Ammonia Volatilization: Process, Amounts, and Effects on Yield and Protein

Created for the Web

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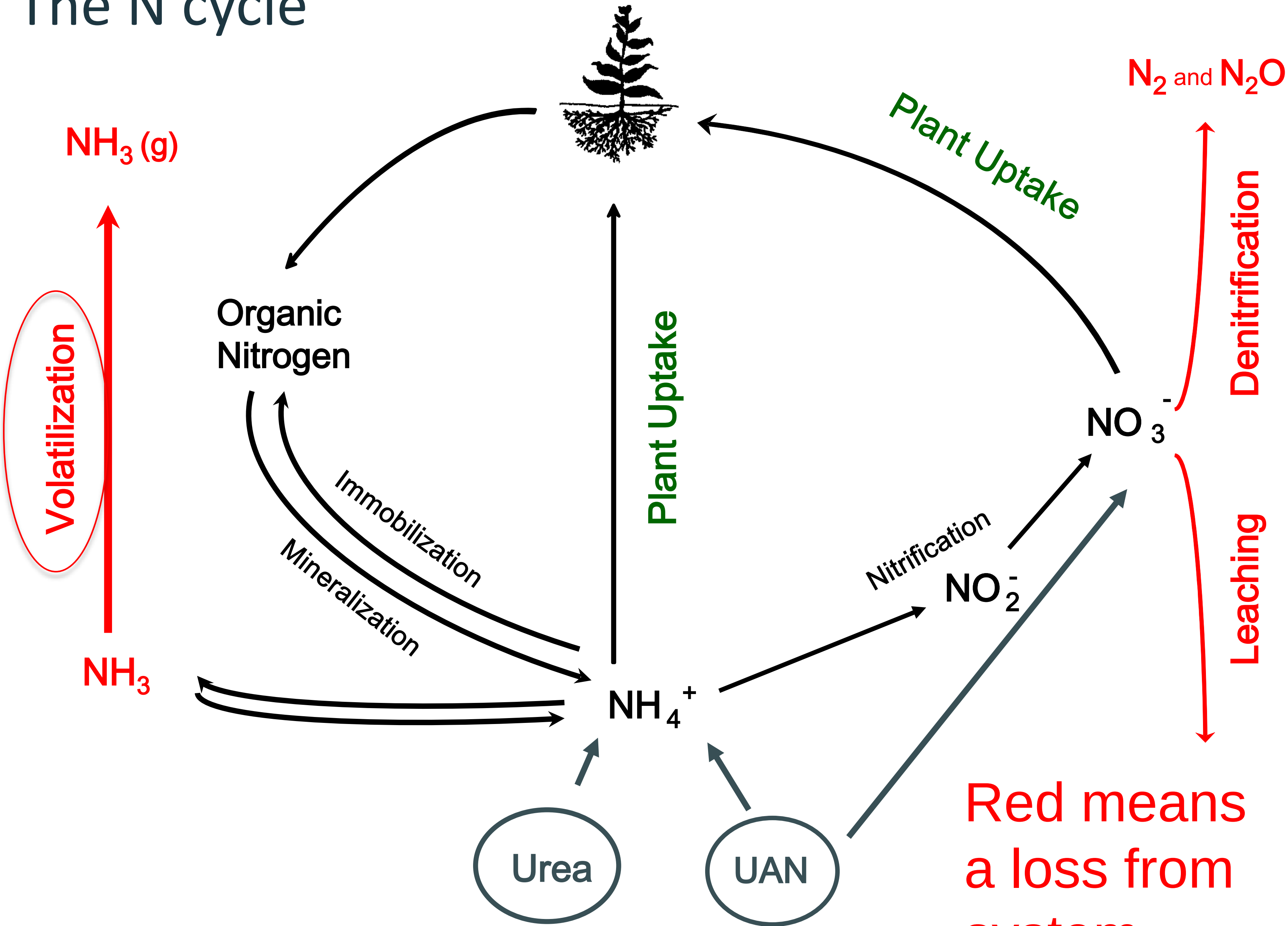
Objectives

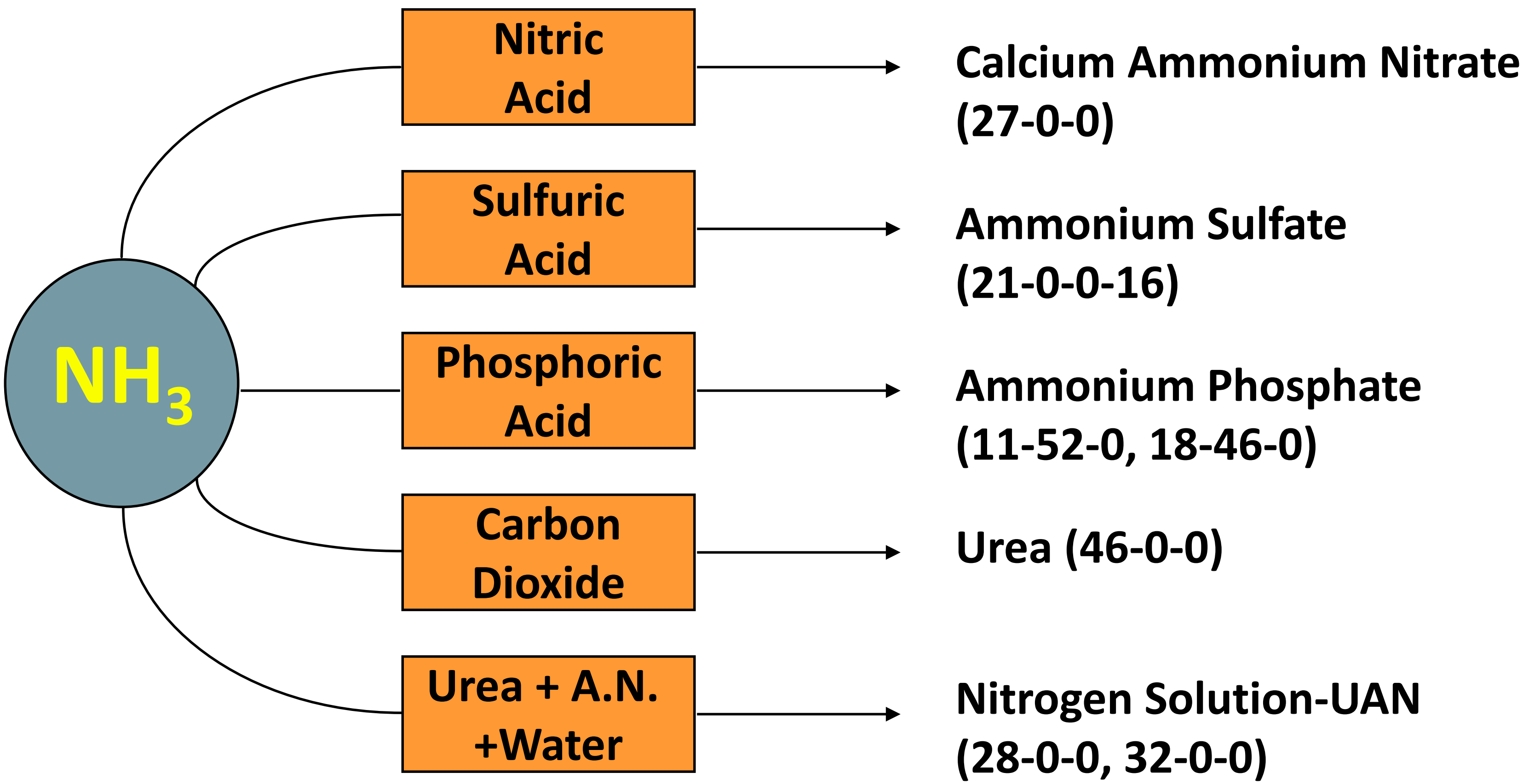
- Discuss factors that affect volatilization and high risk conditions for volatilization
- Present timing, placement and source options to reduce volatilization
- Present results of different sources and placement on yields and grain protein in the Northern Great Plains

The N cycle



Red means a loss from system

Anhydrous ammonia - The base material



Ammonia Volatilization

ammonium + hydroxide $\longrightarrow$ ammonia gas + water

($NH_4^+ + OH^-$) $\longrightarrow$ ($NH_{3\,(gas)} + H_2O$)

- Can occur with urea and all ammonia or ammonium based fertilizers
- Losses vary with environment and are difficult to predict.

Looking at above equation, what is 1 factor that increases volatilization? **High pH (high OH^-)**

N fertilizer can increase pH during ‘hydrolysis’ (example with urea)

Urease enzyme (found naturally in soil)

urea + water → ammonium + carbonate

$(CO(NH_2)_2 + 2H_2O) \rightarrow (2NH_4^+ + CO_3^{2-})$

carbonate + water → bicarbonate + hydroxide

$(CO_3^{2-} + H_2O) \rightarrow (HCO_3^- + OH^-)$

Effect on pH? Increases *temporarily*. Why? Produces OH^-

Good or bad? Bad: ↑ pH, ↑ volatilization

ammonium + hydroxide → ammonia gas + water

$(NH_4^+ + OH^-) \rightarrow (NH_{3(gas)} + H_2O)$

Ammonium sulfate volatilization in calcareous soils

ammonium sulfate + lime → **ammonium +gypsum + hydroxide**

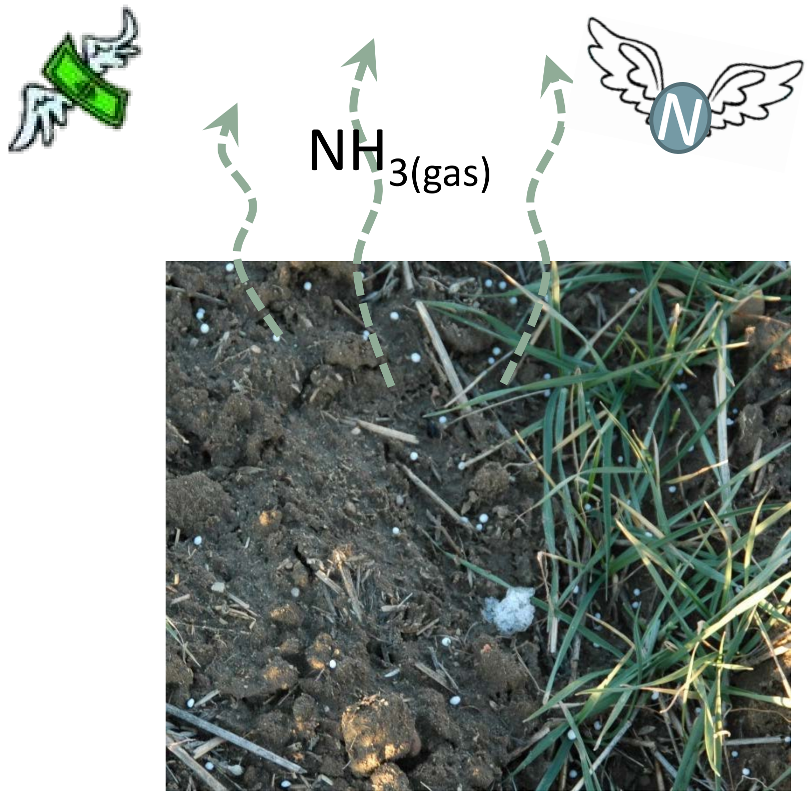
($(NH_4)_2SO_4$ + $CaCO_3$) → ($2NH_4^+$ + $CaSO_4$ + OH^-)

Not balanced

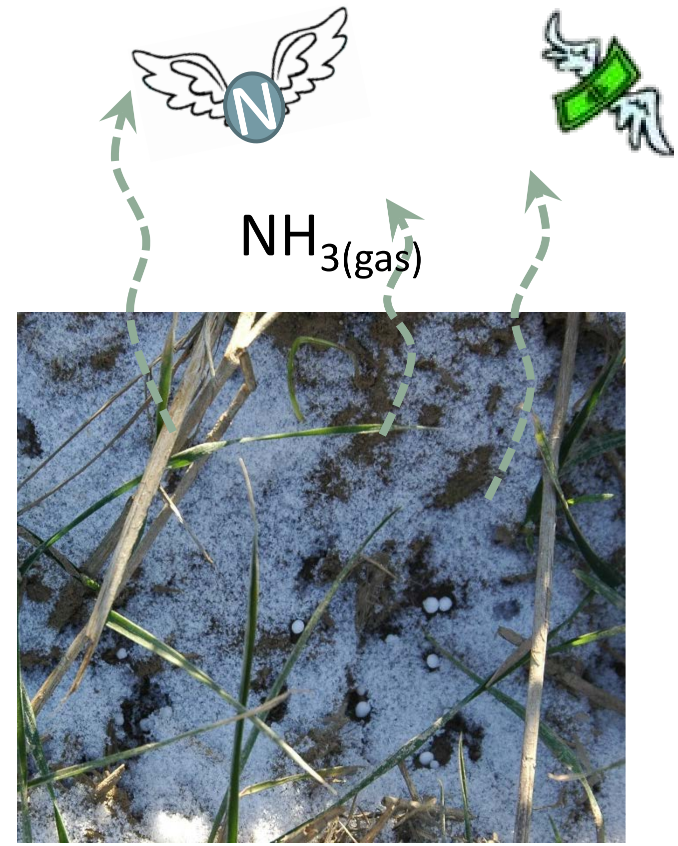
NOTE: Generation of OH^-, so pH rises.

