

Managing Nitrogen for Yield and Protein in Winter Wheat

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Outline

- **N Cycle in the soil-plant-atmosphere system**
- **Fate of N fertilizers**
- **Management Practices that affect N Use Efficiency**
- **Tools and Technologies for N Management**
- **WSU N management tools**
 - **Dryland Wheat N Fertilizer Calculator**
 - **Post-Harvest N Efficiency Calculator**

Nitrogen Forms in Soil

❑ Inorganic N compounds

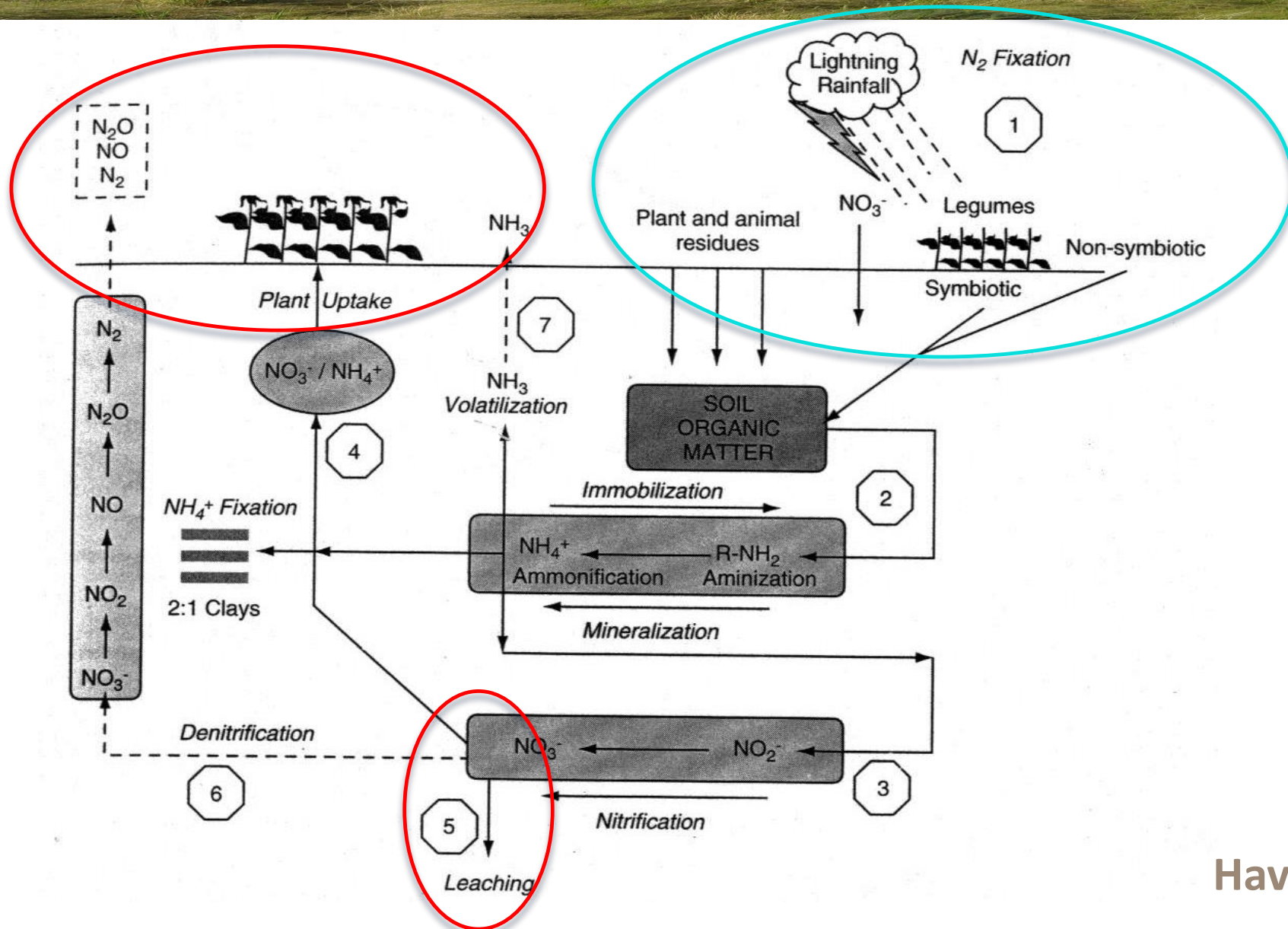
- ✓ 2-5% of the total of soil N
- ✓ Ammonium N (NH_4^+), nitrate N (NO_3^-), nitrite N (NO_2^-), ammonia (NH_3), nitrous (N_2O) and nitric (NO) oxides

❑ Organic N

- ✓ 95-98% of the total soil N
- ✓ Among the total organic N:
 - Bound amino acids, 20-40%
 - Amino sugars, 5-10%;
 - Purine and pyrimidine derivatives, <1%;
 - Unknown, 50%.



N cycle in the soil-plant-atmosphere system



N cycle in the soil-plant-atmosphere system

N transformations

Mineralization = organic N to mineral N (NH_4^+)

Immobilization = mineral N to organic N by microbes

Nitrification = NH_4^+ to NO_3^-

Denitrification = nitrate to gaseous NO, N_2O , or N_2

Volatilization = Gaseous NH_3 loss to the atmosphere (NH_4^+ to NH_3 at high pH >7.6 and urea to NH_3)

NH_4^+ Fixation = movement of ammonium into clays

Nitrate leaching = movement of nitrate in water below root zone

N Cycling Effects on Soil N Content

<i>N Gains</i>	<i>N Losses</i>	<i>No Net Change (Cycling)</i>
N₂ Fixation (natural)	Plant uptake	Immobilization
Fertilizer (N₂ fixation by human)	Denitrification	Mineralization
Animal manure Sewage sludge	Volatilization	Nitrification
Crop residue	Leaching	NH₄⁺ Fixation

Optimize



Minimize



Control



NUE

Factors Affecting Mineralization

- **C:N Ratio** less than 20:1 = mineralization
 greater than = immobilization
- **Moisture Level** Optimum at 50-70% of field capacity
- **Temperature** Maximum: 40 - 50° C (104 - 140° F)
 Optimum: 25 - 35° C (77 - 95° F)
 Minimum: 5 - 10° C (40 - 50° F)
- **Aeration** Most mineralizing bacteria are aerobic.
- **pH** Microbes can be sensitive to pH



	C: N
Soil Microorganisms	8:1
Soil	10:1
Grain Straw	80:1

In general, conditions are good for root growth ➡ good for N mineralization

N supply from Mineralization

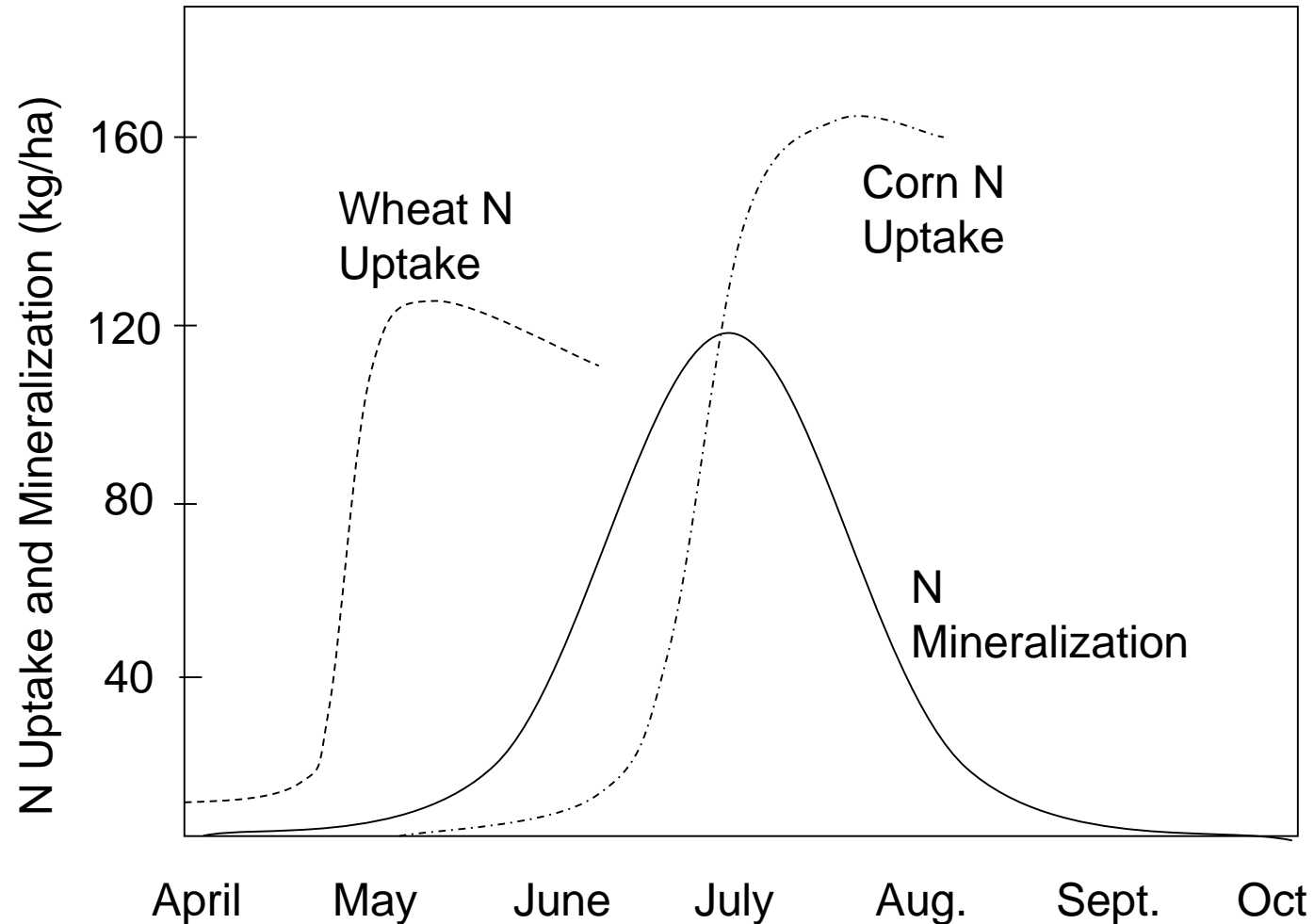
- Soil organic matter (SOM) contains about **5% N**.
- During a single growing season 1 - 4% of the SOM is mineralized to inorganic N.
 - 4% SOM @ 2% mineralization → 80 lbs N/acre
 - 4% SOM @ 4% mineralization → 160 lbs N/acre
- This is one reason it is very difficult to accurately predict the N fertilizer requirement of a crop.
- The amount of N a crop will remove or uptake is fairly uniform from year to year, but the amount of N available to the crop from the soil changes from year to year.

N supply from Mineralization in WA

	Annual net N mineralization	Fall net N mineralization	Spring net N mineralization
	September 2012-August 2013	September 2012-April 2013	April 2013 - August 2013
	----- kg N ha ⁻¹ -----		
Pullman, WA	84	37	47
Davenport, WA	64	12	52

Source Zaac T.

