Immobilization of nitrate in winter-fallow vegetable production beds to reduce nitrate leaching

2024 Irrigation and Nutrient Management Meeting

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- N Management in Cool season vegetables (2-3 crops/ season)
- In-season N management practices have made N use more efficient: nitrate quick test for measuring residual soil nitrate, CropManage – irrigation efficiency, nitrogen fertilizer technologies
- Winter fallow N management is uncontrolled and a time when significant nitrate leaching can occur during rain events

Regulation of Loading of Nitrate-N in Groundwater

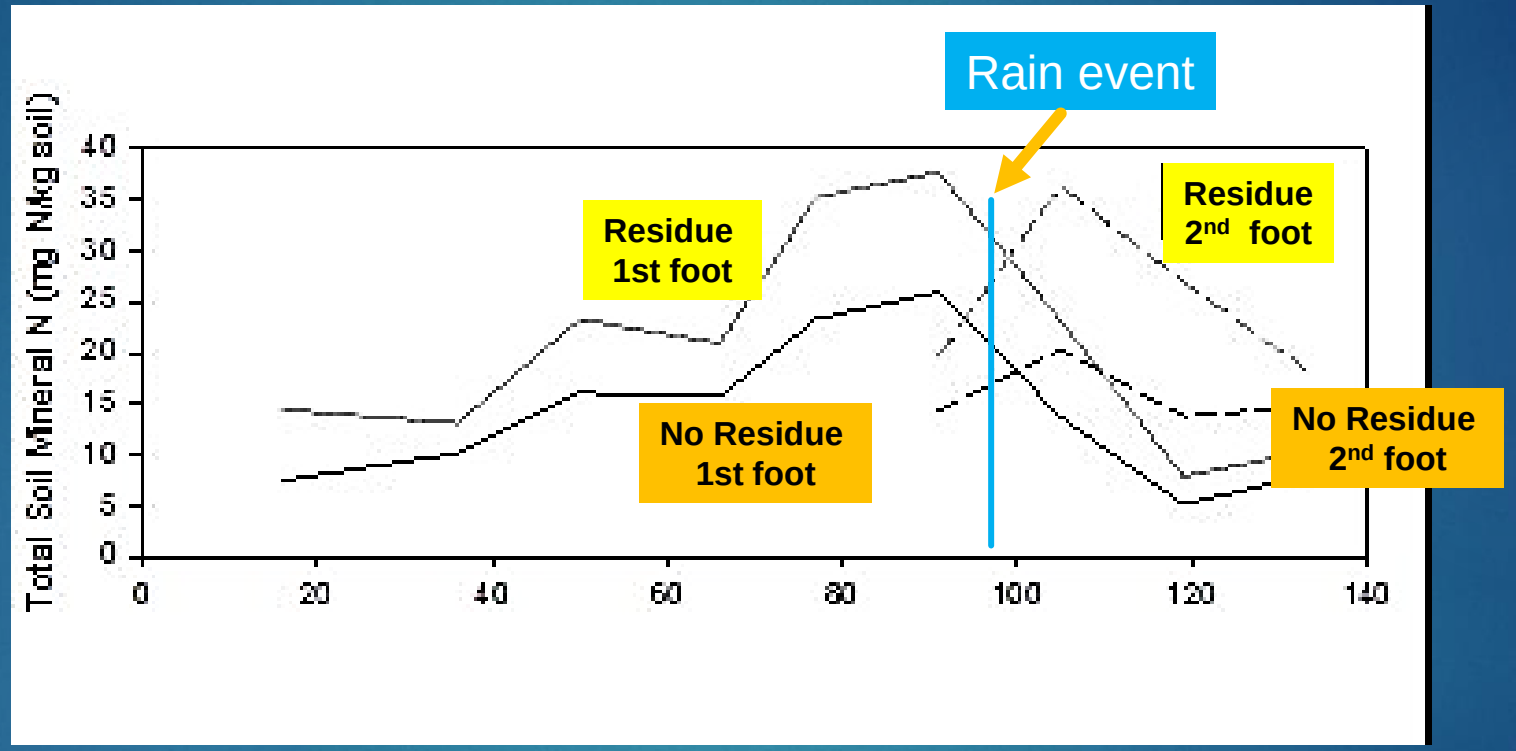
- Municipalities in coastal California depend on ground water to supply drinking water
- The Central Coast Regional Water Quality Control Board (Region 3) is the lead agency enacting regulations to reduce loading of nitrate in the ground water
- In April 2021, they approved Ag Order 4.0 which for the first time set limits on the amount of nitrogen loading allowed by agricultural production in order to reduce nitrate leaching to groundwater resources

Residual Soil Nitrate at the End of the Cropping Season

Incorporation of N rich crop residues:

- **40-60 lbs for lettuce and spinach**
- **100-150 for celery**
- **>200 for broccoli and cauliflower**

Fate of Nitrogen Mineralized from Broccoli Residue



Even where there was no broccoli residue, there was significant mineralization of soil organic matter resulting in high levels of soil nitrate-N (25 ppm)

Bridging soil nitrate to next season

Role of Cover Crops/High-Carbon Amendments

At end of crop cycle residual soil nitrate can increase over the winter from mineralization of soil organic matter and crop residues (e.g. 20-40 ppm nitrate-N)

Nitrate from season A is immobilized/ sequestered and carried to season B

Any nitrogen mineralized from the cover crop can be measured with the nitrate quick tests that allow growers to adjust fertilizer N applications

Second Crop of Season A

Fallow Period

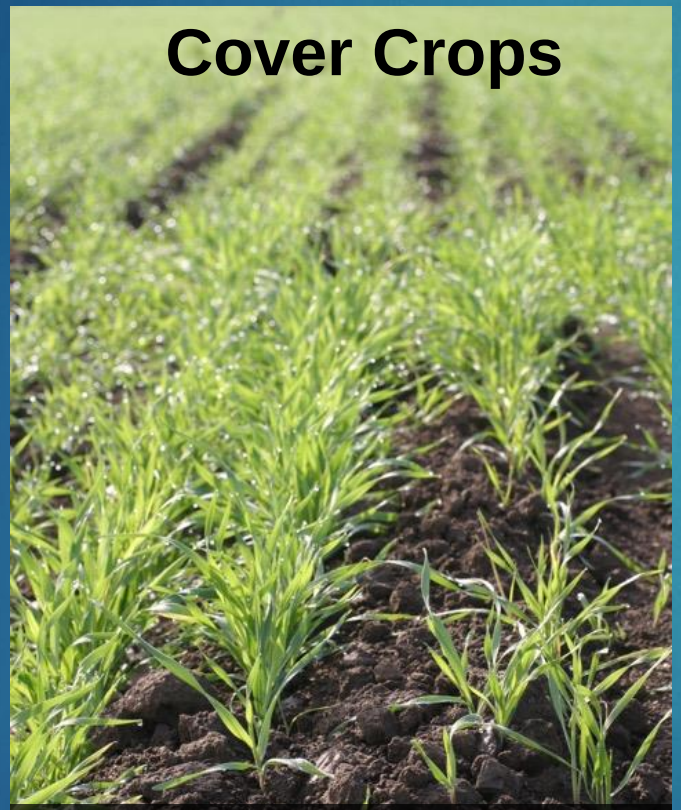
First Crop of Season B

Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr

Rainy Season

Capturing and Cycling N at the End of the Production Season

Cover Crops



Only 5% of vegetable acreage is cover cropped due to high land rents, planting schedule conflicts and opportunity costs

