Integrating Enhanced Efficiency Fertilizers into 4R practices

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THE FERTILIZER INSTITUTE

My Background

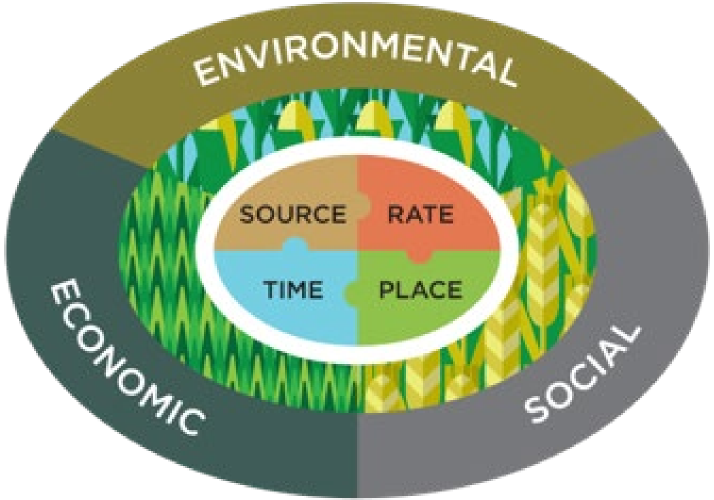
Agenda

- 4R Nutrient Stewardship & EEFs
- N Cycle & Loss Pathways
- EEFs & modes of action
- EEFs in the Research
- EEFs & the 4Rs

4R Nutrient Stewardship

4Rs

Improve agricultural production while contributing to social well being and minimizing environmental impacts (benefits water and air quality)



4R Nutrient Stewardship

RIGHT SOURCE
Matches fertilizer type to crop needs.

Right Source: Ensure a balanced supply of essential nutrients, considering both naturally available sources and the characteristics of specific products, in plant available forms.

RIGHT RATE
Matches amount of fertilizer to crop needs.

Right Rate: Assess and make decisions based on soil nutrient supply and plant demand.

4R Nutrient Stewardship

RIGHT TIME
Makes nutrients available when crops need them.

Right Time: Assess and make decisions based on the dynamics of crop uptake, soil supply, nutrient loss risks, and field operation logistics.

RIGHT PLACE
Keeps nutrients where crops can use them.

Right Place: Address root-soil dynamics and nutrient movement and manage spatial variability within the field to meet site-specific crop needs and limit potential losses from the field.

4R Nutrient Stewardship

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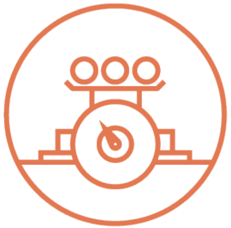

RIGHT RATE
Matches amount of fertilizer to crop needs.

RIGHT TIME
Makes nutrients available when crops need them.

RIGHT PLACE
Keeps nutrients where crops can use them.

EEFs

Enhanced Efficiency Fertilizers – products that target minimizing nutrient losses by slowing nutrient availability

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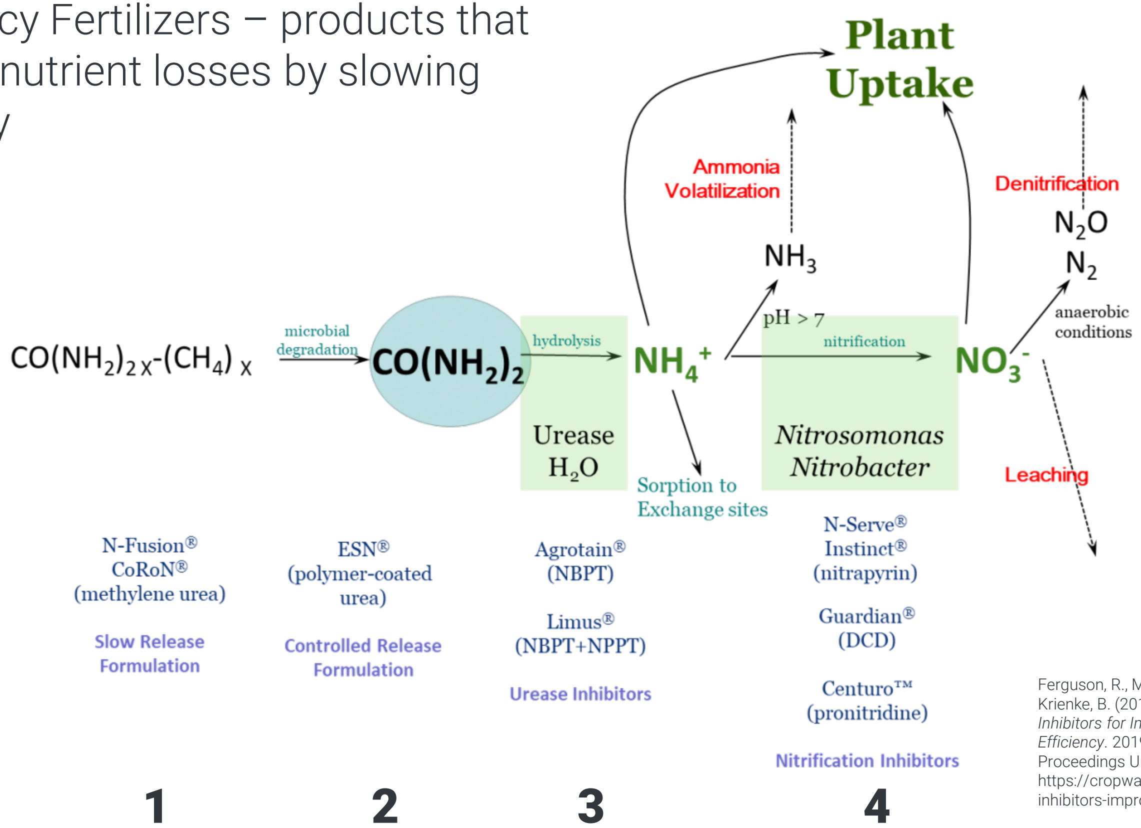
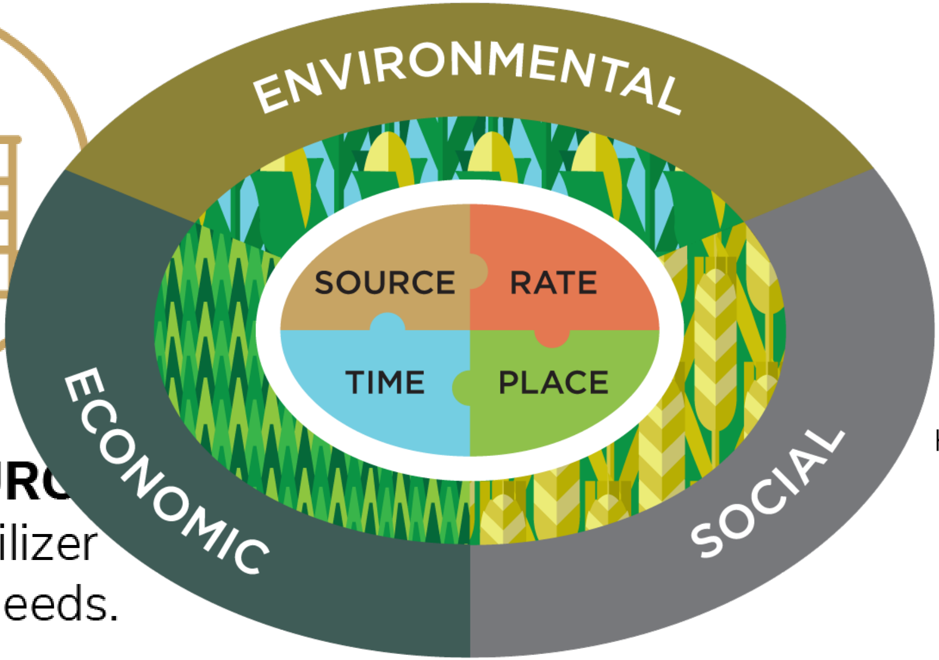


Ferguson, R., Maharjan, B., Wortmann, C., & Krienke, B. (2019, January 14). *Nitrogen Inhibitors for Improved Fertilizer Use Efficiency*. 2019 Crop Production Clinic Proceedings University of Nebraska Lincoln. https://cropwatch.unl.edu/2019/nitrogen-inhibitors-improved-fertilizer-use-efficiency

