High Carbon Amendment Applications for Reducing Nitrate Leaching Potential from Vegetable and Strawberry Fields in Rainy Winters

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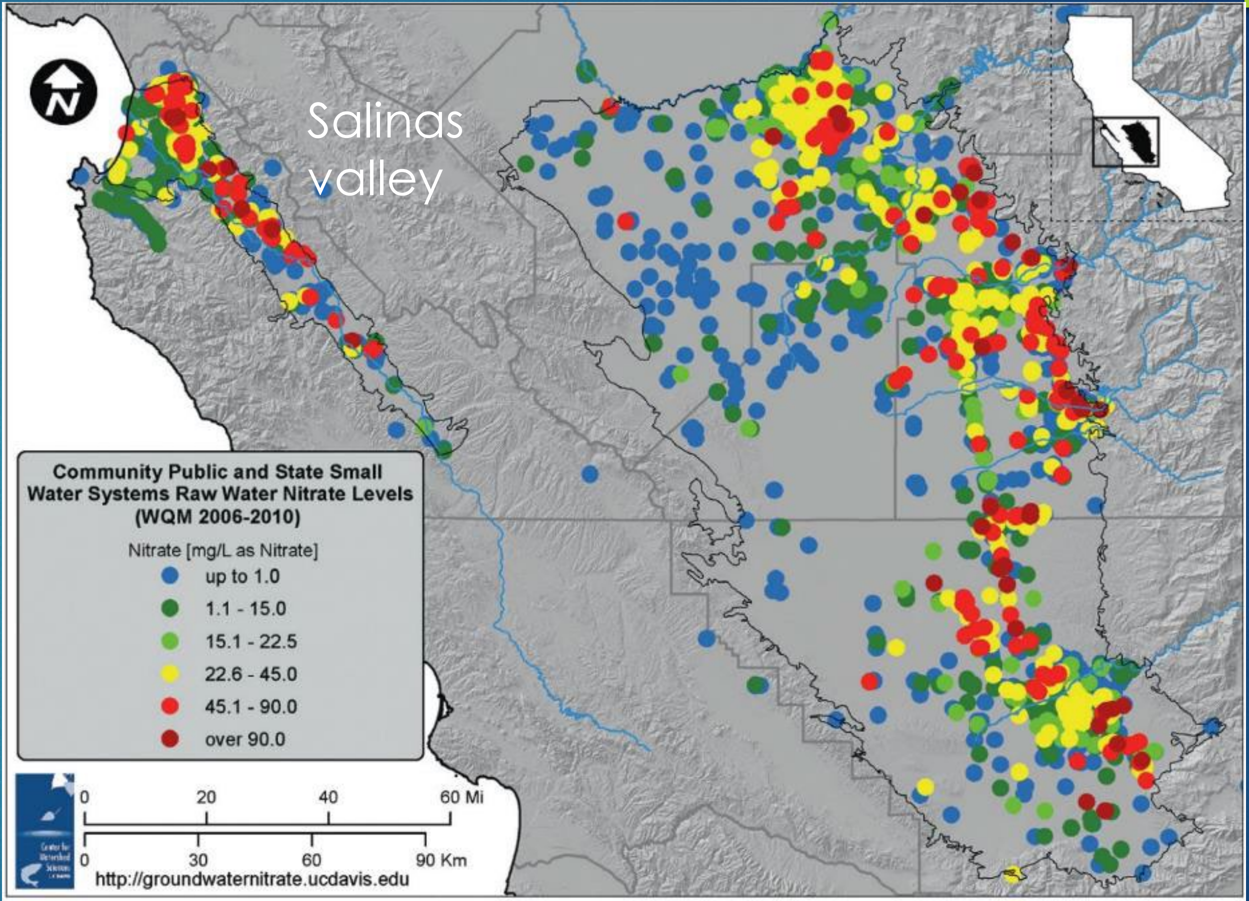
Background: Nitrate contaminated groundwater

- ~254,000 people in Tulare Lake Basin and Salinas Valley face health risks
- Main causes:
  1. Agricultural fertilizers and animal wastes applied to croplands
  2. Autumn incorporation of **N-rich crop residues**



Maximum reported raw-level nitrate concentration in community public water systems and state-documented state small water systems, 2006–2010. *Source:* CDPH PICME WQM Database.

(Center for Watershed Science, 2012)

Background

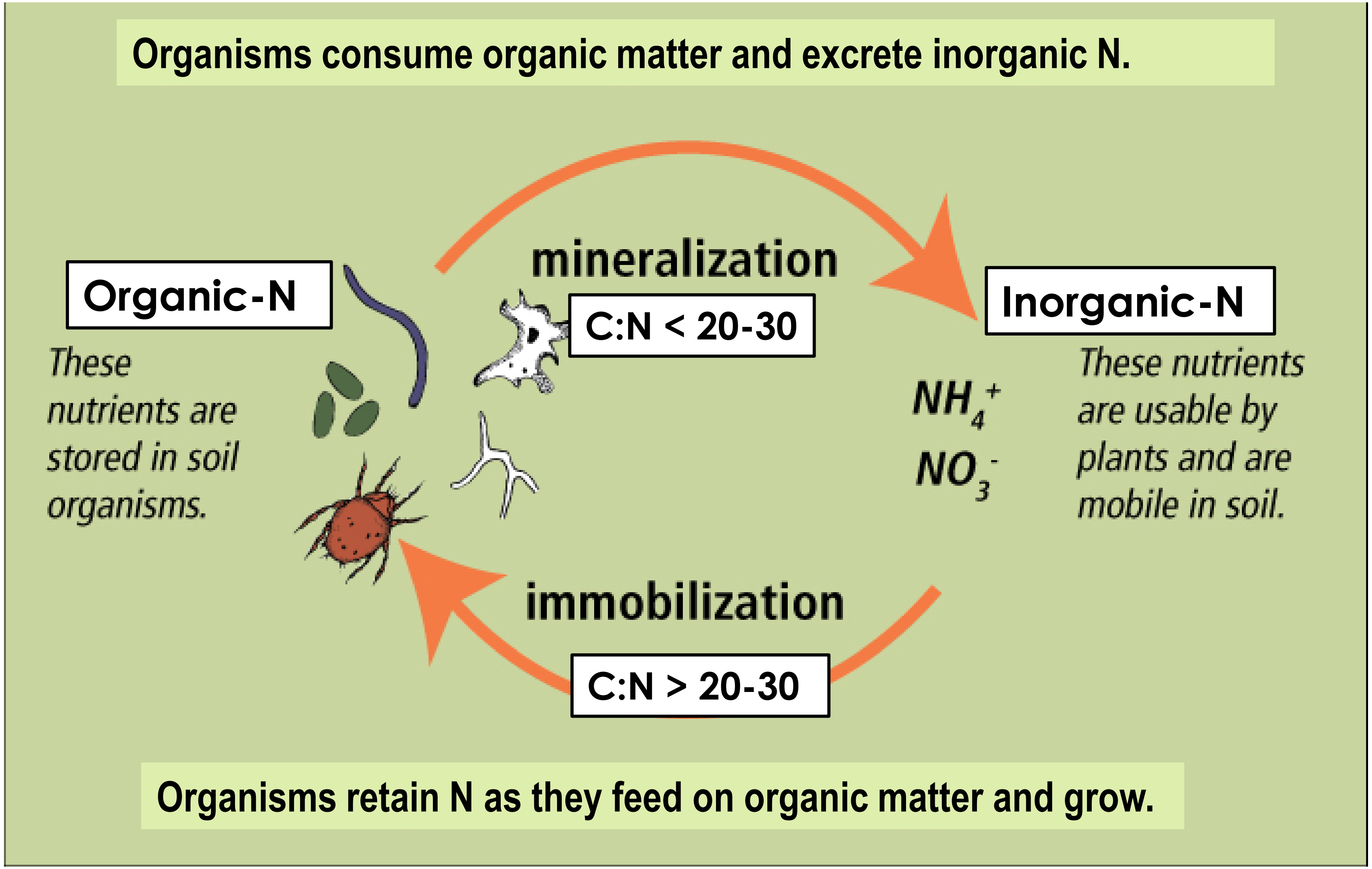
- **Broccoli and cauliflower residues**; **~220 lb-biomass N/ac, grown at ~160,000 ac** in CA
- **Winter soil temp** at 6" depth; **68-77 deg F**
- **~120 N-lb/ac of broccoli-derived N lost in a broccoli field** after 5" of rain in Dec (Smith et al., 2016)
- **Cover crop** is not widely adopted due to high land lease and a conflict with spring planting

- Studies in EU and Canada; use of **high CN amendment to immobilize residual N in soil** (Chaves et al., 2007 and many others)
- **Compost application in Autumn**; a common practice in Salinas valley -> Switching compost to high CN amendment… a **Best Management Practice?**
- **Working on this practice since 2016**