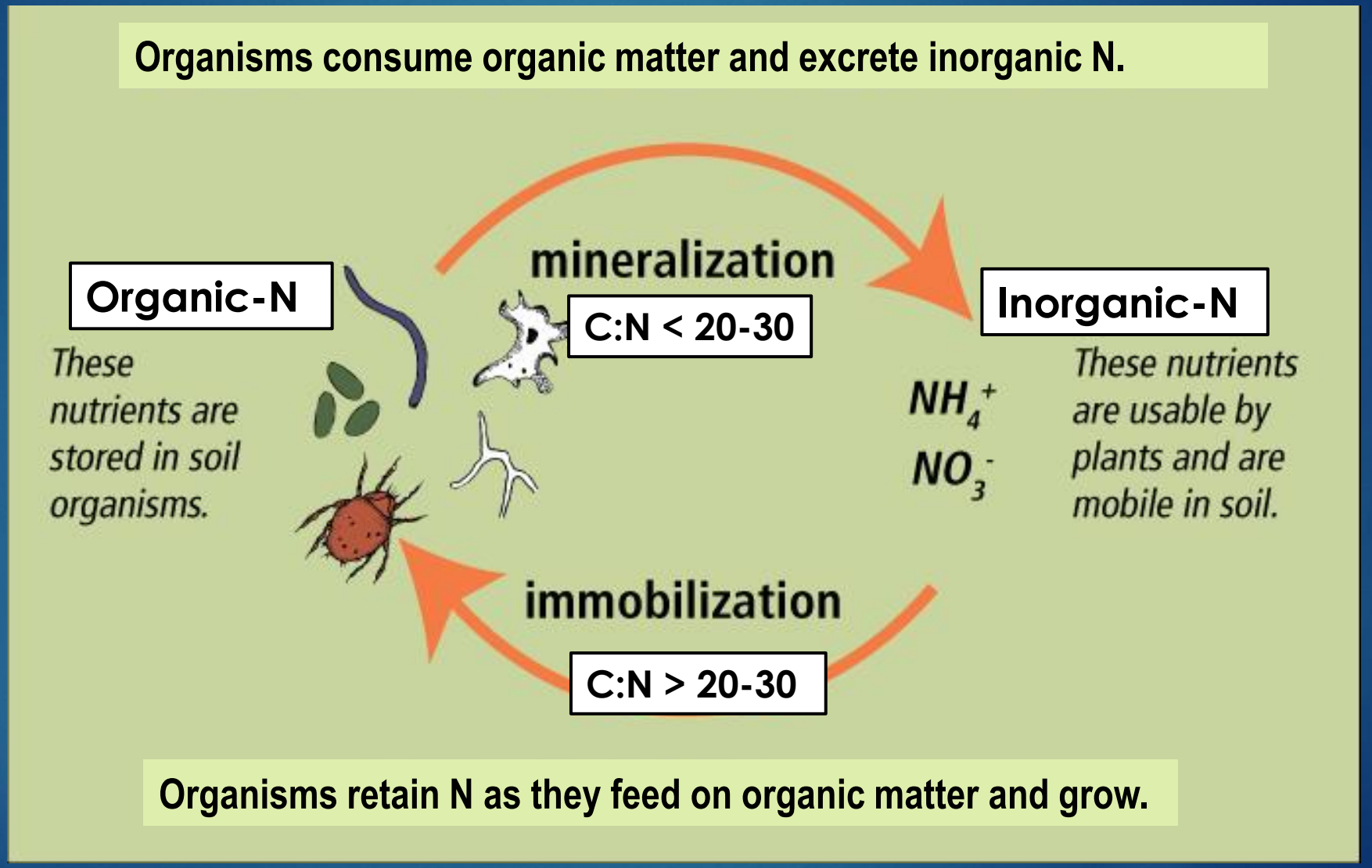
High Carbon Amendments

Residual soil nitrate can be immobilized over the winter and then made available for subsequent crop needs.

High Carbon Amendment

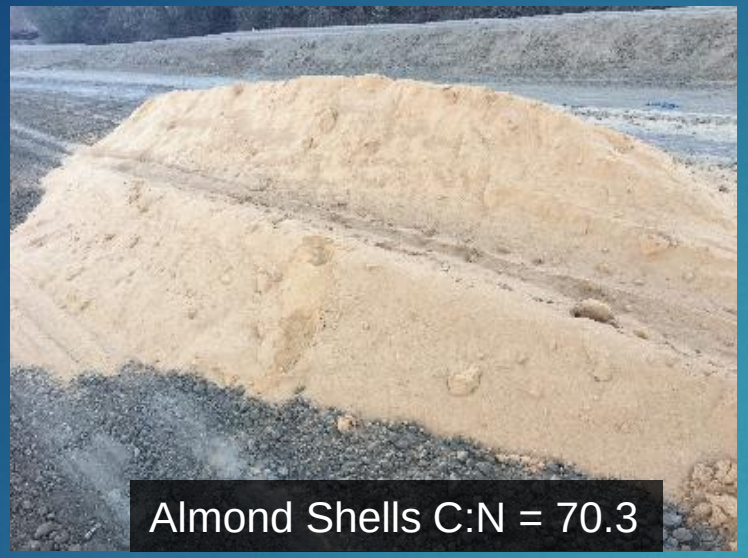
- The use of composts in the fall/winter is a familiar and accepted practice
- High carbon amendments could be substituted
- Typical composts: C:N ratio 12-15
- High carbon amendments: C:N ratio >30
- The carbon serves as a food source for soil microbes which then take up nitrate from the pool of residual soil nitrate thereby reducing the risk of nitrate leaching
- It remains in the microbes bodies for a period of time and then cycles back as C is used up

N mineralization vs. N immobilization



(Adopted from USDA-NRCS, 2017)

Initial Trials with High Carbon Amendments


Almond Shells C:N = 70.3


Shells ground to 2 mm


Commercial Application @ 5.0 and 10.0 T/A


Glycerol Application

High Carbon Amendments Defined in Ag Order 4.0

- Based initial results, high carbon amendments were included in the Ag Order:
- They defined it: 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

Limits of High Carbon Amendments

- High carbon amendments can continue immobilizing N during the subsequent production season - may necessitate the need for higher rates of starter fertilizer
- Cost is an issue:
  - Glycerol is clearly too expensive
  - Trucking from the Central Valley and grinding almond shells increases their cost

Search for Cheaper High Carbon Amendment


Almond Shells


Local Woody Materials

- Given the high cost of trucking & grinding almond shells and of glycerol, we spent a few years looking for a cheaper local source of labile carbon
- Bottom line is that there was not the infrastructure to grind the locally woody materials sufficiently to make them more active
- We have circled back to the use of partially ground almond shells