4R Nutrient Stewardship



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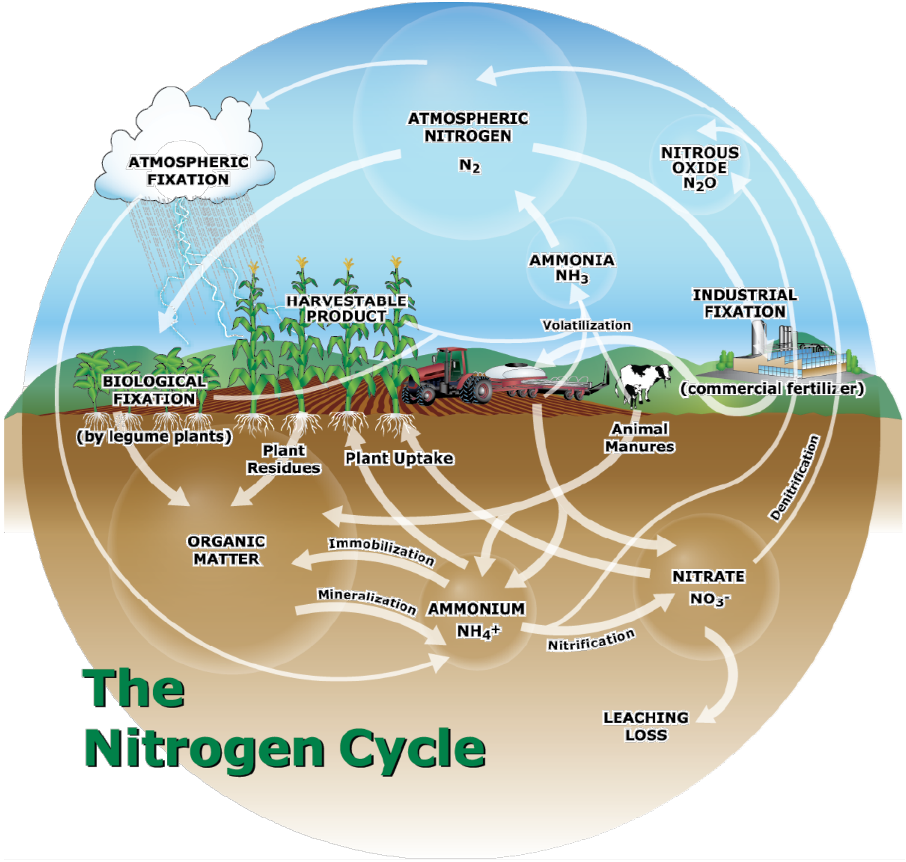
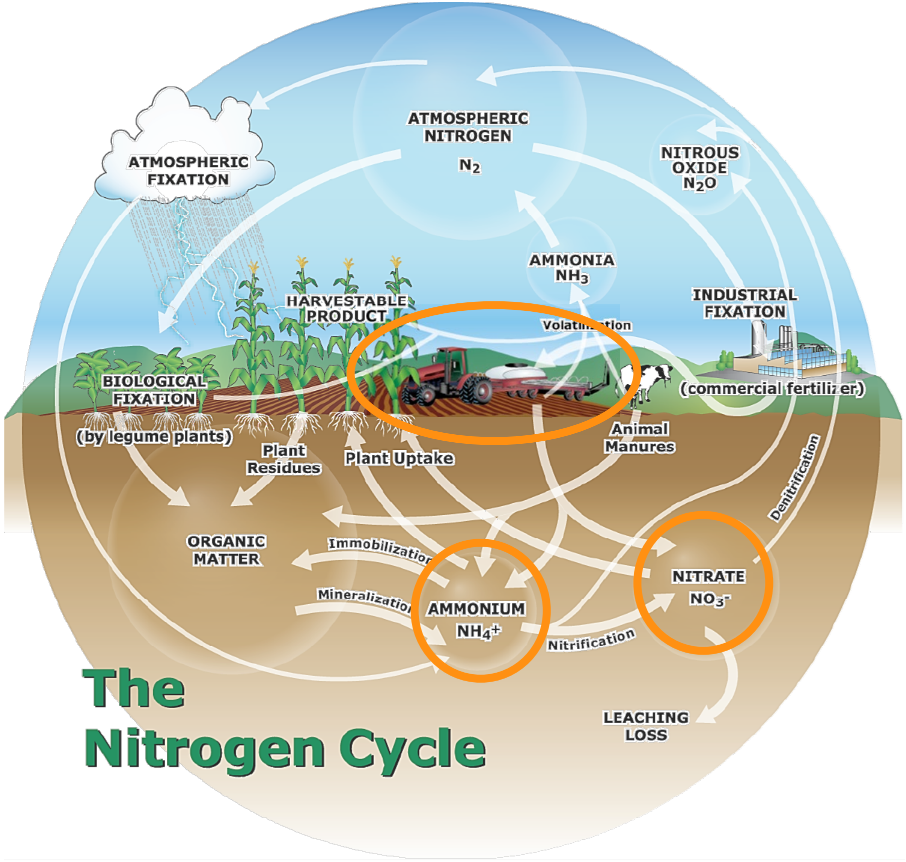
N Cycle & Loss Pathways

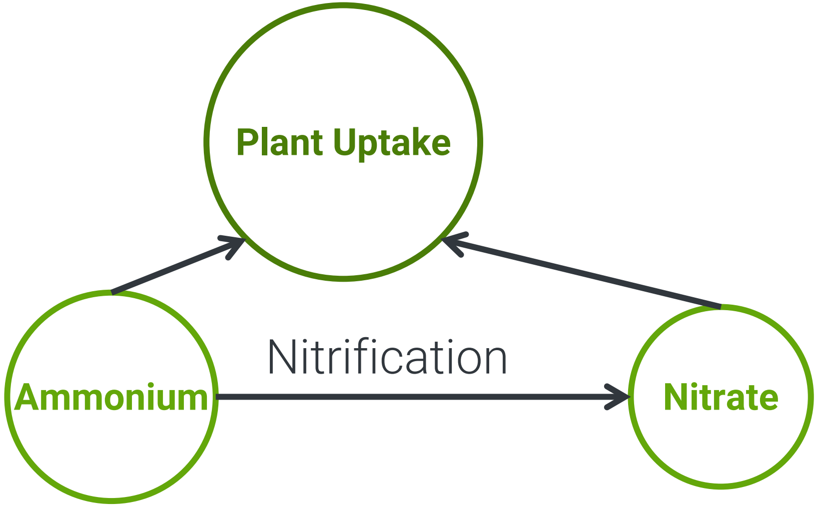
Understanding the N Cycle



Understanding the N Cycle



Fertilizer Fate



Adapted from Alan Blaylock, Nutrien eKonomics resources

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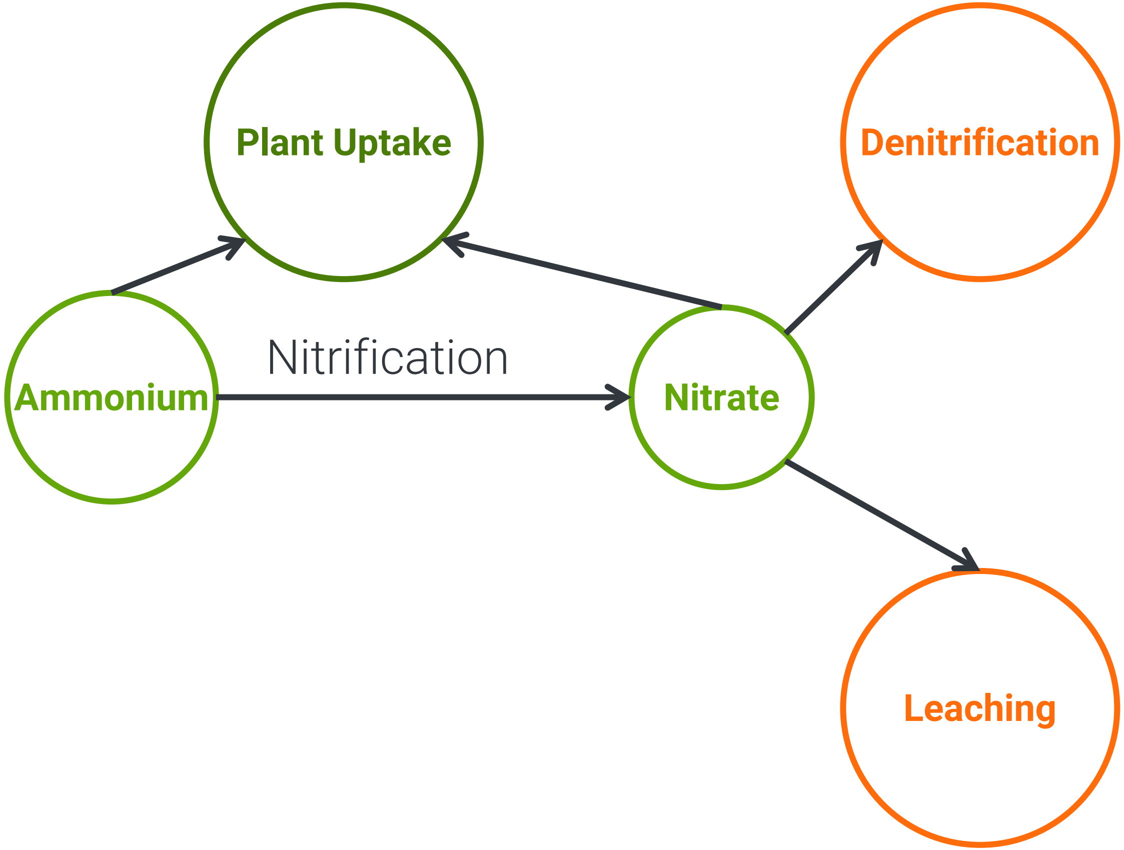