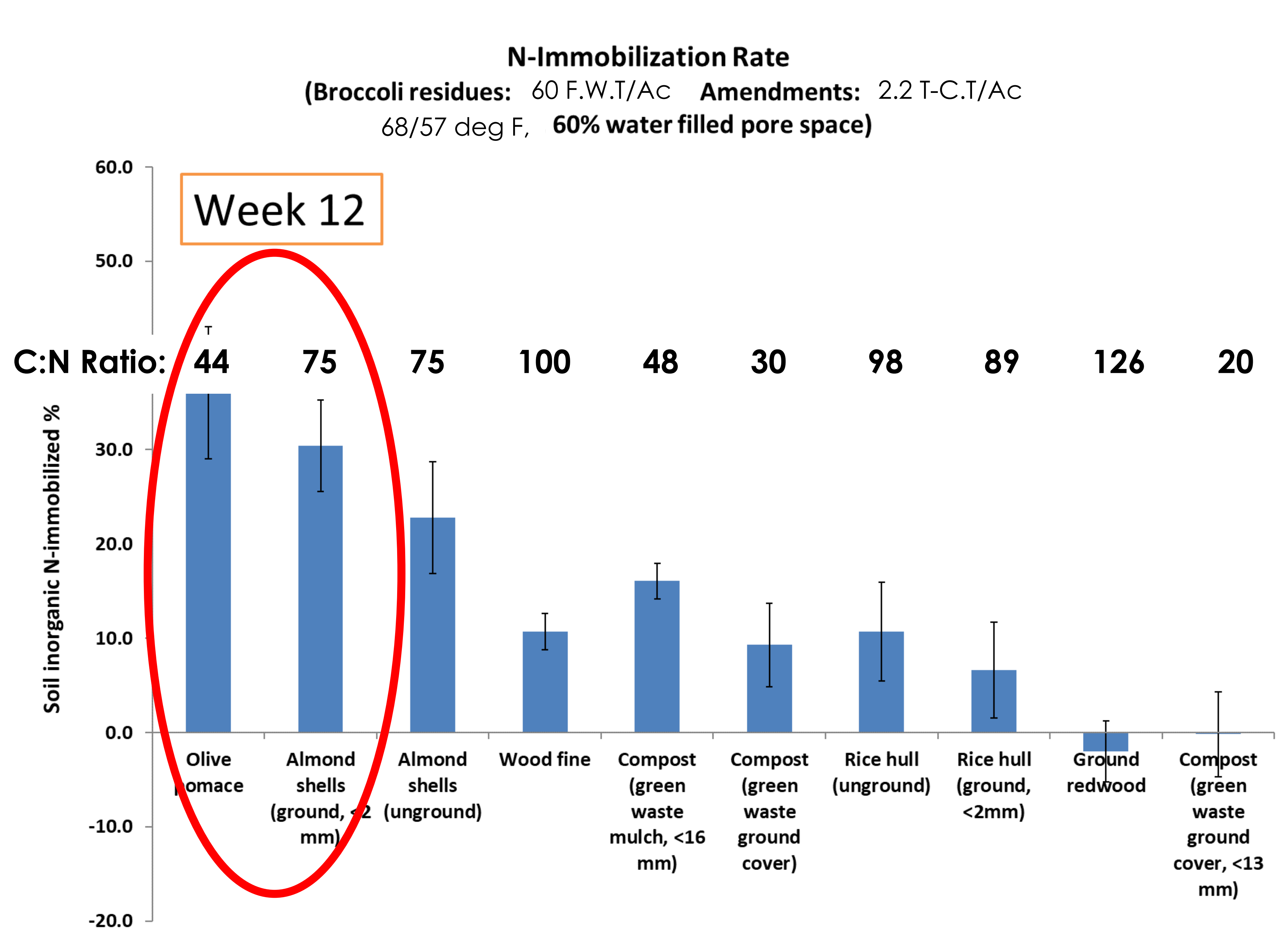
Outline

- **Nitrogen Mineralization & Immobilization**
- **High Carbon Amendment Applications (HCAAs)**
  - Type of Amendments (Lab incubation)
  - Broccoli-Lettuce Rotation (Replicated field trial)
  - Broccoli-Strawberry Rotation (Replicated field trial)
  - Broccoli-Strawberry Rotation (Unreplicated demo field trial)
  - Almond shells: particle sizes and rates (Lab incubation)
- **HCAAs and AgOrder 4.0 by the Central Coast Regional Water Quality Control Board**

N mineralization vs. N immobilization



(Adopted from USDA-NRCS, 2017)



N-Immobilization Rate
(Broccoli residues: 60 F.W.T/Ac Amendments: 2.2 T-C.T/Ac
68/57 deg F, 60% water filled pore space)
Week 12
C:N Ratio: 44 75 75 100 48 30 98 89 126 20
Soil inorganic N-immobilized %
60.0
50.0
30.0
20.0
10.0
0.0
-10.0
-20.0
Olive pomace
Almond shells (ground, <2 mm)
Almond shells (unground)
Wood fine
Compost (green waste mulch, <16 mm)
Compost (green waste ground cover)
Rice hull (unground)
Rice hull (ground, <2mm)
Ground redwood
Compost (green waste ground cover, <13 mm)

