Increasing Efficiency of Nitrogen Fertilization in Loblolly Pine Plantations

Thomas Fox
and
PINEMAP Team
NSF Center for Advanced Forest Systems
Industry/University Research Coops

Pine Plantation Research and Decision Support Tool Rollout
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PINEMAP

USDA United States Department of Agriculture National Institute of Food and Agriculture

Overall Goals

To create, synthesize, and disseminate the knowledge that enables southern forest landowners:

- to harness pine forest productivity to mitigate atmospheric CO_2,
- to more efficiently utilize nitrogen and other fertilizer inputs,
- and to adapt their forest management approaches to increase resilience in the face of changing climate.

PINEMAP

Long-Term Outcome of Program
Reduce the use of energy, *nitrogen fertilizer*, and water by 10% and increase carbon sequestration by 15% through resilient forest production systems under changing climate by 2030

Provide New Management Methods

- ***Mitigation*** – Reduce greenhouse gas emissions in forestry and maximize carbon sequestration
- ***Adaptation*** – Maximize resiliency and reduce impact of climate change on productivity of forest systems and reduce carbon, nitrogen and water footprints under changing climate
- ***Climate Education and Extension***- Increase number of scientists, educators and extension professionals with skills to address climate change in forestry

PINEMAP

Forest Fertilization

Growth Response to P Fertilization on A Group Soils

Age 20 Loblolly Pine Plantations in Coastal Georgia

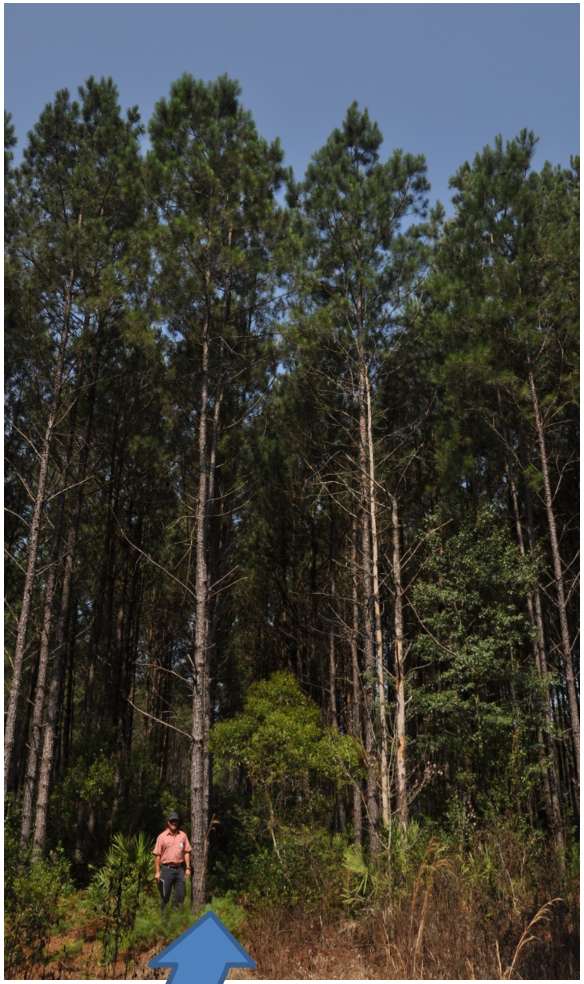
0 kg/ha P at Planting
Poorly Drained Clay Soil

50 kg/ha P at Planting
Poorly Drained Clay Soil

Increase Carbon Sequestration

11 Year Fertilizer Response at 184202 in Southeast Georgia

Control



Fertilized

Increase Carbon Sequestration

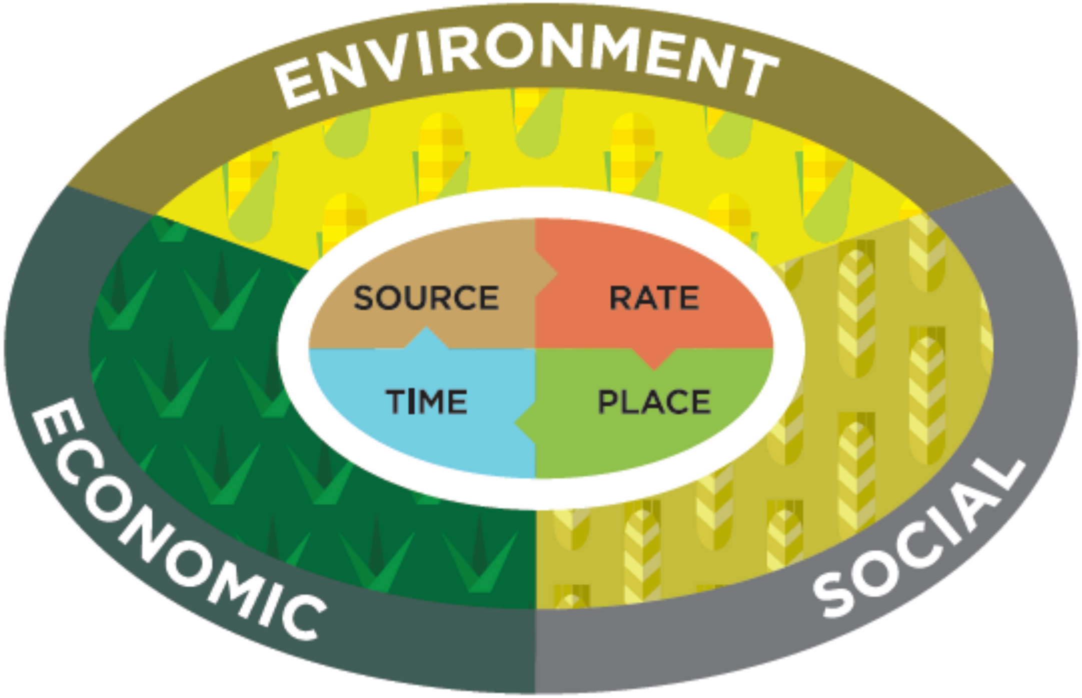
4R's of Fertilization to Increase Efficiency

Right Place

Right Rate

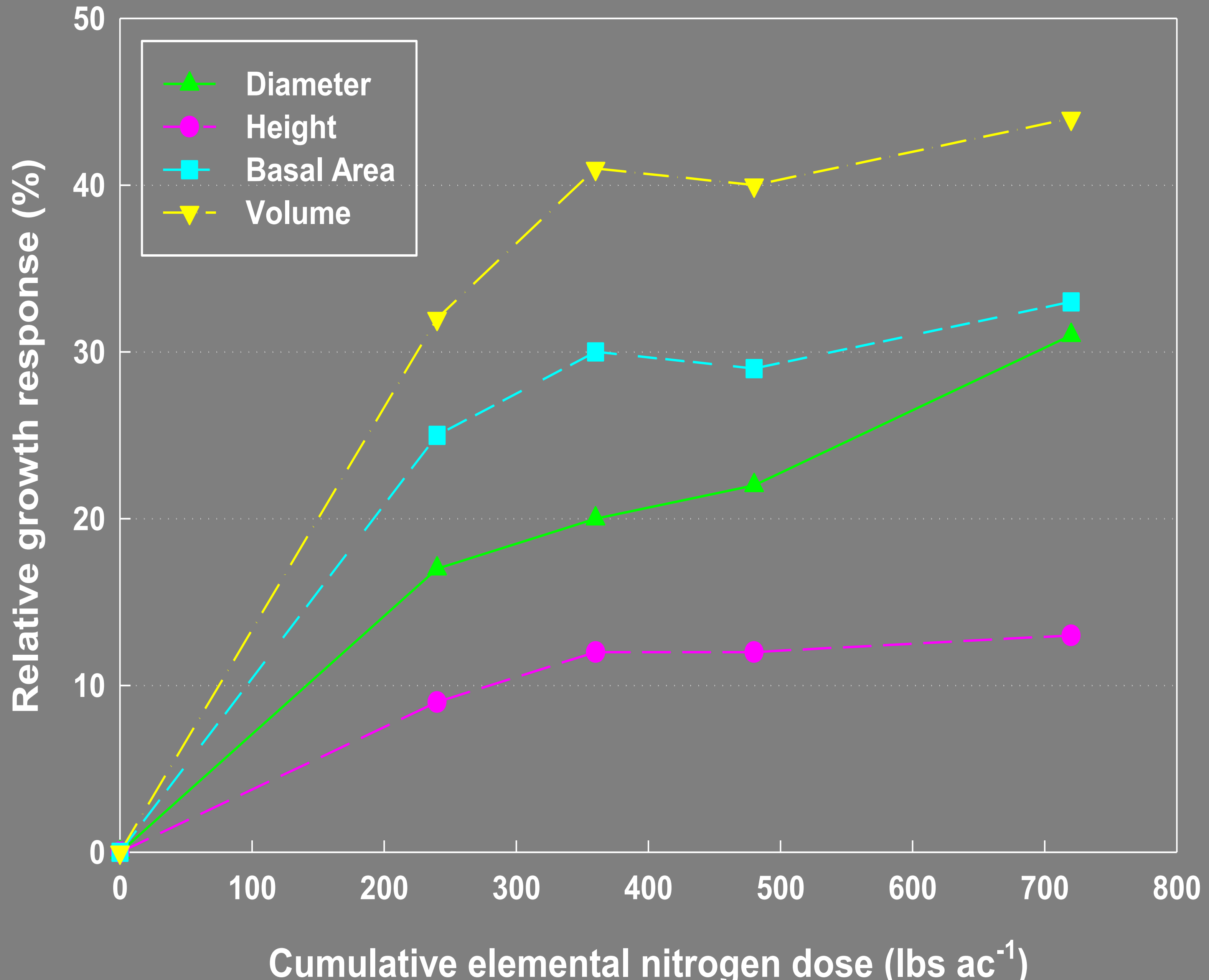
Right Time

Right Source

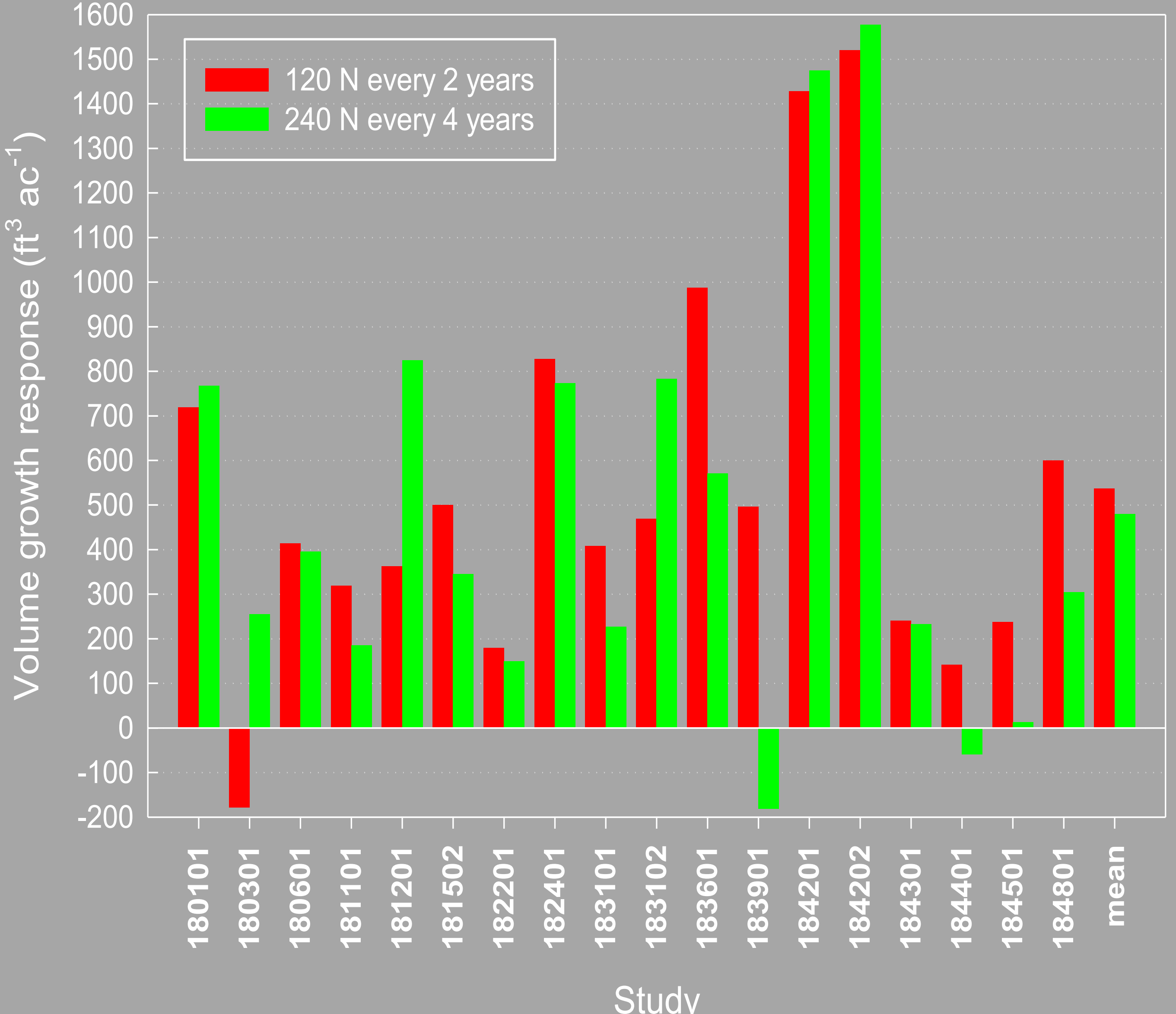


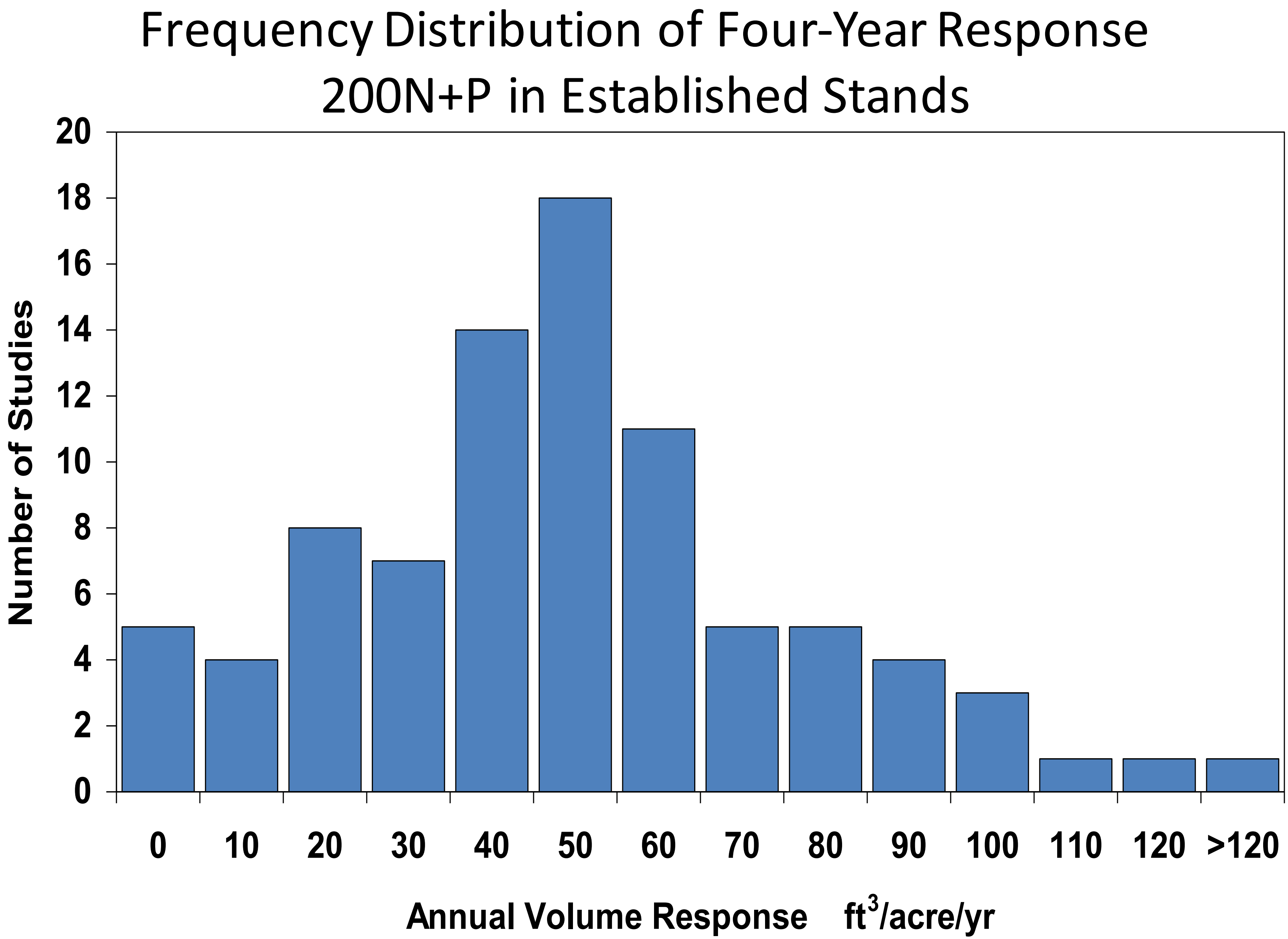

FERTILIZATION

Growth Response of Juvenile Loblolly Pine to Fertilization

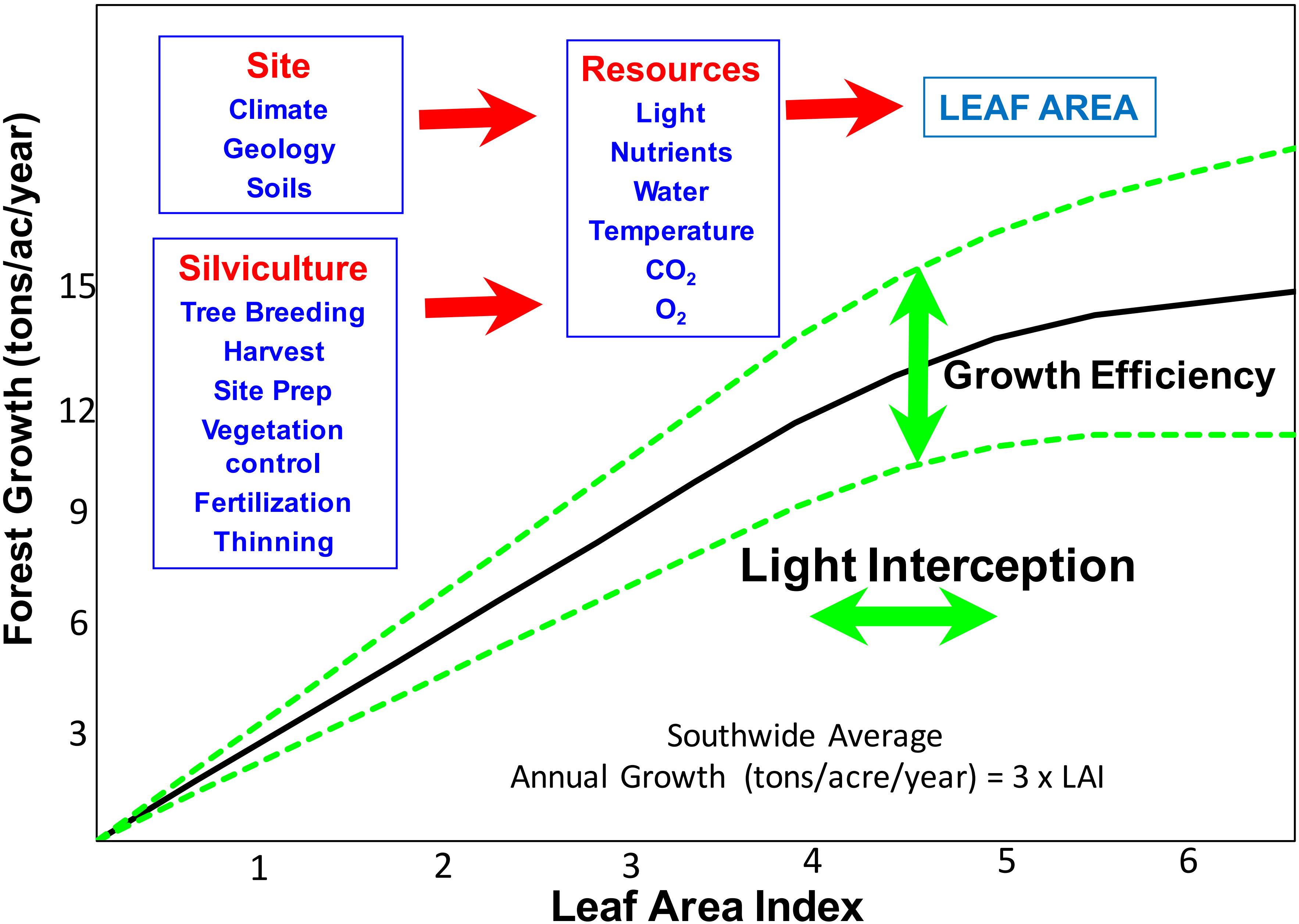


Frequency effect at 8 years
Cumulative dose 480 lbs ac^{-1} elemental N




Frequency Distribution of Four-Year Response
200N+P in Established Stands
Number of Studies
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100
110
120
>120
Annual Volume Response ft3/acre/yr

