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Examining the effect of fertilizer application practices on soil nitrate and water quality

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U.S. Department of the Interior
U.S. Geological Survey

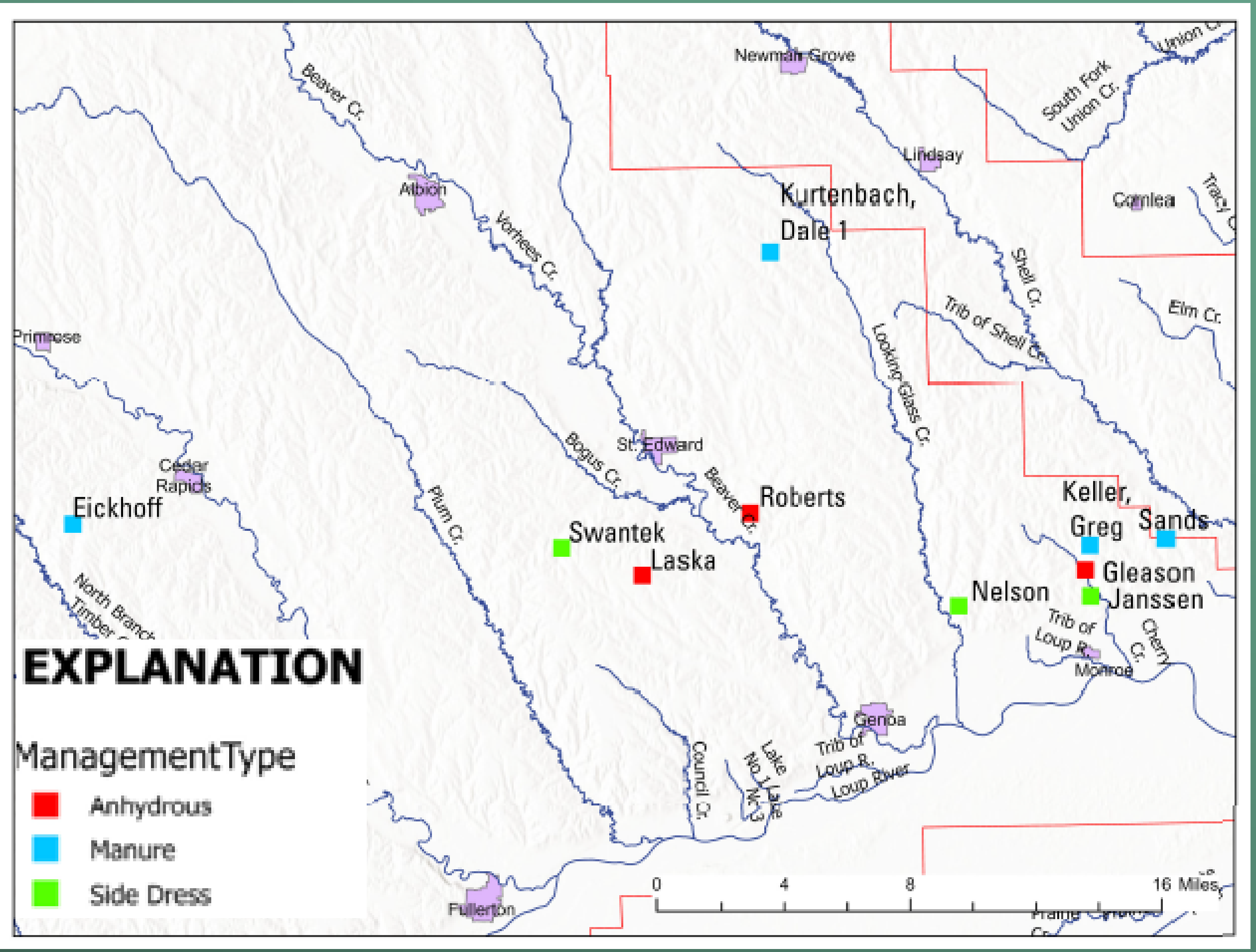
LOWER LOUP
NATURAL RESOURCES DISTRICT

Project timeline

- Starting in fall of 2022 the LLNRD began discussions on banning fall application of commercial fertilizer across the District
- Proposed rule changes received a lot of push back during public meetings in January 2023
- February Board adopted all proposed rule changes EXCEPT the fall fertilizer ban with the idea it would be revisited in one year
- Shortly thereafter LLNRD staff began conversation with USGS on how to assess the influence of fertilizer application practices on nitrate movement
- In spring 2023, the LLNRD and the USGS began developing a study plan to sample soil N (ammonia and nitrate) through the 2024 growing season

Site selection and initial work plan

- Board encouraged affected producers to participate in study with NRD
- 10 groundwater irrigated fields were selected that used different fertilizer application practices: fall anhydrous, manure, and side dress
- Thank you to all study participants!



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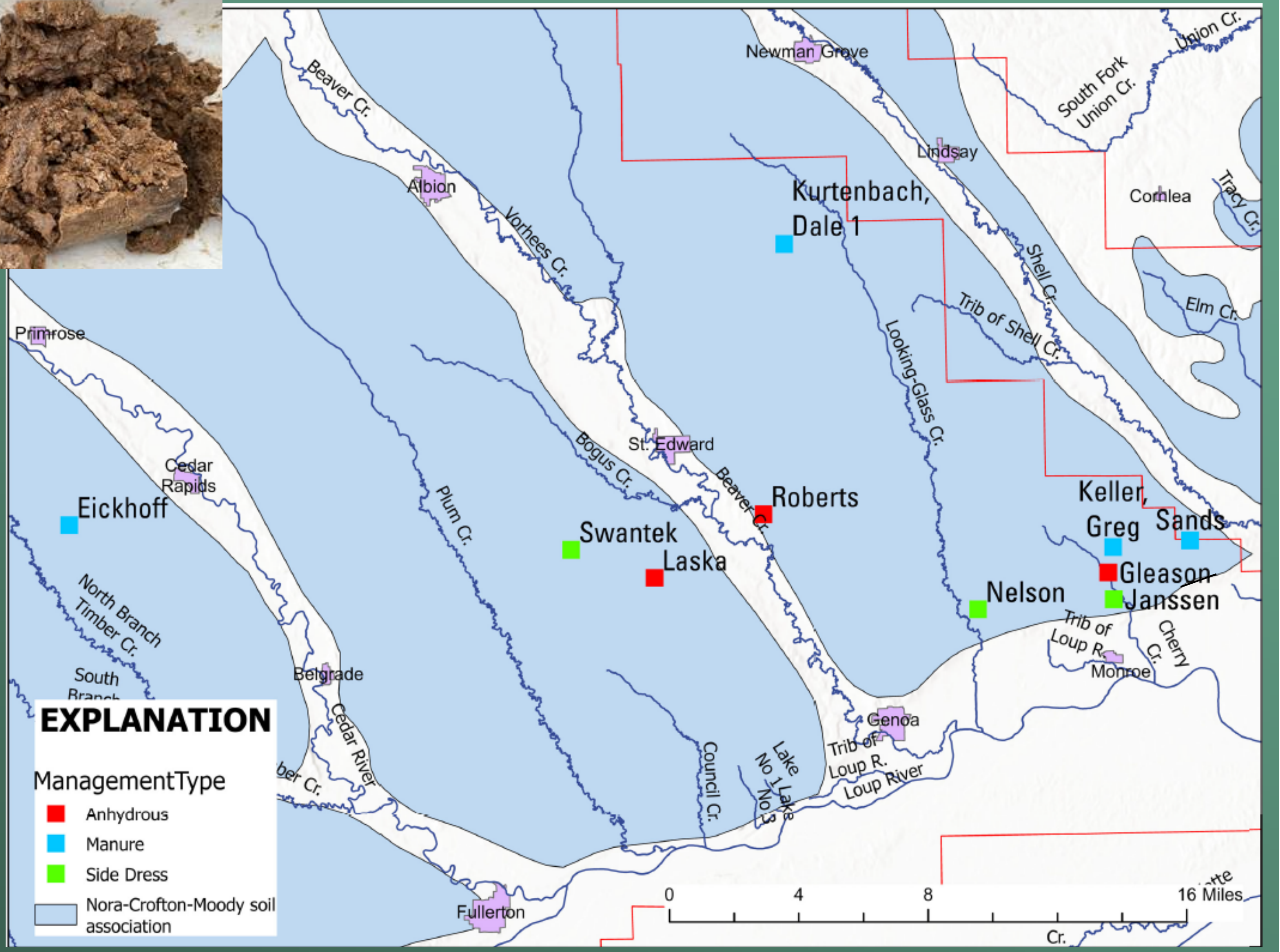
Area soils and site characteristics

- All sites are in areas mapped as Nora-Crofton-Moody soil association
- These soils are deep, well-drained, and located in upland areas
- Texture is generally silt loam or silty clay loam
- Moderately high to high infiltration rate (0.2 to 2.0 in/hr)
- Typically, irrigated corn and soybeans (where there is sufficient groundwater available)



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Soil parent material and hydrologic characteristics

- Nora Crofton soils are derived from Peoria Loess parent material
- Loess is wind blown silt deposited during last glacial period
- Soil structure and development of macropores (voids, cracks, etc) can lead to higher infiltration rates

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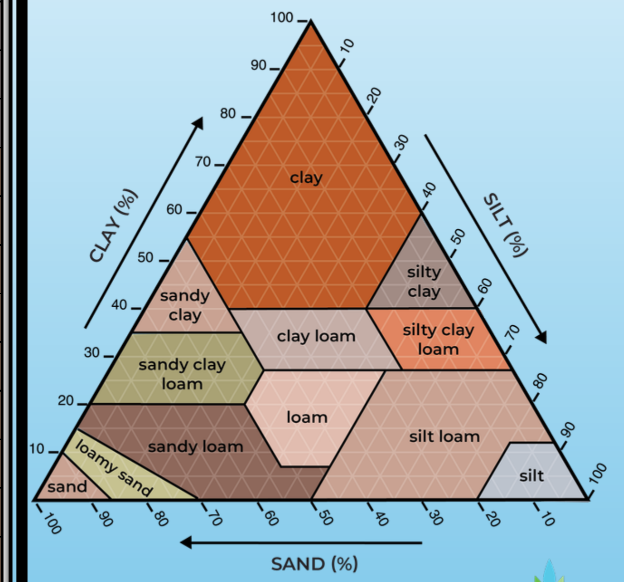
Field Textures

Depth	Laska 1	Roberts 2	Gleason 1	Eickhoff 2	Sands 2	Keller 2	Kurtenbach 2	Janssen 3	Nelson 1	Swantek 2	Choat #3
0-1	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Clay Loam
1-2	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Clay Loam
2-3	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Clay Loam
3-4	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay	Silty Clay	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silt Loam
4-5	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
5-6	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
6-7	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
7-8	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
8-10	Silty Clay Loam	Silty Clay Loam	Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
10-12	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
12-14	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
14-16	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
16-18	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
18-20	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silt Loam
20-22	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silt Loam
22-24	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam		Silty Clay Loam	Silty Clay	Silty Clay Loam	Clay Loam	Silt Loam
24-26	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam		Silty Clay	Silty Clay	Silty Clay Loam		Silt Loam
26-28	Silty Clay	Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam		Silty Clay Loam	Silty Clay Loam	Silty Clay Loam		Clay Loam
28-30	Silty Clay	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam	Silty Clay Loam		Silty Clay Loam	Silty Clay Loam	Silty Clay Loam		Clay Loam

Silty Clay Loam | **Silty Clay** | **Silt Loam** | **Clay Loam**



USDA soil textural triangle

Source: National Agronomy Manual, USDA

Study approach – soil-N sampling

- Soil cores collected at 10 fields through growing season at specific crop stages
  - 30-ft samples when fields were accessible
  - 8-ft samples collected during growing season
- For each field, cores were collected at three locations
- Each core was subdivided into 1-ft increments to 8-ft, then 2-ft increments to 30-ft and sent to Ward Labs for analyses