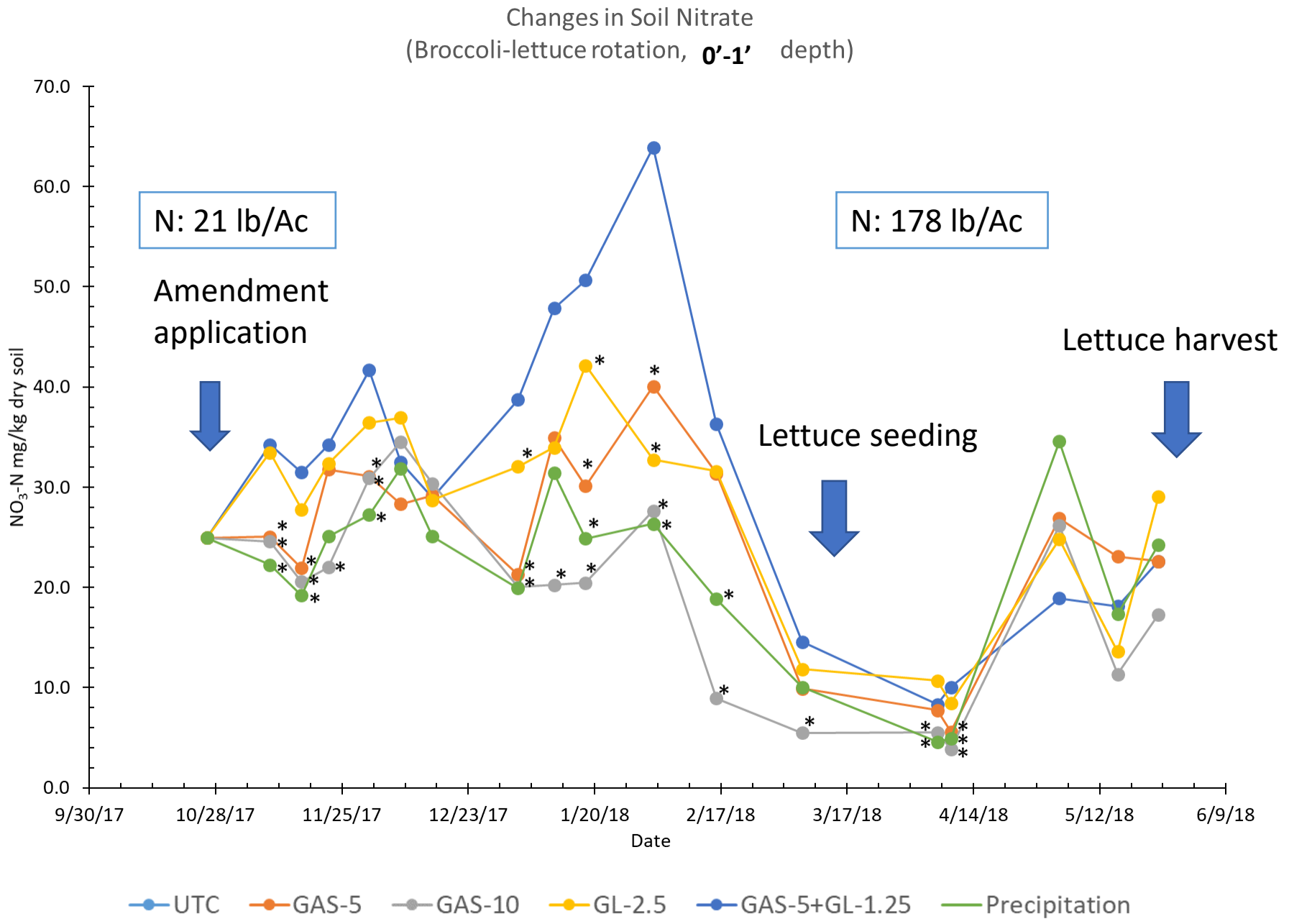
Outline

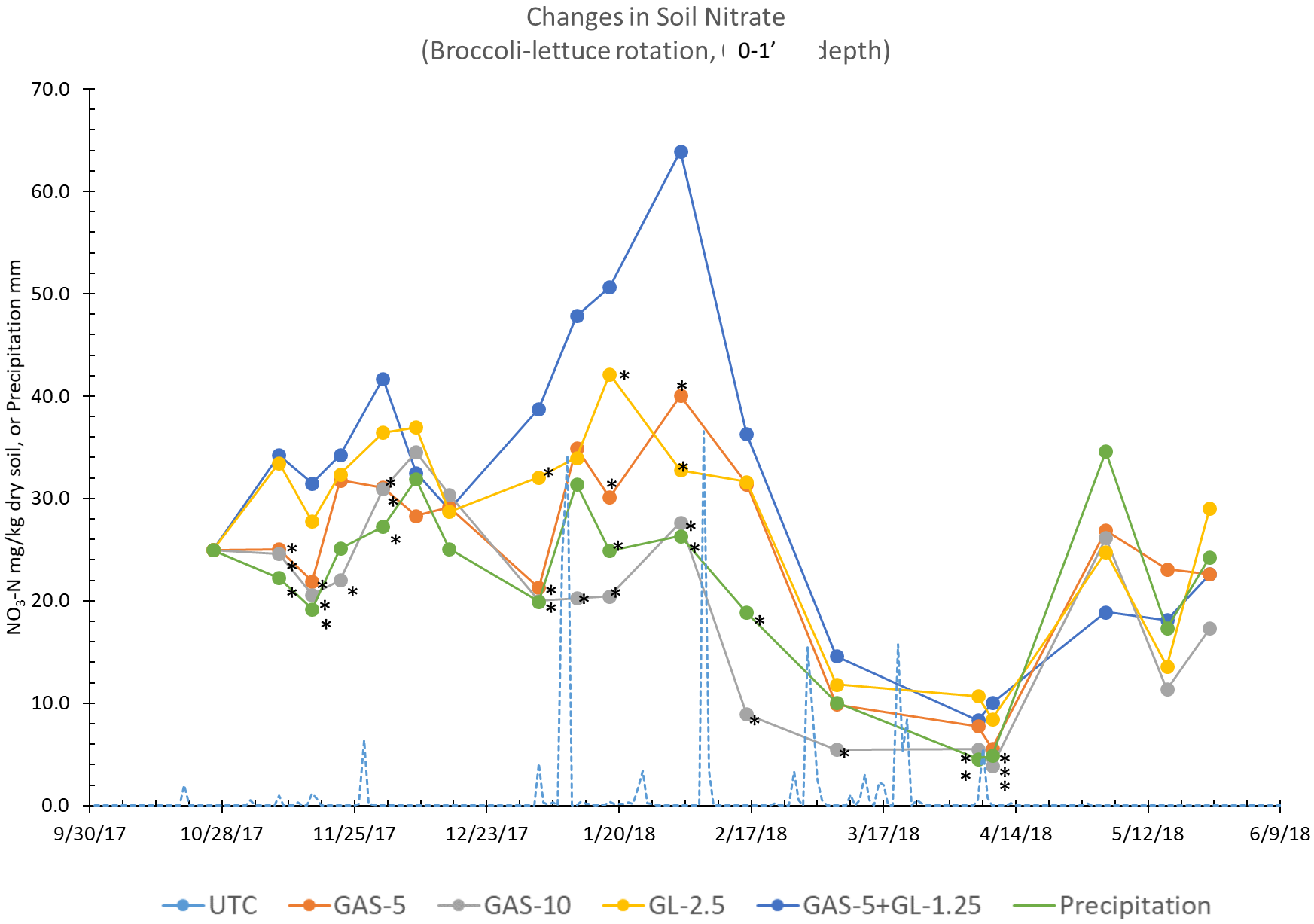
- **High Carbon Amendment Application Trials**
  - Broccoli-Lettuce Rotation (Replicated field trial)
  - Almond shells: particle sizes and rates (Lab incubation)
- **Next Steps**