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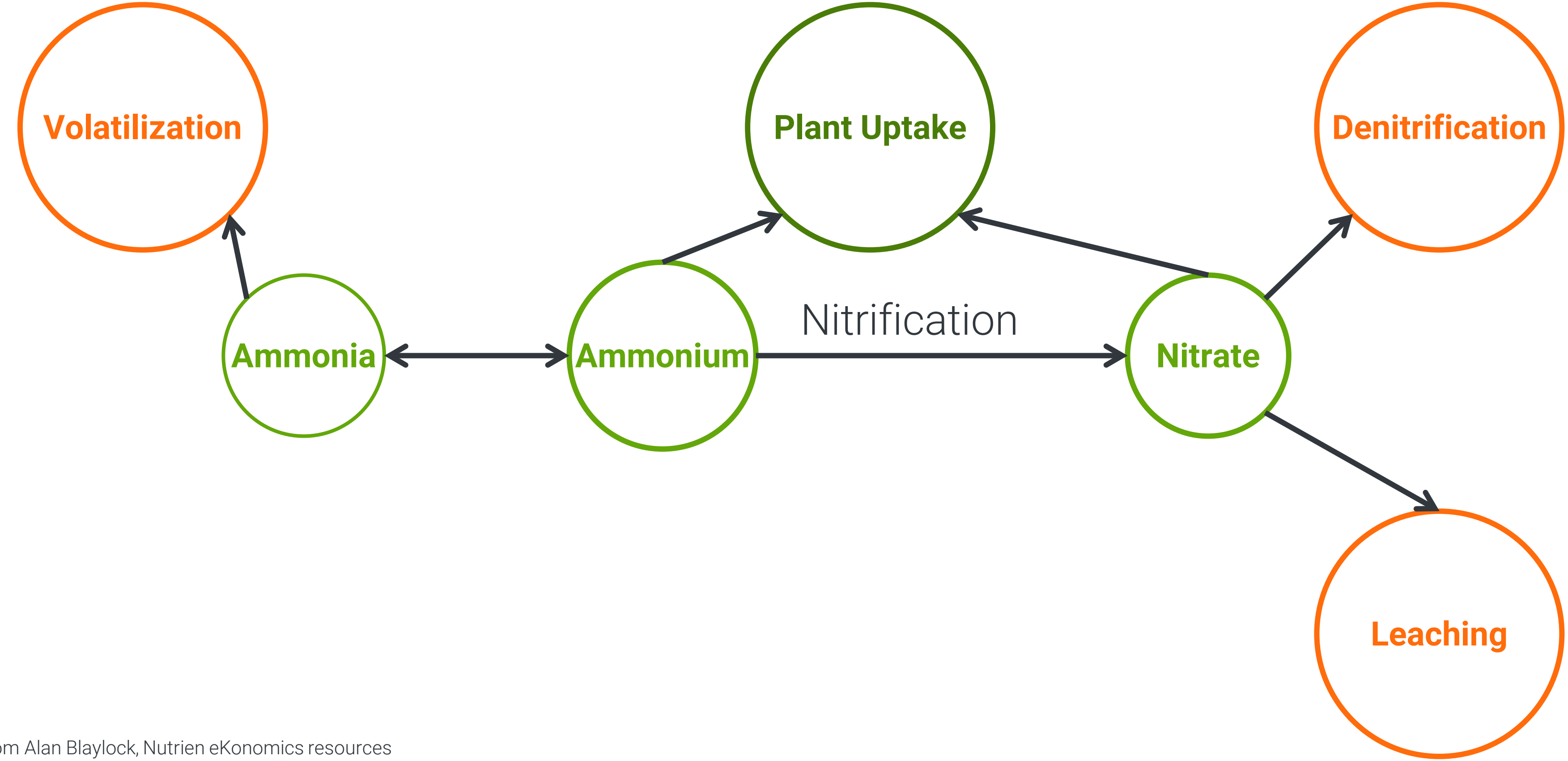

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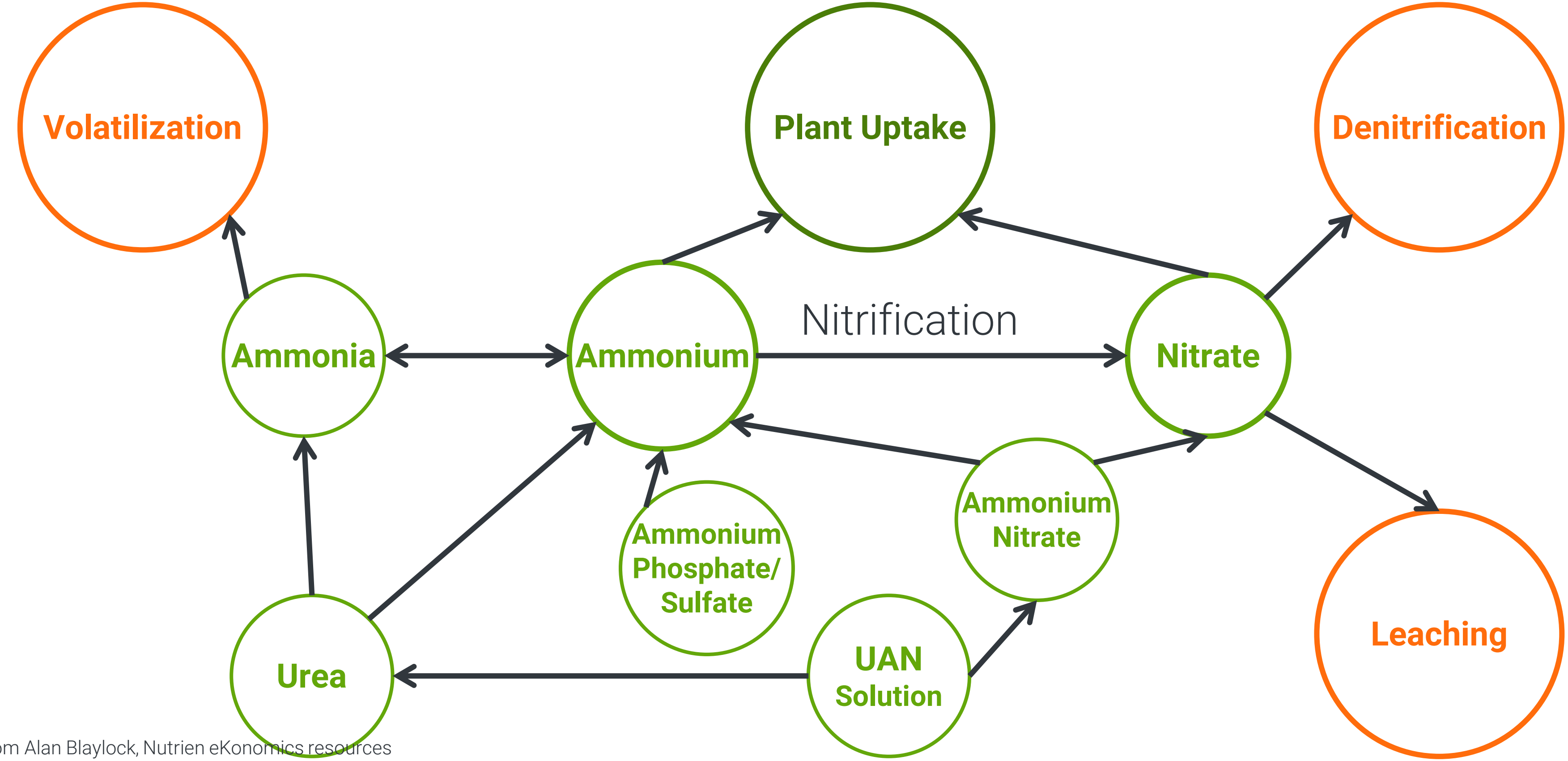

