2012

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Donald J. Kaczmarek
USDA Forest Service

Brian C. Wachelka
Formerly MeadWestvaco Forest Research

Jeff Wright
ArborGen Inc.

Victor C. Steel
ArborGen Inc.

Doug P. Aubrey
Georgia Southern University, daubrey@georgiasouthern.edu

See next page for additional authors

Recommended Citation

Kaczmarek, Donald J., Brian C. Wachelka, Jeff Wright, Victor C. Steel, Doug P. Aubrey, David R. Coyle, Mark D. Coleman. 2012. "Development of High-Yielding Sweetgum Plantation Systems for Bioenergy Production in the Southeastern United States." *Biology Faculty Presentations*. Presentation 1. source: http://www.woodycrops.org/NR/rdonlyres/B3645F29-CA4D-4F49-AE4A-8612EDC48D7B/3463/3DonaldJKaczmarek.pdf
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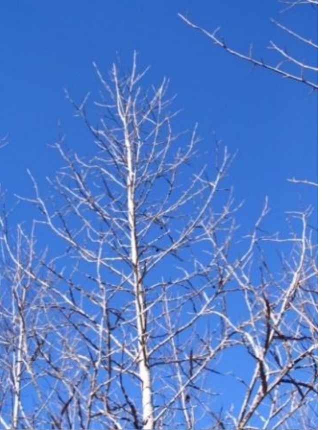

Development of High-Yielding Sweetgum Plantation Systems for Bioenergy Production in the Southeastern United States

Donald J. Kaczmarek[1], Brian C. Wachelka[2], Jeff Wright[3], Victor C. Steel[3], Doug P. Aubrey[4], David R. Coyle[5], and Mark D. Coleman[6]

[1]USDA Forest Service, Southern Research Station, Aiken, SC.
[2]Formerly MeadWestvaco Forest Research, Summerville, SC.
[3]ArborGen Inc., Ridgeville, SC.
[4]Georgia Southern University. Department of Biology. Statesboro, GA.
[5]University of Georgia. Warnell School of Forestry and Natural Resources. Athens, GA.
[6]University of Idaho Department of Forest, Rangeland, and Fire Sciences. Moscow, ID.

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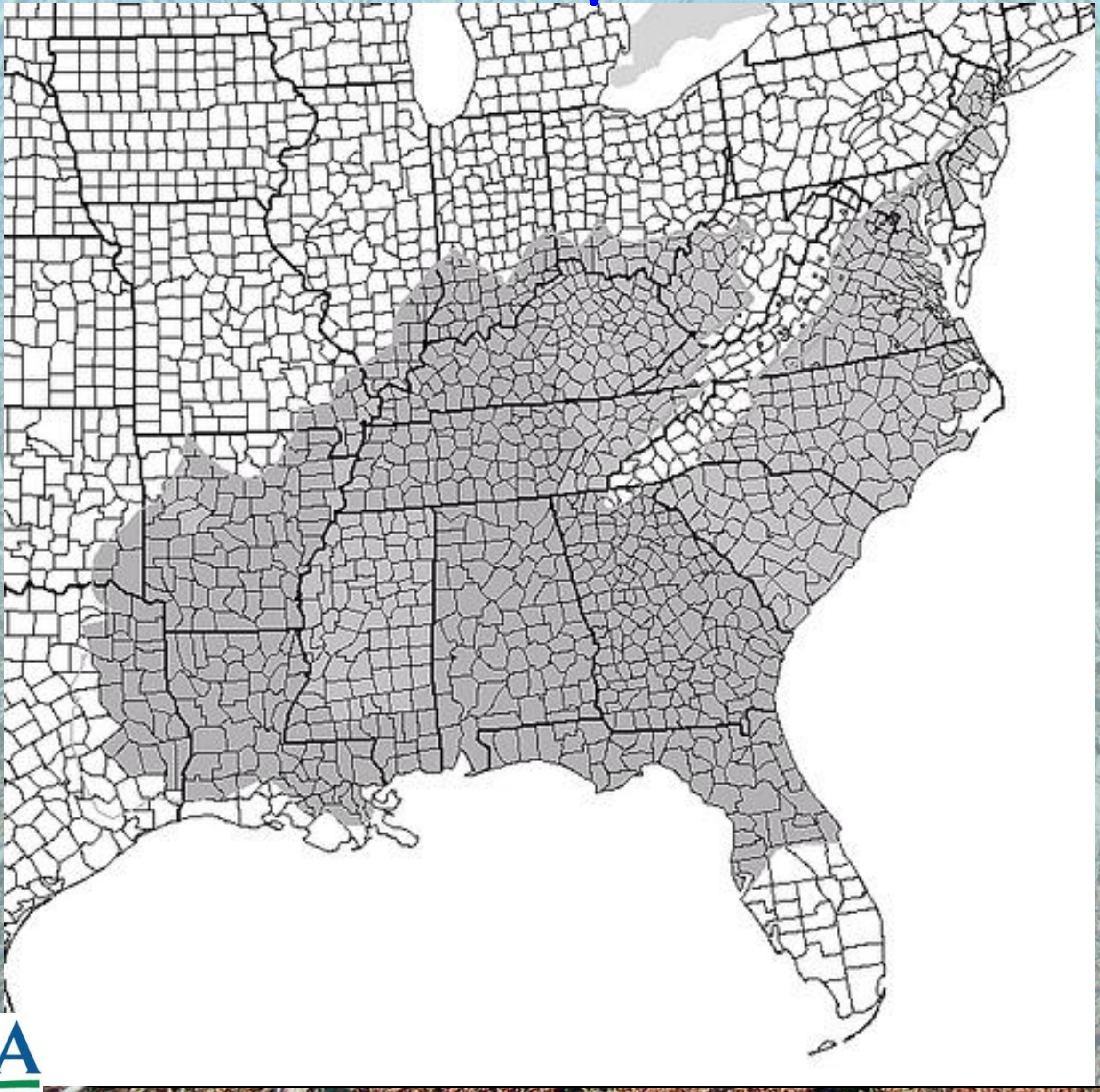
Potential Bioenergy Species For The Southeastern United States

- *Populus* species or hybrids
- Loblolly or slash pine
- Sweetgum
- Sycamore
- *Eucalyptus* species or hybrids
- Various grasses such as switchgrass, *Miscanthus,* or various tropical grasses
- Sorghum

Potential Advantages of Sweetgum for SRWC

- The most adaptable hardwood species across the region (similar to loblolly pine).
- It is a native species.
- Silvicultural regimes for establishing and growing sweetgum are well understood and practical.
- Productivity range: 6-10 Green tons/ac/yr
- Existing genetic resources for tree improvement.
- Generally insect and disease resistant.

Sweetgum Is One Of The Most Widely Distributed Hardwood Species In The Eastern US



Sweetgum also occurs in northwestern and central Mexico, Guatemala, Belize, El Salvador, Honduras, and Nicaragua

14-Year Old Sweetgum Plantation, Berkeley County, SC (135 Mg/ha, 9.6 Mg/Ha/year)

Potential Disadvantage of Sweetgum for SRWC

- Sweetgum has a reputation for more moderate levels of productivity. Is this view valid in light of new research findings?
- Large-scale, extensive commercial deployment has not occurred.