In words: Sulfate dissolves some calcium carbonate (lime) releasing carbonate which increases pH and hence volatilization. Does not happen in non-calcareous soils.

Based on recent MSU research, 3-44% of fall/winter broadcast urea N can be lost to volatilization.



Moist soil



Snow covered soil

MSU Fertilizer eFacts 70 & 71 (Engel et al., 2015 and 2016)

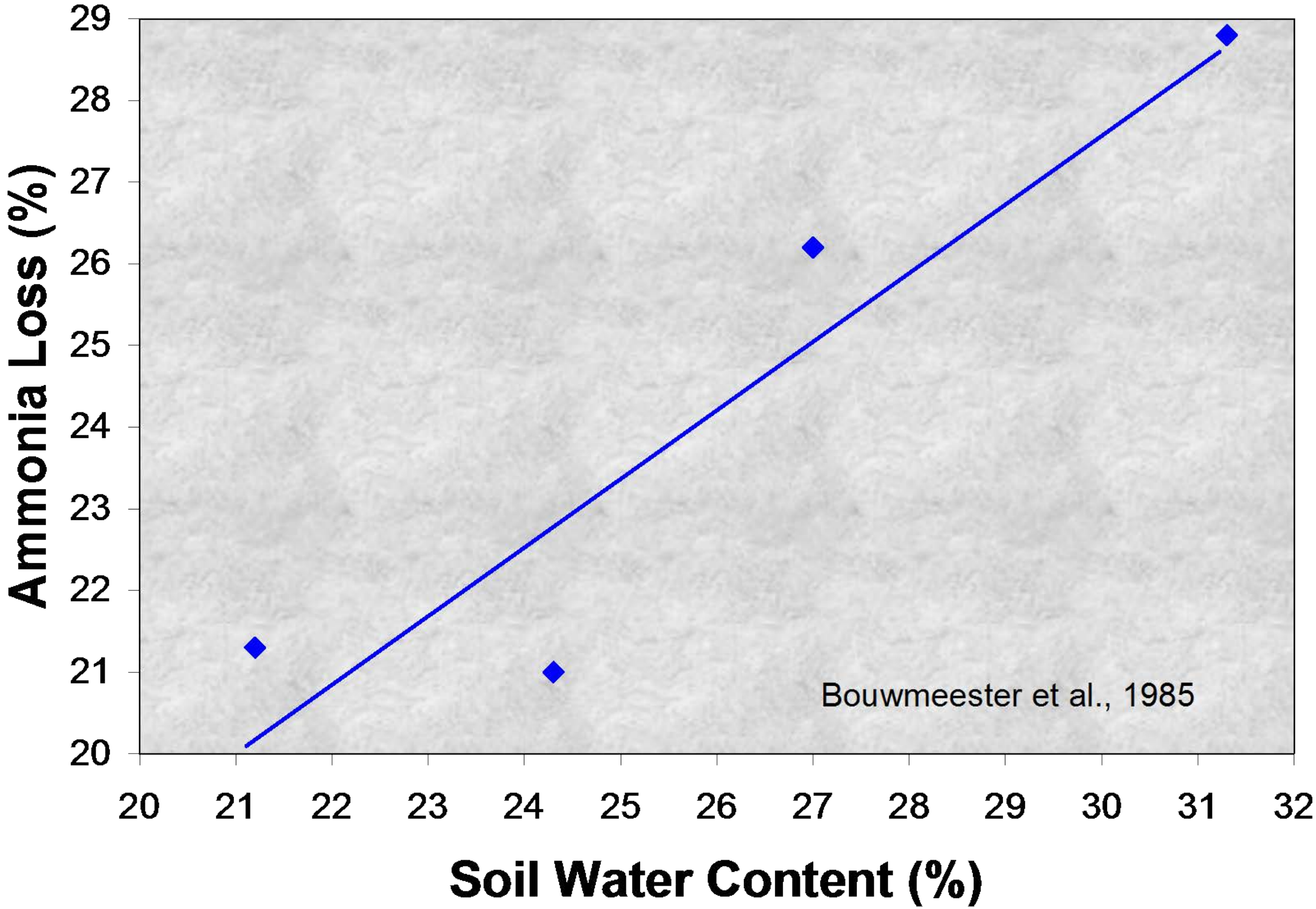
CONTRIBUTING FACTORS
for volatilization

High risk conditions for urea volatilization

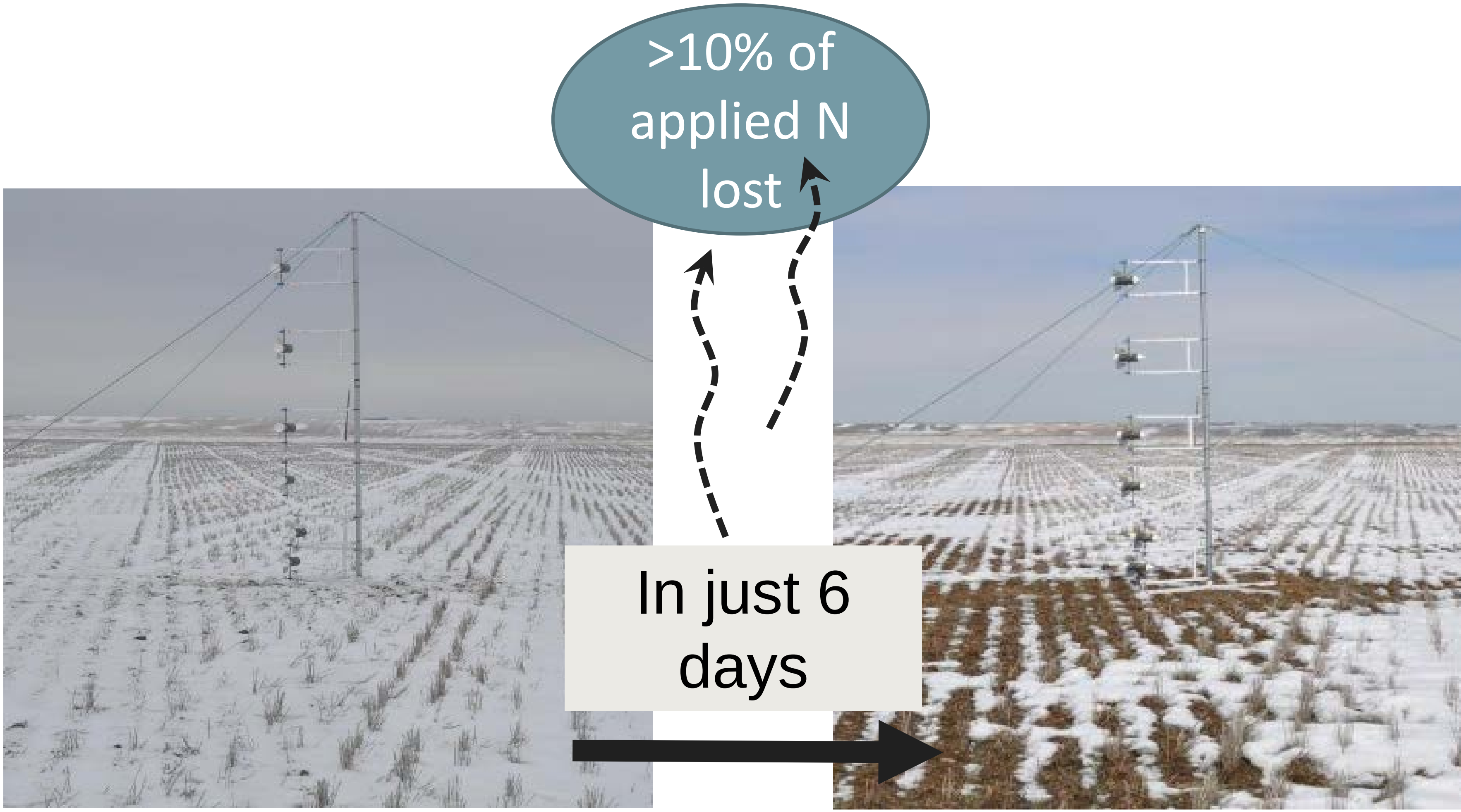
- Moist soil, heavy dew, or high humidity
- Low amounts of rainfall
- Wind
- High soil pH (>7.0)
- High soil temperature (>50 °F) or frozen soil
- Crop residue, perennial thatch or sod
- Low cation exchange capacity soil (sandy)
- Poorly buffered soils (low soil organic matter, coarse textured, low bicarbonate content)

- Large number of factors make volatilization amounts variable and difficult to predict.
- The risk of volatilization increases as the number of high risk conditions increase, with soil moisture likely being the most important.

1. Soil moisture



Worst case for volatilization loss: broadcast on moist surface, worse if followed by light scattered precipitation

