modeling Approach



Tilled Surface Parameters

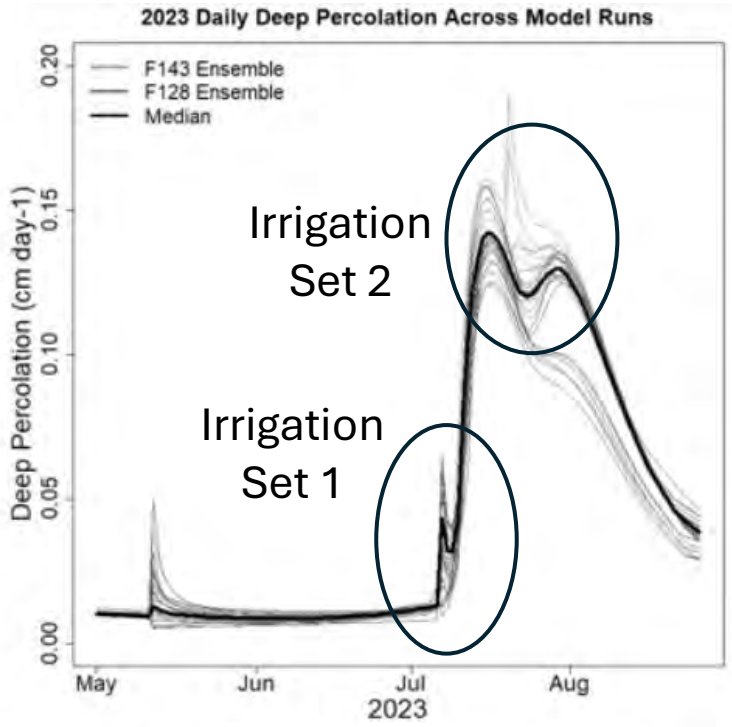
Deep Soil Parameters: Static

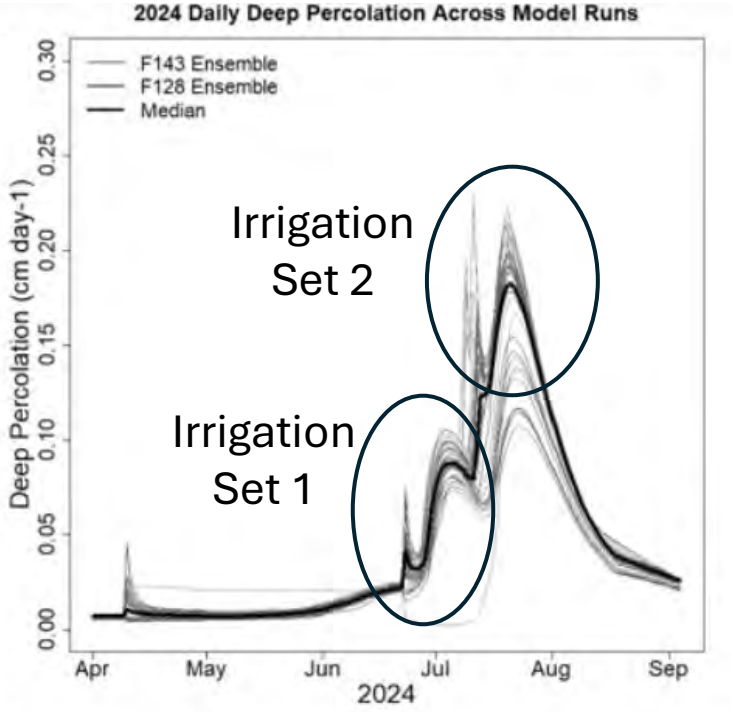
Cracked Surface Parameters

Deep Soil Parameters: Static

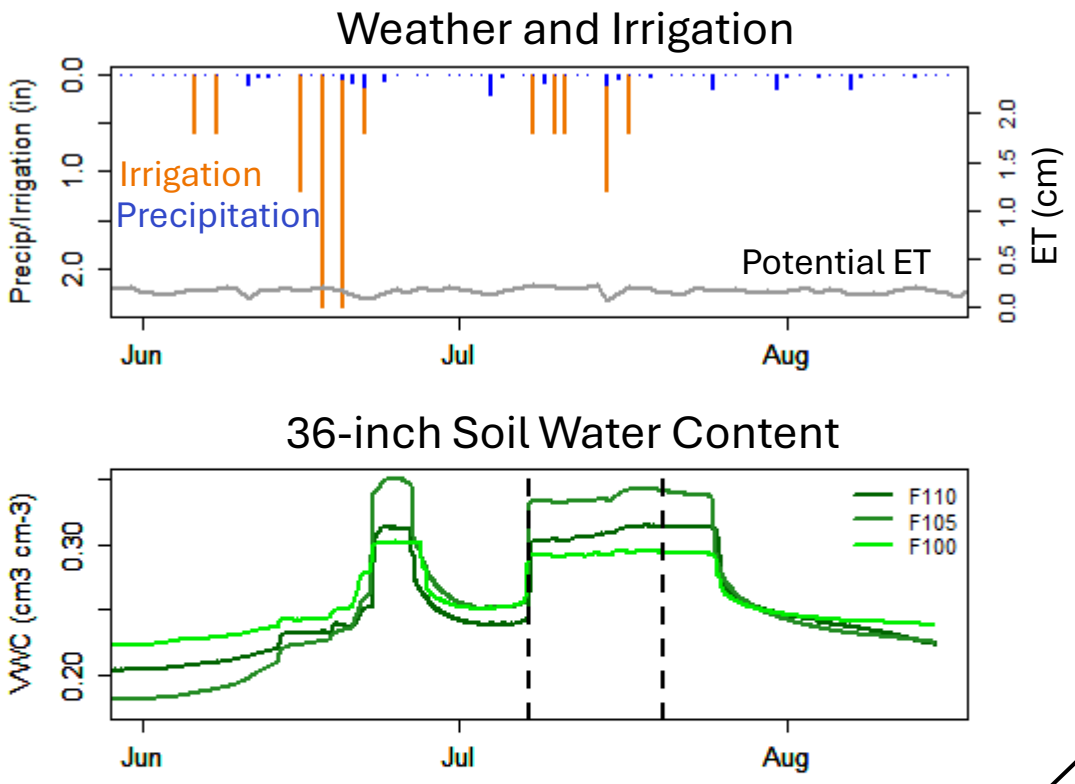
Run Early Season Model → Run Late Season Model

