

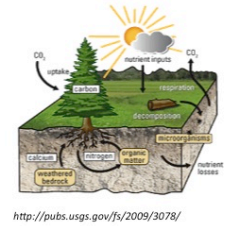
**Nutrient Cycling and Nutrient Deficiencies in Production Forests**

March 20, 2014

Jeremy Stovall

## Objectives

- What limits growth in southern pine forests?
- How do nutrients cycle in forests?
- Will climate change impact forest nutrition?



## Pop Quiz 1

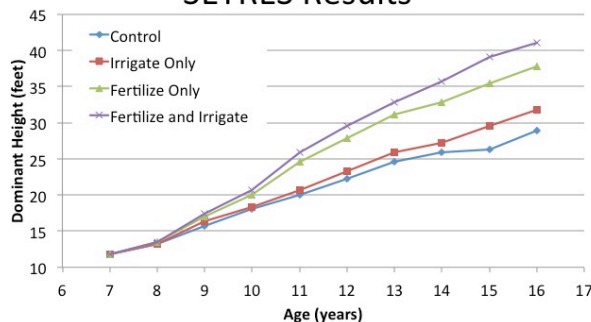
What most limits growth in pine plantations in the southern US?

- A. Water
- B. Nutrients
- C. Temperature
- D. Soil Physical Properties

## What Limits Growth? SouthEast Tree Research and Education Site



## What Limits Growth? SETRES Results



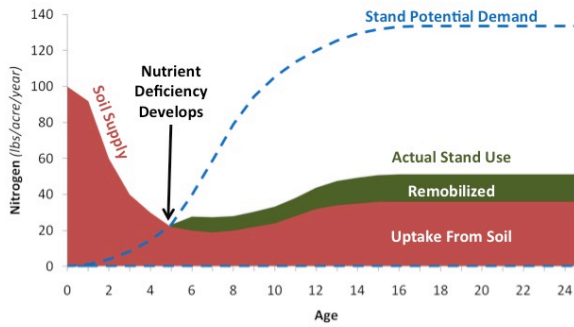
Adapted from: Albaugh, T. J., H. L. Allen, P. M. Dougherty, and K. H. Johnsen. 2004. Long term growth responses of loblolly pine to optimal nutrient and water resource availability. *Forest Ecology and Management* 192:3-19.

## Nutrient Supply: Liebig's Law of the Minimum



<http://www.greencare-concept.nl/eng/pagina/141/prevention-through-nutrition.html>

## Nutrient Supply: Fox et al. Model

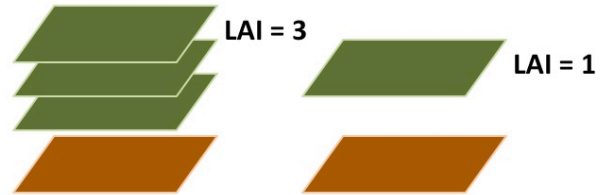


Adapted from: Fox, T. R., Allen, H. L., Albaugh, T. J., Rubilar, R., & Carlson, C. A. (2007). Tree nutrition and forest fertilization of pine plantations in the southern United States. *Southern Journal of Applied Forestry*, 31(1), 5-11.

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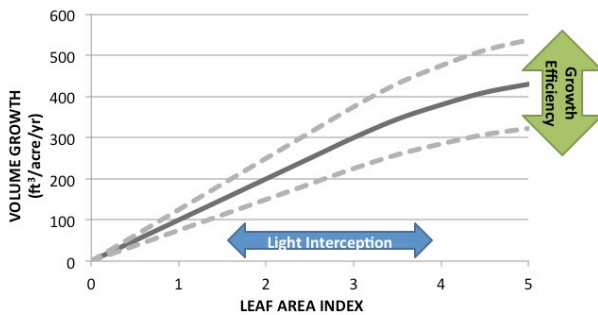
Nutrients Grow Leaves → Leaves Grow Trees  
Leaf Area Index (LAI)

- unit area leaf / unit area ground



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## Why is LAI Important?