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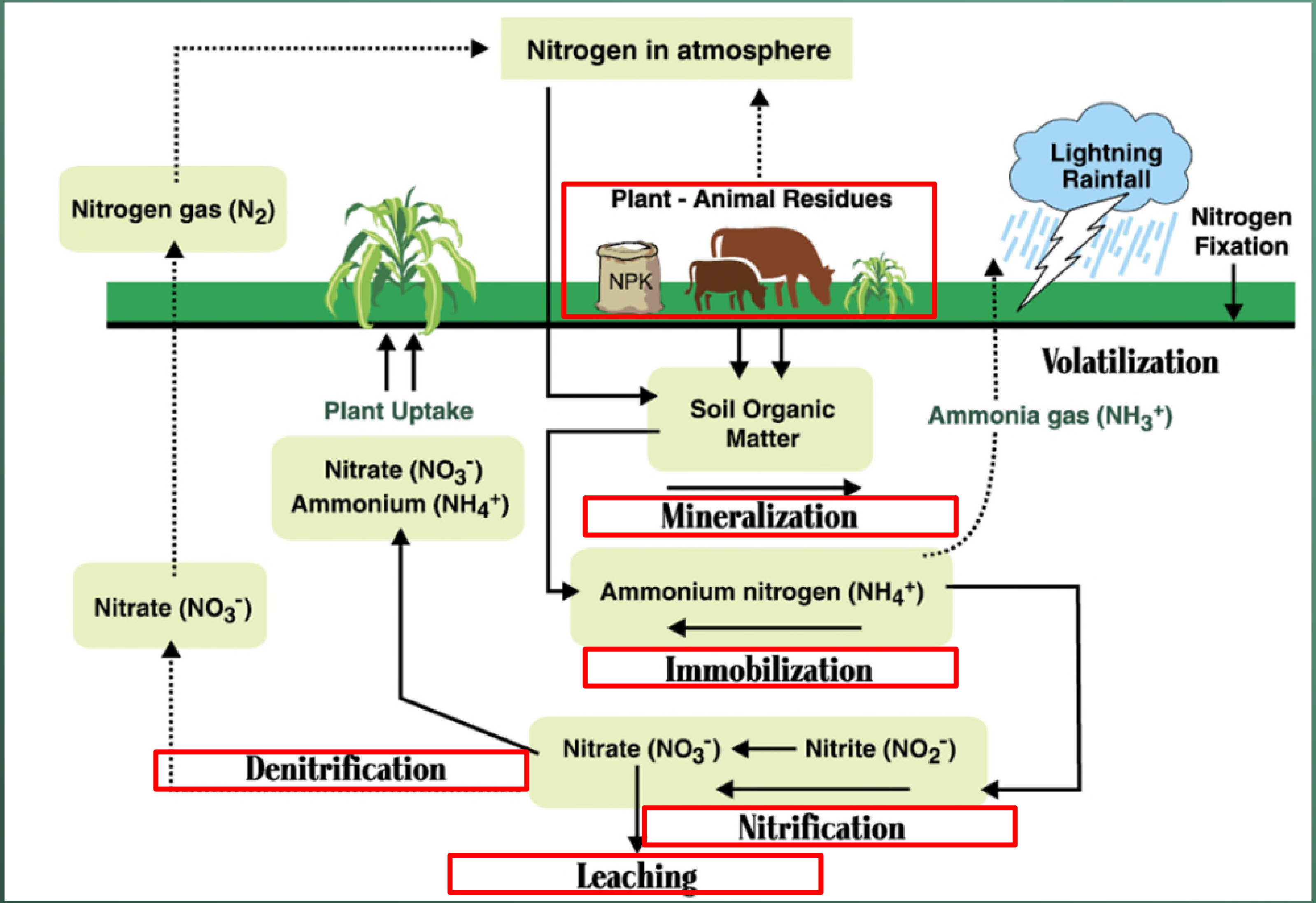
The nitrogen cycle in agricultural landscapes



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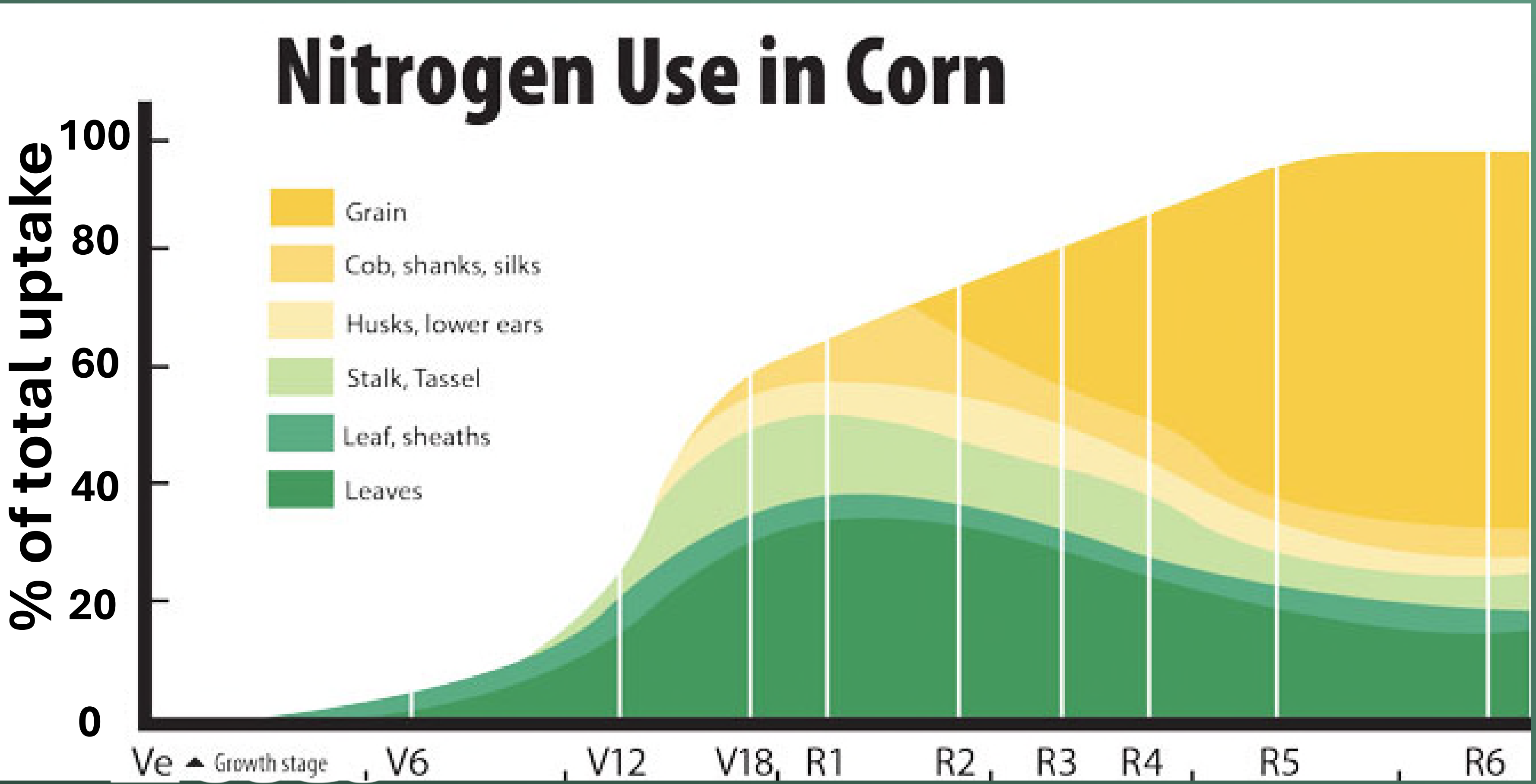
From Keena and others, 2022

When is nitrogen needed?



- Much of N use is between V6 to V18 (typically mid-June to mid-July
- For context commercial fertilizer application mid-November to early December

Study approach – Bromide tracer test

- Bromide was applied at land surface to estimate the infiltration rates of solutes through the soil
- Bromide (negatively charged ion) is an ideal conservative tracer (will not bind to soil particles or lost by plant uptake)
- Repeated soil coring can track solute movement and can be used to determine the maximum rate of percolation

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Study approach – Bromide tracer test

- Potassium bromide, was applied to all 10 fields in June in a 10 ft by 10 ft area
- Soil cores were collected ~9 weeks later to determine how much bromide moved
- The time elapsed from application to sampling, total precipitation, and irrigation water applied affect the depth that bromide had reached

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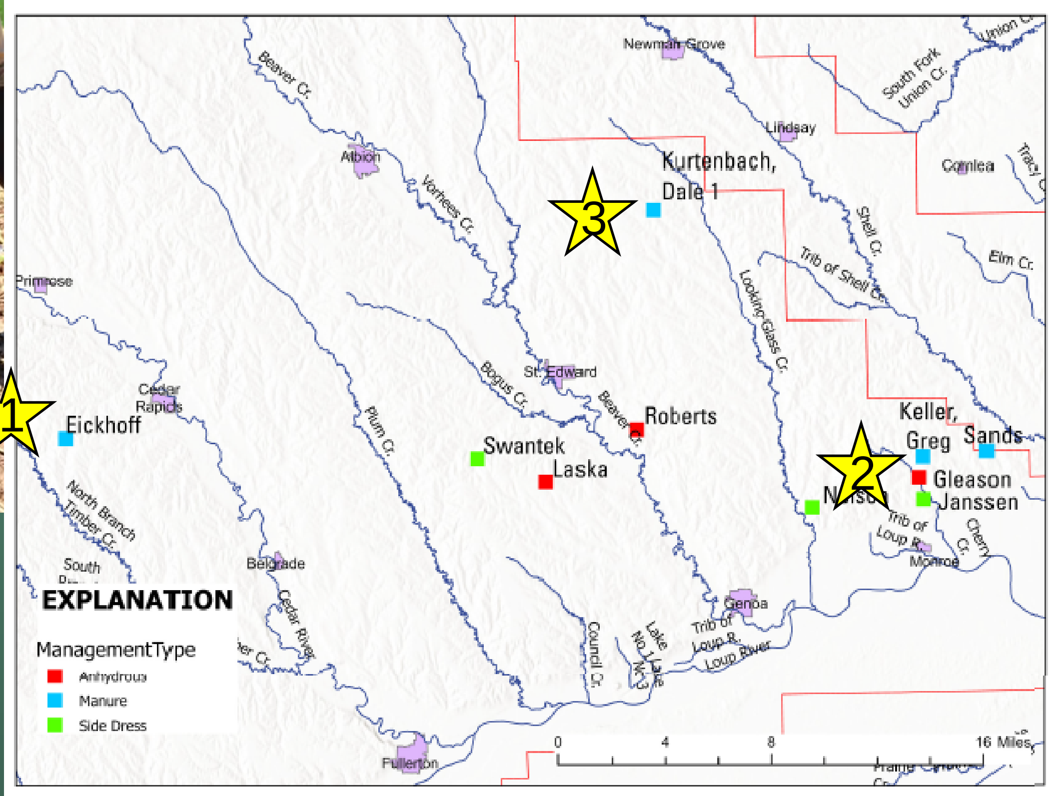
Soil moisture monitoring

- Soil moisture was collected continuously at 3 sites
  - Capture extreme precipitation events
  - Identify irrigation events
  - Track the development and extent of the root zone through the growing season
- Continuous water content data at 9 depths down to 3.3 ft