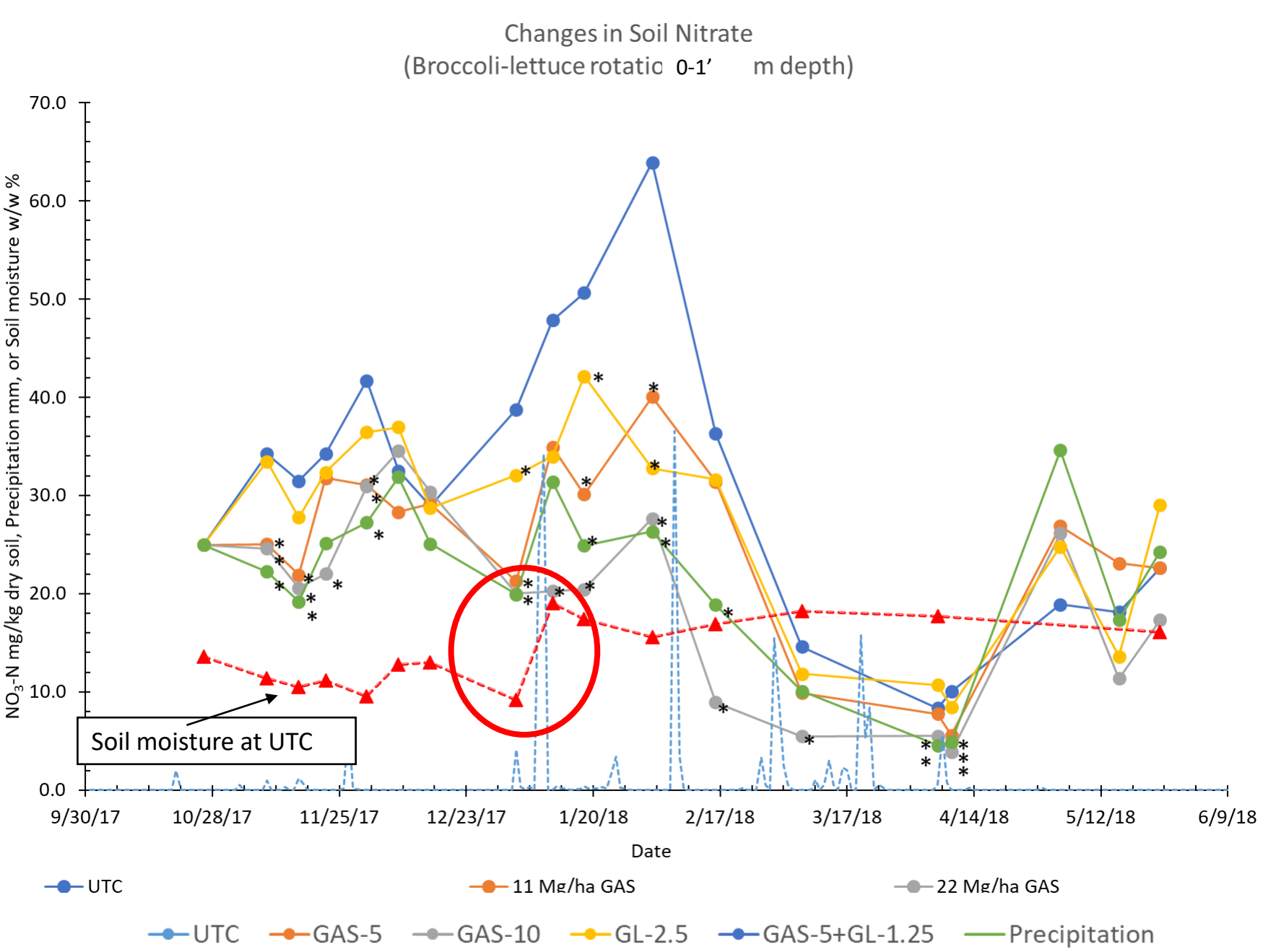
Field Trial (2017-18, Randomized complete block design)

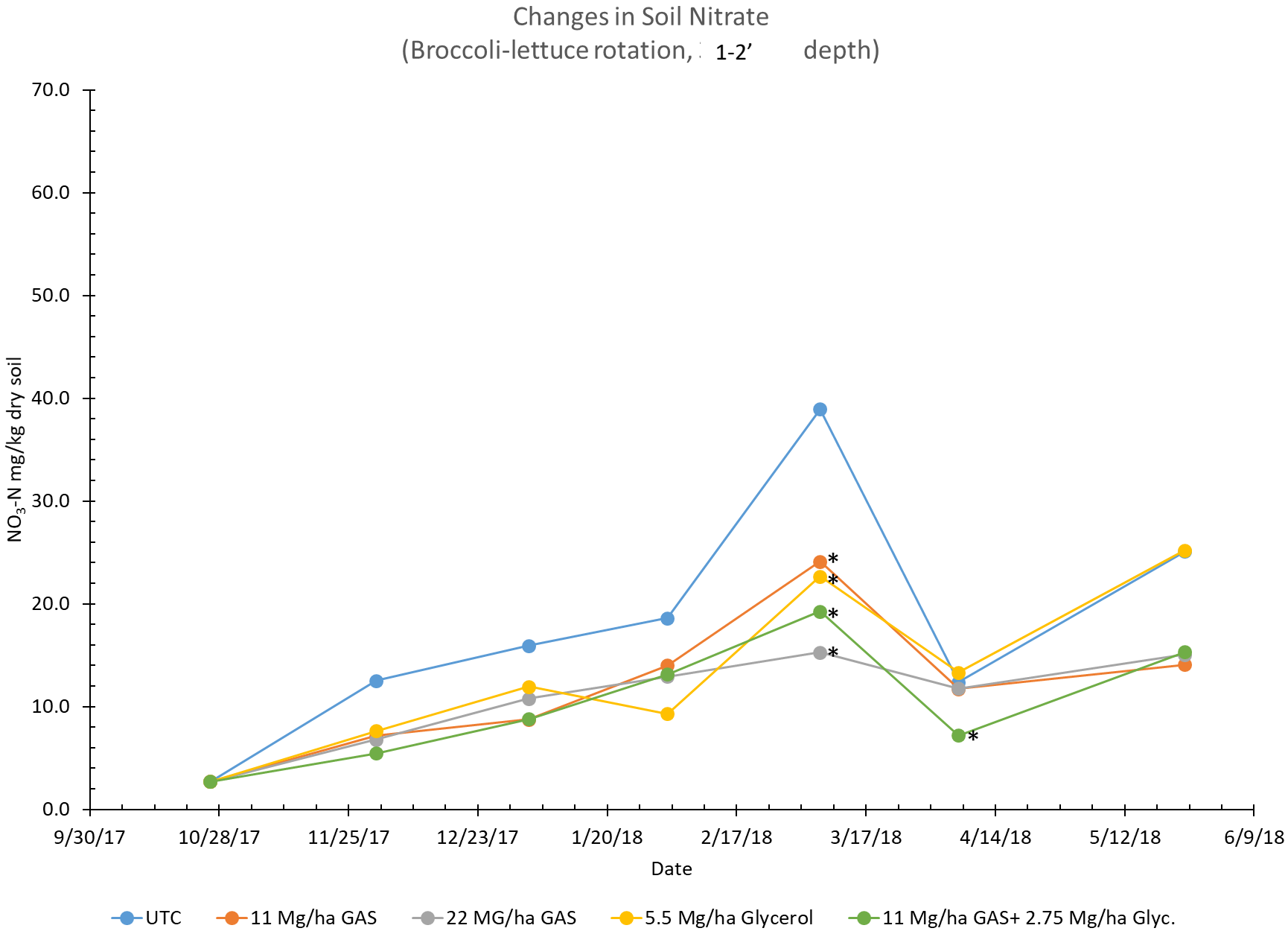
- Broccoli – Lettuce rotation (Conv. Silty clay loam. 4 reps)
  - Ground almond shell (GAS) 5 T/Ac
  - GAS 10 T/Ac
  - Glycerol 2.5 T/Ac
  - GAS 5 T/Ac + Glycerol 1.25 T/Ac
  - Untreated control (UTC)