Modeled Deep Percolation





Groundwater Influence



*Groundwater data was collected by MBMG: preliminary, subject to review

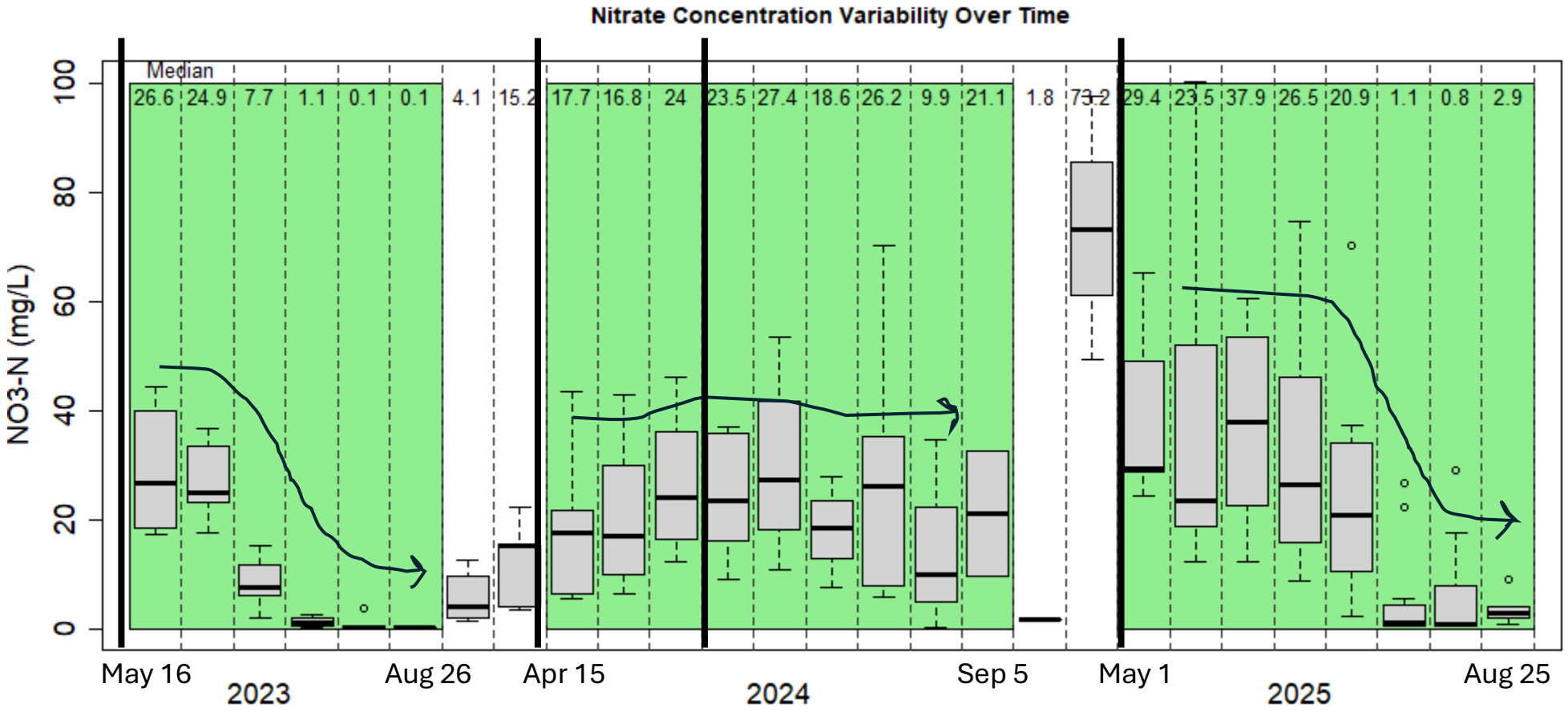
Groundwater shallower than 36 inches

Nitrate Patterns

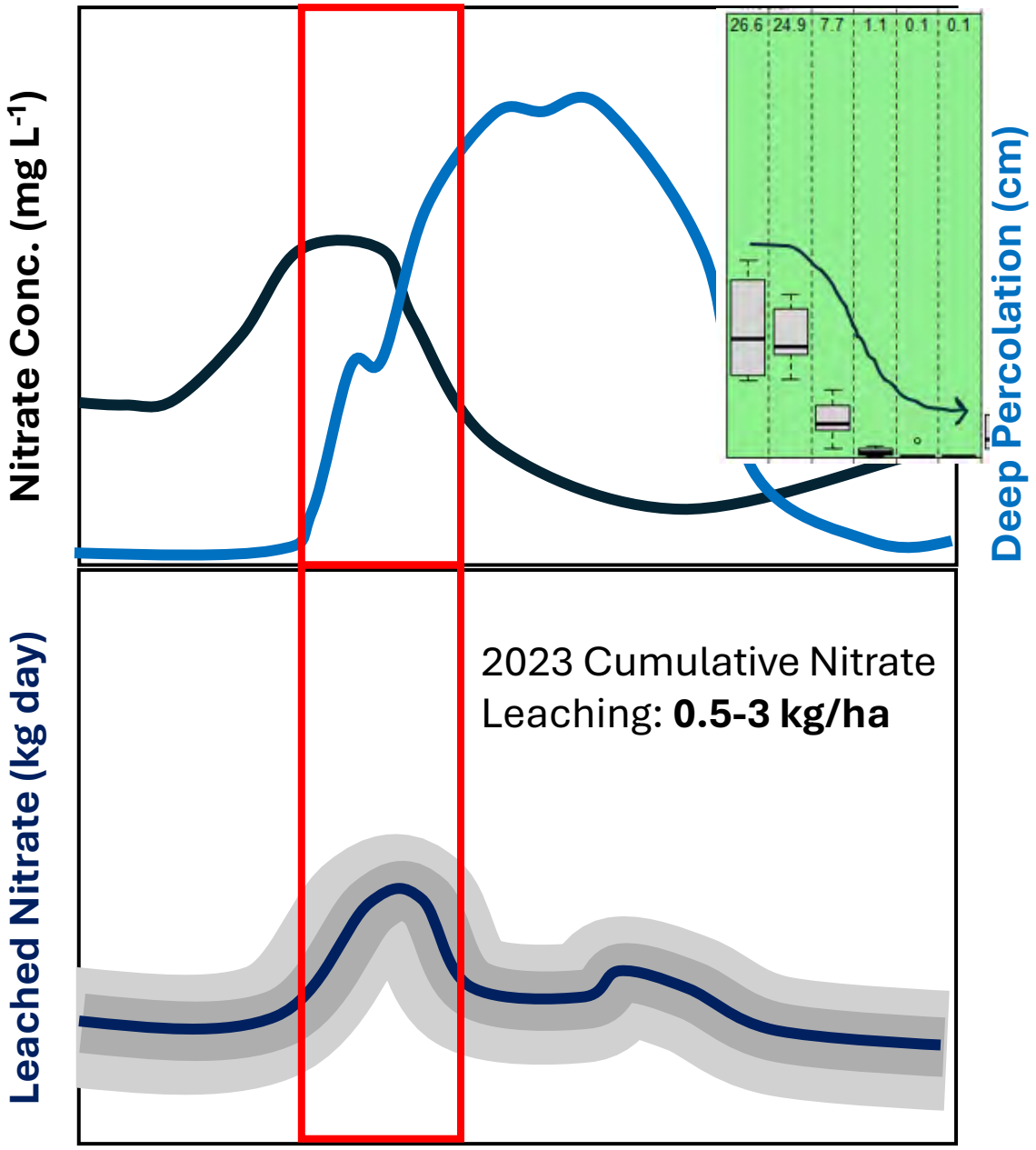
Single Fertilizer Application

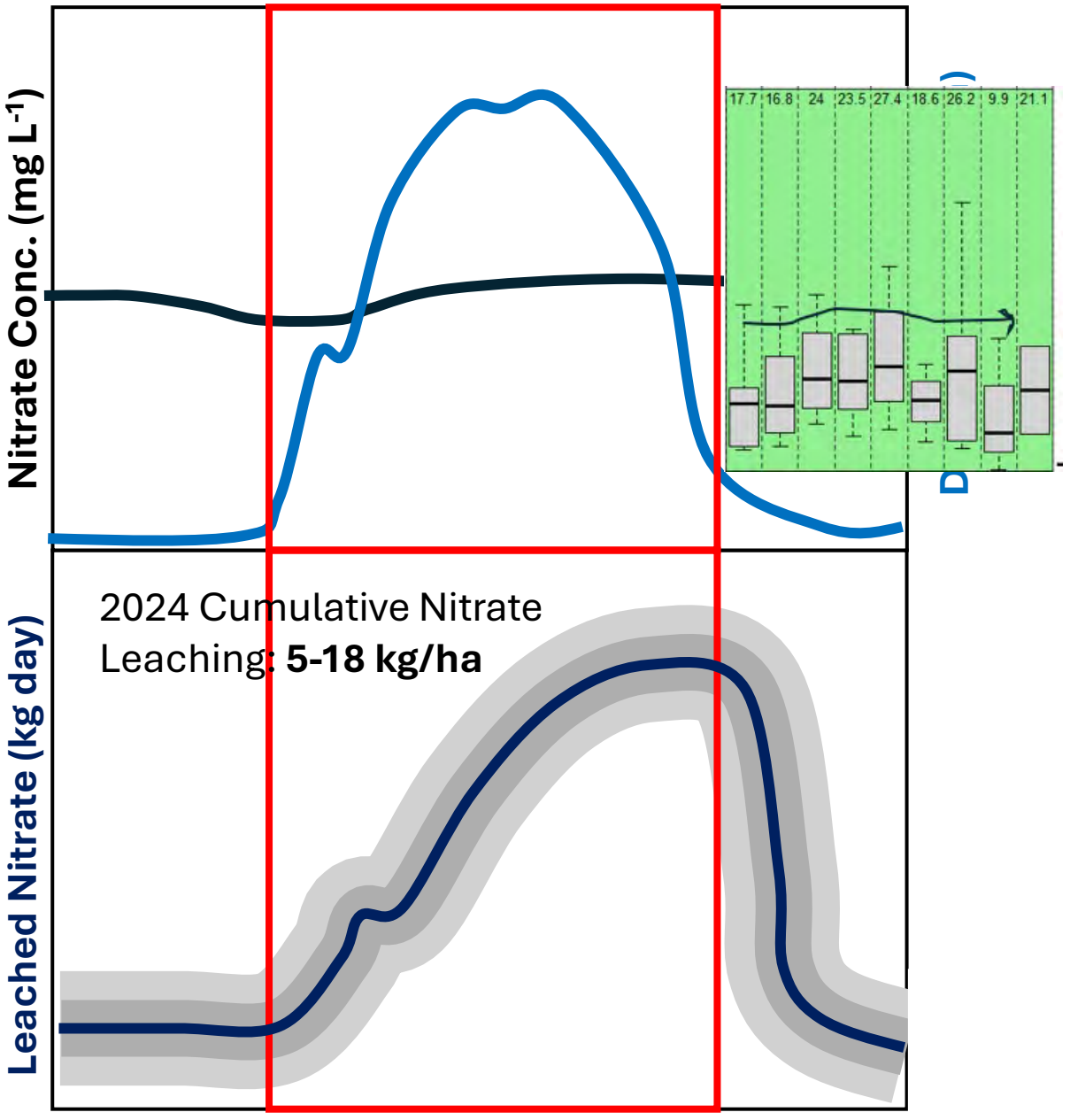
Multiple Fertilizer Applications

Single Fertilizer Application



Nitrate Leaching Risk





Discussion and Takeaways

- Seasonal development of soil cracks results in variable deep percolation risk throughout the growing season.
- Nitrate leaching is possible, with specific periods of highest leaching risk depending on irrigation scheduling and fertilizer management.
- Licor-710 data shows good agreement with data sources such as Mesonet weather stations and OpenET, suggesting tools for understanding crop water use and scheduling irrigation are available.

