Soil and Site Productivity Concepts for Forestry

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Progressive Forestry for Production Forests

Sustainability?

- Broad view
  - Maintain capacity of a landscape to provide the range of products, services, and values desired by society for future generations
- Narrow view
  - Maintain capacity of the soil to produce a non-declining amount of woody biomass
- System inputs?
  - Required, desired, not feasible, not allowed

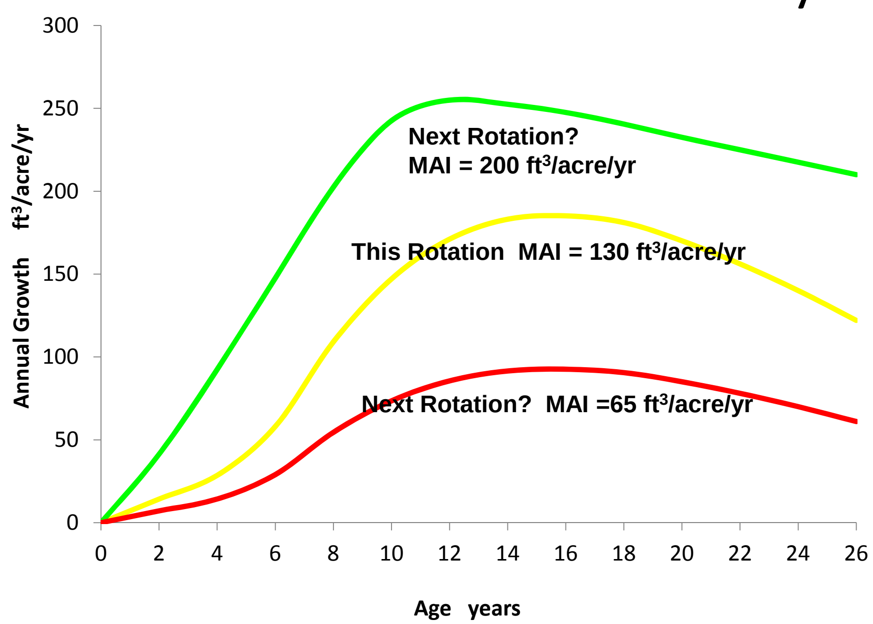
Soil

I am soil.
Look at me!
Smell me, touch me, feel me
walk on me with your bare feet
sing and dance on me
observe me closely…
as a living, changing , vital link
in a vast and ancient web
intricate and delicate
of which you too are part…

Nurture me
plant in me
shelter me with trees
rescue me where
I am thin and worn
but above all
teach your children…
to know me
and to value me…
I am soil.

Excerpts from Shelia M. Weaver's 1987 poem "Soil"
The Canadian Theosophist 68(4).

Narrow View of Sustainability



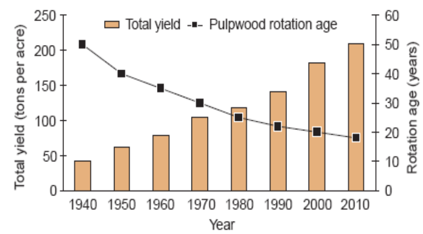
Managing for Sustained Productivity Requires an Understanding of the Factors Affecting Productivity

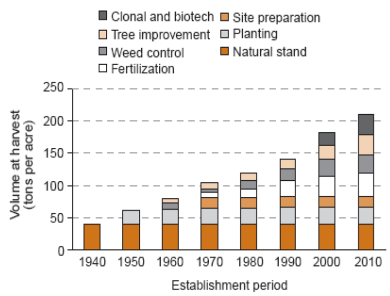
Production Varies Across Sites Why?

- Species composition
- Stocking
- Site conditions
  - Soil
  - Climate
- Age
- Management

Southern Pine Success Story

1 to10 tons/acre/yr



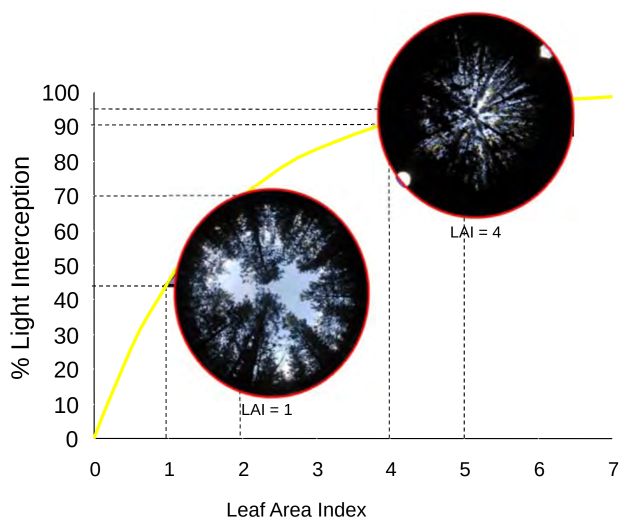


Fox, Jokela, Allen 2004

Stand Productivity

- Physiological processes
  - Light interception
  - Light use efficiency
    - Carbon gain (photosynthesis)
    - Carbon partitioning