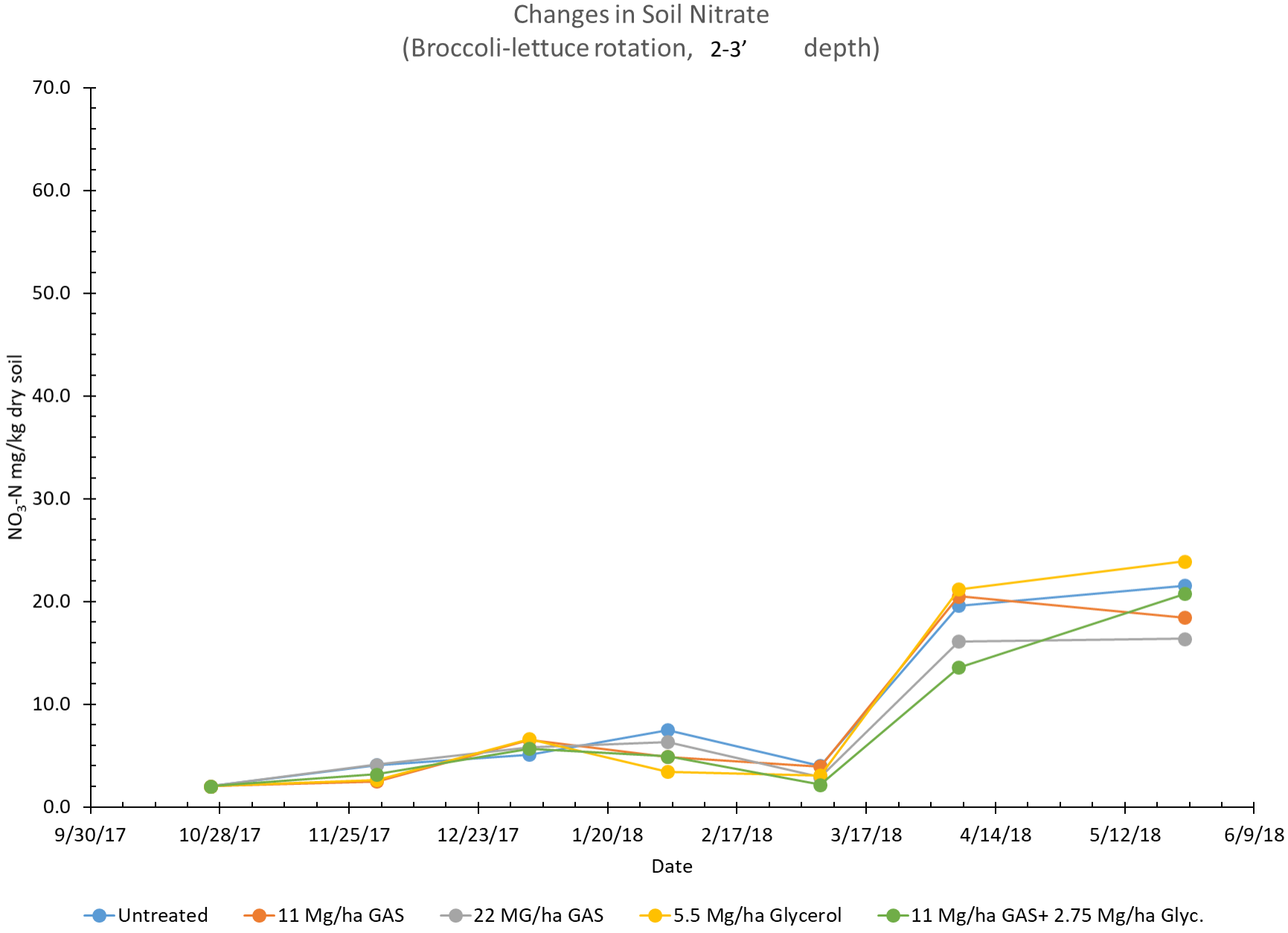
- Each plot: 100’ x 20’
- Soil inorganic N monthly at 0’-1’, 1’-2’, 2’-3’depth
- Yield of successive lettuce crop monitored


Changes in Soil Nitrate
(Broccoli-lettuce rotation, 0'-1' depth)
N: 21 lb/Ac
N: 178 lb/Ac
Amendment application
Lettuce seeding
Lettuce harvest
NO3-N mg/kg dry soil
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
UTC
GAS-5
GAS-10
GL-2.5
GAS-5+GL-1.25
Precipitation