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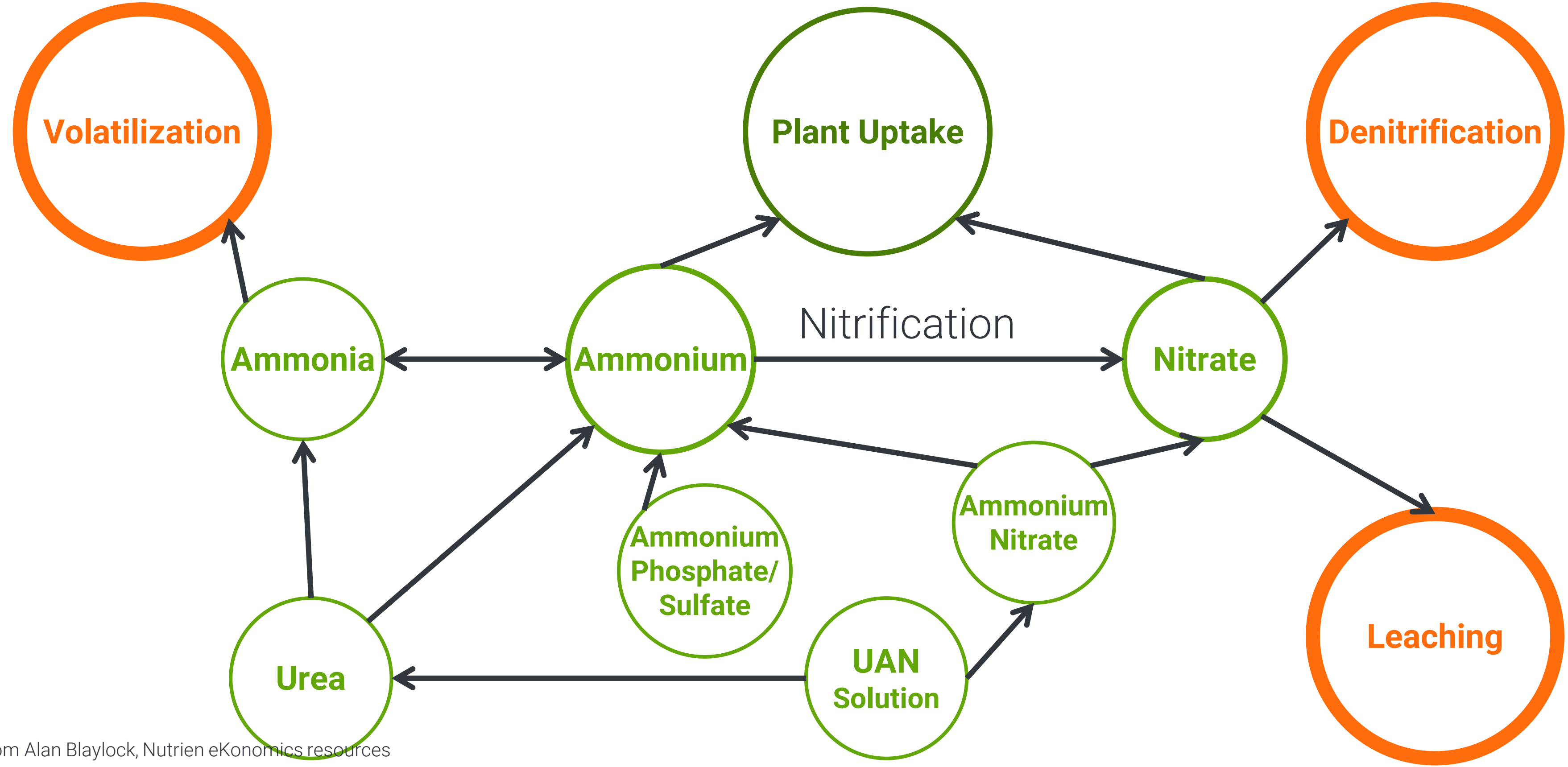

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Major Loss Pathways in Ag

Ammonia/Urea

Volatilization of NH3 (ammonia) to the atmosphere

Nitrate

Leaching of NO3 (nitrate) to water sources

Nitrate

Denitrification of NO3 to N gas forms

Loss possible within days of application

Loss possible anytime within the season

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Volatilization

Volatilization is driven by:

- Incorporation depth
  - Too shallow
- Soil moisture conditions
- Weather (if incorporation method)

Volatilization: Anhydrous Ammonia

NH3 + H2O → NH4 + OH

Can be lost is not at the right depth or soil moisture

High pH can increase volatilization

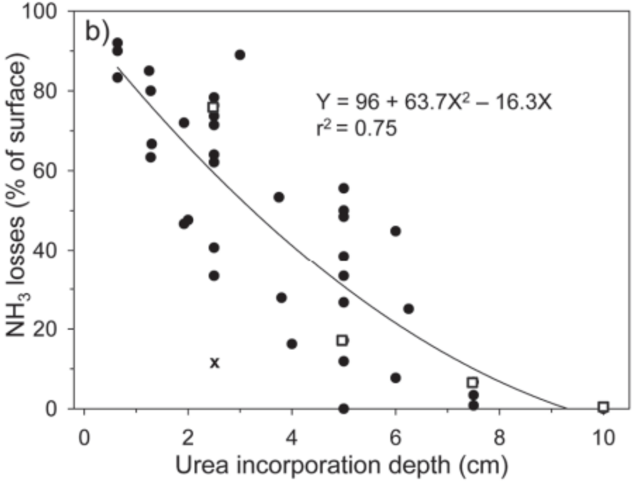
Ammonia will eventually convert to Nitrate

Volatilization: Urea

Urea converts to Ammonium and then Nitrate

$CO(NH_2)_2 + H_2O$ + urease → $2NH_3 + CO_2$ (urea)

- Process is driven by soil moisture
- Urea will hydrolyze (covert to NH_3 + CO_2) in 2-4 days
- Must incorporate or apply before rainfall
- High pH & temperature increases volatilization



Once hydrolyzed, it behaves like anhydrous ammonia

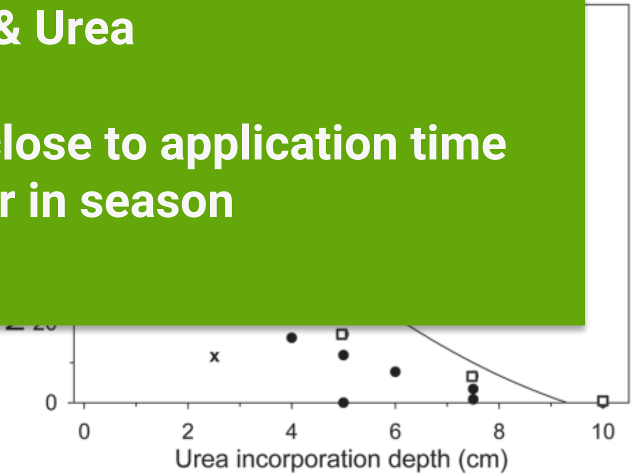
Rochette, P., Angers, D. A., Chantigny, M. H., Gasser, M.-O., MacDonald, J. D., Pelster, D. E., & Bertrand, N. (2013). Ammonia Volatilization and Nitrogen Retention: How Deep to Incorporate Urea? *Journal of Environmental Quality*, *42*(6), 1635–1642.

Fertilizer Fates: Urea

Urea converts to Ammonium and then Nitrate

Anhydrous Ammonia & Urea

Risk for Ammonia loss (volatilization) close to application time
Risk for Nitrate losses later in season