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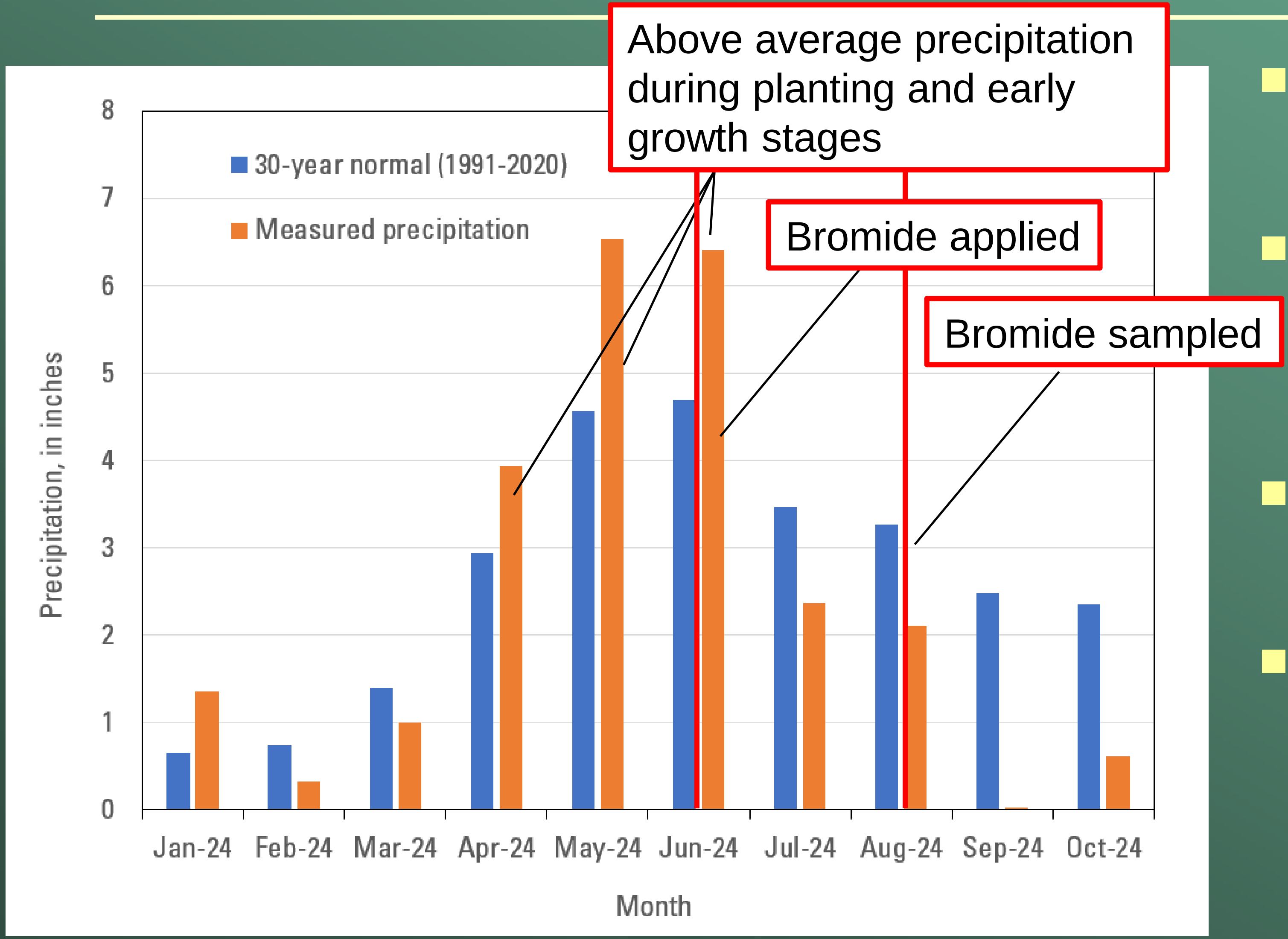
Measured precipitation vs. 30-year normal

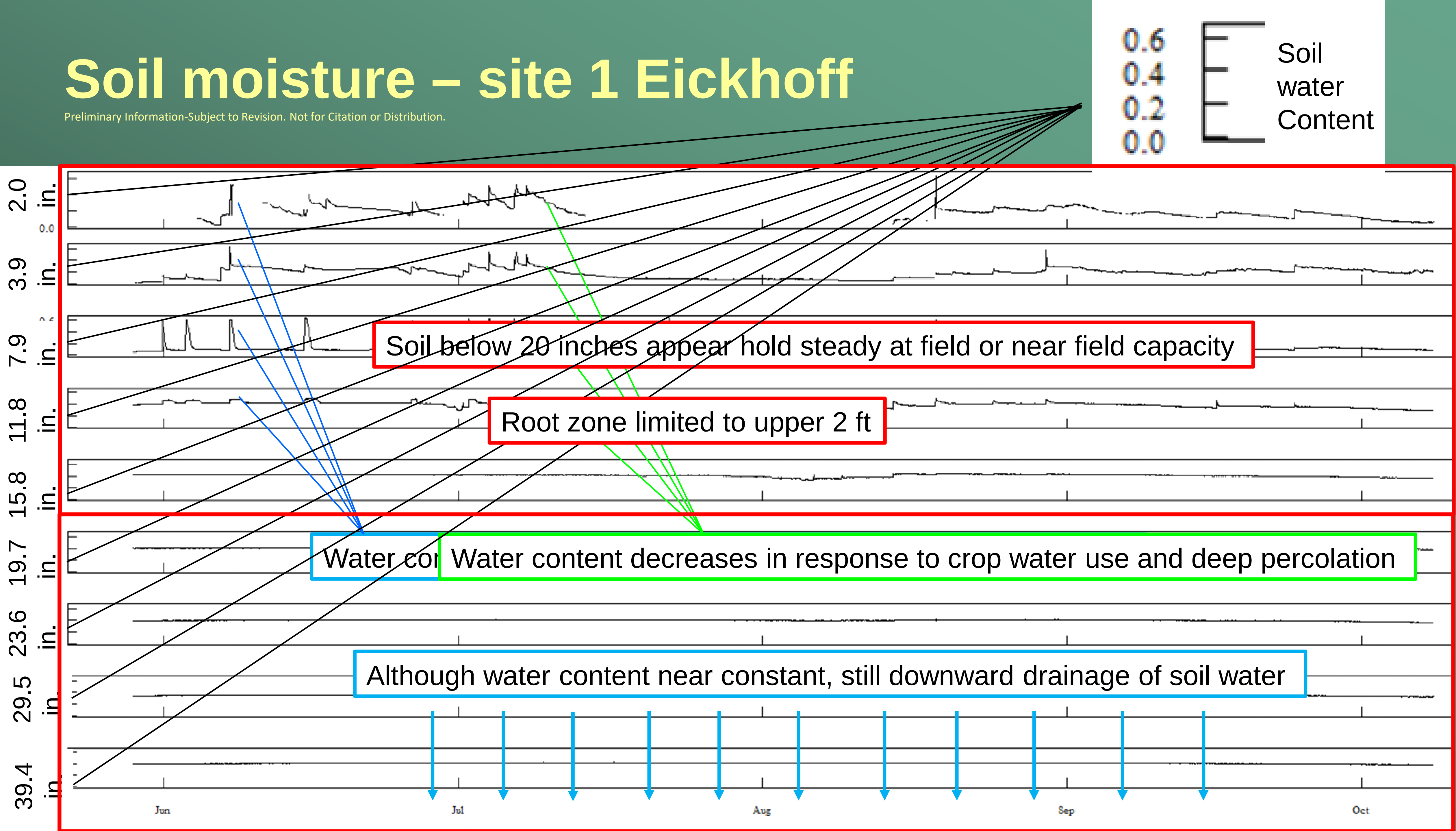


- Above normal precipitation totals April through June
- Increased precipitation affected planting and soil sampling schedules
- Later summer to early fall extremely dry
- Bromide movement expected following precipitation and/or irrigation

Data from National Center for Environmental Information, 2024

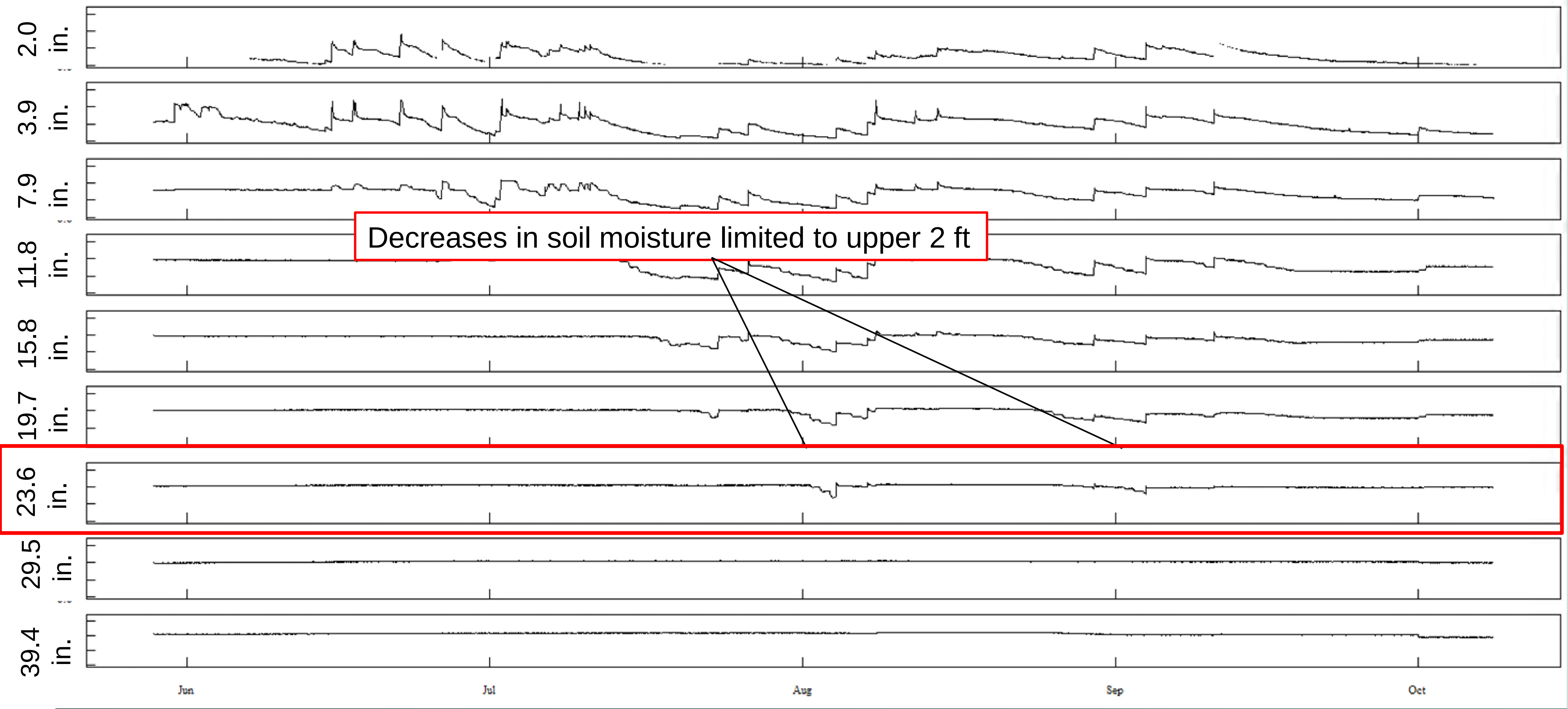
Soil moisture – site 1 Eickhoff

Preliminary Information-Subject to Revision. Not for Citation or Distribution.