Silviculture - Site Resources - Leaf Area



Efficiency *represents how "**healthy**" are the needles*

1 ton/ac/yr per 1 LAI

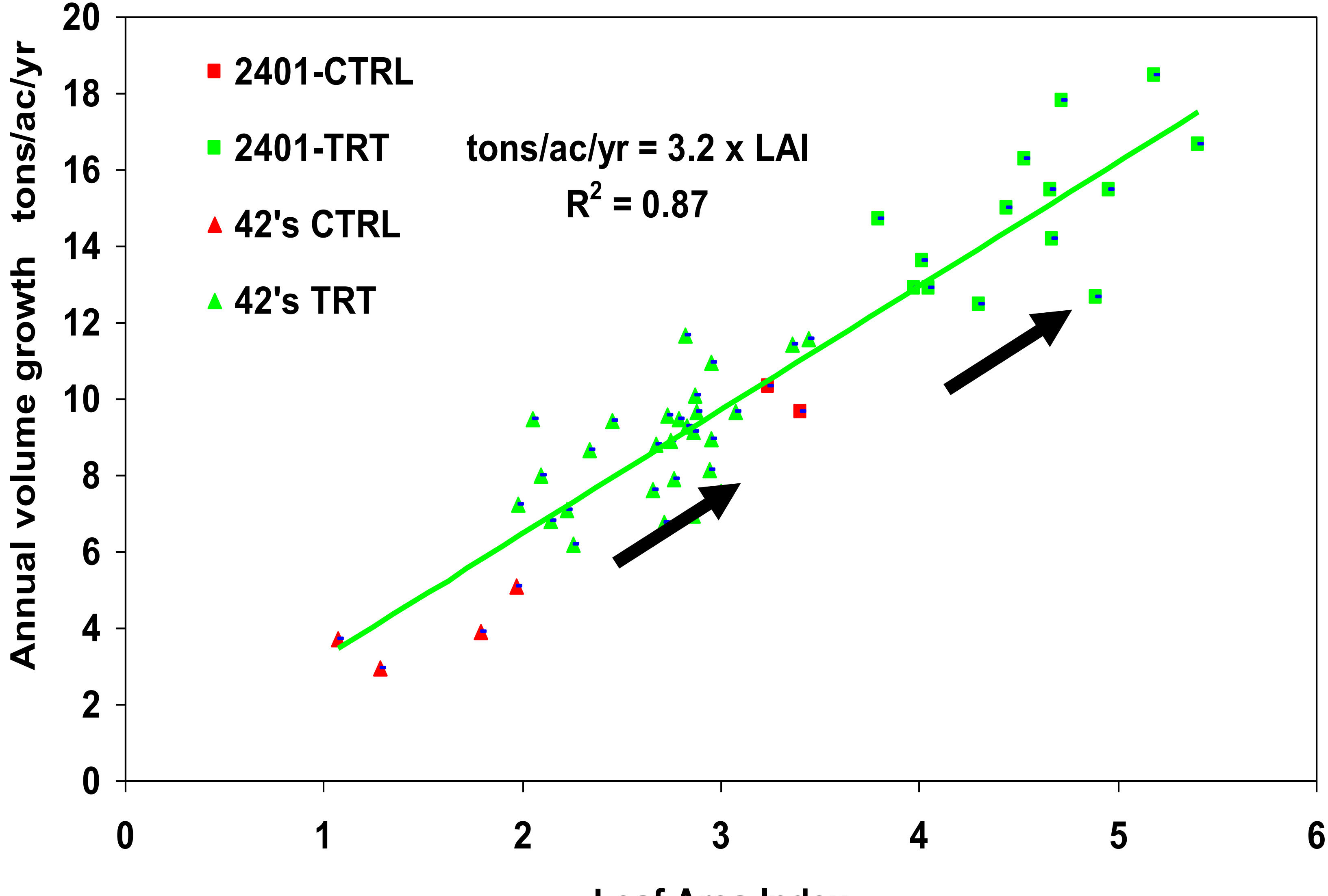
3 ton/ac/yr per 1 LAI

Nutrient Deficient

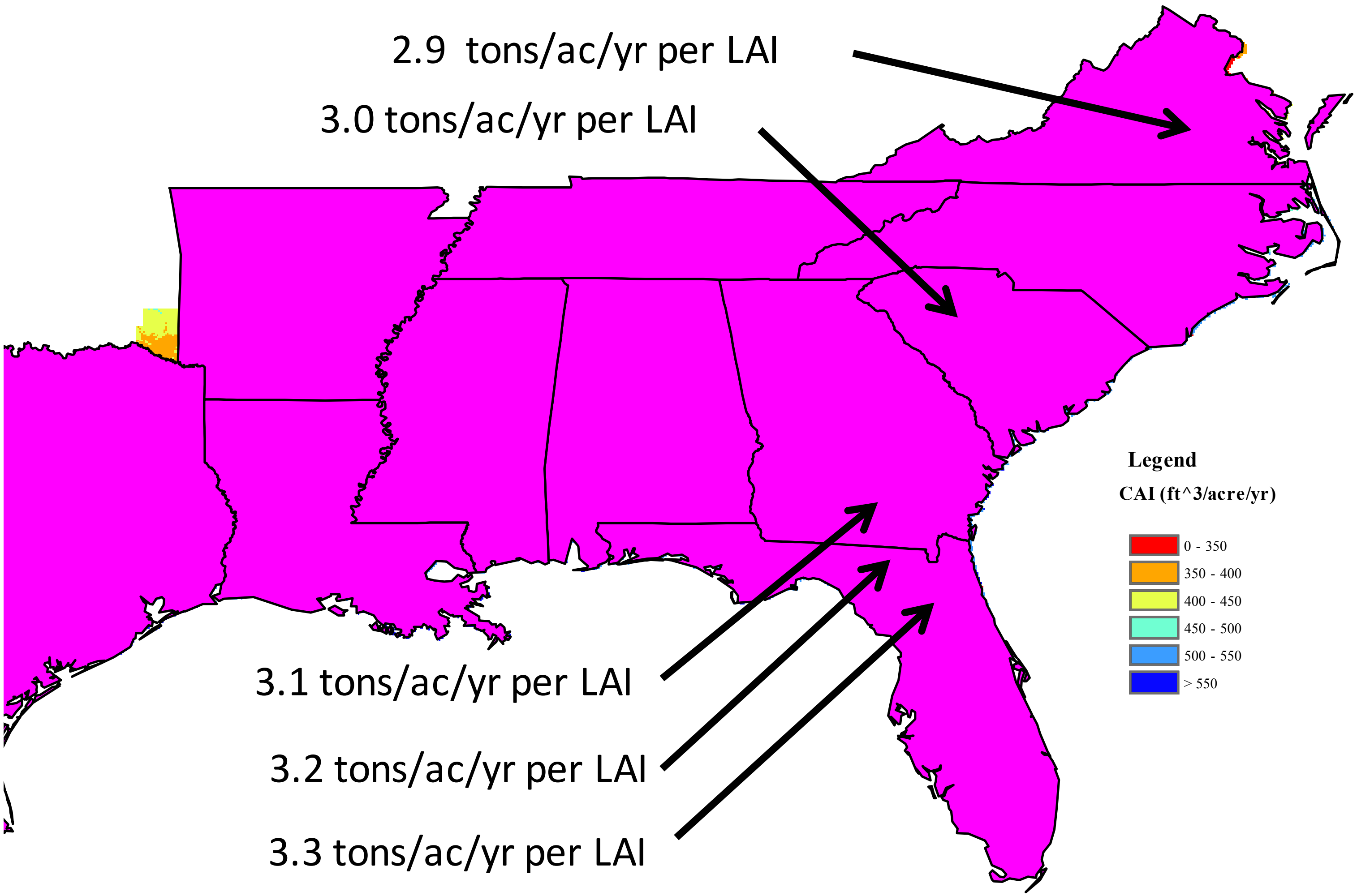
Fertilized

NUTRITION

Annual Volume Growth – LAI Relationship
RW18 Studies in Florida and Georgia

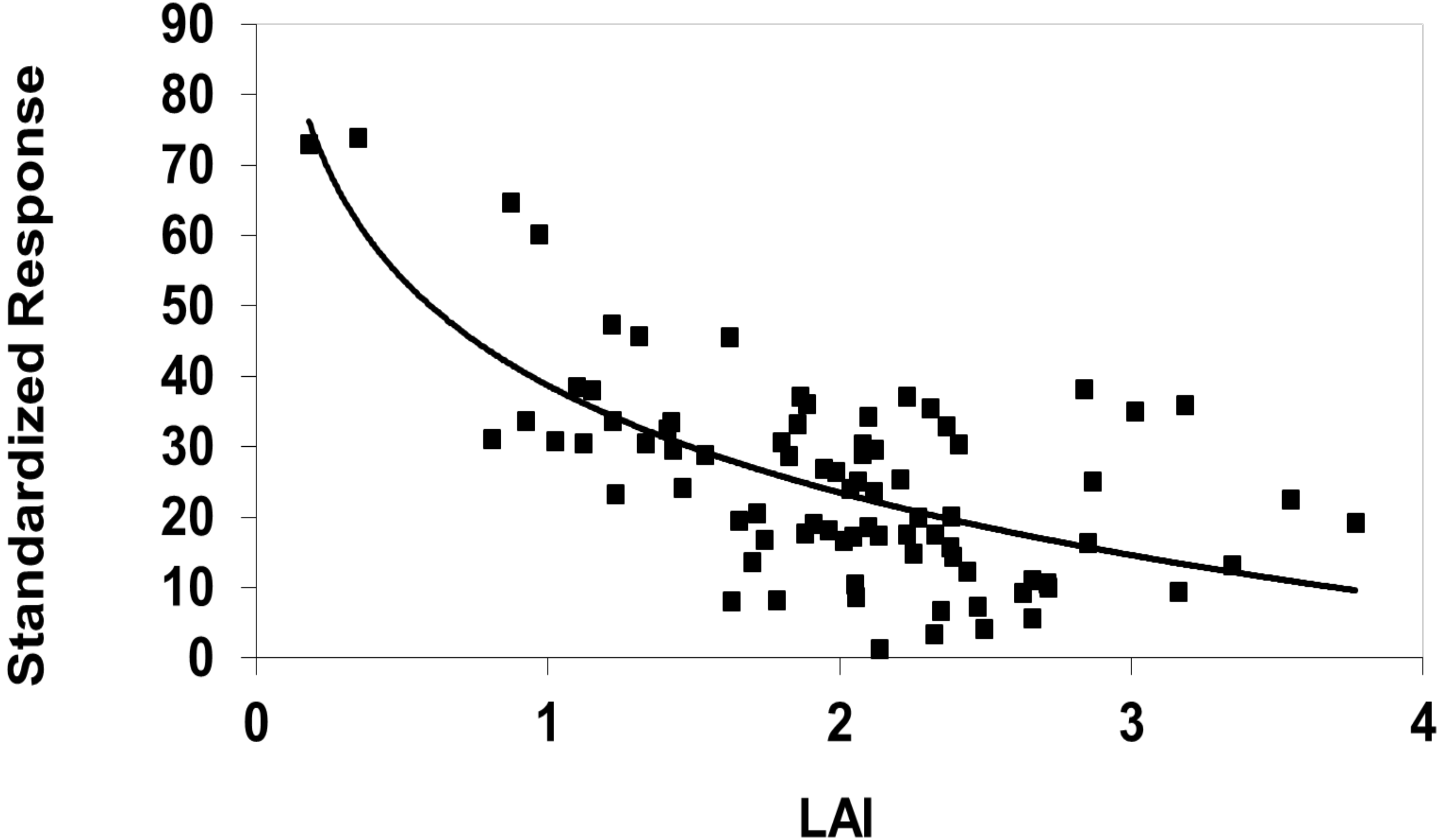


Potential Current Annual Increment of Loblolly Pine In the South Based on Climate



Elite Genotypes of Loblolly Pine Have Greater Growth Efficiency

LAI Impact On Standardized Fertilizer Response



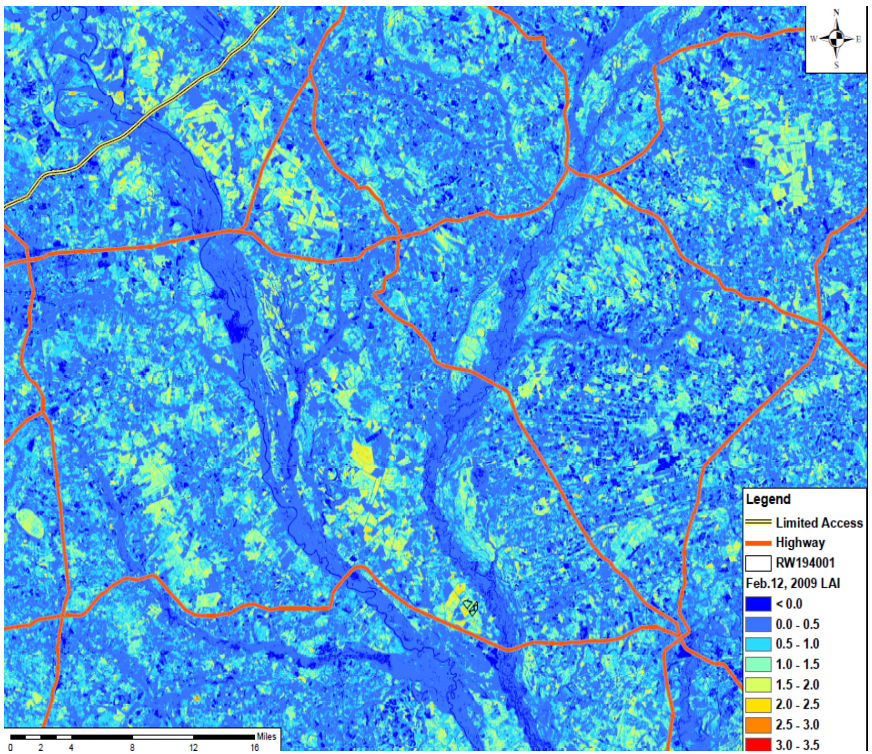
Integrating Technology into Silviculture

Landsat 8 Launched February 11, 2013

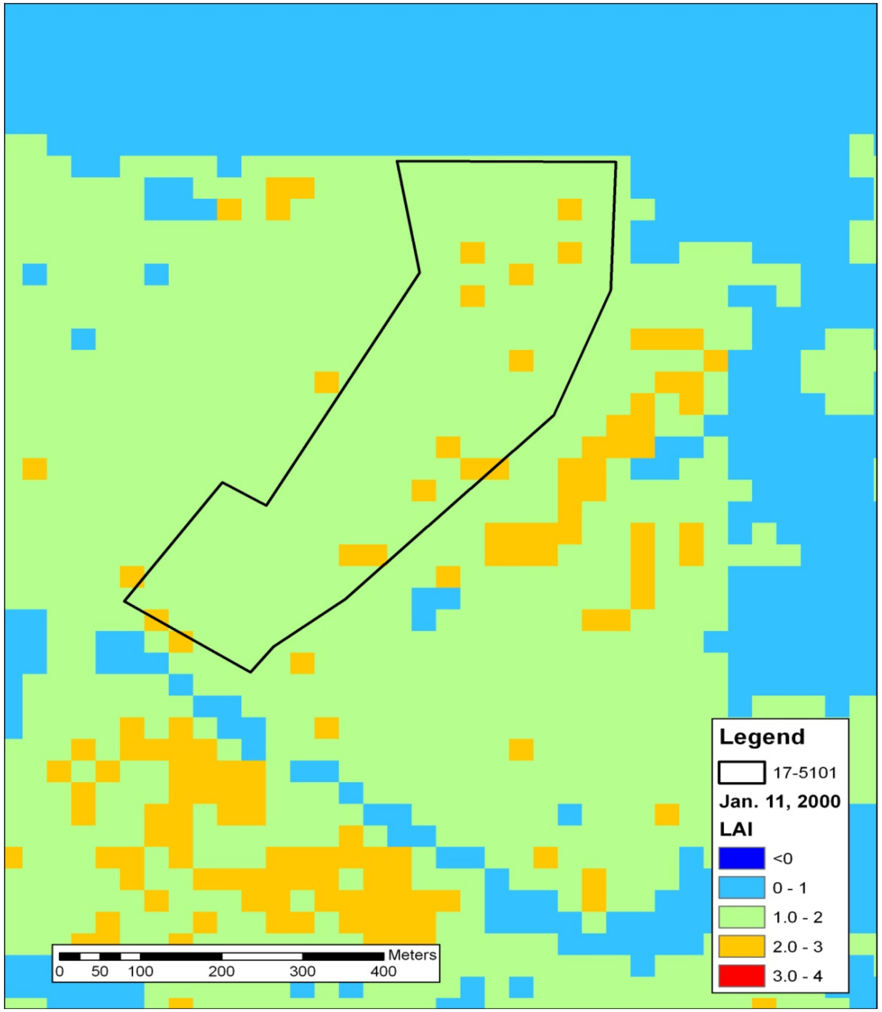
Operational May 30, 2013

FPC LAI Tool March 2014

Winter Leaf Area in South Carolina Derived from Landsat

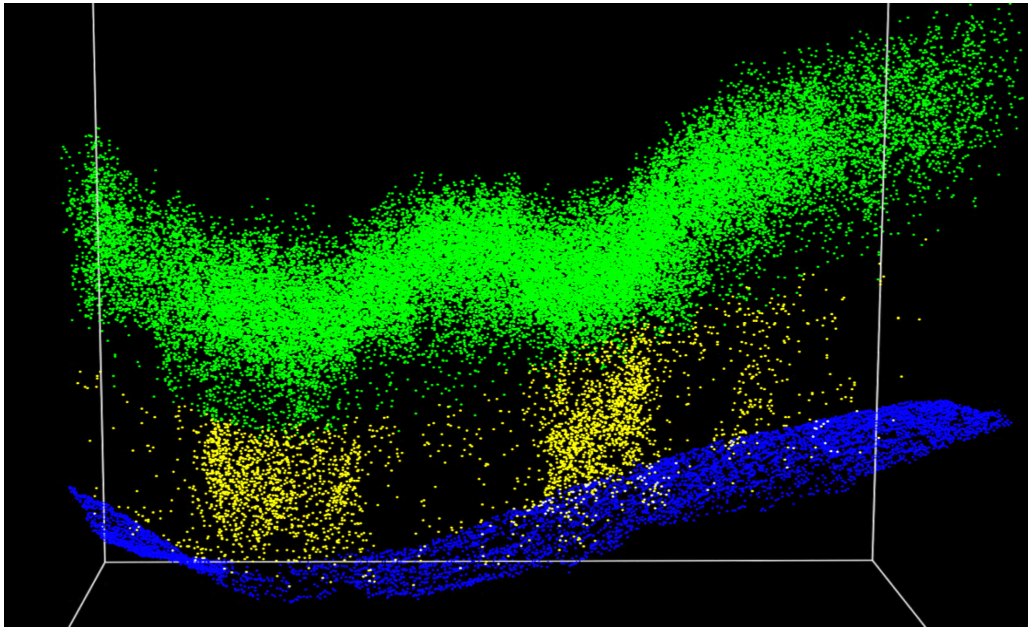


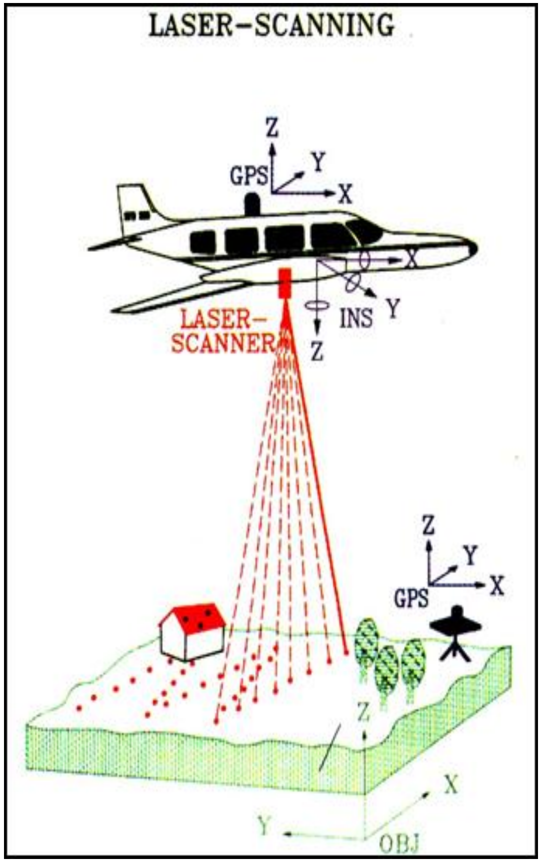
Regional Leaf Area



Individual Stand Leaf Area

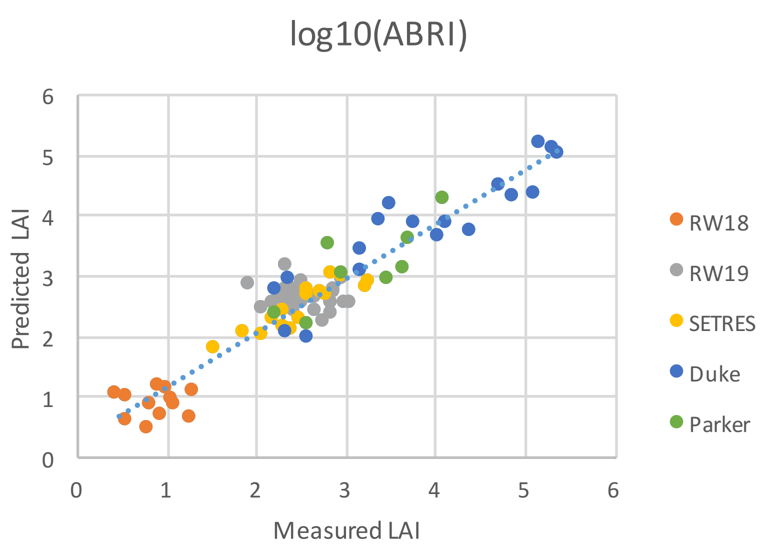
Light Detection and Ranging (LiDAR)