Synchrony of soil N mineralization VS Crop N uptake in corn and winter wheat

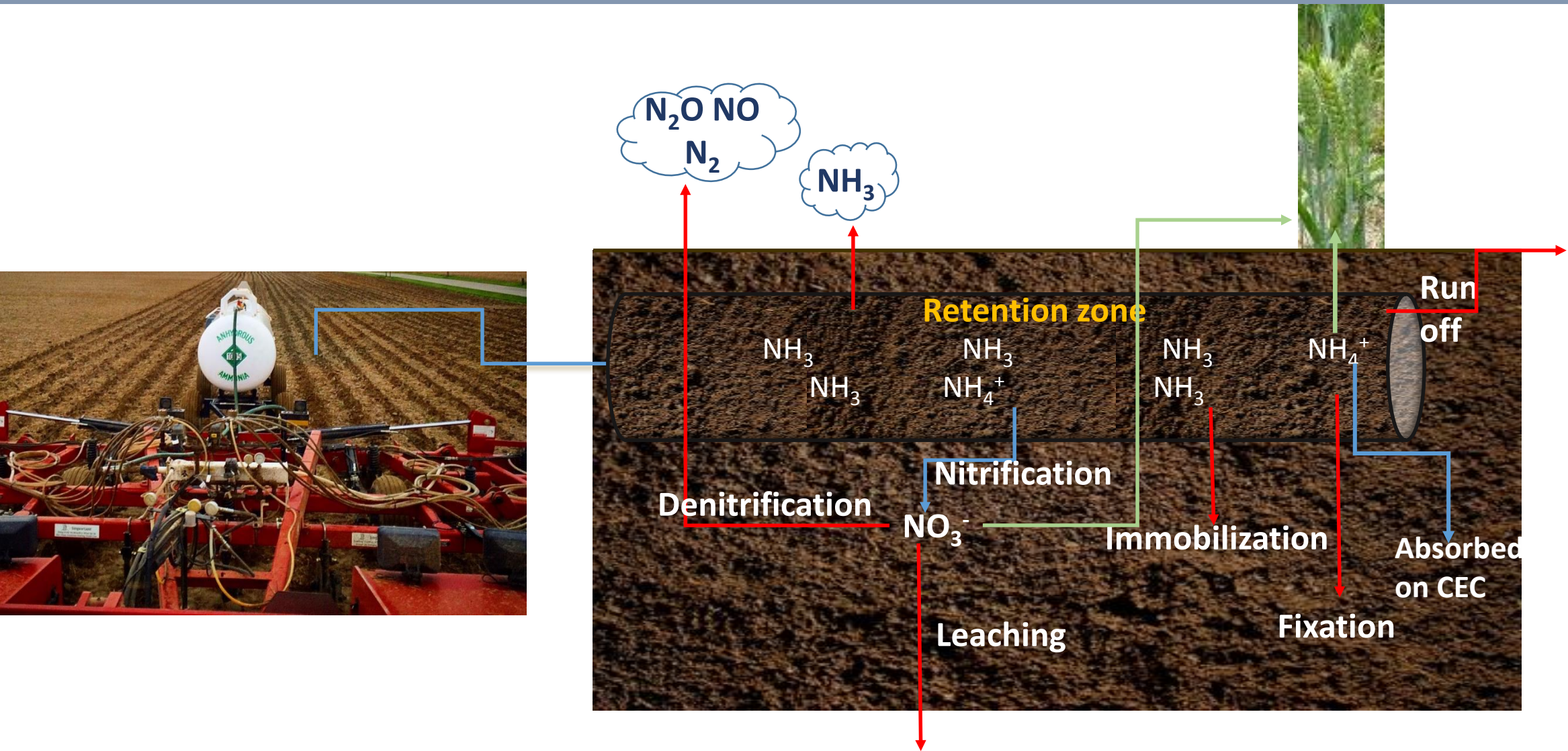


Havlin et al.

The background image shows a vast landscape of rolling hills. The foreground is a grassy slope with green and yellowish grass. In the middle ground, there are large, flat fields, some of which are a deep green, suggesting crops like corn, and others are a light brown, suggesting they have been harvested. The hills in the distance are also covered in similar vegetation. The sky is a clear, pale blue. The text is overlaid on the lower half of the image.

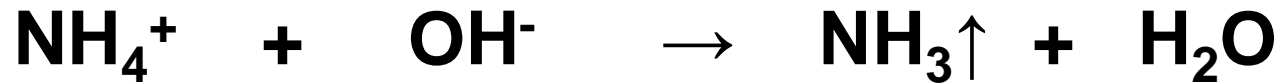
Fate of Anhydrous Ammonia (AA) in Soils

Reactions of Anhydrous Ammonia in Soil



Volatilization

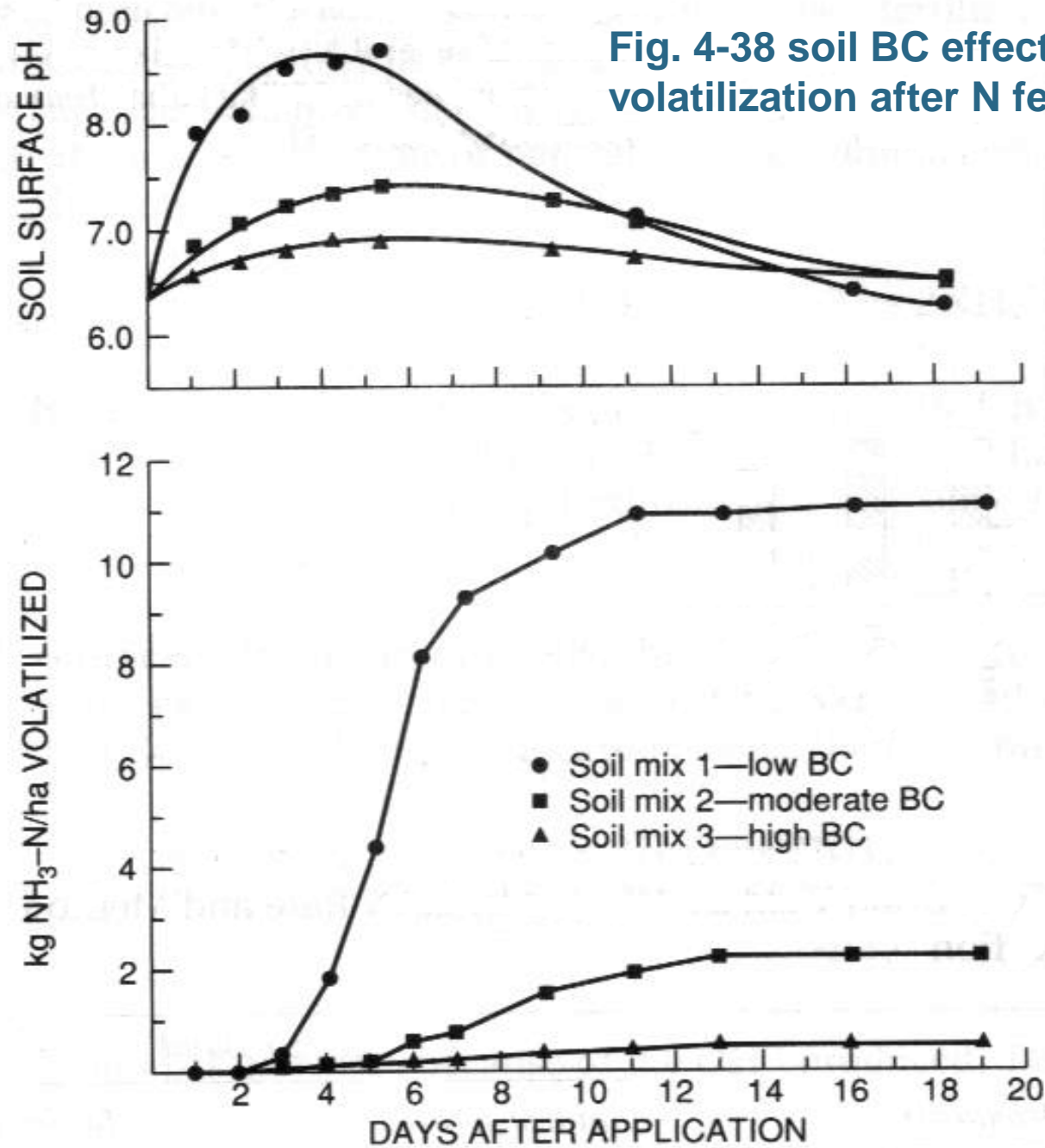
Volatilization — Gaseous NH_3 loss to the atmosphere.



Soil pH effects on percentages of N present as NH_3 and NH_4^+

Soil pH	Ammoniacal N	
	Ammonia	Ammonium
	-----%-----	
6	0.058	99.94
7	0.57	99.43
8	5.4	94.6
9	36.5	63.5

Fig. 4-38 soil BC effects on soil pH and NH_3 volatilization after N fertilizer application.



Factors Favoring Volatilization

- **Initially moist soil followed by drying**
- **No rain or irrigation after application**
- **High crop residue on the soil surface**
- **High temperatures**
- **High wind**
- **High soil pH, >7.8**
- **Low clay & organic matter (low CEC)**

NH₃ Volatilization Losses

- **Injection or tillage**
- **Rain 2-3 days control loss**
- **Maximum loss of N through volatilization = 20-30% of N**
- **Up to 50% loss of N through volatilization on calcareous soils**

Nitrification

Nitrification --- Conversion of NH_4^+  NO_3^-

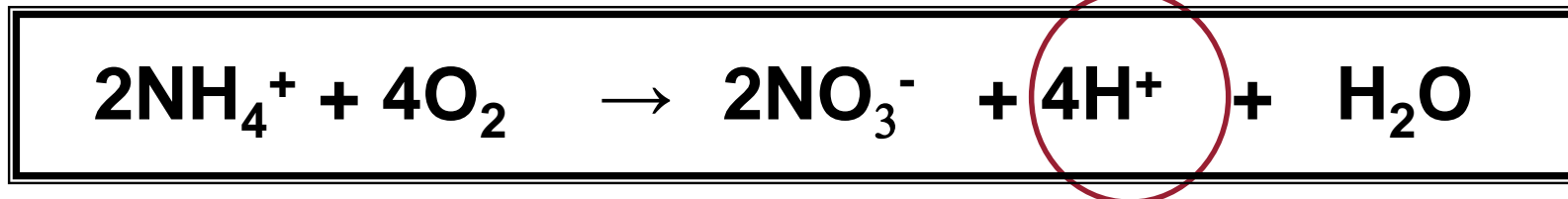
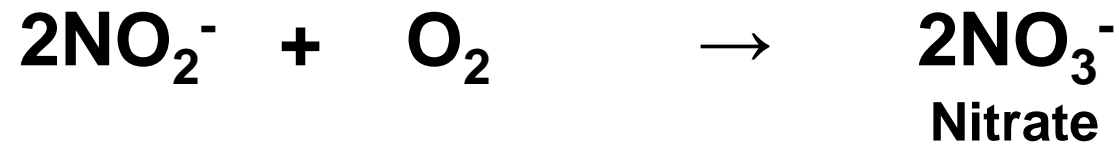
- **Exclusively carried out by aerobic autotrophs**
- **Nitrification is fairly rapid under favorable conditions**

Processes of Nitrification

- **Step 1: Nitrosomonas**



- **Step 2: Nitrobacter**



Soil
pH ↓

Factors Affecting Nitrification

- **Moisture Level** Optimum at 50-70% of field capacity
- **Temperature** Optimum at 30 - 35° C (86 - 95° F)
- **Aeration** O₂ necessary for nitrification, associated with soil moisture
- **pH**
 - Nitrification bacteria sensitive to soil pH
 - Optimum at 6.8 - 7.0 or higher
 - Slower at low pH, negligible with pH ≤ 5.0
 - At high pH free NH₃ is toxic to nitrobacter which may result in buildup of toxic levels of NO₂⁻
 - Nitrification lowers pH

Ammonium (NH_4^+) Fixation

- NH_4^+ enters interlayer of 2:1 clay minerals such as vermiculite and mica minerals to replace existing K^+ .
- NH_4^+ fixation \neq exchangeable NH_4^+ , but the fixation is not permanent and may protect the fertilizer from nitrification and leaching for short periods of time (1 to 8 weeks).
- Not very important in most soils. Maximum fixation 30 lbs N/acre.