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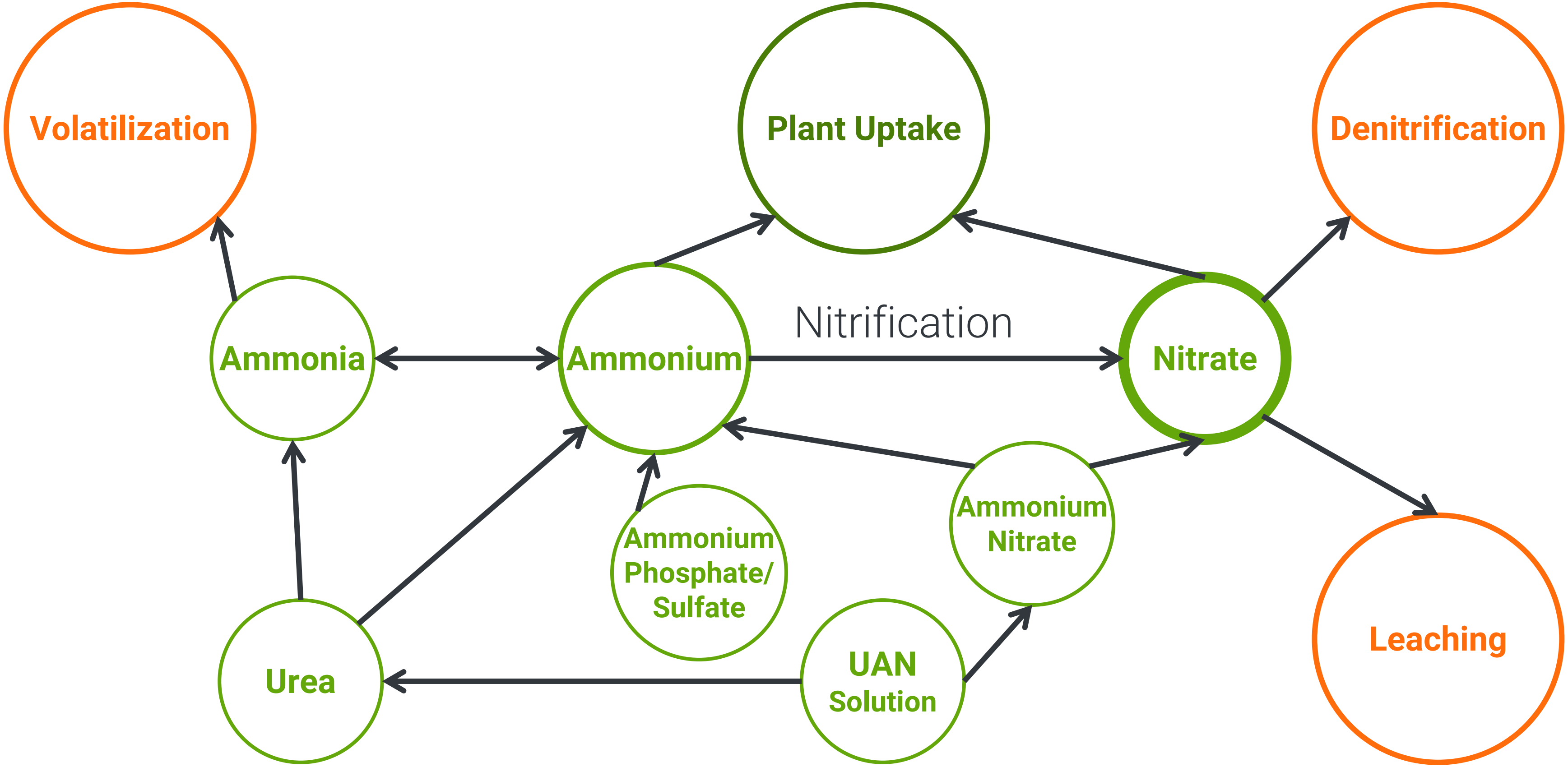
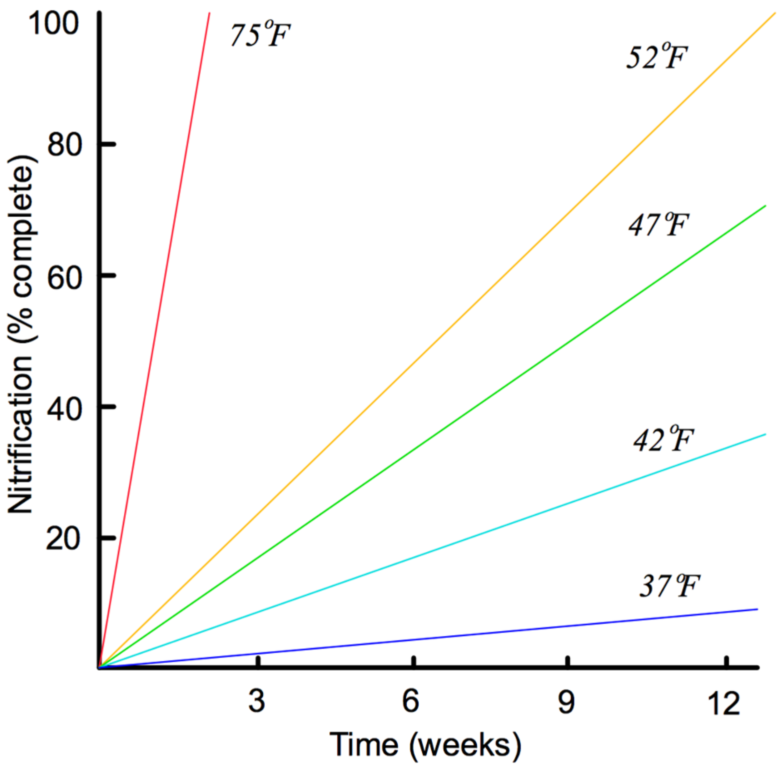


Nitrification to Nitrate

2NH4 + 4O2 → 2NO3 + 4H + H2O

- Most ammonium nitrifies in a few weeks
- Microbial Process driven by soil water and temperature

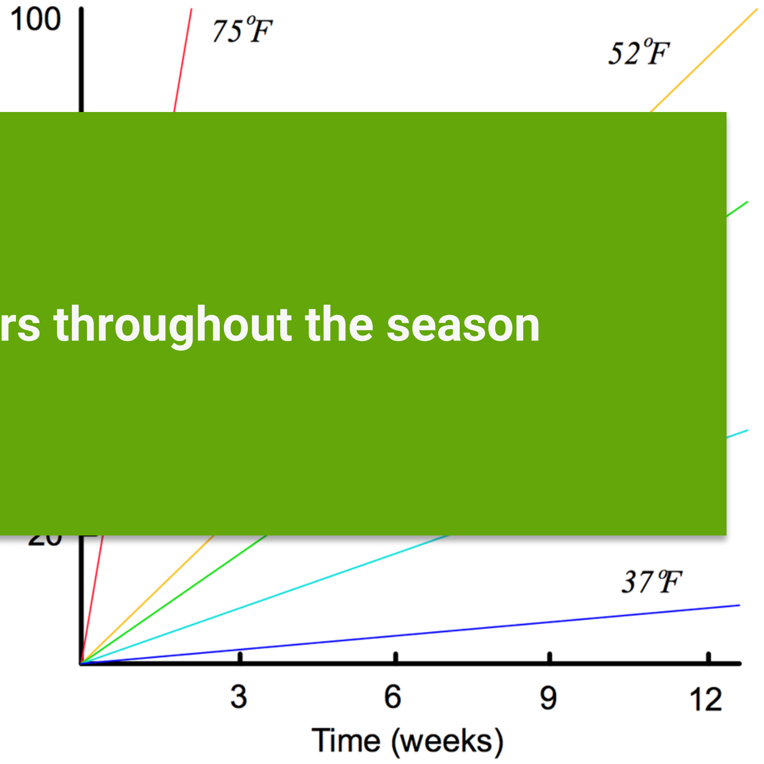


Reductions in nitrification over time based on temperature. (Source: Nutrient Management for Agronomic Crops in Nebraska, Nebraska Extension EC155)

Nitrification to Nitrate

$2NH4 + 4O2 \rightarrow 2NO3 + 4H + H2O$

Risk for Nitrate losses occurs throughout the season



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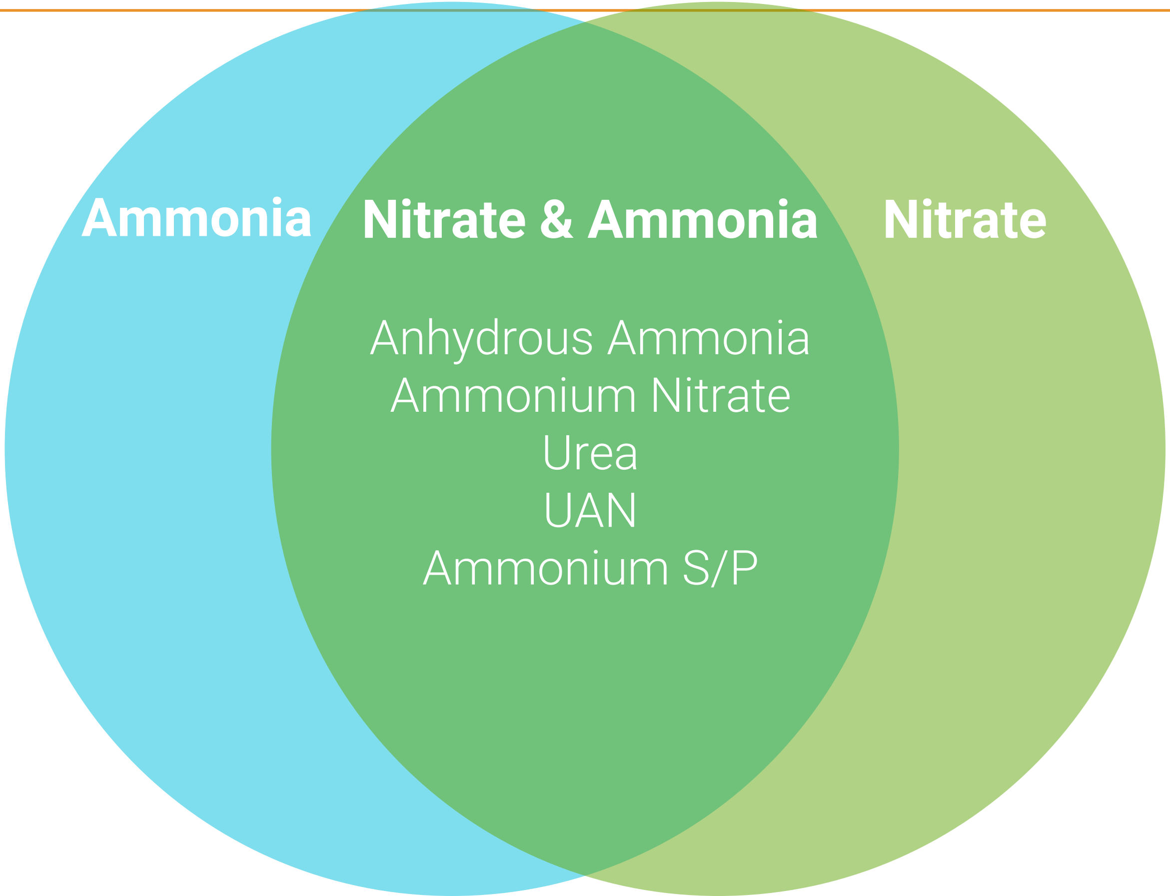
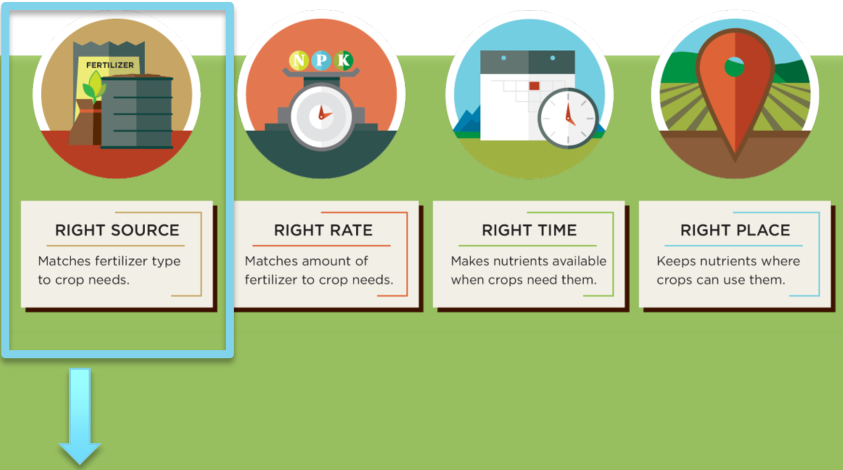
Fertilizer Loss Potential



Tools for Reducing N losses

4Rs
1. Minimize loss
2. Increase nutrient availability



EEFs

1. ***Slow or Controlled release***
2. ***Inhibitors***

N available at the right time

EEFs & Modes of Action

EEFs

Enhanced Efficiency Fertilizers - What are they?