Adapted from: Fox, T. R., H. L. Allen, T. J. Albaugh, R. Rubilar, and C. A. Carlson. 2007. Tree nutrition and forest fertilization of pine plantations in the southern United States. *Southern Journal of Applied Forestry* 31:5-11.

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## Fertilizer Applied in the South

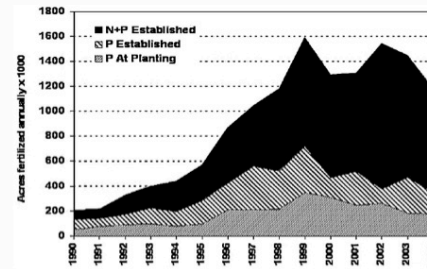


Figure 3. Area of southern pine plantations annually fertilized in the southeastern United States.

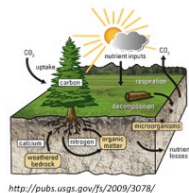
Figure Source: Fox, T. R., H. L. Allen, T. J. Albaugh, R. Rubilar, and C. A. Carlson. 2007. Tree nutrition and forest fertilization of pine plantations in the southern United States. *Southern Journal of Applied Forestry* 31:5-11.

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## Objective 1 Review

- What most limits growth in Southern Pine Forests?

1. Nitrogen
2. Phosphorus
3. Potassium
4. Micronutrients
5. Water\*



\*N and P are generally most limiting, but the specific order varies by site

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## Pop Quiz 2.1

Which nutrient is the least mobile in the soil, and thus the most difficult for trees to obtain?

- A. Nitrogen
- B. Phosphorus
- C. Potassium
- D. Calcium
- E. Magnesium

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## Pop Quiz 2.2

What nutrient makes up the greatest percentage of a tree's mass?

- A. Nitrogen
- B. Phosphorus
- C. Potassium
- D. Calcium
- E. Magnesium

## What Makes a Tree?

Element	Symbol	% Plant Dry Mass	Source
Carbon	C	45.0	Atmosphere
Oxygen	O	45.0	Water, Atmosphere
Hydrogen	H	6.0	Water
Nitrogen	N	1.5	Soil
Potassium	K	1.0	Soil
Calcium	Ca	0.5	Soil
Magnesium	Mg	0.3	Soil
Phosphorus	P	0.2	Soil
Sulfur	S	0.1	Soil

## Where Do Trees Get Nutrients From?

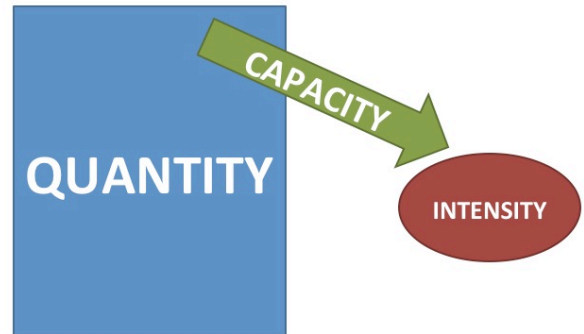
Element	Source	Controlling Process	Plant Available Form
<b>N</b>	Soil OM	Biological	$\text{NH}_4^+$ , $\text{NO}_3^-$
<b>P</b>	Soil OM Ca, Fe, Al-Phosphates	Biological & Chemical	$\text{H}_2\text{PO}_4^-$
<b>K</b>	Primary & Secondary Minerals	Chemical	$\text{K}^+$

N can be controlled by managing organic matter (leaving tops) and by fertilizer application. N fertilizer responses are short-lived (8 years).

P can be controlled by managing soil pH (not done in forestry) and by fertilizer application. P fertilizer responses are long-lived (2 rotations).

K can be controlled through fertilizer application.

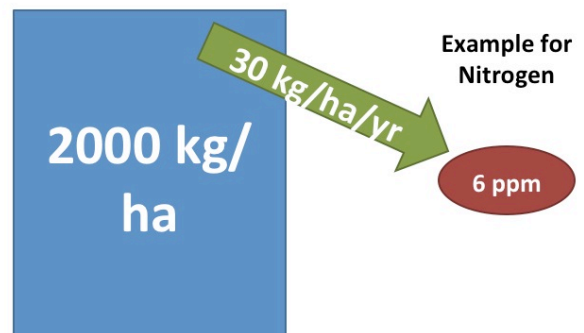
## How Do Nutrients Get to the Tree?