Acknowledgements

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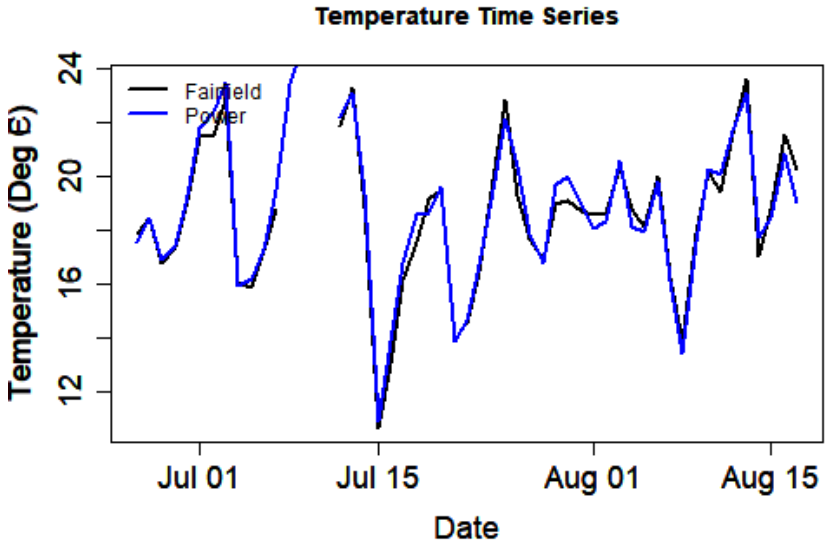
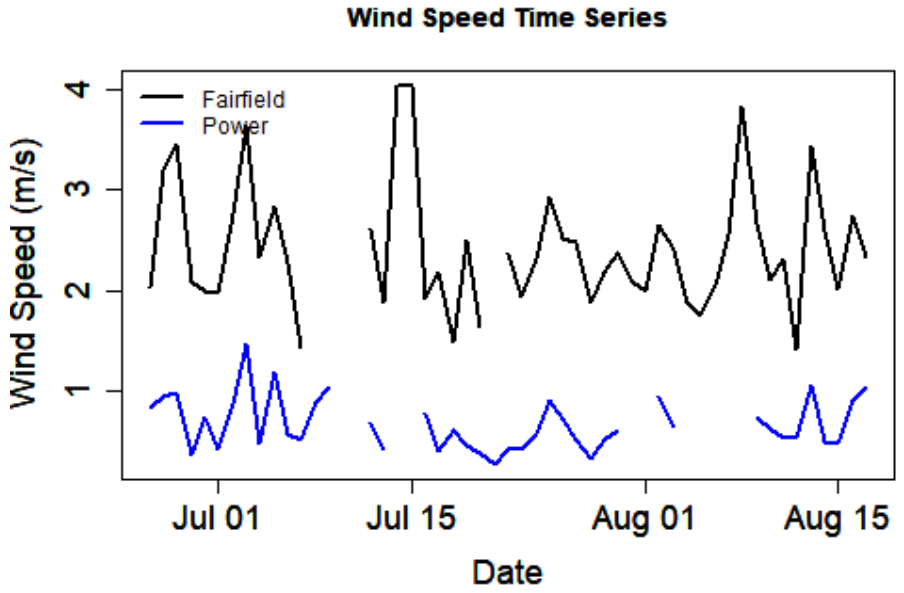
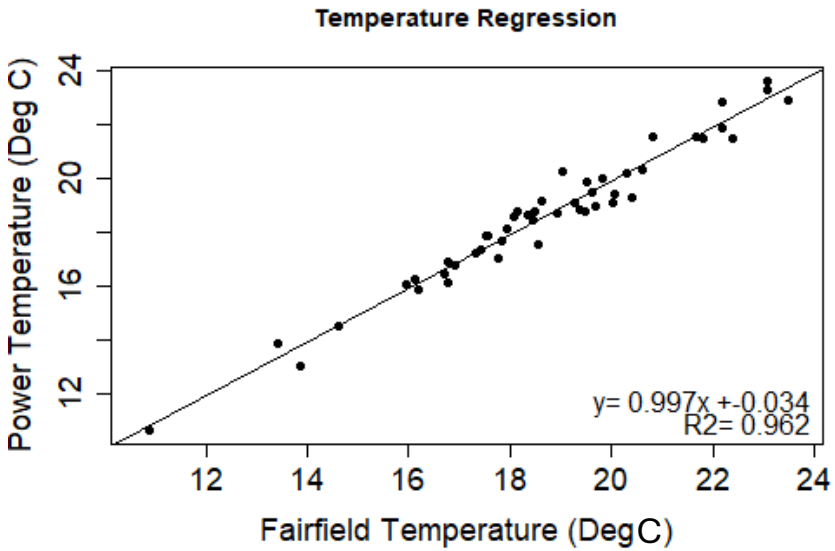