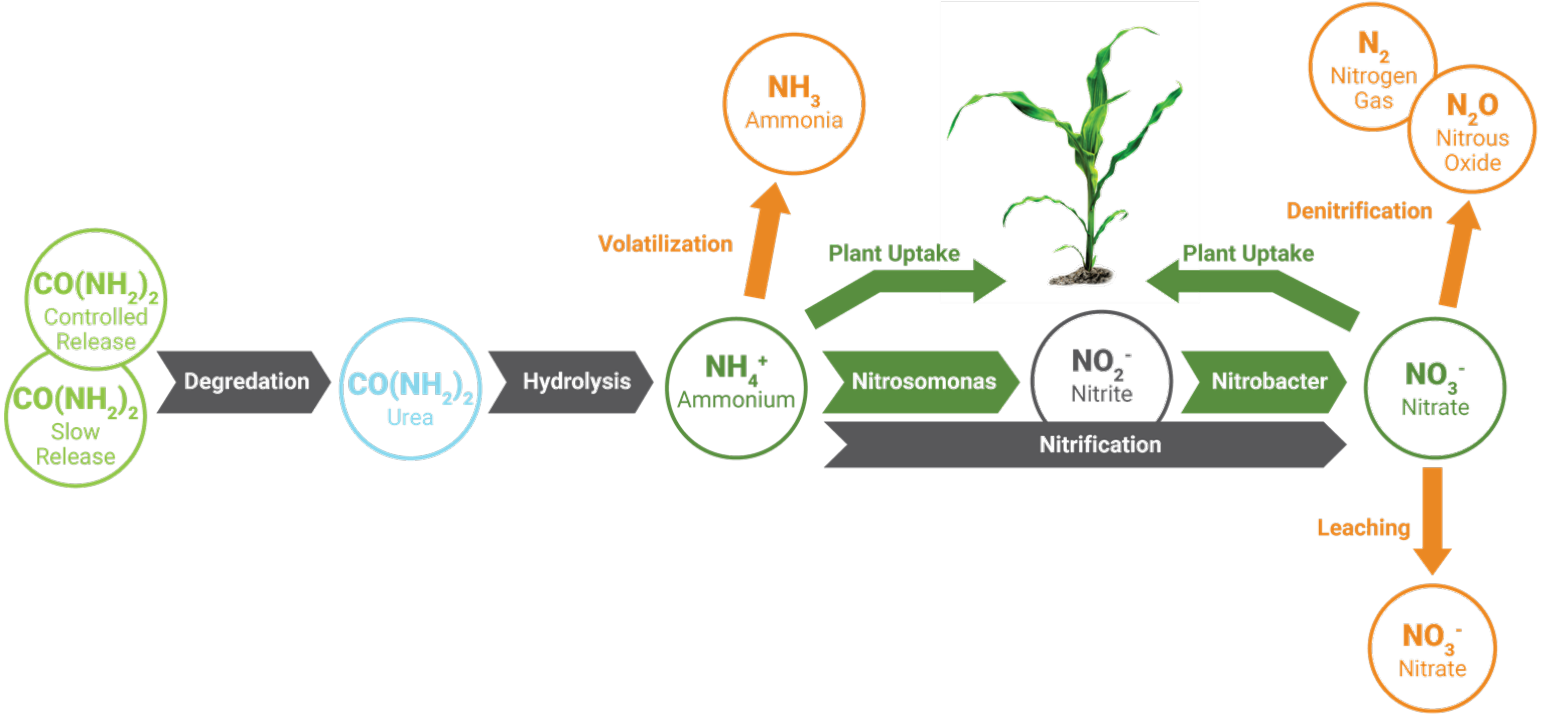
- **Target minimizing nutrient losses** by slowing nutrient availability.
- **Slow the release of nutrients** for uptake or **the conversion of nutrients** to other forms that may be susceptible to losses
- Commonly designed for nitrogen (N), though there are some EEFs for phosphorus (P)
- **Two main categories**: inhibitors/stabilizers & slow/controlled release fertilizers.

EEFs in short

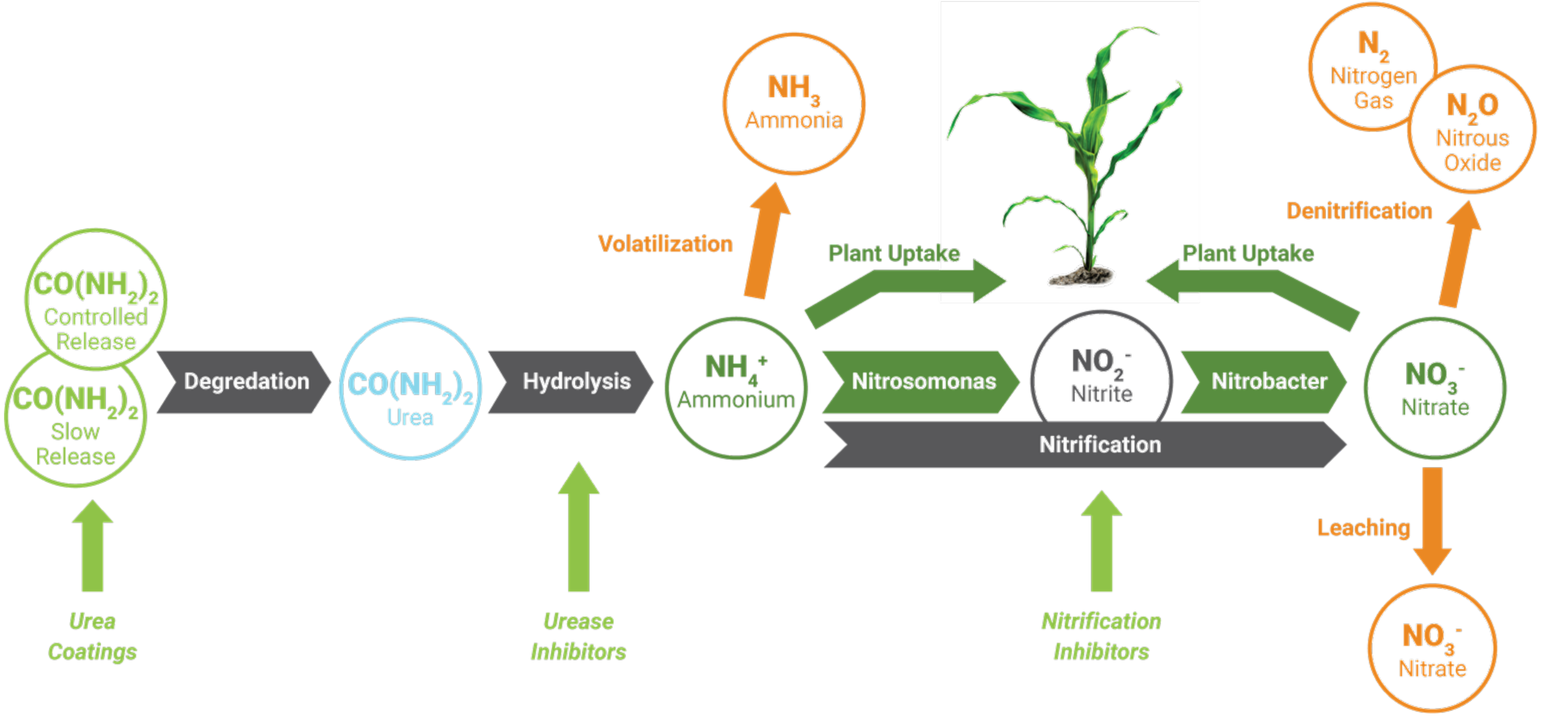
Fertilizer that has been modified in some way to

1. Reduce N Loss
2. Increase Nutrient Availability to the crop

Understanding EEFs & N Cycle



Understanding EEFs & N Cycle



Types of EEFs

Slow and controlled release coatings

- Coatings on the fertilizer that slow the delivery of nitrogen.
- Release time is determined by the mechanism of release.
  - Can use physical processes or biochemical processes
  - Same objective, but different release mechanism