NH_4^+ Fixation

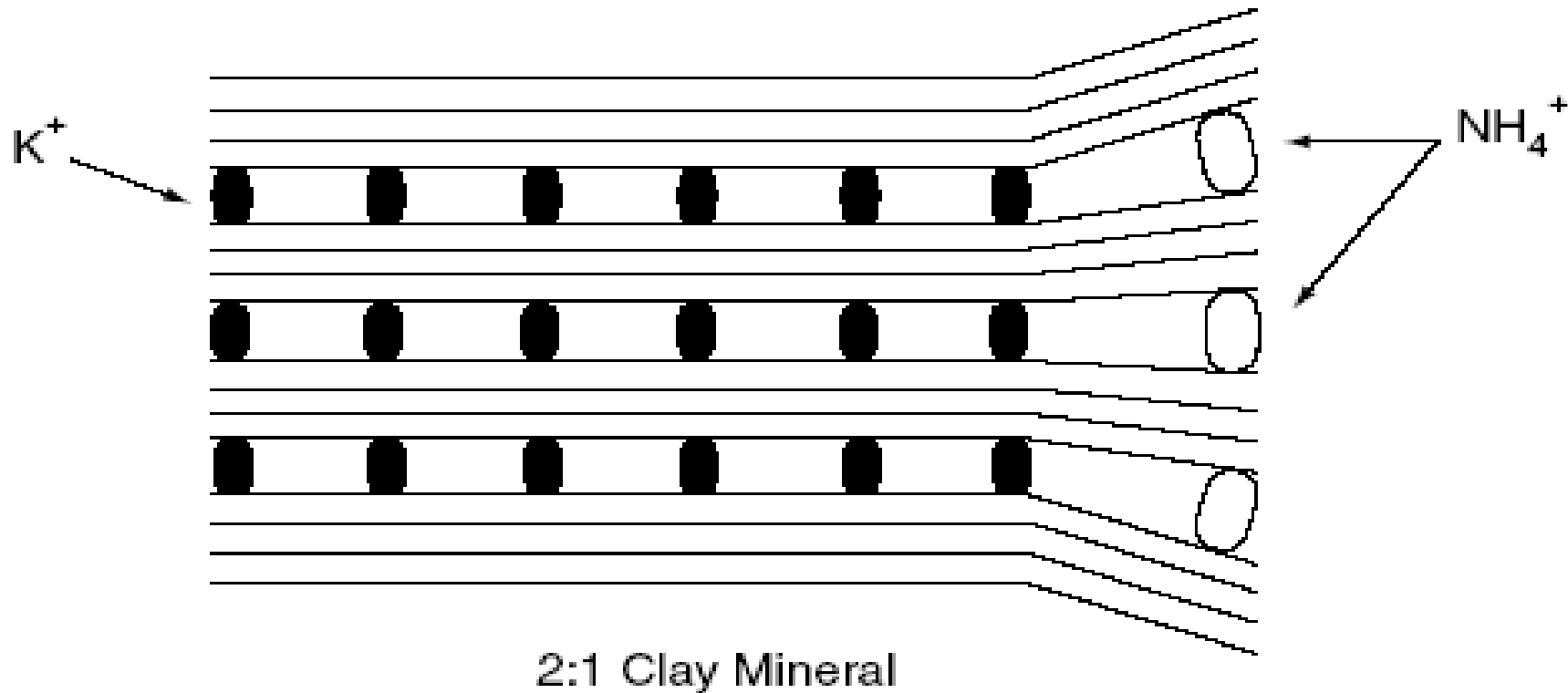


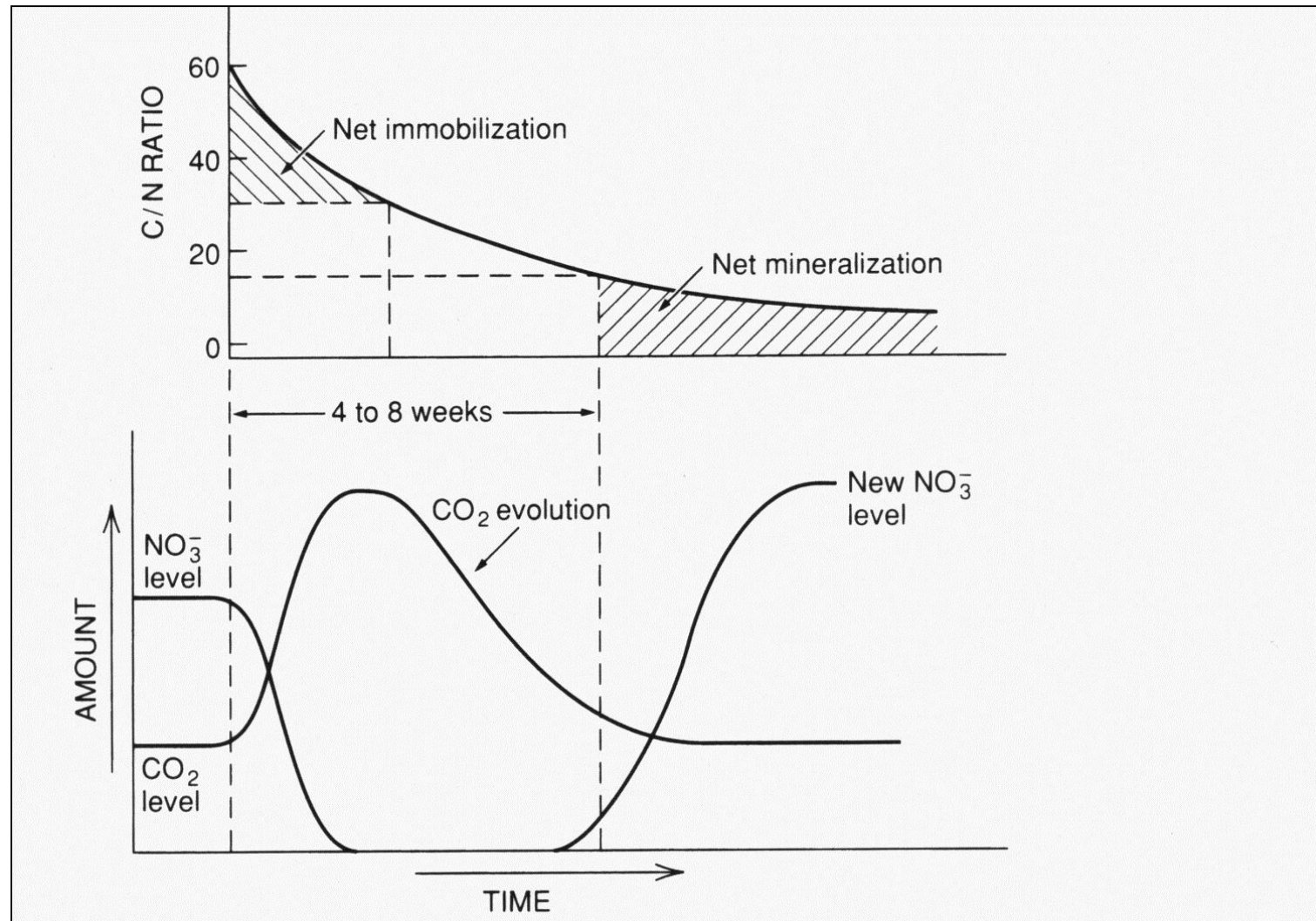
Diagram of an expanding clay mineral capable of fixing native or applied NH_4^+

Immobilization

Immobilization --- Conversion of mineral N to organic N by microbes

- **Organisms that decompose organic matter as an energy source require nitrogen.**
- **Organic materials with a low N content cannot supply the needs of these organisms, thus they use soil N and compete with the crop.**
- **Freshly immobilized N = 5-15% of soil N.**

NH_4^+ Immobilization



Havlin et al.

N mineralization and immobilization following addition of residue to soil

The background image shows a vast agricultural landscape. In the foreground, there is a field of tall, green grass. Beyond this, the land rises into rolling hills. Some hills are covered in vibrant green crops, while others are a golden-brown color, suggesting they have been harvested or are fallow. The horizon is flat under a clear, light blue sky. The text is overlaid on the middle of the image, centered horizontally.

Fate of Urea-Ammonium Nitrate (UAN) Fertilizers

Reactions of **UAN** in Soil

- A solution of Urea and NH_4NO_3
- 50% NO_3NH_4 : 50% Urea \longrightarrow 25% NO_3^- + 75% NH_4^+
- % by weight:
 - UAN 32 : 45% NH_4NO_3 + 35% Urea + 20% Water
 - UAN 30: 42% NH_4NO_3 + 33% Urea + 25% Water
 - UAN 28: 40% NH_4NO_3 + 30% Urea + 30% Water

Behavior of Nitrate (NO_3^-) in Soil

- Most common mineral form of N in most soils
- Plant uptake
- Anion, therefore is not adsorbed on CEC
- Leaching loss
- Denitrification loss

Denitrification

Denitrification --- Conversion of NO_3^- -N to gaseous NO, N_2O , or N_2



Most denitrifying bacteria are chemoheterotrophic (aerobic) bacteria (e^- acceptor = O_2) that are capable of anaerobic growth only in the presence of N oxides (nitrate).

Under anaerobic conditions these bacteria use NO_3^- as the e^- acceptor and carbon (OM) as the e^- donor.

Denitrification

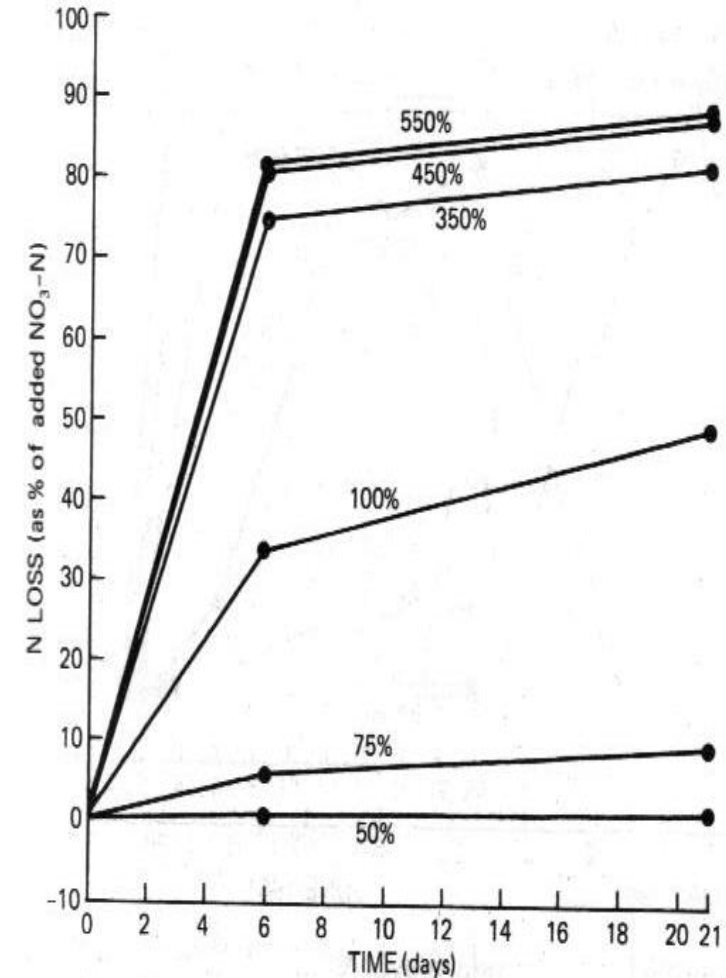
Conditions needed for denitrification to occur:

- Lack of oxygen (or extremely low oxygen levels)**
- A source of carbon (OM)**
- A source of nitrate**

Factors that Favor Denitrification

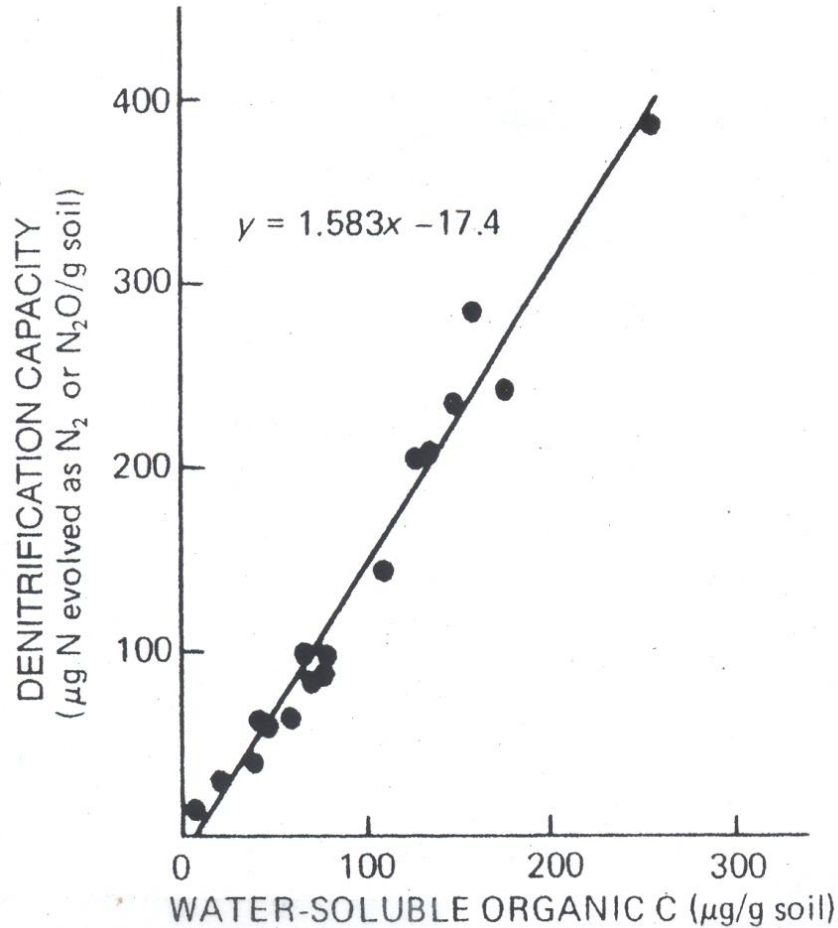
- **Poor soil structure.**
- **Soil alternately wet and dry.**
- **Recent additions of easily decomposed carbon such as an alfalfa crop plowed down.**
- **Flooding.**
- **pH greater than 5.0, and the higher the pH the quicker the denitrification.**
 - **pH < 5.5 = NO favored**
 - **pH < 5.5-6.0 = N₂O favored**
 - **pH > 6.0 = N₂ favored**