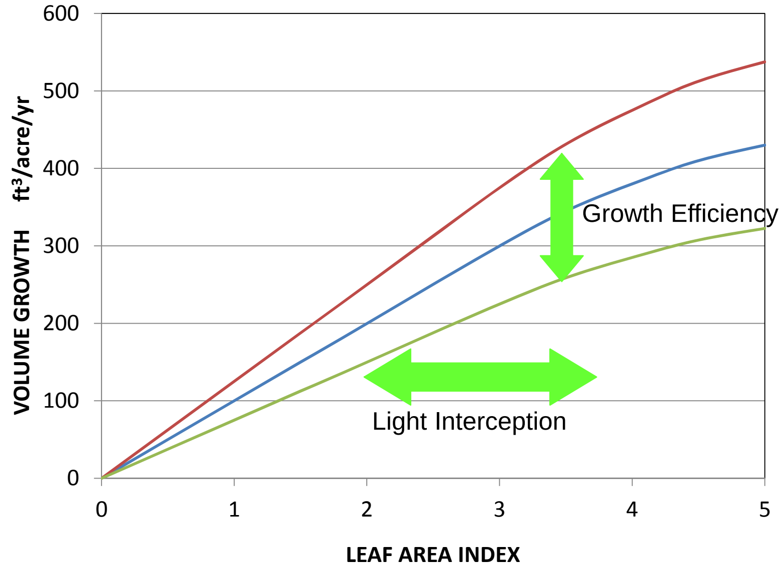
Light Interception and Leaf Area Index



Beer's-Lambert Law

$I = 1 - (e^{(-k * L)})$

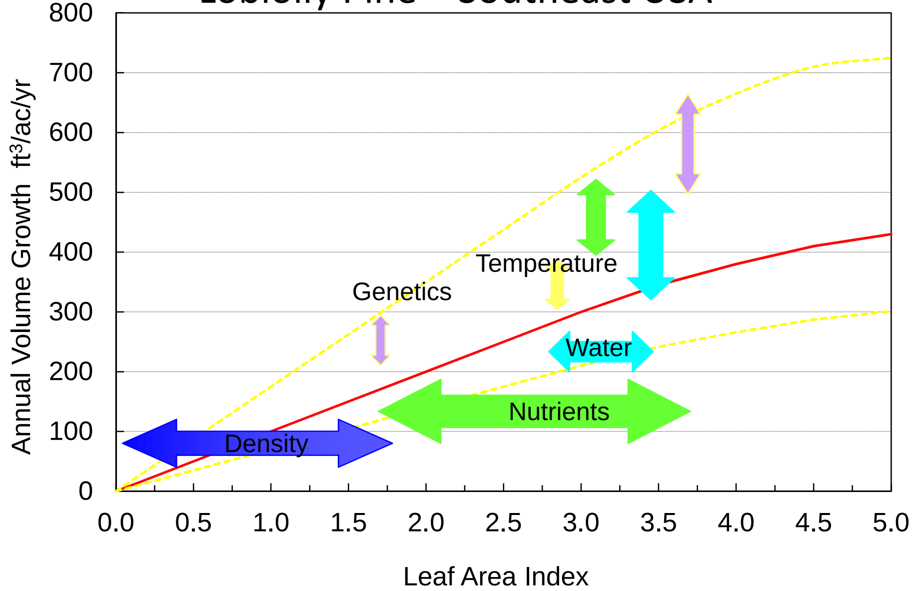
k = 0.6



Stand Productivity

- Factors affecting physiological processes
  - Genetics
    - species, genotype within species
  - Stand density
  - Resource availability
    - Light, water, NUTRIENTS, temperature
  - Age
    - Size and maturity

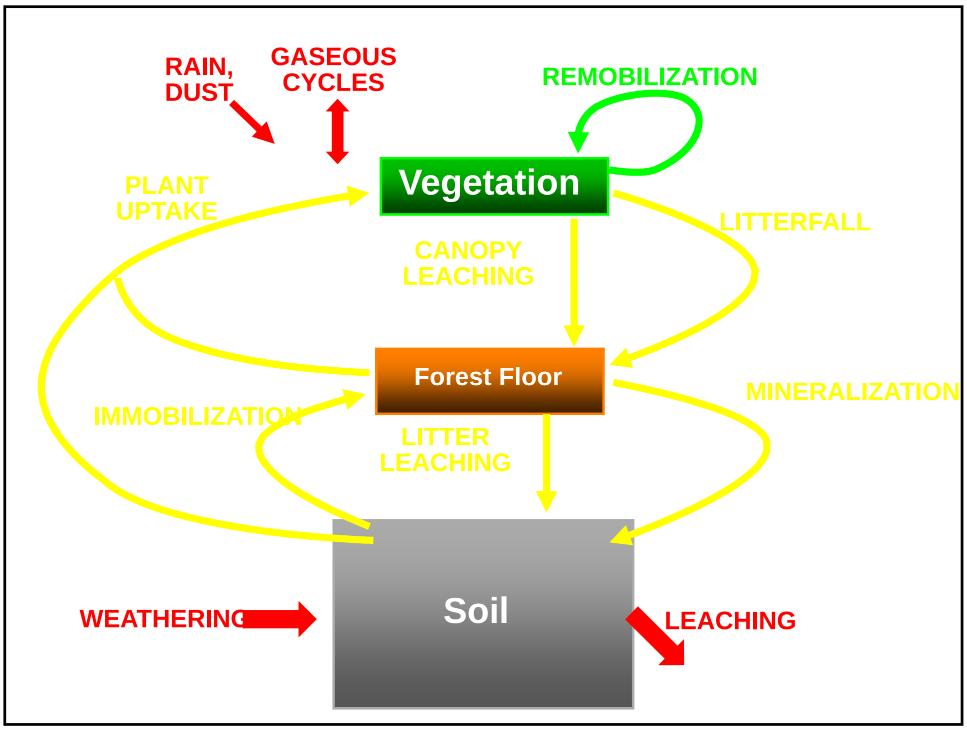
Factors Influencing Leaf Area and Growth
Loblolly Pine – Southeast USA



Biomass Harvesting
Questions about Sustainability and Nutrition

- Will repeated harvest of timber crops deplete soil organic matter and nutrients enough to reduce productivity?
- How do intensive management practices affect soil nutrient availability?
- How do we determine if a forest stand's growth is limited by nutrients?
- If nutrients are limiting, what elements, rates, sources, and timing of application should be used?