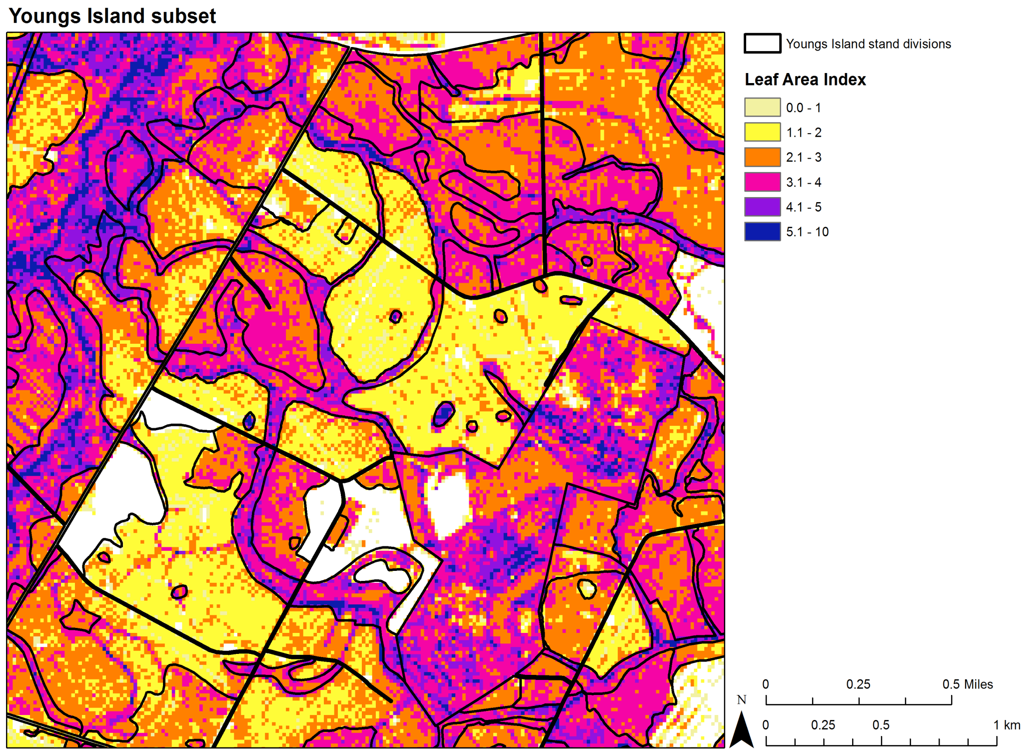


Source: TopScan, Germany

Leaf Area Index (LAI) from LiDAR
Youngs Island, GA



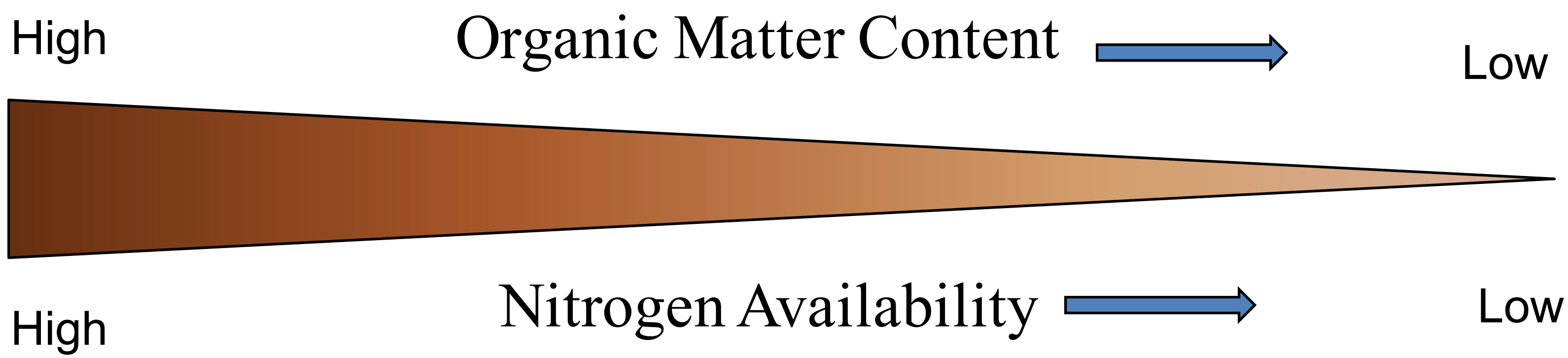
$$ABRI = \frac{\sum R_{>T}}{\sum R_{<T}}$$



Estimated Stand Peak LAI

LAI Class

- 0 - 1.3
- 1.3 - 3.5
- > 3.5



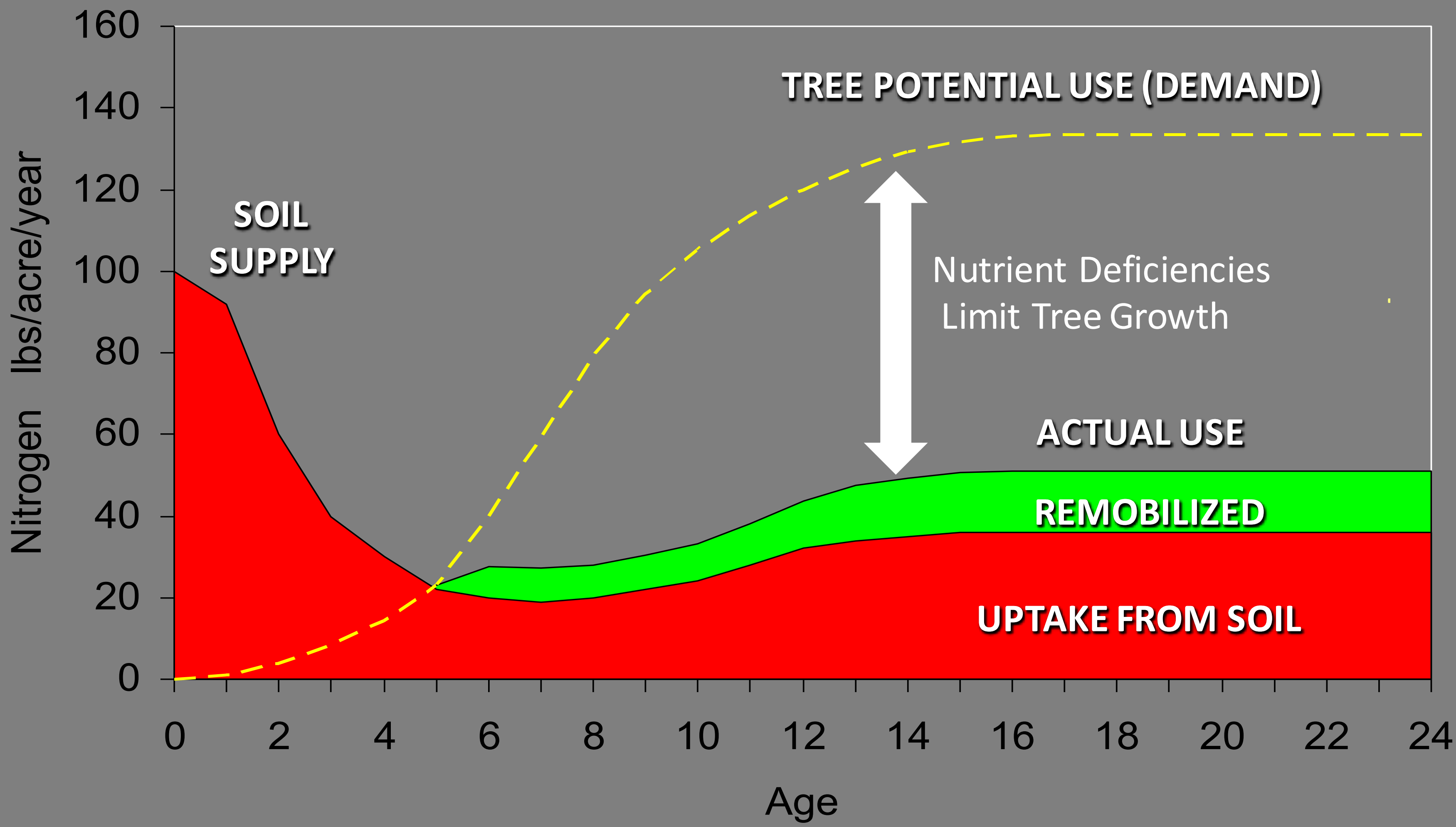
Very Poorly Drained Clay with Umbric (A Group)

Poorly Drained Sandy Clay Loam (B Group)

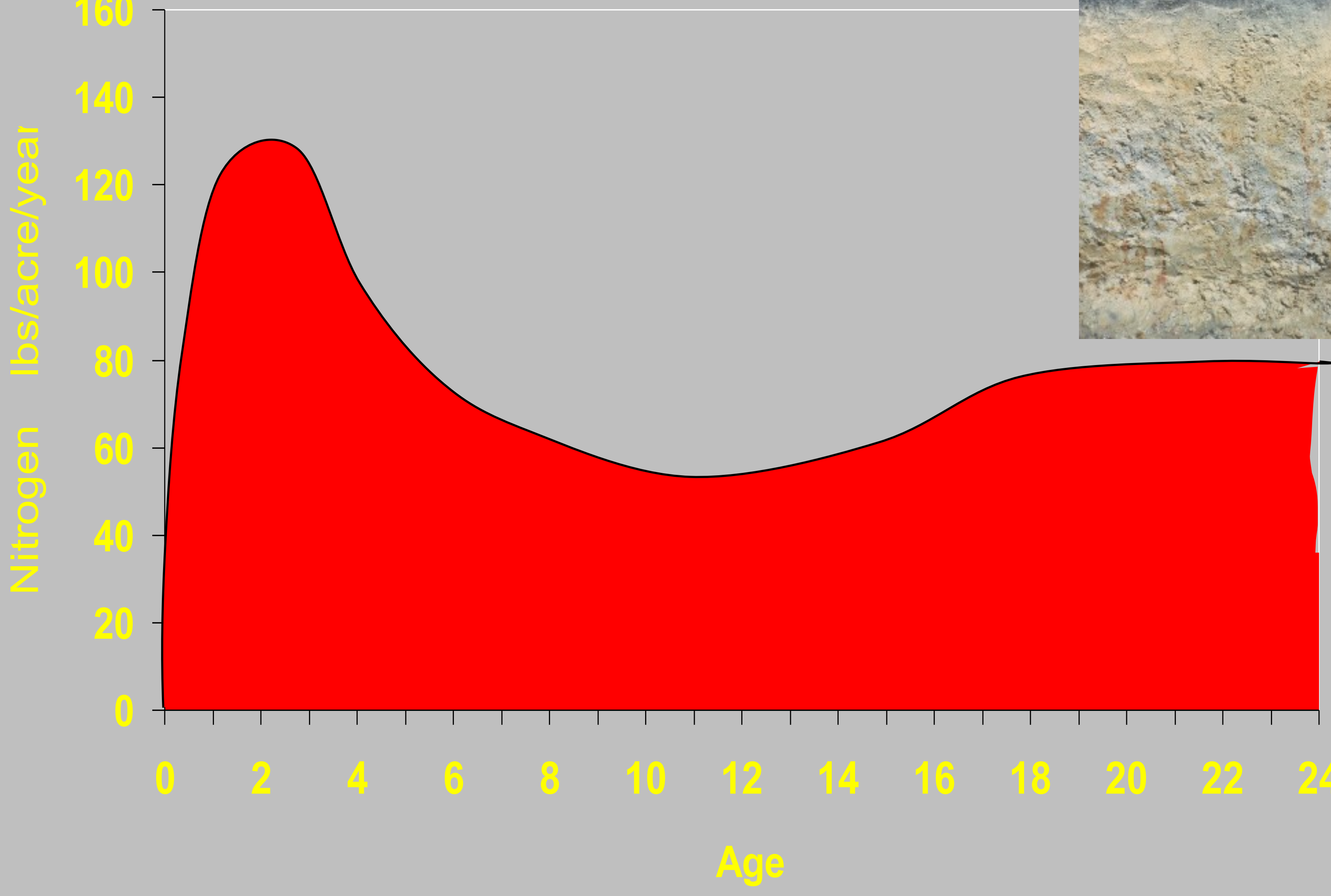
Somewhat Poorly Drained Sandy Clay Loam (B Group)

Poorly Drained Spodic with Sandy Clay Loam (C Group)

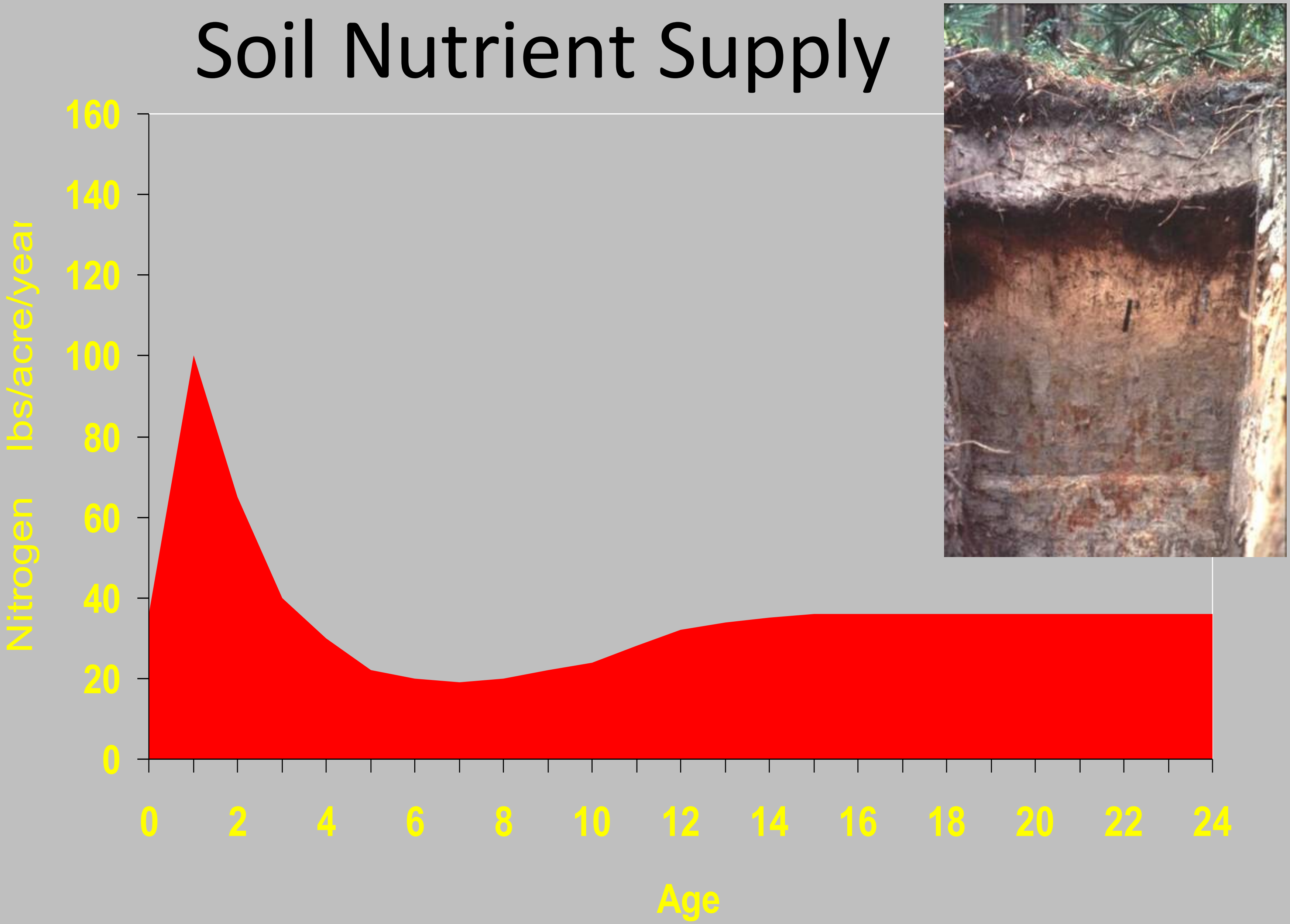
Changes in Nutrient Supply and Demand Through Time in Pine Plantations