## Nutrient Supply: QCI Framework

- Quantity: Total Amount Present
- Capacity: Rate of Supply
- Intensity: Amount Available
- Even if there is a large quantity of an element present in the soil it does not mean that the plants can get it!

## Nutrient Supply: QCI Framework



## Nitrogen Cycling

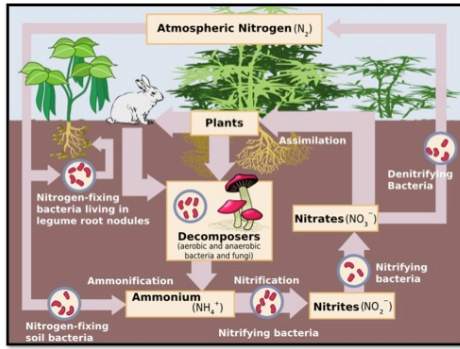


Figure source: [http://commons.wikimedia.org/wiki/File:Nitrogen\\_Cycle.svg](http://commons.wikimedia.org/wiki/File:Nitrogen_Cycle.svg)

## Nitrogen Cycling

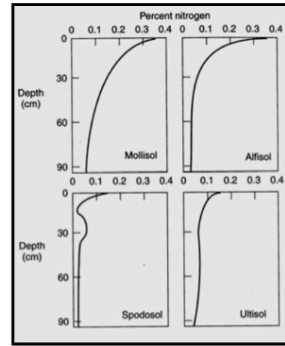


Figure source: <http://upload.wikimedia.org/wikipedia/en/5/5c/SoilNitrogen.jpg>

## Nitrogen Cycling

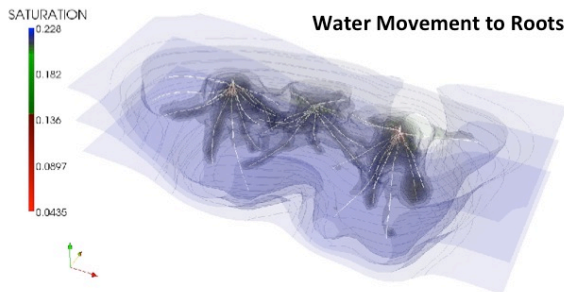
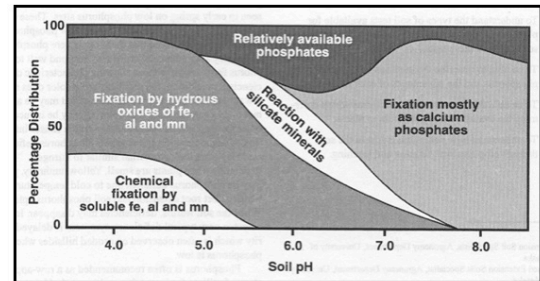


Figure source: <http://www.ufz.de/index.php?en=13976>

## Phosphorus Cycling



Reproduced from: Brady, N. C., & Weil, R. R. (2010). *Elements of the nature and properties of soils* (p. 383). Pearson Prentice Hall.

## Phosphorus Cycling

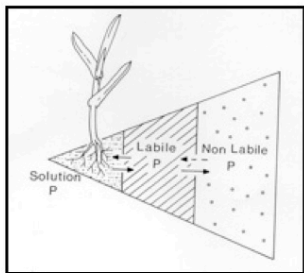
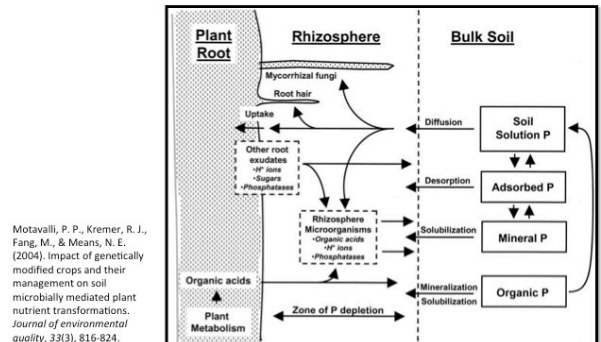


Figure source: Menzies, N., & Lucia, S. (2009). The science of phosphorus nutrition: Forms in the soil, plant uptake, and plant response. *Grains Research & Development Corporation Update Papers*, 18.