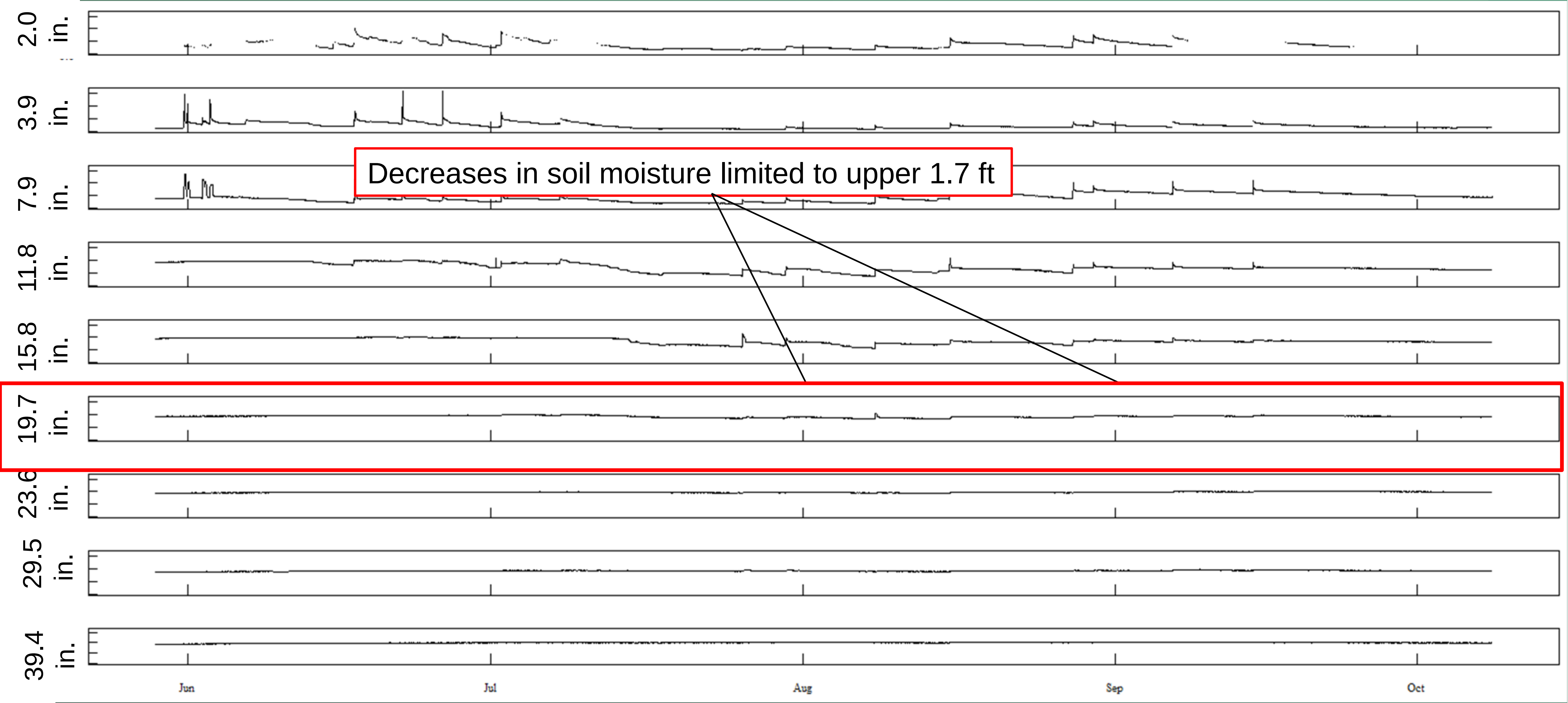
Soil moisture – site 2 Keller

Preliminary Information-Subject to Revision. Not for Citation or Distribution.



Soil moisture – site 3 Kurtenbach

Preliminary Information-Subject to Revision. Not for Citation or Distribution.

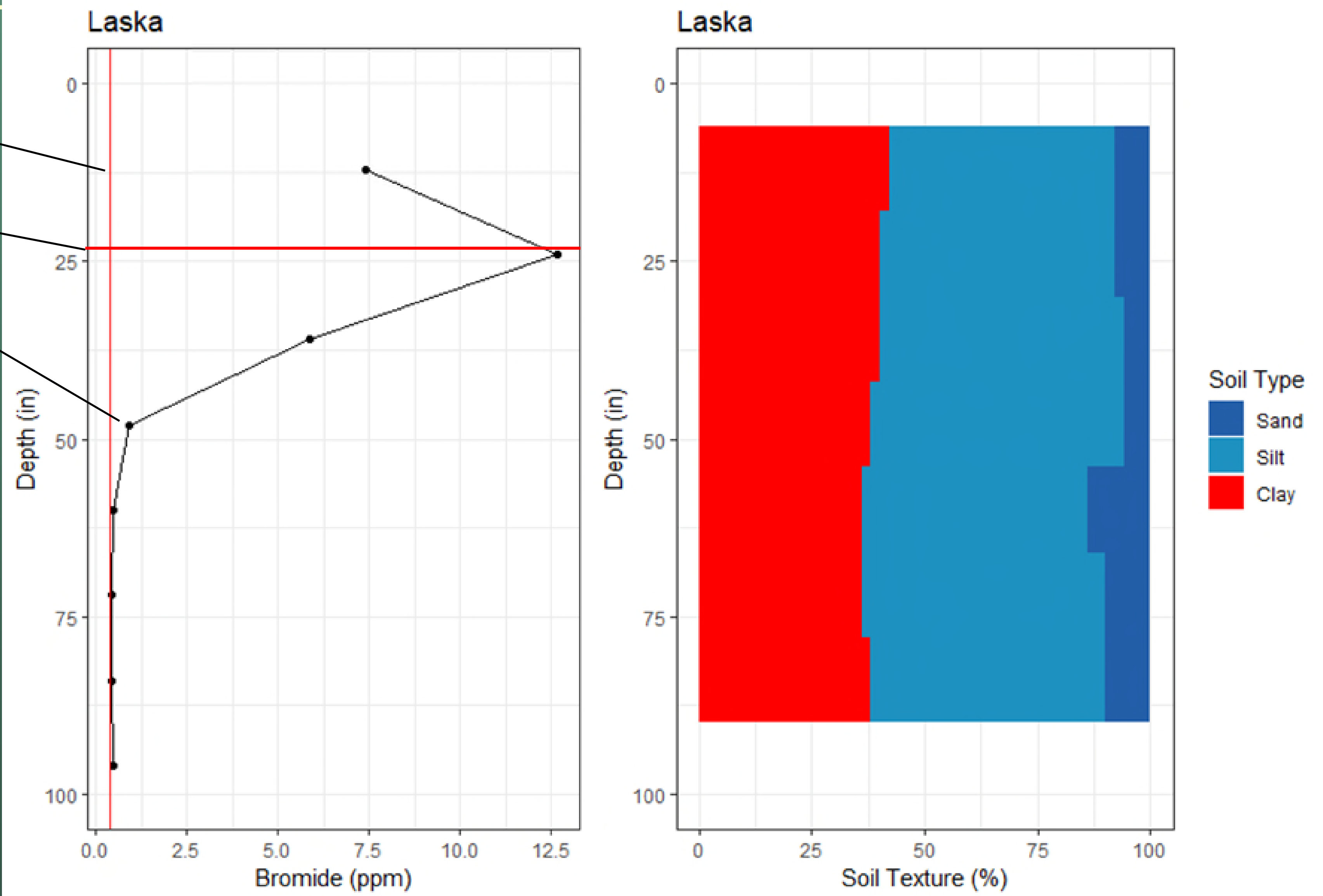


Example bromide tracer and soil texture data

Natural background concentration of bromide (0.5 ppm)

Maximum depth of root zone

Leading edge, or maximum depth



Bromide Tracer Movement

Fe

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Measured rainfall between Br-application and sampling

Practice	Anhydrous			Manure				Sidedressed		
Days Applied	79	73	48	56	48	52	56	52	55	58
Rainfall - In.	11.6	11.5	6.8	7.5	8.6	8.3	7.5	8.3	9.8	9.8
Depth-Ft.	Laska 1	Roberts 2	1	Eickhoff 2	Sands 2	Keller 2	Kurtenbach 2	Janssen 3	Nelson 1	Swantek 2
0-1										
1-2										
2-3										
3-4										
4-5										
5-6										
6-7										
7-8										
8-10										
10-12										
12-14										
14-16										
16-18										
18-20										
20-22										
22-24										
24-26										
26-28										
28-30										

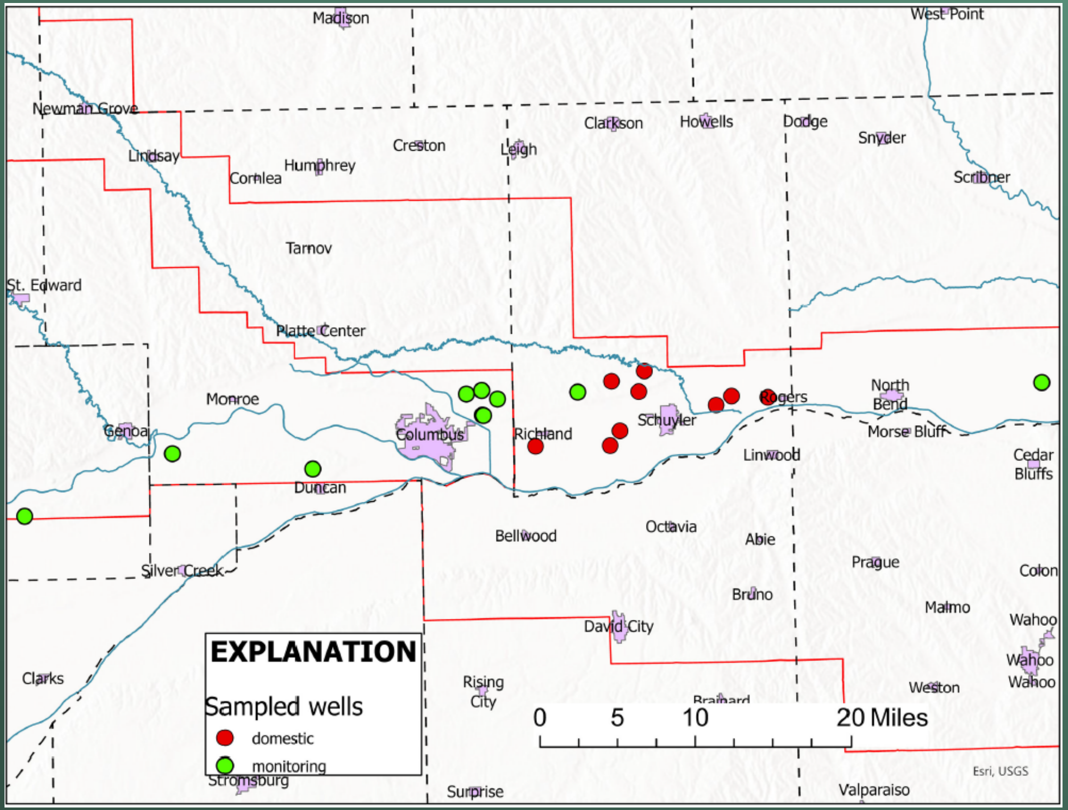
Depth sampled

Silty Clay Loam | Silty Clay | Silt Loam | Clay Loam

Bromide Leading Edge

Depth sampled

Legacy nitrate groundwater sampling project



- Complimentary study with Lower Platte North NRD assess role of legacy nitrate in current groundwater conditions
- Assess effectiveness of current water management strategies to reduce nitrate concentrations
- Sampled 24 wells to determine the age and nitrate concentration in groundwater