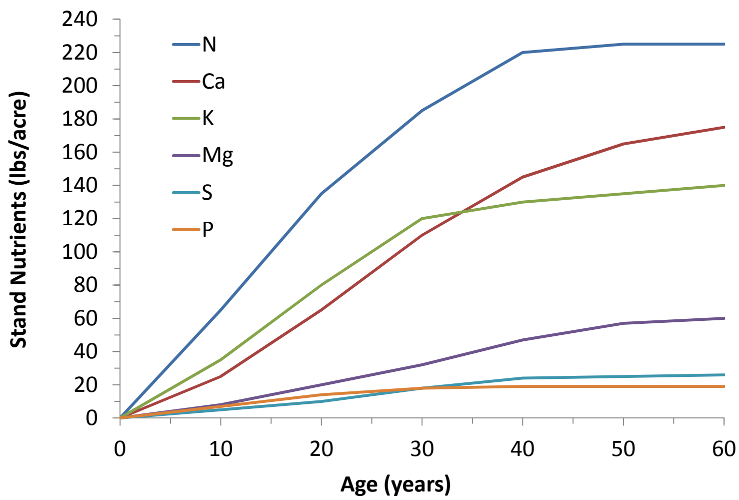
Nutrient Cycling Primer
for
Foresters



Carbon and Nutrient Cycling

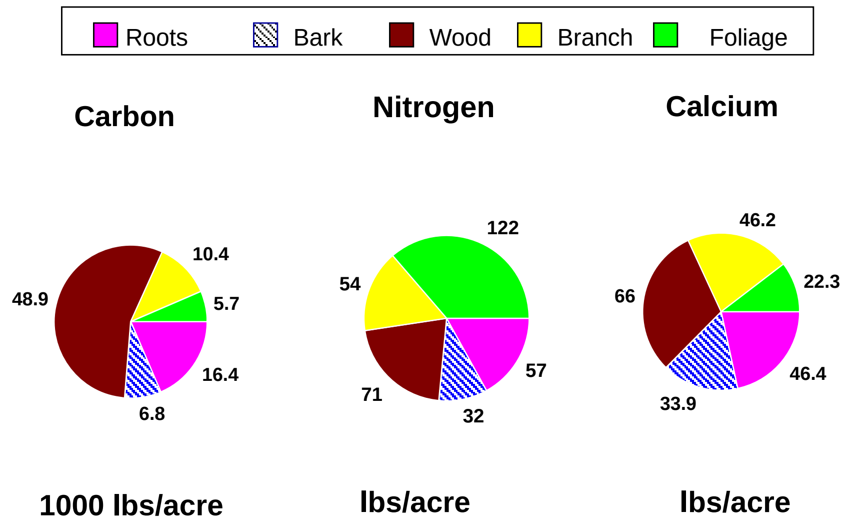
- Pools – what is out there today - "yield"
  - Important for estimating removals
- Fluxes – movement between pools
  - Geochemical – ecosystem inputs and outputs
    - Important for long term sustainability
  - Biochemical – within vegetation cycling
    - Conservation of nutrients already taken up
  - Biogeochemical – within ecosystem cycling
    - Important for current production

Above-ground Nutrient Accumulation Loblolly Pine



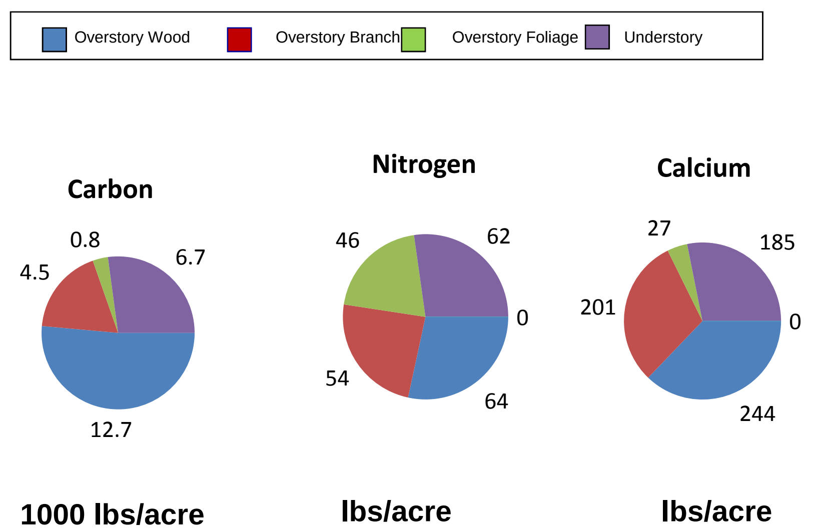
Switzer and Nelson, 1972

DISTRIBUTION OF BIOMASS AND NUTRIENTS
16-Year Old Loblolly Pine Stand



Wells *et al. (1975)*

DISTRIBUTION OF BIOMASS AND NUTRIENTS
40-Year Old Upland Oak Stand



Frederick *et al. (1988)*

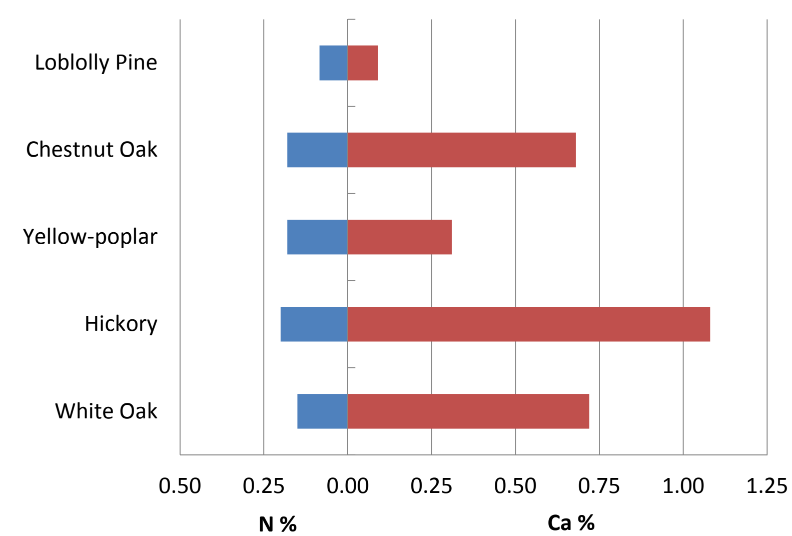
Henderson Site Productivity Study

Harvest Removals @ 22 years

	Stem Only	Complete Tree	Additional Removal (tops)	% Increase in Removal	Nutrients Removed lbs/dry ton of stem	Nutrients Removed lbs/dry ton of tops
Biomass (dry tons/acre)	30.9	37.9	7.0	23		
C (dry tons/acre)	15.4	18.9	3.5	23	1000	1000
N (lbs/acre)	54.2	120.7	66.5	123	1.8	9.5
P (lbs/acre)	4.4	9.9	5.5	127	0.1	0.8
K (lbs/acre)	33.7	57.4	23.8	71	1.1	3.4
Ca (lbs/acre)	49.6	76.3	26.6	54	1.6	3.8
Mg (lbs/acre)	13.2	20.4	7.1	54	0.4	1.0