Factors that Favor Denitrification

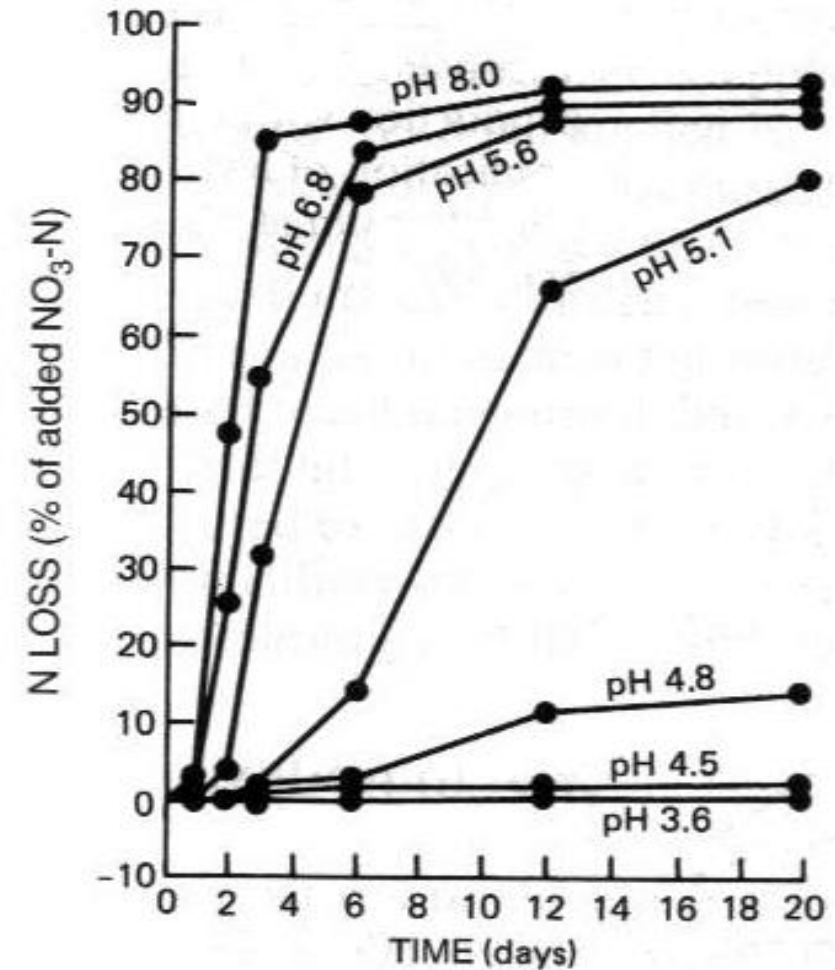


Effect of soil water content (% of water-holding capacity) on denitrification in soil (Havlin et al., 2005)

Factors that Favor Denitrification

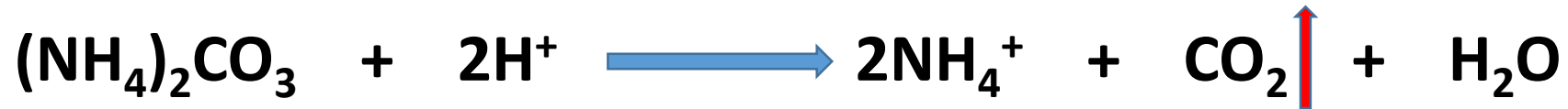
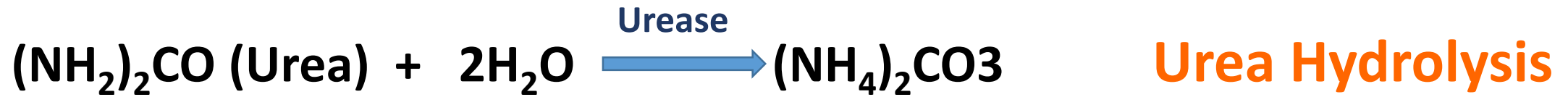


Relationship between denitrification capacity and water-soluble organic C (Burford & Bremner, 1975)

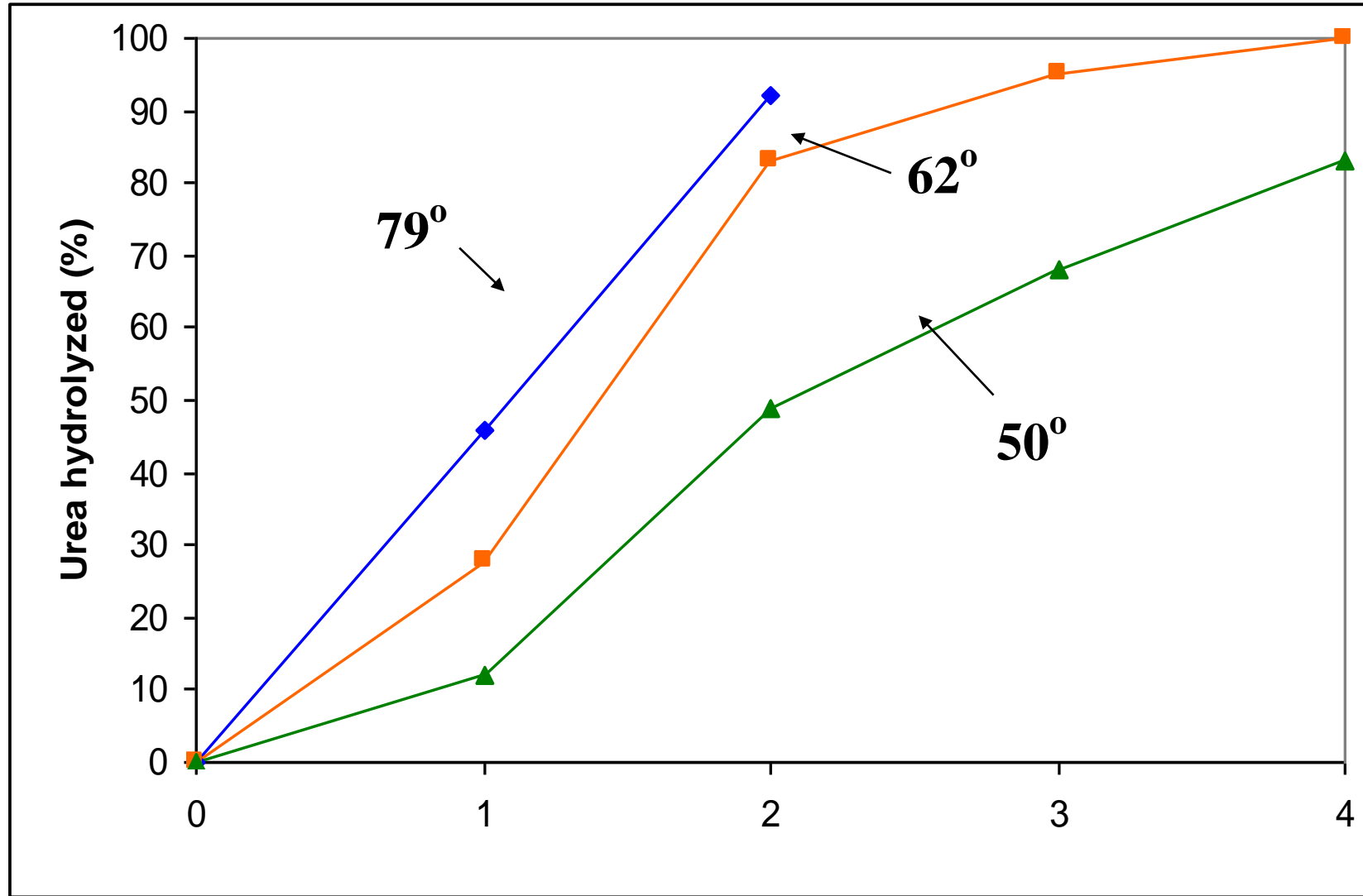


Effect of soil pH on denitrification in soil (Havlin et al., 2005)

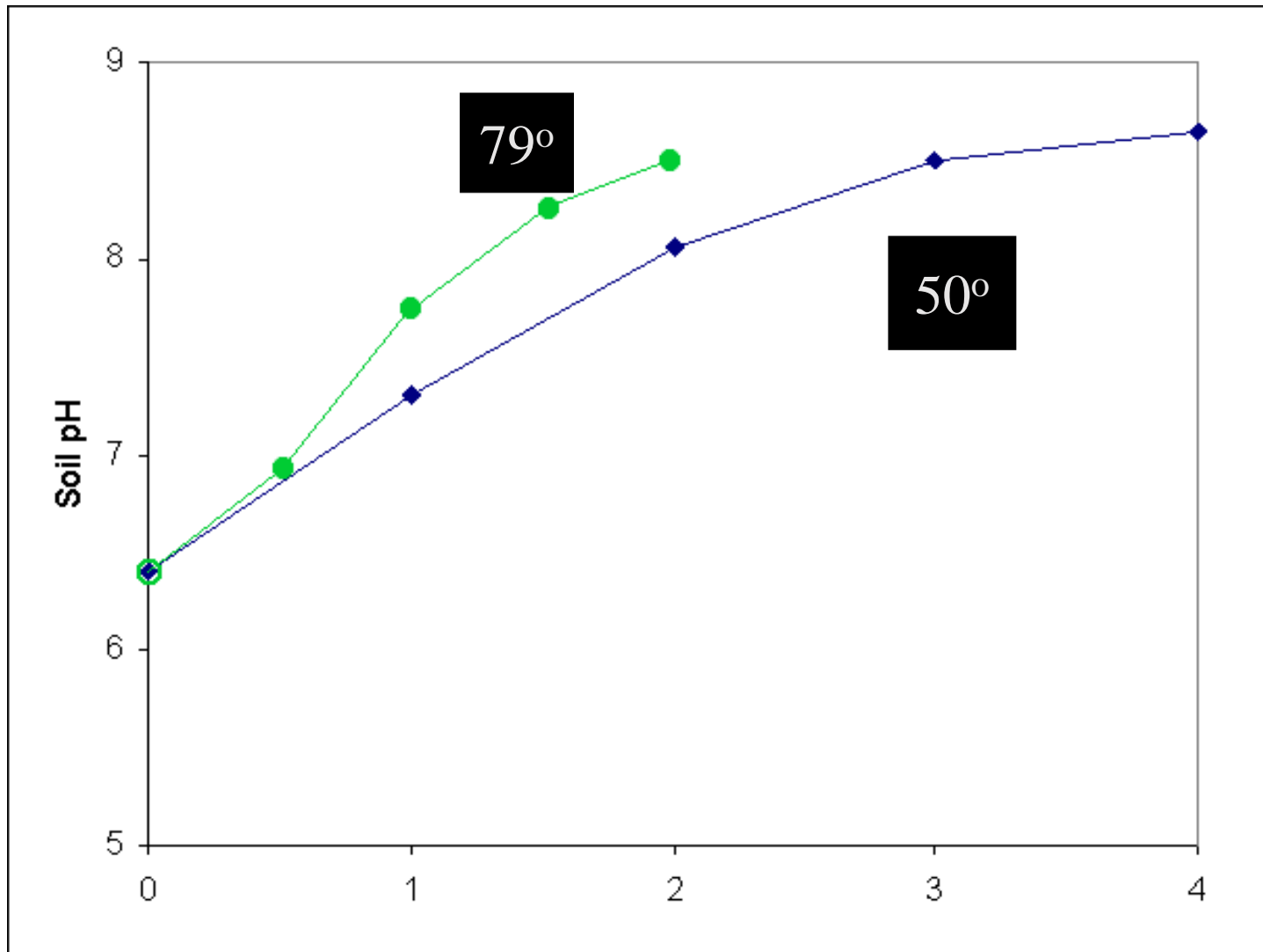
Reactions of Urea in Soil



⋮



Rates of urea hydrolysis in a silt loam soil at three temperatures (L.G. Bundy)



Change in soil pH in a urea-treated silt loam at two temperatures (L.G. Bundy)

N fertilization and soil quality

Application of large amounts of ammonium fertilizers can cause a decrease of **soil pH**, can be a problem in no-till system.