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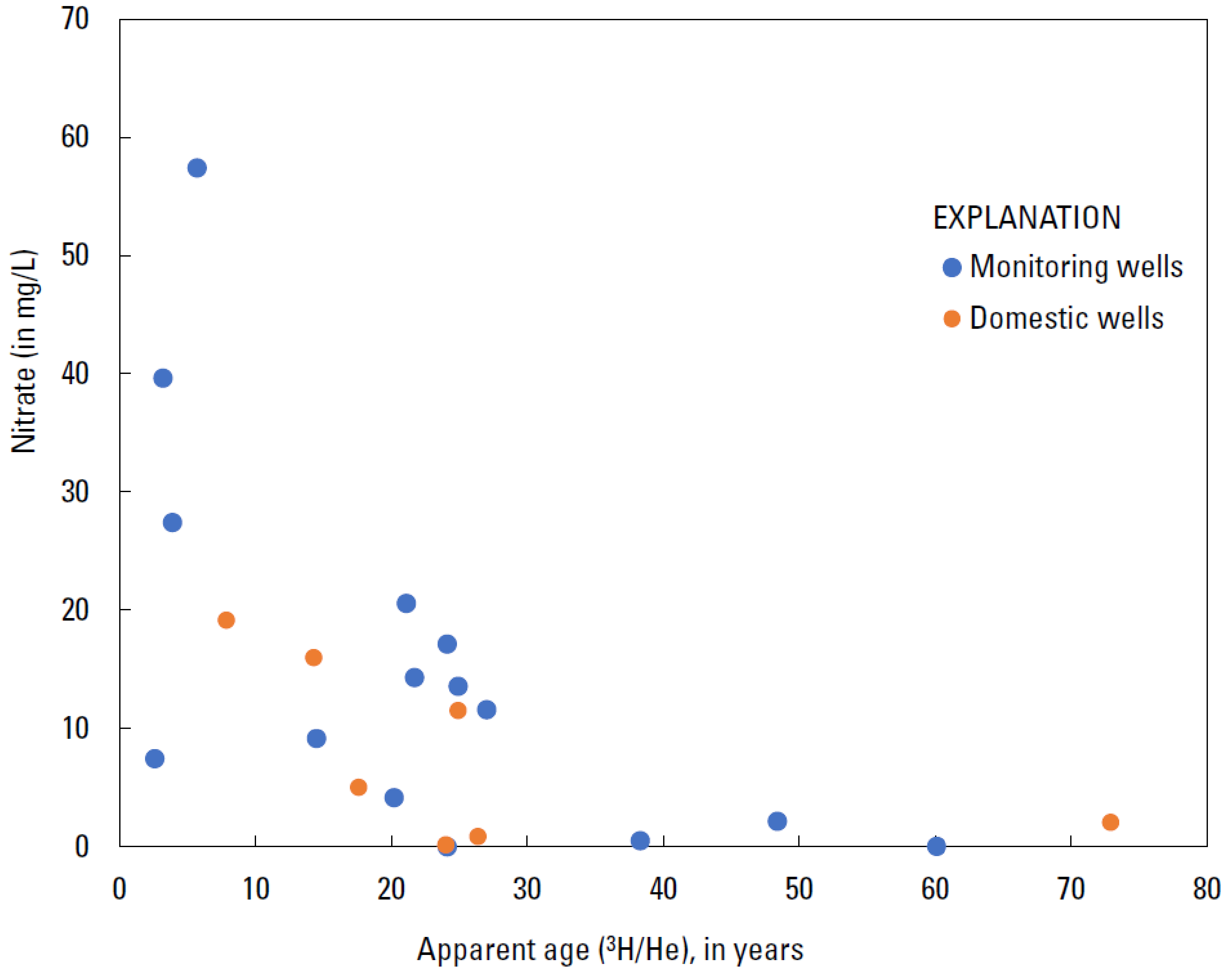
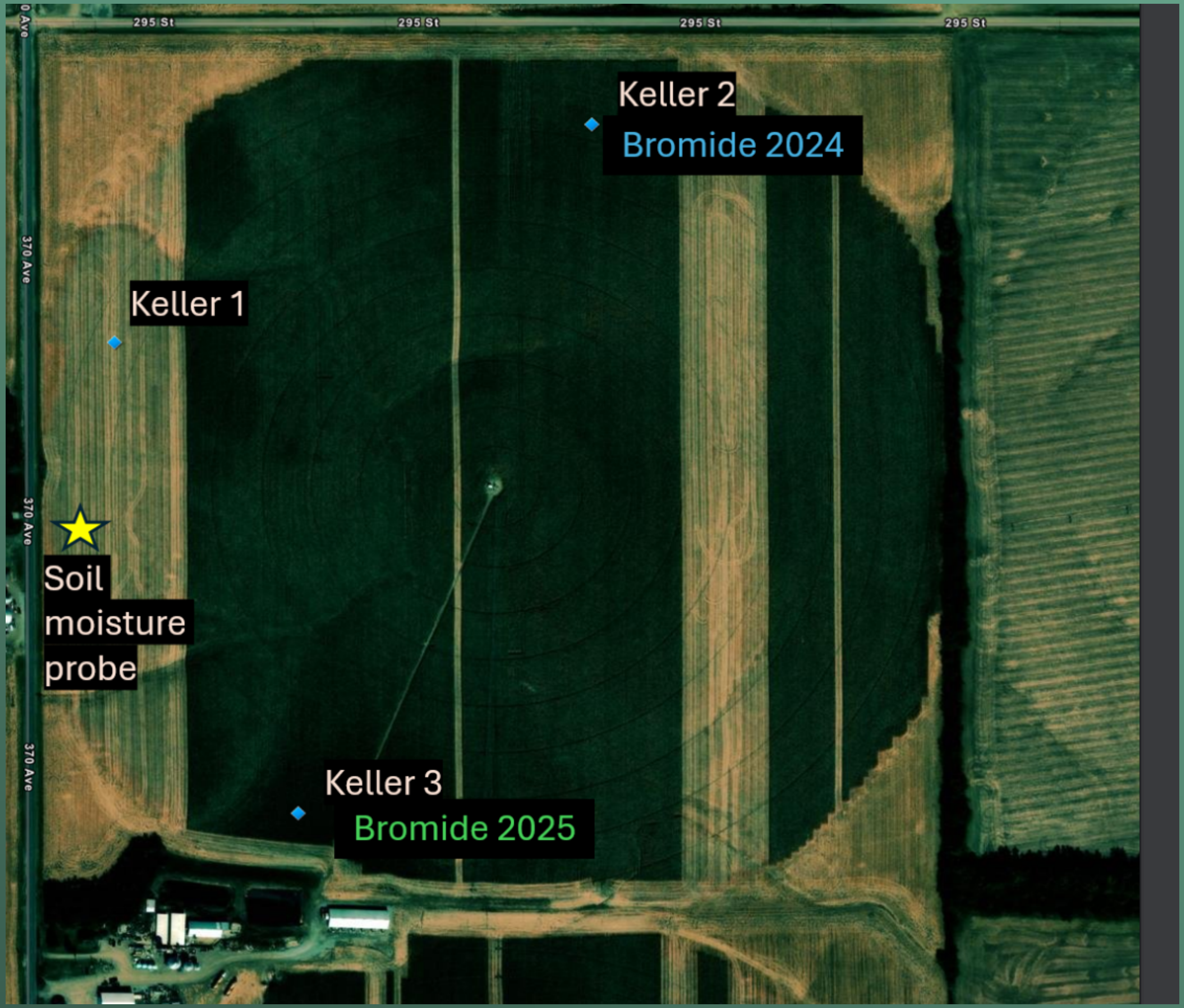
Groundwater age and nitrate concentration



- Apparent age and nitrate inversely related
- All samples that exceed EPA MCL of 10 mg/L are less than 27 years old
- Samples with the 3 highest concentrations of nitrate are less than 5 years old

Bromide tracer tests for 2025 growing season

- Bromide tracer tests repeated in new part of same fields
- Primary purpose was to determine how reproducible the results were
- Examine influence of different climatic conditions on results



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Bromide Tracer Movement

Summer 2025

Practice	Anhydrous			Manure				Sidedressed		
Days Applied	25	35	28	37	43	35	35	44	36	25
Rainfall - In.	10.4	12.9	13.8	11.7	10.9	9.1	11.7	10.9	12.9	10.4
Depth-Ft	Laska 3	Roberts 1	Connelly 3	Eickhoff 1	Sands 1	Keller 3	Kurtenbach 1	Janssen 2	Nelson 2	Swantek 1
0-1										
1-2										
2-3										
3-4									Did not detect	
4-5										
5-6										
6-7										
7-8										
8-10										
10-12										
12-14										
14-16										
16-18										
18-20										
20-22										
22-24										
24-26										
26-28										
28-30										

Silty Clay Loam	Silty Clay	Silt Loam	Clay Loam

Bromide Leading Edge

Testing Depth

Leaching rates: Bromide vs nitrate

- Bromide tracer tests are a standard approach to estimating nitrate movement in the unsaturated zone
- Bromide and nitrate are both anions and are expected to move through soils at similar rates
- Published literature suggests that if bromide is used to estimate loss of nitrate to leaching, it could lead to a 25% overestimate (Clay and others, 2004)
- Actual transport rates (i.e. maximum rate of movement) for nitrate and bromide were nearly identical (Jiang and others, 1997)