Adapted from Tew, Morris, & Allen, 1986

Wood Nutrient Concentrations - Species Differences

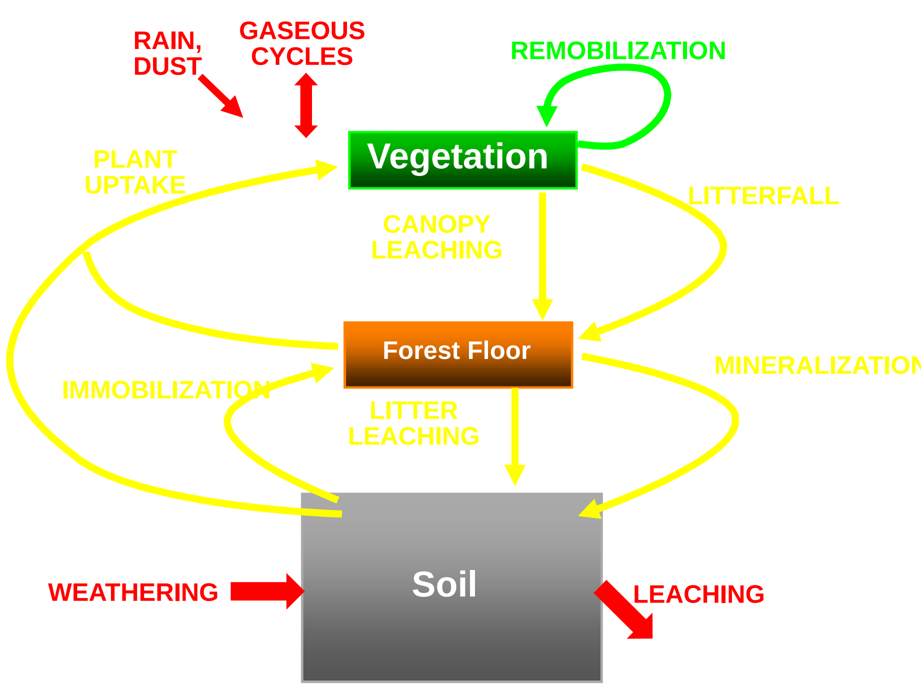


From Johnson et.al., 1990

Nutrient Pool Sizes
Mature Forest Stands in the SE USA

	N	P	K	Ca	Mg
	lbs/acre				
Vegetation	300 – 500	20-60	100-350	200-700	40-120
Forest Floor	200-400	10-30	20-40	100-200	20-40
Soil	2000-8000	100-500	>500	>1000	>500
Total	3000-9000	100-600	600+	2000+	550+

Soil N is total, soil P is extractable, soil K, Ca, and Mg are exchangeable

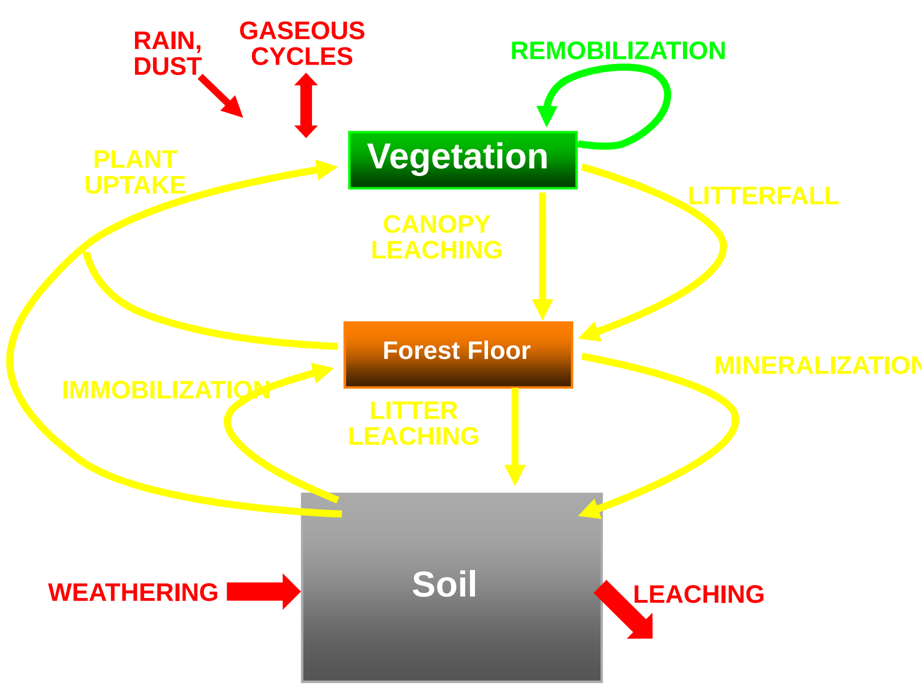


Nutrient Outputs Below Rooting Zone

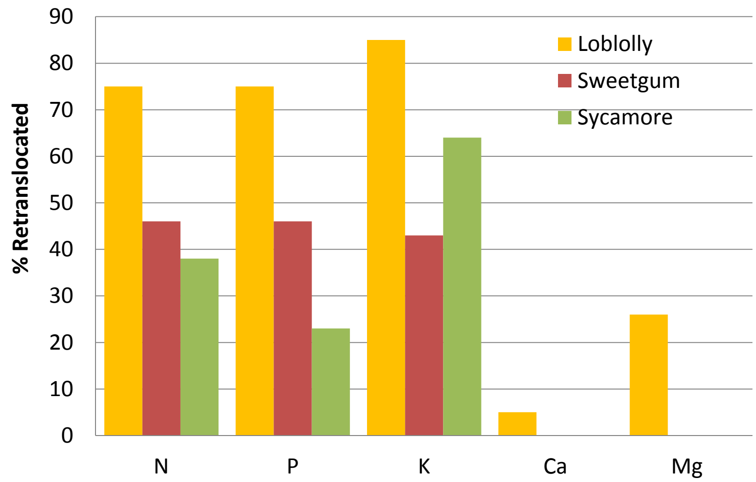
kg/ha

	N	P	K	Ca	Mg
Loblolly Pine Santee, SC	0	0	1.0	9.3	2.1
Loblolly Pine Clemson, SC	0	0	0.7	1.2	0.9
Loblolly Pine Duke Forest	0	0	7.0	10.6	3.3
Mixed Hardwoods Maryland	0.3	0	3.8	4.3	3.5