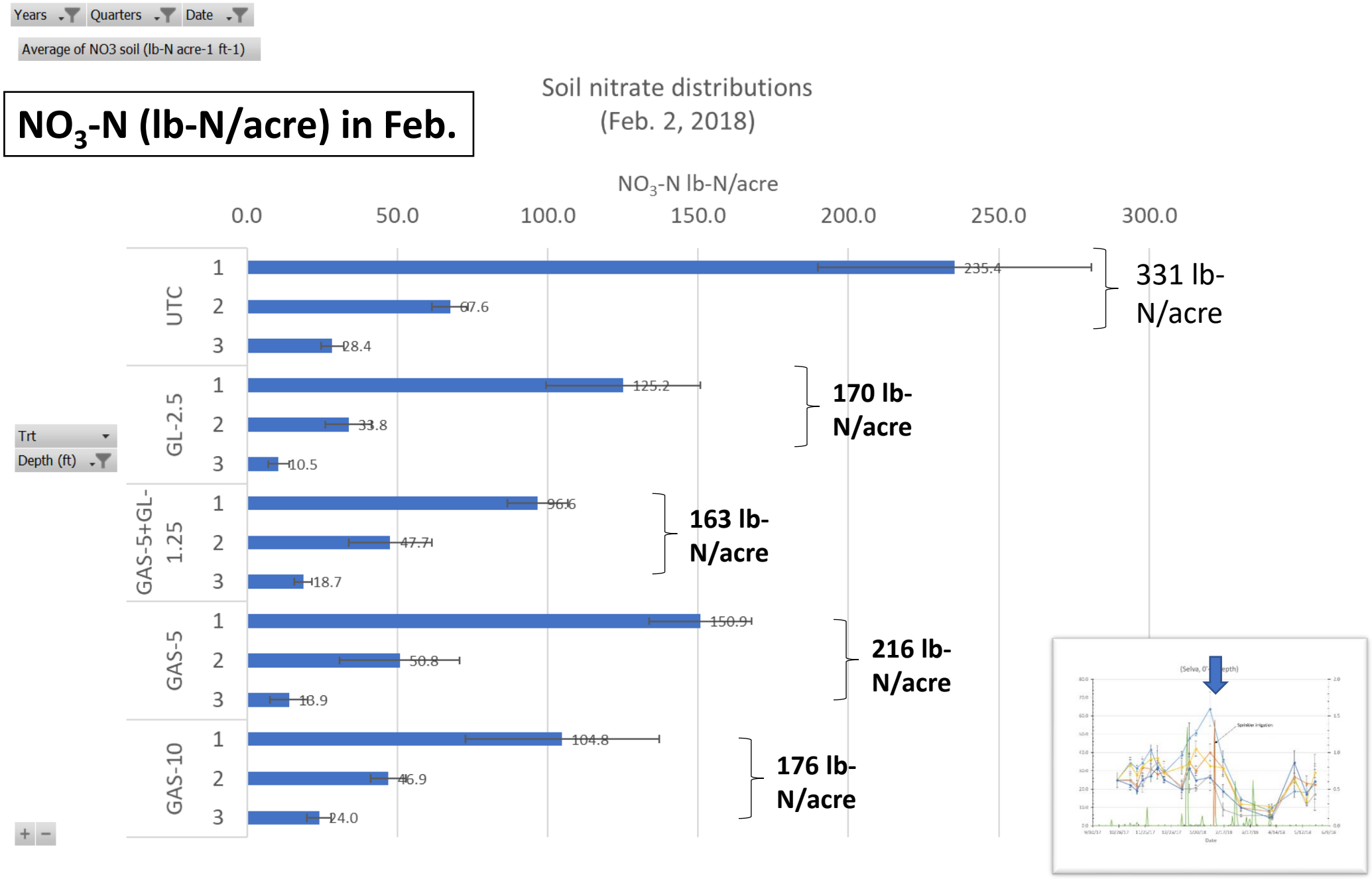

Changes in Soil Nitrate
(Broccoli-lettuce rotation, 0-1’ depth)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
NO3-N mg/kg dry soil, or Precipitation mm
9/30/17
10/28/17
11/25/17
12/23/17
1/20/18
2/17/18
3/17/18
4/14/18
5/12/18
6/9/18
UTC
GAS-5
GAS-10
GL-2.5
GAS-5+GL-1.25
Precipitation


Changes in Soil Nitrate
(Broccoli-lettuce rotatio 0-1’ m depth)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
NO3-N mg/kg dry soil, Precipitation mm, or Soil moisture w/w %
Soil moisture at UTC
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
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
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
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.

NO_3-N (lb-N/acre) in Feb.



Soil Nitrate 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.

Visualizing N-Immobilization (Incubation Trial)

Almond shells
CN: 86

Unground

Ground < 2 mm

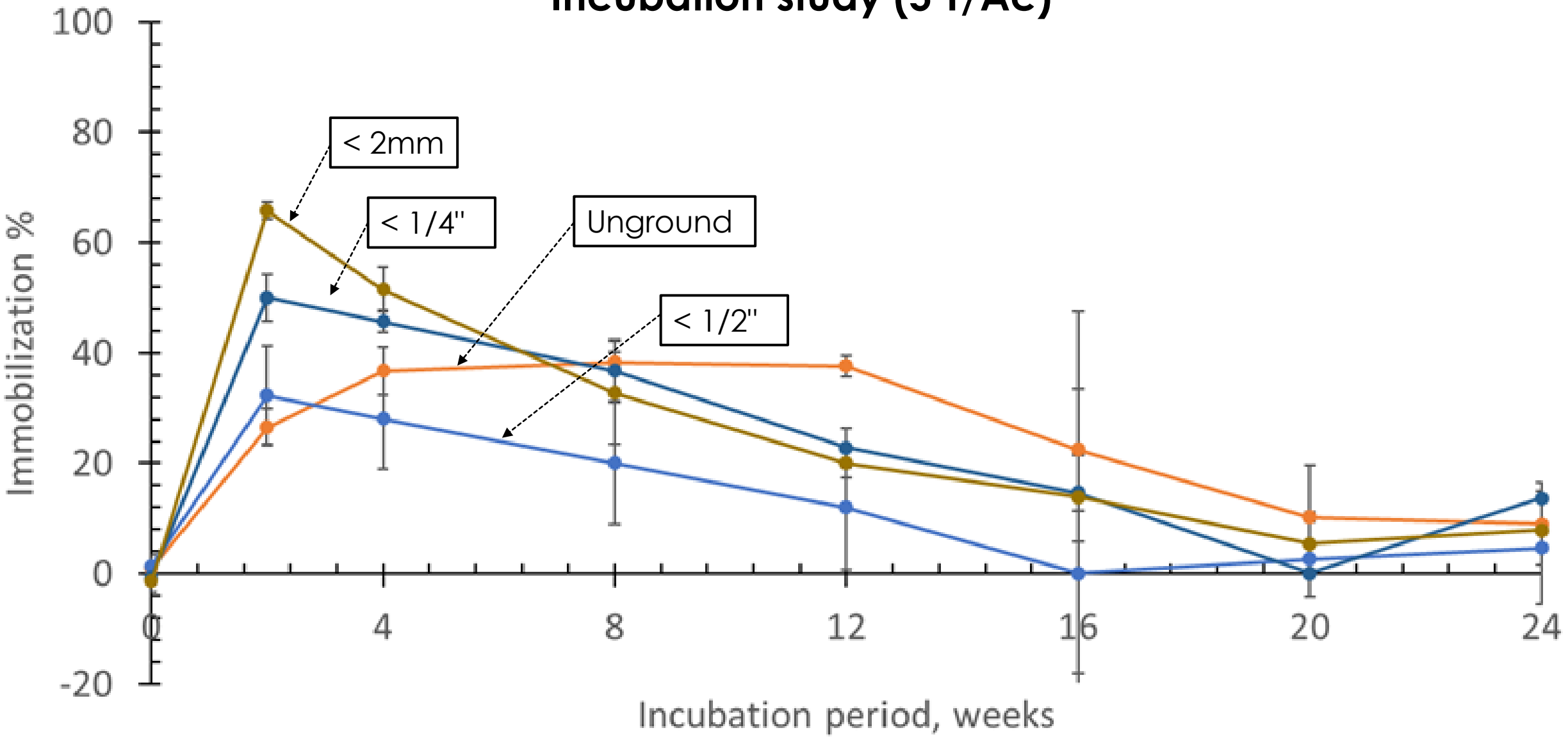
Almond shells 17 T/A, 60% WFPS
1 week after incubation at 77 °F