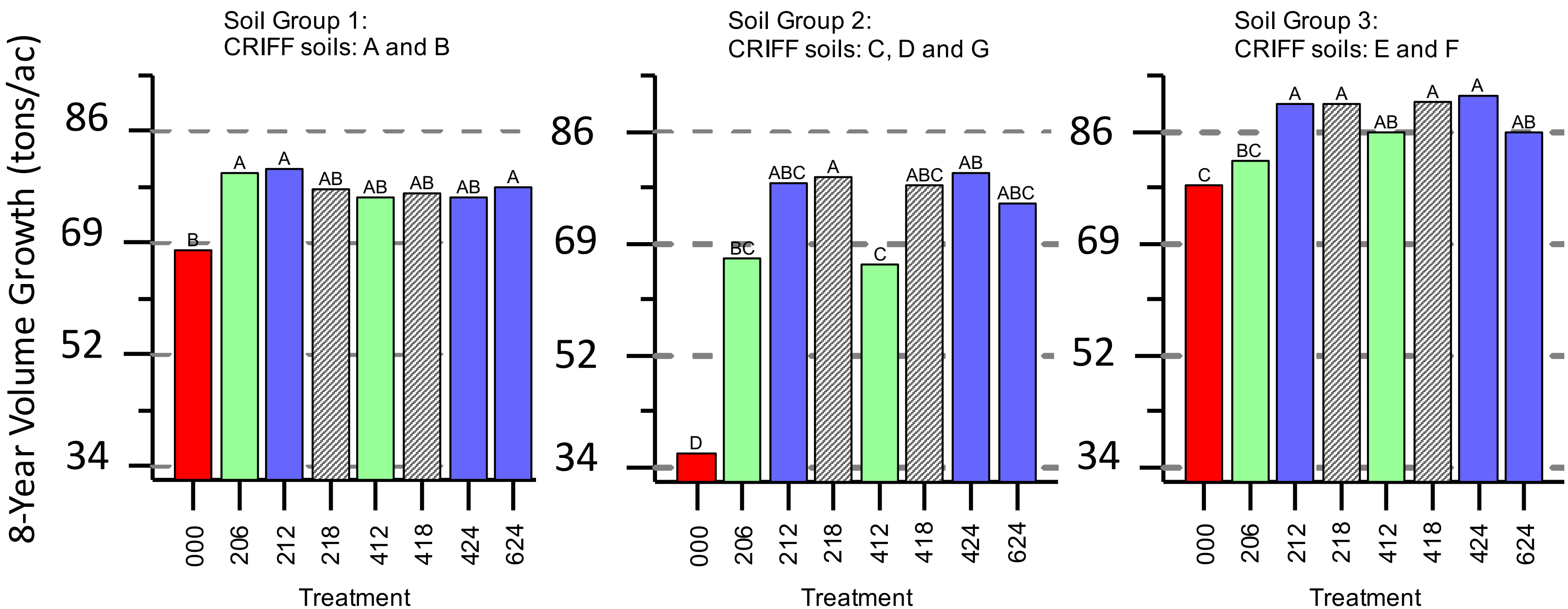
Soil Nutrient Supply



Soil Nutrient Supply



8-Year Volume Growth Response Following Fertilization with N&P Affected by Soil



RW18 Juvenile Stand Fertilization
8 Year Growth Response

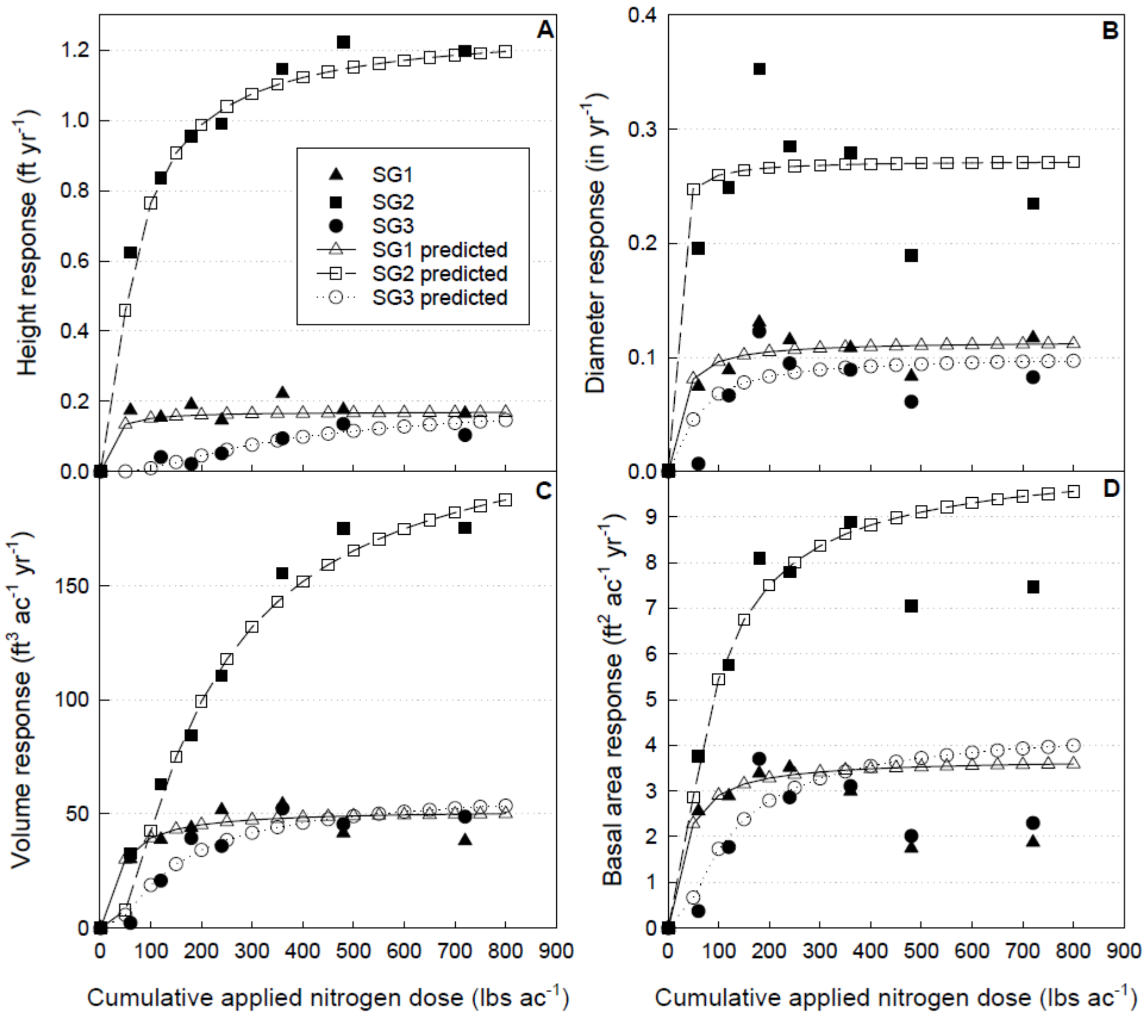
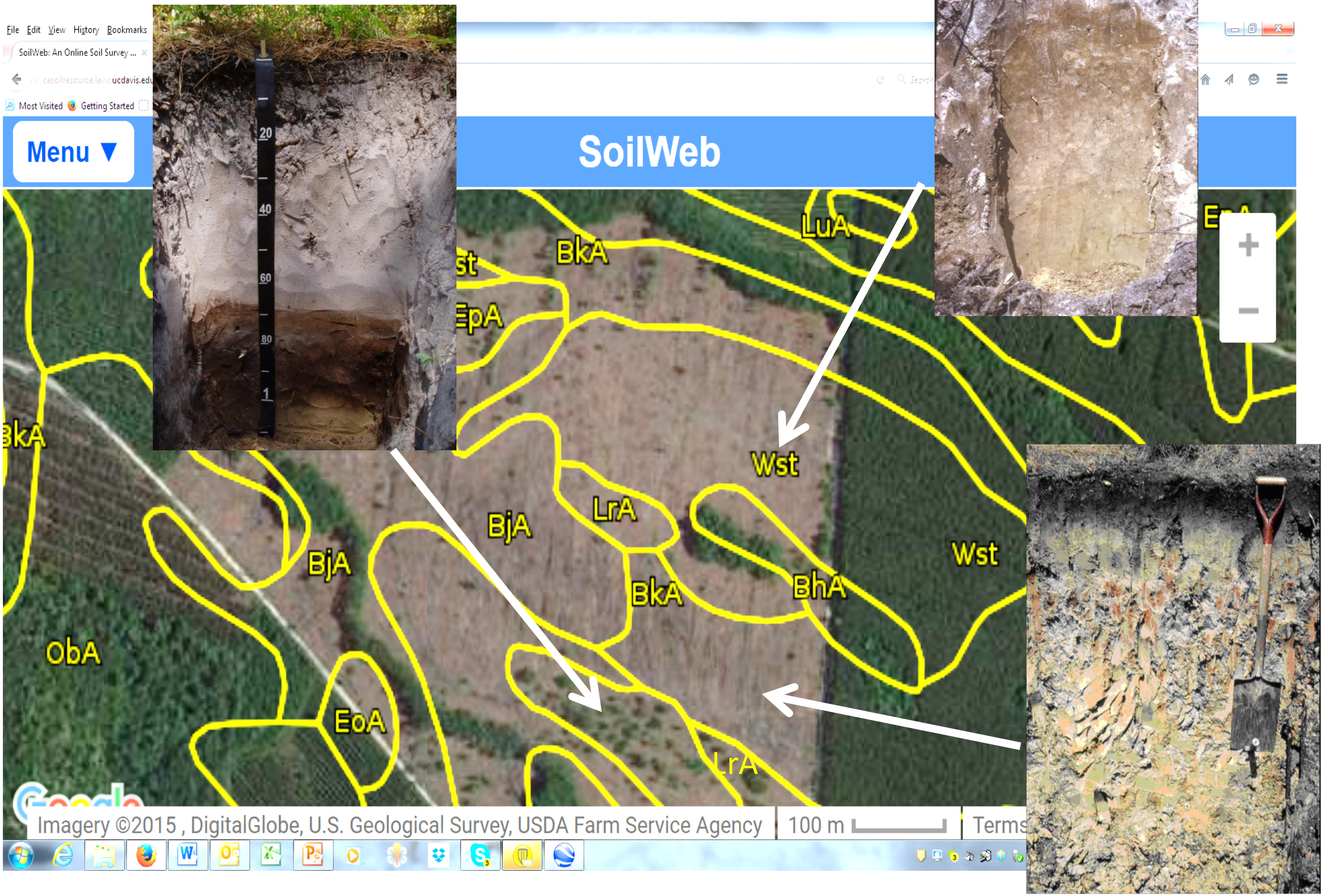


Figure 2.

Land Classification & Soil Mapping



Variation in Performance of Elite Genotypes Due to Silviculture

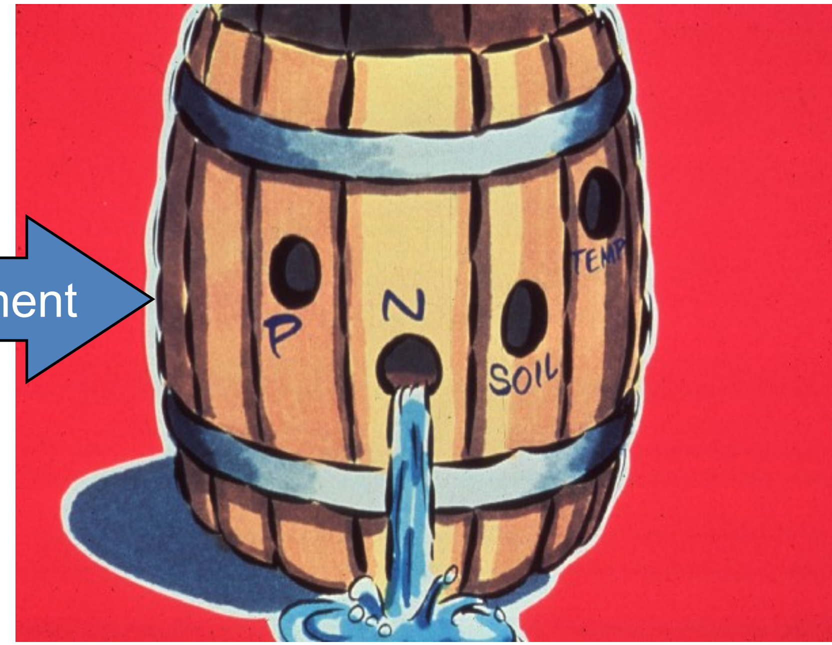
Low Intensity Mgt

High Intensity Mgt

Both Plots Planted With the Same Clone

Genetics Determines the Potential Growth of the Tree

Tree Improvement

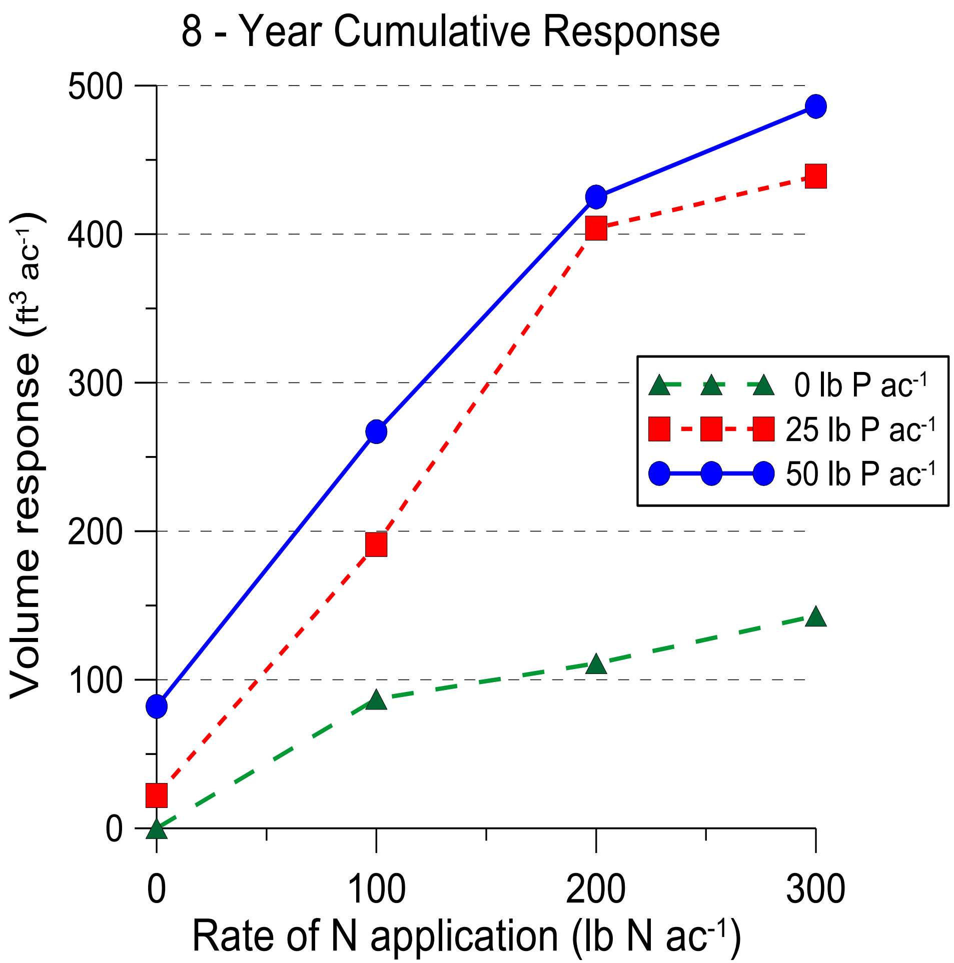


Poor Genotype

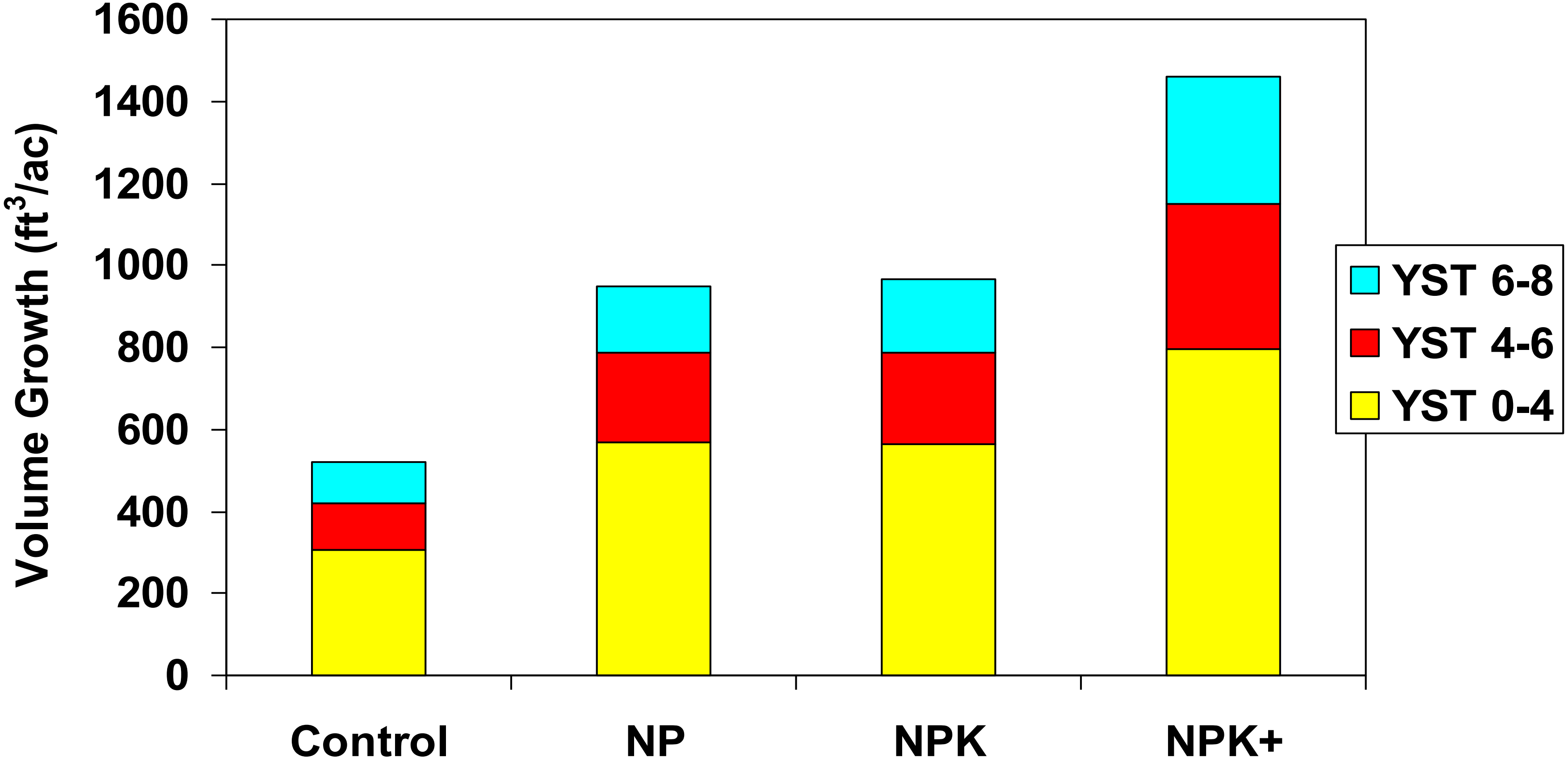
Good Genotype

But Resource Availability
Will Still Limit Growth of Even the Best Genotypes

Midrotation Growth Response Following Fertilization of Loblolly Pine



Micronutrient Response
Volume Growth at RW152603
(Sandy Spodosols – C, D Group)



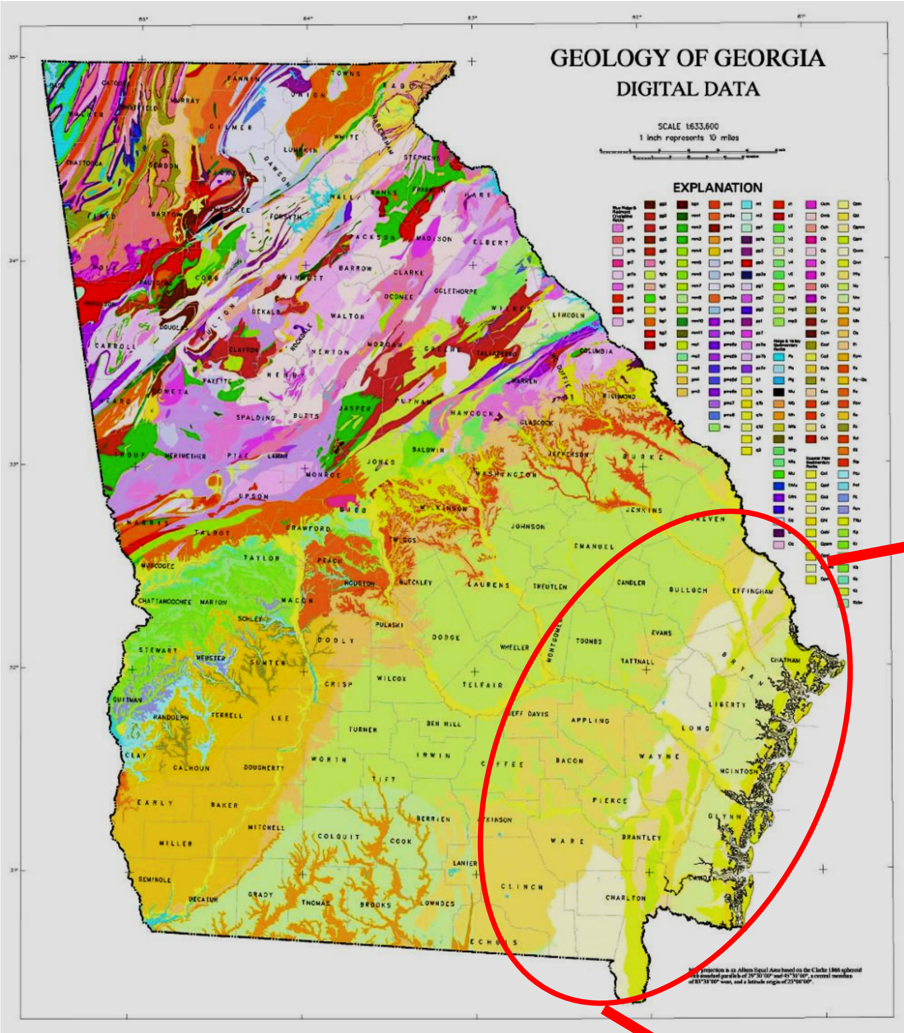
185302 - Four Years after Fertilization
Slash Pine - Florida