## Phosphorus Cycling



Motavalli, P. P., Kremer, R. J., Fang, M., & Means, N. E. (2004). Impact of genetically modified crops and their management on soil microbially mediated plant nutrient transformations. *Journal of environmental quality*, 33(3), 816-824.

# Phosphorus Cycling

Loblolly with abundant ectomycorrhizae



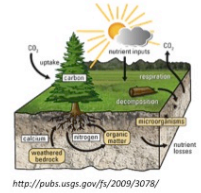
Loblolly with normal ectomycorrhizae



Photos from: Cordell, C.E.; Anderson, R.L.; Hoffard, W.H.; Landis, T.D.; Smith, R.S. Jr.; Toko, H.V. Forest Nursery Pests. U.S. Department of Agriculture, Forest Service. Agriculture Handbook No. 680. December 1989. 184 p.

# Assessing Nutrient Cycling & Limitations

- Chlorosis
- Foliar concentration
- Region-specific soil data models
- Leaf Area Index



<http://pubs.usgs.gov/jf/2009/3078/>

# Assessing Nutrient Limitations

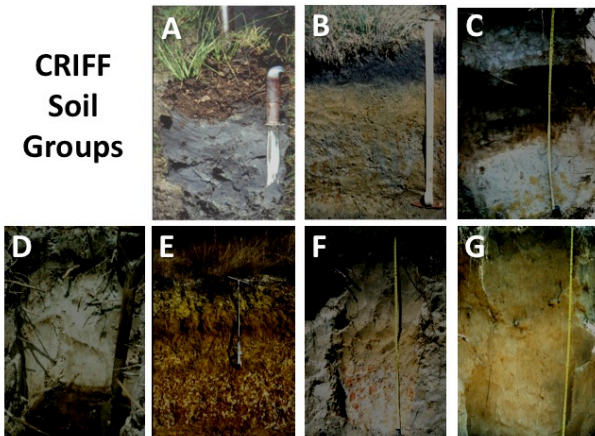


# Critical Levels of Foliar Nutrients

Species	Nitrogen	Phosphorus
Loblolly pine	1.1 – 1.2%	0.11 – 0.12%
Slash pine	0.9 – 1.1%	0.09 – 0.10%
Douglas-fir	1.2 – 1.4%	0.12 – 0.15%



# CRIFF Soil Groups

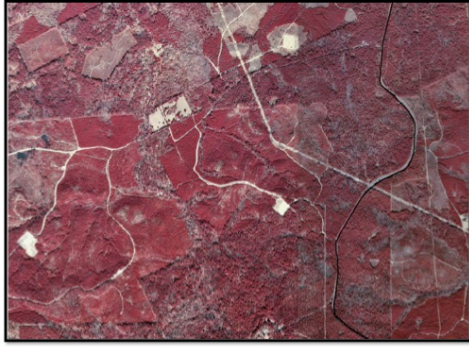


Slide provided by Tom Fox

CRIFF A: Severely P deficient soils tend to occur in a band near the coast



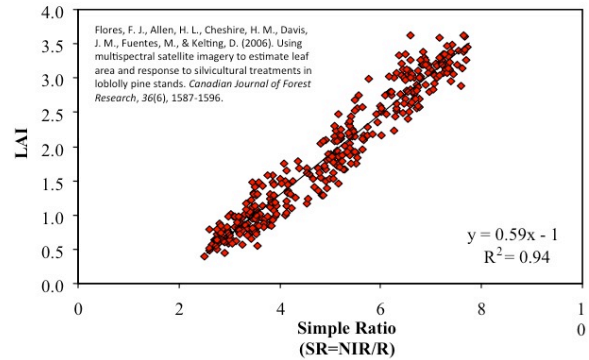
## LandSat Image of East Texas



Flores, F. J., Allen, H. L., Cheshire, H. M., Davis, J. M., Fuentes, M., & Kelting, D. (2006). Using multispectral satellite imagery to estimate leaf area and response to silvicultural treatments in loblolly pine stands. *Canadian Journal of Forest Research*, 36(6), 1587-1596.