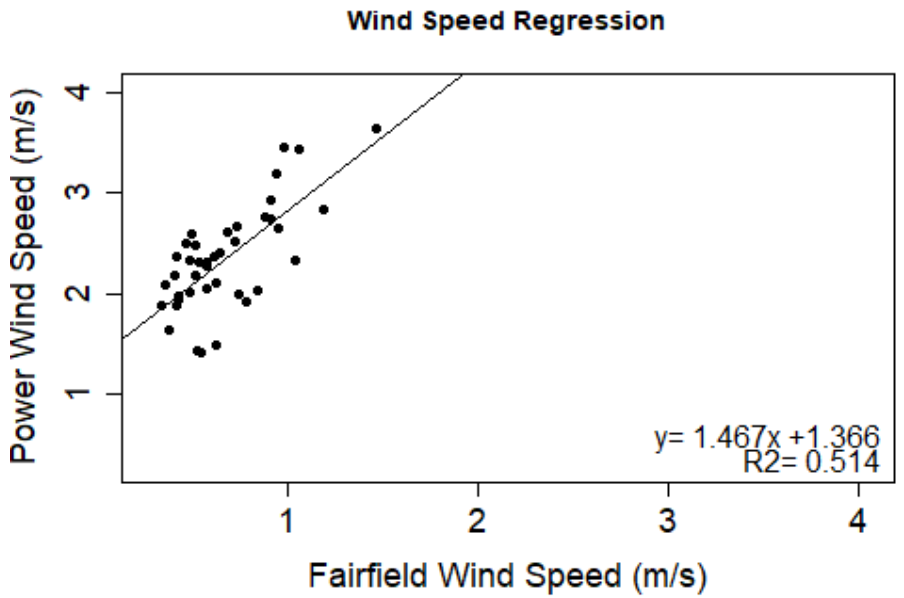
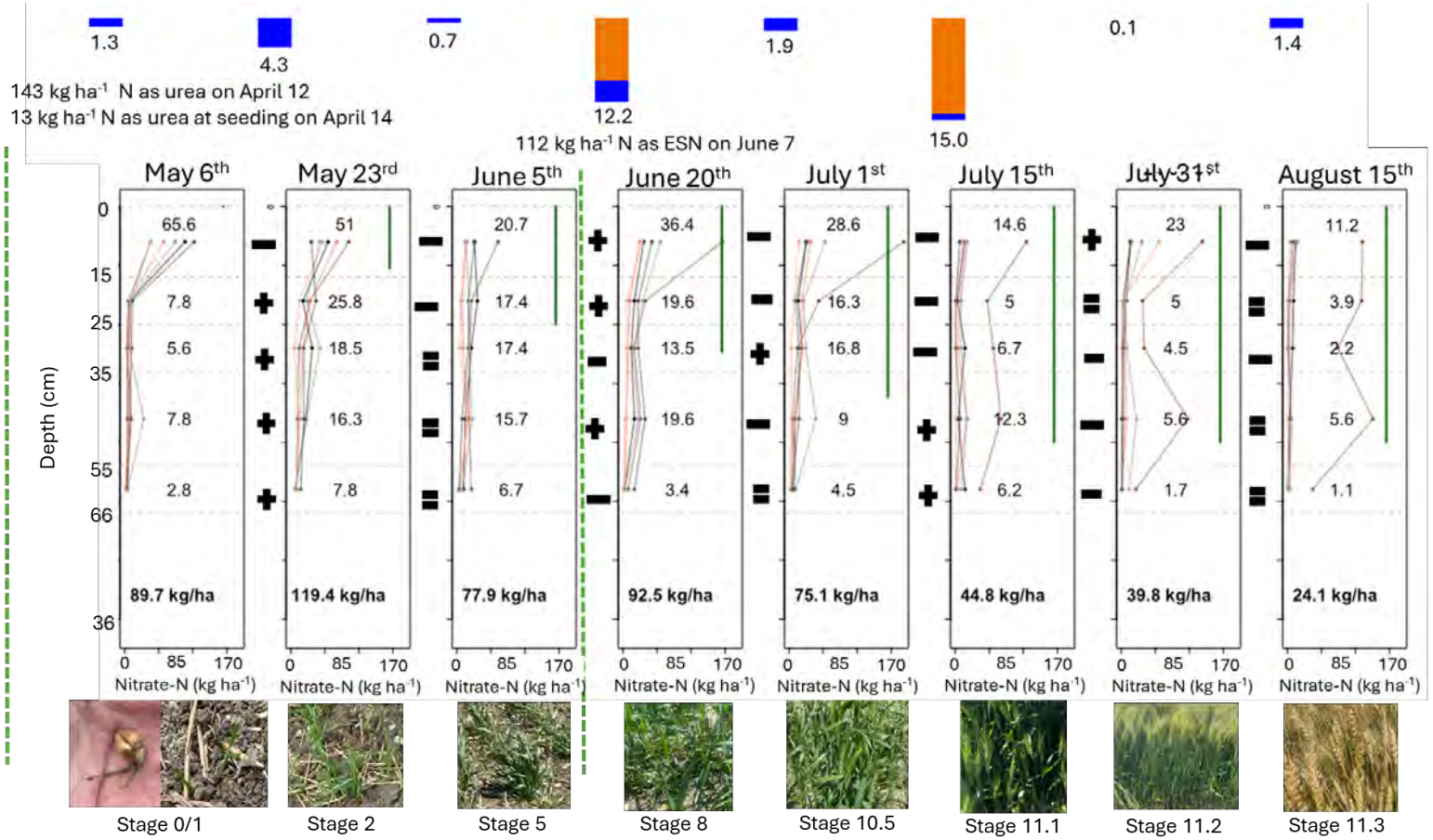
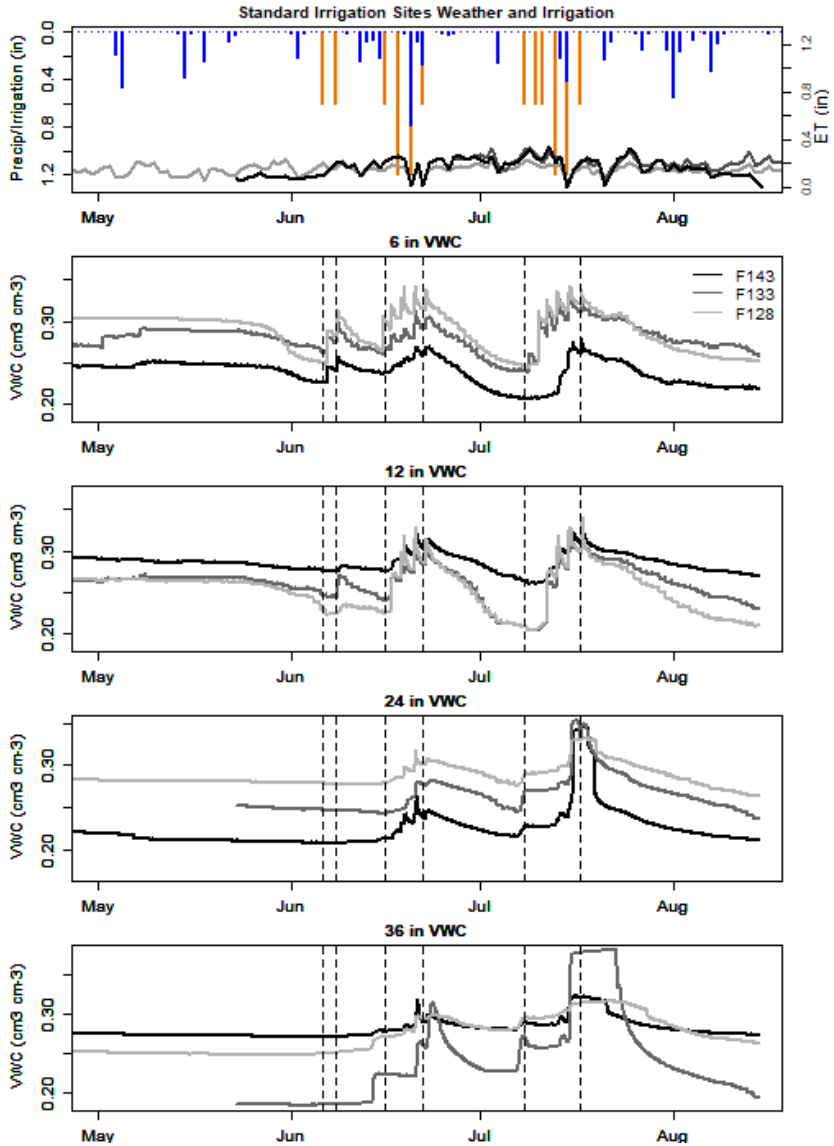

Temperature Time Series
Fairfield
Power
Temperature (Deg E)
12
16
20
24
Jul 01
Jul 15
Aug 01
Aug 15
Date