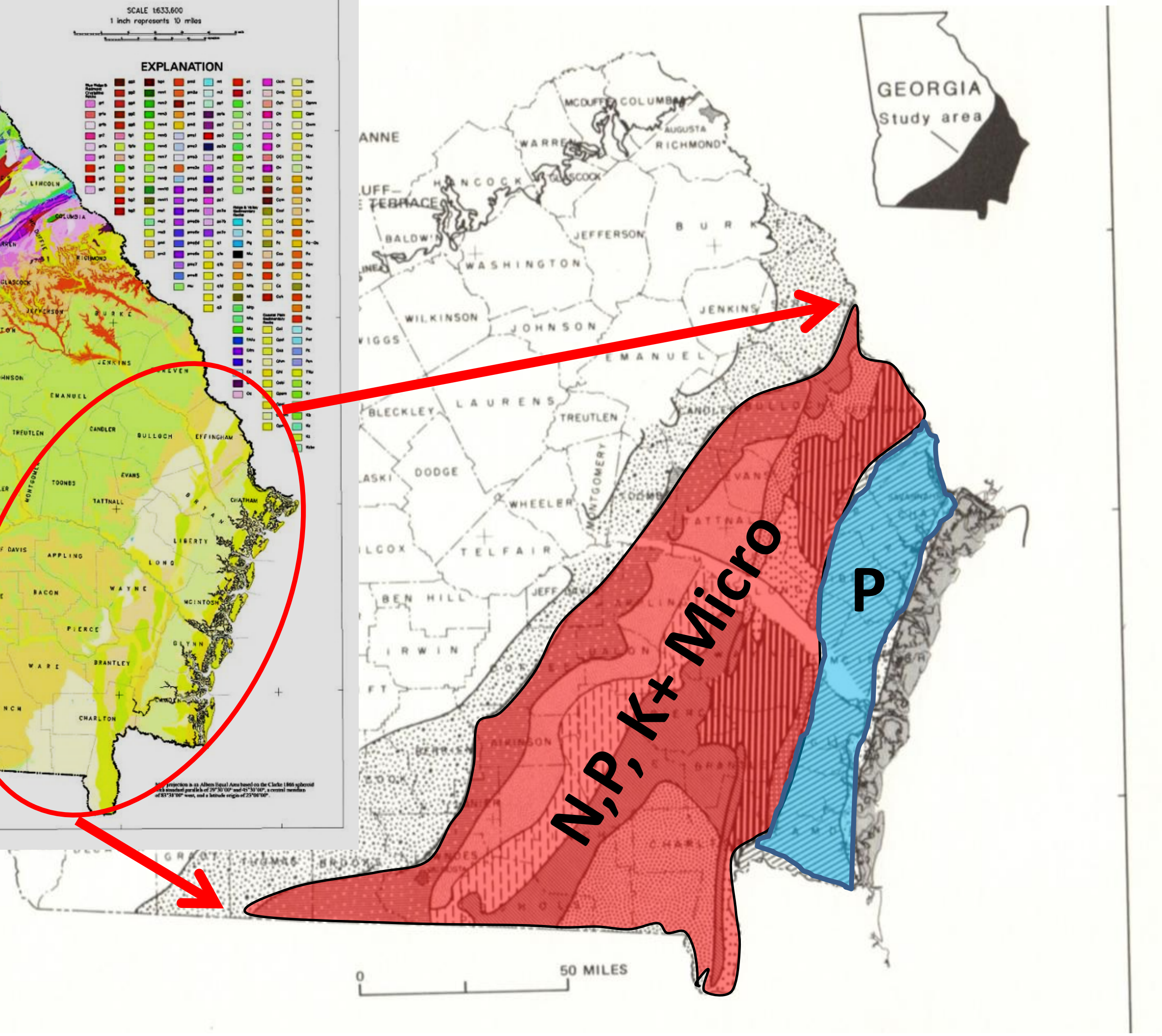
Control

N, P, K, B

Increase Carbon Sequestration

Geology Influences Forest Management



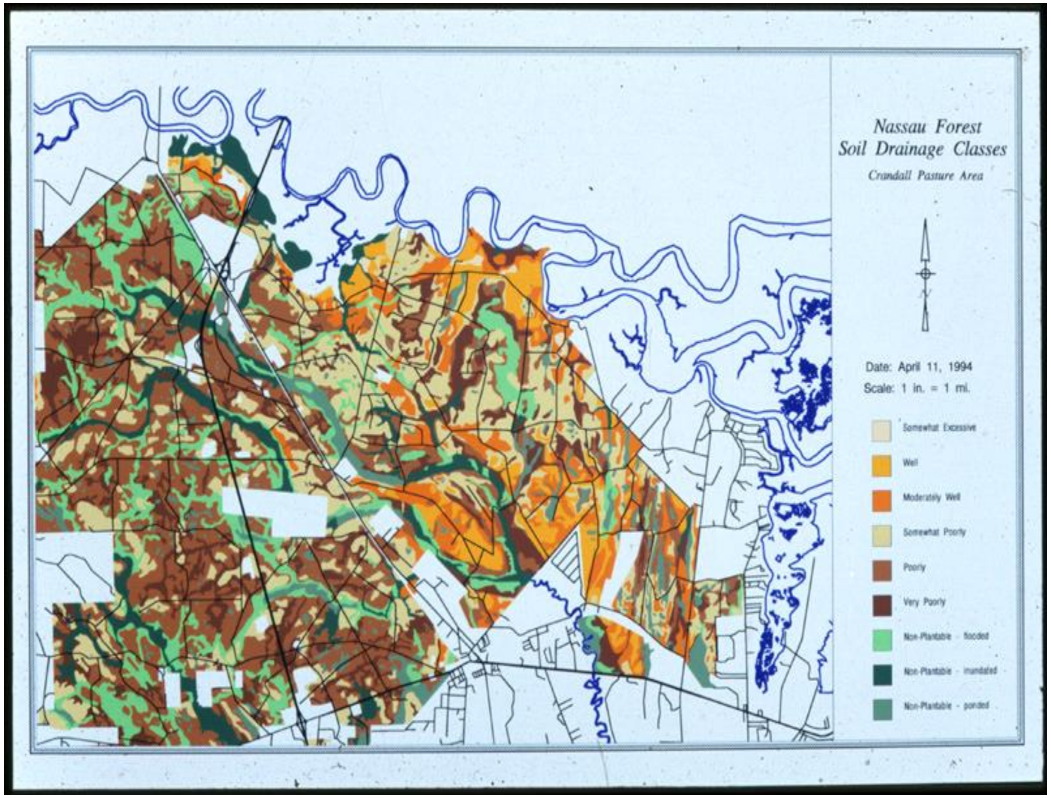


Location of Nutrient Deficiencies on Pleistocene Terraces in Georgia

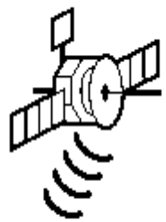
Site Specific Silvicultural Silviculture Prescriptions Based on Soils And Geology

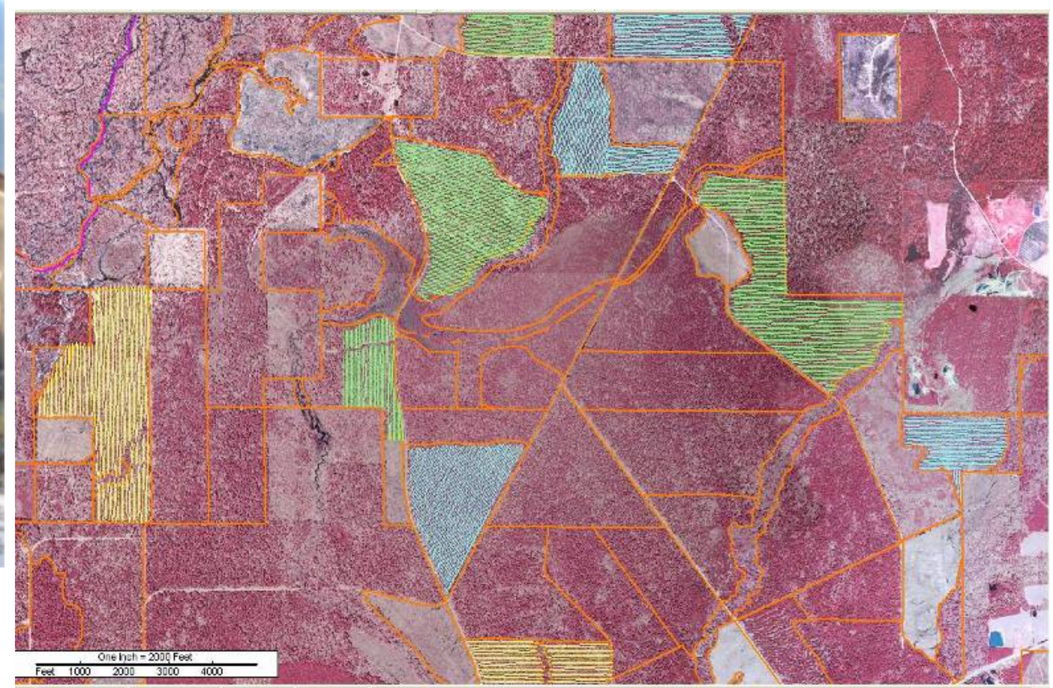
Soil Variability

Soil Map as a GIS Layer



Technology for Precision Silviculture Prescriptions

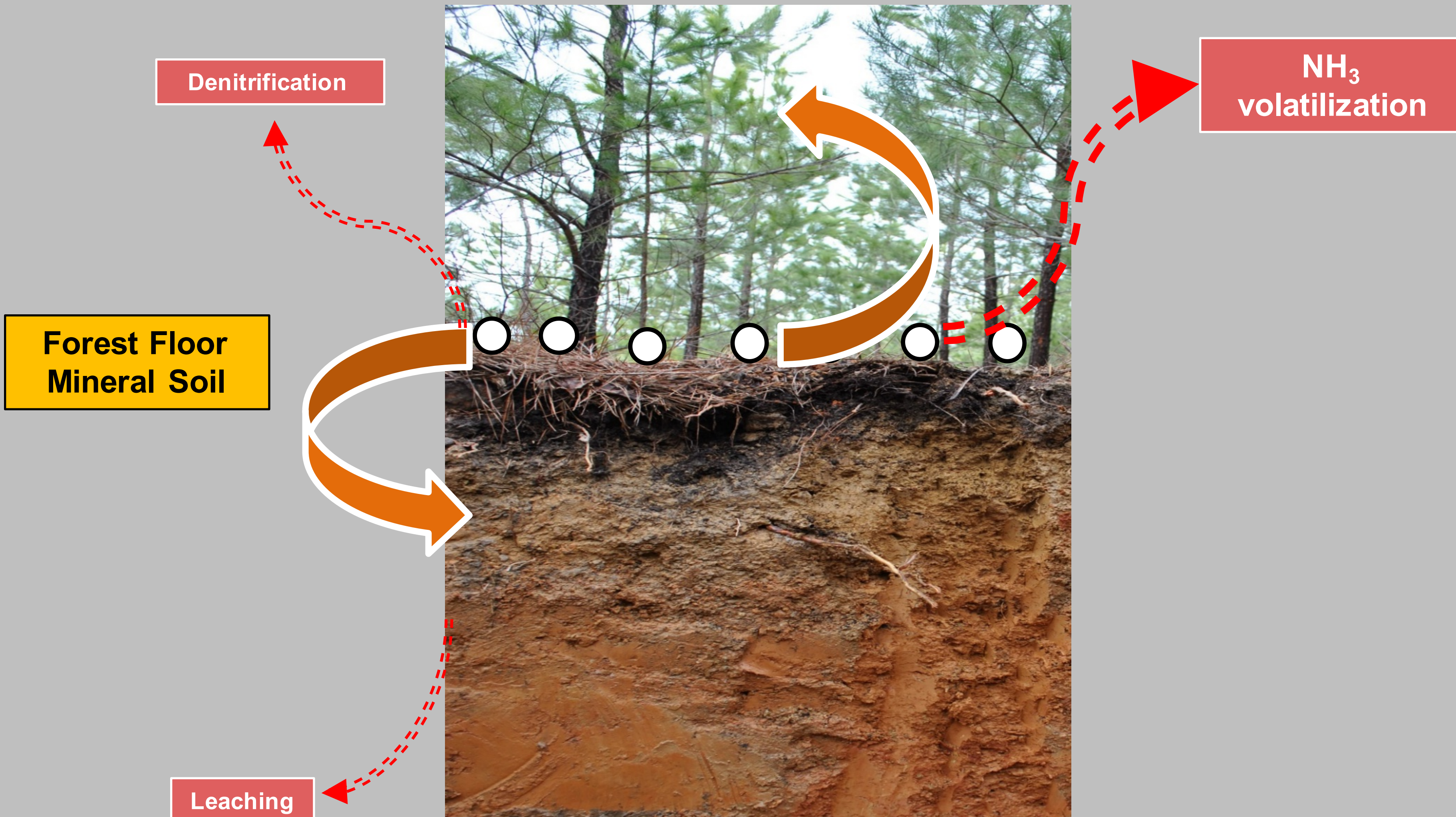





Forest Fertilization with Urea
Fertilizer Uptake Efficiency is Low When Operational Application Rates Such as 200 lbs/acre N Are Used, 20-25% of N from Fertilizer Gets Into Crop Trees

Rationale for Study

Improve our understanding of the fate of applied nitrogen in loblolly pine plantations and search for ways to increase N fertilizer efficiency



Urea Loss Through NH_3 Volatilization
Up to 50% of N lost

$$CO(NH_2)_2 + 2H_2O \xrightarrow{\text{(urease)}} 2\,NH_3 + CO_2$$

Volatilization

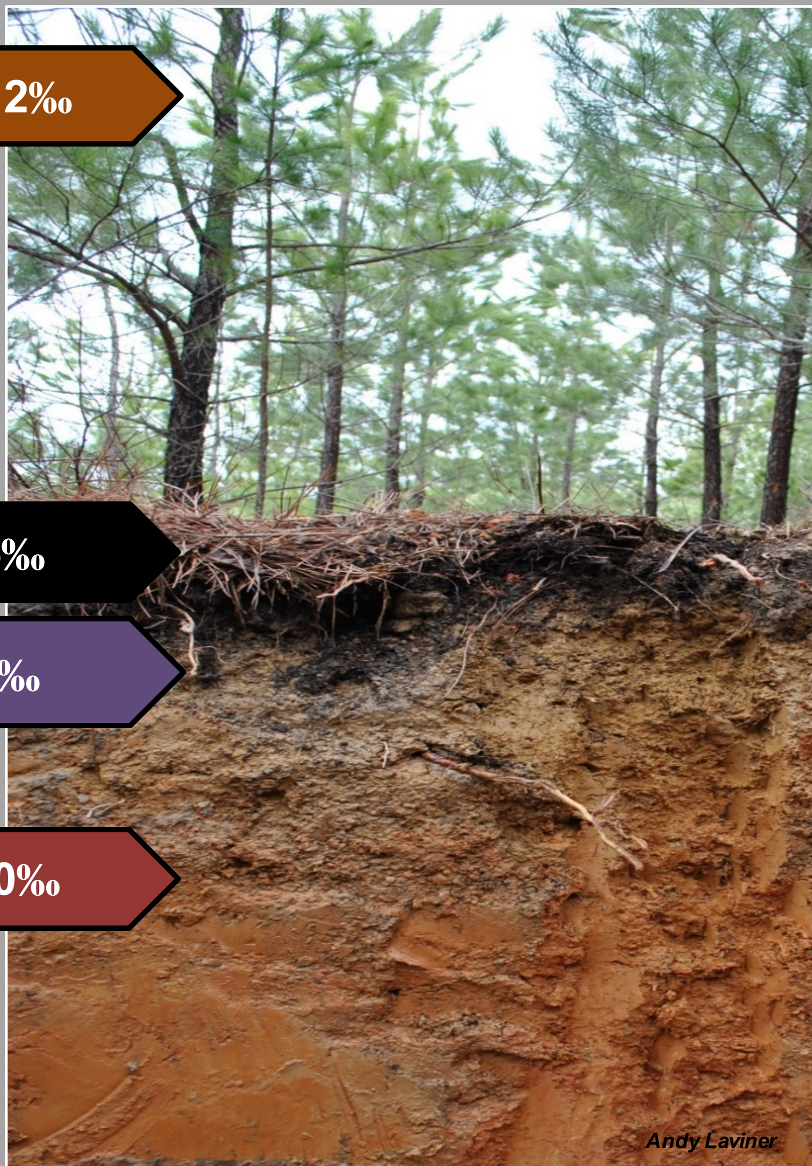
- High Urease Activity in Forest Floor
- Relative humidity > Critical Relative Humidity (~80%)
- High Temperatures
- High Wind Speeds
- Low Precipitation After Fertilization
- Low pH Buffering Capacity in Soil

Compare Uptake and Environmental Fate of Urea vs Enhanced Efficiency N Fertilizers

Use of Stable Isotopes of N (^{15}N) to Follow the Fate of Fertilizer N in the Ecosystem

Stable Isotope Theory

Natural abundance



Difficult to distinguish N originating from fertilizer vs. naturally occurring N in forest ecosystems because the N in soil large. (Fertilizer adds 200 lbs/acre to ecosystem that contains 3,000 to 10,000 lbs/acre)

Atmosphere is 78% N

^{14}N (99.63%)
7 electrons, 7 protons, 7 neutrons

^{15}N (0.3663%)
7 electrons, 7 protons, ***8 neutrons***

Conventional Fertilizer has this same N signature

^{14}N ← N_2 → ^{15}N

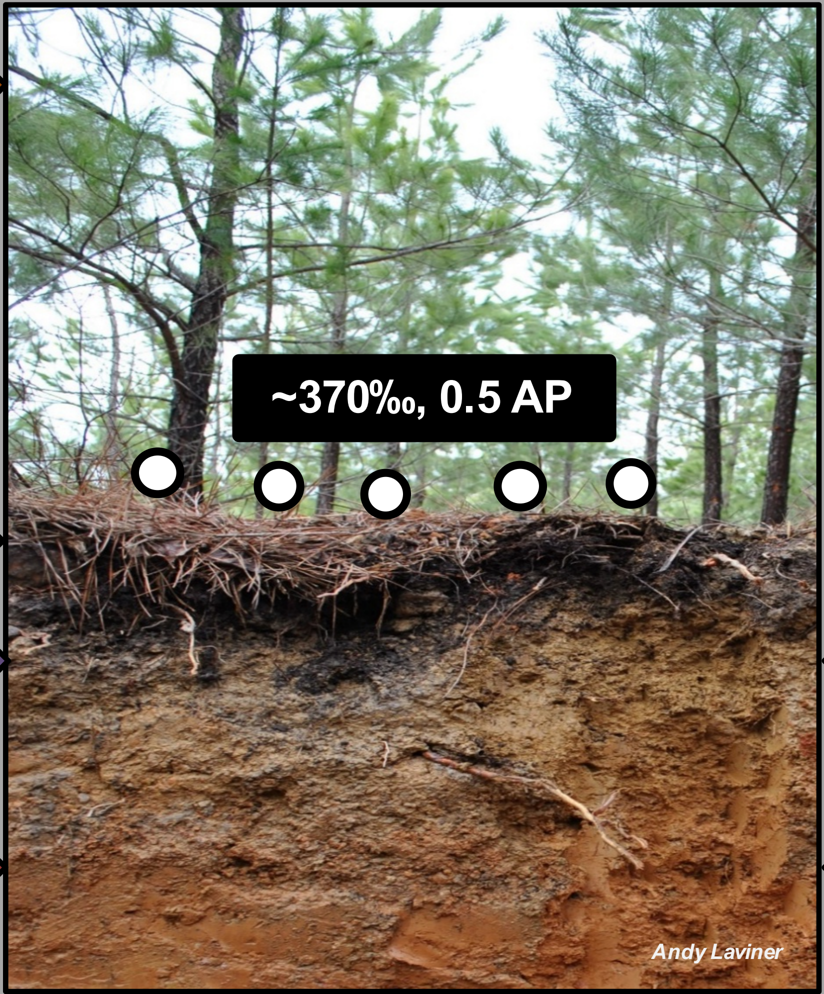
-100‰ 0‰ 100‰

Using Stable Isotopes to Track Fertilzer

loblolly pine plantations

Natural abundance | **After fertilization**

Natural abundance	After fertilization
-10 to 2‰	30 to 210‰
-5 to 5‰	30 to 150‰
0 to 8‰	10 to 50‰
2 to 10‰	6 to 20‰