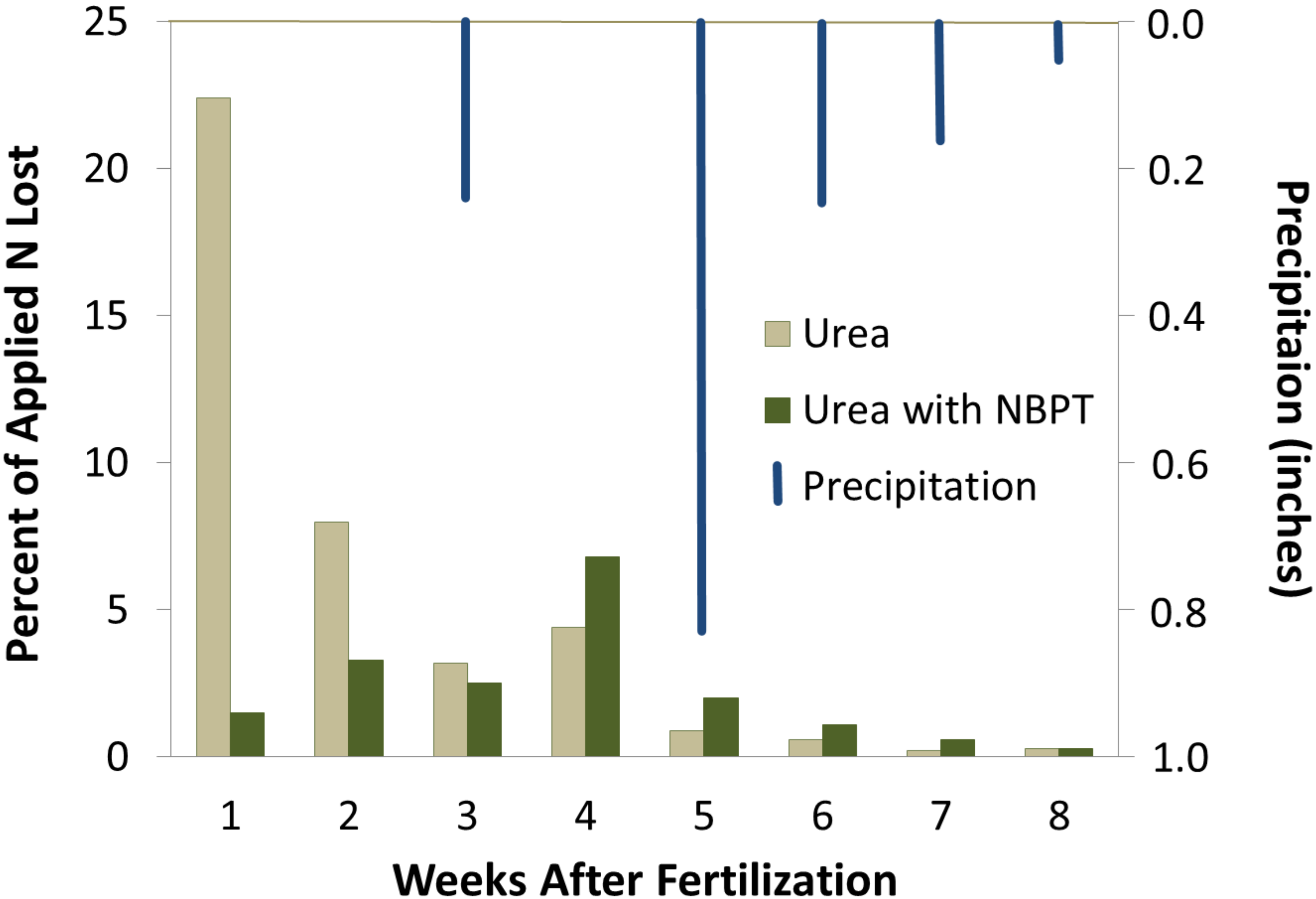


MSU Fertilizer eFact 70

2. Rainfall/Irrigation

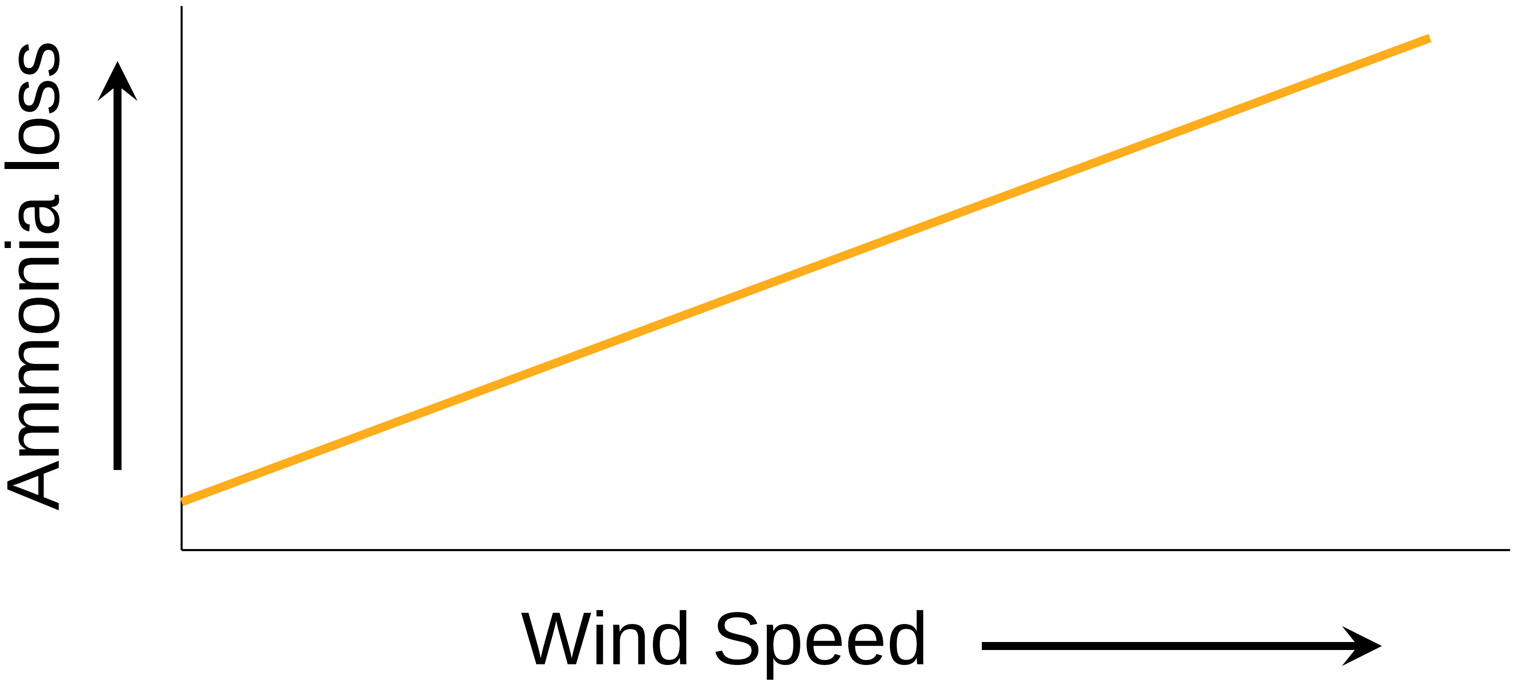
- 1/10 inch of rain/irrigation dissolves fertilizer, allowing volatilization
- 1/2 inch of rain/irrigation pushes dissolved fertilizer about 2 in. into soil, essentially stopping volatilization if within about 2 days of fertilization

Effect of rainfall on urea volatilization



Late March, Havre, N applied to snow covered soil, temps around freezing
Engel et al. 2011

3. Wind

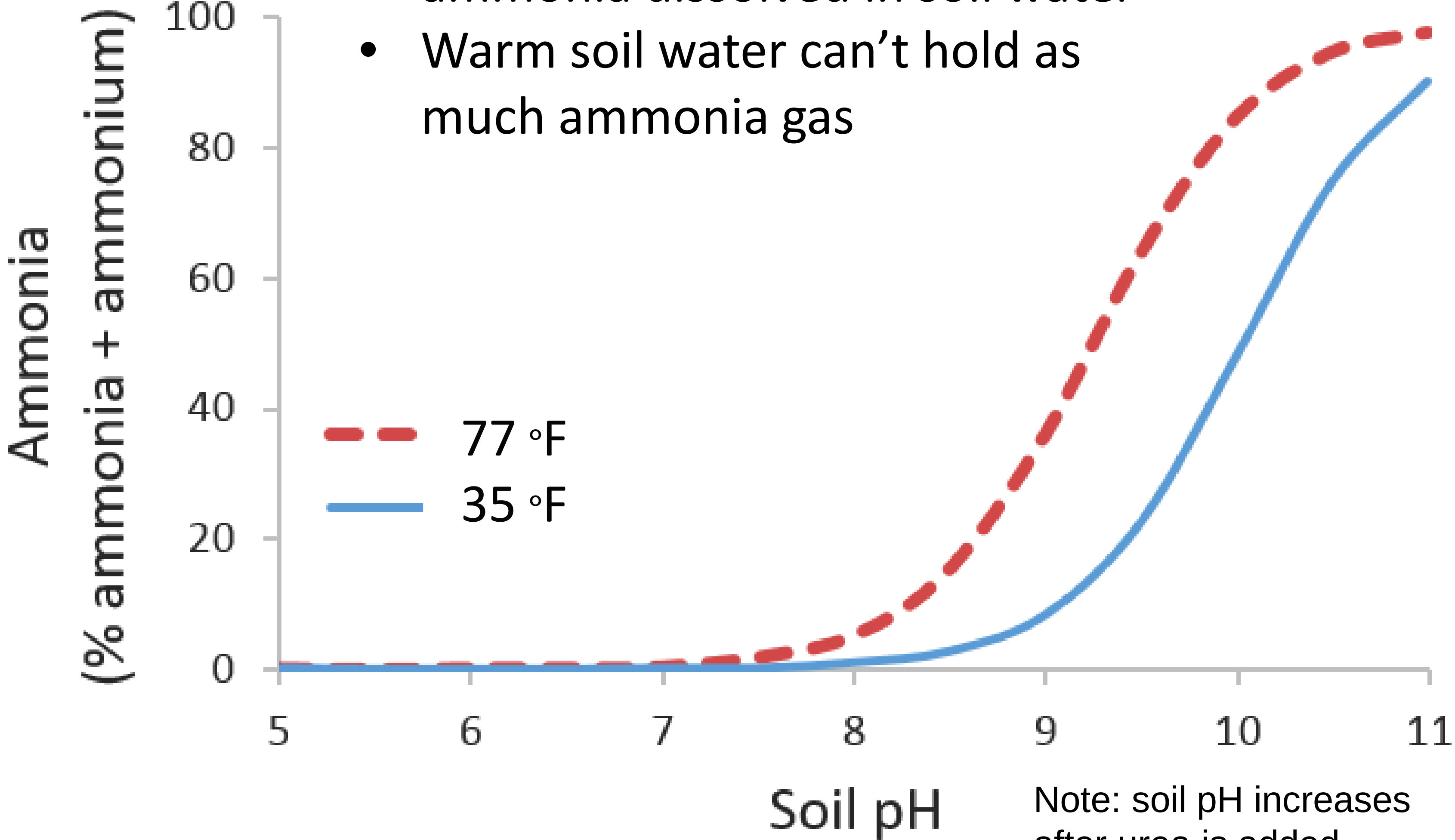


SO, don’t apply on windy day or with high winds in short term forecast.

Fillery et al., 1984

4 & 5. Soil pH and temperature

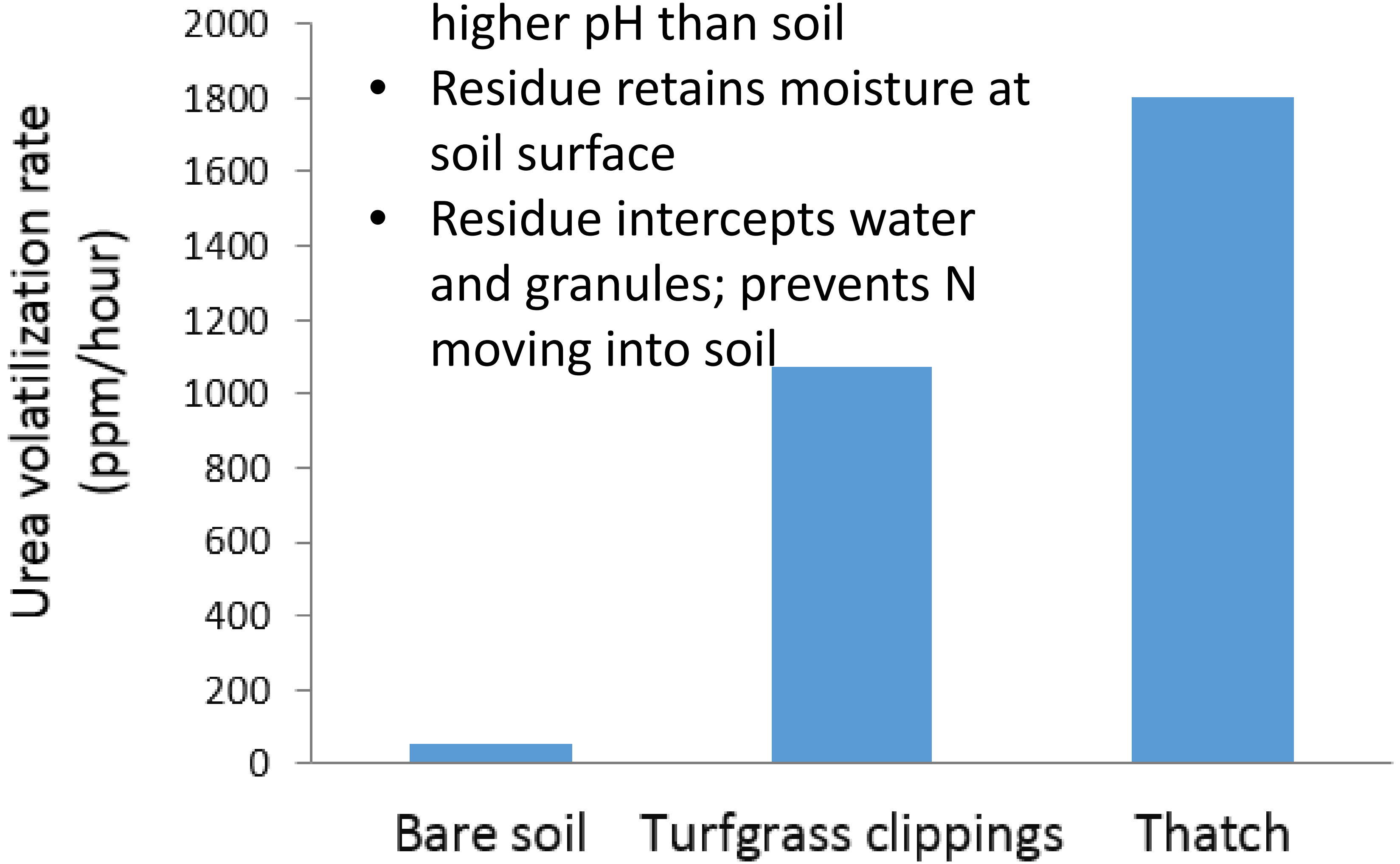
- High soil pH and temp increase ammonia dissolved in soil water
- Warm soil water can't hold as much ammonia gas



Note: soil pH increases after urea is added

6. Residue and thatch

- Crop residue often has higher pH than soil
- Residue retains moisture at soil surface
- Residue intercepts water and granules; prevents N moving into soil



Torello and Wehner, 1983

Effect of residue, cont’d

Volatilization was found to be approximately 2 times higher in the upper 1.5 inches under no-till than under conventional tilled systems (Dick, 1984).