Visualizing N-Immobilization

Almond shells
CN: 86

Unground

Ground < 2 mm

Almond shells 17 T/A, 60% WFPS
1 week after incubation at 77 °F

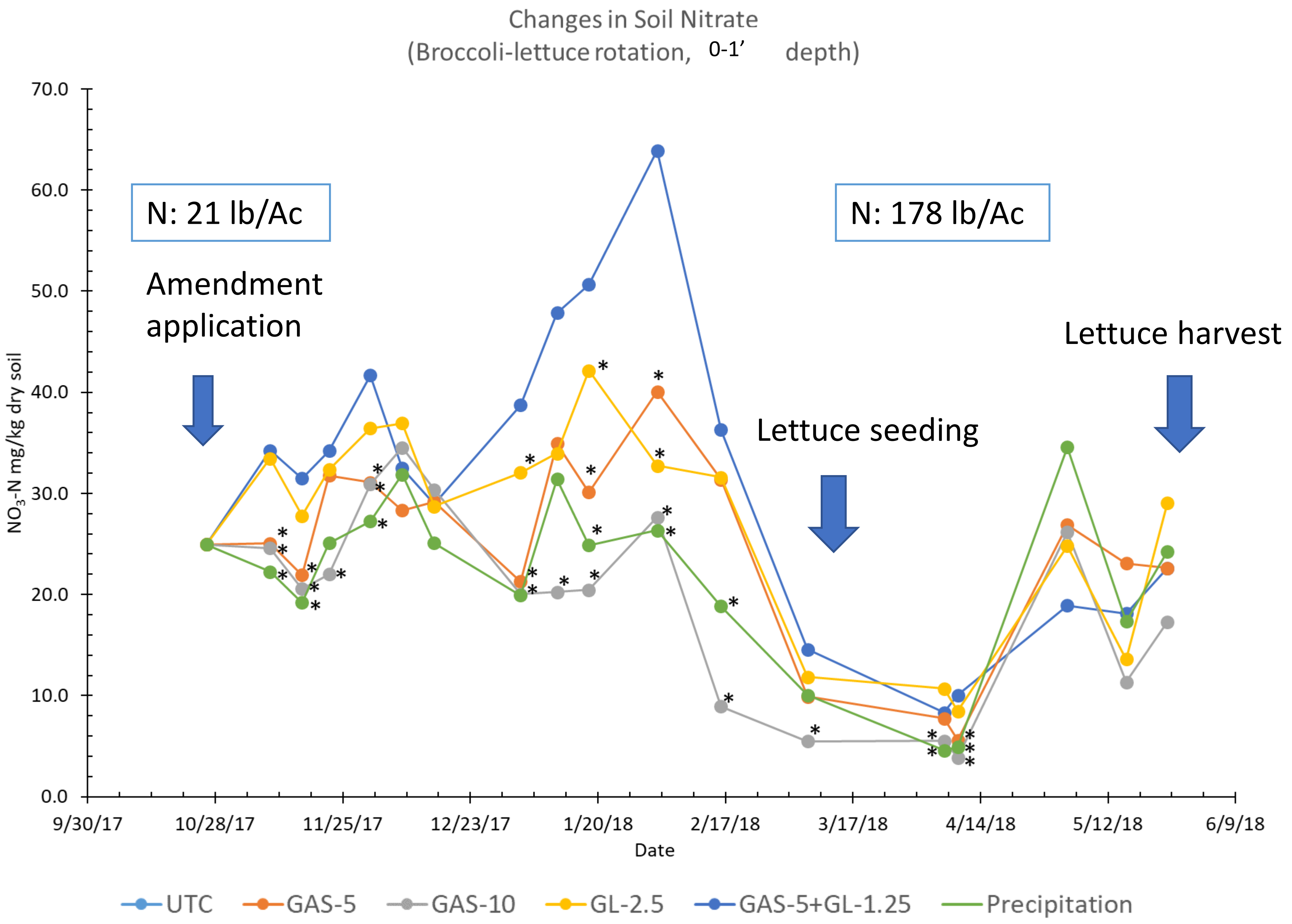
Penicillium, Rhizopus, Mucor

No primary plant pathogens found

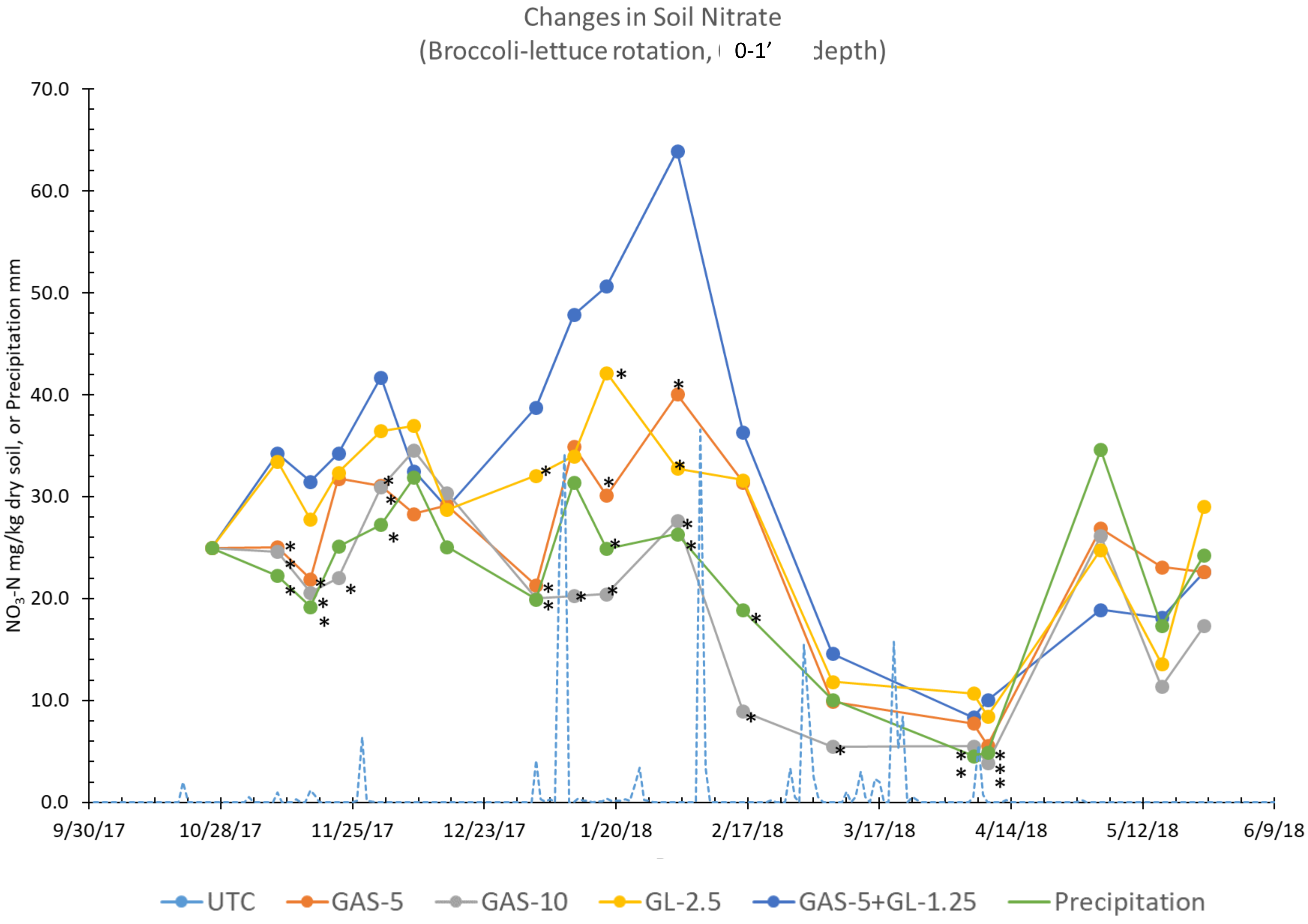
Field Trials (Randomized complete block design)

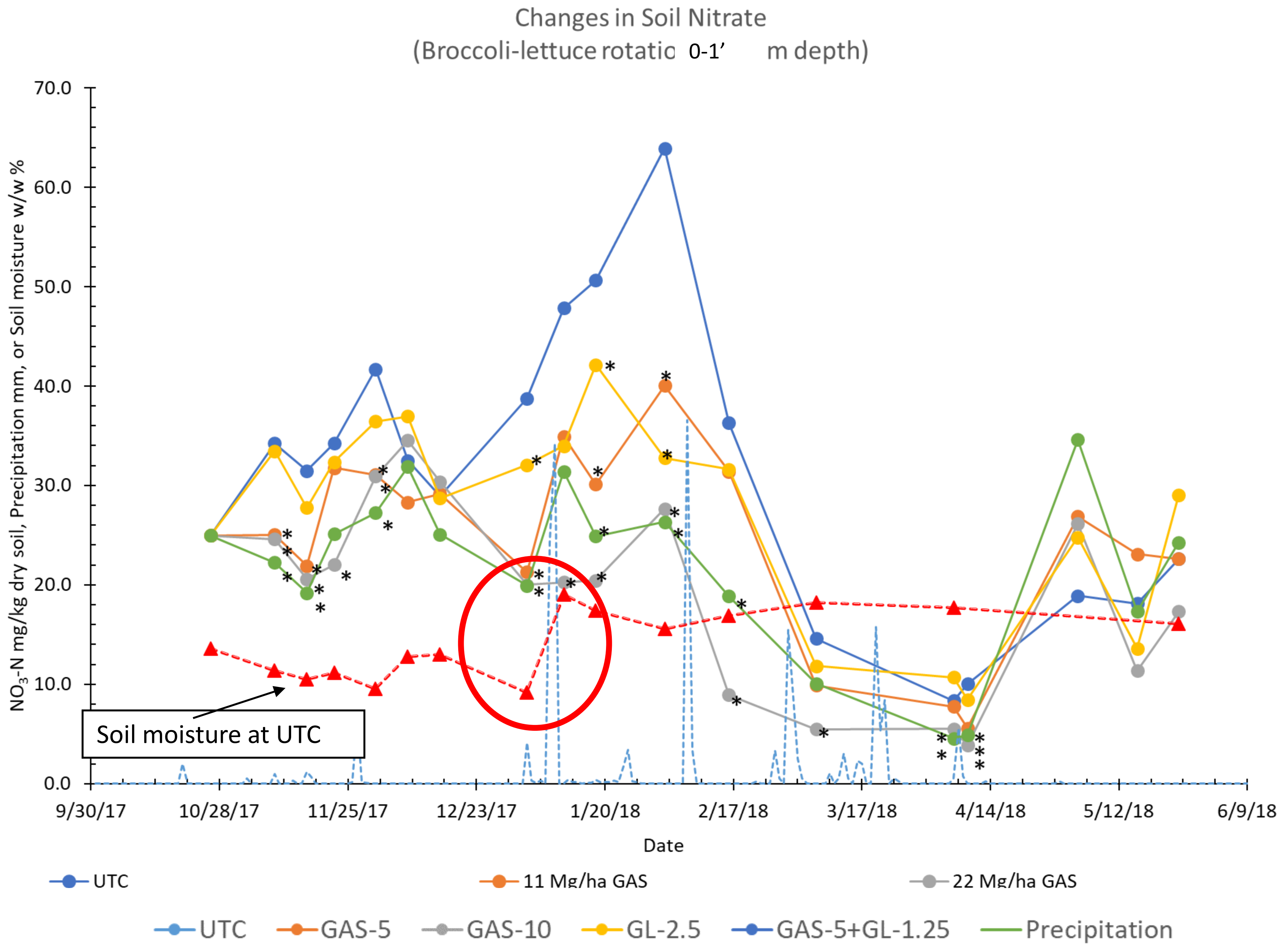
- **<u>Broccoli – Lettuce rotation (Conv. Silty clayloam. 4 reps)</u>**
  - 2017-18; Ground almond shell (GAS)5 T/Ac
    GAS 10 T/Ac
    Glycerol 2.5 T/Ac
    GAS 5 T/Ac + Glycerol 1.25 T/Ac
    Untreated control (UTC)
- **<u>Broccoli – Strawberry rotation (Organic. Clay. 3 reps)</u>**
  - 2017-18; GAS 5 T/Ac
    Ground olive pomace (GOP) 5 T/Ac
    UTC

- Each plot: 100' x 20'
- Soil inorganic N monthly at 0'-1', 1'-2', 2'-3'depth
- Yield of successive crop