Fertilizer Treatments Used ^{15}N Labeled Urea

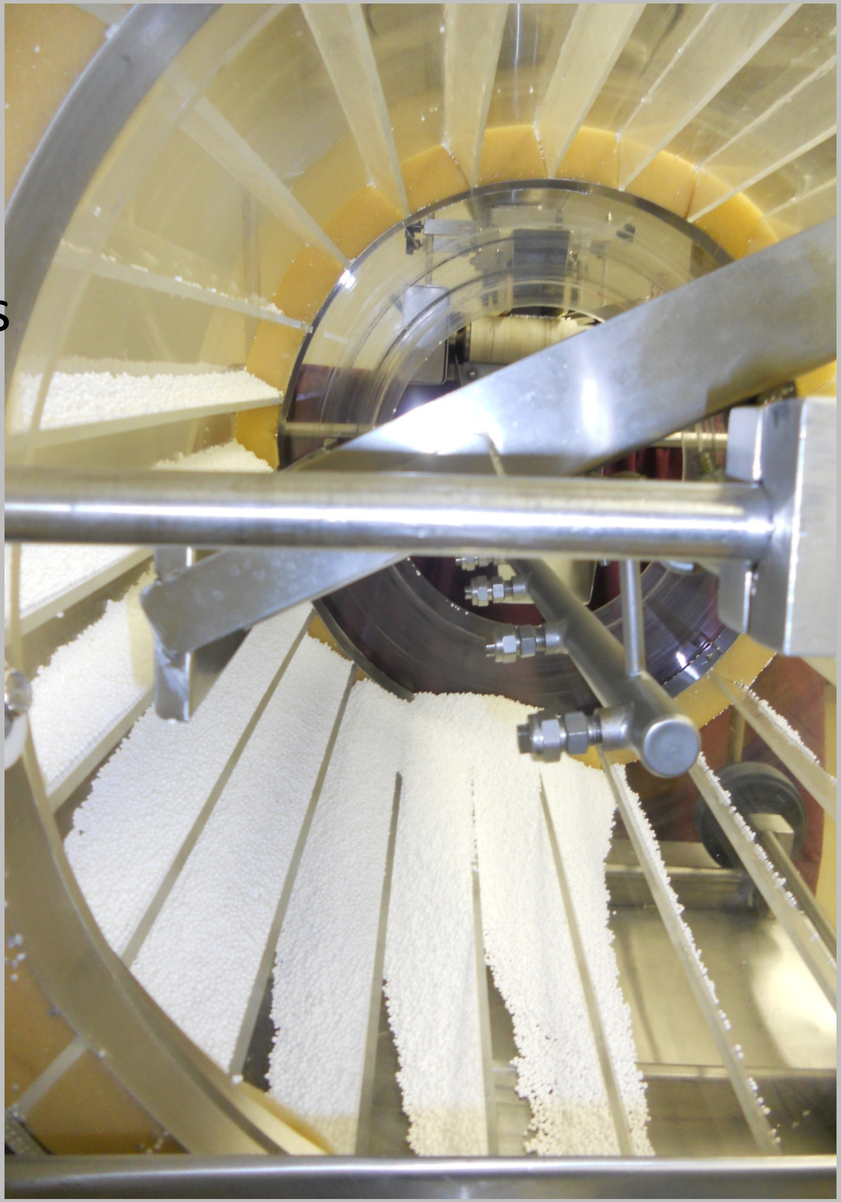
- ^{15}N Urea
- ^{15}N Urea + N(n-butyl) thiophosphoric triamide (NBPT)
- ^{15}N Urea + NBPT + Monammonium Phosphate Coating
- Polymer Coated ^{15}N Urea

Purchased 2.5 kg of 99% ^{15}N Enriched Urea

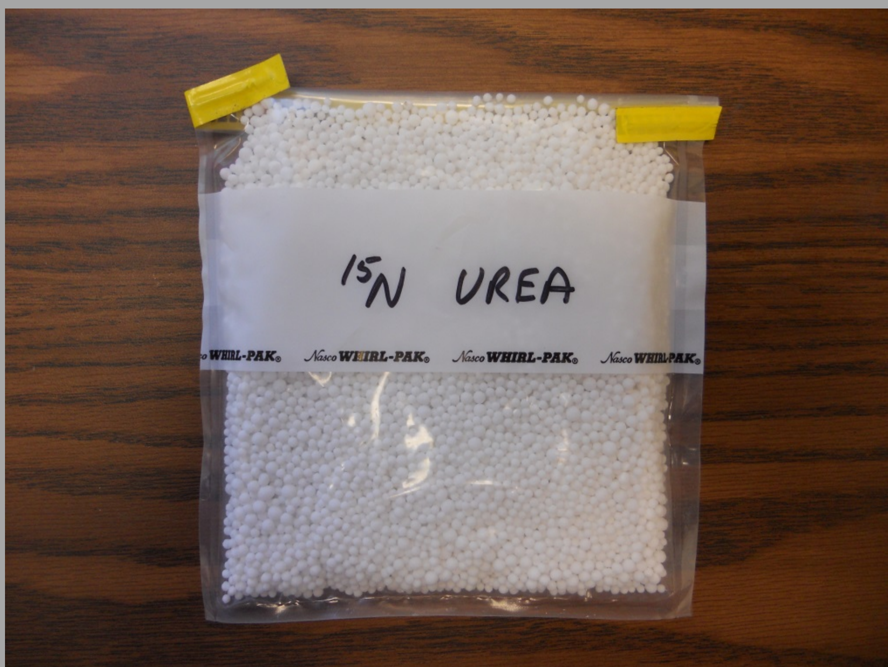
Used Falling Curtain Process to Produce 0.5% ^{15}N Urea Granules

Spray Liquid Urea onto "seed" and build up coating to desired thickness.

Created Granules with 4-5 mm Diameter



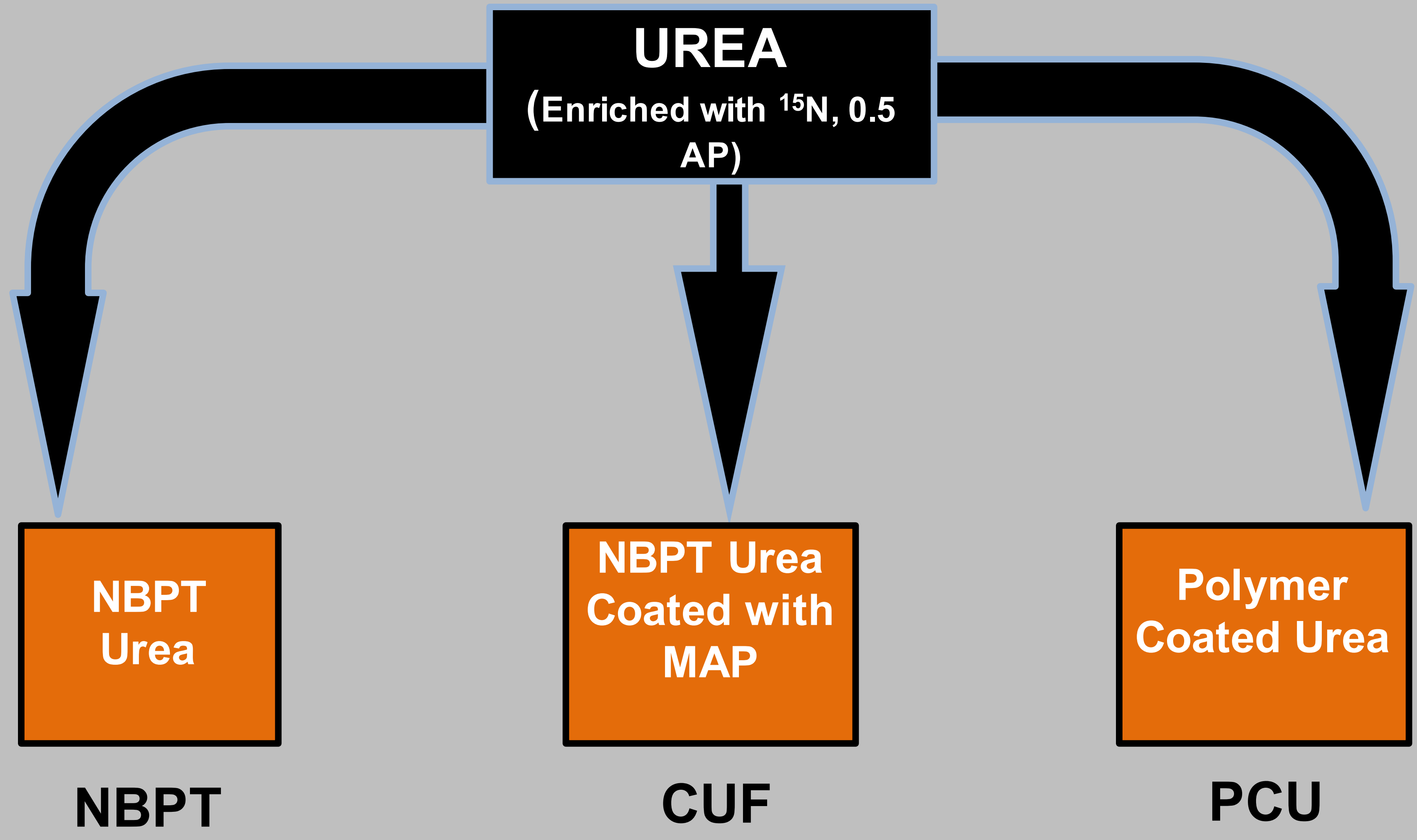
Stable Istopes
^{15}N labelled Fertilizer



$115,000/ton

Produced 1500 kg of urea enriched with ^{15}N at 370‰

Enhanced Efficiency Fertilizers (EEFs) Reduce Fertilizer N Losses




^{15}N NBPT
-PAK®
Nasco WHIRL-PAK®
Nasco WHIRL-PAK®
Nasco WHIRL-PAK®

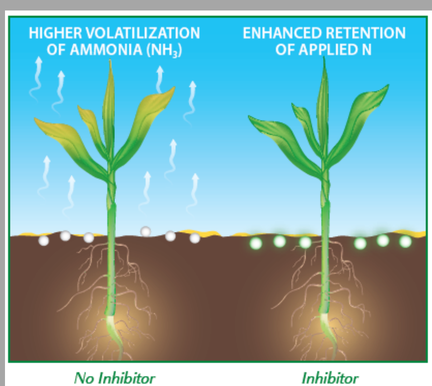

^{15}N CUF
39-9-0
Nasco WHIRL-PAK


^{15}N PCU

Enhanced Efficiency Fertilizers (EEFs)

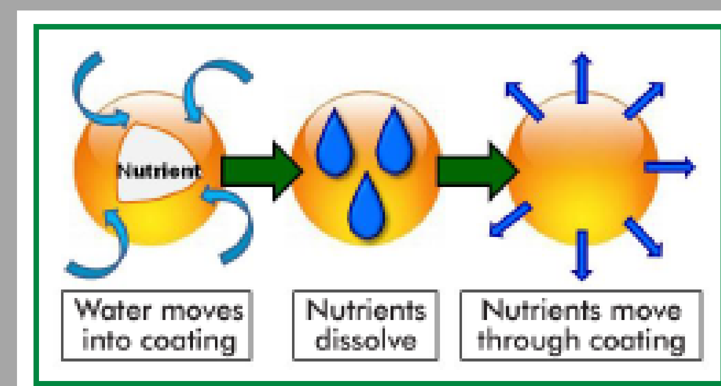
Two Mechanisms Examined: Urease Inhibitors vs Controlled Release

- Urea + NBPT N(n-butyl) thiophosphoric triamide (NBPT)
- Urea + NBPT coated with Monoammonium Phosphate (CUF)
- Polymer Coated Urea (PCU)



NBPT

CUF



PCU

Urease Inhibitors (NBPT, CUF)

Controlled Release (CUF, PCU)

Objectives for ^{15}N Study

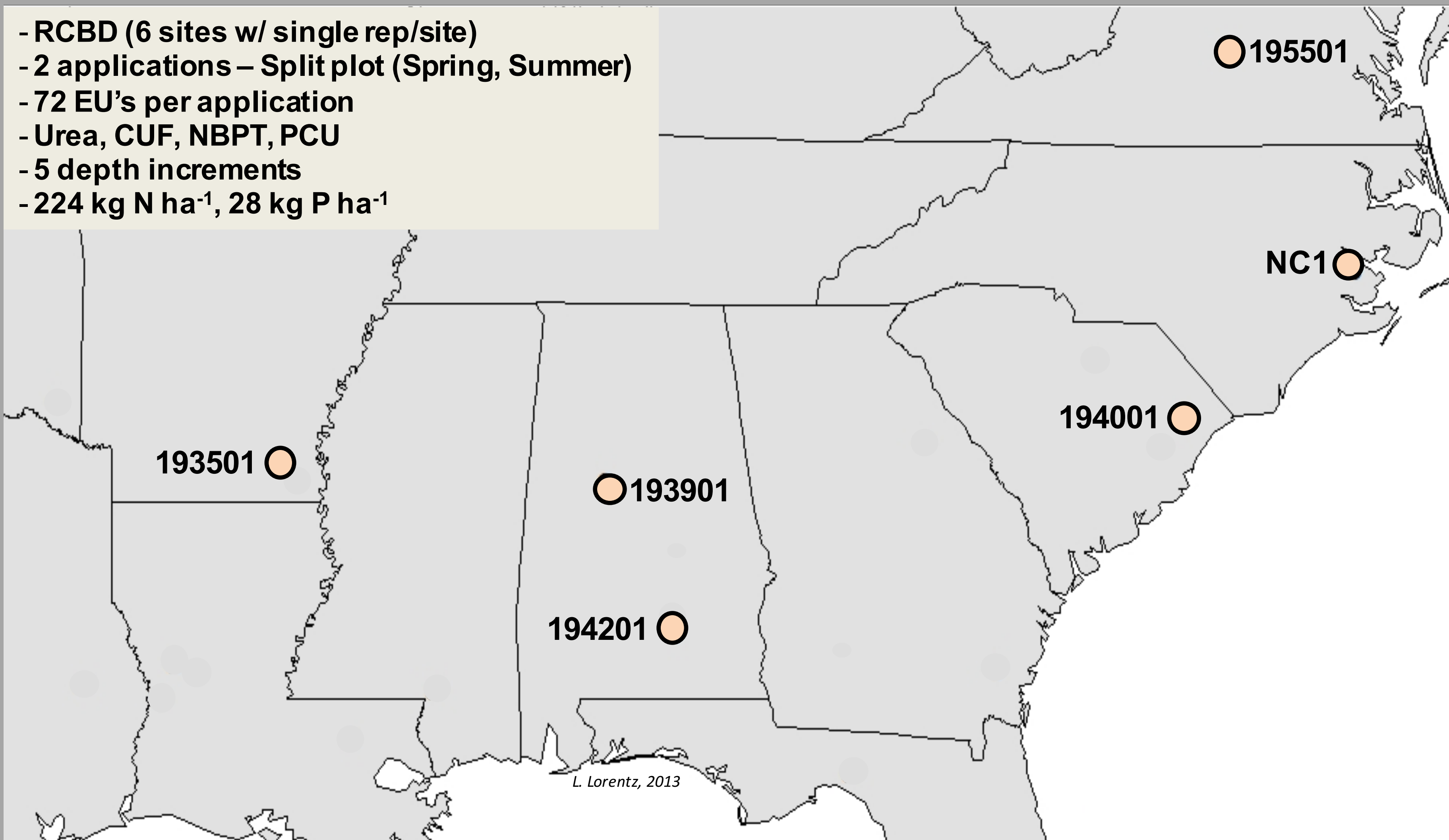
Is there a difference between conventional and enhanced efficiency fertilizers?

Is there a difference between a spring versus summer applications?

- **NH_3 volatilization**
- **Crop tree uptake of applied N**
- **Effect of the understory on uptake of applied N?**
- **Cycling of applied N in the plantation system**

NH_3 Volatilization - Sites

- RCBD (6 sites w/ single rep/site)
- 2 applications – Split plot (Spring, Summer)
- 72 EU's per application
- Urea, CUF, NBPT, PCU
- 5 depth increments
- 224 kg N ha^{-1}, 28 kg P ha^{-1}

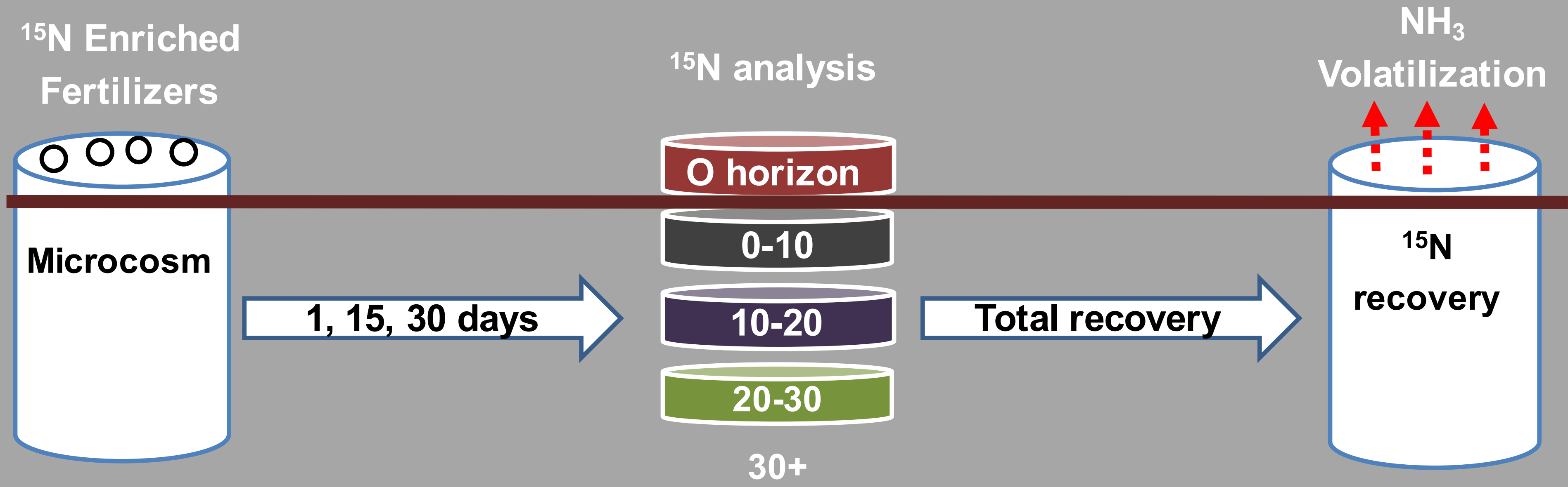


NH_3 Volatilization

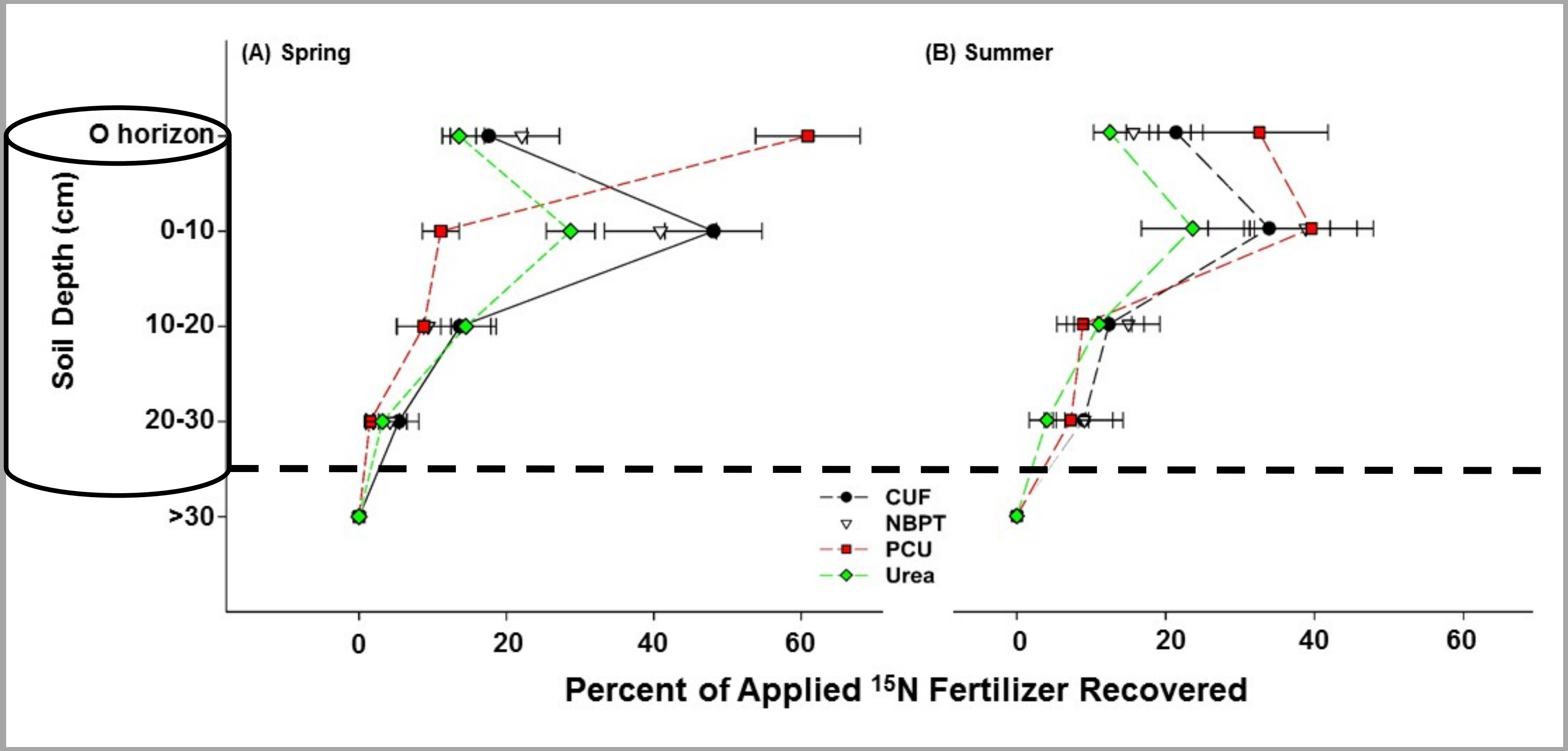
Is there a difference in fertilizer N losses between conventional and enhanced efficiency fertilizers?