Inhibitors/Stabilizers

- Additives that slow N transformations in the soil.
- Urease inhibitor: slows conversion of urea to NH4
  - slows the process of hydrolysis
- Nitrification inhibitor: slows conversion of NH4 to NO3
  - Temporarily suppresses microbes

Types of EEFs

Slow and controlled release coatings

- Coatings on the fertilizer that slow

Inhibitors/Stabilizers

- Additives that slow N

microbes

Many products
Different modes of action
Various benefits

Need to select the product based on the challenge you are trying to solve

Slow and Controlled Release Fertilizers

Fertilizers that release N over a period of time (few weeks to months)

Slow-Release Fertilizers

Release controlled by either microbial or chemically decomposable compound

- Release pattern & rate not easily predicted/controlled
- May be affected by moisture, temperature, and microbial activity

Controlled-Release Fertilizers

Release is controlled by a “physical coating” applied to the fertilizer

- Coated fertilizers have a more predictable release time based on temperature

Slow and Controlled Release Fertilizers

Two mechanisms for N release

Chemical/Biological Process		Physical Process
Typically water soluble, combinations of methylated urea		Typically coated (controlled release) fertilizers
• Methylene urea • Urea formaldehyde • Urea triazon	**Sulfur Coated Urea** Poly-S	**Coated Ureas** • ESN • Polyon • PurKote

Slow and Controlled Release Fertilizers

Two mechanisms for N release

Chemical/Biological Process	Physical Process
Typically water soluble, combinations of methylated urea	Typically coated (controlled release) fertilizers

Different mechanisms,
Same objective: Slow N availability

Inhibitors & Stabilizers

Urease Inhibitors

Slows urea to NH4 conversion

Controls volatilization for roughly 7-14 days

NBPT
Agrotain, Nitrain, Limus

Duramide
Anvol

Nitrification Inhibitors

Slows NH4 to NO3 conversion

Controls denitrification and leaching for roughly 4-8 weeks

Nitrapyrin
N-serve, Instinct

DCD
Guardian

Pronitrodine

UI & NI

SuperU
Tribune

Longevity of EEFs

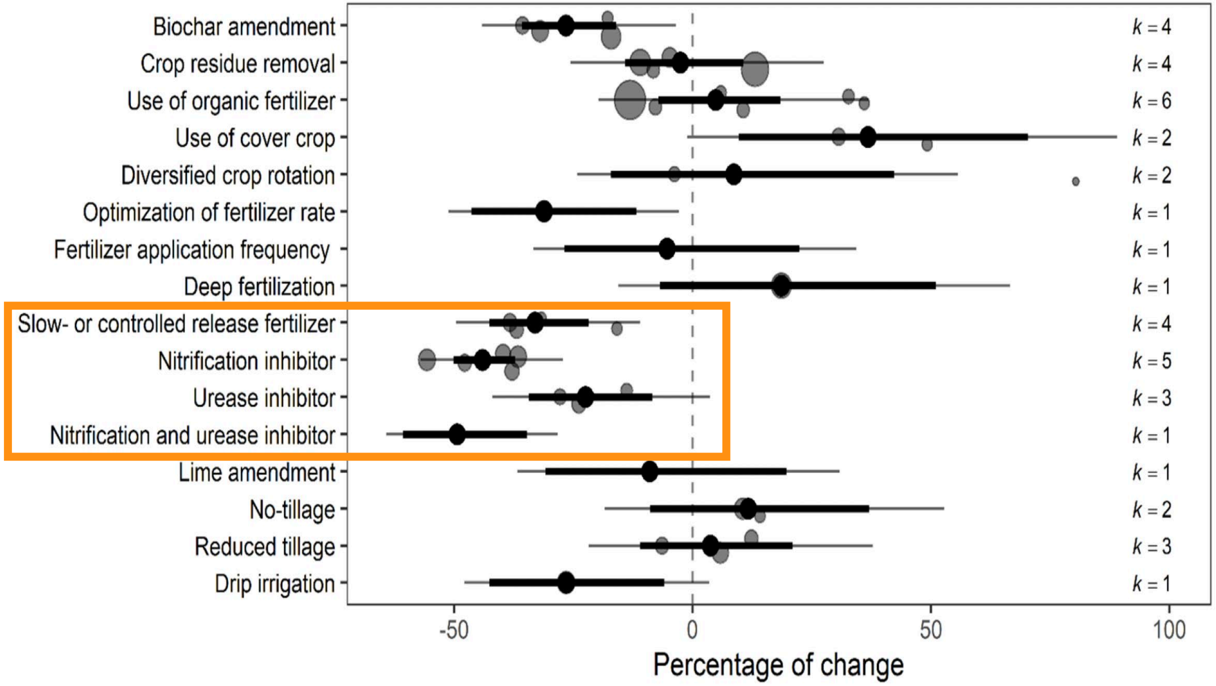
N Change	Timeline
Urea hydrolysis to ammonium	2-3 days
Urea with urease	7-14 days
Nitrification of ammonium to nitrate	7-21 days
Nitrification with nitrification inhibitor	30-50 days
Urease inhibitor + nitrification inhibitor	30-50 days
Controlled release	50-80 days

Products vary in function & can be impacted by soil conditions

Adapted from Alan Blaylock, Nutrien eKonomics resources

EEFs in the Research

EEF Research



Grados, et al. (2022). Synthesizing the evidence of nitrous oxide mitigation practices in agroecosystems. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/AC9B50

EEF 4R Research

	4R Research	2016 Meta-Analysis
Nitrification Inhibitor	Reduced N_2O **24%**	Reduced N_2O **38%**
Double N Inhibitor (Urease and Nitrification)	Reduced N_2O **30%**	Reduced N_2O **30%**
Slow Release/Polymer Coating	Reduced NH_3 **81%** and N_2O **55%**	Reduced N_2O **19%**

Varies by soil & environment

Thapa, R., Chatterjee, A., Awale, R., McGranahan, D. A., & Daigh, A. (2016). Effect of Enhanced Efficiency Fertilizers on Nitrous Oxide Emissions and Crop Yields: A Meta-analysis. *Soil Science Society of America Journal*, *80*(5), 1121–1134. https://doi.org/10.2136/sssaj2016.06.0179

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EEF 4R Research

Minnesota

According to a Farmer survey (accounting for 5.4M acres) and field data:

Split N with EEF = $129M return

Adding split N applications using polymer coated urea to acres indicated by farmers in the study could lead to $129M annual economic returns across the state overall. $63/acre on average

EEFs reduced N emissions by 81% NH_3 and 55% N_2O

Using a polymer coated urea (instead of urea) reduced losses for both ammonia (NH_3) and nitrous oxide (N_2O) by 81% and 55% respectively

Translates to **1.83US tons** (1.66 metric tons) in **NH_3-N** and **2.81US tons** (3.09 metric tons) in **N_2O-N emissions** for the 5.4M acres

EEF Research

- 2022 meta-analysis found that the overall range of **N_2O mitigation** potential for the technology-driven solutions like EEFs was **22%–49%** (Grados et al., 2022).

- Another 2022 meta-analysis found that urease inhibitors ***reduced NH_3 volatilization by 51% and nitrification inhibitors reduced N_2O emissions by 49%.*** The authors also stated using a combination of nitrification and urease inhibitors "*…enables producers to balance crop production and environmental conservation goals without pollution tradeoffs.*" (Fan et al., 2022).

- In a 2016 meta-analysis, nitrification inhibitors (DCD and nitrapyrin) were found to ***reduce emissions on average by over 40%, and polymer coated urea by 20%*** (Thapa et al., 2016).

- 2023 meta-analysis found EEFs were as effective in reducing annual mean emissions as those during just the growing season (Pelster et al., 2023).

EEF Research

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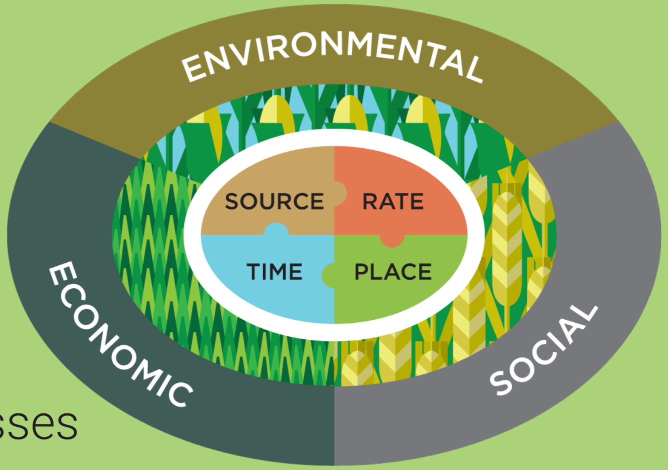
The Bottom Line

EEFs are beneficial to

Grower: Increasing NUE
Society: reduced emissions & N losses



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EEFs & the 4Rs

Why to use EEFs

"I'll use the cheapest one"

- What is your objective? Will you achieve anything this way?