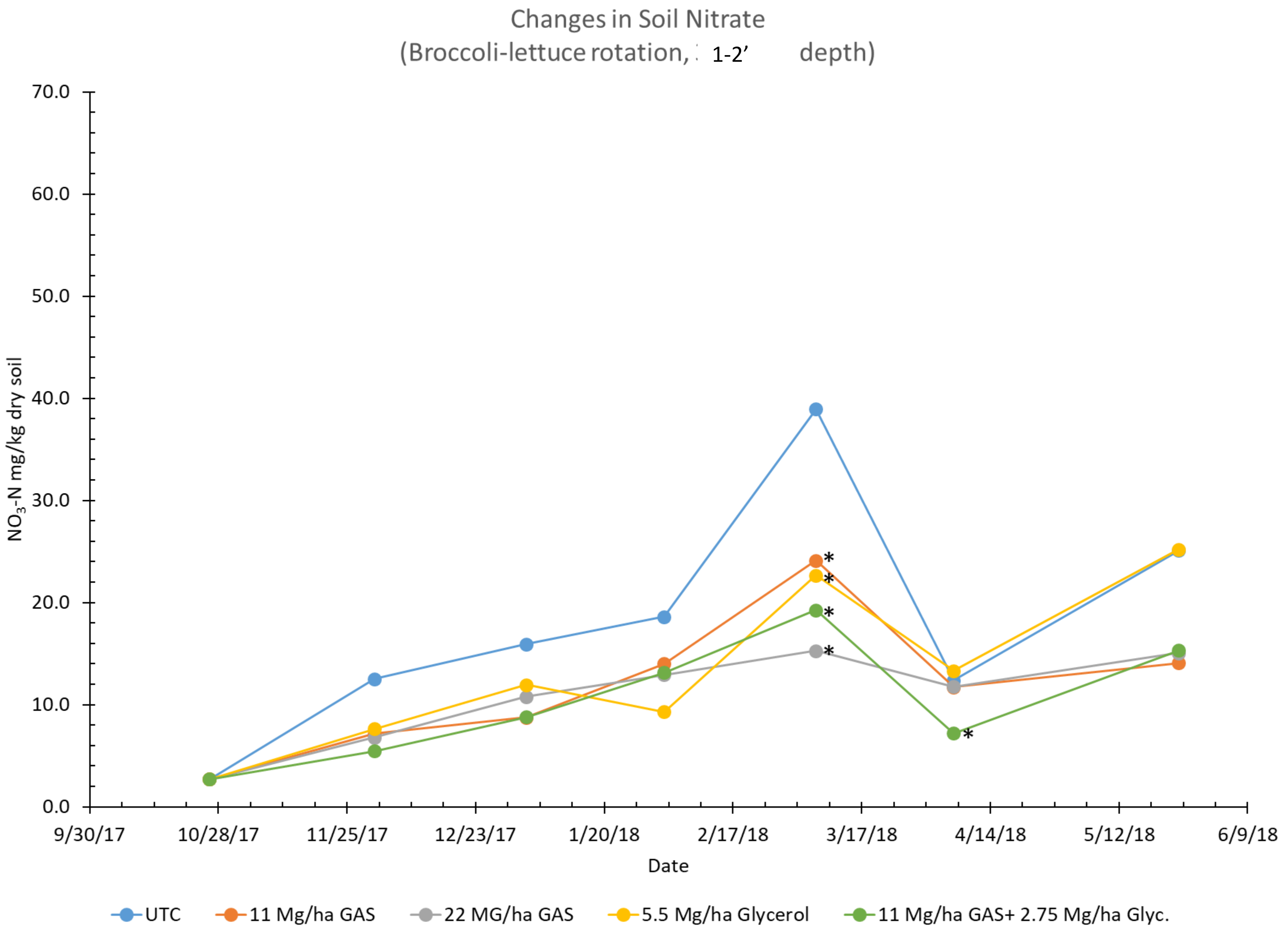


Changes in Soil Nitrate
(Broccoli-lettuce rotation, 0-1' depth)
N: 21 lb/Ac
N: 178 lb/Ac
Amendment application
Lettuce seeding
Lettuce harvest
NO_3-N mg/kg dry soil
Date
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
9/30/17
10/28/17
11/25/17
12/23/17
1/20/18
2/17/18
3/17/18
4/14/18
5/12/18
6/9/18
UTC
GAS-5
GAS-10
GL-2.5
GAS-5+GL-1.25
Precipitation

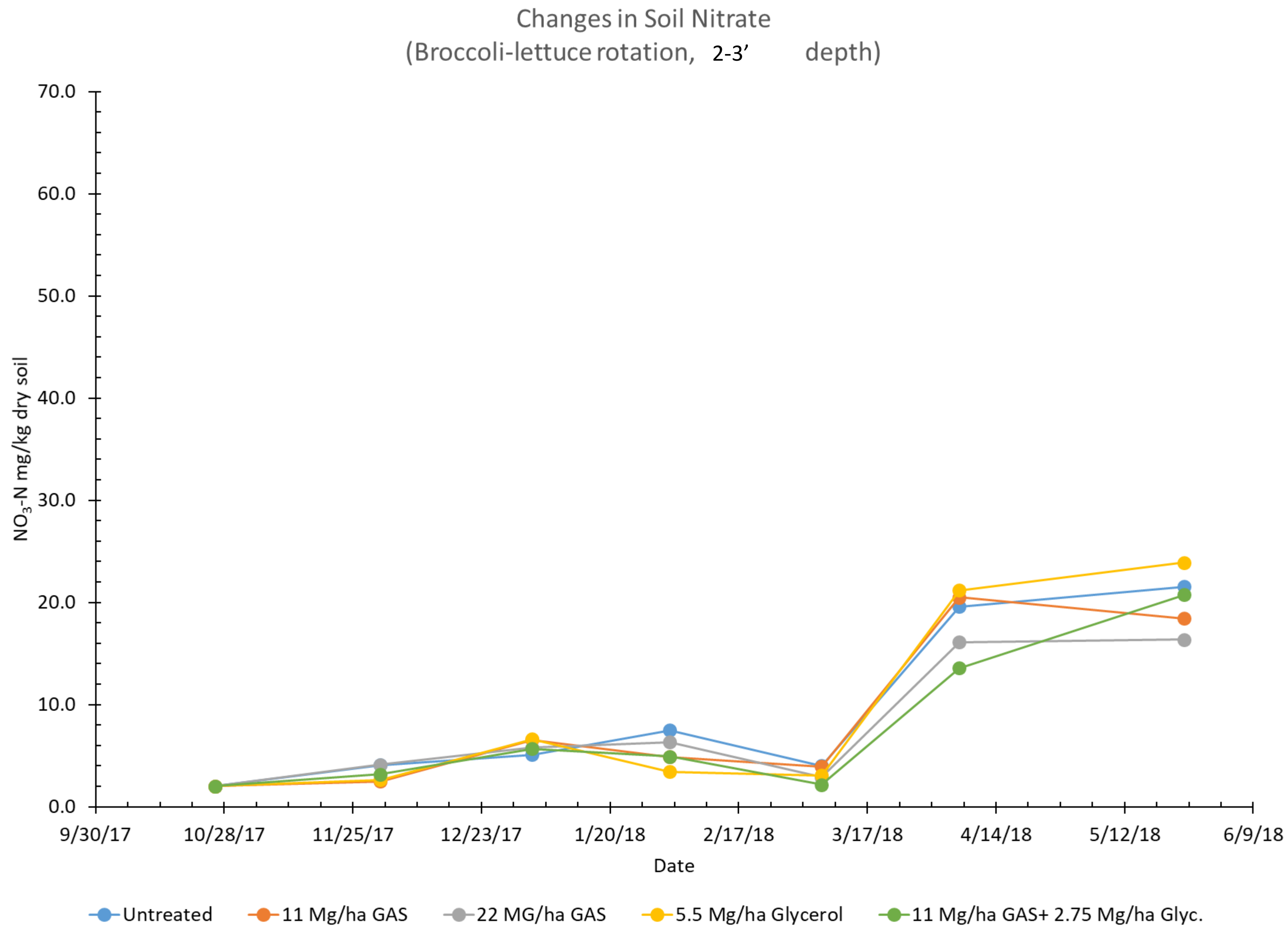

Changes in Soil Nitrate
(Broccoli-lettuce rotation, 0-1' depth)
NO_3-N mg/kg dry soil, or Precipitation mm
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
9/30/17
10/28/17
11/25/17
12/23/17
1/20/18
2/17/18
3/17/18
4/14/18
5/12/18
6/9/18
UTC
GAS-5
GAS-10
GL-2.5
GAS-5+GL-1.25
Precipitation



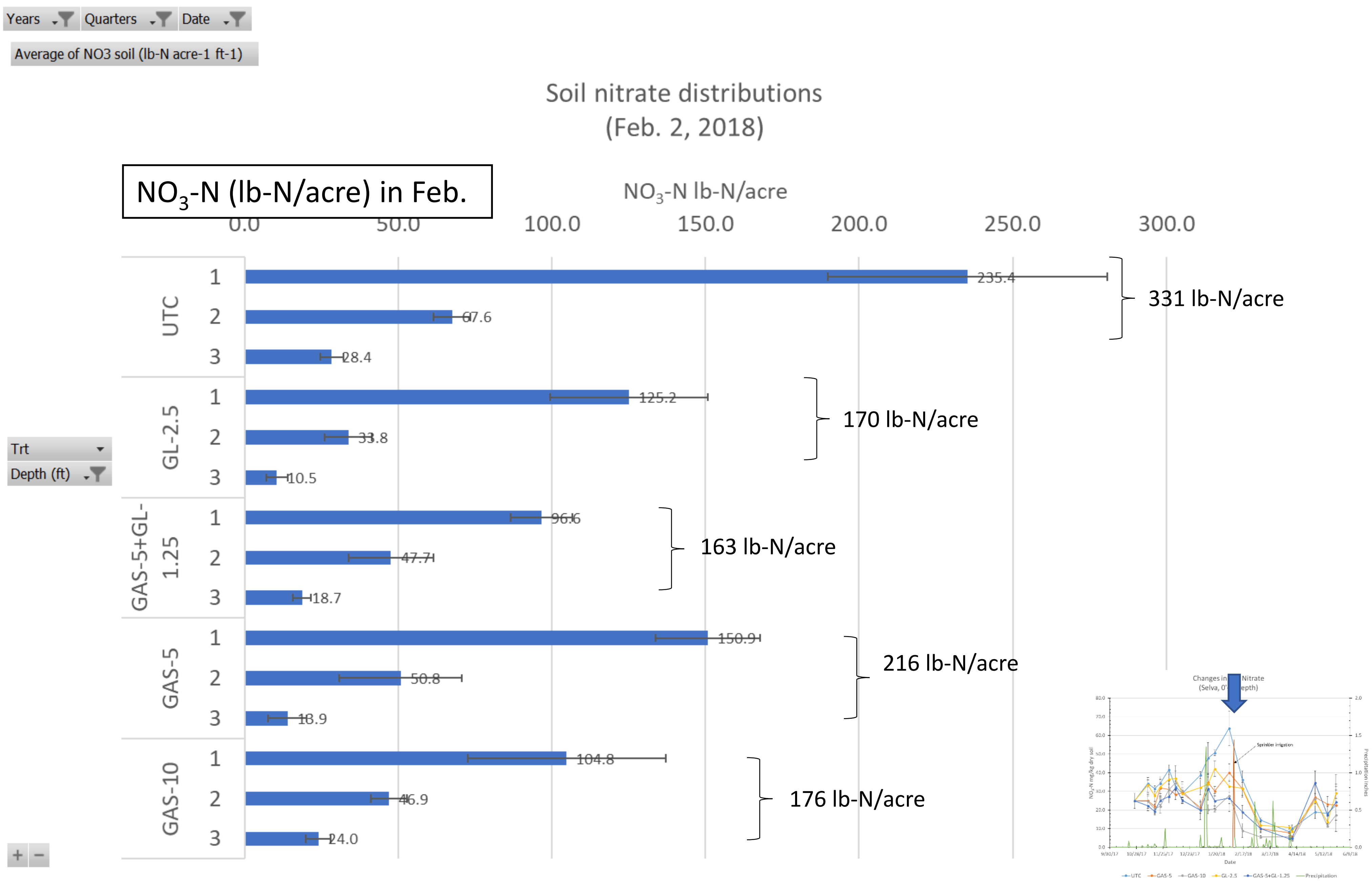
Changes in Soil Nitrate
(Broccoli-lettuce rotatic 0-1' m depth)
NO3-N mg/kg dry soil, Precipitation mm, or Soil moisture w/w %
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
9/30/17
10/28/17
11/25/17
12/23/17
1/20/18
2/17/18
3/17/18
4/14/18
5/12/18
6/9/18
Date
Soil moisture at UTC
UTC
11 Mg/ha GAS
22 Mg/ha GAS
UTC
GAS-5
GAS-10
GL-2.5
GAS-5+GL-1.25
Precipitation



Changes in Soil Nitrate
(Broccoli-lettuce rotation, 1-2' depth)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
NO_3-N mg/kg dry soil
*
*
*
*
*
9/30/17
10/28/17
11/25/17
12/23/17
1/20/18
2/17/18
3/17/18
4/14/18
5/12/18
6/9/18
Date
UTC
11 Mg/ha GAS
22 MG/ha GAS
5.5 Mg/ha Glycerol
11 Mg/ha GAS+ 2.75 Mg/ha Glyc.