From: Binkley et.al. 1989

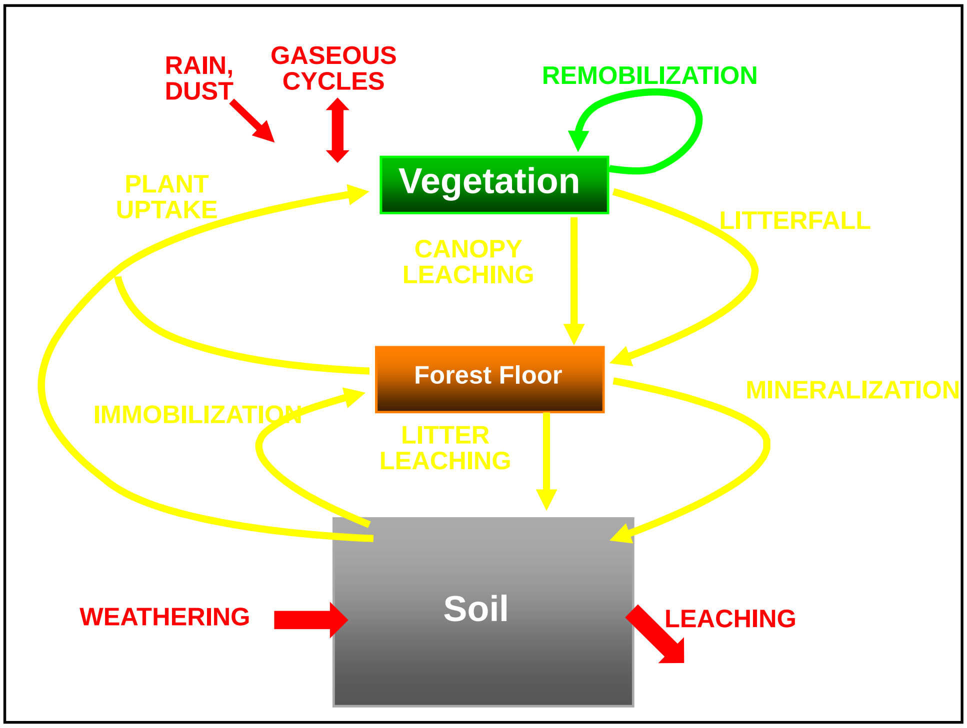


RETRANSLOCATION FROM FOLIAGE



Mobility

- Very mobile
  - N, P, K
- Intermediate mobility
  - Mg, S, Mn, Cu, Zn
- Immobile
  - Ca, B, Fe



How much N, P, K…. are needed to grow a ton of wood?

Loblolly Pine Nutrient Use
SETRES Control – Age 8, CAI = 1.8 tons/acre/yr - LAI = 0.6

	N	P	K	Ca	Mg
	lbs/acre				
Foliage	18.6	1.9	5.9	3.5	1.6
Branch	2.6	0.4	1.2	1.7	0.4
Stem	2.6	0.4	1.8	1.6	0.5
Coarse Roots	1.7	0.3	1.6	1.3	0.4
Fine Roots	12.8	1.3	4.0	3.8	1.1
Total	38.2	4.1	14.5	11.9	3.9
Nutrient/ton wood	21.2	2.3	8.0	6.6	2.2

From Albaugh, Allen, & Fox 2008

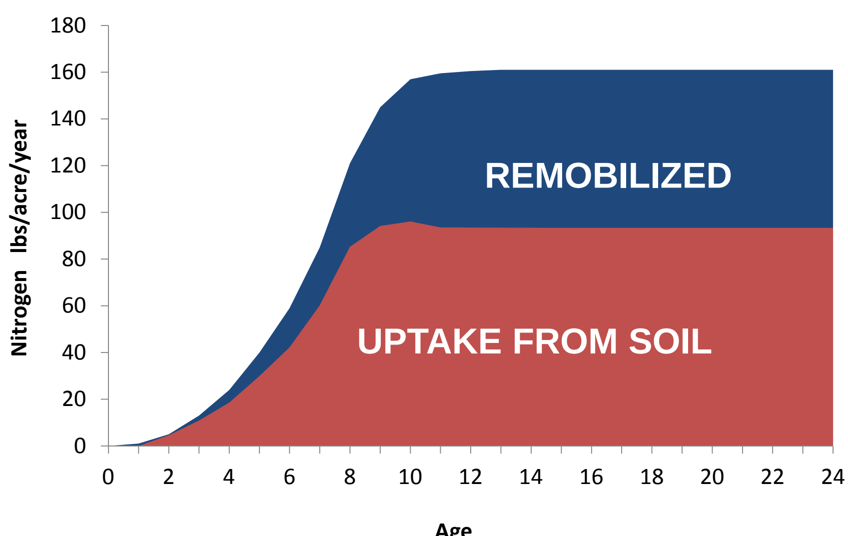
Loblolly Pine Nutrient Use

SETRES Fert Only – Age 21, CAI = 7.1 tons/acre/yr - LAI = 2.6

	N	P	K	Ca	Mg
	lbs/acre				
Foliage	75.3	6.8	28.3	9.4	5.1
Branch	8.4	1.0	4.1	4.0	1.3
Stem	7.2	0.4	3.1	3.6	1.3
Coarse Roots	6.3	0.5	4.7	1.8	0.4
Fine Roots	14.4	1.3	3.8	3.3	1.1
Total	111.5	10.1	44.0	22.1	9.2
Nutrient/ton wood	15.7	1.4	6.2	3.1	1.3