- *anhydrous ammonia* $\text{NH}_3 + 2\text{O}_2 \rightleftharpoons \text{NO}_3^- + \text{H}_2\text{O} + \text{H}^+$
- *urea* $(\text{NH}_2)_2\text{CO} + 4\text{O}_2 \rightleftharpoons 2\text{NO}_3^- + 2\text{H}^+ + \text{CO}_2 + \text{H}_2\text{O}$
- *ammonium nitrate* $\text{NH}_4\text{NO}_3 + 2\text{O}_2 \rightleftharpoons 2\text{NO}_3^- + 2\text{H}^+ + \text{H}_2\text{O}$
- *ammonium sulfate* $(\text{NH}_4)_2\text{SO}_4 + 4\text{O}_2 \rightleftharpoons 2\text{NO}_3^- + 2\text{SO}_4^{2-} + 4\text{H}^+ + \text{H}_2\text{O}$
- *monoammonium phosphate*
 $\text{NH}_4\text{H}_2\text{PO}_4 + \text{O}_2 \rightleftharpoons 2\text{NO}_3^- + 2\text{H}^+ + \text{H}_2\text{PO}_4^- + \text{H}_2\text{O}$
- *diammonium phosphate*
 $(\text{NH}_4)_2\text{HPO}_4 + \text{O}_2 \rightleftharpoons 2\text{NO}_3^- + 3\text{H}^+ + \text{H}_2\text{PO}_4^- + \text{H}_2\text{O}$
- *elemental S* $2\text{S} + 3\text{O}_2 + \text{H}_2\text{O} \rightleftharpoons 2\text{SO}_4^{2-} + 4\text{H}^+$
- *ammonium thiosulfate*
 $(\text{NH}_4)_2\text{S}_2\text{O}_3 + 6\text{O}_2 \rightleftharpoons 2\text{SO}_4^{2-} + 2\text{NO}_3^- + 6\text{H}^+ + \text{H}_2\text{O}$

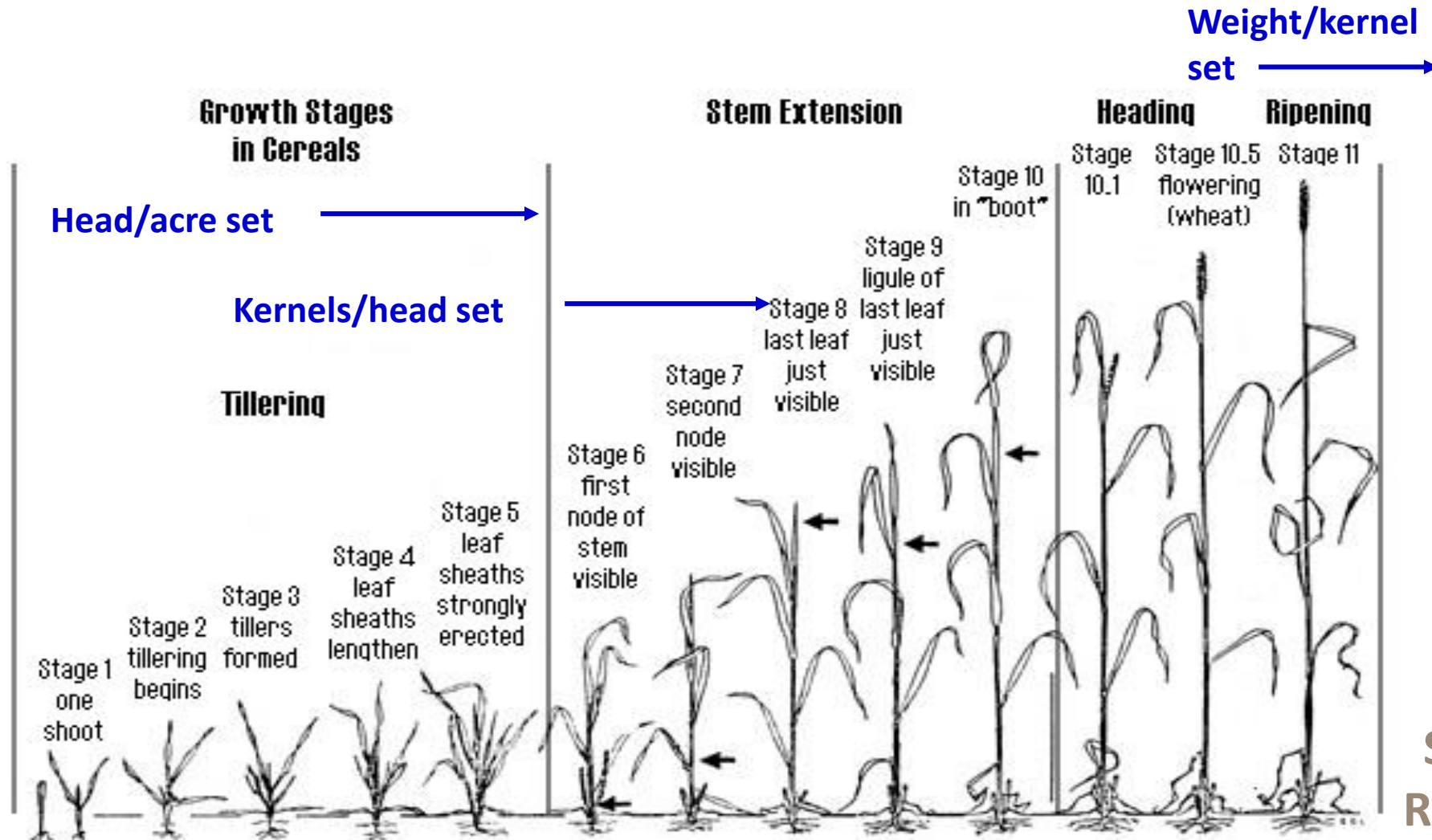
N fertilization and soil quality

- Long-term excessive application of fertilizer N have negative effect on **soil C sequestration**. – found by numerous studies
- A research studying effect of N fertilization on soil C sequestration for different crop rotation grown on Mollisols: net decline in soil C despite increasingly massive residue C incorporation.
- Fertilizer N applications increase biomass production, but have little benefit to soil C sequestration. – found by numerous studies

Management Practices and NUE

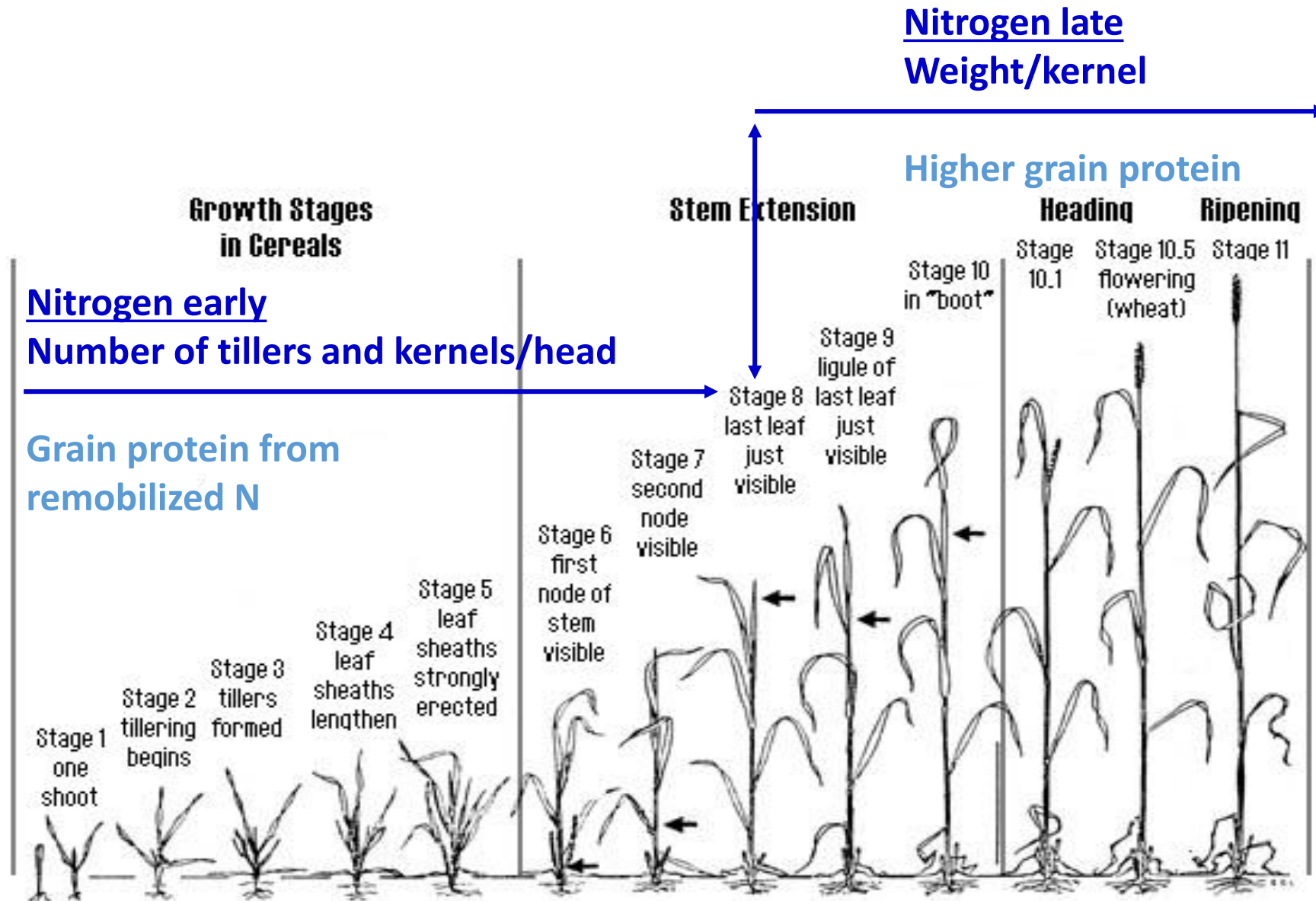
- Climate: rainfall, temperature
- 4Rs of nutrient stewardship: Rate, Form, Timing, Placement;
5th R – right data
- Variety
- Soil: type, drainage, microbiology, soil pH, etc.
- Tillage
- Crop rotation
- Residue management
- Fungicides
- Herbicides

When are yield components “set”?



Source:
R. Koenig

Impacts of nitrogen



Source:
R. Koenig

What makes yield?