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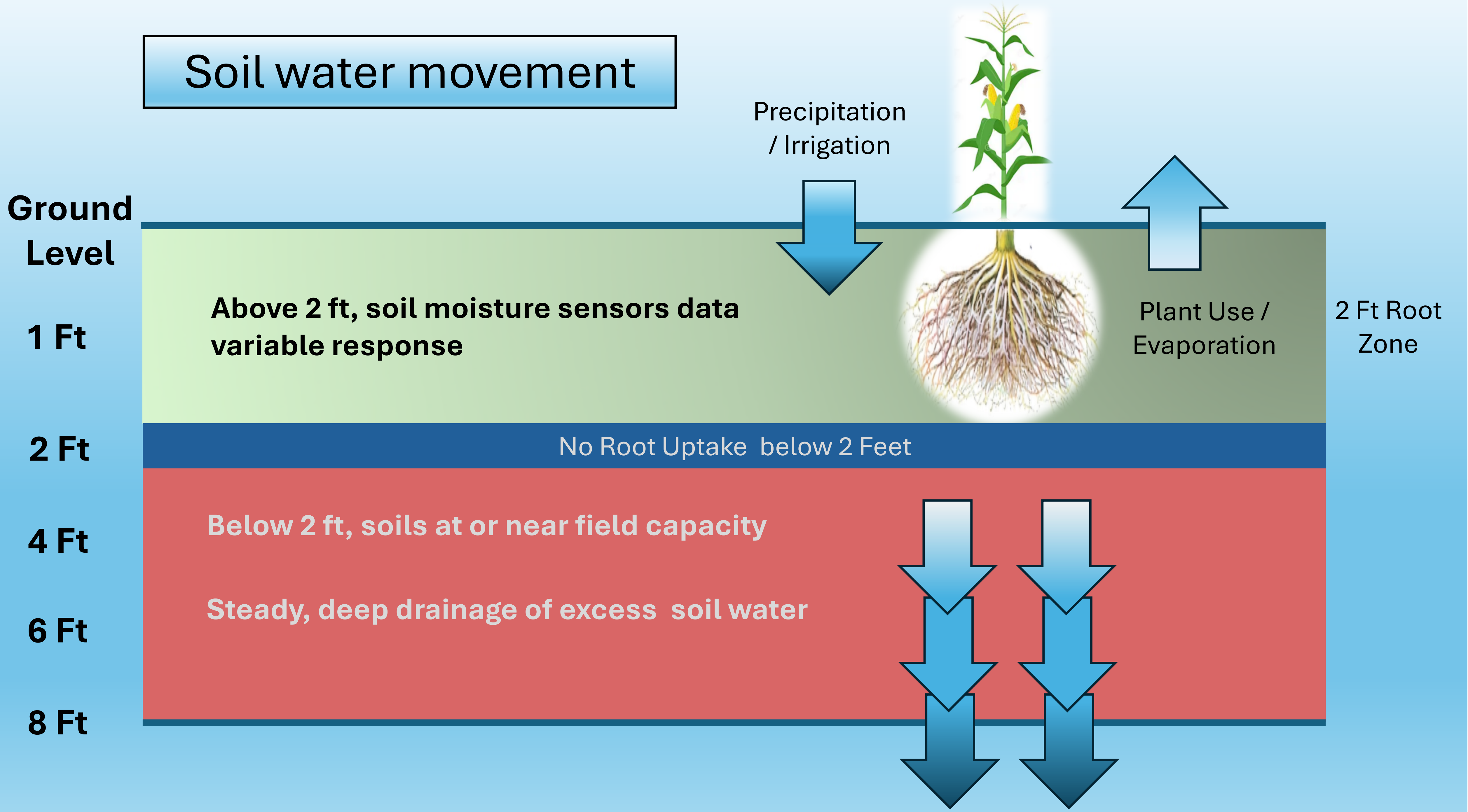
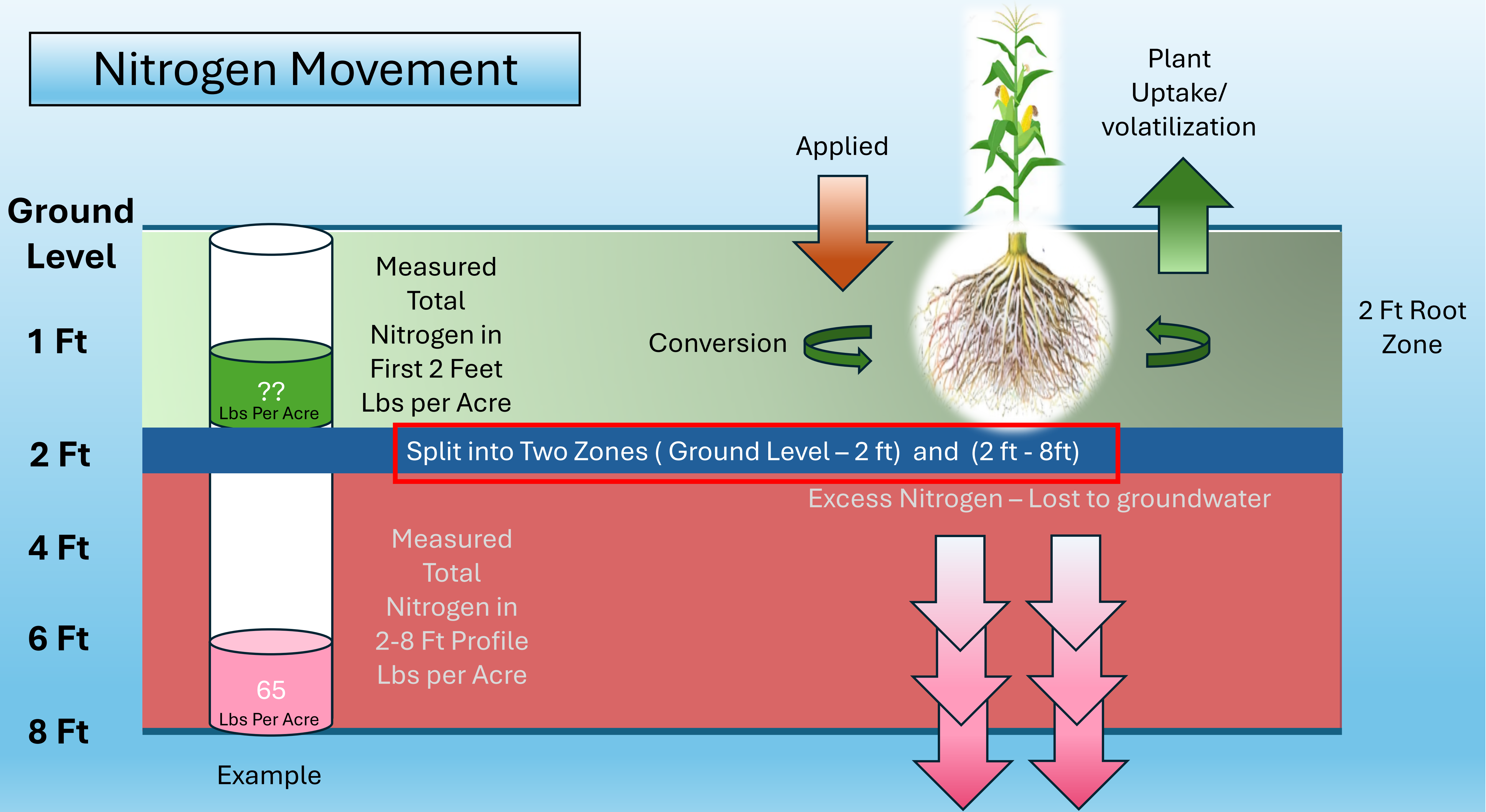
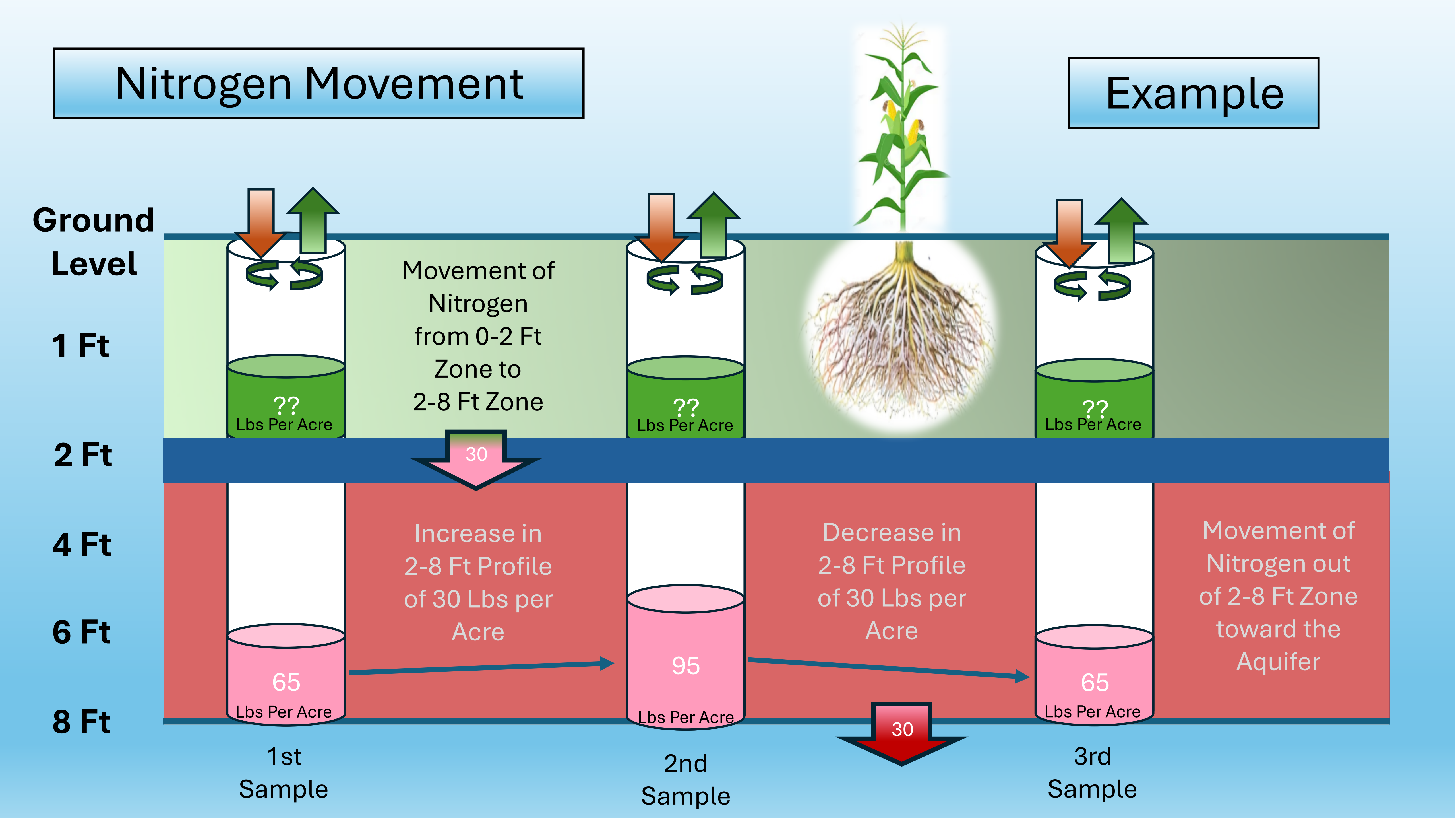
Soil water movement



Nitrogen Movement





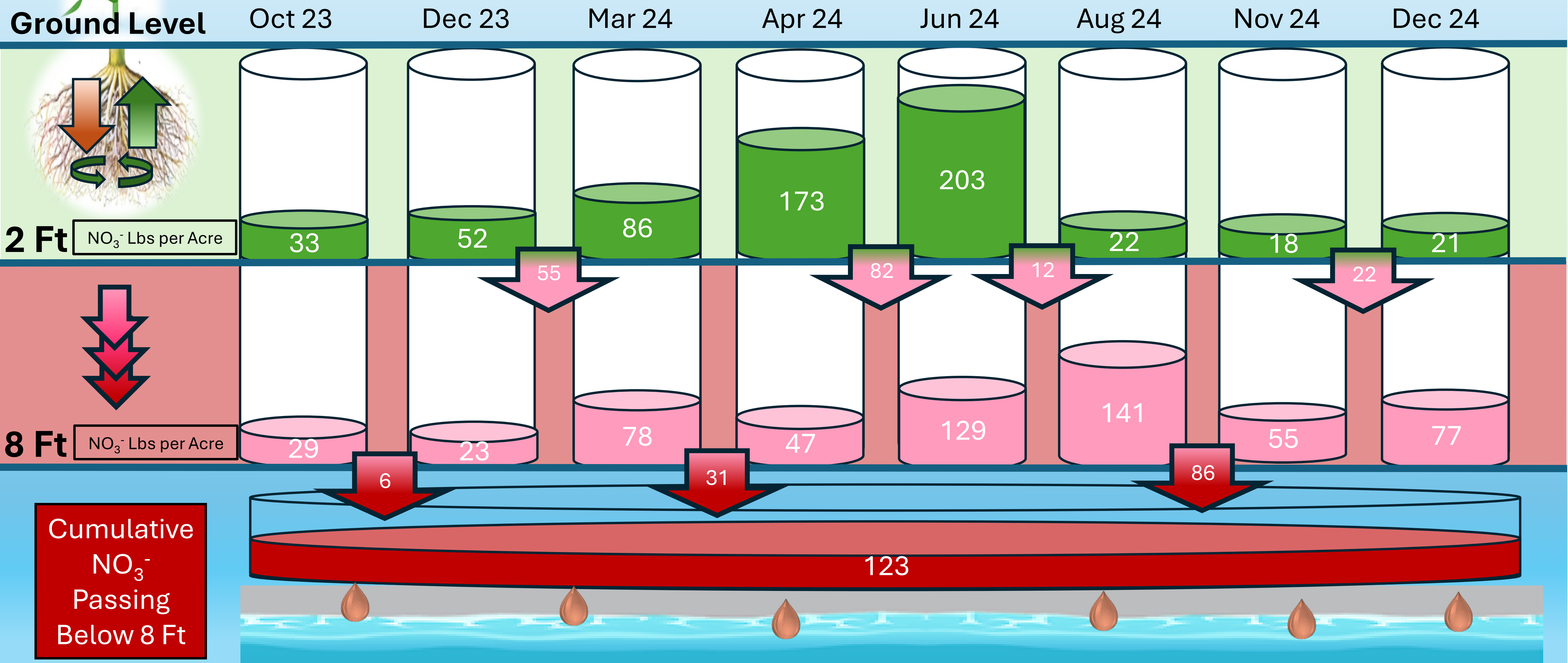
Nitrogen Movement
Example
Ground Level
1 Ft
2 Ft
4 Ft
6 Ft
8 Ft
?? Lbs Per Acre
Movement of Nitrogen from 0-2 Ft Zone to 2-8 Ft Zone
?? Lbs Per Acre
?? Lbs Per Acre
30
65 Lbs Per Acre
Increase in 2-8 Ft Profile of 30 Lbs per Acre
95 Lbs Per Acre
Decrease in 2-8 Ft Profile of 30 Lbs per Acre
65 Lbs Per Acre
Movement of Nitrogen out of 2-8 Ft Zone toward the Aquifer
30
1st Sample
2nd Sample
3rd Sample

NO_3^- Movement Through 8 Foot Profile

Anhydrous

Laska #1

3 Miles SE of St Edward



Preliminary Information-Subject to Revision. Not for Citation or Distribution.