Between a spring versus summer application?

NH_3 Volatilization Experiment - Methods

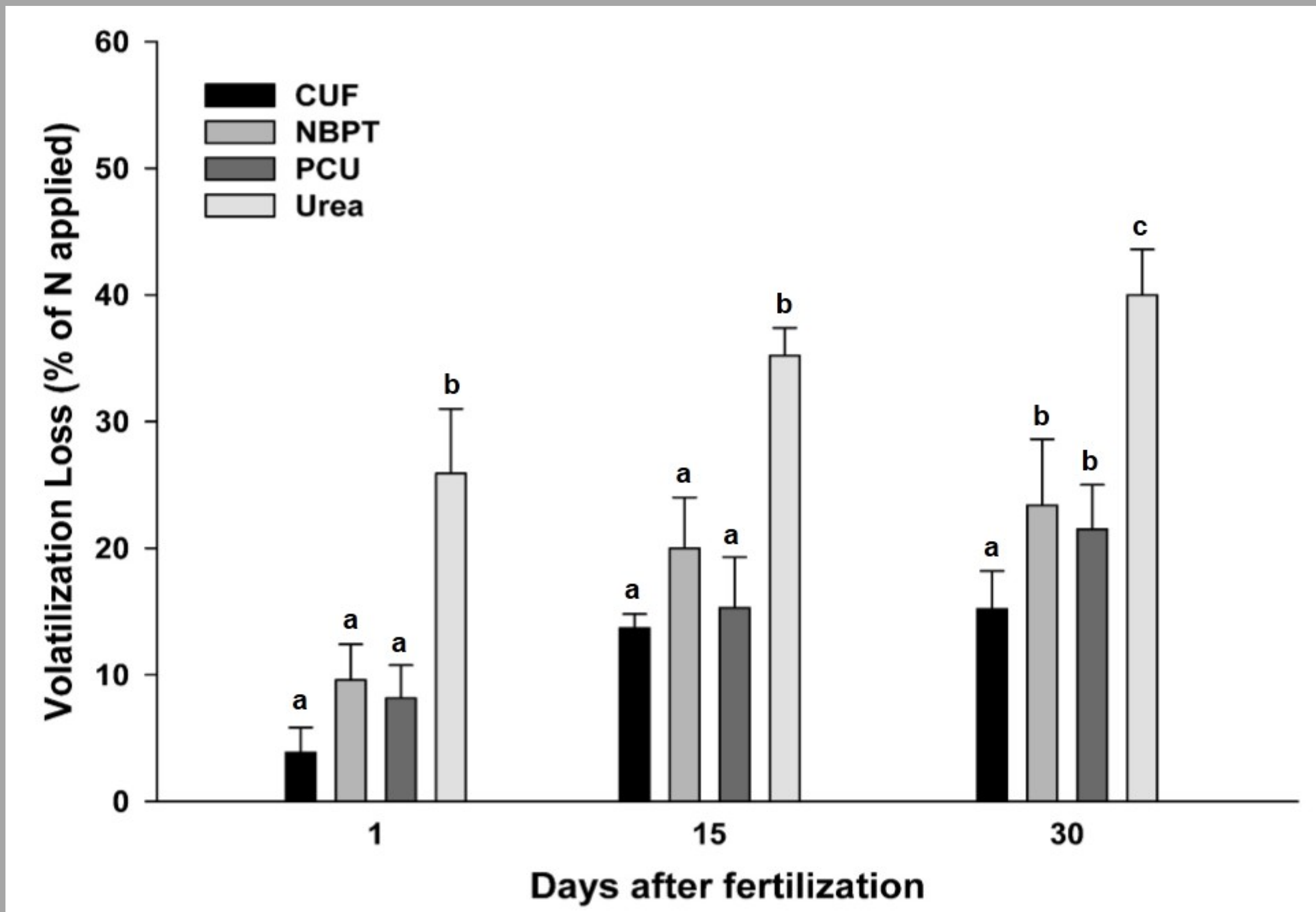


Distribution of ^{15}N with Soil Depth



Sites: n = 6

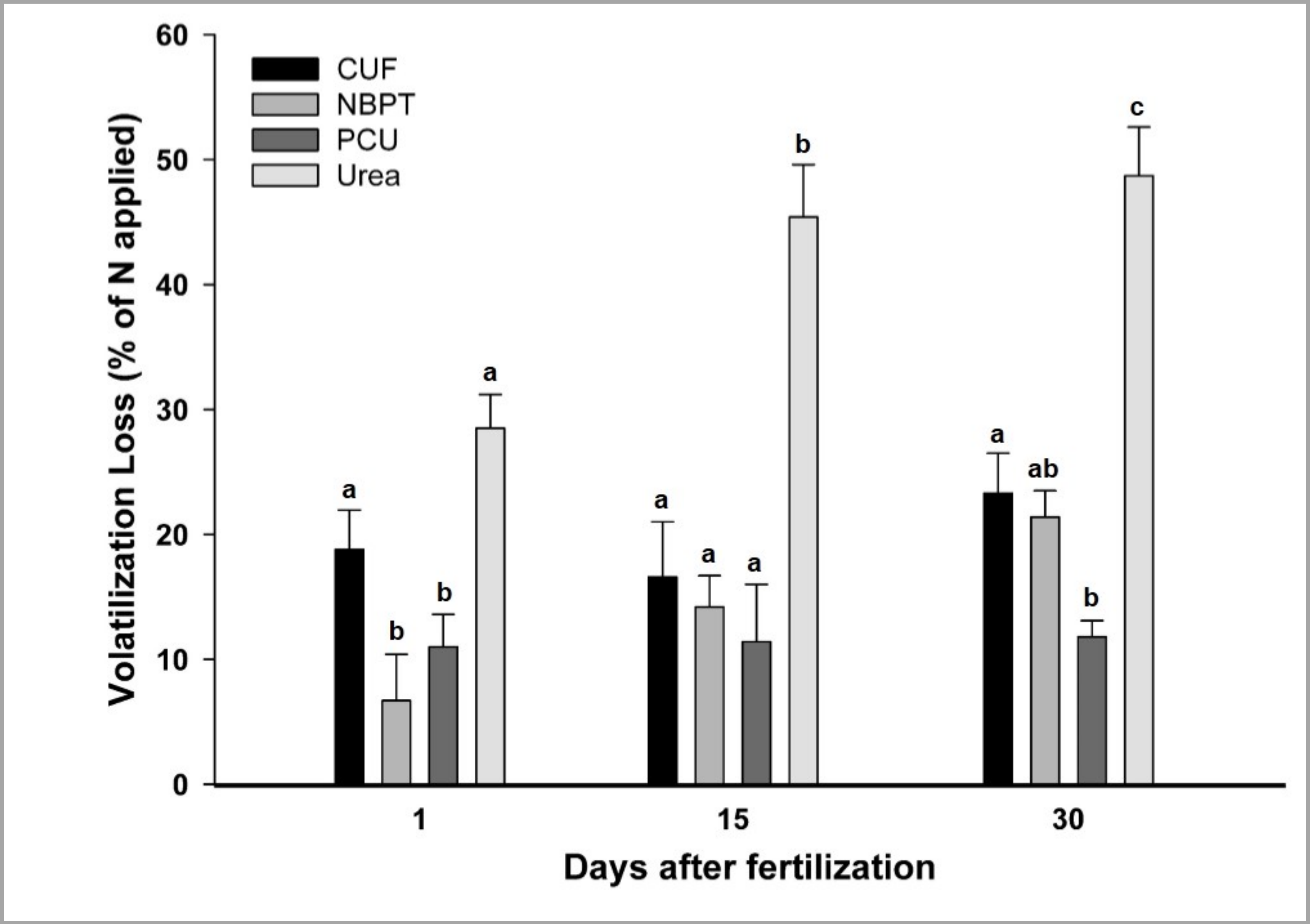
NH_3 Volatilization – Percent Loss of ^{15}N
Spring



Sites: n = 6

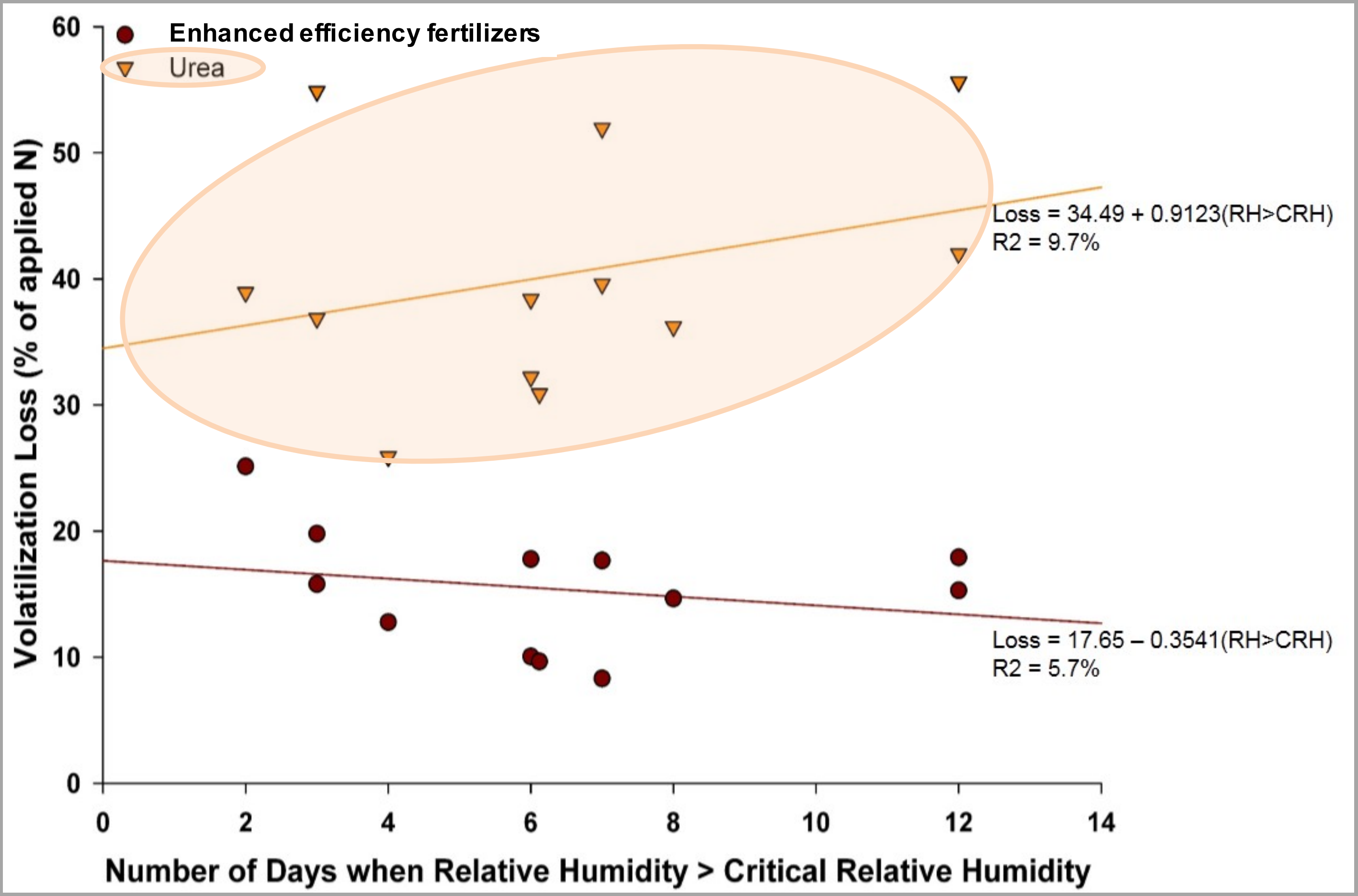
NH_3 Volatilization – Percent Loss of ^{15}N

Summer



Sites: n = 6

NH_3 Volatilization and Critical Relative Humidity Spring + Summer



First 15 days of experiment

n = 6

NH_3 Volatilization - Conclusions

- Minimal leaching within 30 days for both seasons
- Large NH_3 volatilization losses (30-50%) for Urea in Spring and Summer
- Low NH_3 volatilization losses (5-25%) for EEFs in Spring and Summer
- NH_3 volatilization losses from Urea increase when RH > CRH and can occur year round

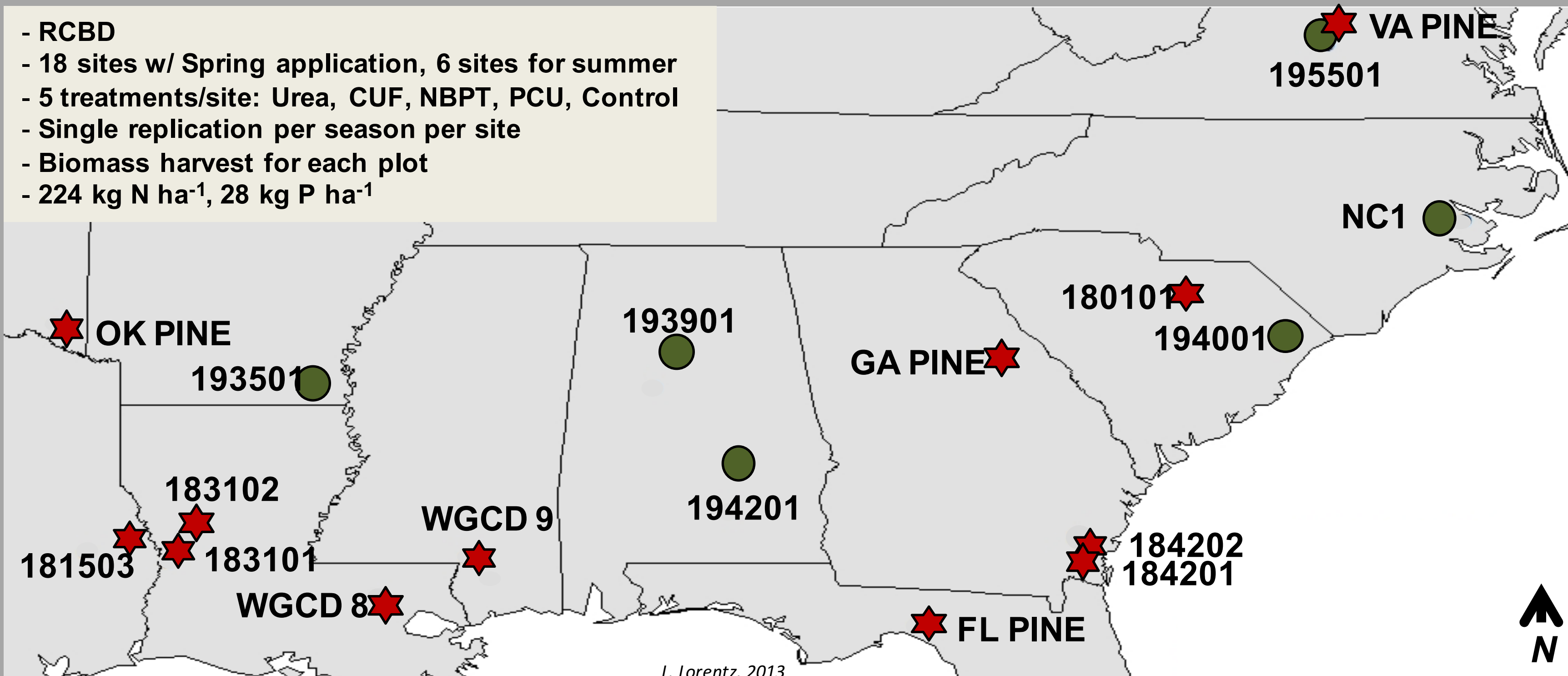
Fertilizer N Uptake

Is there a difference in the uptake of fertilizer N for loblolly pine trees among different fertilizer treatments?

Between a spring versus summer application?

Fertilizer N Uptake- Sites

- RCBD
- 18 sites w/ Spring application, 6 sites for summer
- 5 treatments/site: Urea, CUF, NBPT, PCU, Control
- Single replication per season per site
- Biomass harvest for each plot
- 224 kg N ha^{-1}, 28 kg P ha^{-1}

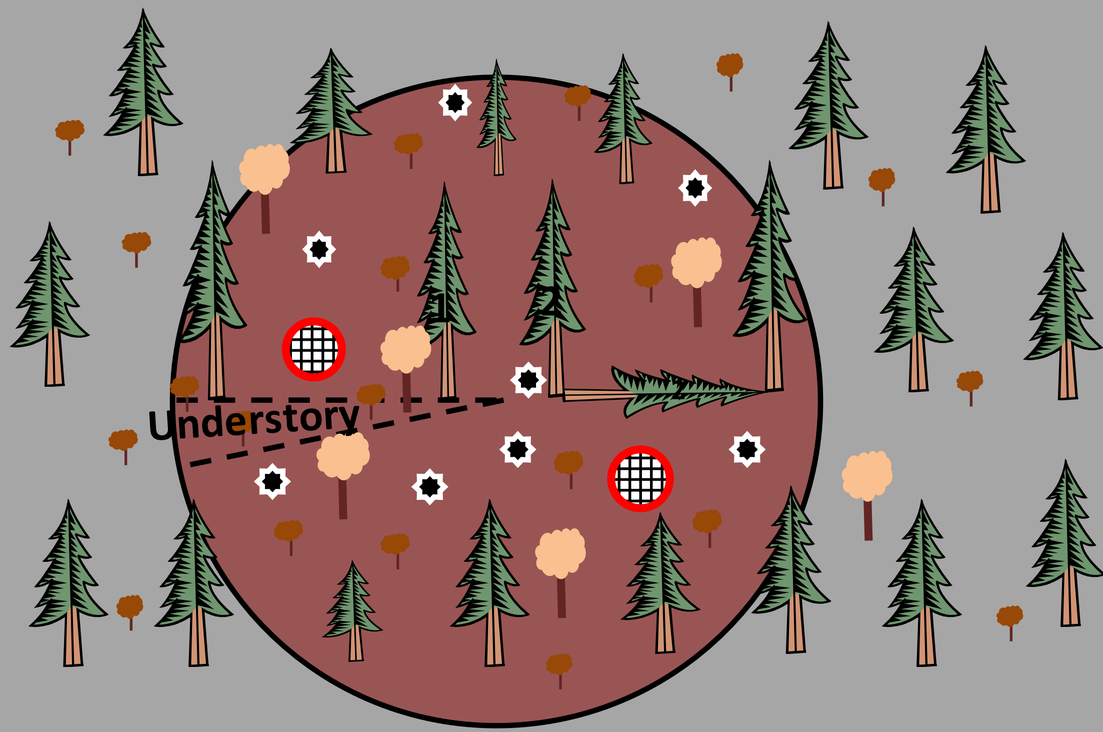


2011 Sites

2012 Sites

Fertilizer N Uptake – Plot Layout

Crop tree
- Foliage
- Fine branches
- Coarse branches
- Stem
- Roots



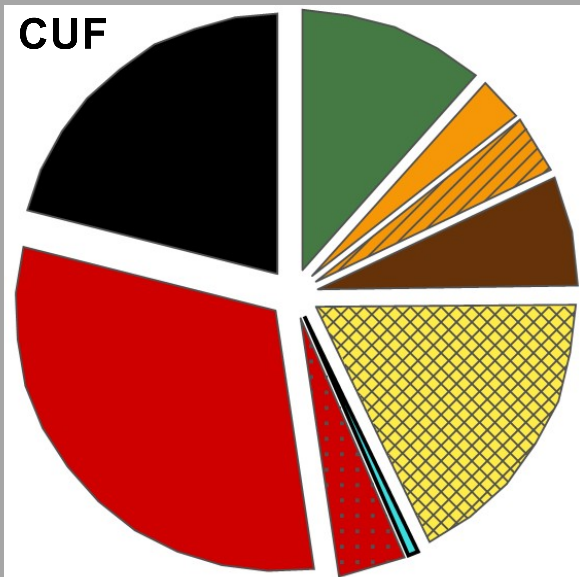
Understory
- Volunteers
- Deciduous Trees
- Shrub
- Vines
- Herbaceous