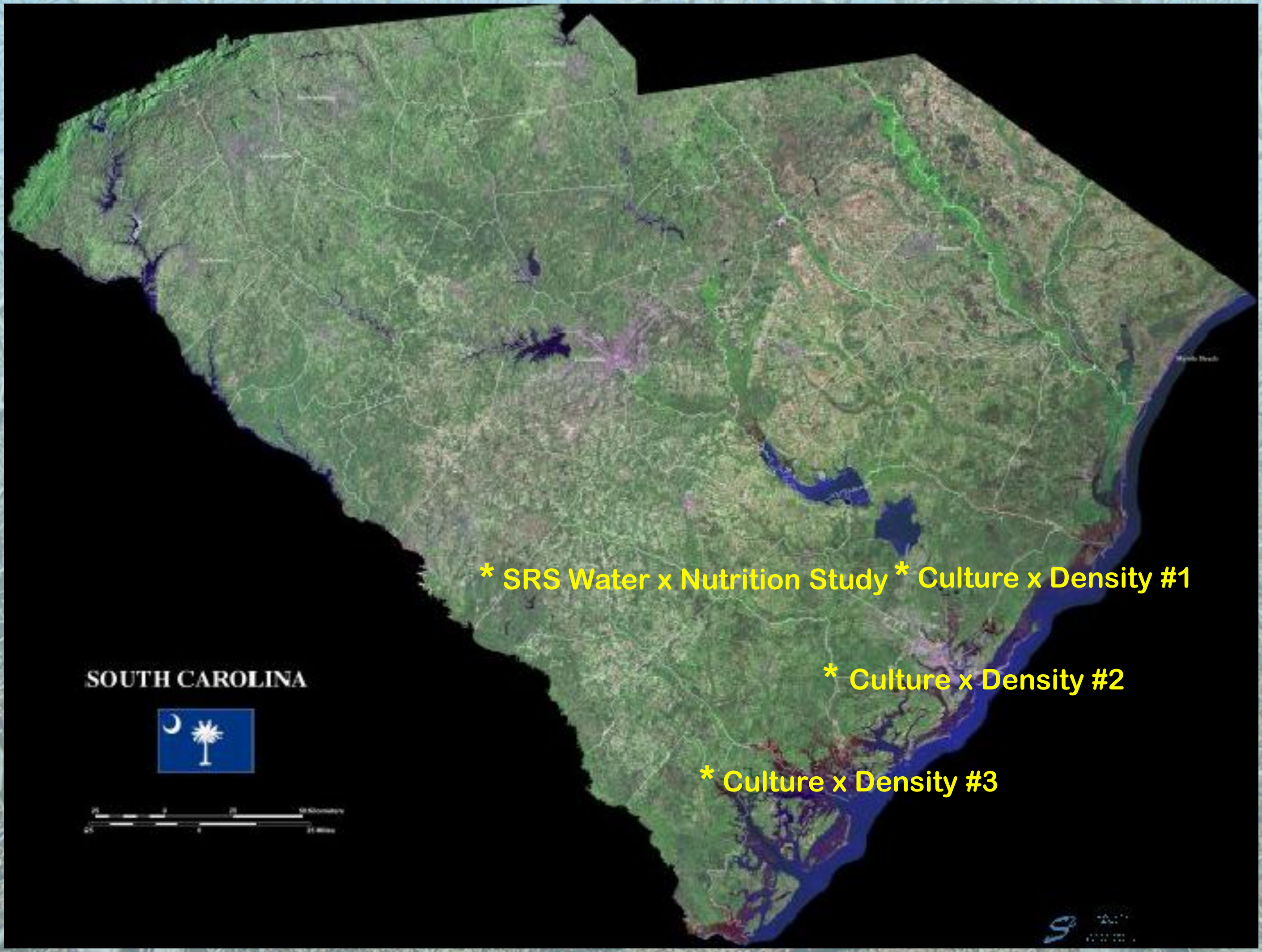
Two Series of Sweetgum Research Studies Are Discussed

- Sweetgum Water × Nutrition Study at the Savannah River Site, a National Environmental Research Park in West Central South Carolina.
- Three separate locations of a Sweetgum Culture × Density Study installed by MWV (MeadWestvaco) in the Lower Coastal Plain of South Carolina.

Objectives

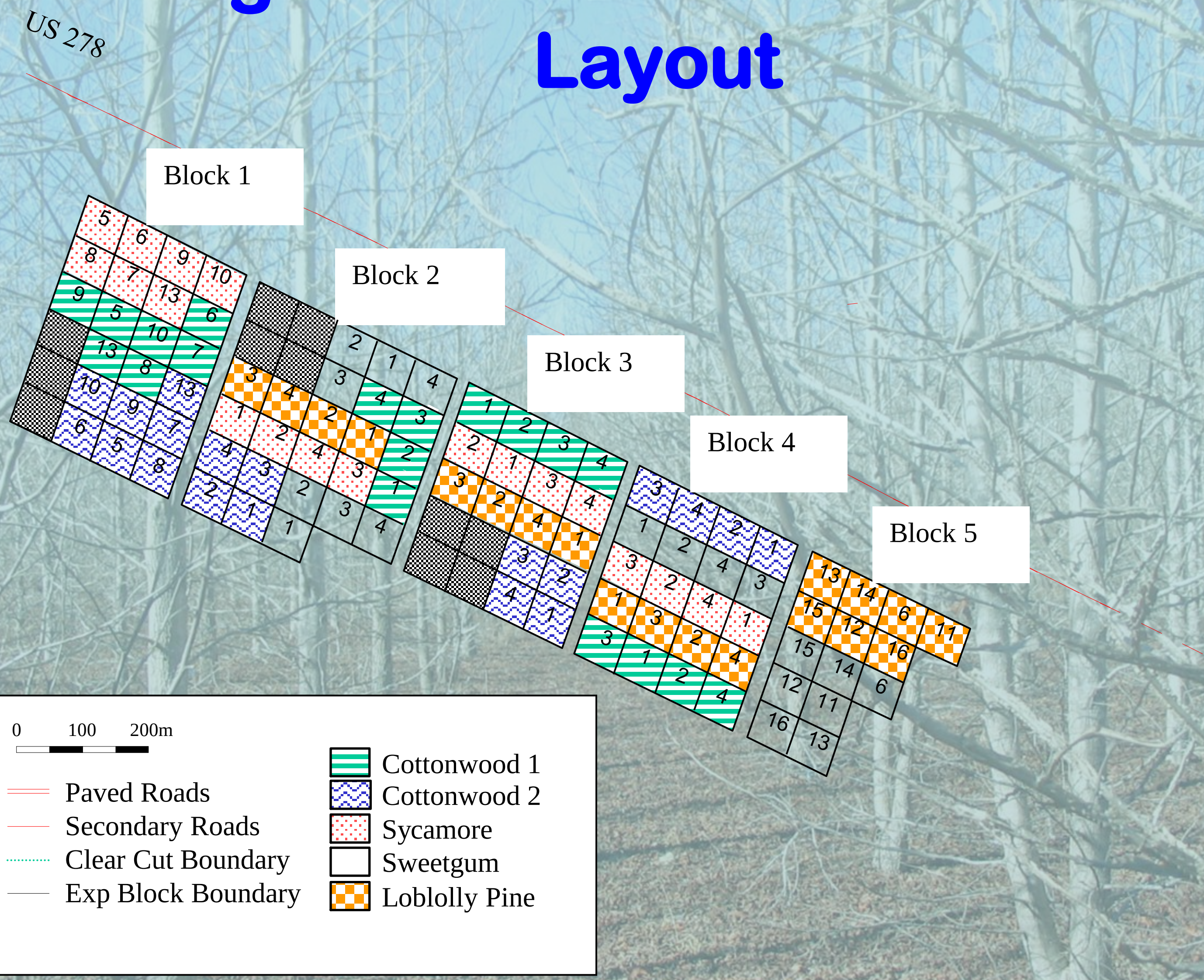
- To understand how altered water and nutrient availability influence productivity of sweetgum.
- To begin exploring soil nutrient supply and plant nutrient demand relationships.
- To understand how altered plantation densities and cultural regimes influence productivity.
- To project rotation length yield potentials based on midrotation measured growth.

Study Site Locations



Site Preparation Treatments Following Harvest of Mixed Pine Stand at SRS

Sweetgum Water × Nutrition Study Layout



Sweetgum Water × Nutrition Study At SRS

- Established in early February 2000 on a well-drained, deep, sandy Sandhill Test Location. Soil is a Blanton Sand.
- Study contains sweetgum, sycamore, 2 cottonwood clones, and loblolly pine. Only sweetgum results are presented.
- Genetic source was a single, select open-pollinated sweetgum family from MWV (LCP SC seed source).
- Planting density was fixed at 1,333 trees per hectare.