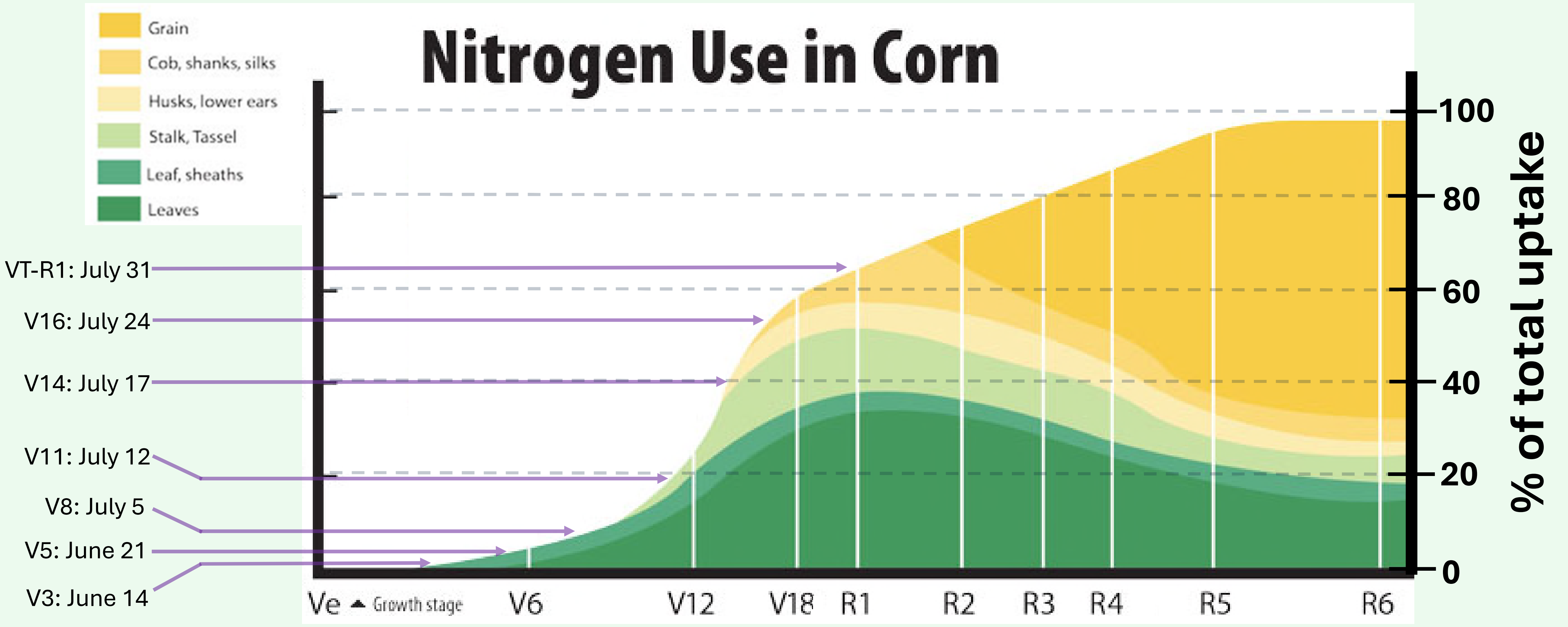
Corn Growth Stages 2024

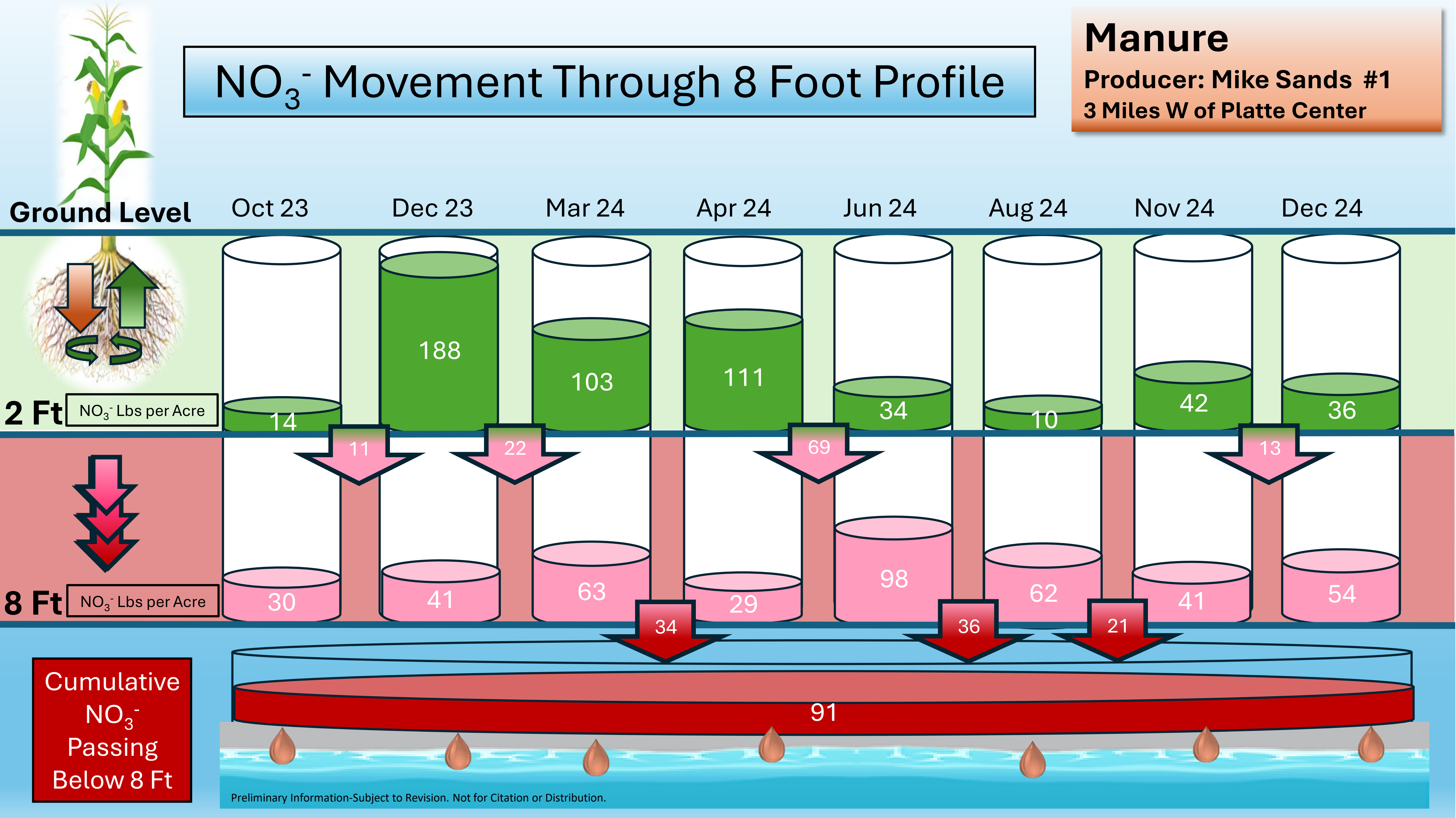
Field Two

- Planted: May 17
- Emerged: May 27

Anhydrous Application: 12/07/2023

Our wet spring caused delayed planting for this field. A corn plant has only taken up 10% of it's total required N for the season at growth stage V6, which for this field was around 06/25/2024





NO3- Movement Through 8 Foot Profile
Manure
Producer: Mike Sands #1
3 Miles W of Platte Center
Ground Level
Oct 23
Dec 23
Mar 24
Apr 24
Jun 24
Aug 24
Nov 24
Dec 24
2 Ft
NO3- Lbs per Acre
14
188
103
111
34
10
42
36
11
22
69
13
8 Ft
NO3- Lbs per Acre
30
41
63
29
98
62
41
54
34
36
21
Cumulative NO3- Passing Below 8 Ft
91
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