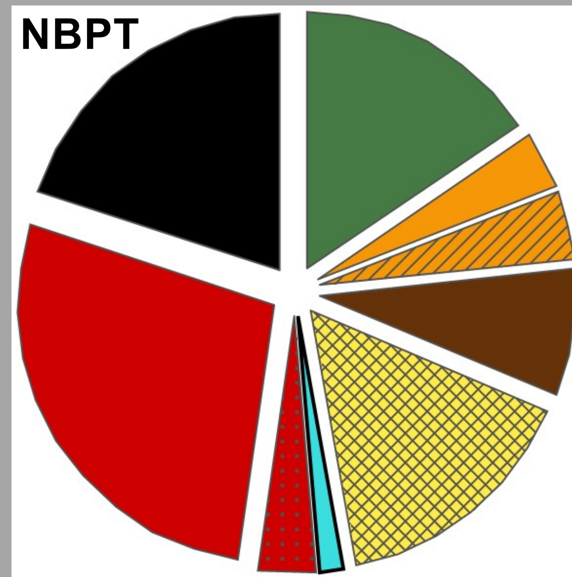
Soils
- O horizon
- 0-15cm
- 15-30cm

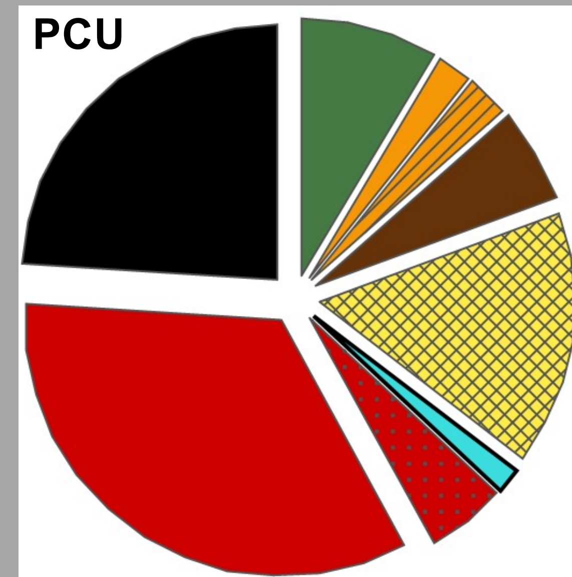
Litterfall

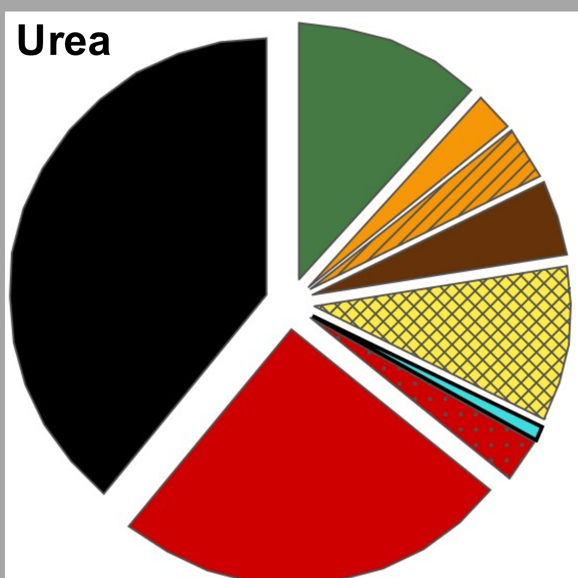
Destructive Sample of Trees to Determine Fate of Fertilizer

Mean ^{15}N Percent Recovery - Spring





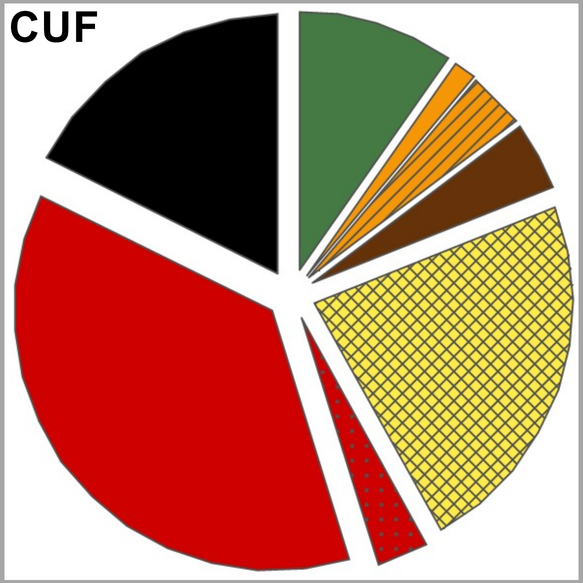


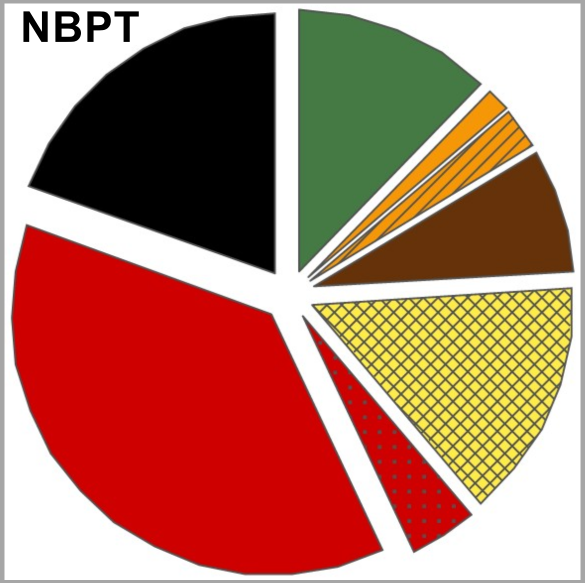


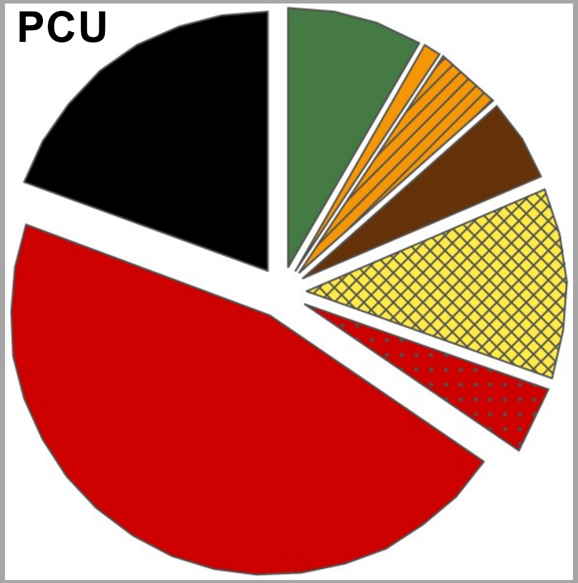
Treatment	Tree	Roots	Understory	Soil	Total
CUF[a]	25	18	<1	36	79%
NBPT[a]	29	16	4	31	80%
PCU[a]	19	16	5	39	79%
Urea[b]	22	10	3	28	63%

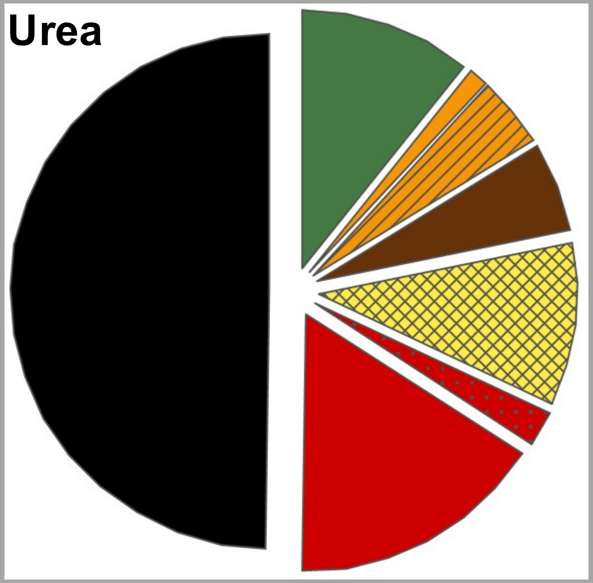
Sites: n = 17

Mean ^{15}N Percent Recovery - Summer







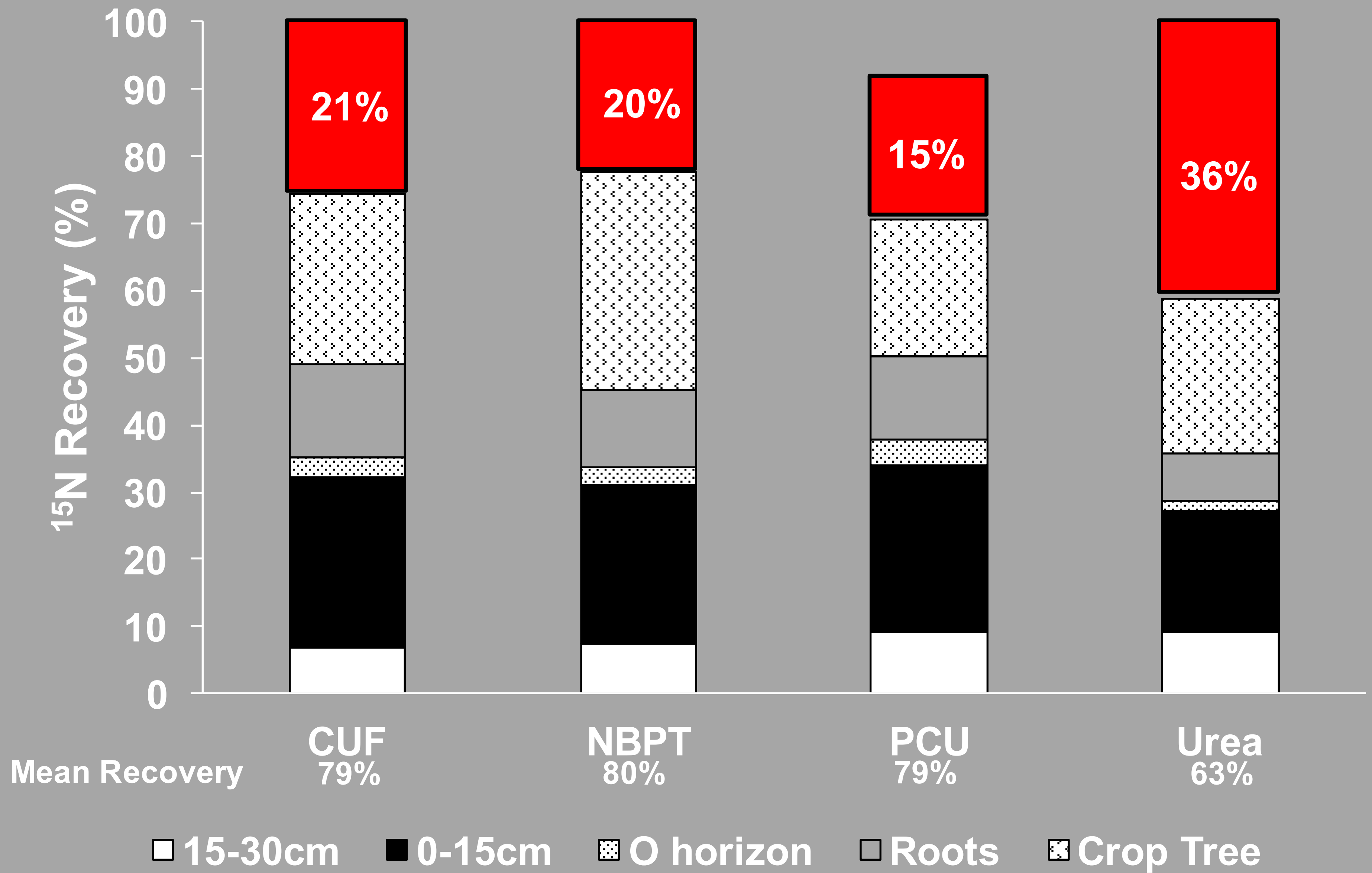


Treatment	Tree	Roots	Soil	Total
CUF[a]	19	23	41	83%
NBPT[a]	25	15	42	82%
PCU[a]	19	12	50	81%
Urea[b]	22	10	18	50%

- Foliage
- Fine Branches
- Coarse Branches
- Stem
- Roots
- Understory (None)
- Forest Floor
- Mineral Soil (0-30 cm)
- Losses - Volatilization (Assumed)

Sites: n = 5

^{15}N Ecosystem Recovery - Spring



N = 17

Impact of Understory on Fertilizer N Uptake

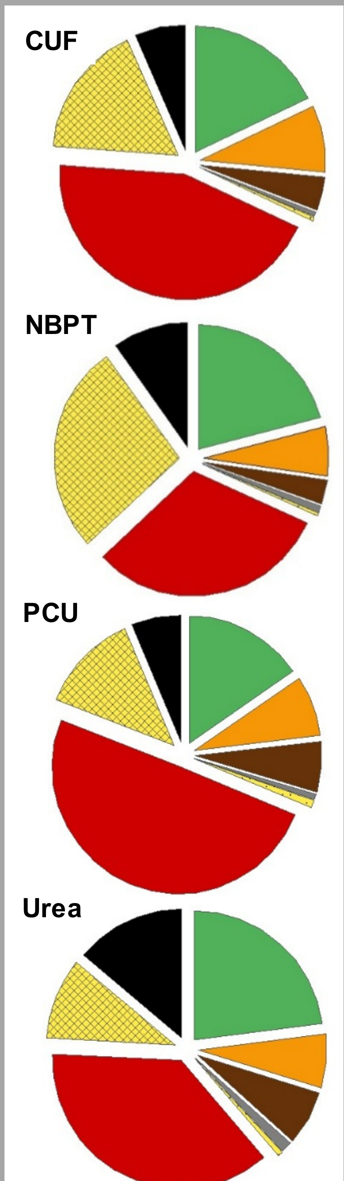
None – Low (0% Cover)

Medium (25-50% Cover)

Low (0-25% Cover)

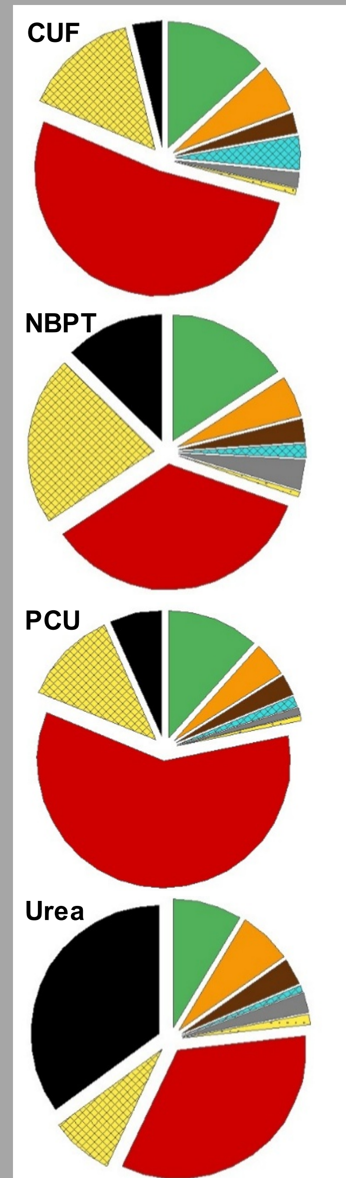
High (>50% Cover)

Impact of Understory on ^{15}N Ecosystem Recovery

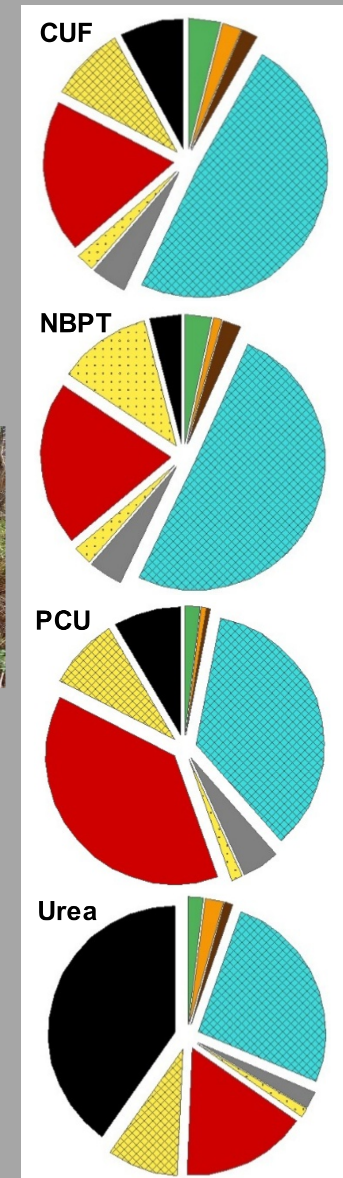


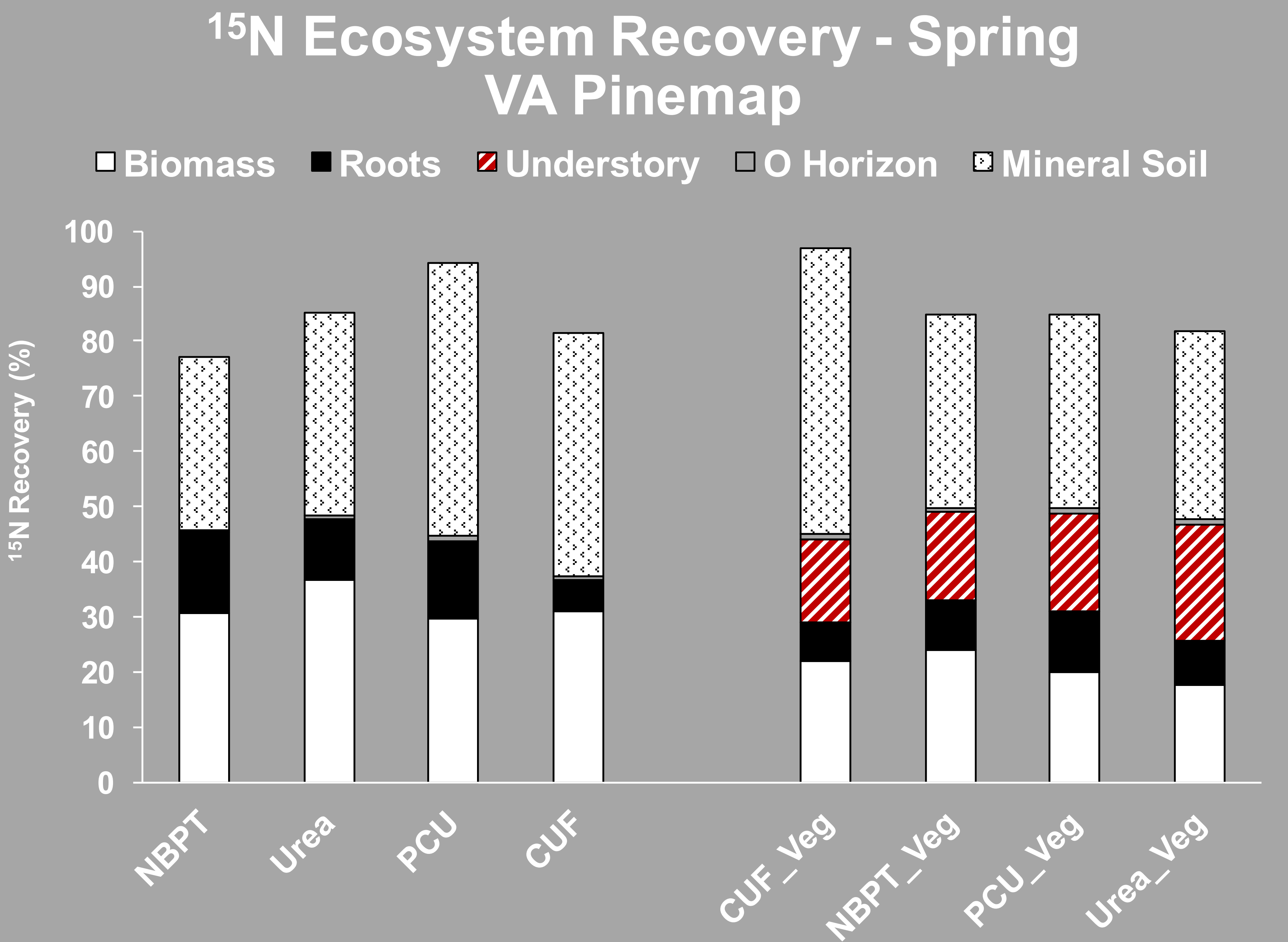
Low
(0% ground cover)

Medium
(40% ground cover)



High
(80% ground cover)





^{15}N Ecosystem Recovery - Spring
VA Pinemap
Biomass
Roots
Understory
O Horizon
Mineral Soil
^{15}N Recovery (%)
100
90
80
70
60
50
40
30
20
10
0
NBPT
Urea
PCU
CUF
CUF_Veg
NBPT_Veg
PCU_Veg
Urea_Veg

Summary

- Less NH_3 volatilization for EEFs compared to urea
- Fertilizer ^{15}N recovery greatest in foliage and the mineral soil.
- Greater fertilizer N uptake crop trees in EEFs compared to urea
- Significant fertilizer N uptake by understory vegetation
- Greater overall ecosystem recovery of fertilizer N from EEFs compared to urea
- ^{15}N remaining in the mineral soil may influence long term cycling of fertilizer N

4R's of Fertilization to Increase Efficiency

Right Place

Right Rate

Right Time

Right Source