Changes in Soil Nitrate
(Broccoli-lettuce rotation, 2-3' depth)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
NO3-N mg/kg dry soil
9/30/17
10/28/17
11/25/17
12/23/17
1/20/18
2/17/18
3/17/18
4/14/18
5/12/18
6/9/18
Date
Untreated
11 Mg/ha GAS
22 MG/ha GAS
5.5 Mg/ha Glycerol
11 Mg/ha GAS+ 2.75 Mg/ha Glyc.



Years
Quarters
Date
Average of NO3 soil (lb-N acre-1 ft-1)
Soil nitrate distributions
(Feb. 2, 2018)
NO$_3$-N (lb-N/acre) in Feb.
NO$_3$-N lb-N/acre
0.0
50.0
100.0
150.0
200.0
250.0
300.0
UTC
GL-2.5
GAS-5+GL-1.25
GAS-5
GAS-10
1
2
3
235.4
67.6
28.4
125.2
33.8
10.5
96.6
47.7
18.7
150.9
50.8
13.9
104.8
46.9
24.0
331 lb-N/acre
170 lb-N/acre
163 lb-N/acre
216 lb-N/acre
176 lb-N/acre
Trt
Depth (ft)

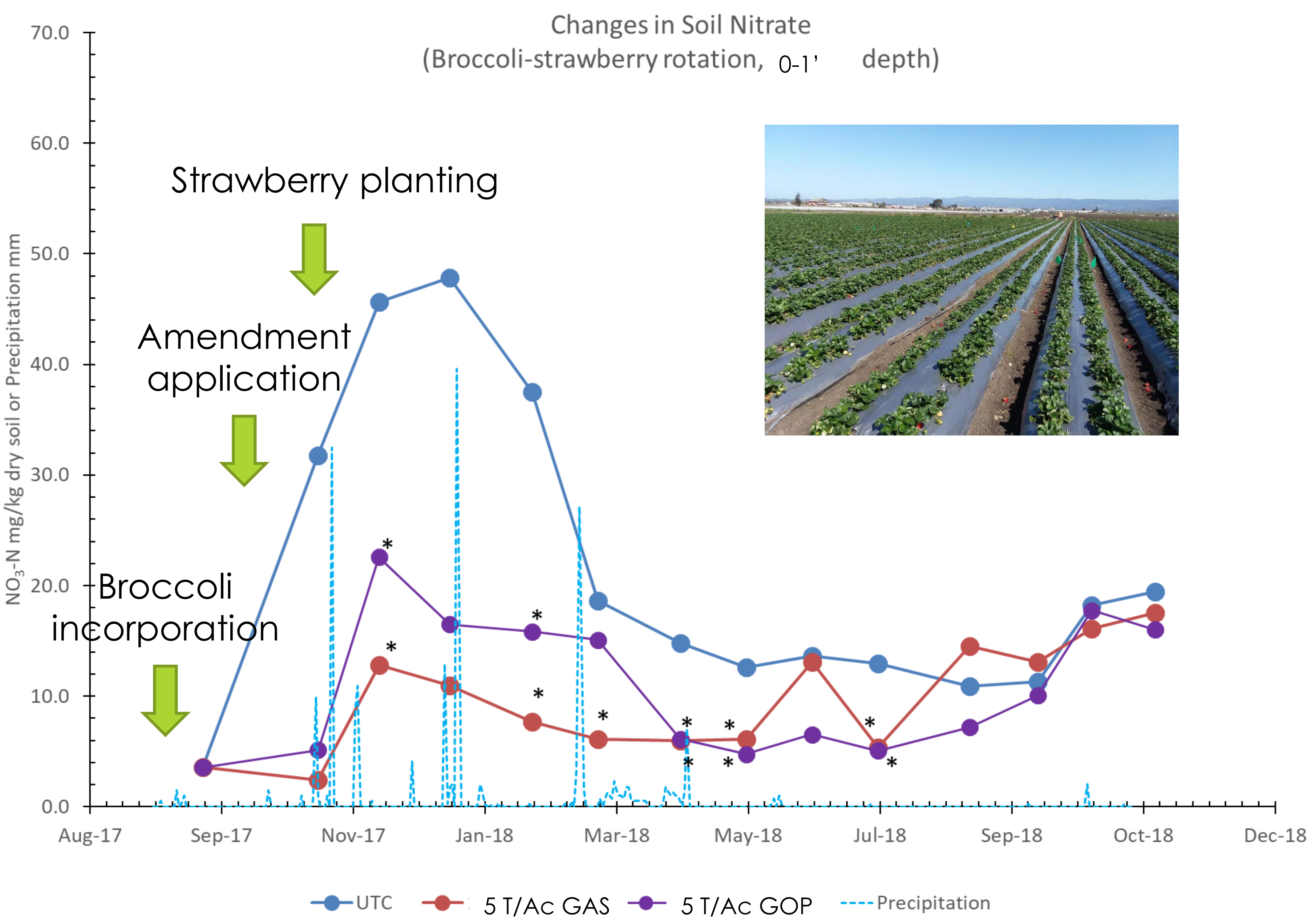
Soil Nitrate and Its Reduction (Feb. 2018)

Treatment	Soil Nitrate (N-lb/Ac/3')	Soil Nitrate Reduction (lb-N/Ac/3')
UTC	**331**	-
GAS 5	**216**	115
GAS 10	**176**	155
Glyc. 2.5	**170**	161
GAS 5+Glyc. 1.25	**163**	168

Iceberg Lettuce Yield and Economics

Treatment	Marketable yield (T/Ac)	Amendment cost ($/Ac)	Net return above pre-plant and harvest costs ($/Ac)
UTC	23.4a*	130**	5,468
GAS 5	22.8a	400	5,048
GAS 10	14.6b	800	2,468
Glyc. 2.5	24.2a	850	4,956
GAS 5+Glyc. 1.25	21.3a	825	4,213

* Averages with the same letter have no significant difference according to Tukey's HSD test at P=0.001.
** UTC assumed compost 2 T/Ac.



Changes in Soil Nitrate
(Broccoli-strawberry rotation, 0-1' depth)
Strawberry planting
Amendment application
Broccoli incorporation
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
NO_3-N mg/kg dry soil or Precipitation mm
Aug-17
Sep-17
Nov-17
Jan-18
Mar-18
May-18
Jul-18
Sep-18
Oct-18
Dec-18
UTC
5 T/Ac GAS
5 T/Ac GOP
Precipitation

Strawberry Yield and Economics

Treatment	Marketable yield (T/Ac)	Amendment cost ($/Ac)	Net return above pre-plant and harvest costs ($/Ac)
UTC	32.6b*	325**	11,924
GAS 5	**41.0a**	**400**	**15,100**
GOP 5	34.5ab	550	12,553