Heads/area x Kernels/heads x Weight/kernel

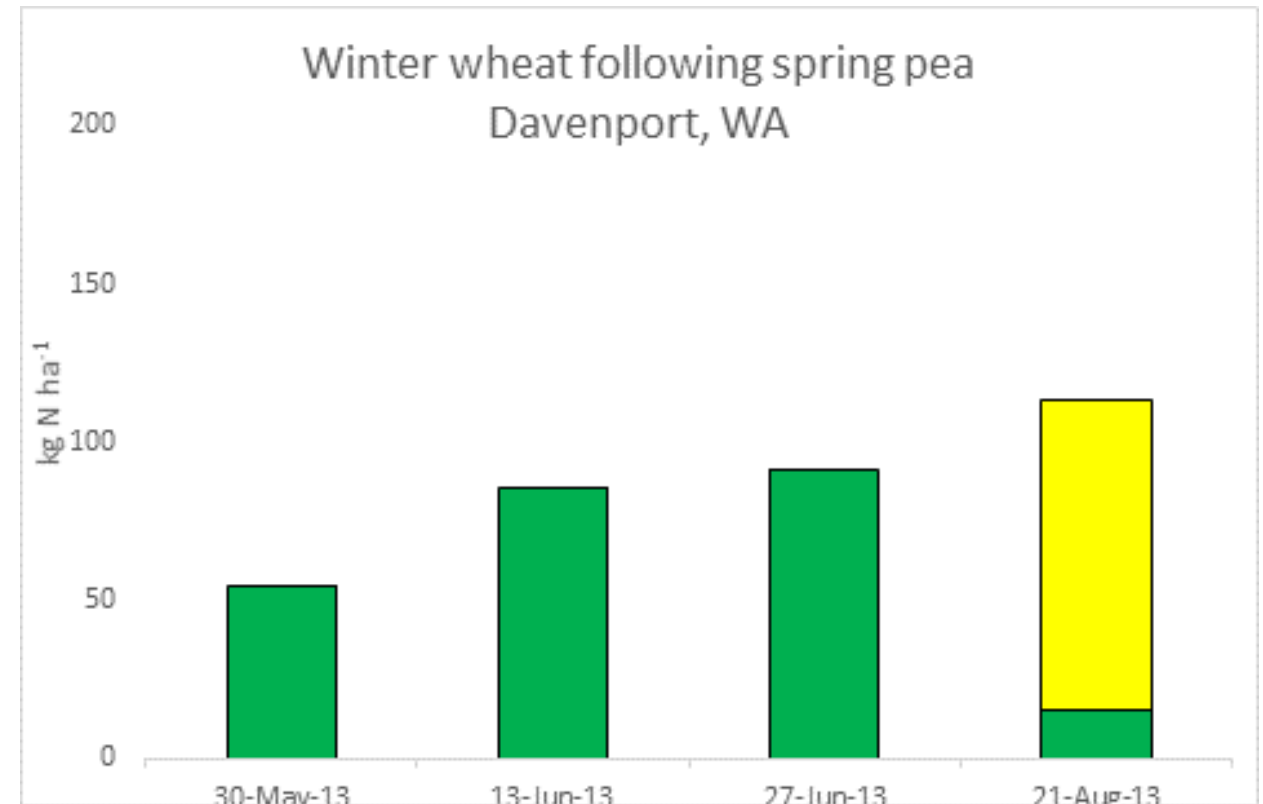
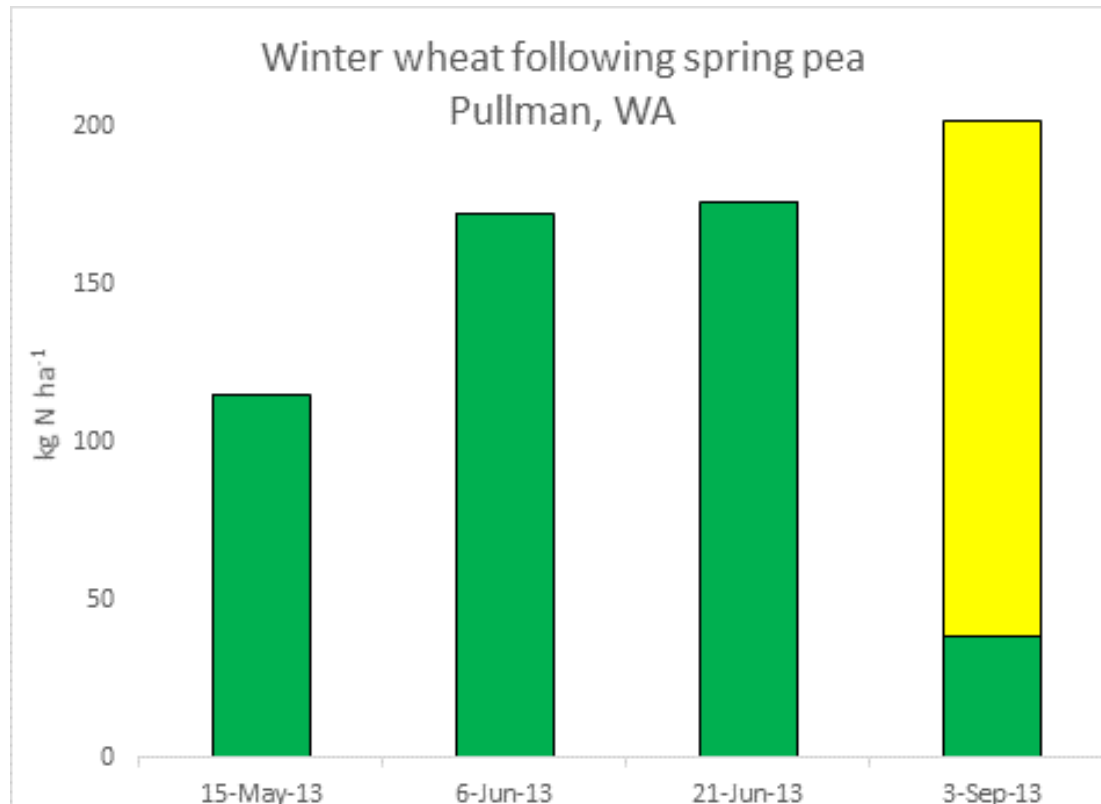
**Source:
R. Koenig**

What makes high grain protein?

- **Nitrogen taken up during vegetative growth (before flowering)**
 - **Used to grow the plant and make yield, but also stored**
 - **Later, remobilized to grain during grain filling period**
- **Nitrogen taken up during grain filling**

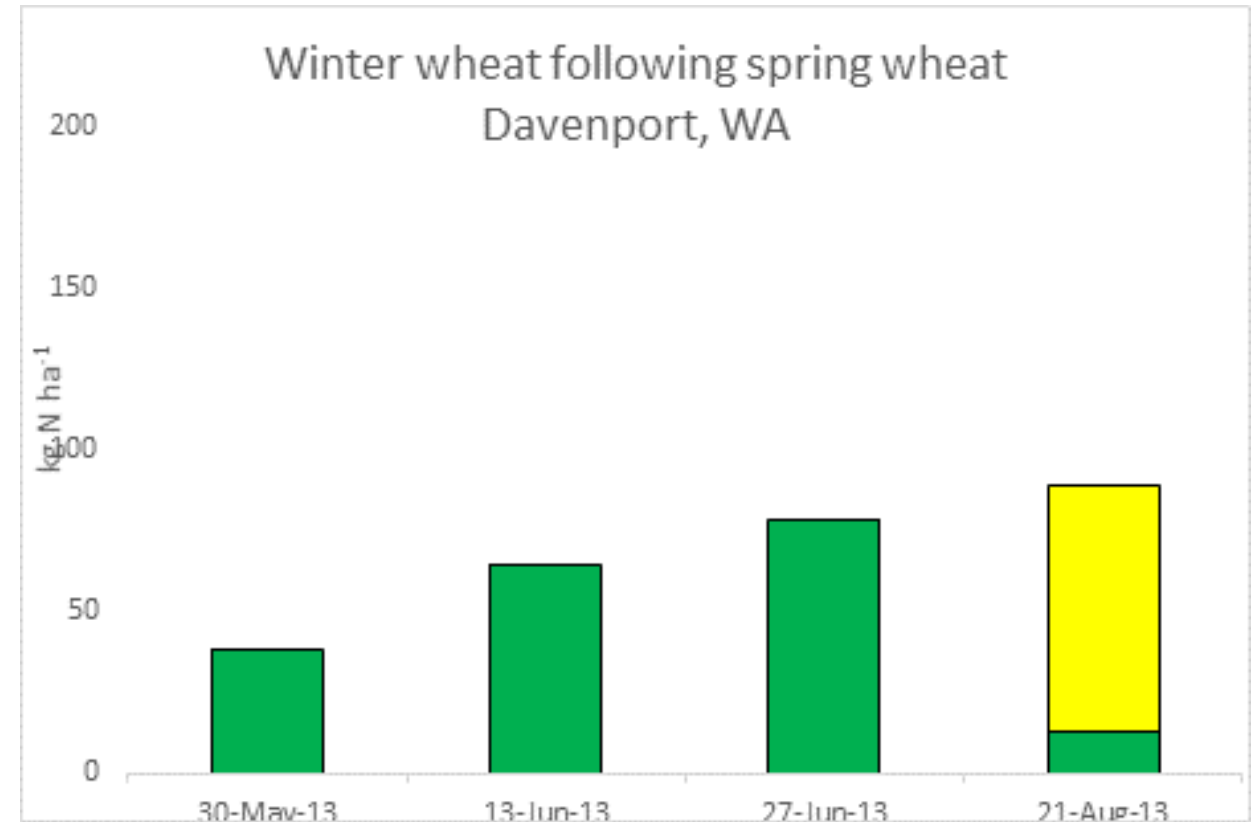
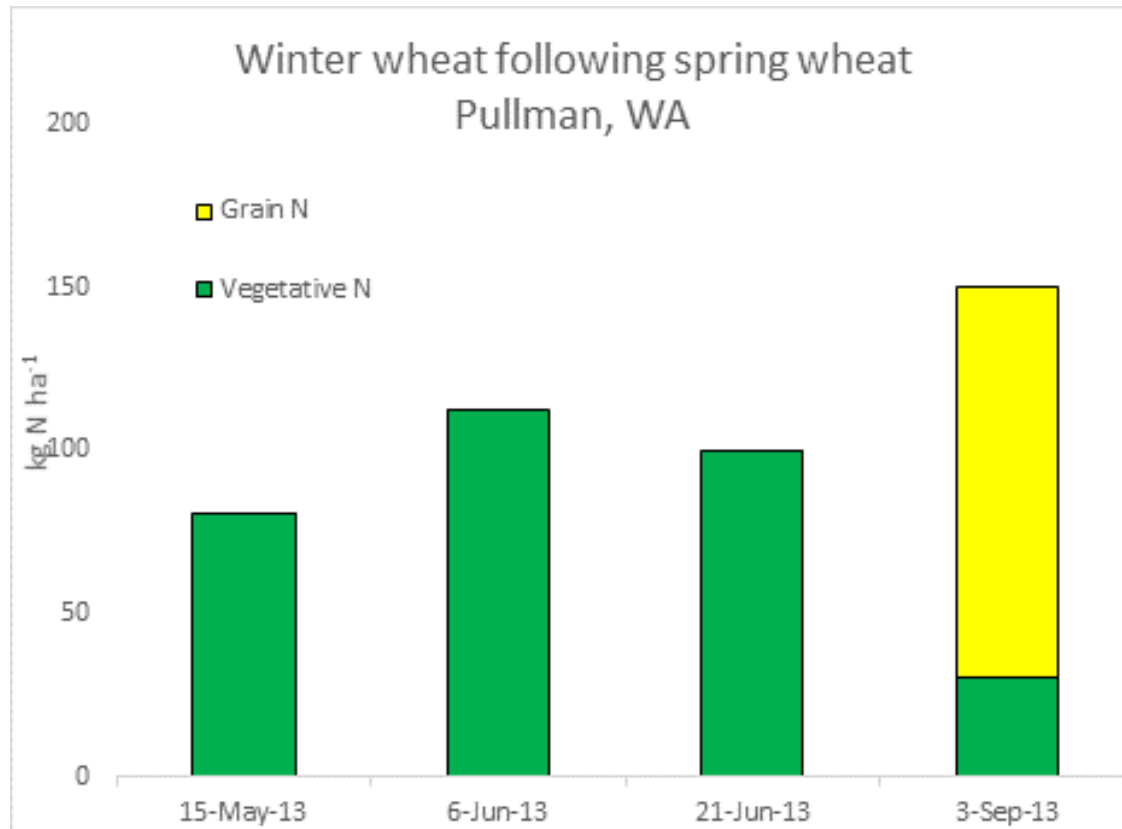
Source:
R. Koenig

Rainfall & Crop Rotation vs N Uptake



Source: Zaac T.