Sweetgum Water × Nutrition Study At SRS

- 2 × 2 Factorial Study with High and Low Water and Nutritional treatments.
- Water and Nutrients were added via drip irrigation system from April through October.
- Fertilizer sources were 7-0-7 NPK+ Ca, Mg, and micronutrients liquid fertilizer mix.
- Nitrogen application rates were 45 kg/ha in years 1 and 2 and 90 kg/ha in years 3 to 7. Total N application was 540 Kg/Ha.
- Complete weed control (Ages 1 to 7) was achieved through premergent (oxyflourfen) and multiple directed spray applications (glyphosate).

Sweetgum Culture × Density Studies

- Established in early February 2001 on 3 diverse site and soil types in the LCP of South Carolina. All sites were cutover pine sites without any irrigation.
  - Site 1: Very poorly drained. Byars soil series.
  - Site 2: Moderately-well drained. Yauhannah soil.
  - Site 3: Poorly Drained. Argent soil.
- At each site, the treatment structure is a 4 × 2 factorial with 4 planting densities and 2 fertilization rates. The experimental design is a RCBD with 3 reps.

Sweetgum Culture × Density Studies

- Density Treatments: 897, 1076, 1346, and 1794 trees per hectare.
- High and Low nutritional regimes:
  - Low-No added N.
  - High: N and P applied at rate of 168 kg/ ha N and 56 kg/ha P at the start of the 3rd season.
- Competition control:
  - Pre-emergent aerial (Oust and Escort, March) in years 1, 2 and 3
  - Single, directed spray (Oust and Glyphosate, June/July) in the summer of years 1 and 2.
  - Late summer directed spray application of Oust and glyphosate was made near the end of the 3rd growing season.
  - No competition control in years 4 through 7.

All 3 Locations of the Culture × Density Test were Bedded Before Establishment

Bedding Can Be Critical On Many Lower Coastal Plain Soils

Sweetgum Culture × Density Study Location 2

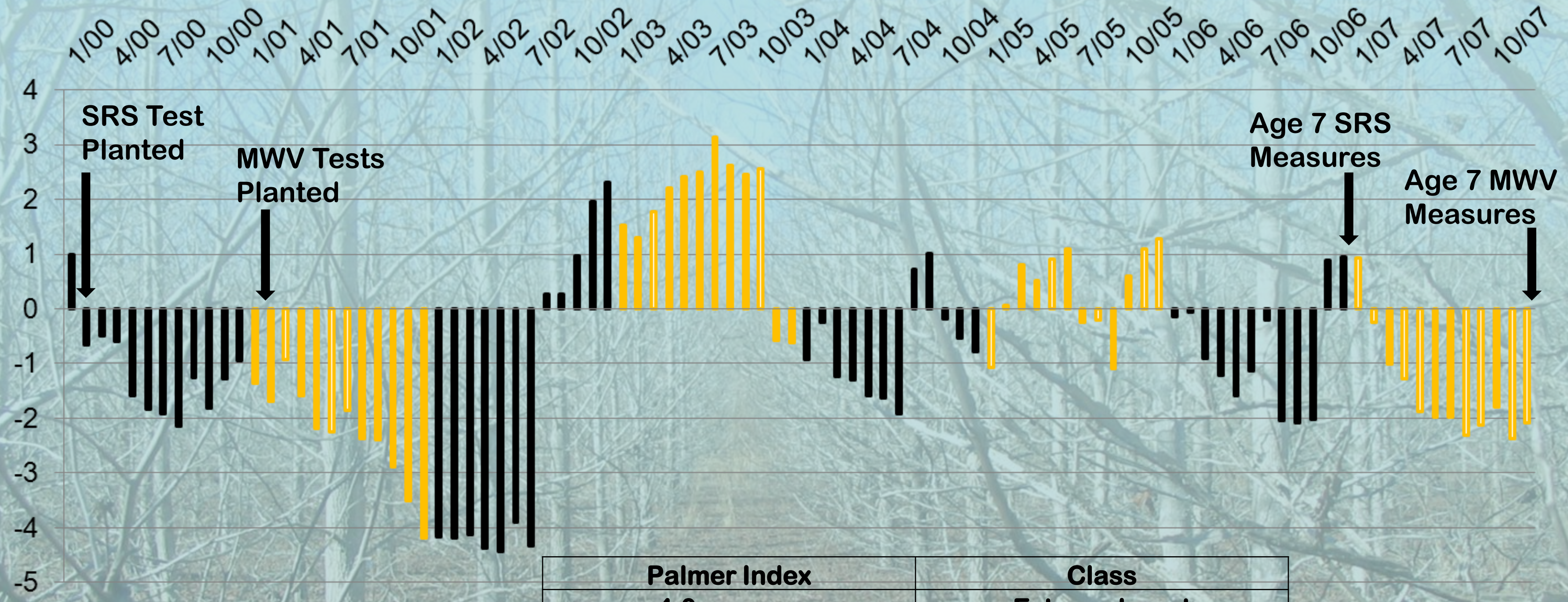
Methodology

- Foliage samples were collected annually for the first 3 growing seasons.
- For Culture × Density tests, *in-situ* N availability was assessed for the first 3 growing seasons at 28-day intervals using ion exchange resins.
- At age 7, Survival and growth assessments were made in all studies (survival, height, DBH, and stem form assessments).
- Within plot (GINI Coefficients)and between plot variability (CV's) were assessed for each location.

Methodology

- Destructive harvests in the SRS test at ages 7, 8, and 11 (58 Total trees harvested) were used to develop total aboveground biomass equations based on DBH^2 and tree height.
- Total aboveground dry biomass included stem wood, stem bark, and branch components, but not foliage. (R^2=0.974).
- We predicted age 15 growth based on age 7 measures using proprietary sweetgum growth and yield models developed by Jerry Hansen for International Paper Corporation.