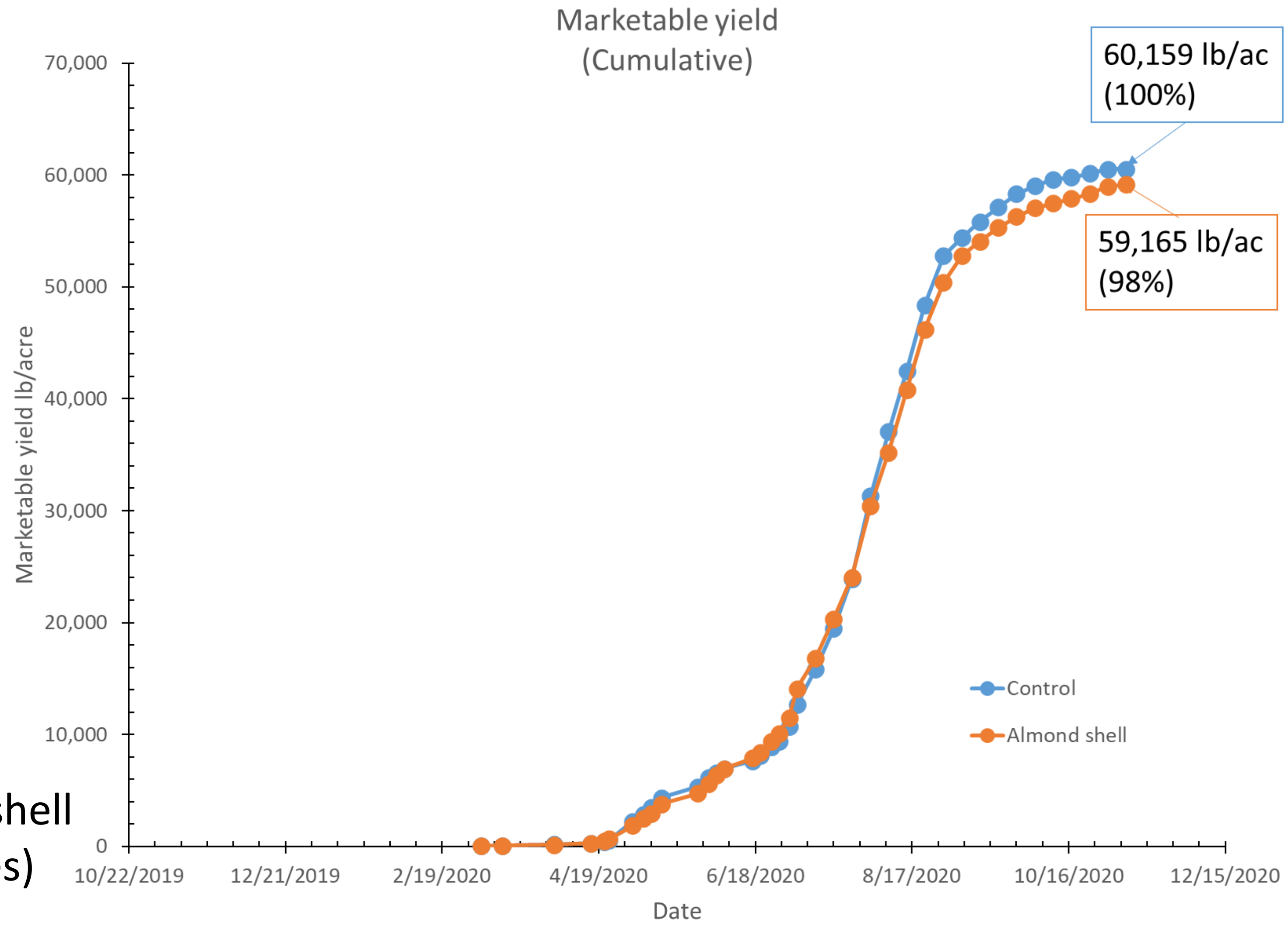
*Averages with the same letter have no significant difference according to Tukey's HSD test at P=0.05.
** UTC assumed compost 5 T/Ac

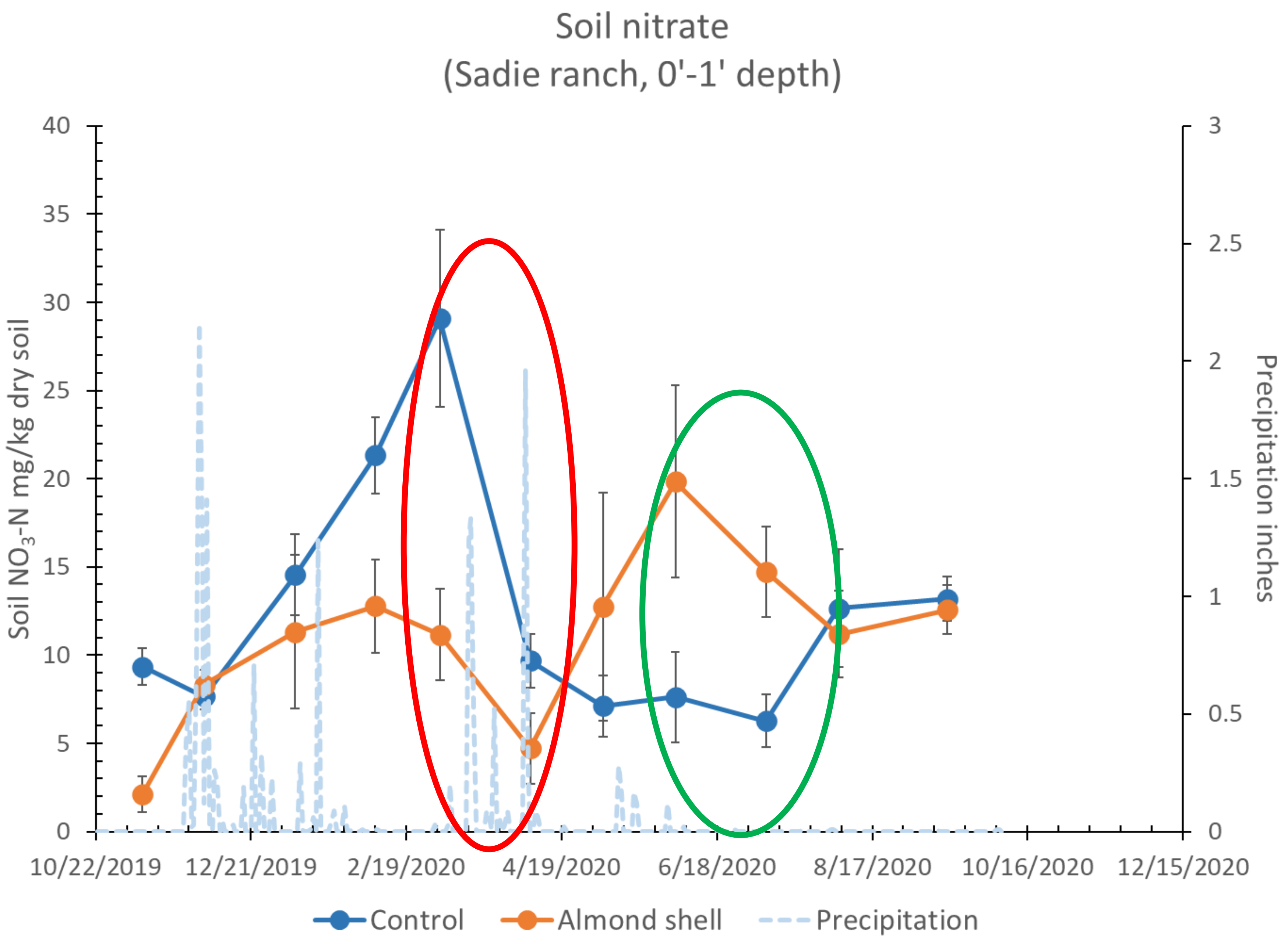
Large-scale non-replicated demonstration trial (Watsonville, 2019-20)

Sandy loam – loam.
Organic broccoli-strawberries.

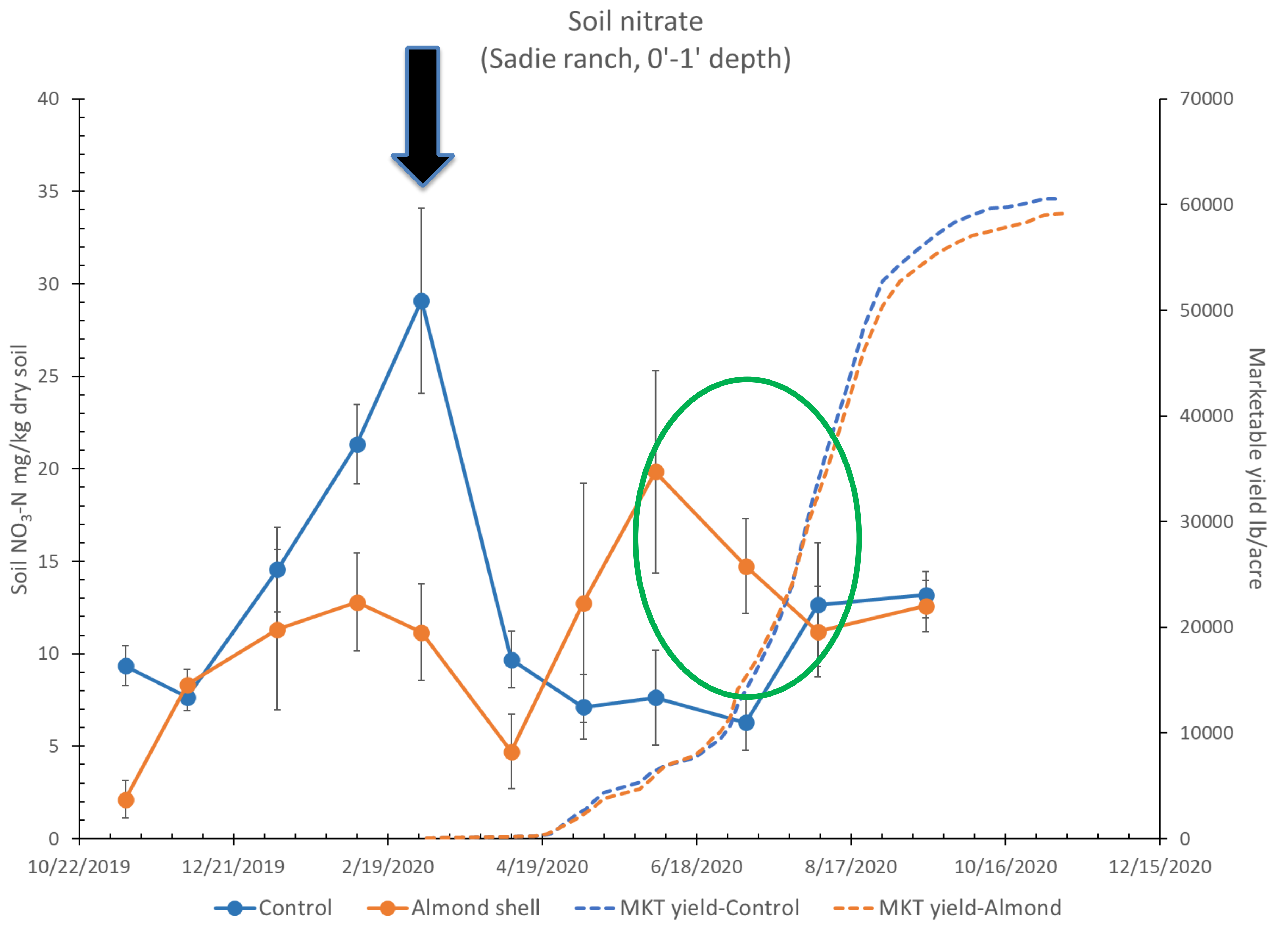
Ground almond shell
6 t/acre (3.3 acres)