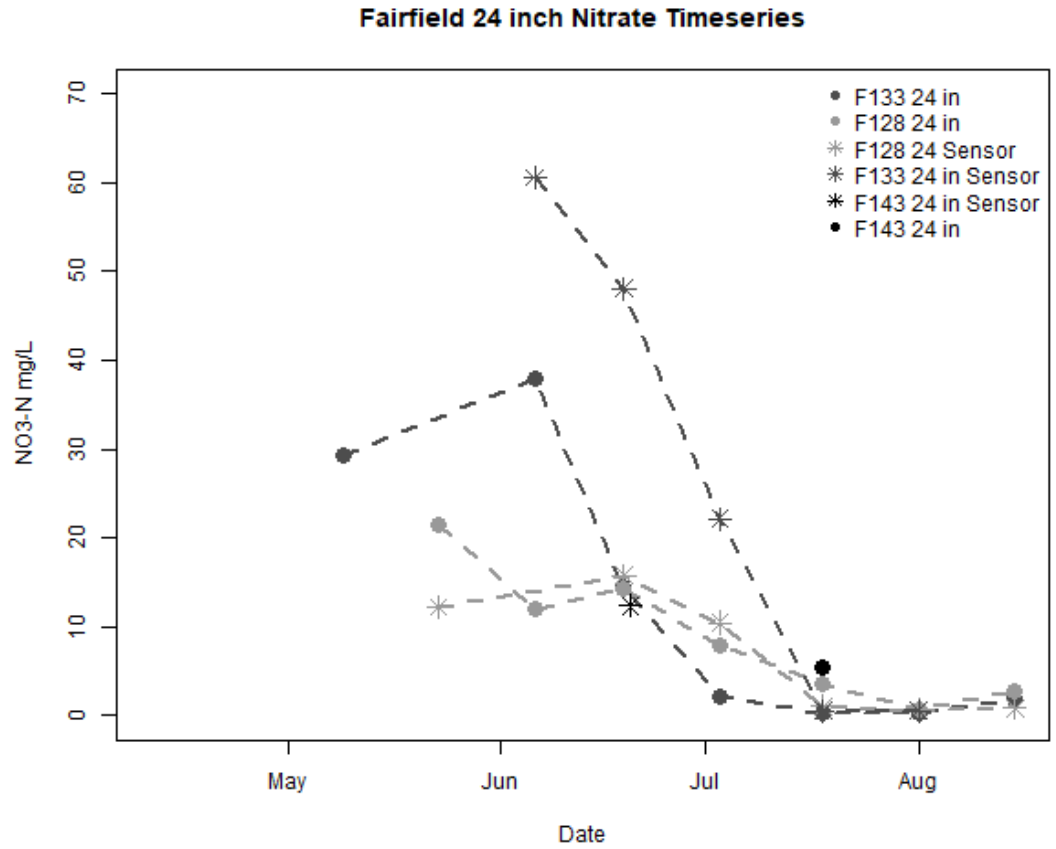

Wind Speed Time Series
Fairfield
Power
Wind Speed (m/s)
1
2
3
4
Jul 01
Jul 15
Aug 01
Aug 15
Date

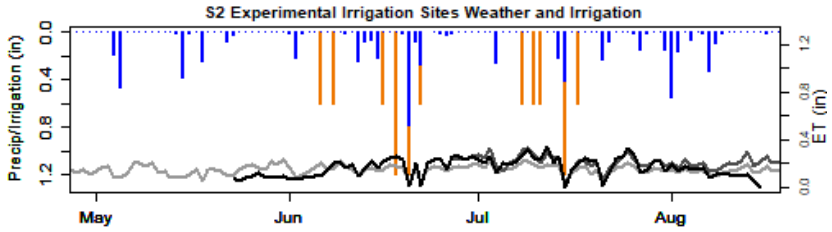

Temperature Regression
Power Temperature (Deg C)
12
16
20
24
y= 0.997x +-0.034
R2= 0.962
12
14
16
18
20
22
24
Fairfield Temperature (DegC)

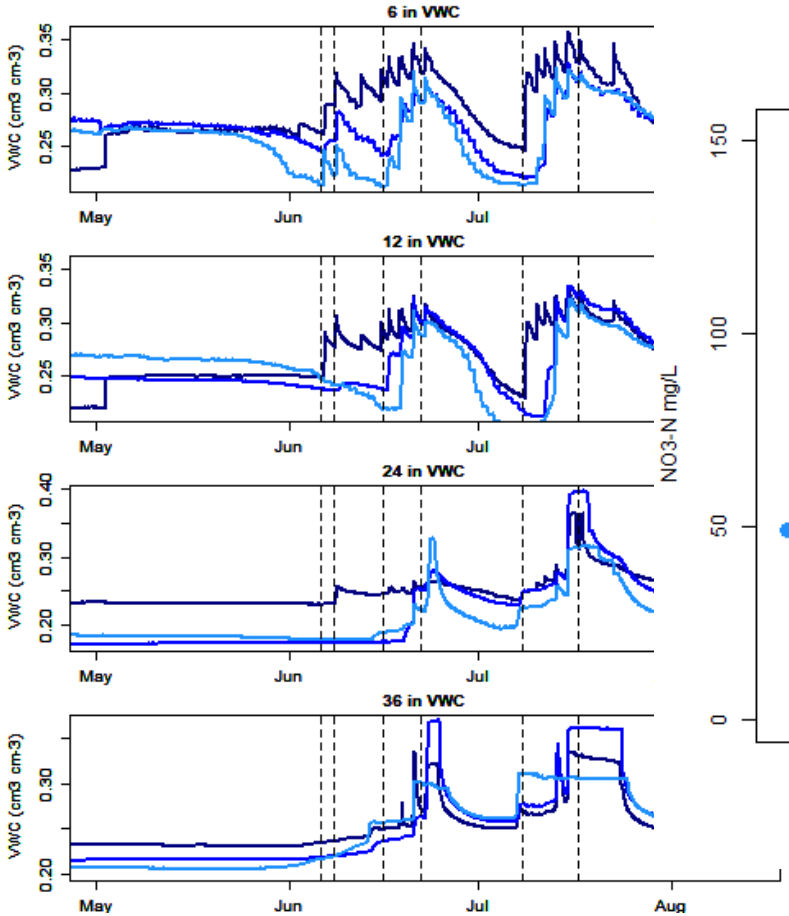

Wind Speed Regression
Power Wind Speed (m/s)
1
2
3
4
y= 1.467x +1.366
R2= 0.514
1
2
3
4
Fairfield Wind Speed (m/s)

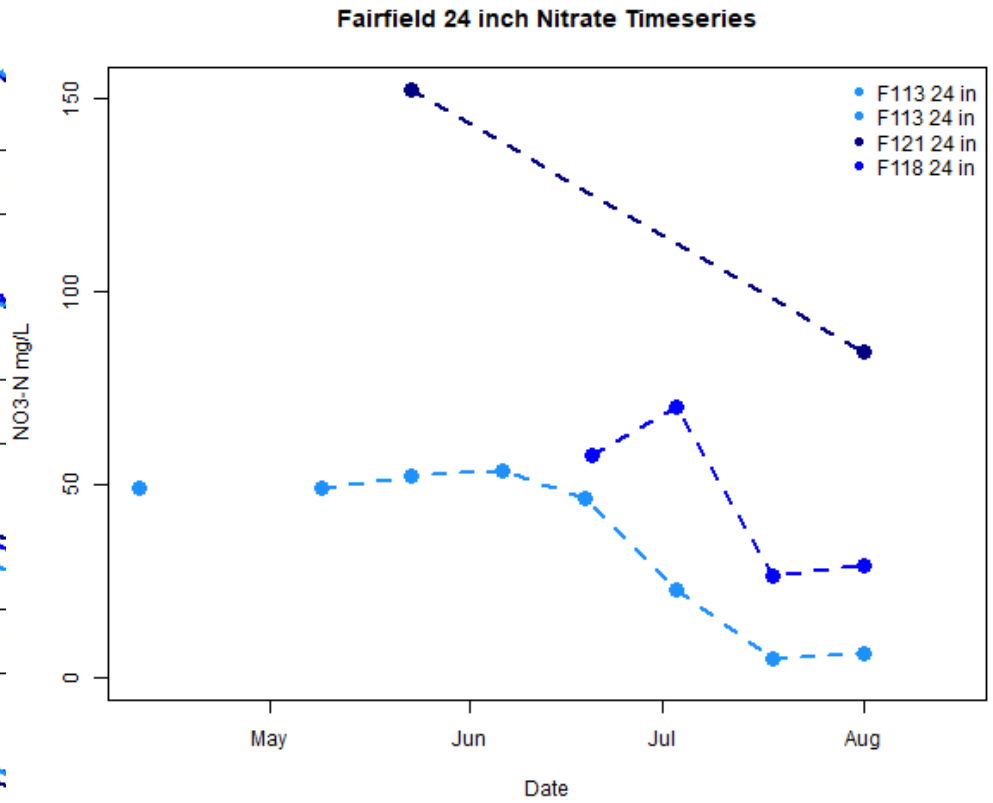

1.3
4.3
0.7
12.2
1.9
15.0
0.1
1.4
143 kg ha-1 N as urea on April 12
13 kg ha-1 N as urea at seeding on April 14
112 kg ha-1 N as ESN on June 7
May 6th
May 23rd
June 5th
June 20th
July 1st
July 15th
July 31st
August 15th
Depth (cm)
0
15
25
35
55
66
36
65.6
7.8
5.6
7.8
2.8
89.7 kg/ha
51
25.8
18.5
16.3
7.8
119.4 kg/ha
20.7
17.4
17.4
15.7
6.7
77.9 kg/ha
36.4
19.6
13.5
19.6
3.4
92.5 kg/ha
28.6
16.3
16.8
9
4.5
75.1 kg/ha
14.6
5
6.7
12.3
6.2
44.8 kg/ha
23
5
4.5
5.6
1.7
39.8 kg/ha
11.2
3.9
2.2
5.6
1.1
24.1 kg/ha
0 85 170
Nitrate-N (kg ha-1)
Stage 0/1
Stage 2
Stage 5
Stage 8
Stage 10.5
Stage 11.1
Stage 11.2
Stage 11.3