7. Cation exchange capacity (CEC)

As CEC increases, volatilization rates generally decrease (Fenn and Kissel, 1976). Why?

1. Less NH_4^+ (a cation) in solution to volatilize
2. Generally higher exchangeable Ca (next slide)

Exchangeable Ca^{2+} decreases volatilization

urea + water + Ca → ammonium + carbonate

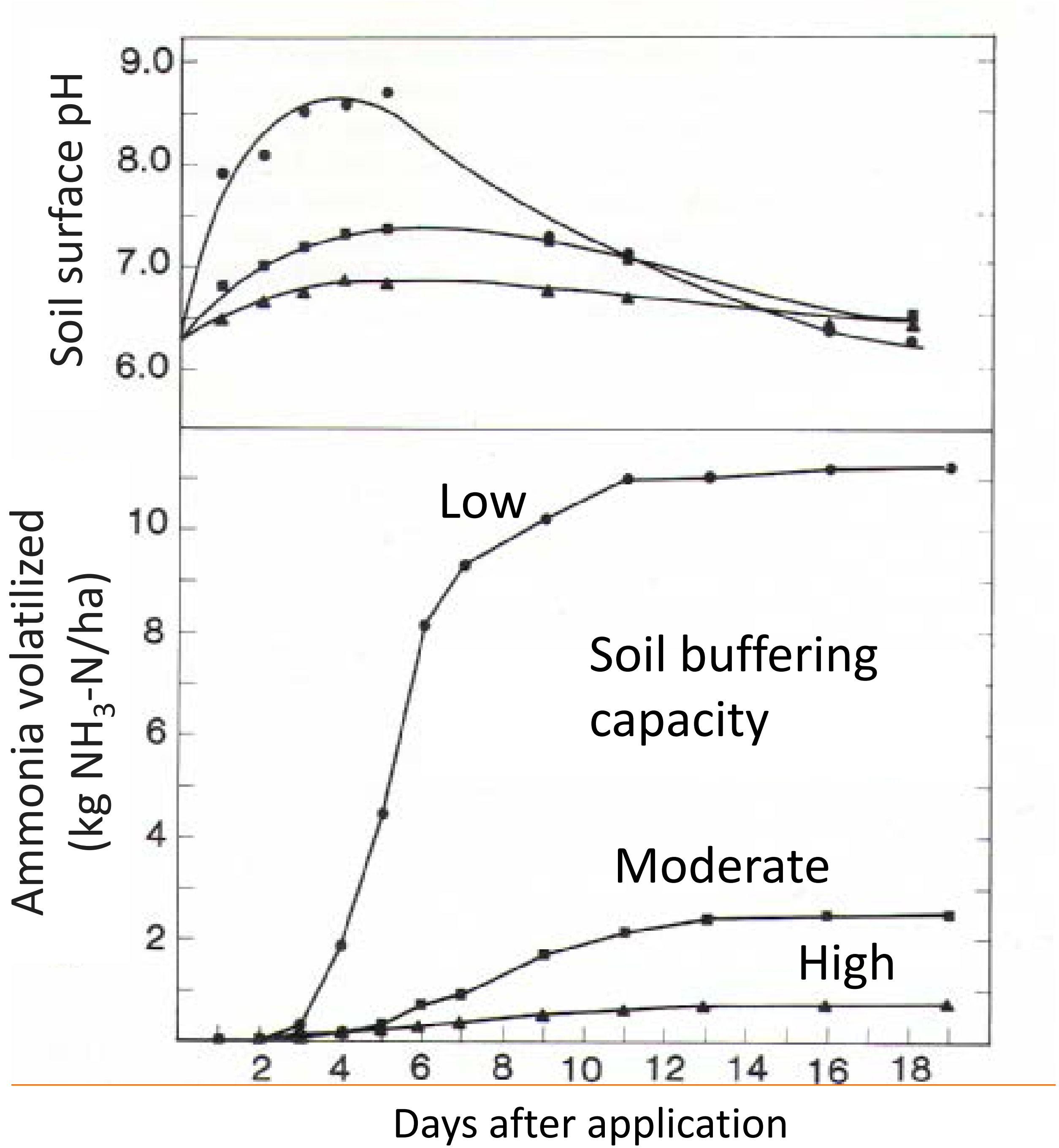
($CO(NH_2)_2$ + $2H_2O$ + Ca^{2+}-soil) ($2NH_4^+$-soil + $CaCO_3$)

In words: When urea hydrolyses to ammonium, the calcium can combine with the carbonate ion, preventing pH rise AND opening up 2 exchange sites for ammonium.

NOTE: No generation of OH^-, so no pH rise.

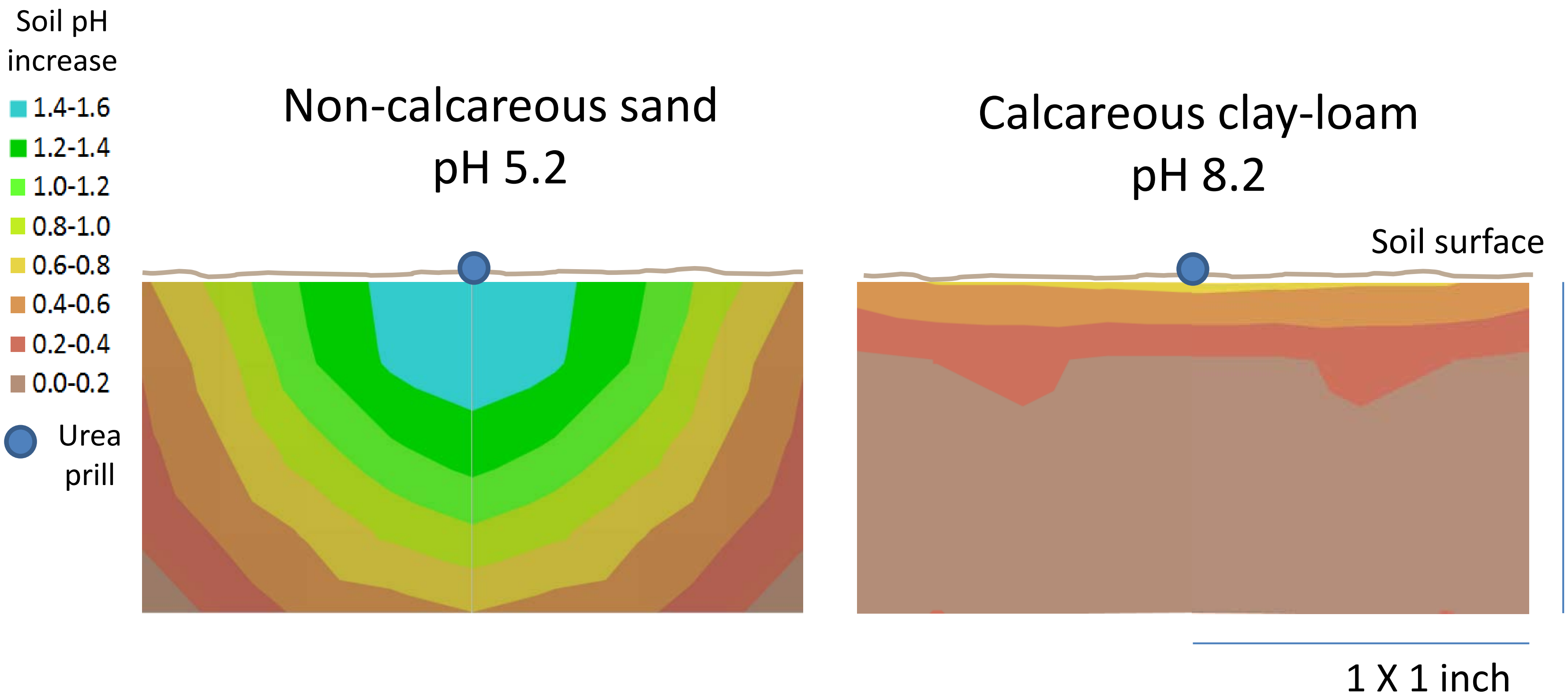
Implication: Less concern with volatilization on soils with high exchangeable Ca levels (generally indicated by high CEC). Good news for MT. Doesn't matter though if urea doesn't reach soil.

8. Buffering capacity



Ferguson et al., 1984

Change in soil pH 6 days after urea surface applied



Adapted from Christianson et al., 1993

N Management

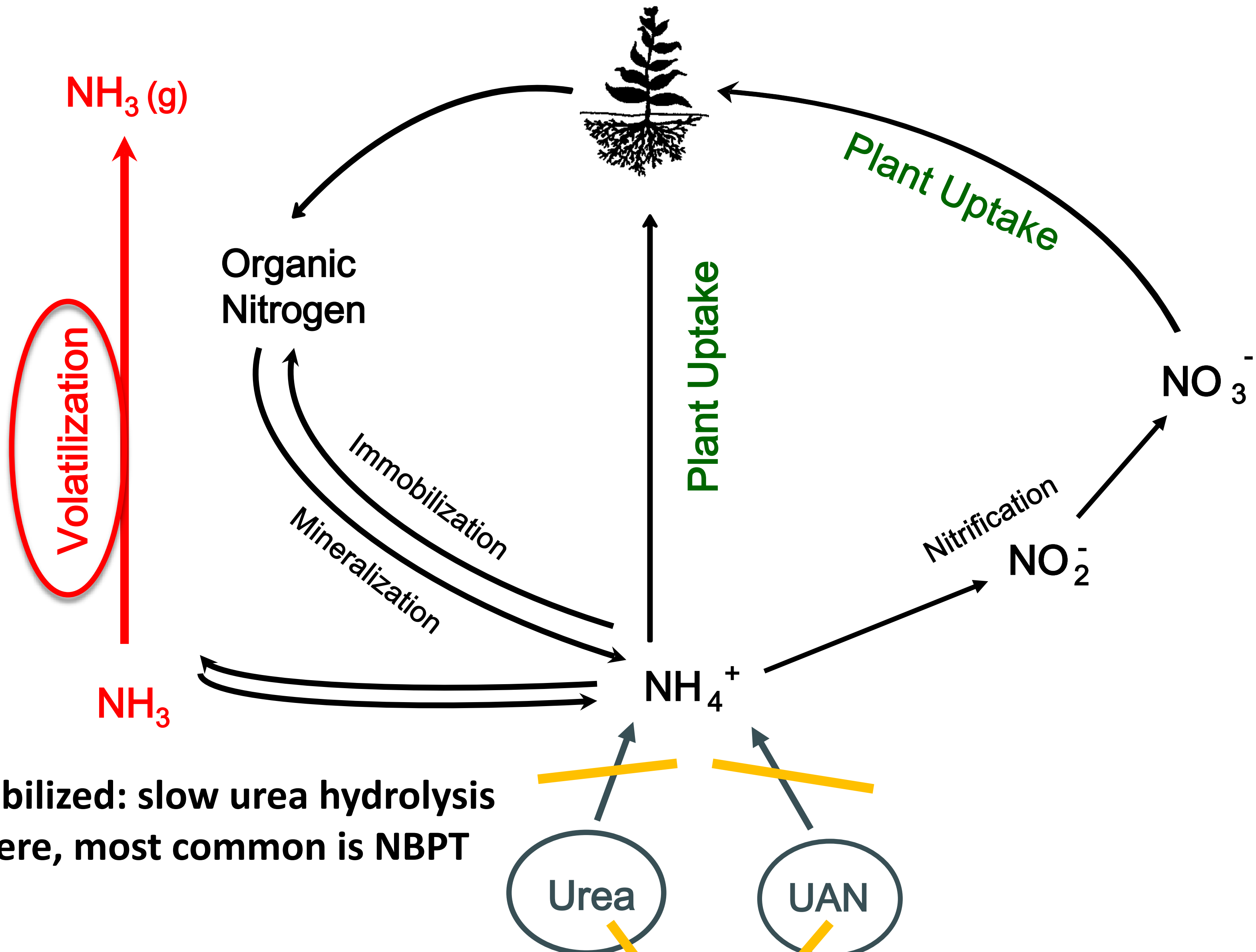
- Source
- Enhanced efficiency fertilizers
- Placement
- Timing

Urease Inhibitors

Agrotain (NBPT) is main product. Delays hydrolysis by up to 14 days, minimizing volatilization

- advantage: allows more chance for rain or irrigation to push N into ground
- disadvantage: will delay time to become available, volatilization can still occur, and cost (adds ~$60/ton urea).