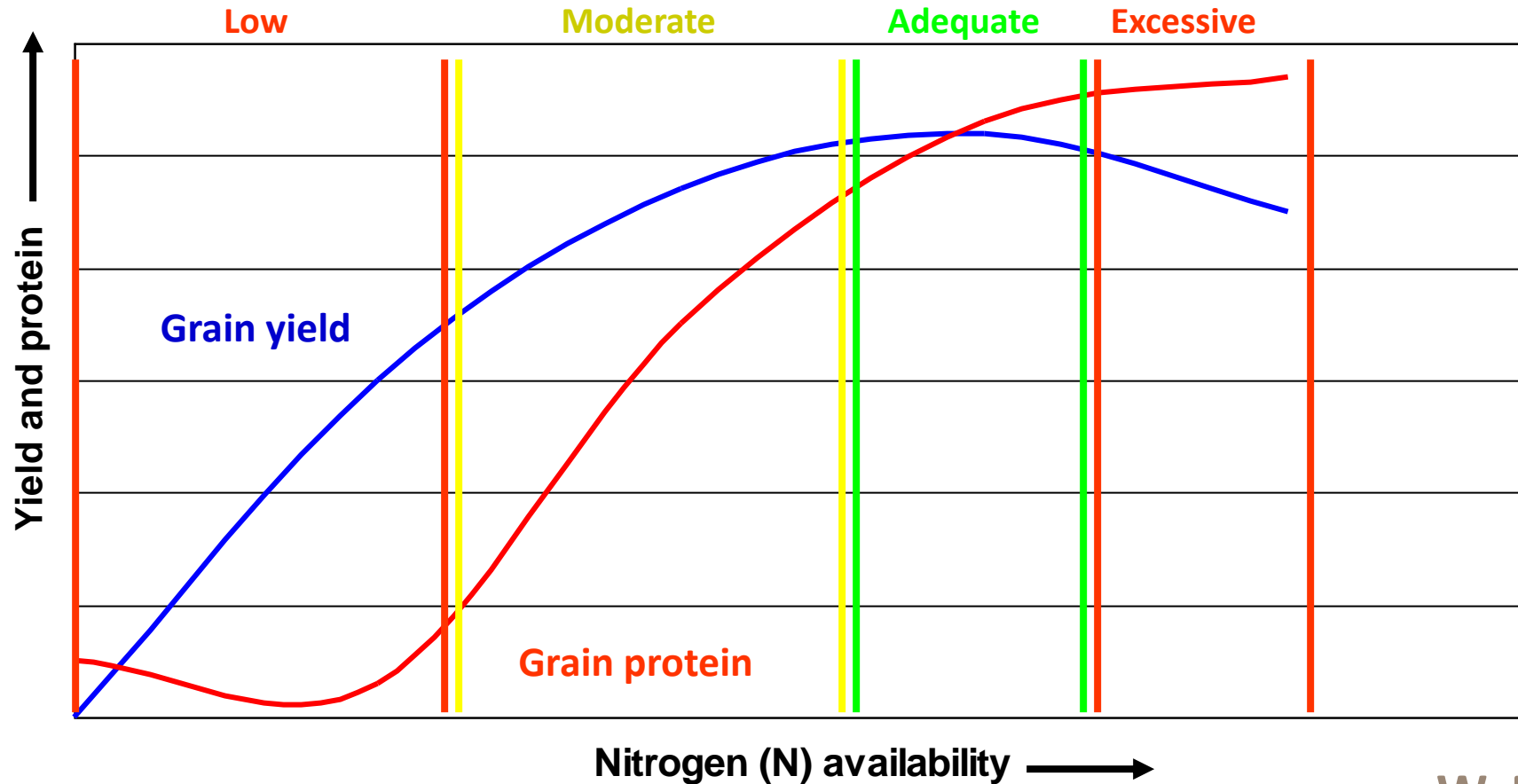
Rainfall & Crop Rotation vs N Uptake



Source: Zaac T.

Right Rate

Yield-Protein basics: Hard Wheats

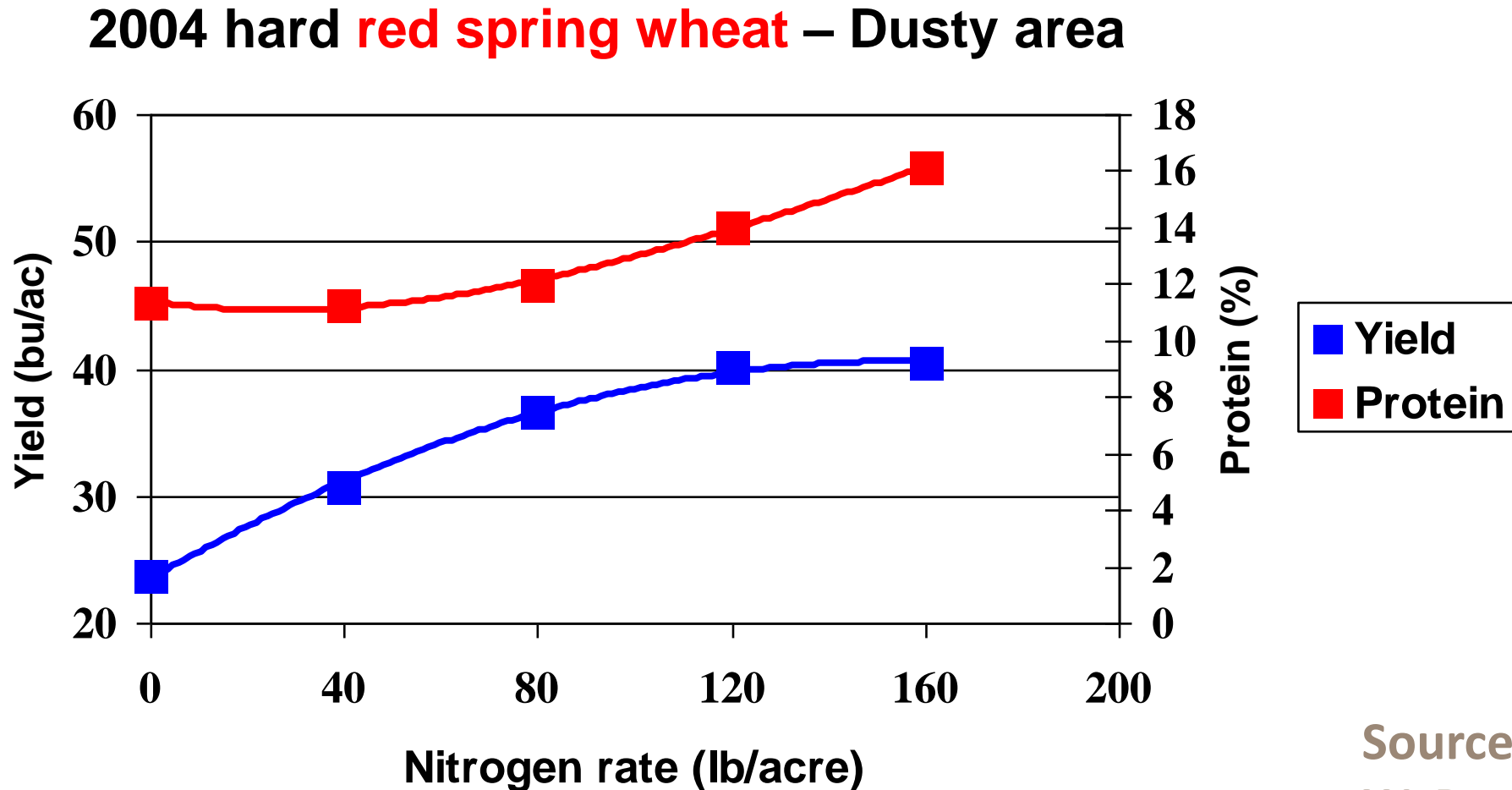


Source:

W. Pan & R. Koenig

Right Rate

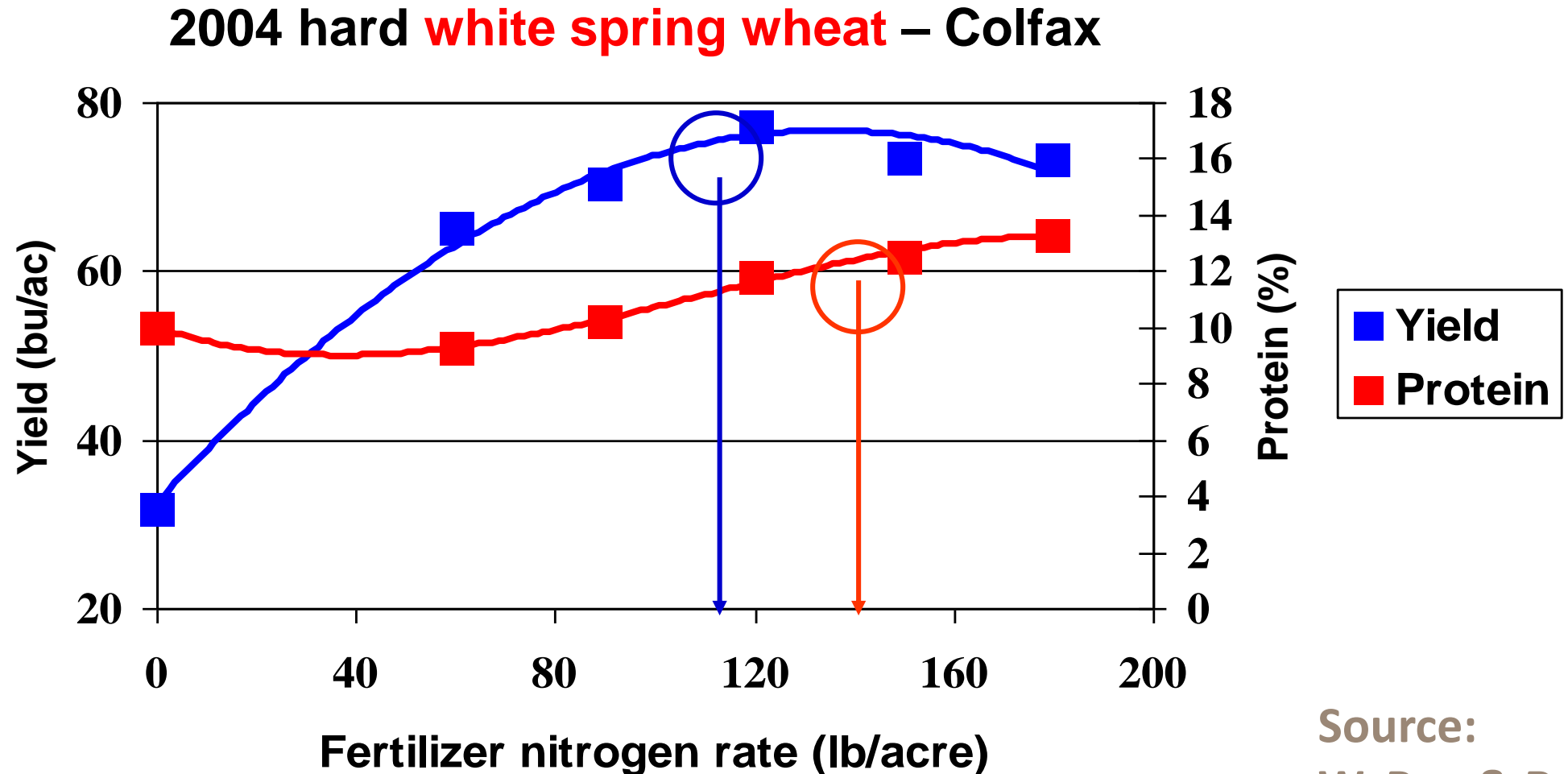
Yield-Protein basics: Hard Wheats



Source:
W. Pan & R. Koenig

Right Rate

Yield-Protein basics: Hard Wheats



Source:
W. Pan & R. Koenig

Right Rate

More N is Required for Hard Wheat Protein

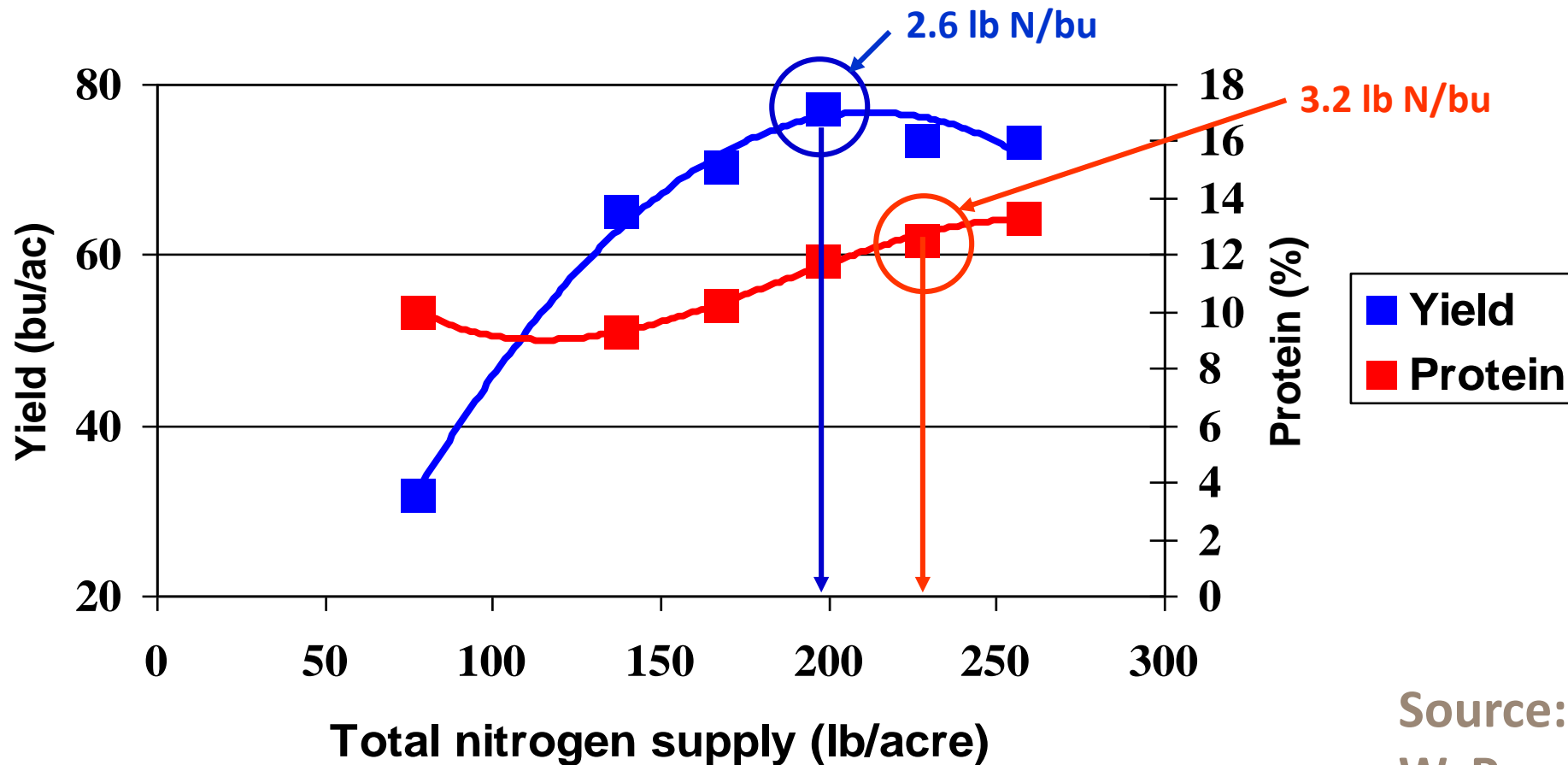
- **Maximum yield occurs at 12.5% grain protein in hard red spring, 11.5% grain protein in hard white spring, and 10.5% grain protein in soft white winter wheat**
- **The amount of N required to reach protein goals of 12.5% (hard white) or 14% (hard red) is slightly more than the amount necessary for maximum yield**
- **How much more? About 0.4 to 0.5 lb N/bushel more than for maximum yield**

Source:

W. Pan & R. Koenig

Right Rate

N supply - yield and protein trends



Source:
W. Pan & R. Koenig

Right Rate

It's not the N applied but the total N supply

- **The total amount of N available to wheat is the most important factor in achieving yield and protein goals, not the N fertilizer rate**
- **Soil residual N, mineralized N, and immobilized N must be accounted for before determining how much fertilizer N is needed**
- **Soil testing is the only way to quantify soil N contributions**
 - **Soil testing will be required (CSP program)**

Source:

W. Pan & R. Koenig

Right Timing

Early and late N availability are critical

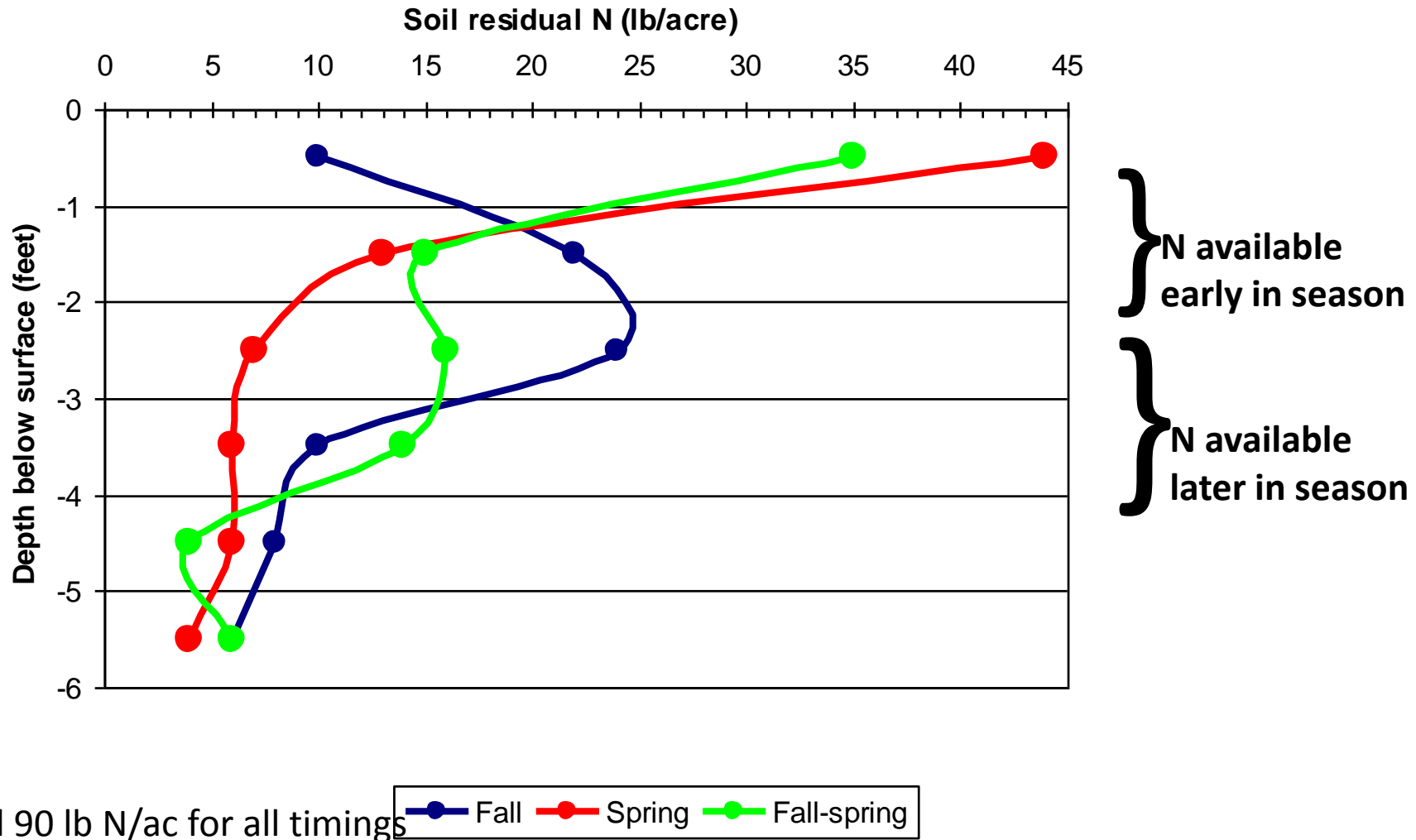
- **N taken up during vegetative growth (before flowering) is used primarily to set the yield potential (tillers → heads/plant and kernels/head)**
- **Vegetative N is later remobilized to the kernels to make grain protein**
- **N taken up after flowering is used to increase size of kernels and grain protein**
 - **This is critical to reach protein goals in hard wheats**

Source:

W. Pan & R. Koenig

Right Timing

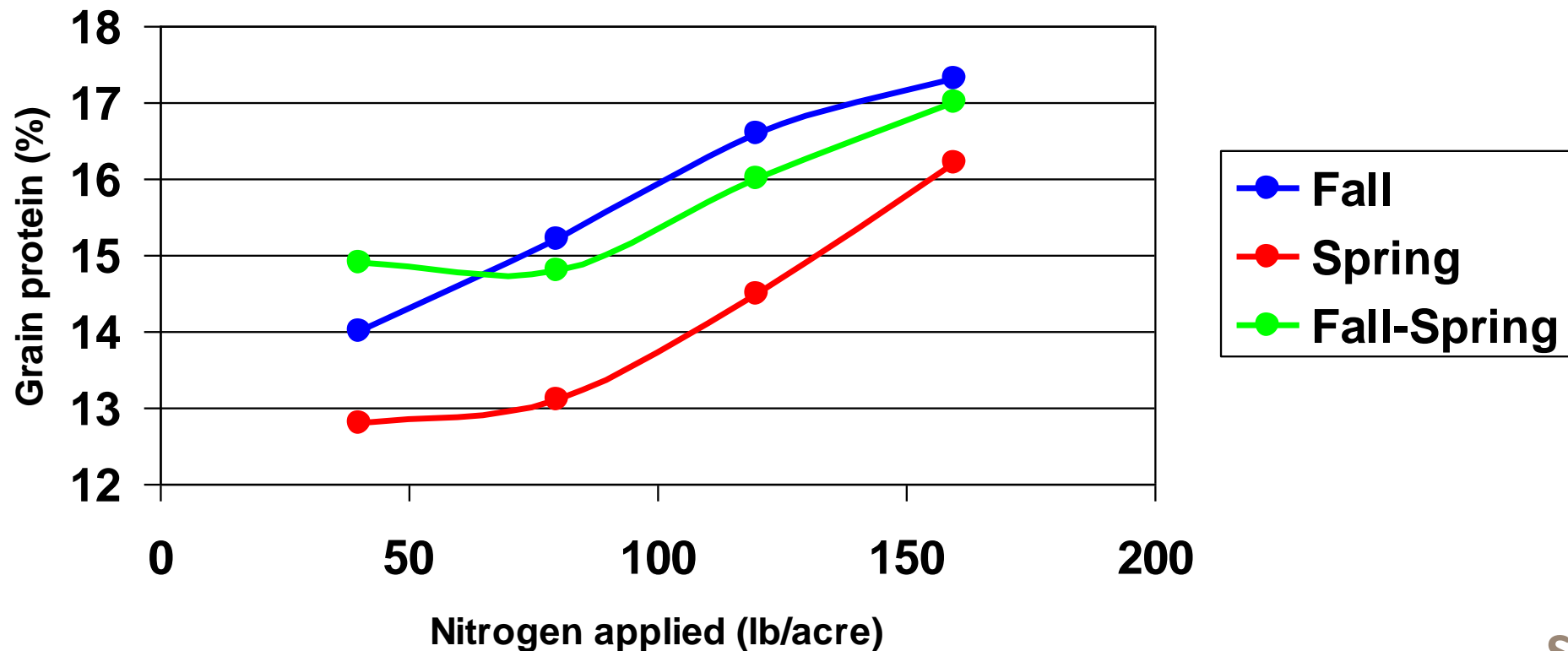
Soil N and application timing scenarios (dryland spring sampling)



Source:
R. Koenig

Right Timing

N application timing and hard red spring wheat grain protein



No difference in yield among application timings

Source:
Huggins, 1991

Right Location

Positional availability of N is important

Spatial variability of N within- and across-field

Availability of N at key times is critical

- Shallow N available early in the season establishes yield potential
 - N = tillers → heads and kernels per head
 - Some protein later
- *Subsoil availability of N is critical late in the season when precipitation is limited*
 - Helps kernels fill, but is also critical to make higher protein in hard wheat

Source

W. Pan & R. Koenig

Tools and Technologies in N Management

- Soil Tests
- Tissue Tests
- In-season nutrient deficiency symptoms
- Post-harvest Evaluation
- Sensors: ground sensors, remote sensing
- Precision Ag.
-

Some Thoughts

- **Optimize N Form × Timing × Rate for target protein**
- **Right N rate for different varieties**
- **Variable N rate for spatial variation**
- **Benchmark best management practices for N in WA**
- **Post-harvest evaluation for N management**
- **Continuous improvement of N management : Adaptive nutrient Management**

Your input

Soil fertility and residue research and extension/information needs

- Current issues & Long-term issues
- Cooperative projects and joint efforts

Immediate Extension Needs

Some issues can be resolved with existing knowledge and resources

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N Recommendation for Winter Wheat

Eastern Washington Nutrient Management Guide:

<http://cru.cahe.wsu.edu/CEPublications/EB1987E/EB1987E.pdf>

N management for hard wheat protein enhancement:

<http://plantbreeding.wsu.edu/pnw0578.pdf>

Yield, Protein, N use efficiency of spring wheat: evaluating field-scale performance:

<http://csanr.wsu.edu/publications/researchreports/CFF%20Report/CSANR2010-001.Ch17.pdf>

N Recommendation for Winter Wheat

Wheat and Small Grains: www.smallgrains.wsu.edu

Nitrogen Calculator:

<http://wheattools.wsu.edu/Applications/Fertilizer%20Use%20Calculator/>

Post Harvest Calculator:

<http://wheattools.wsu.edu/Applications/Fertilizer%20Use%20Calculator/>

Acknowledgement

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N Calculator

Post Harvest Calculator

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