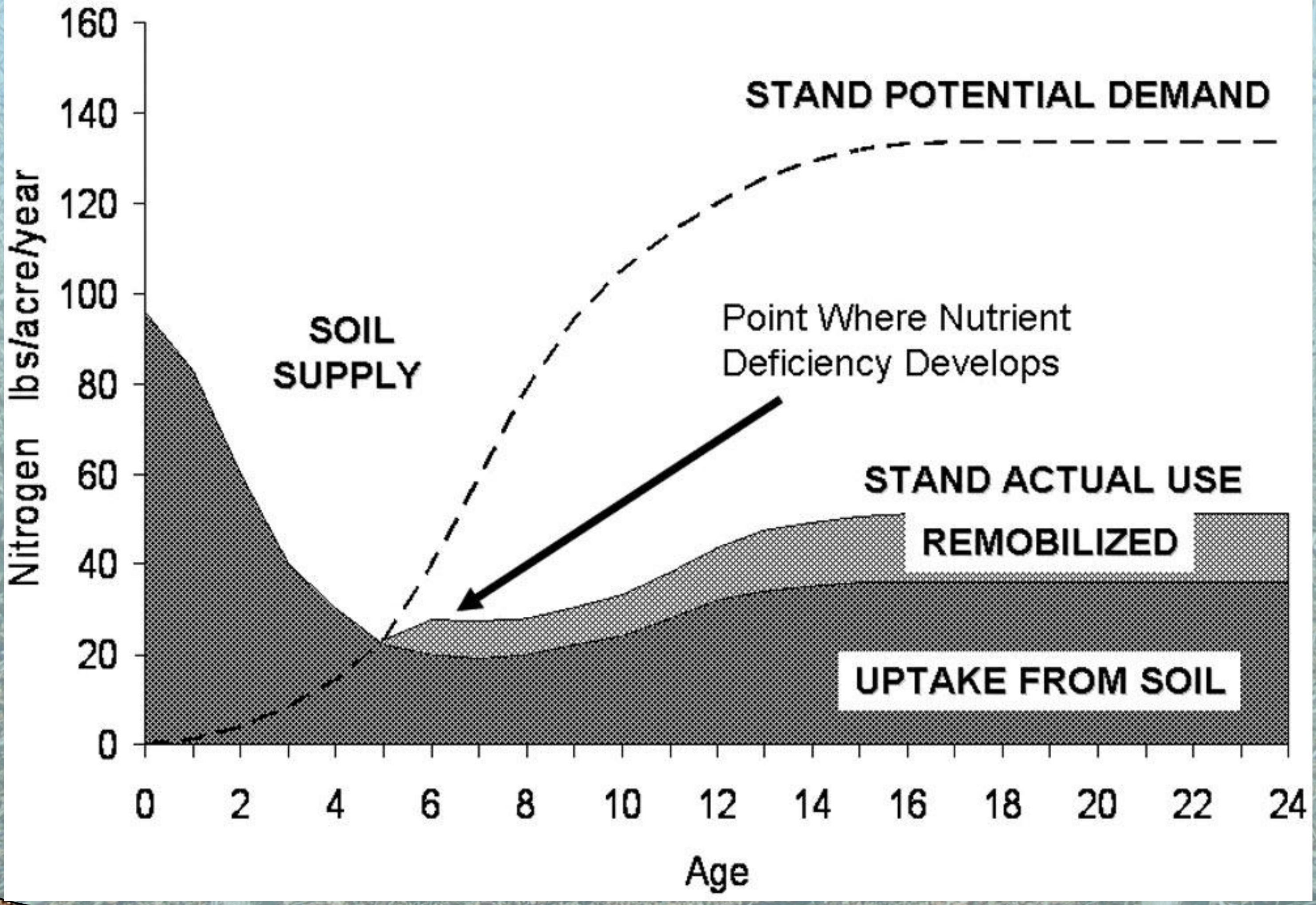
Regional South Carolina Palmer Drought Severity Index From January 2000 through December 2007



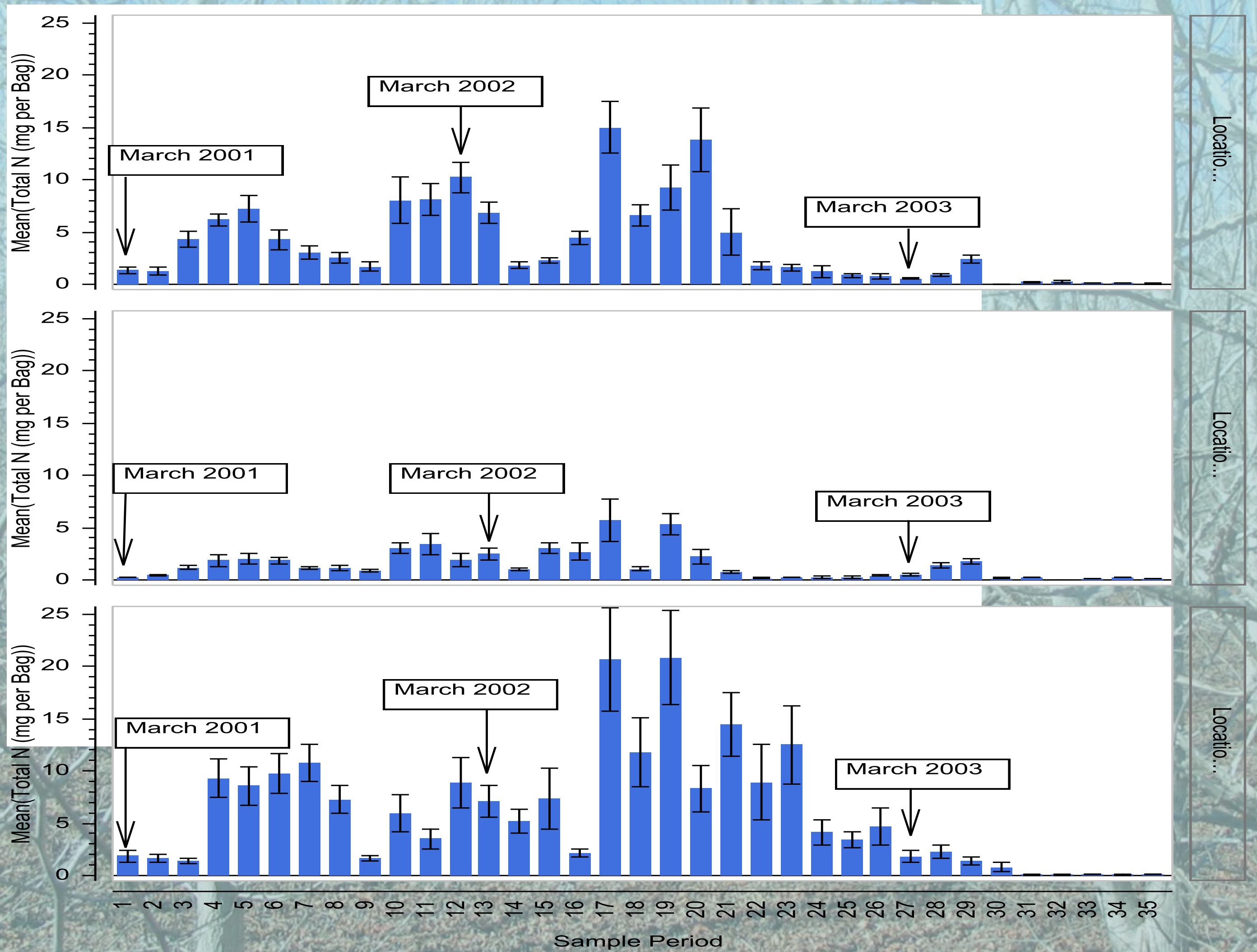
Black Bars Indicate Even Years (2000, 2002, etc.)
Yellow Bars Indicate Odd Years (2001, 2003,etc.)

Palmer Index	Class
4.0 or more	Extremely wet
3.0 to 3.99	Very wet
2.0 to 2.99	Moderately wet
1.0 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1.0 to -1.99	Mild drought
-2.0 to -2.99	Moderate drought
-3.0 to -3.99	Severe drought
-4.0 or less	Extreme drought