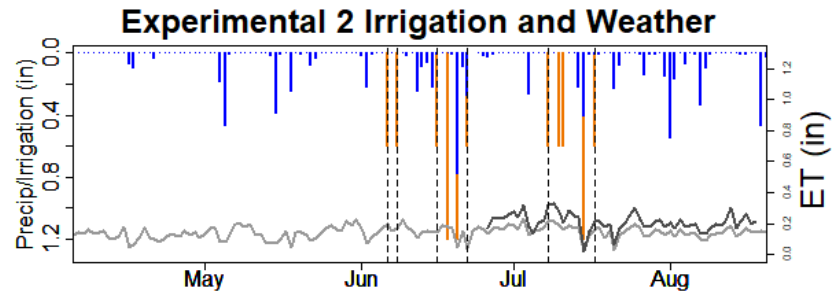

Standard Irrigation Sites Weather and Irrigation
Precip/Irrigation (in)
ET (in)
May
Jun
Jul
Aug
6 in VWC
12 in VWC
24 in VWC
36 in VWC
VWC (cm3 cm-3)
F143
F133
F128

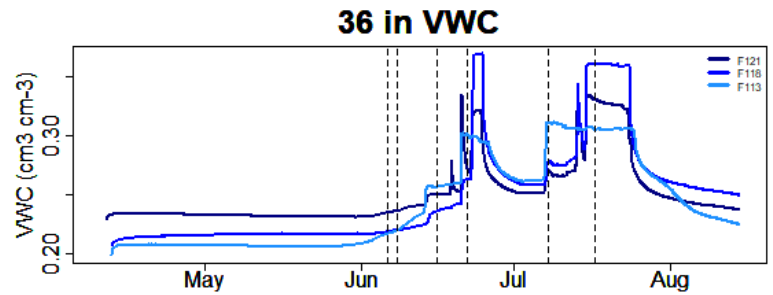

Fairfield 24 inch Nitrate Timeseries
NO3-N mg/L
Date
May
Jun
Jul
Aug
F133 24 in
F128 24 in
F128 24 Sensor
F133 24 in Sensor
F143 24 in Sensor
F143 24 in

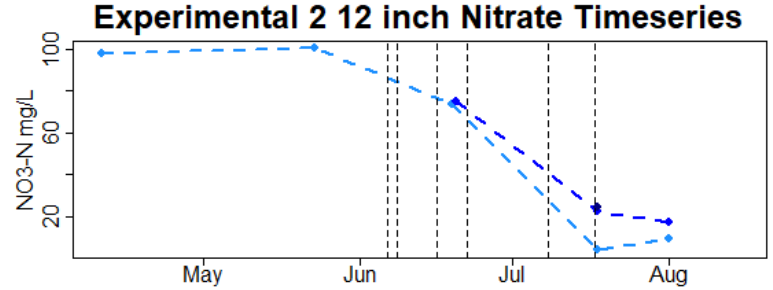

S2 Experimental Irrigation Sites Weather and Irrigation
Precip/Irrigation (in)
ET (in)
May
Jun
Jul
Aug

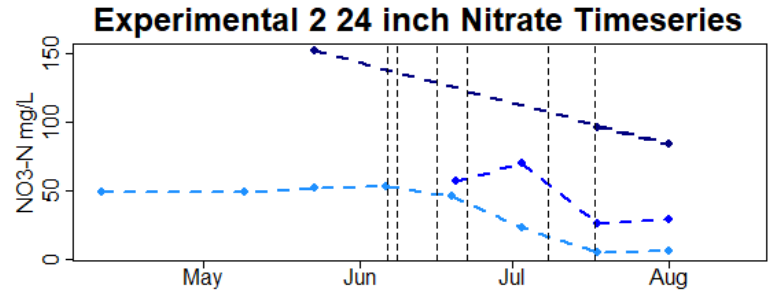

6 in VWC
12 in VWC
24 in VWC
36 in VWC
VWC (cm3 cm-3)
May
Jun
Jul
Aug

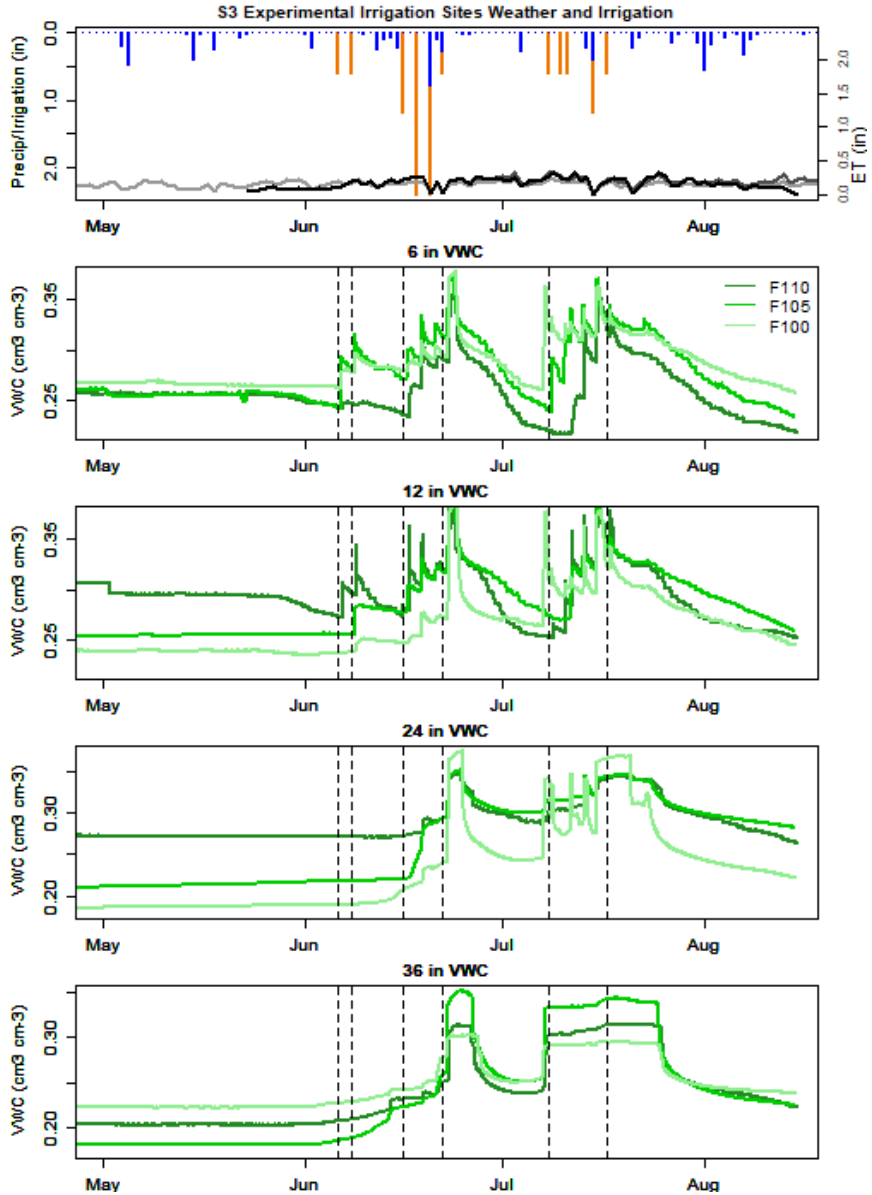

Fairfield 24 inch Nitrate Timeseries
F113 24 in
F113 24 in
F121 24 in
F118 24 in
NO3-N mg/L
Date
May
Jun
Jul
Aug