Penicillium, Rhizopus, Mucor

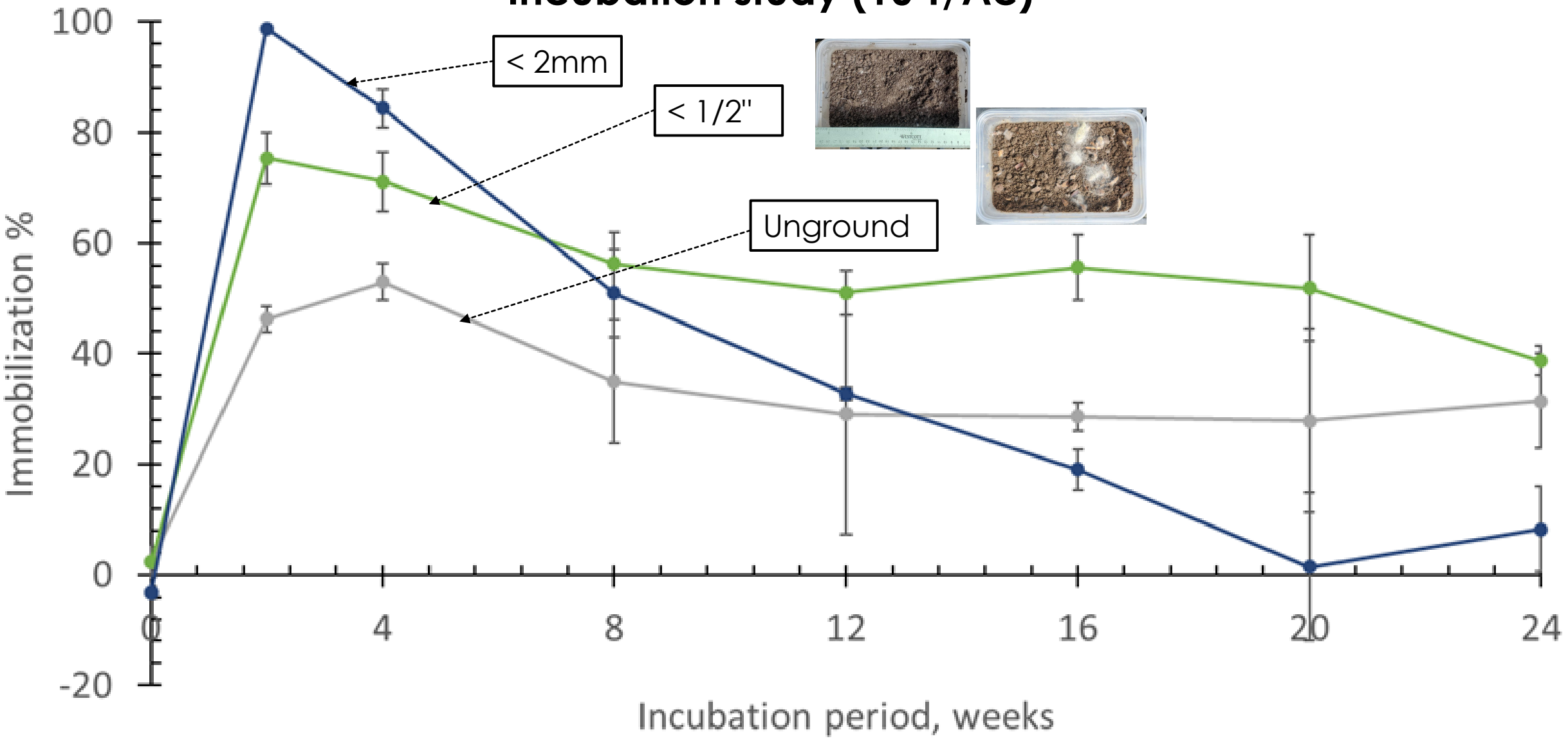
No *Verticillium dahliae* found

No primary plant pathogens found

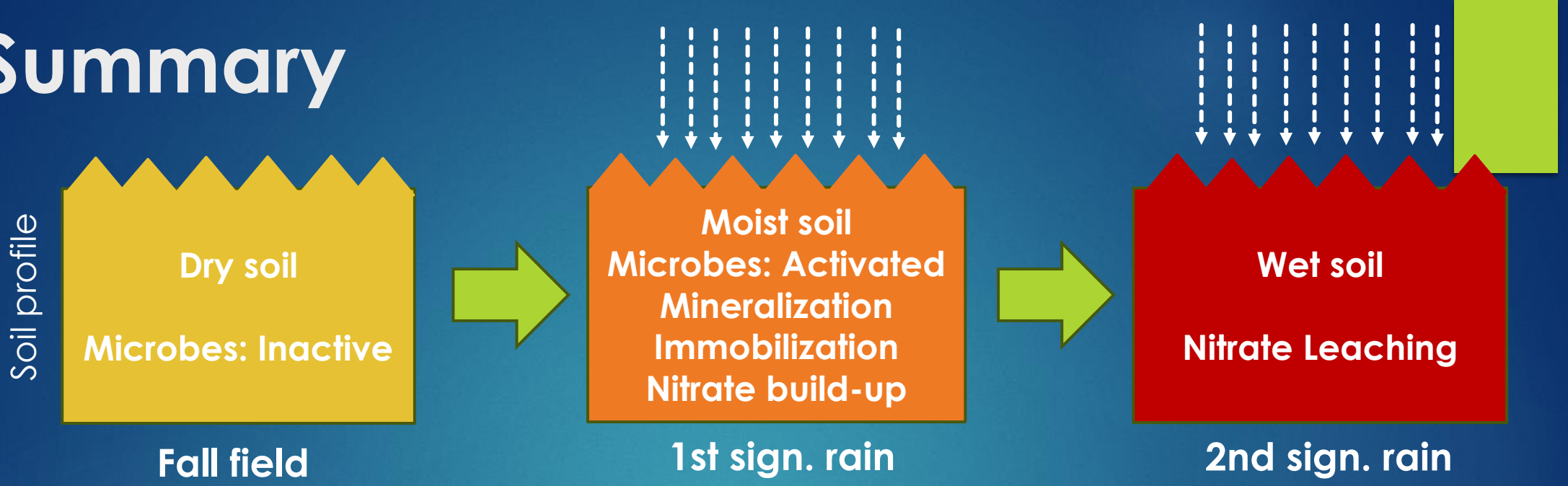
Incubation study (5 T/Ac)



Incubation study (10 T/Ac)



Summary



- To be effective, almond shell particles must be fine enough to immobilize soil nitrate quickly before they are leached down
- Field trial: a significant reduction of soil nitrate with **2 mm-sieved almond shells at 5 tons/ac** and a negative effect on the yield of a successive lettuce crop at **10 tons/ac (causing N deficiency)**
- Lab incubation: **at least <¼"-sieved almond shells 5 tons/ac** may be necessary for reducing soil nitrate without causing a negative effect on a successive vegetable crop……..**Cost?**