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## Remote Sensing Estimation of LAI Using Landsat Imagery



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## Estimated Stand Peak LAI



**Peak LAI**  
1.3 - 2.3  
2.3 - 3.3  
> 3.3

Flores, F. J., Allen, H. L., Cheshire, H. M., Davis, J. M., Fuentes, M., & Kelting, D. (2006). Using multispectral satellite imagery to estimate leaf area and response to silvicultural treatments in loblolly pine stands. *Canadian Journal of Forest Research*, 36(6), 1587-1596.

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## Objective 2 Review

- Nutrient cycling varies among nutrients
- Nutrient cycling depends on soil texture
- Most of the nutrients in a soil are not available to trees
- Assessing nutrient limitations and availability requires an understanding of nutrient cycling

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## Pop Quiz 3.1

Compared to now, climate change is projected to have what effect on forest nutrition in the SHORT TERM?

- Increasing nutrient availability.
- Decreasing nutrient availability.
- No change in nutrient availability.
- We do not know much yet.

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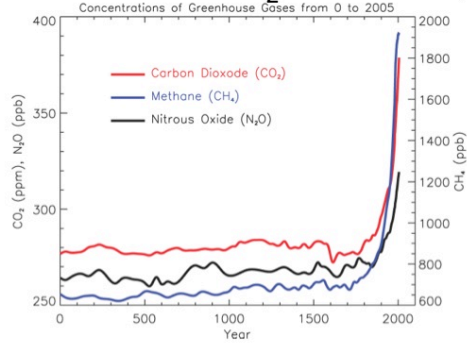
## Pop Quiz 3.2

Compared to now, climate change is projected to have what effect on forest nutrition in the LONG TERM?

- Increasing nutrient availability.
- Decreasing nutrient availability.
- No change in nutrient availability.
- We do not know much yet.

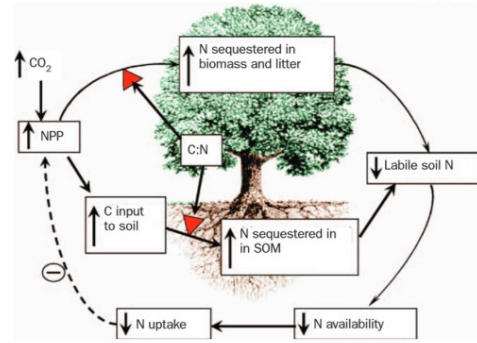
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# Climate and CO<sub>2</sub> Availability



Source: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., ... & Miller, H. L. (2007). IPCC, 2007: Climate change 2007: The physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. SO Solomon (Ed.).

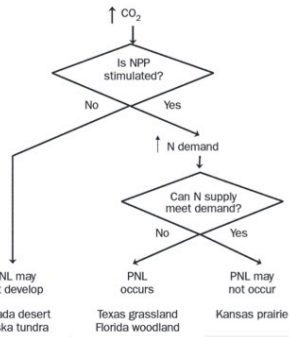
# Climate and Nitrogen Supply



Luo, Y., Su, B. O., Currie, W. S., Dukes, J. S., Finzi, A., Hartwig, U., ... & Field, C. B. (2004). Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. *Bioscience*, 54(8), 731-739.