Untreated control (4.2 acres)



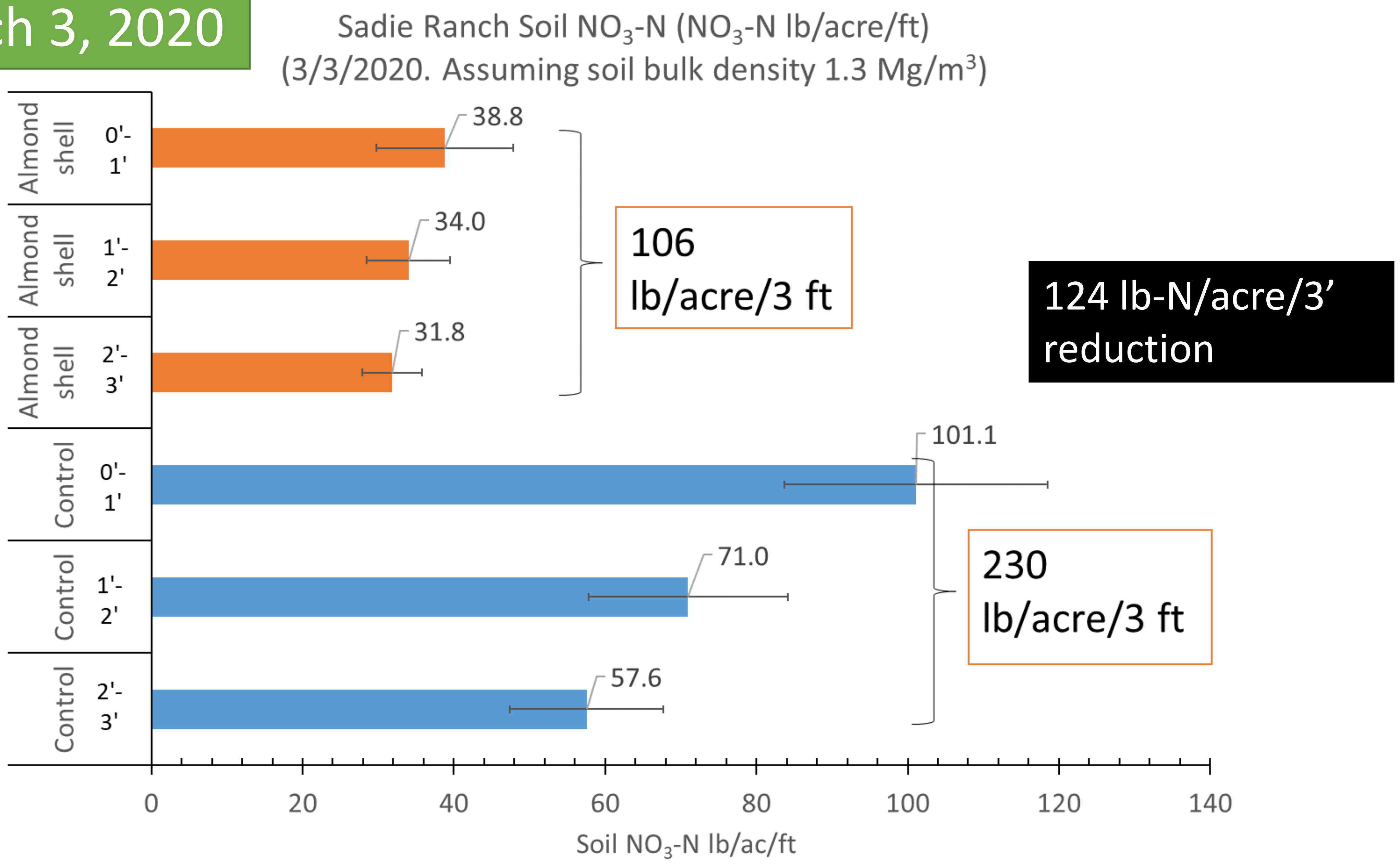


(CIMIS Pajaro)

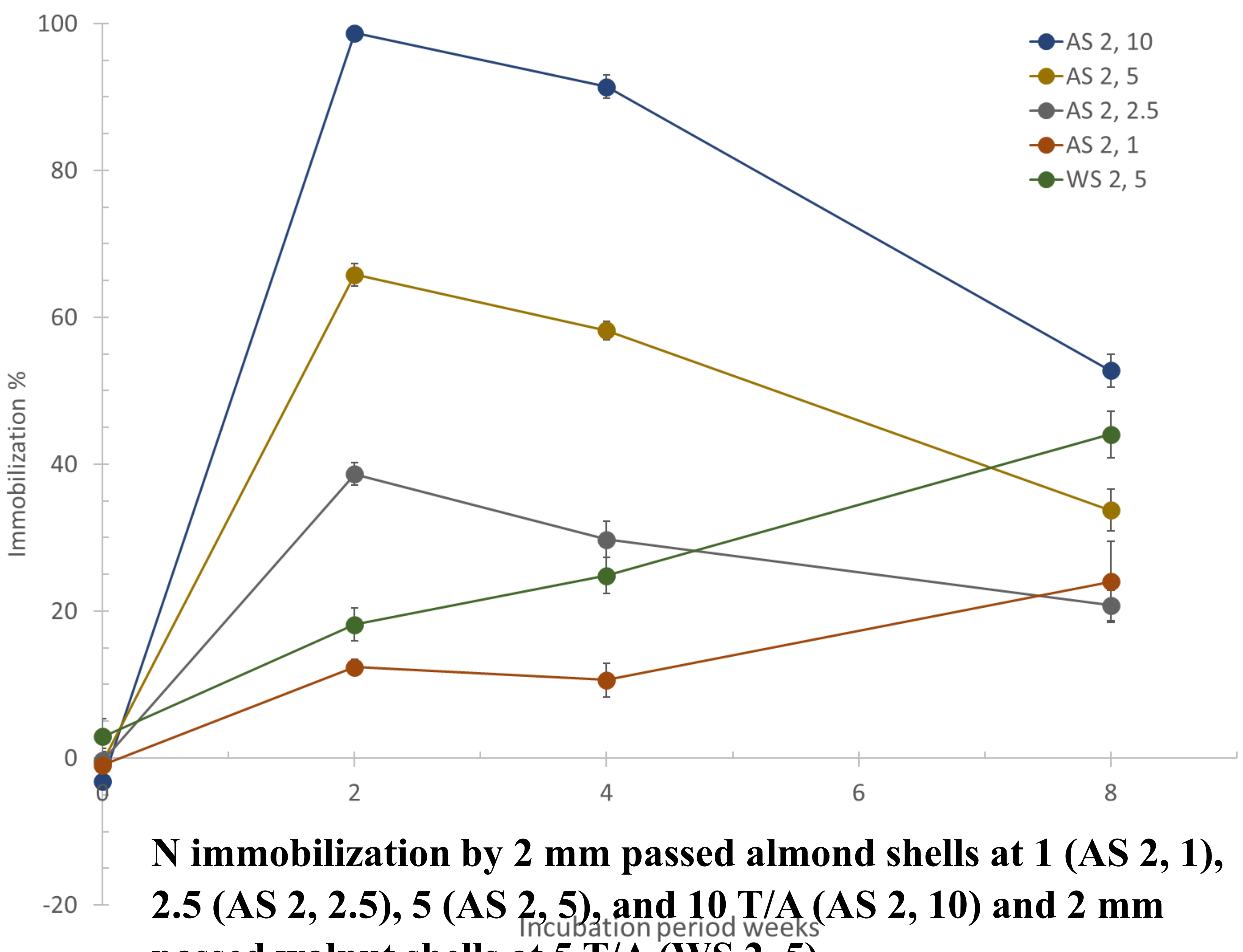


Soil nitrate
(Sadie ranch, 0'-1' depth)
Soil NO_3-N mg/kg dry soil
Marketable yield lb/acre
0
5
10
15
20
25
30
35
40
0
10000
20000
30000
40000
50000
60000
70000
10/22/2019
12/21/2019
2/19/2020
4/19/2020
6/18/2020
8/17/2020
10/16/2020
12/15/2020
Control
Almond shell
MKT yield-Control
MKT yield-Almond