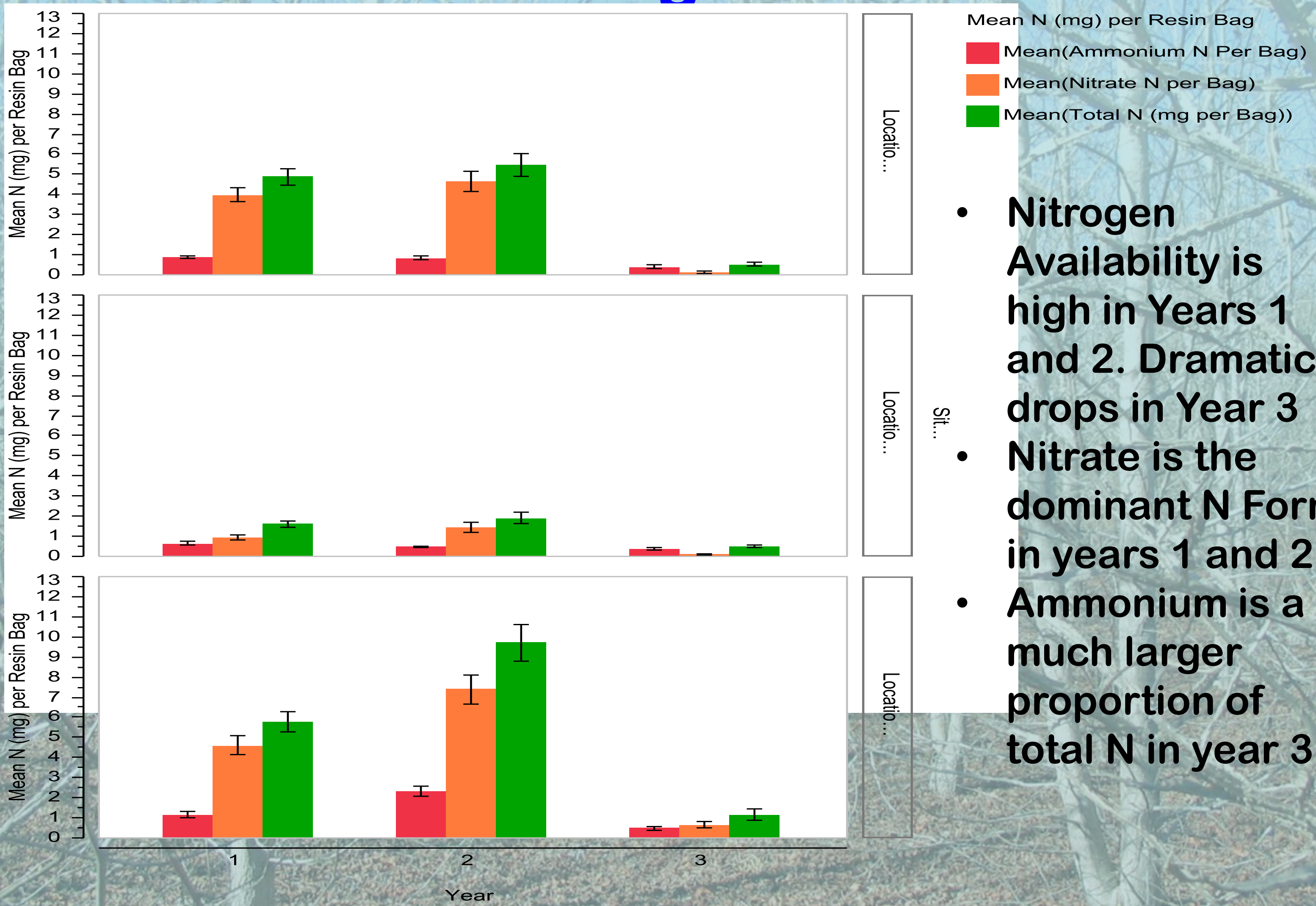
Hypothesized Relationship Between Soil N Supply and Potential and Actual Use of N as Related to Age (Fox et al. 2007)



Changes in Soil N Availability Over First 3 Growing Seasons (28-day Sampling Period)