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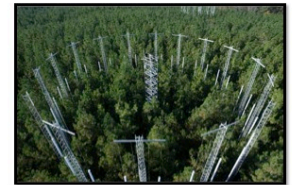
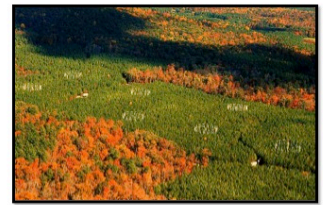


**PNL: Progressive Nitrogen Limitation**

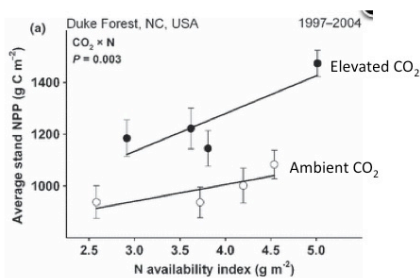
Examples: Nevada desert, Alaska tundra, Texas grassland, Florida woodland, Kansas prairie

# Duke FACE Site

- Loblolly pine plantation
- 4 control plots
- 4 +200 ppm CO<sub>2</sub> plots
- Fertilizer treatments
- 1996 - 2011

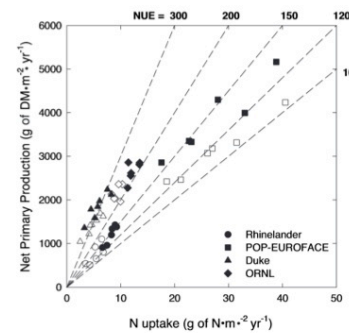


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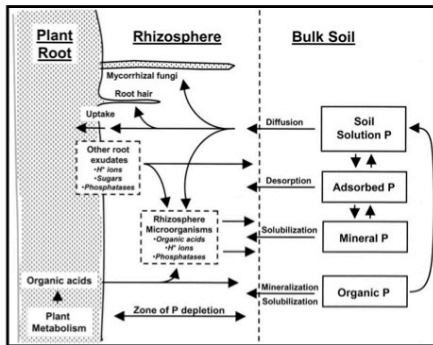
McCarthy, H. R., Oren, R., Johnsen, K. H., Gallet-Budynek, A., Pritchard, S. G., Cook, C. W., ... & Finzi, A. C. (2010). Re-assessment of plant carbon dynamics at the Duke free-air CO<sub>2</sub> enrichment site: interactions of atmospheric [CO<sub>2</sub>] with nitrogen and water availability over stand development. *New Phytologist*, 185(2), 514-528.

# Climate and Nitrogen Supply



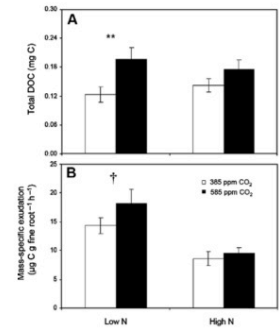
Finzi, A. C., Norby, R. J., Calafapietra, C., Gallet-Budynek, A., Gielen, B., Holmes, W. E., ... & Ceulemans, R. (2007). Increases in nitrogen uptake rather than nitrogen-use efficiency support higher rates of temperate forest productivity under elevated CO<sub>2</sub>. *Proceedings of the National Academy of Sciences*, 104(35), 14014-14019.

## Climate and Phosphorus Supply



Motavalli, P. P., Kremer, R. J., Fang, M., & Means, N. E. (2004). Impact of genetically modified crops and their management on soil microbially mediated plant nutrient transformations. *Journal of environmental quality*, 33(3), 816-824.

## Climate and Phosphorus Supply



Phillips, R. P., Bernhardt, E. S., & Schlesinger, W. H. (2009). Elevated CO<sub>2</sub> increases root exudation from loblolly pine (*Pinus taeda*) seedlings as an N-mediated response. *Tree physiology*, 29(12), 1513-1523.

## Longer Term



## Objective 3 Review

- In the short-term trees are able to increase rates of N and P cycling due to carbon fertilization affect, preventing increased nutrient limitations
- This will be confounded with potential changes in temperature and water availability
- Longer-term impacts are still unknown

## Synthesis

- What limits growth in southern pine forests?
  - Nitrogen and Phosphorus
- How do nutrients cycle in forests?
  - It depends on the nutrient
- Will climate change impact forest nutrition?
  - Perhaps not in the short-term, but longer-term effects are unknown

## Questions?