"I tried that and it didn't work"

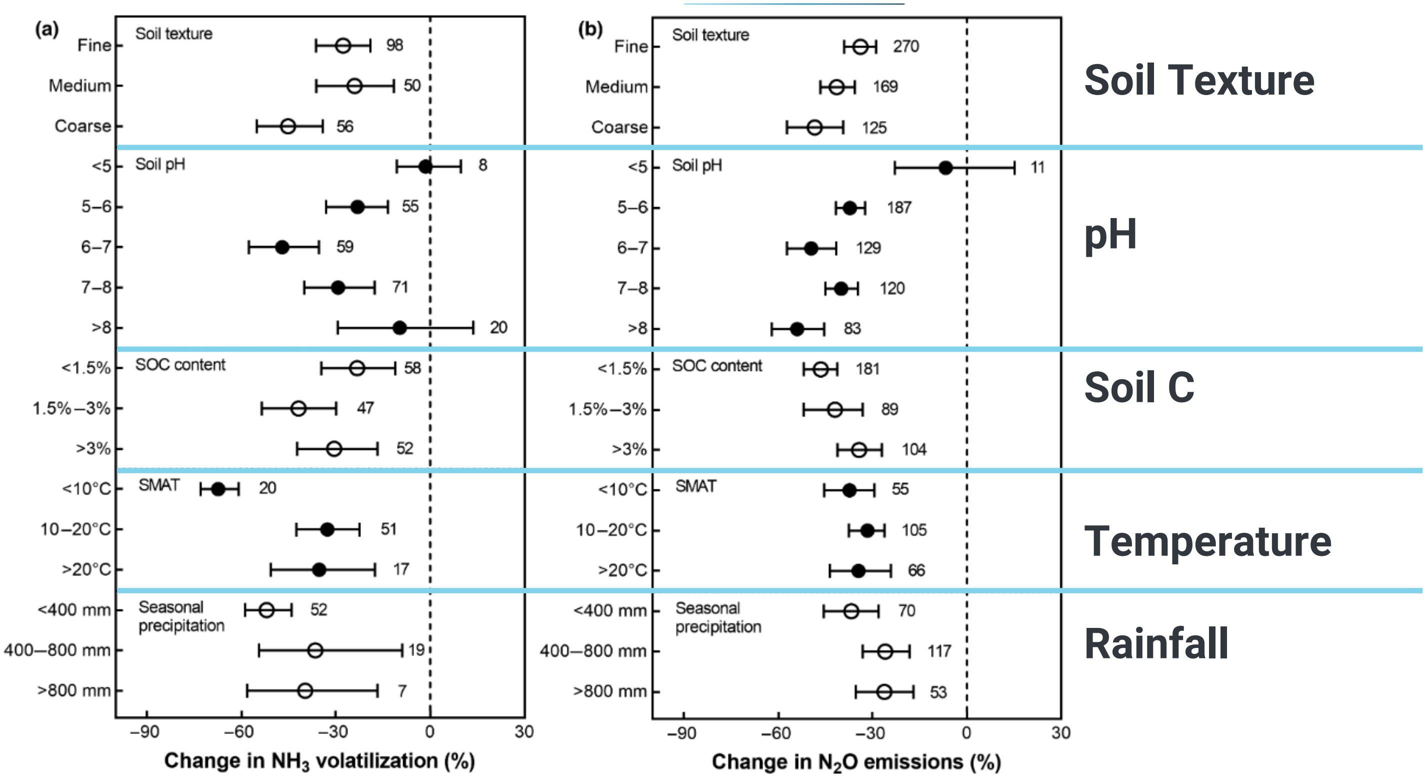
- What were the soil and weather conditions? Did you choose the right product for the problem?

"It doesn't matter as long as I can say I'm using an EEF"

- Missing the point of the 4Rs and maximizing the technology

Adapted from Alan Blaylock, Nutrien eKonomics resources

EEFs (inhibitors) and Soil Factors



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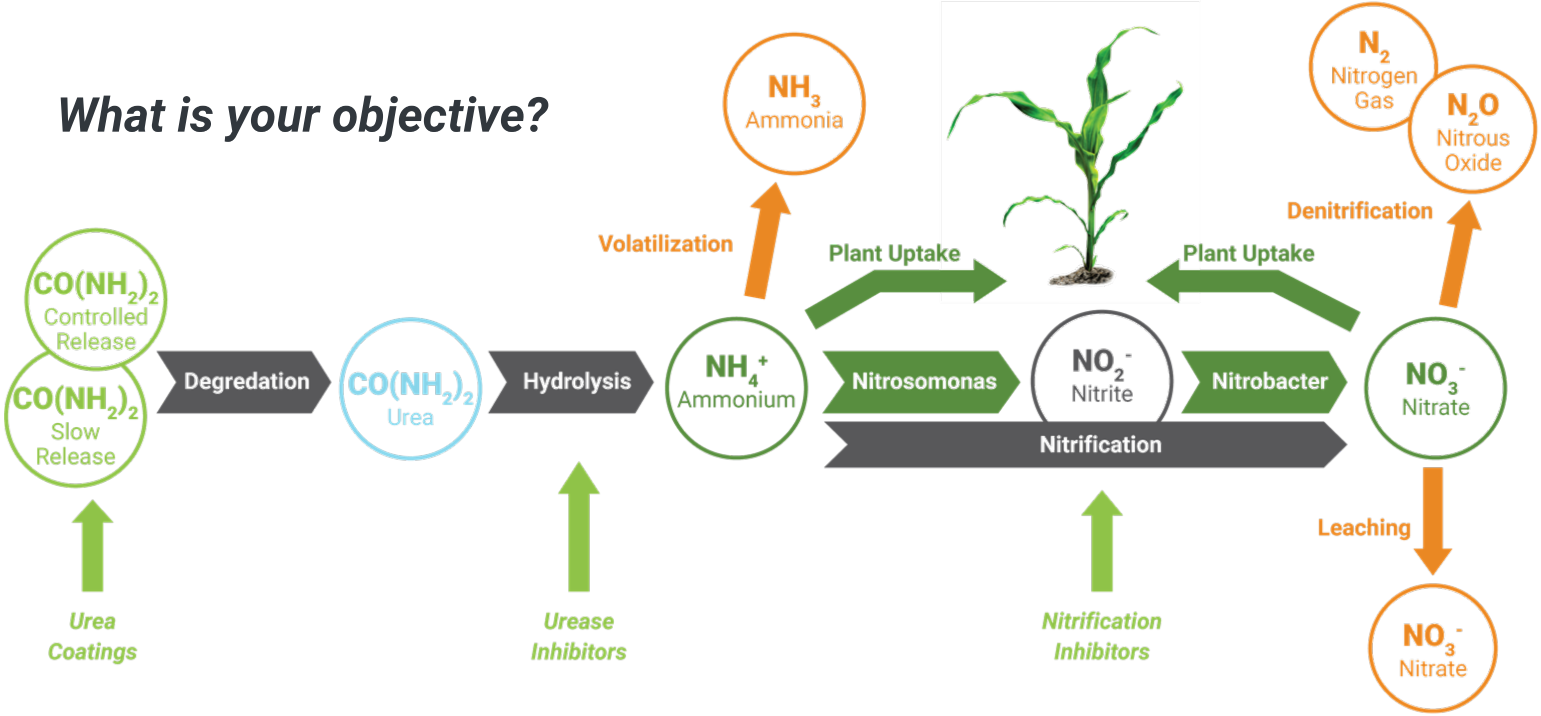
Understanding EEFs & N Cycle

What is your objective?



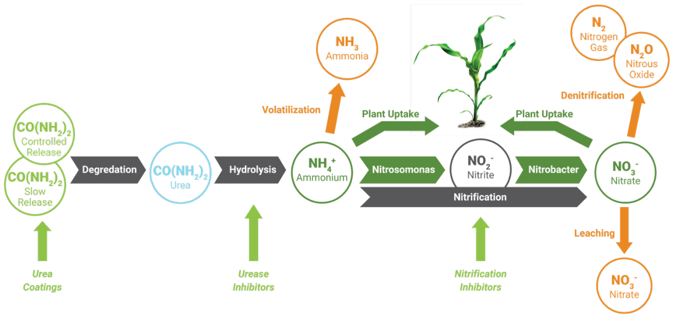
4R Questions to Consider

Where do I think my N program is weakest or leakiest?

What is my NUE (PFP)? Can I improve that? Where can you target in the N cycle?

What sources am I using and is there a need to add an EEF?

Can I add in a split application to help with timing? If that's not possible, can I use a "long-term" EEF?



Summary

- EEFs can impact all 4Rs, preventing loss and improving NUE
  - Controlled release – Time, Place, Rate
  - Urease Inhibitors – Source, Time, and Place
  - Nitrification inhibitors – Time and Place

- Climate-smart programs will likely increase the value of EEFs
  - EEFs can improve economic, social, and environmental benefits that are key to the 4Rs
  - Carbon programs: N and C are linked in the soil

- Use the right tool for the problem: pick the **right** mode of action EEF

Thank you & Questions

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