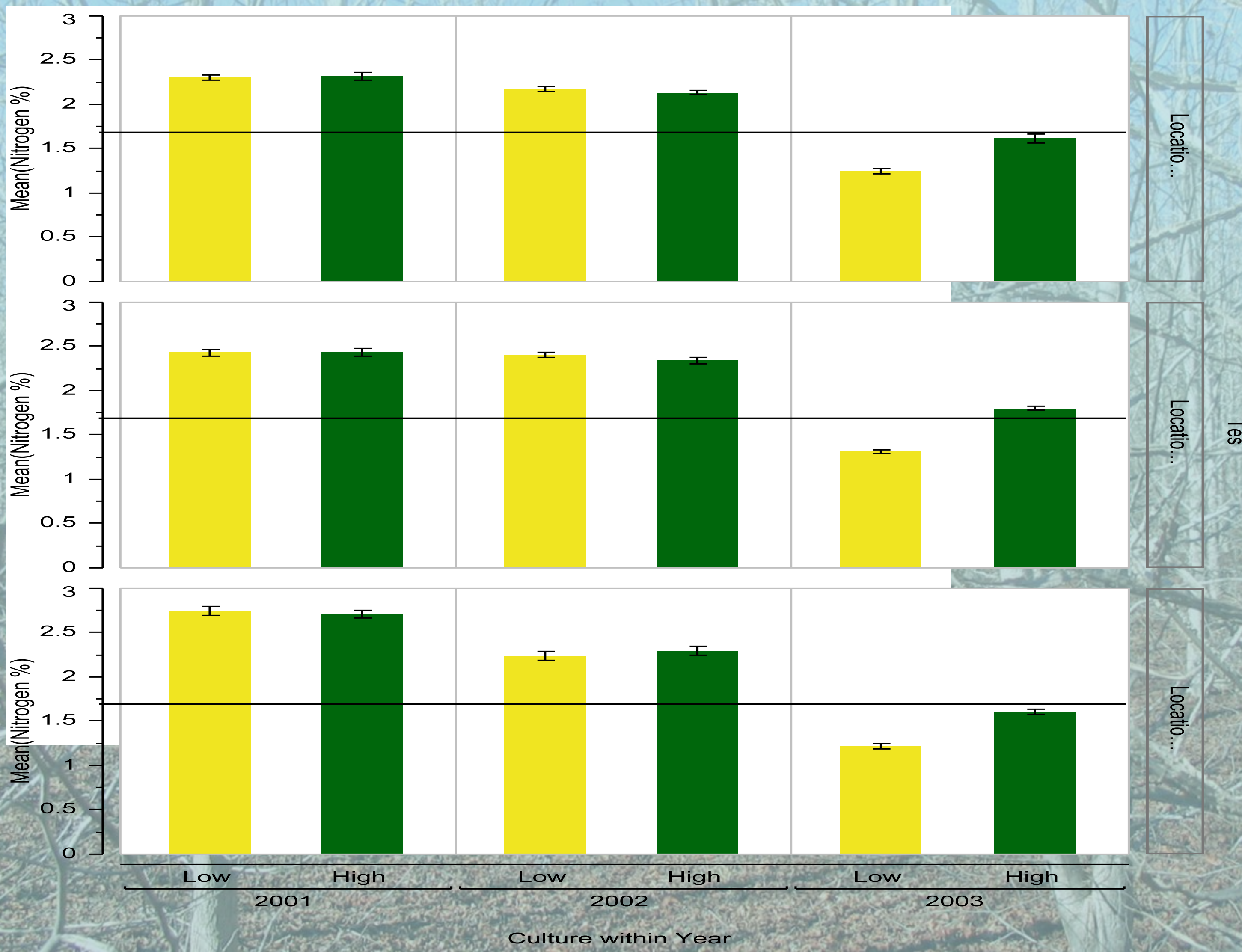


Temporal Changes By Year Over First 3 Growing Seasons

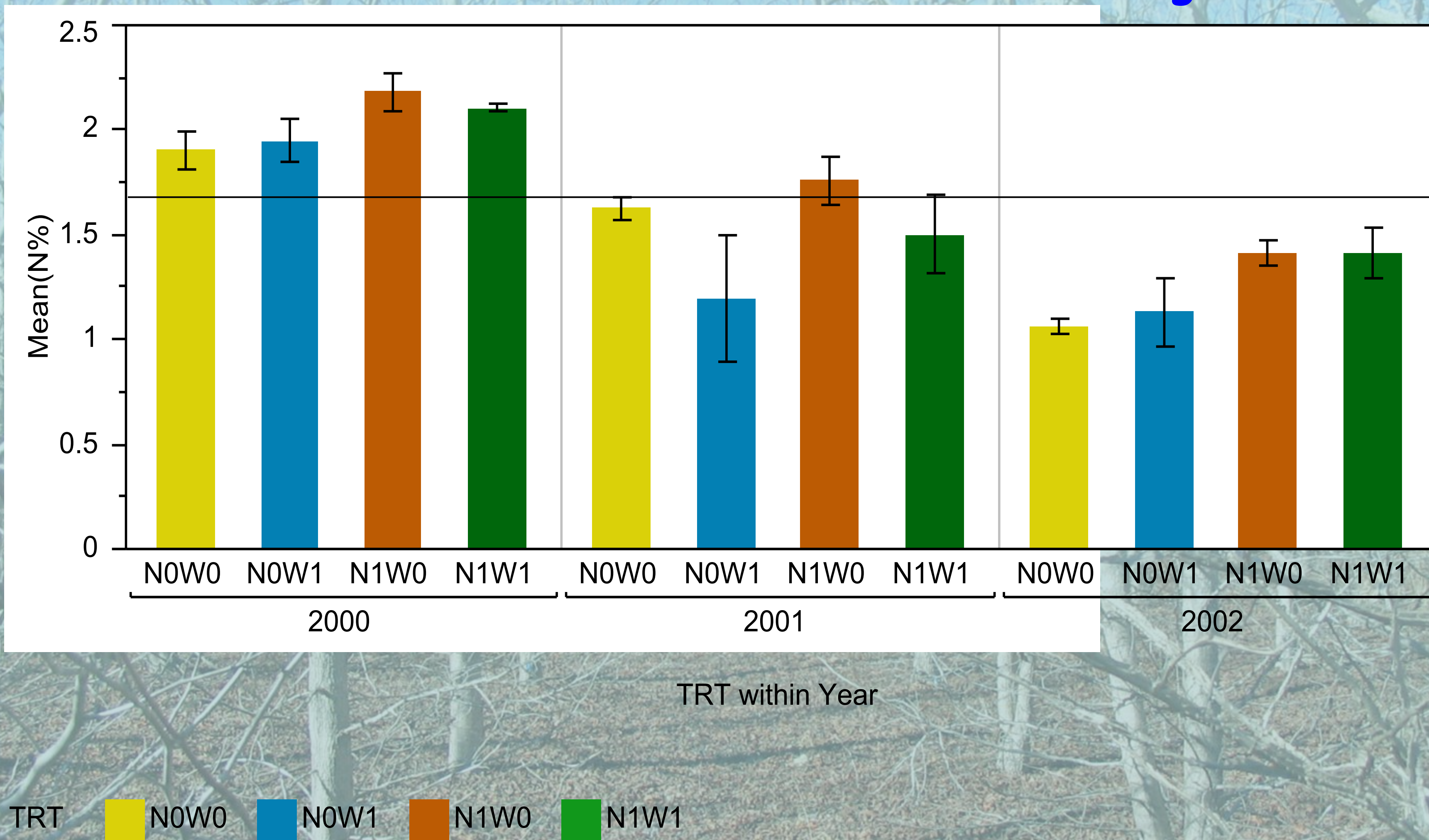


- Nitrogen Availability is high in Years 1 and 2. Dramatic drops in Year 3
- Nitrate is the dominant N Form in years 1 and 2.
- Ammonium is a much larger proportion of total N in year 3

Temporal Changes in Foliar Nitrogen %. Three Culture × Density Locations



Temporal Changes in Foliar Nitrogen %. SRS Water × Nutrition Study



ANOVA for SRS Water × Nutrition Study

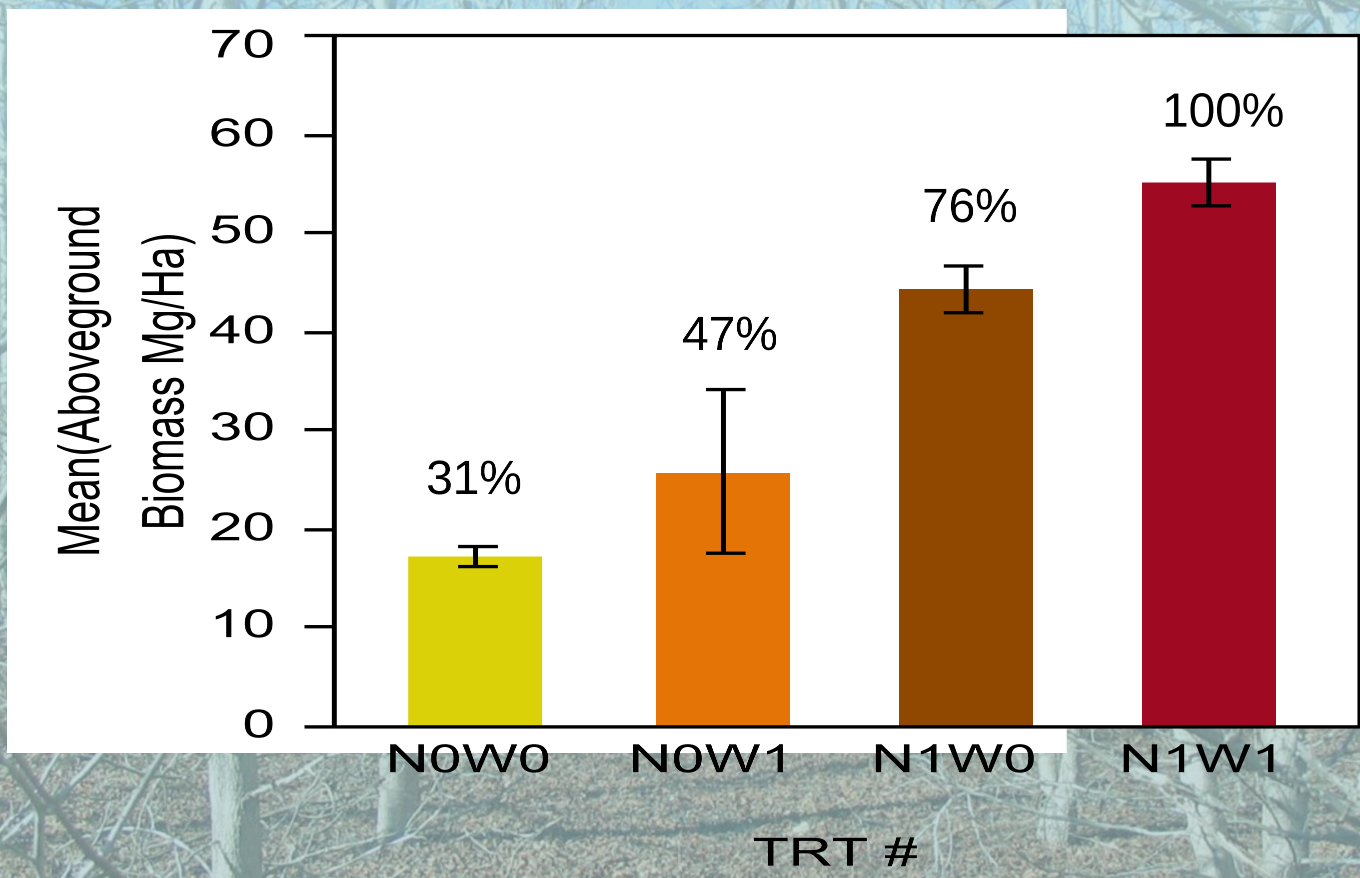
	Individual Tree Attributes			Stand Level Attributes		
Factor	*Height*	*DBH*	*Individual Tree Biomass*	*Survival*	*Basal Area/ Ha*	*Aboveground Biomass/Ha*
Block	**0.3064**	**0.4900**	**0.4084**	**0.4219**	**0.5011**	**0.4149**
Fertility	**0.0041**	**0.0049**	**0.0055**	**0.0300**	**0.0052**	**0.0053**
Water	**0.1977**	**0.2688**	**0.2349**	**0.0300**	**0.2451**	**0.2258**
Fertility x Water	**0.9590**	**0.9071**	**0.8061**	**0.0924**	**0.9983**	**0.8342**

Red Text Indicates Significance at 5% Level

Age 7 Growth Summary for SRS Water × Nutrition Study

	Individual Tree Attributes				Stand Level Attributes		
Treatment	*Height (m)*	*DBH (cm)*	*Individual Tree Biomass (kg)*	*Survival*	*Basal Area (m^2/Ha)*	*Aboveground Biomass (Mg/Ha)*	*Aboveground Biomass Mean Annual Increment (Mg/Ha/year)*
N0W0	**7.81**	**8.21**	**13.12**	**98.8**	**7.10**	**17.3**	**2.47**
N0W1	**8.69**	**9.23**	**19.40**	**100.0**	**9.44**	**25.9**	**3.69**
N1W0	**10.57**	**11.84**	**33.26**	**100.0**	**14.87**	**44.3**	**6.33**
N1W1	**11.41**	**12.72**	**41.26**	**100.0**	**17.20**	**55.0**	**7.86**