From Albaugh, Allen, & Fox 2008

Potential Nutrient Use

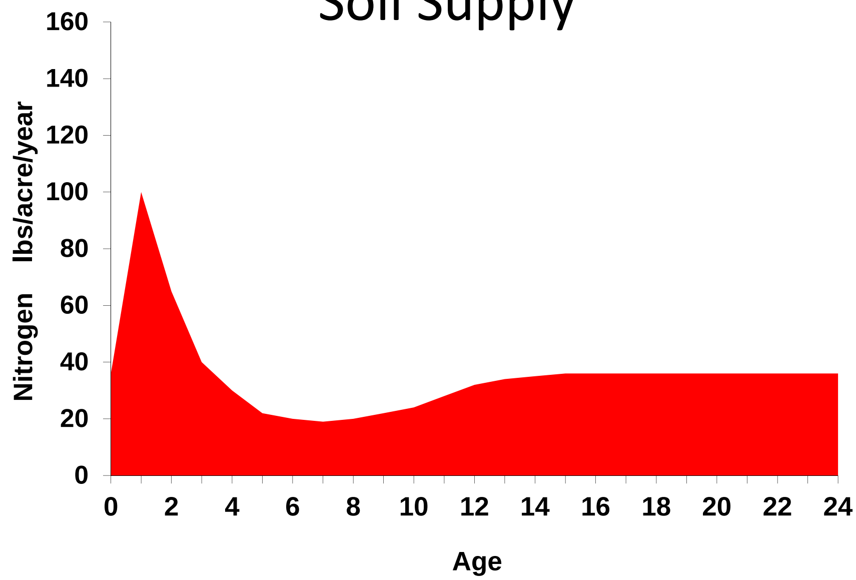


Adapted from Allen et al 1991

How much N, P, K…. are needed to grow a ton of wood?

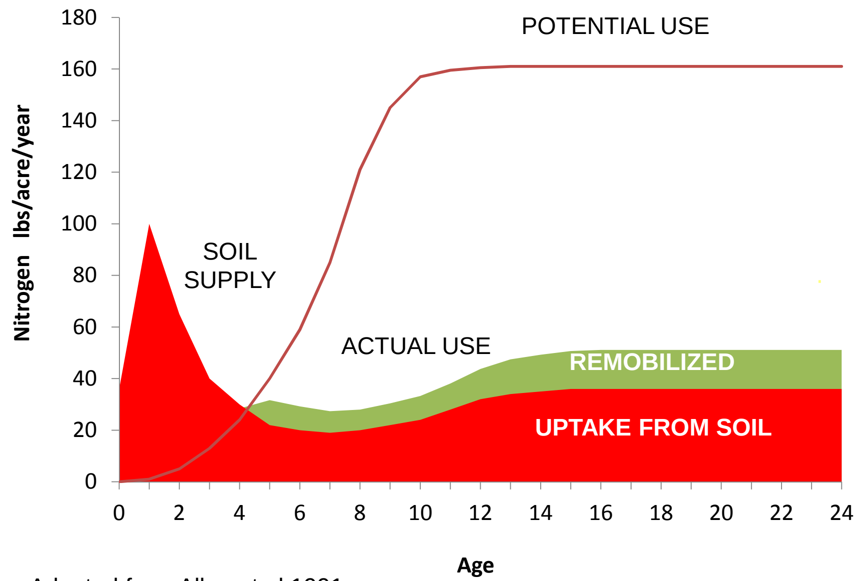
How much N, P, K… can the soil supply?

Soil Supply



Adapted from Allen et al 1991

Nitrogen Deficiency



Adapted from Allen et al 1991

Nutrient Limitations

develop where or when

Soil Supply < Potential Stand Use

Where does the nitrogen come from?