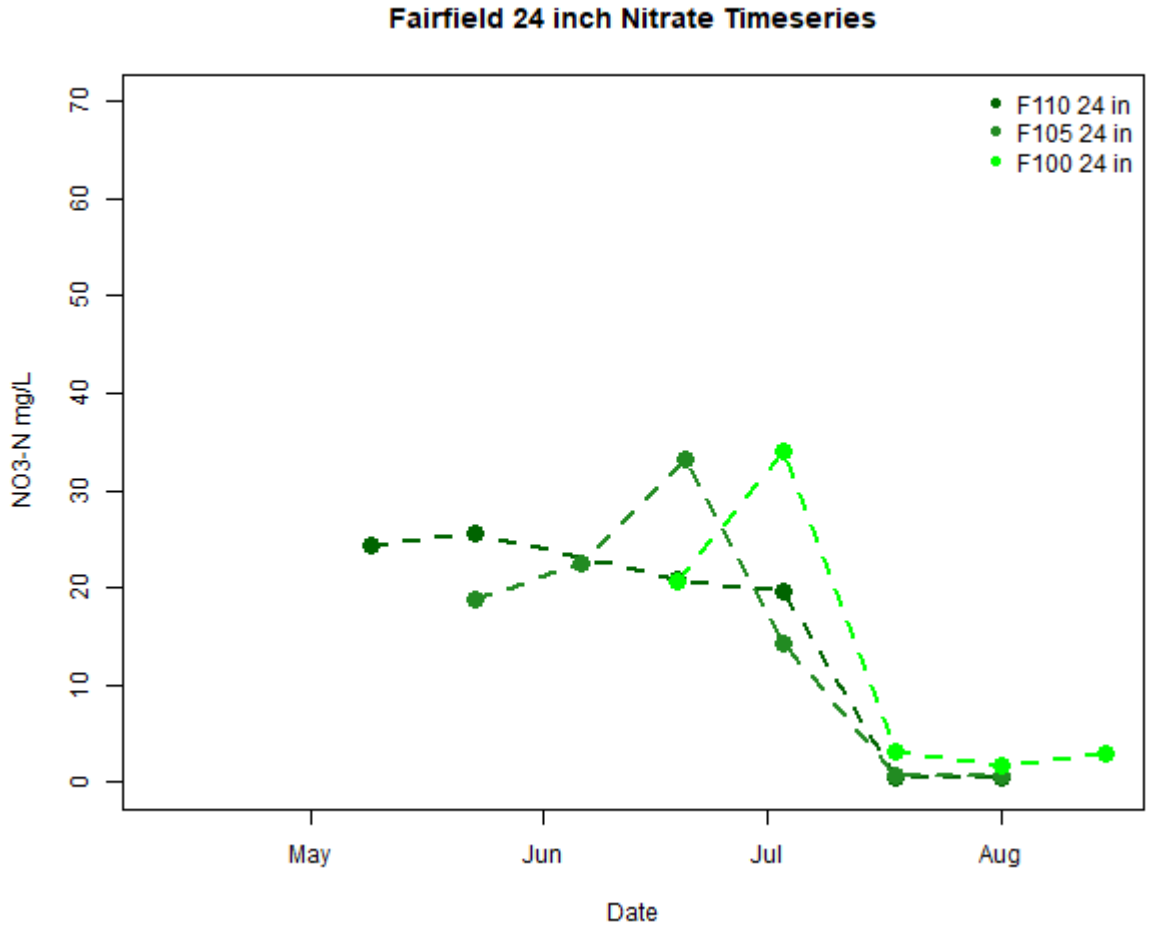

Experimental 2 Irrigation and Weather
Precip/Irrigation (in)
ET (in)
May
Jun
Jul
Aug