Stabilized & slow/controlled release fertilizers



Stabilized: slow urea hydrolysis here, most common is NBPT

Slow/controlled release here

Different N sources have different volatilization loss potential

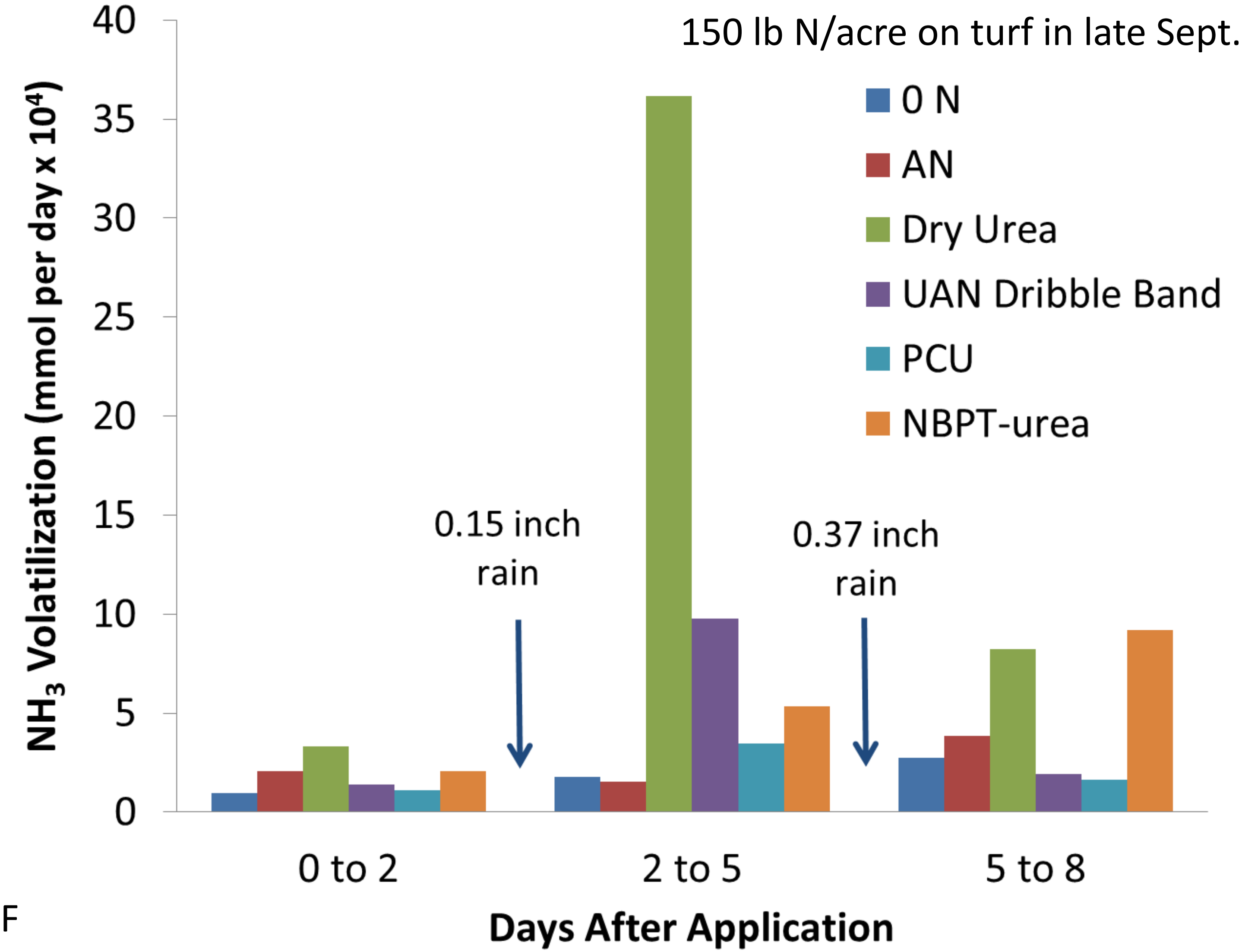
***POTENTIAL* volatilization loss compared to urea**

Conventional Fertilizers	
Ammonium nitrate, CAN (27-0-0), ammonium sulfate	less
UAN (solution 28 or 32)	less
Enhanced Efficiency Fertilizers	
Urease inhibitors (NBPT=Agrotain)	less
Nitrification inhibitors (DCD, N-Source, N-Serve, Instinct)	≈
Combinations (SuperU)	less
Controlled release polymer coated (ESN)	less
Slow release (Nitamin, N-Sure, N-Demand)	≈

Why differences in volatilization?

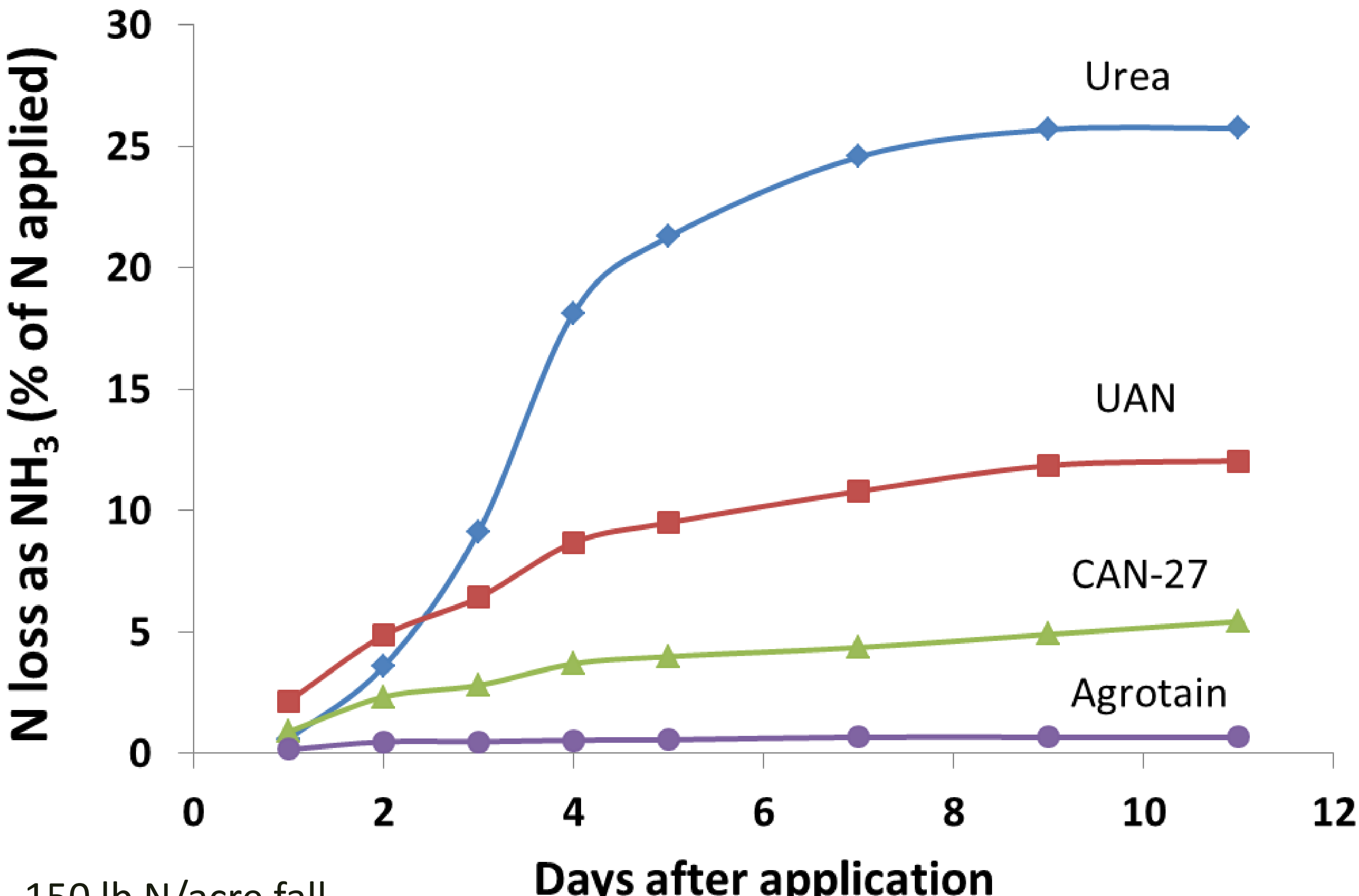
- Urea, UAN, and AS (in calcareous soils) cause larger pH increases than CAN and AN.
- ½ of N in AN and ¼ of N in UAN is nitrate which can't volatilize
- UAN does not consistently have lower volatilization loss than urea.
- Bottom line: Both urea and UAN can volatilize - selection should likely be based on equipment and price.

Effect of N source on volatilization



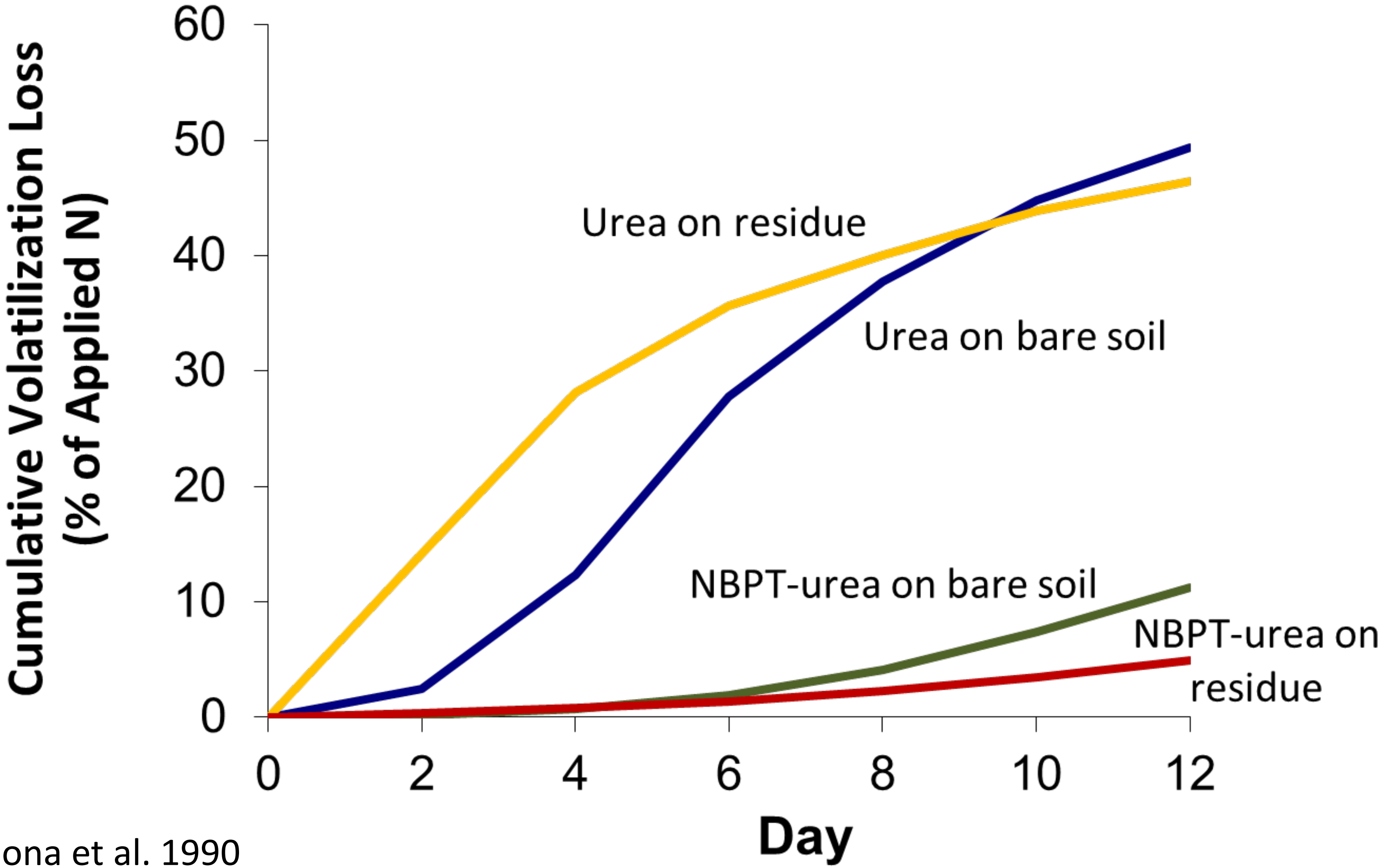
Washington
Soil Temp = 50°F
Koenig unpub. data