Fixation of atmospheric N
into organic matter

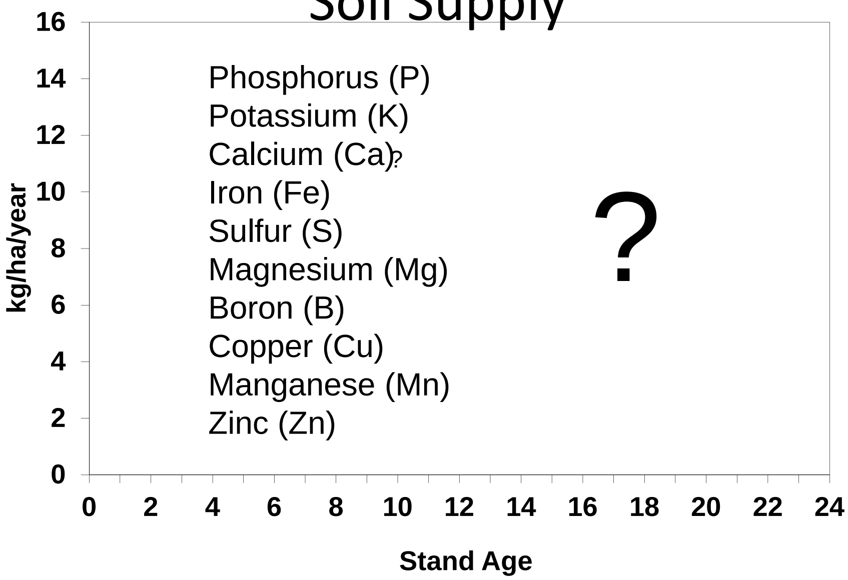
Factors Influencing N Mineralization

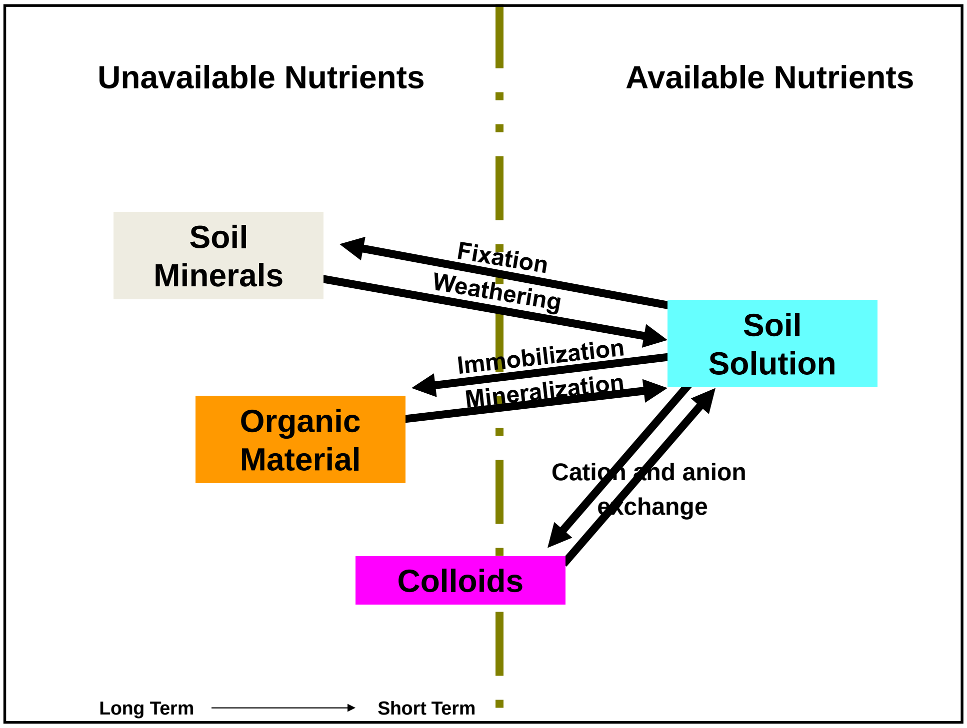
- Environmental conditions that influence microbial activity
  - Temperature
  - Aeration
  - Moisture
- Substrate (Labile Carbon)
  - Quantity
  - Type of compounds

Big Questions

- What is the capacity of soils to supply nutrients to forest stands?
- What nutrient(s) already limit stand growth?
- Can fertilization be used to effectively ameliorate existing and future nutrient limitations?

Soil Supply





Silviculture in the 21st Century

- Manipulation of:
  - Species composition
    - Species, genotypes, clones
  - Stocking
    - Quantity and distribution of crop and non-crop vegetation
  - Site resource availability
    - Quantity and quality of the soil rooting environment

to optimize value for the current landowner and future generations

Site Resource Availability

Natural variation through time and potential for management

Potential for change with management activity	Natural change through time	
	No	Yes
No	Fixed Non-manipulatable	Variable Non-manipulatable
Yes	Fixed Manipulatable	Variable Manipulatable

Soil Resources

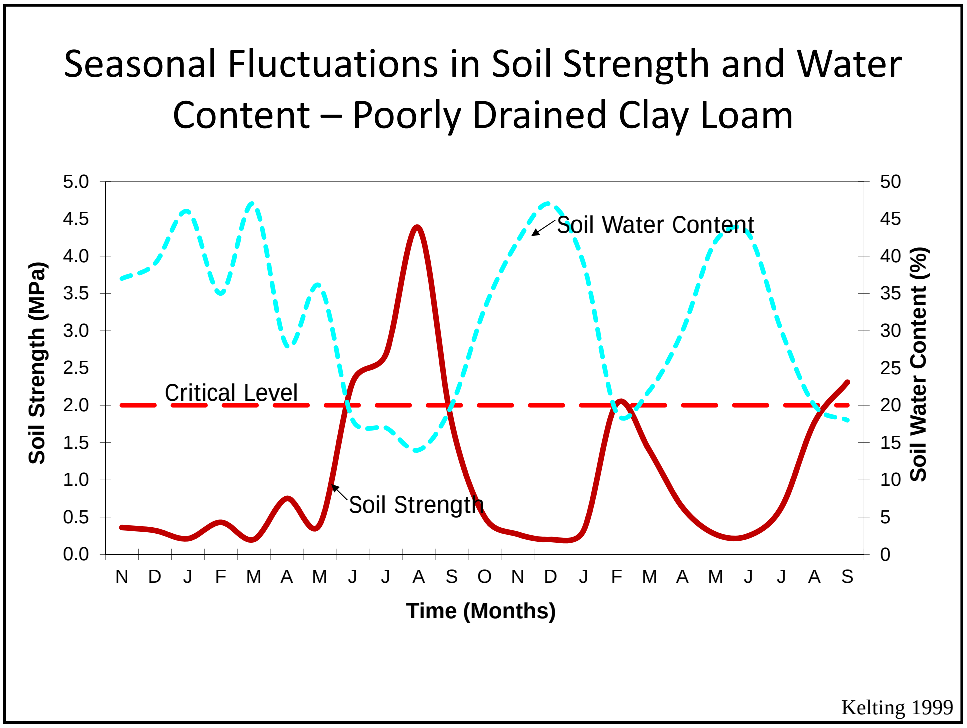
- Quantity - Soil Volume
  - Depth to restrictive layer (water table, bedrock, hardpan, ironstone)
  - % rock
- Quality - Physical environment
  - Soil strength, available water holding capacity
  - Aeration
- Quality - Chemical environment
  - Nutrient availability, acidity/alkalinity

Soil, Site, and Climatic Factors Affecting Soil Strength

Potential for change with management activity	Natural change through time	
	No	Yes
No	**Texture** **Type of Clay**	**Precipitation**
Yes	**Organic Matter** **Porosity** **Water Table** **Soil Water Content**	

Soil, Site, and Climatic Factors Affecting Soil Water Availability

Potential for change with management activity	Natural change through time	
	No	Yes
No	**Texture** **Type of Clay** ***Landscape Position***	**Precipitation** ***Vapor Pressure Deficit***
Yes	***Soil Depth*** **Organic Matter** **Porosity** **Water Table** ***Irrigation***	

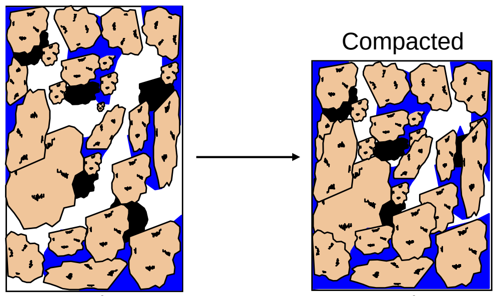

Seasonal Fluctuations in Soil Strength and Water Content – Poorly Drained Clay Loam
Soil Strength (MPa)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Soil Water Content (%)
50
45
40
35
30
25
20
15
10
5
0
Soil Water Content
Critical Level
Soil Strength
N D J F M A M J J A S O N D J F M A M J J A S
Time (Months)
Kelting 1999