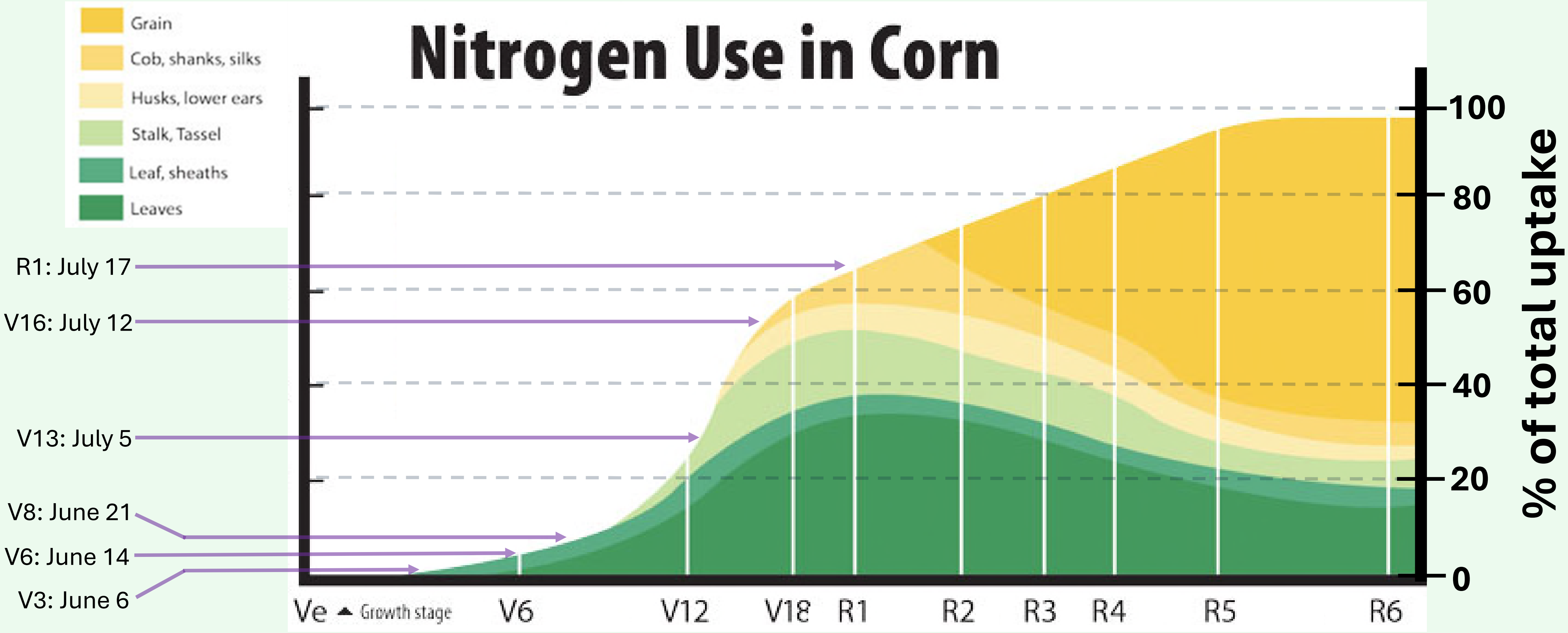
Corn Growth Stages 2024

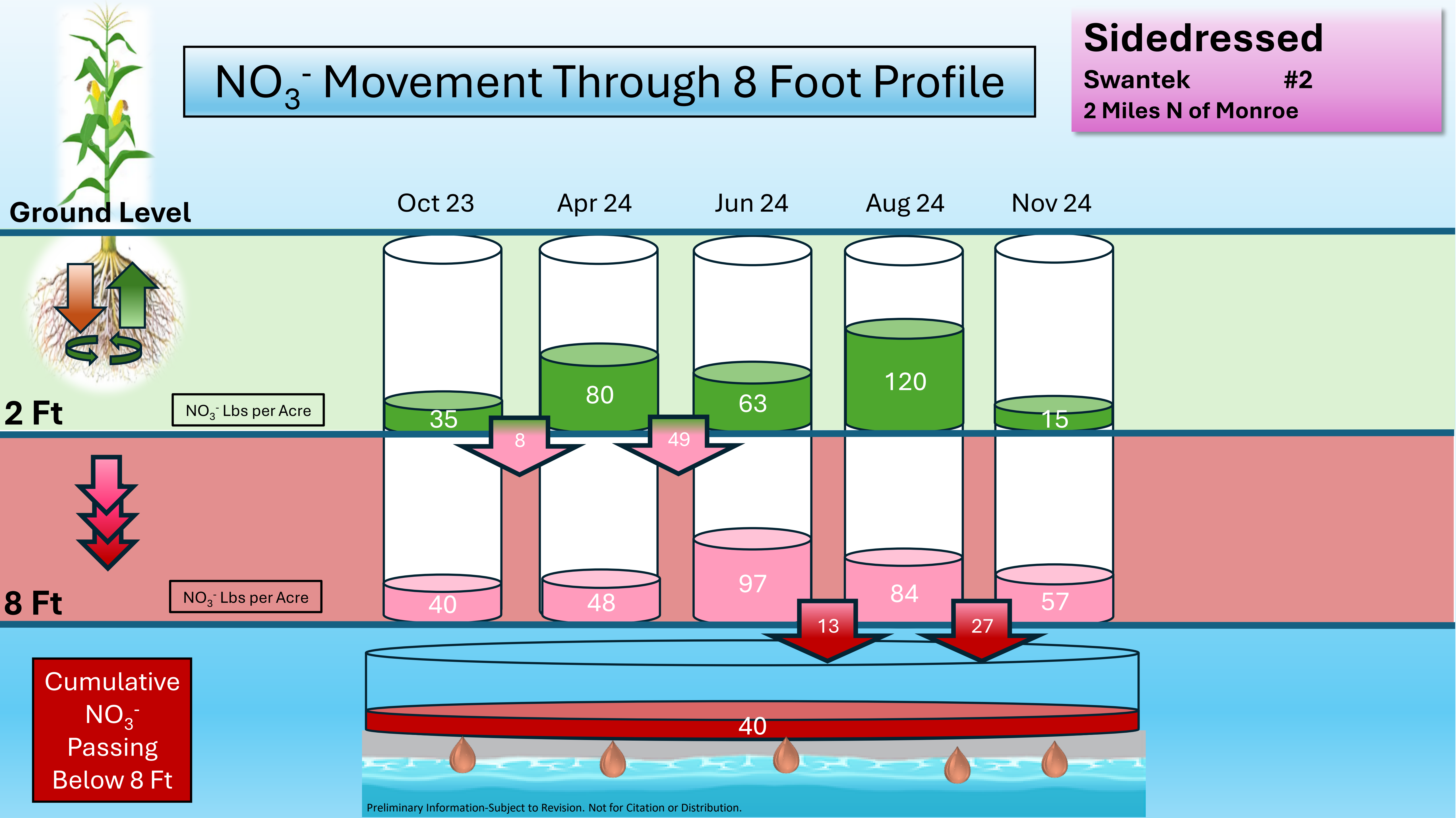
Field One

- Planted: April 24
- Emerged: May 10

Fall Applied Hog Slurry

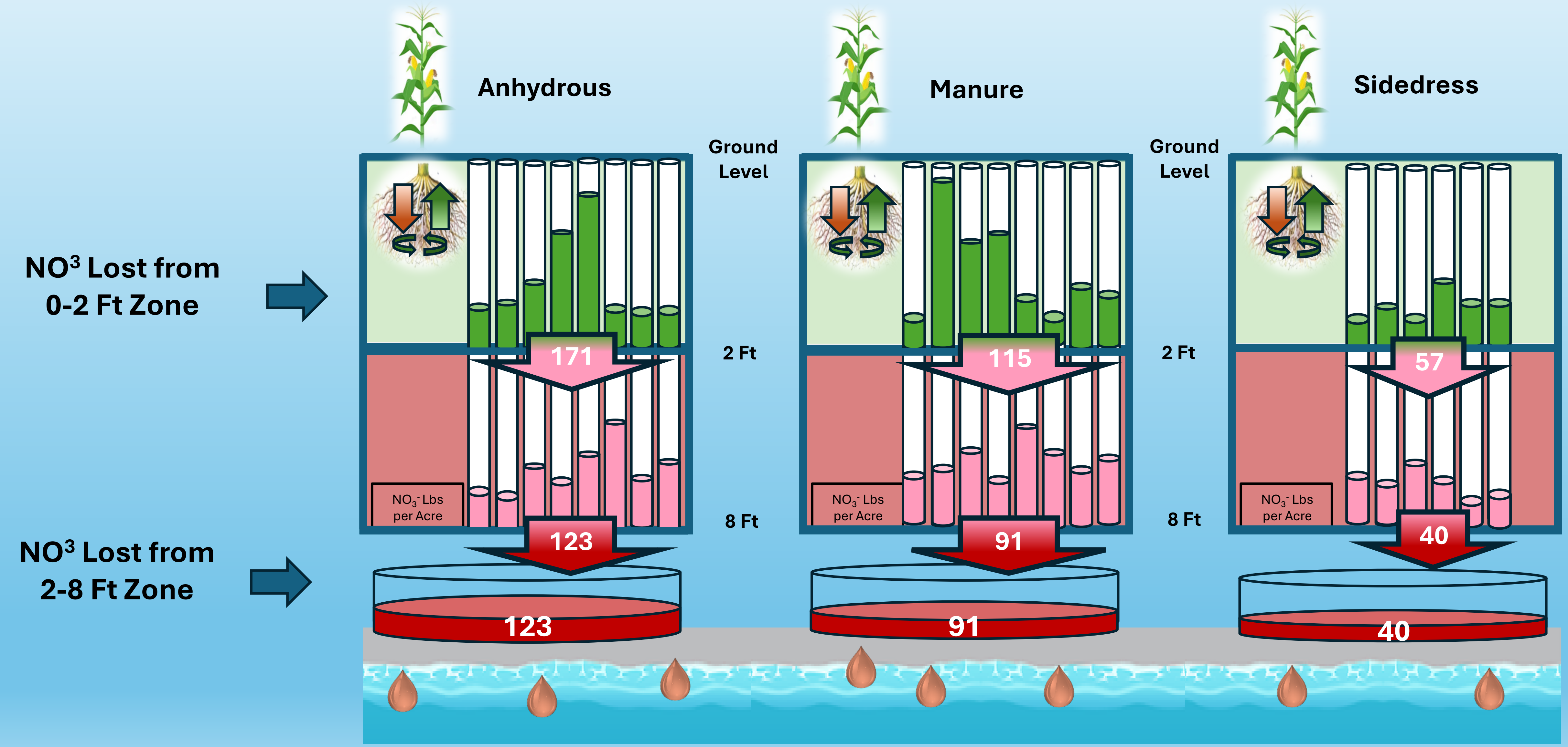
A corn plant has only taken up 10% of it's total required N for the season at growth stage V6, which for this field was around 06/14/2024





NO_3^- Movement Through 8 Foot Profile
Sidedressed
Swantek #2
2 Miles N of Monroe
Ground Level
Oct 23
Apr 24
Jun 24
Aug 24
Nov 24
2 Ft
NO_3^- Lbs per Acre
35
80
63
120
15
8
49
8 Ft
NO_3^- Lbs per Acre
40
48
97
84
57
13
27
Cumulative NO_3^- Passing Below 8 Ft
40
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

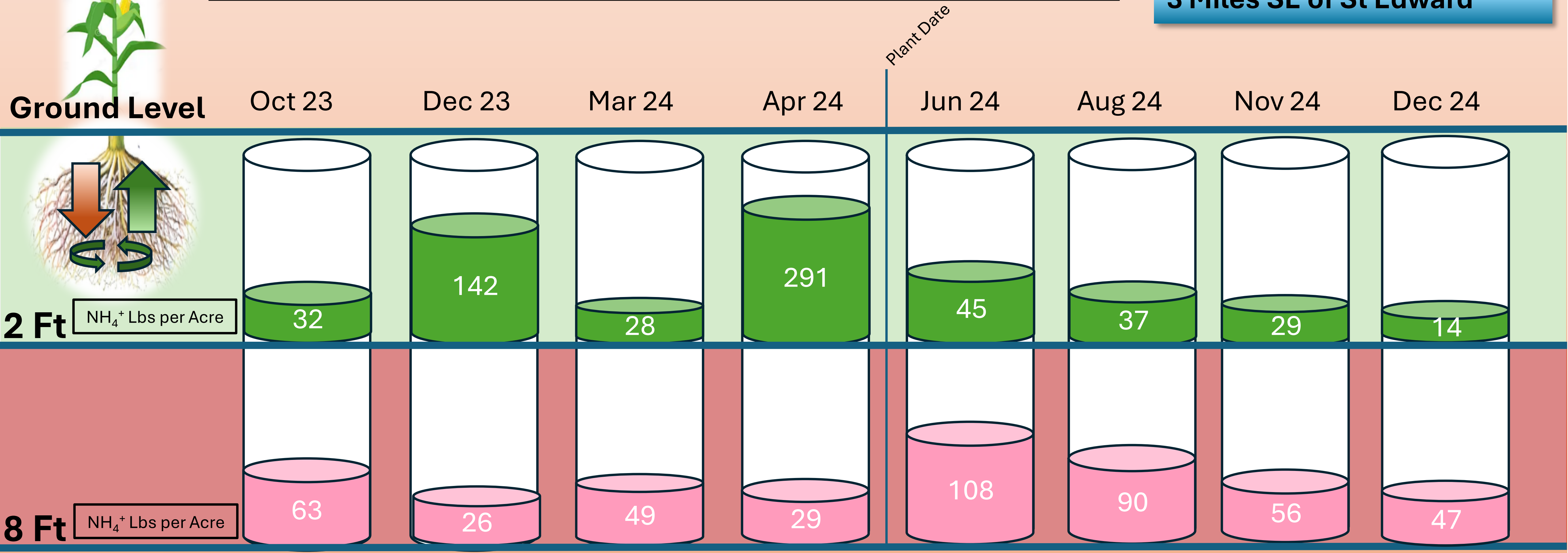
October 2023 to December 2024 NO_3^- Losses



Preliminary Information-Subject to Revision. Not for Citation or Distribution.

NH_4^+ concentrations in 8-foot profile

Anhydrous
Laska #1
3 Miles SE of St Edward



Questions remain: Is NH_4^+ moving through the profile?
Why is NH_4^+ so variable?
Why are NH_4^+ +concentrations so high at depth?

Preliminary observations and lessons

- Deep, loess-derived soils lack restrictive layer that would limit N movement
- Early spring/summer precipitation may have limited root zone development to 2 ft
- Maximum movement of bromide was near 1 inch per day; comparable to maximum rate of nitrate
- Rapid water movement and shallow root zone increases the likelihood some N is not being used by the crop and lost to groundwater

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Preliminary observations

- N movement influenced by application of groundwater - water application and nitrogen management go hand in hand
- Questions remain about ammonium concentrations and movement

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Next steps

- Continued soil coring and analysis
  - 2025 growing season soil core collection and analysis is ongoing
  - Continue to track migration of bromide
- Examine and interpret soil moisture data from 2025 growing season
  - Temperature Sensors added to sites
  - Estimate root zone depth and capture potential extreme rain events
  - Different precipitation patterns could produce different results
- Water Sustainability Fund grant: expanding pilot project into new areas of the LLNRD and include focus areas within Central Platte and Upper Big Blue NRDs

Questions

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