Age 7 Total Aboveground Yields: SRS Water × Nutrition Study



ANOVA for Sweetgum Culture × Density Study-Location 1

	Individual Tree Attributes			Stand Level Attributes		
Factor	*Height*	*DBH*	*Individual Tree Biomass*	*Survival*	*Basal Area/ Ha*	*Aboveground Biomass/Ha*
Block	**0.0441**	**0.5337**	**0.3263**	**0.6323**	**0.5006**	**0.4266**
Culture	**0.5588**	**0.7674**	**0.7970**	**0.0556**	**0.6935**	**0.7749**
Density	**0.0044**	**0.0077**	**0.0046**	**0.1360**	**0.0142**	**0.0052**
Culture x Density	**0.0235**	**0.2988**	**0.0937**	**0.2197**	**0.4346**	**0.2380**

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ANOVA for Sweetgum Culture × Density Study-Location 2

	Individual Tree Attributes			Stand Level Attributes		
Factor	*Height*	*DBH*	*Individual Tree Biomass*	*Survival*	*Basal Area/ Ha*	*Aboveground Biomass/Ha*
Block	**0.8669**	**0.0468**	**0.2520**	**0.5465**	**0.0161**	**0.1675**
Culture	**0.3381**	**0.0002**	**0.0053**	**0.6688**	**0.0011**	**0.0286**
Density	**0.1788**	**0.0200**	**0.0409**	**0.3599**	**0.0006**	**0.0445**
Culture x Density	**0.1735**	**0.2184**	**0.1260**	**0.9721**	**0.7290**	**0.2577**

Red Text Indicates Significance at 5% Level

ANOVA for Sweetgum Culture × Density Study-Location 3

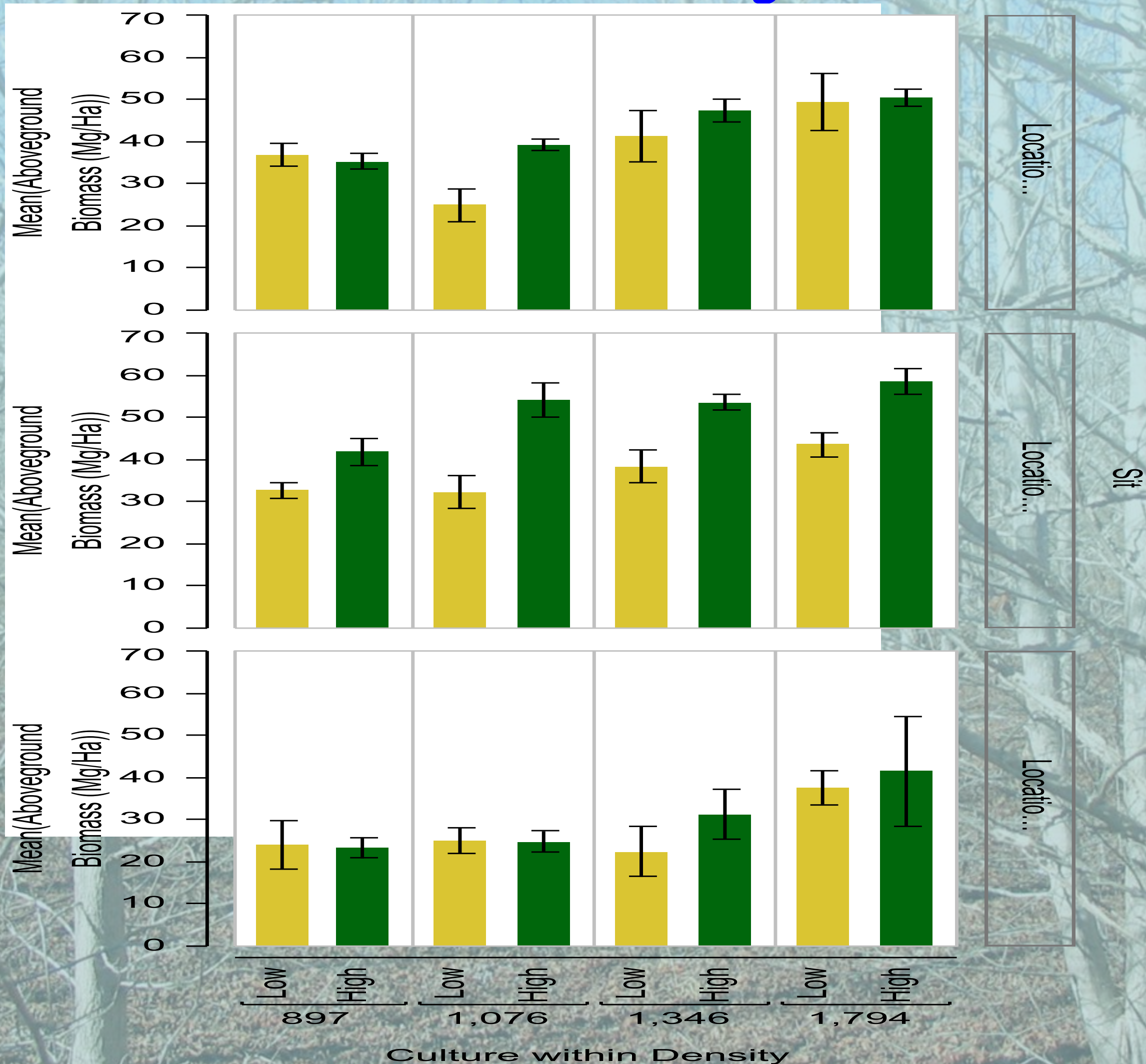
	Individual Tree Attributes			Stand Level Attributes		
Factor	*Height*	*DBH*	*Individual Tree Biomass*	*Survival*	*Basal Area/ Ha*	*Aboveground Biomass/Ha*
Block	**0.0810**	**0.0455**	**0.09610**	**0.9049**	**0.1042**	**0.1698**
Culture	**0.6470**	**0.6130**	**0.9510**	**0.4707**	**0.7788**	**0.9342**
Density	**0.4195**	**0.1381**	**0.3728**	**0.2828**	**0.0764**	**0.2778**
Culture x Density	**0.5940**	**0.4495**	**0.8070**	**0.4081**	**0.6168**	**0.8334**