Soil Compaction

Compression of an unsaturated soil resulting in a reduction in pore volume

Undisturbed

Compacted



1.32 g/cm3
50% Solid
50% Pores

1.60 g/cm3
60% Solid
40% Pores

Key Factors Affected:

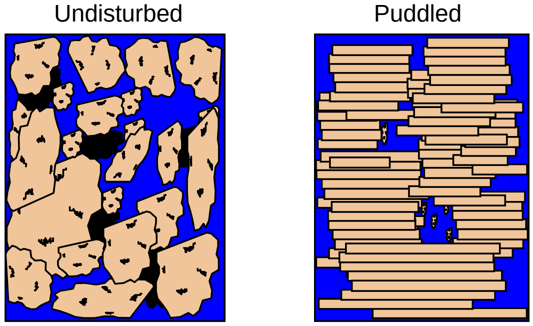
- Bulk Density ↑
- Soil Strength ↑
- Soil Aeration ↓
- Water Movement ↓

Soil Puddling

Deformation of a saturated soil resulting in the destruction of soil structure

Undisturbed

Puddled



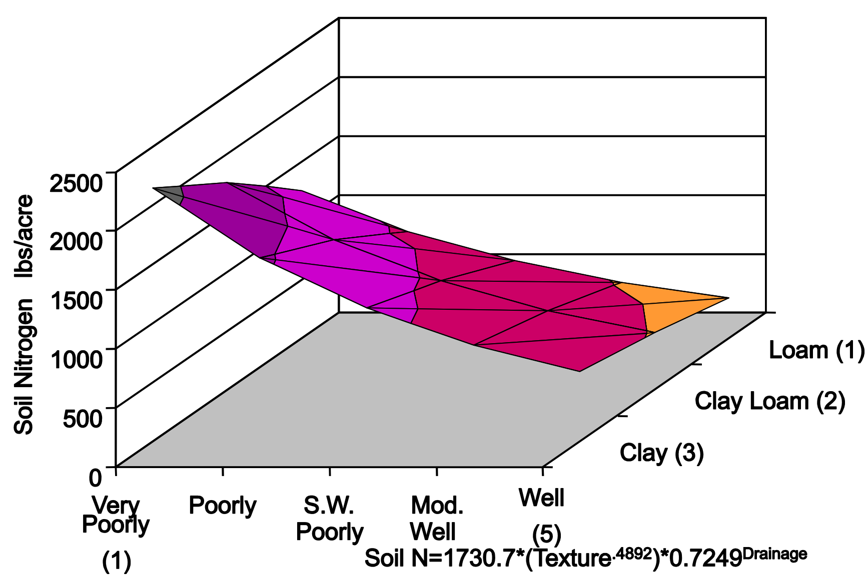
Key Factors Affected:

- Soil Aeration ↓
- Water Movement ↓

Soil, Site, and Climatic Factors Affecting Soil Nitrogen Availability

Potential for change with management activity	Natural change through time: No	Natural change through time: Yes
No	Texture Type of Clay Landscape Position	Precipitation Temperature
Yes	Soil Depth Organic Matter Aeration Porosity Soil Water Content *Microbial Populations* Nitrogen Additions	

Soil Nitrogen as a function of texture and drainage Surface 4 inches



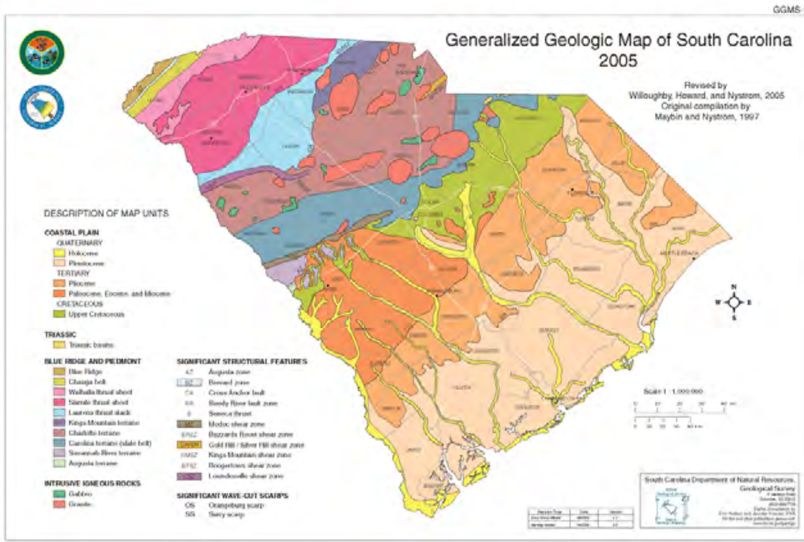
Soil, Site, and Climatic Factors Affecting Soil Phosphorus Availability

Potential for change with management activity	Natural change through time	
	No	Yes
No	*Parent Material* Texture Type of Clay Landscape Position	Precipitation Temperature
Yes	Soil Depth Organic Matter Aeration Porosity Phosphorus Additions	Soil Water Content Microbial Populations

Soil, Site, and Climatic Factors Affecting Soil Calcium Availability

Potential for change with management activity	Natural changes through time	
	No	Yes
No	Parent Material Texture Type of Clay Landscape Position	Precipitation
Yes	Soil Depth Calcium Additions	Soil Water Content

Geology of South Carolina



Nutrients in Piedmont Rocks

Nutrient	Granite	Diorite	Gabbro	Ultrabasic	Shale	Sandstone	Argillite
	- - - - - - - - - - - - - -			ppm - - - - - - - - - - - - - - - - -			
P	600	920	1,100	220	700	170	1,500
K	42,000	25,200	8,300	40	26,600	10,700	25,000
Ca	5,100	25,300	76,000	25,000	22,100	39,100	29,000
Mg	1,600	9,400	46,000	204,000	15,000	7,000	21,000
S	300	300	300	300	2,400	240	1,300
Mn	390	540	1,500	1,620	850	0	6,700
Cu	10	30	87	10	45	0	250
Zn	39	60	105	50	95	16	165
B	10	9	5	3	100	35	230

Adapted from Turekian and Wedepohl (1961)