2020-2021. Cost/ton of immobilization materials

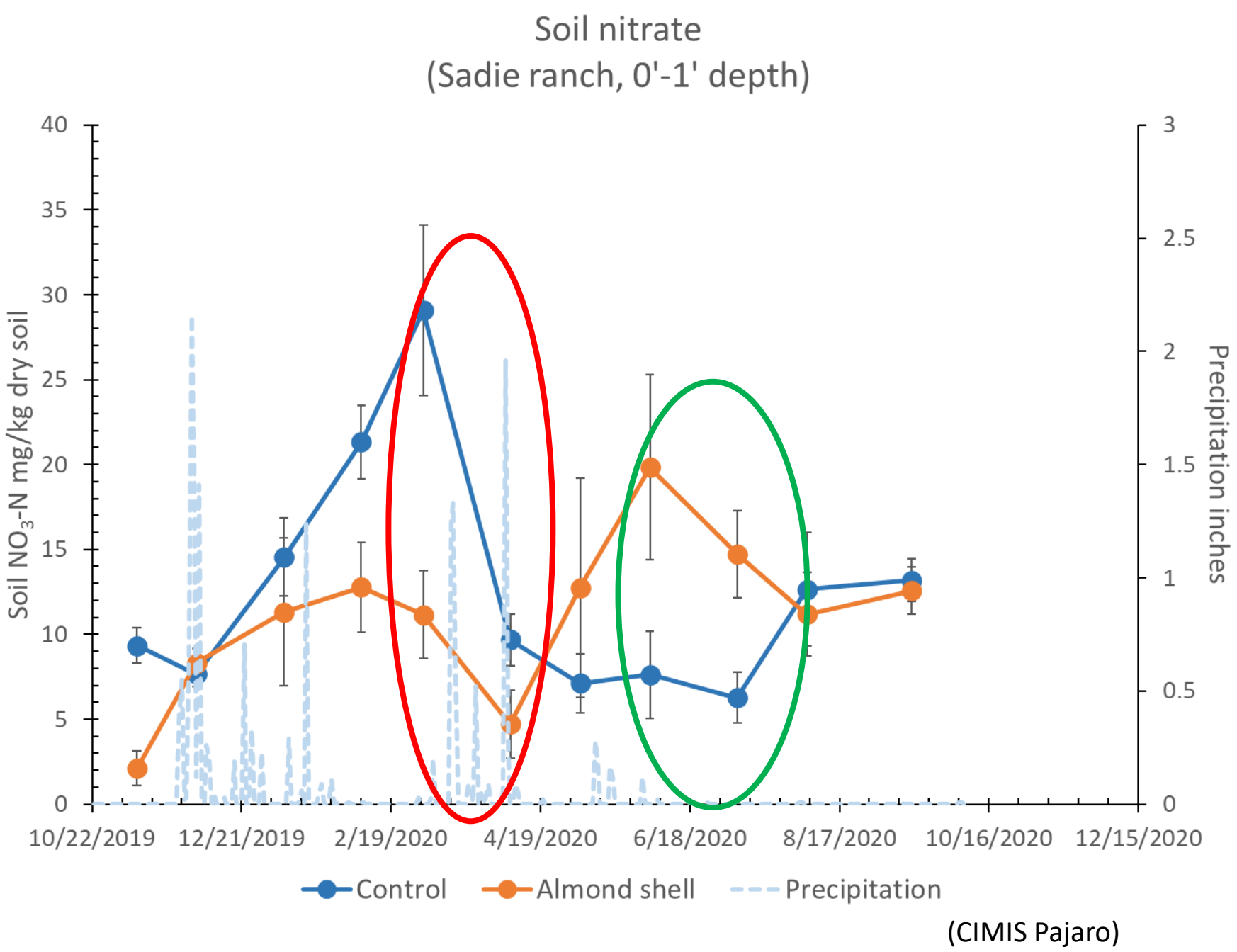
Expense	Ground almond shells	Unground almond shells
Material	15.00	15.00
Trucking	37.50[1]	37.50[1]
Grinding	20.00[2]	0.00
Spreading	8.00	8.00
Total Costs	80.50	60.50

1 – Trucking from Central Valley (2022 cost); 2 – ground to 1/2 inch screen

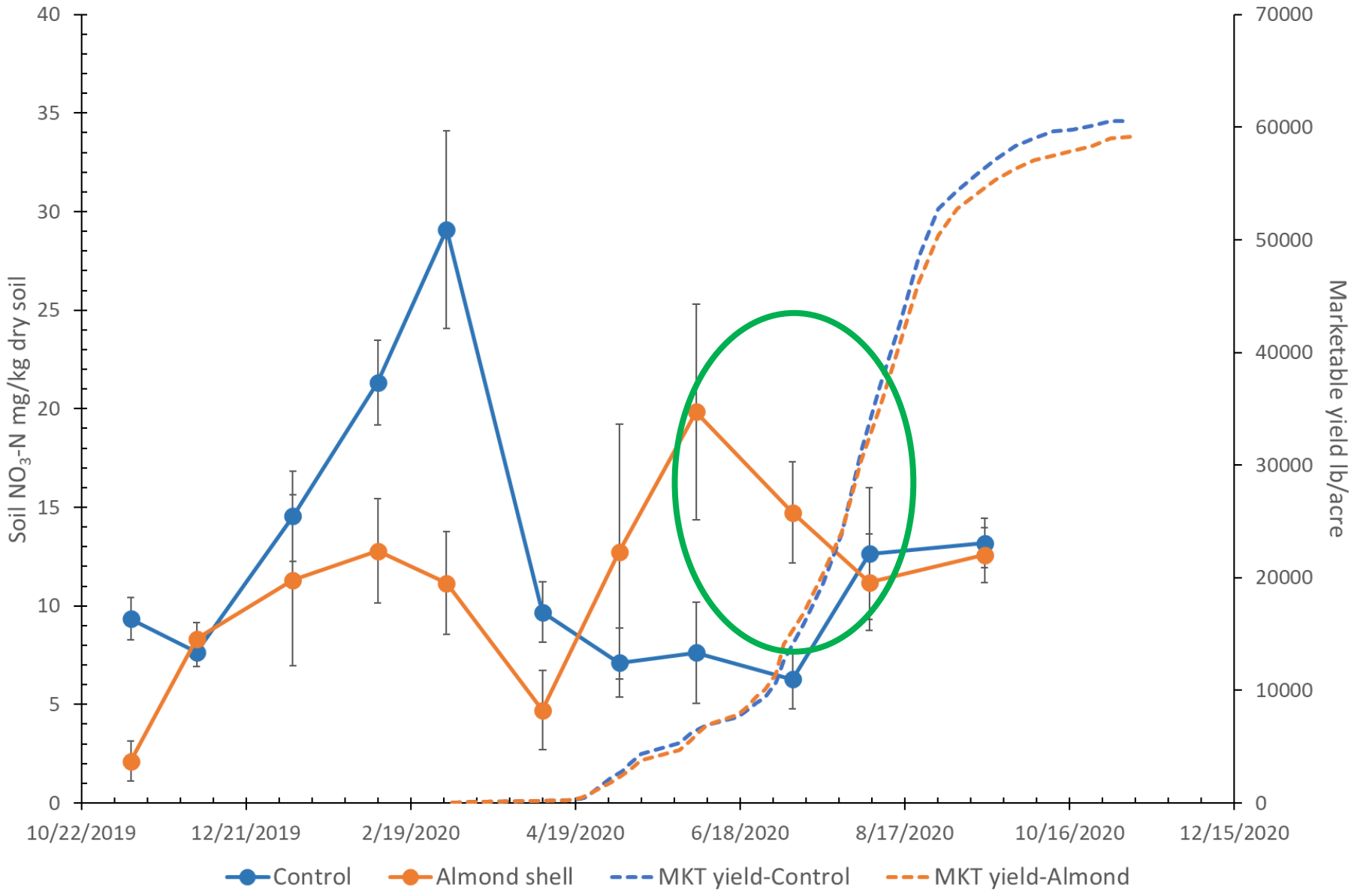
With a **$150/acre budget for compost**, growers can justify
1.9 tons/acre of ground almond shells and
2.5 tons/acre of unground almond shells.

Future Goals and Next Steps

1. Search for less expensive high carbon amendments
2. Give more realistic credit for this practice in AgOrder4.0
   - Simulation model for N-immobilization high-carbon
   - Include the model to CropManage (ABC funding)
3. Reduce N application rate and nitrate leaching without negatively affecting successive crop's yield
   - Manipulate N provision from high N residues by this practice (Strawberry fields)



(CIMIS Pajaro)


Soil nitrate
(Sadie ranch, 0'-1' depth)
Soil NO3-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

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   - Manipulate N provision from high N residues by this practice (Strawberry fields)
   - Field scale demonstrations (Braga Fresh Foods, Driscoll's, Reiter Affiliated Company, Sustainable Conservation)
4. Examining the effect of soil types on N-immobilization (ABC funding)

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- Francisco Estrada, Jaime Mendez, Nolberto Hernandez, Reiter Affiliated Company
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- Elliott Grant, Modibo Keita, Sustainable Conservation
- Staff of UC Cooperative Extension, Salinas
- Students, volunteers, and interns at the Shennan & Muramoto Lab, UCSC

Thank you!
Question?

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