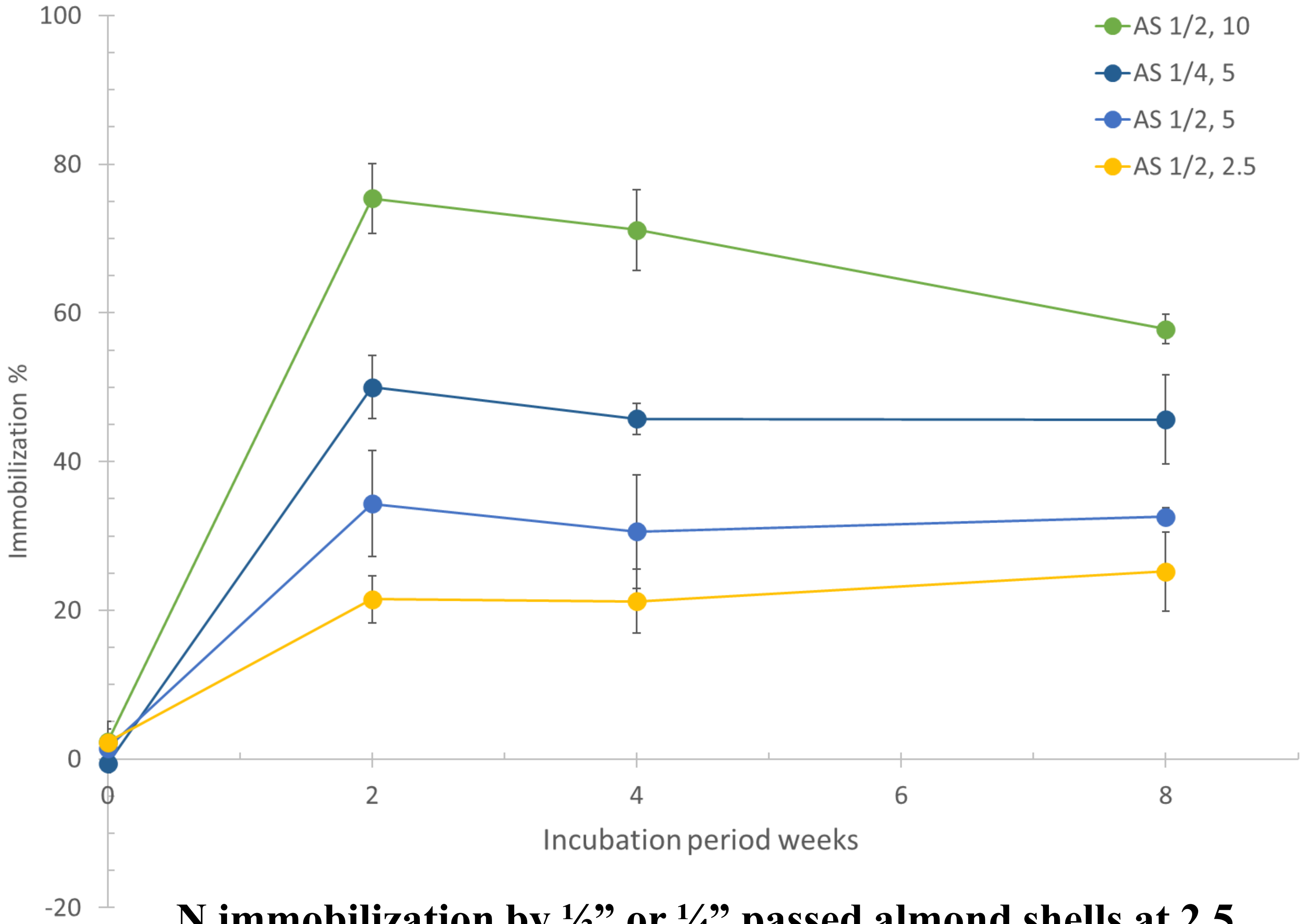
March 3, 2020



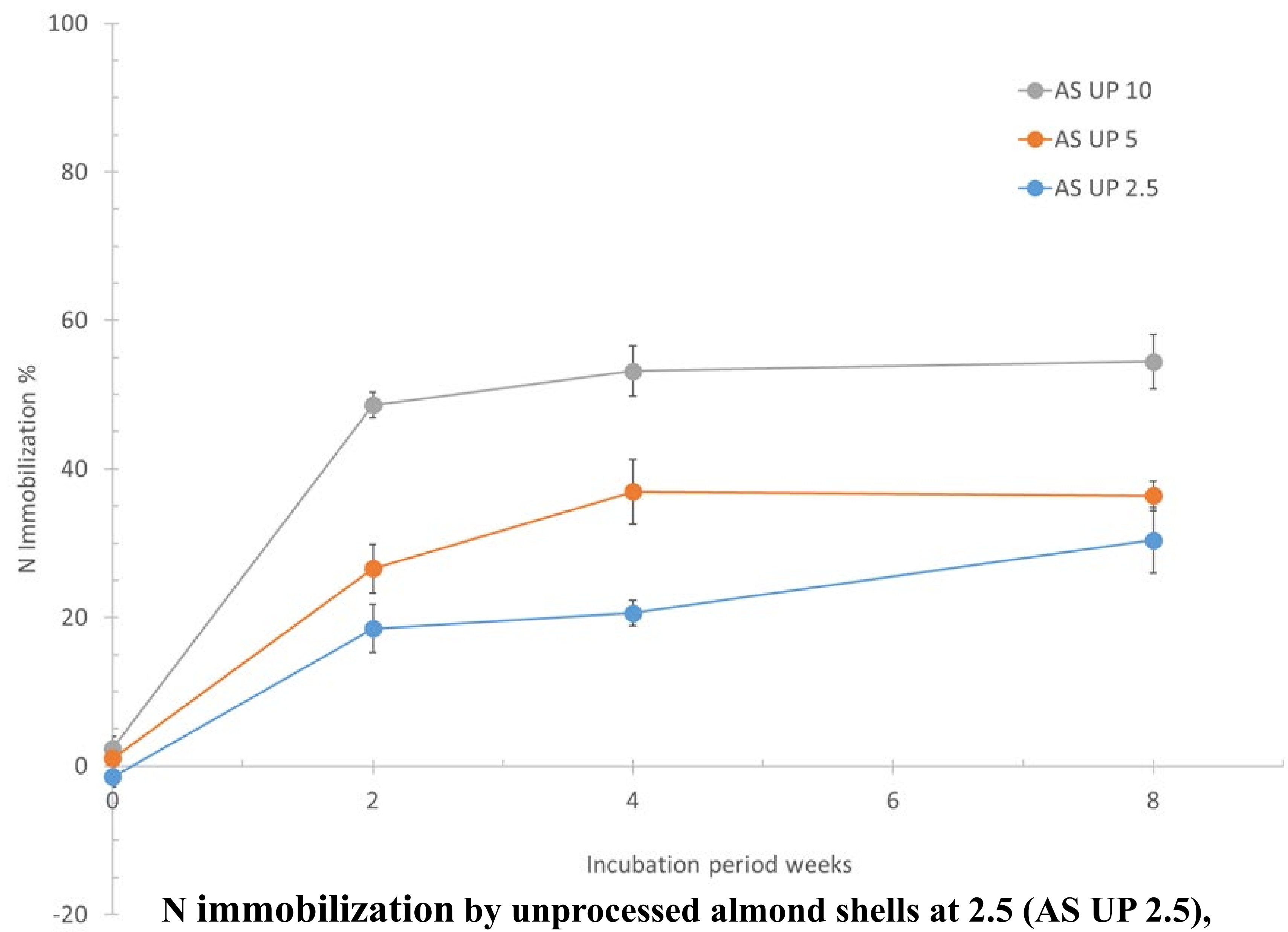
Sadie Ranch Soil NO_3-N (NO_3-N lb/acre/ft)
(3/3/2020. Assuming soil bulk density 1.3 Mg/m^3)
Almond shell 0'-1'
Almond shell 1'-2'
Almond shell 2'-3'
Control 0'-1'
Control 1'-2'
Control 2'-3'
38.8
34.0
31.8
101.1
71.0
57.6
106 lb/acre/3 ft
230 lb/acre/3 ft
124 lb-N/acre/3' reduction
0
20
40
60
80
100
120
140
Soil NO_3-N lb/ac/ft



N immobilization by 2 mm passed almond shells at 1 (AS 2, 1), 2.5 (AS 2, 2.5), 5 (AS 2, 5), and 10 T/A (AS 2, 10) and 2 mm passed walnut shells at 5 T/A (WS 2, 5).



N immobilization by ½” or ¼” passed almond shells at 2.5 (AS ½, 2.5), 5 (AS ½, 5 or AS ¼, 5), and 10 T/A (AS ½, 10).



N immobilization by unprocessed almond shells at 2.5 (AS UP 2.5), 5 (AS UP 5), and 10 T/A (AS UP 10).

Agricultural Order 4.0

- Ag Order 4.0 relies upon the A-R metric to regulate N loading in production fields
- A-R=Nitrogen Application Targets/Limits lbs N/A/year

Compliance Dates*		
Target	500	2023
Target	400	2025
Limit	300	2027
Limit	200	2031
Limit	150	2036
Limit	100	2041
Limit	50	2051

Applied Side of the Equation

$$A_{FER} + (C \times A_{COMP}) + (O \times A_{ORG}) + A_{IRR}$$

- A in fertilizer
- A in compost x mineralization factor
  - C:N<11 = 0.10; C:N>11 = 0.05
- A in organic fert x mineralization factor
  - Uses a regression from Lazicki's paper
- A in Irrigation water (accounting only for the water applied to supply crop Et)

Removed Side of the Equation

$$R_{harv} + R_{seq} + R_{scav} + R_{treat} + R_{other}$$

- R in the harvested crop
- R sequestered (perennial crops - wood)
- R scavenged in cover crop and high carbon compost
- R that is treated to remove N (e.g. denitrification beds)
- R other demonstratable forms of removal (e.g. denitrification from field?)

High Carbon Amendment

- Must have a C:N ratio of greater than 30:1. Must be finely ground to less than ¼ inch in diameter. Must be incorporated into the top foot of soil. Must be retained for a minimum of three months during the wet/rainy season. Must have minimum application rate of 10,000 lbs/A.
- If these criteria are met, can get a credit of 30 lbs N/A

The Role of Research

- Ag Order 4.0 is not a static document
- The Regional Water Quality Control Board will review the state of science in 5 years, and they are open to updating it as new understanding is developed

Next Steps for Research

1. Analyze the cost of the most effective almond shell application methods based on the incubation trial
2. Demonstrate these at a field scale trial
3. Validate a simple N-mineralization/N-immobilization simulation model with data from incubation and field trials
4. Integrate the simple simulation model into CropManage

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Question?

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