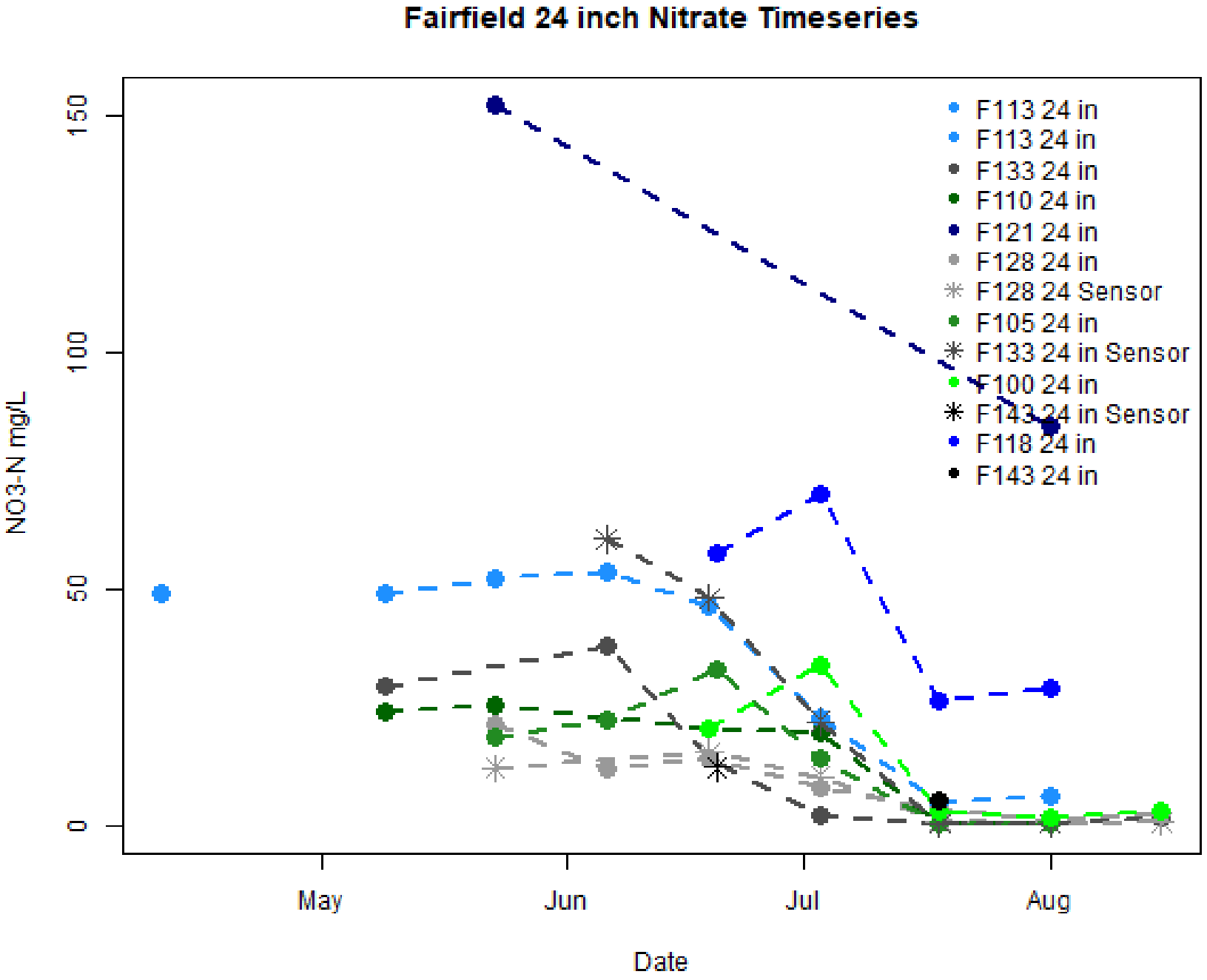

36 in VWC
VWC (cm3 cm-3)
F121
F118
F113
May
Jun
Jul
Aug

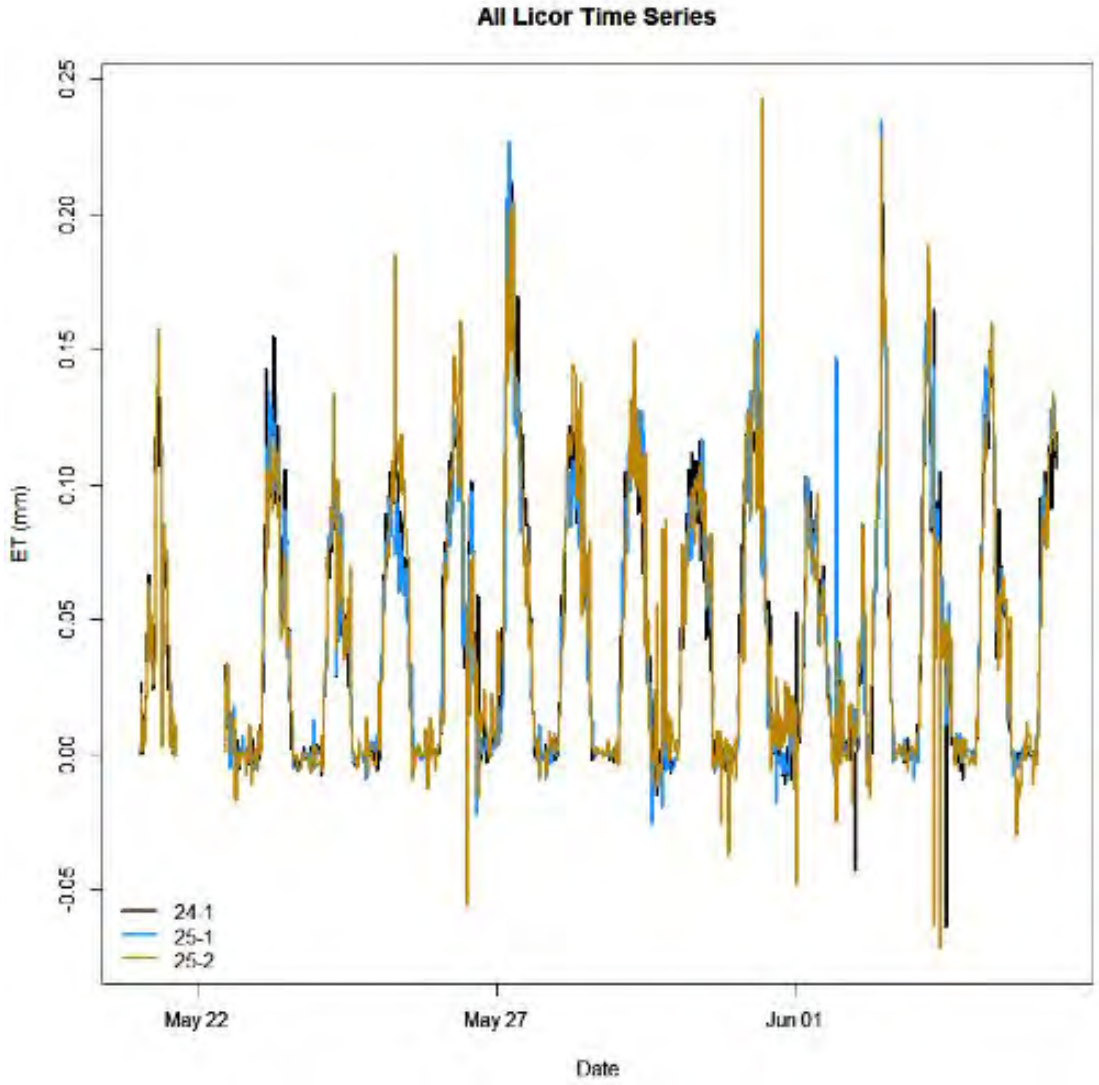

Experimental 2 12 inch Nitrate Timeseries
NO3-N mg/L
May
Jun
Jul
Aug

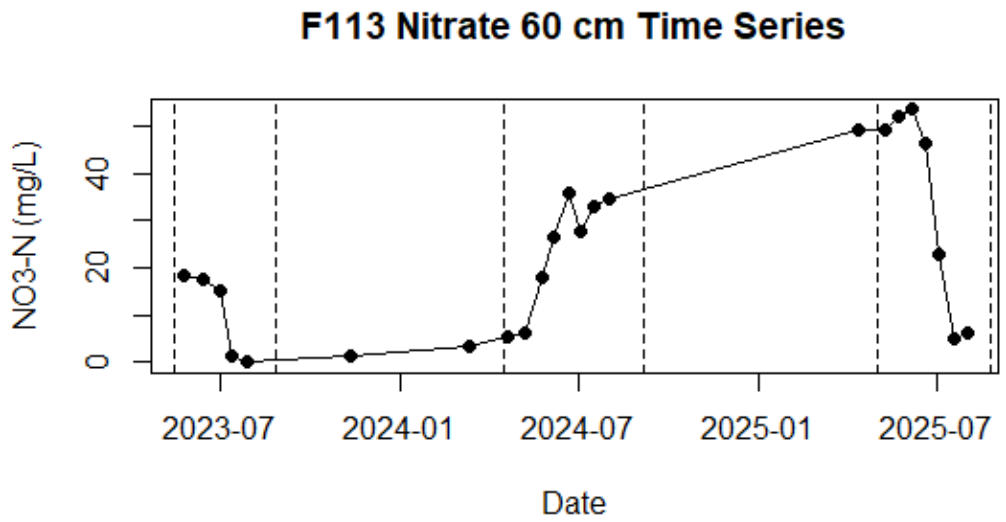

Experimental 2 24 inch Nitrate Timeseries
NO3-N mg/L
May
Jun
Jul
Aug

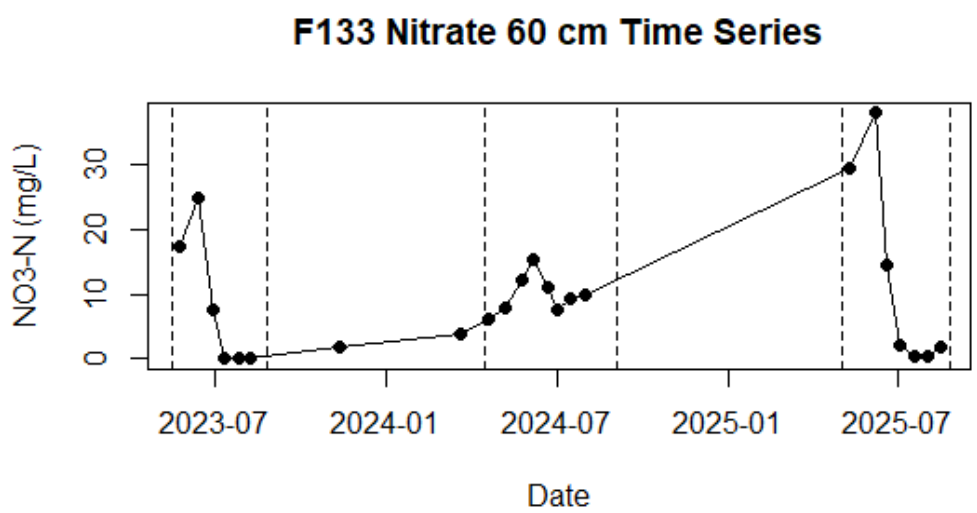

S3 Experimental Irrigation Sites Weather and Irrigation
Precip/Irrigation (in)
ET (in)
May
Jun
Jul
Aug
6 in VWC
12 in VWC
24 in VWC
36 in VWC
VWC (cm3 cm-3)
F110
F105
F100


Fairfield 24 inch Nitrate Timeseries
NO3-N mg/L
Date
May
Jun
Jul
Aug
F110 24 in
F105 24 in
F100 24 in


Fairfield 24 inch Nitrate Timeseries
NO3-N mg/L
0
50
100
150
May
Jun
Jul
Aug
Date
F113 24 in
F113 24 in
F133 24 in
F110 24 in
F121 24 in
F128 24 in
F128 24 Sensor
F105 24 in
F133 24 in Sensor
F100 24 in
F143 24 in Sensor
F118 24 in
F143 24 in


All Licor Time Series
ET (mm)
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
24.1
25-1
25-2
May 22
May 27
Jun 01
Date


F113 Nitrate 60 cm Time Series
NO3-N (mg/L)
0
20
40
2023-07
2024-01
2024-07
2025-01
2025-07
Date


F133 Nitrate 60 cm Time Series
NO3-N (mg/L)
0
10
20
30
2023-07
2024-01
2024-07
2025-01
2025-07
Date