Sources to reduce volatilization on newly seeded grass field



Oregon, 150 lb N/acre fall applied, Horneck et al. 2011

Effect of NBPT and straw residue on volatilization



Carmona et al. 1990
lab conditions

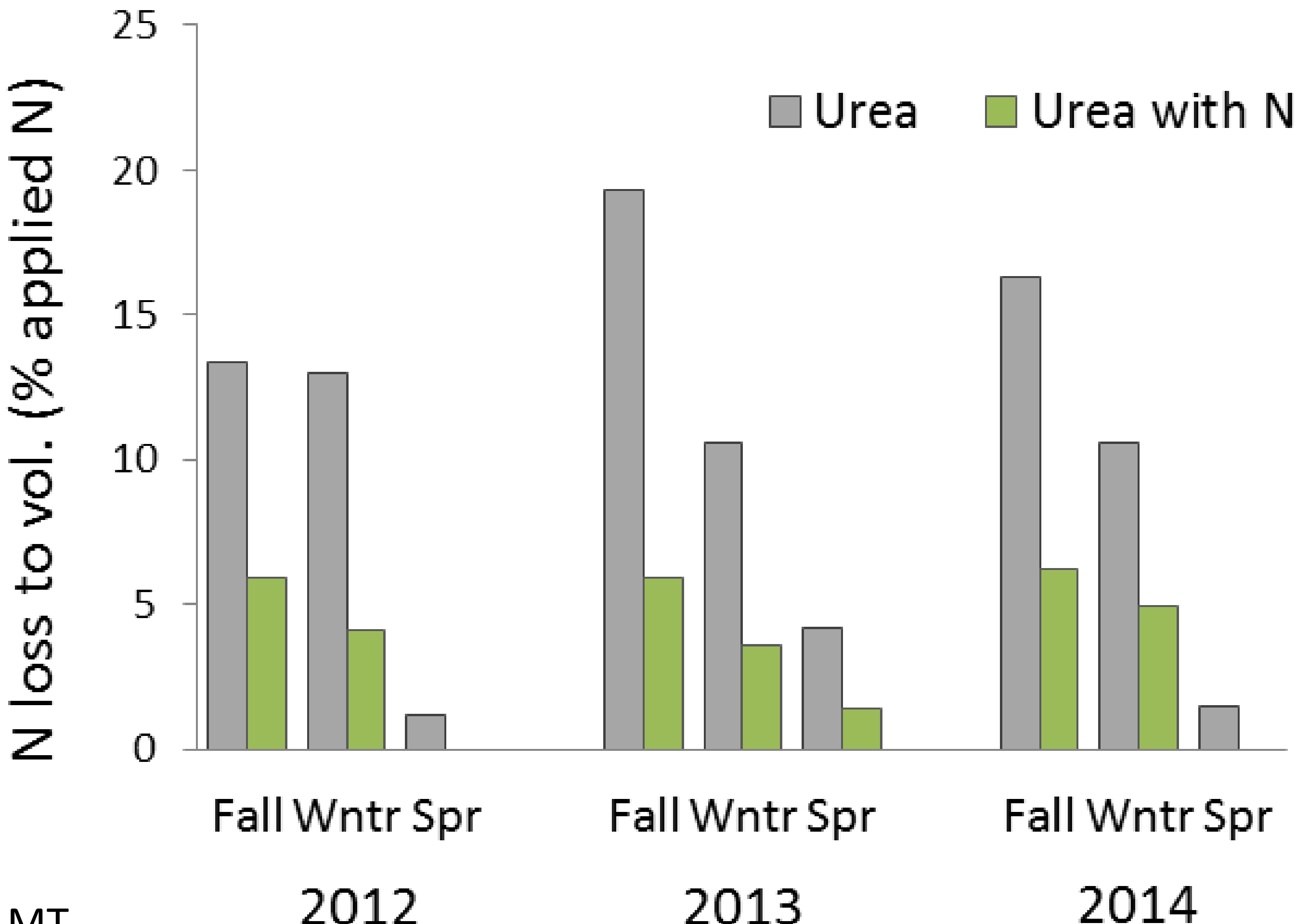
UAN volatilization with and without Agrotain®

% of surface applied N volatilized over 7 days

	Check	UAN	UAN+Agrotain
May (74°F)	0	7	1
July (86°F)	0.6	50	16

Grant et al. 1996, Manitoba

NBPT (Agrotain®) reduces N loss in central MT



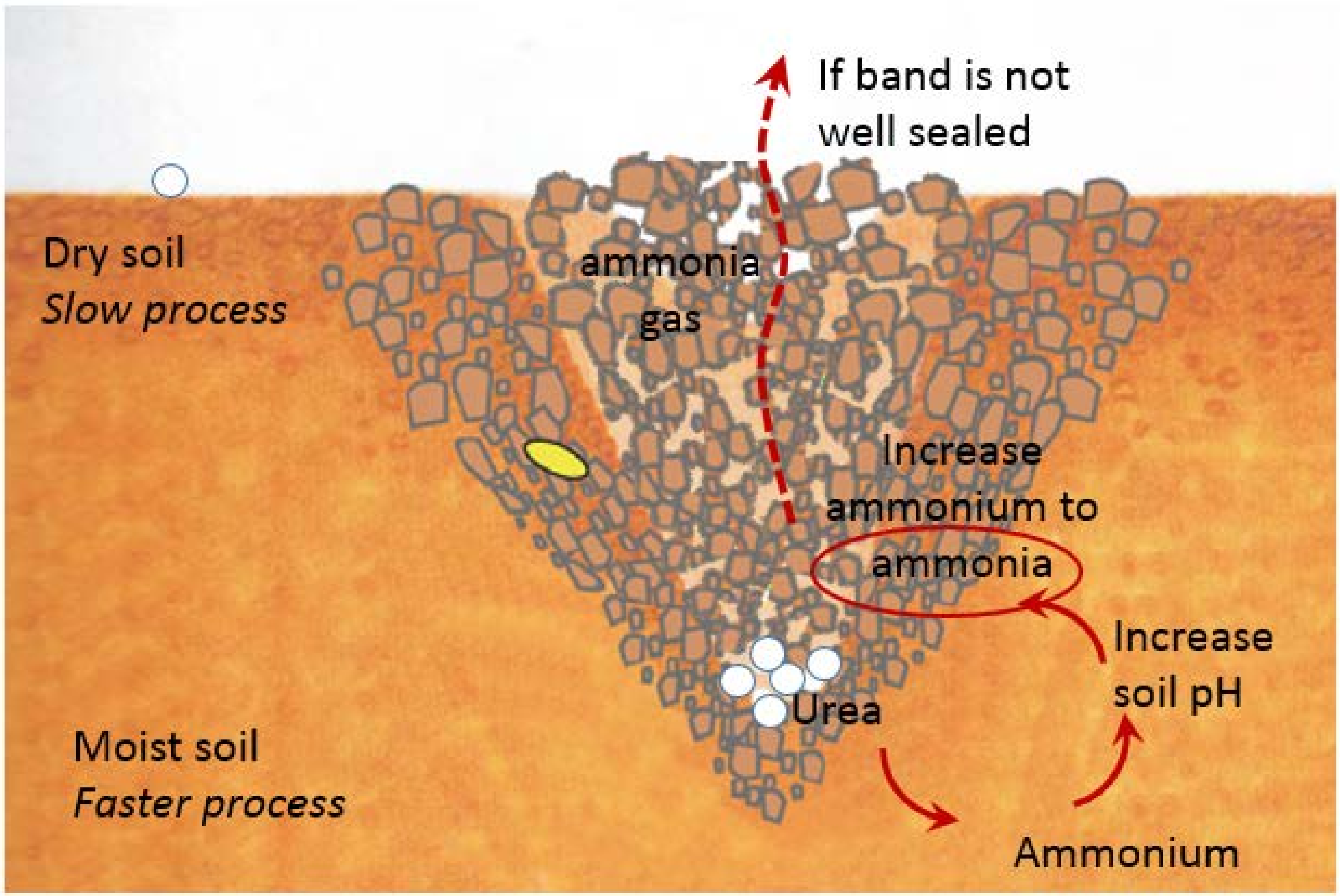
Coffee Creek, MT
MSU Fertilizer eFact No.71

NH_3 losses observed for late-fall and winter app > than spring, even though temperatures were colder; mitigation by NBPT ≈ 65%

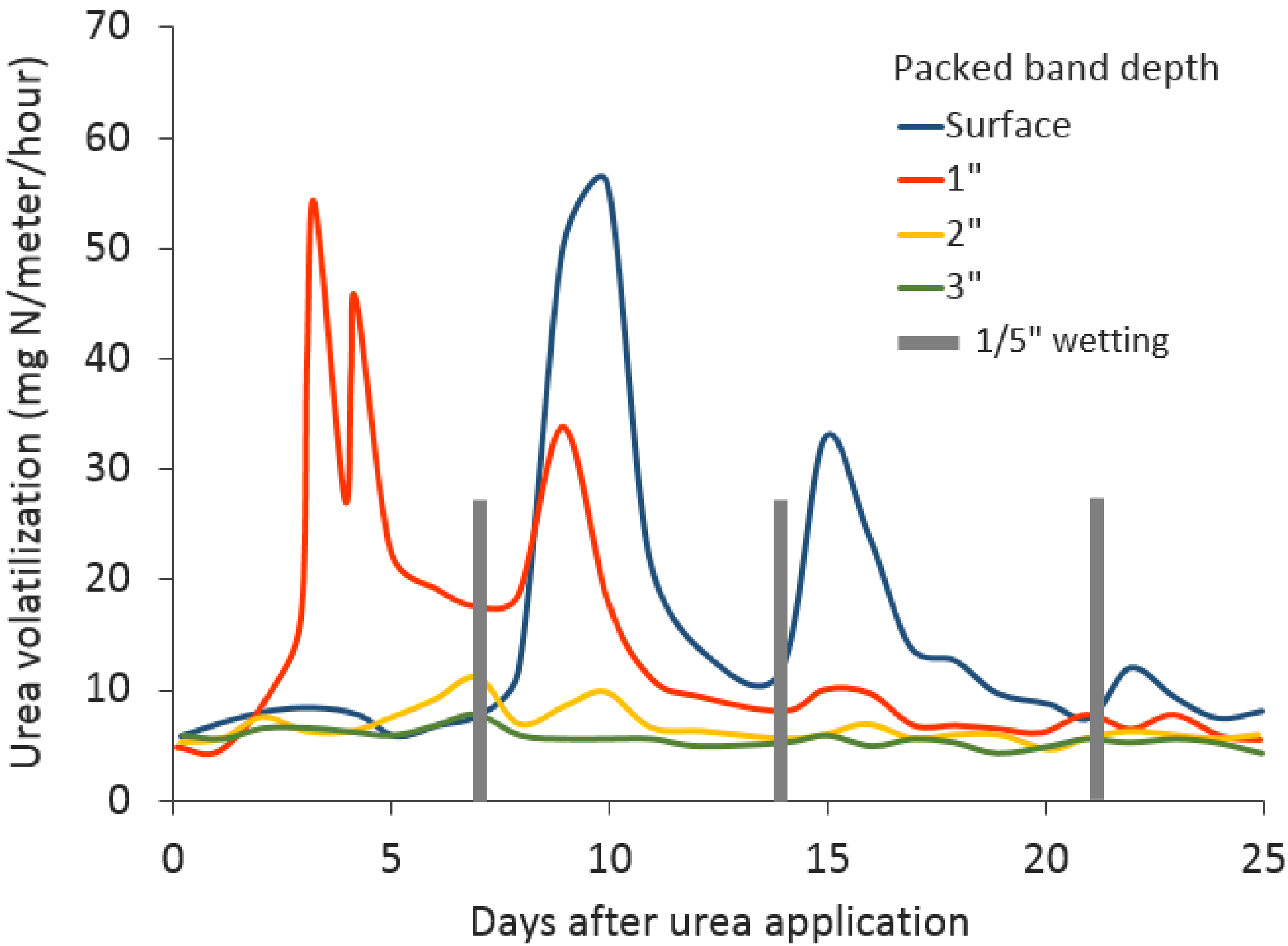
Placement

Concentrated shallow bands (<2" before packing) of UAN or urea may have higher volatilization loss than broadcast or surface band applications (Rochette et al., 2009).

WHY?