Red Text Indicates Significance at 5% Level

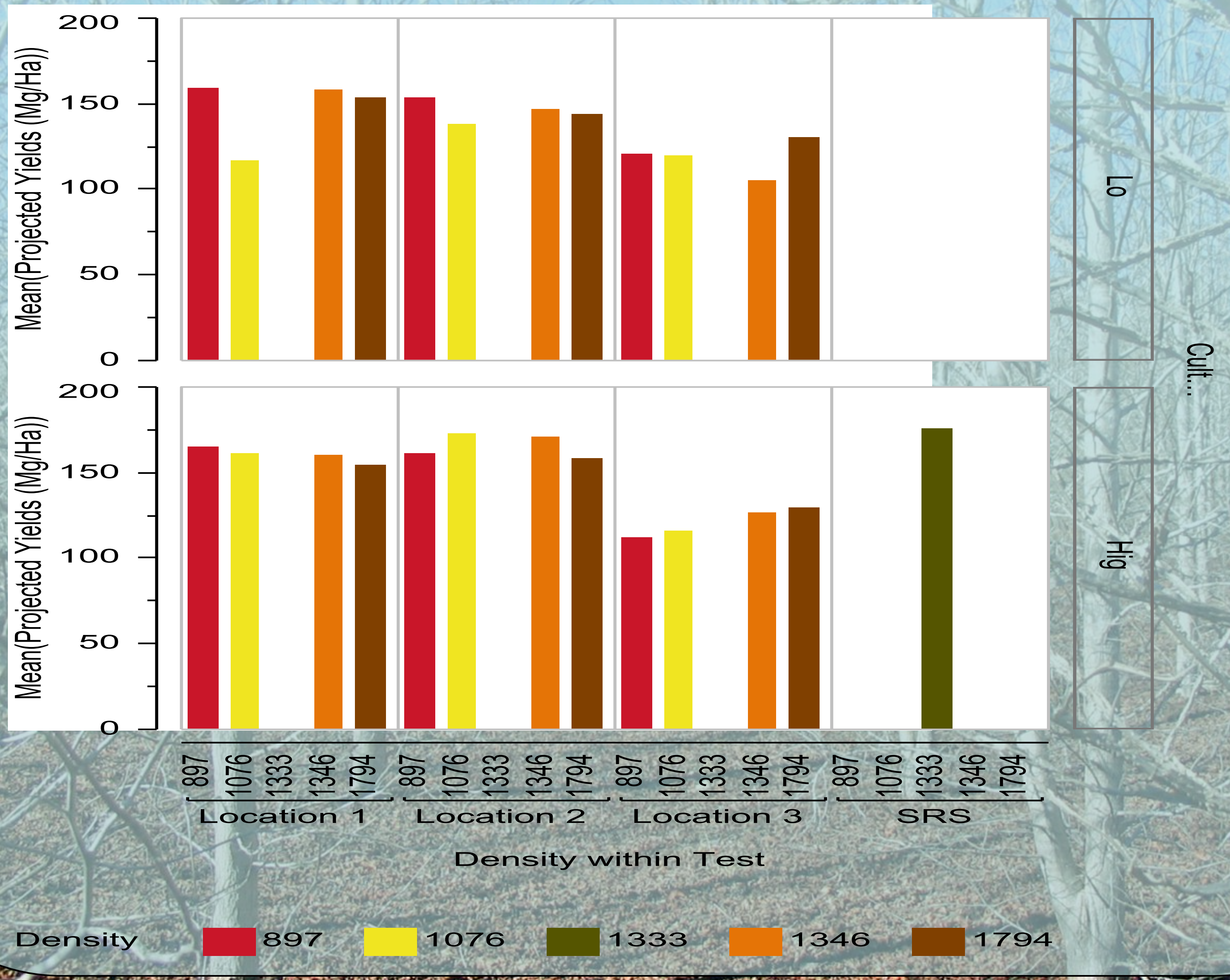
Age 7 Growth Summary for Culture × Density Study-Location 2

Treatment (Density, Culture)	Height (m)	DBH (cm)	Individual Tree Biomass (kg)	Survival	Basal Area (m^2/ Ha)	Aboveground Biomass (Mg/Ha)	Aboveground Biomass Mean Annual Increment (Mg/Ha/year)
1794, Low	9.59	10.45	25.41	95.4	15.21	43.5	6.22
1794, High	10.47	11.36	34.10	95.8	18.03	58.6	8.36
1346, Low	9.71	11.44	29.20	97.5	13.79	38.3	5.48
1346, High	11.08	12.83	40.77	97.5	17.31	53.6	7.65
1076, Low	9.45	11.93	30.35	98.4	12.21	32.2	4.60
1076, High	11.23	13.88	51.18	98.4	16.37	54.2	7.75
897, Low	10.38	12.24	36.74	99.1	10.75	32.6	4.66
897, High	10.80	14.18	48.33	98.1	14.14	42.6	6.08

Age 7 Total Aboveground Yields: 3 Culture × Density Test Sites



Projected Age 15 Total Aboveground Yields



Which Initial Plantation Densities are Best?

- From a biological standpoint, higher densities (1800 trees/ha) may be more suited to biomass harvests on slighter shorter rotations (12-14 years).
- Slightly lower densities (1050-1350 TPH) could offer more flexibility and similar yields at slightly longer rotations (15 years).
- This assumes good early silvicultural techniques and rapid crown closure. Wider spacings (900 TPH or less could require additional time before crown closure.
- All spacings tested here could be used with standard site preparation and harvesting techniques and equipment.
- Economic considerations affecting spacing could be grower specific.

Conclusions

- From the SRS test, nutritional limitations were the primary limiting factor even on this sandy, well-drained site. Responses to added water were small and non-statistically significant.
- Nitrogen limitations became evident in the non-fertilized treatments in year 2 and became progressively worse in year 3.
- Total aboveground biomass at age 7 was up to 55 Mg/ha (7.85 Mg/Ha/year) in the N1W1 Treatment and productivity in N1W0 was 44.3 Mg/Ha.
- Growth projections to age 15 suggest yields of 176 Mg/ha in the N1W1 Treatment (11.73 Mg/ha/year)

Conclusions

- From the Culture × Density Tests, higher initial plantation densities result in slighter higher overall biomass at age 7, but the primary effect is individual tree size differences.
- Nitrogen availability was temporally variable, but generally high in years 1 and 2. Nitrogen limitations became evident in year 3.
- Total aboveground biomass in the best treatments at 2 of the 3 sites exceeded 50 Mg/ha and the best overall treatment at the best site was 58.6 Mg/Ha.
- These yields occurred without supplemental irrigation and despite the fact that moderate to severe drought conditions persisted for 4 of the 7 growing seasons.

Conclusions

- Two of the 3 sites exhibited strong density effects at age 7.
- Response to added N and P was variable. One of the 3 sites had a very strong response while the other sites did not respond despite the sharp reductions in soil N availability and reduced foliar N concentrations.
- Growth projections to age 15 suggest yields of 171 Mg/ha (11.4 Mg/Ha/year) in the best treatment combination and multiple treatments on 2 of the 3 sites yielding greater than 160 Mg/ha (10.7 Mg/ha/year)
- At age 15 yields on the least productive site would be projected to be approximately 130 Mg/ha (8.7 Mg/Ha/year).

Conclusions

- **At age 15, higher initial plantation densities are projected to offer no yield advantages and may actually have slightly lower yields.**
- **Moderate plantation densities ranging from 1076 to 1346 trees per hectare may optimize productivity for moderate rotation lengths (15-20 years) and allow standard stand establishment and harvesting practices to be utilized .**

Potential Growth Productivity Gains in Sweetgum

- All productivity levels obtained in these studies was achieved with first generation wild selections made in the mid 1960’s.
- What is the potential to deploy superior genotypes that may offer greater SRWC productivity potentials?

There Are Multiple Pathways That Can Be Pursued To Improve Productivity

- Identify and select better open-pollinated families (MWV tested approximately 800-900 families).
- Clonal selection from currently available families (over 800 clones tested)
- Controlled crosses of select families.
- Hybridization between American sweetgum (*Liquidambar styraciflua*) and Formosan sweetgum (*Liquidambar formosana)* or Chinese sweetgum (*Liquidambar acalycina*).
- Genetic transformation for selected traits (Wood quality or chemistry, herbicide tolerance, growth rate, etc.).

Potential Growth Productivity Gains in SRWC : 23-Year-Old Sweetgum Selection

Early Growth of Hybrid Sweetgum Vs. Standard Genetics

Acknowledgments

- We would like to thank the DOE and the USDA Forest Service for their support in establishing and maintaining the test at the Savannah River site. Funding was provided by the Department of Energy-Savannah River Operations Office through the U.S. Forest Service Savannah River under Interagency Agreement DE-AI09-00SR22188.
- MeadWestvaco (MWV)Forest Research supported the original design, installation, and maintenance of the 3 Culture × Density Tests.
- We also thank MWV and ArborGen for their continued access to the test sites and use of data.
- International Paper allowed use of their Sweetgum Growth and Yield Model. This model was originally developed by Jerry Hansen. Their assistance is greatly appreciated.


Feedback or Questions?