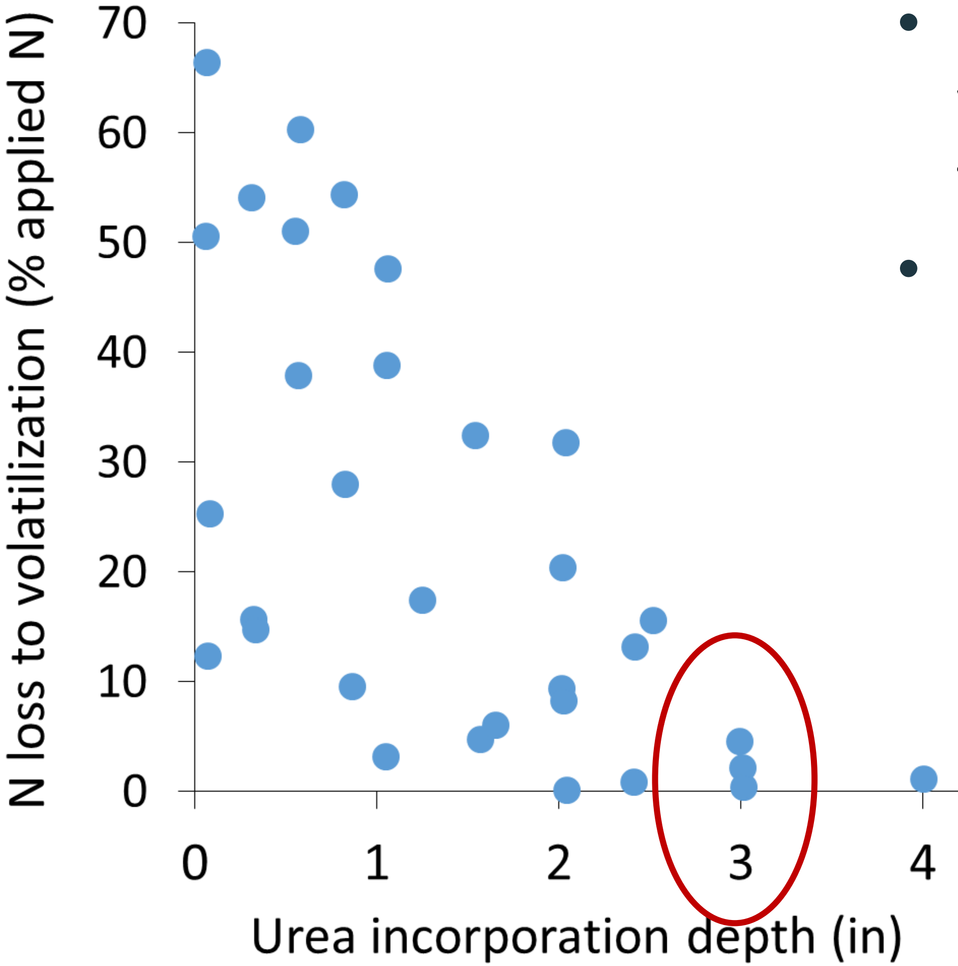


Band depth on volatilization (Rochette et al., 2013)



Silt loam, pH 5.5, 145 lb N/acre, 30” band spacing

Mechanical incorporation depth on volatilization



Rochette et al., 2013, lit review

- ≈ 32% reduction of volatilization for each 1" tillage depth
- Seeding with air drills after broadcasting urea is insufficient (Engel et al., unpub data)

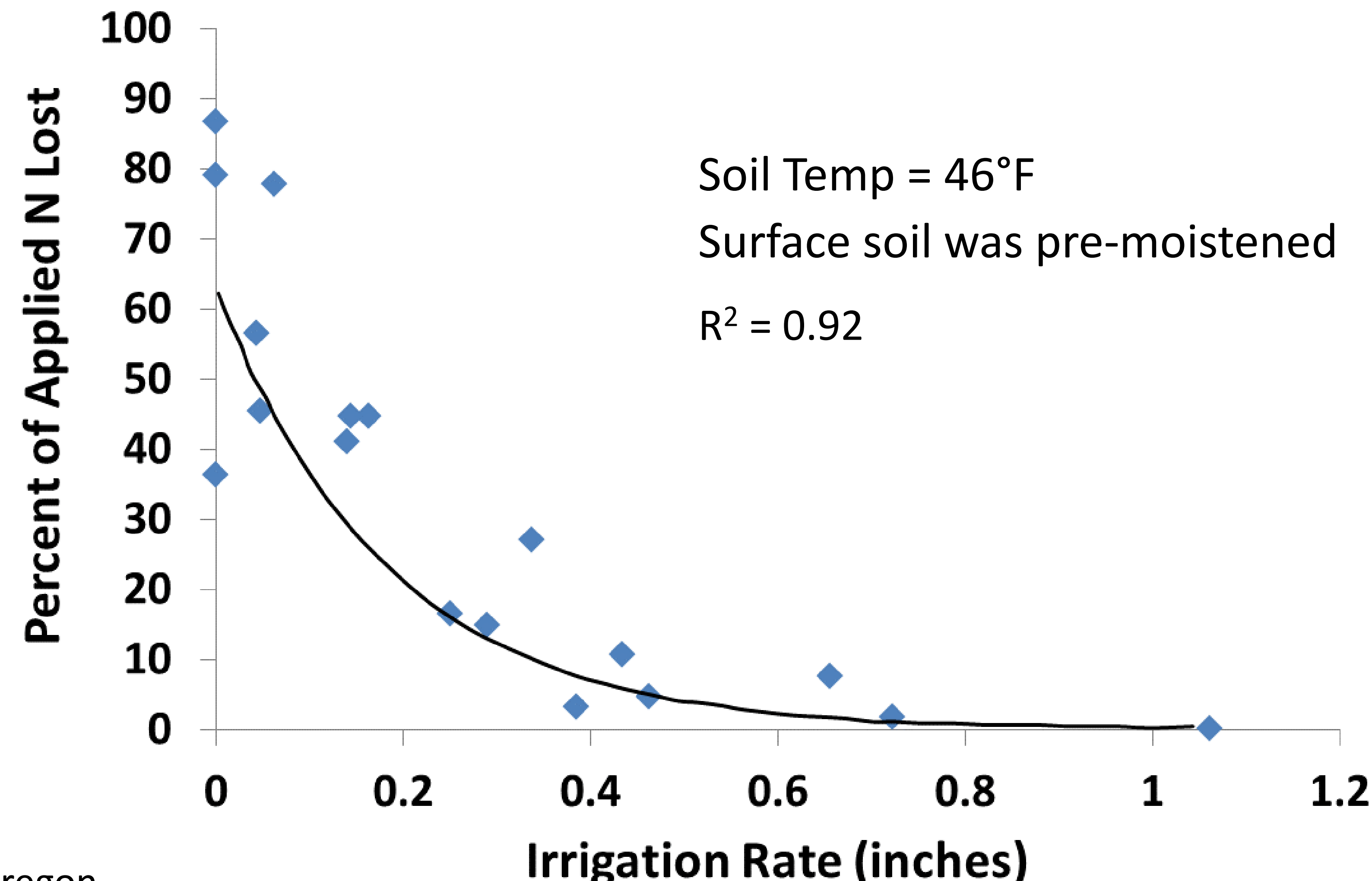
Bottom line: Till at least 3"

Timing

Generally better to apply near peak uptake to avoid losses, however, weather conditions near application and soil texture may be more important.

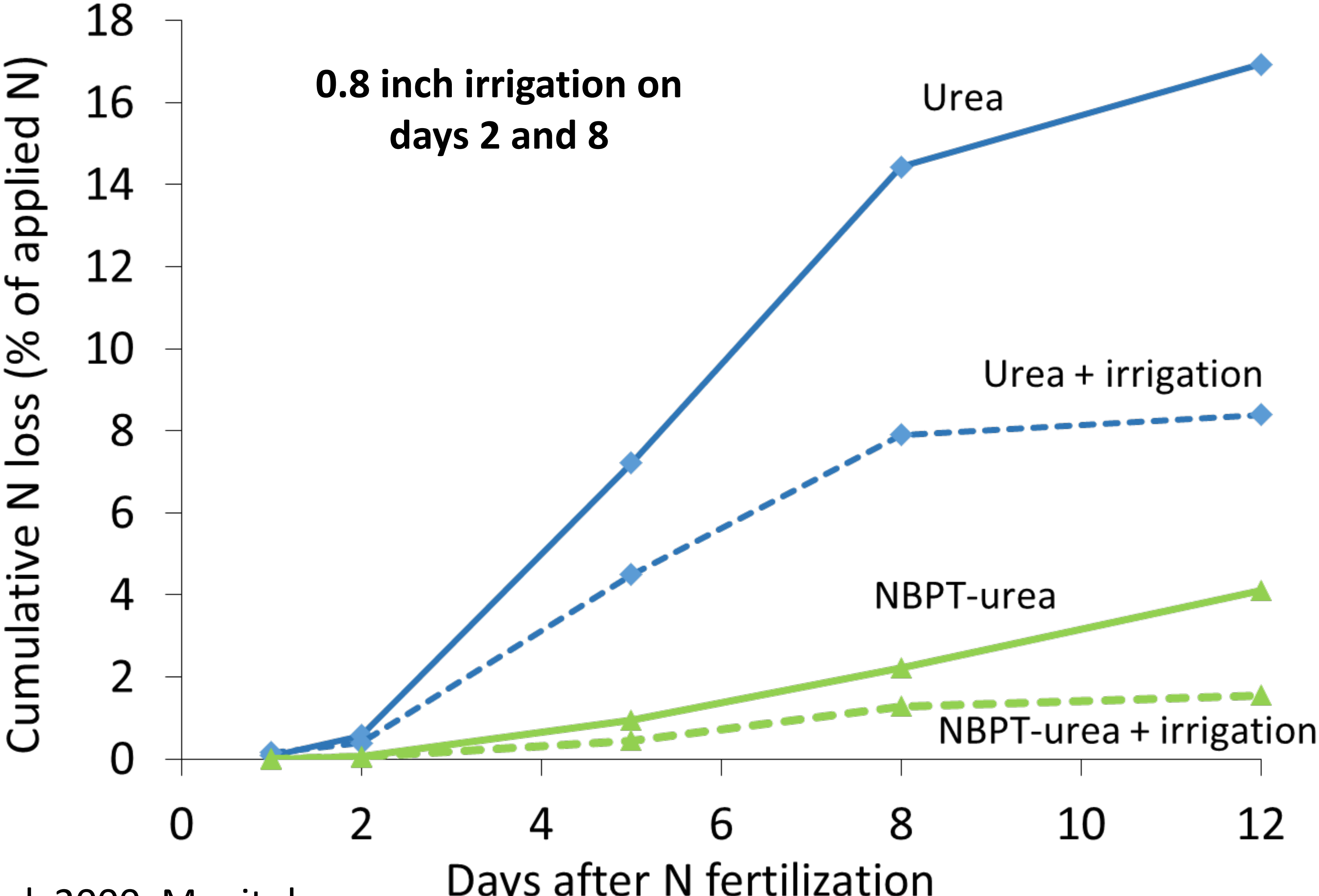
- Shallow, coarse soil. Fall or spring? **Spring**
- Cool fall temps with ability to irrigate or warmer spring temps before irrigation water delivered. Fall or spring? **Fall**

Broadcast before rain or irrigation to minimize volatilization loss



Echo, Oregon
Holcomb et al. 2011

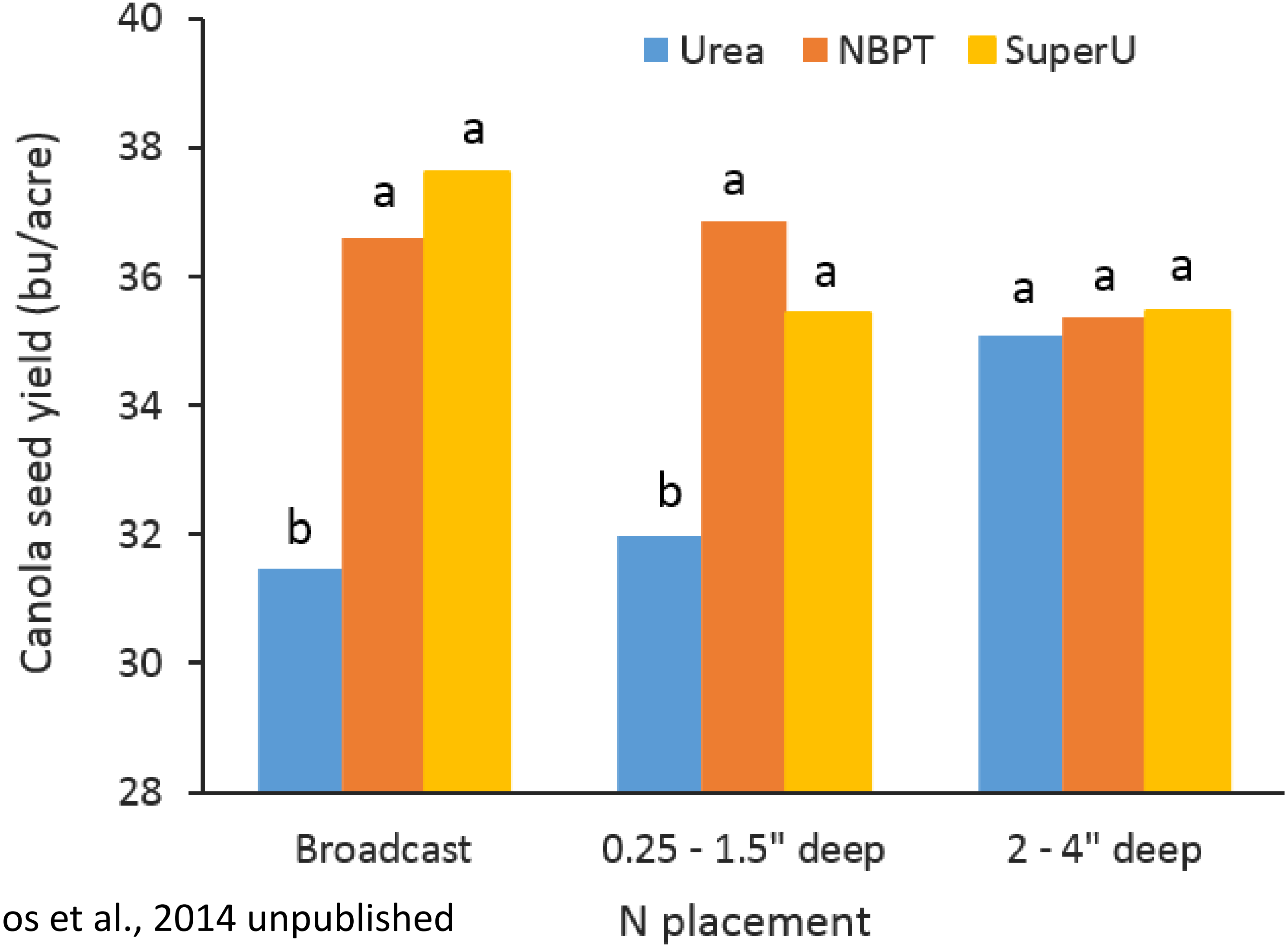
Effect of irrigation and NBPT on volatilization



Rawluk 2000, Manitoba

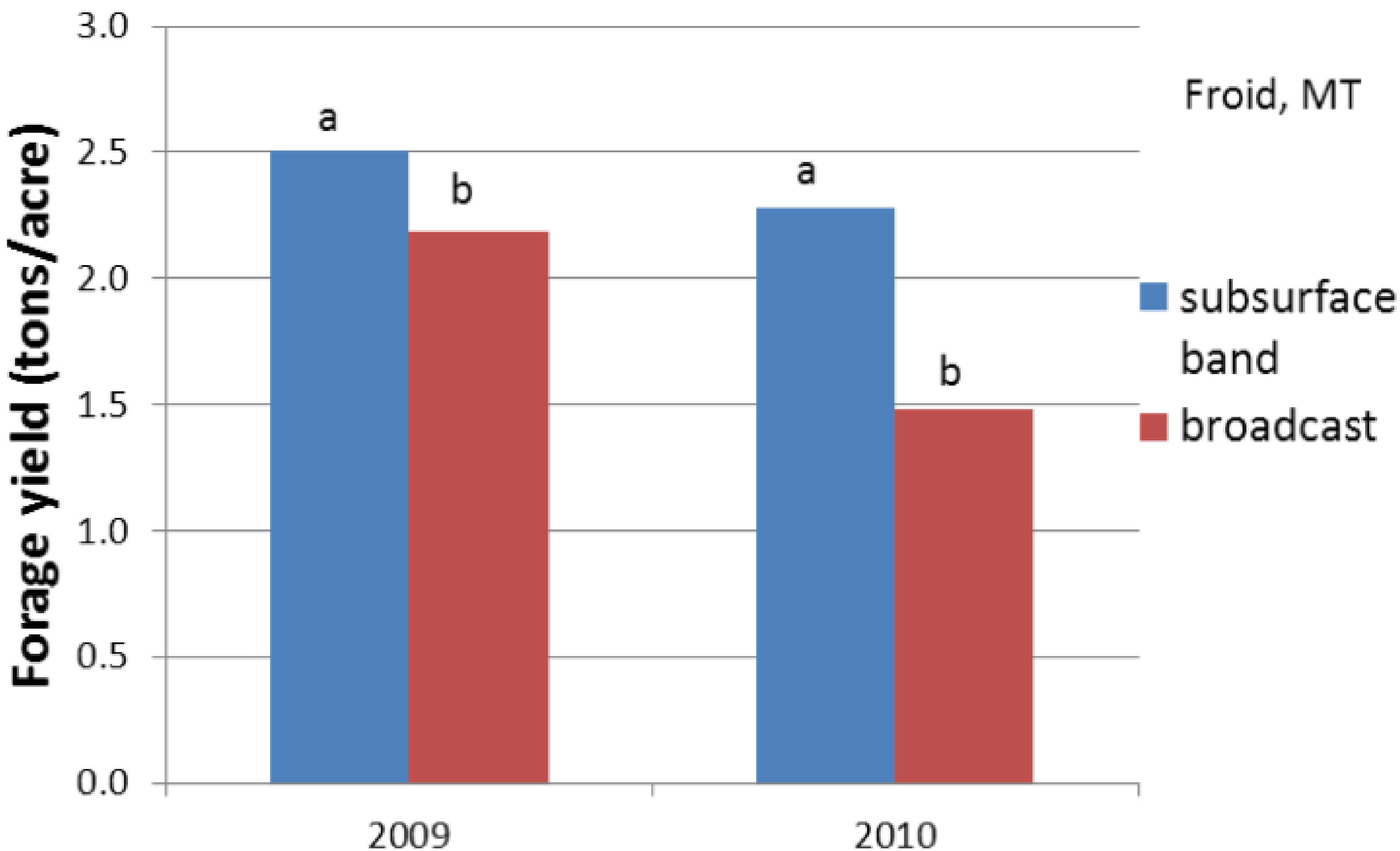
Does controlling volatilization affect yield and protein?

Band depth on canola yield –
band urea at least 2" (before packing)



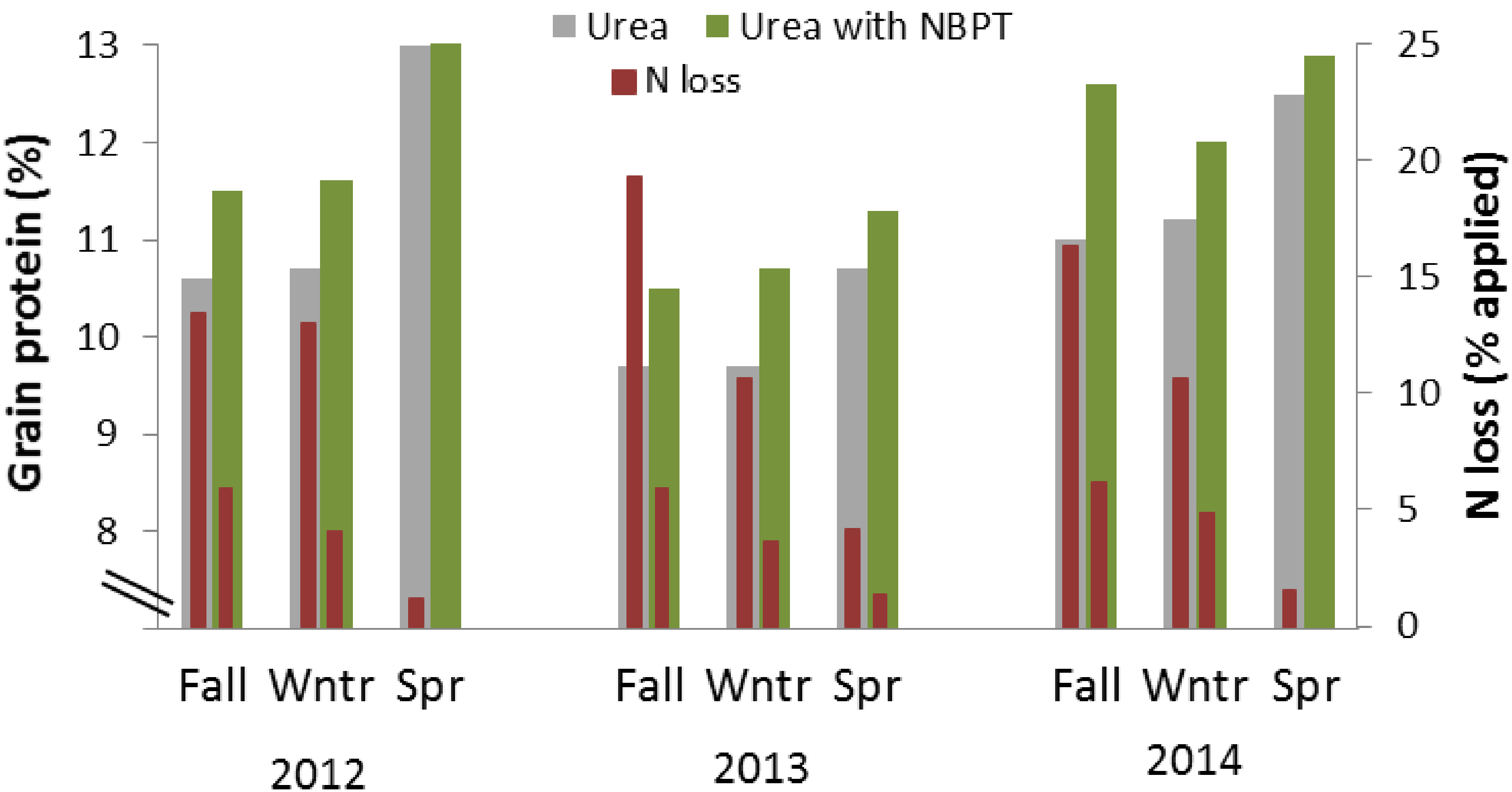
Karamanos et al., 2014 unpublished
from AB, MB, SK

Subsurface band urea yields more forage than broadcast urea



Angvick et al. unpub data

As volatilization goes down, WW grain protein increases (spring application > NBPT > urea)



Coffee Creek, MT MSU
Fertilizer eFacts 71

NBPT sig increased protein by 0.4 to 1.6 % points.
NBPT only increased yield in Fall 2012.

How determine if should use NBPT?

Depends on:

1. Potential for volatilization
   (ex: temperature when apply)

2. Cost

Economics

- Agrotain is about $60/ton-urea. So if applied 200 lb urea/acre this would be an additional $6/acre cost.
- Would need to grow at least 1 bu/acre more, which only happened fall applied (not winter or spring) in 1 of 3 years.
- However, this does not take into account increased protein and N recovery (9-10% increase with NBPT), with reduced risk to air and water quality.
- The best economic solution might be to use NBPT only when you need to apply during high risk conditions.

Practices to decrease volatilization from N fertilizers, especially urea

- Incorporate with tillage if possible, seed place (max 10 lb N/acre), mid-row, or subsurface band (in buffered or calcareous soils) at least 2” deep.
- On thatch, UAN band better than foliar spray
- Apply to dry, cool, but thawed ground
- Apply prior to a large (> 0.5”) rain or irrigation event
- Use a protected product (with NBPT, e.g. Agrotain®, Arborite Ag, Nutrogain) or CAN if can’t apply during low risk periods
- Consider using ESN® (Environmentally Smart Nitrogen). This is a slow release product that is not recommended for surface broadcast, but can be applied directly with the seed

Conclusions

- Many factors contribute to volatilization loss; some can, others cannot be controlled
- Soil moisture and precipitation after application are likely the most important factors
- Mechanical incorporation to 3”, banding > 2” deep, or >0.5” water in one event are best to reduce volatilization
- Products are available with lower volatilization potential (ex: NBPT, CAN, ESN, UAN)
- Management practices to reduce volatilization loss can increase yield and grain protein, and reduce risk to air and water quality

For more information

See:

Factors Affecting Nitrogen Fertilizer Volatilization

Management to Minimize Nitrogen Fertilizer Volatilization

Under “Extension publications” at
http://landresources.montana.edu/soilfertility

For more information on N cycling, fertilizer sources, placement and timing see:
http://landresources.montana.edu/nm

QUESTIONS?

For more info on my Extension and research programs, go to: http://landresources.montana.edu/soilfertility