



# Chuck Davey

1928-2015

NC State Outstanding Professor (1968)  
President of the Soil Science Society of America (1976)  
SAF Barrington Moore Award (1982)  
Gamma Delta Award of Merit (1983)  
NC State Distinguished Graduate Professor (1989)  
Fellow of the Society of American Foresters (2004)



# Chuck Davey

1928-2015

Tree growth and essential nutrient elements - 14 pages

Nutrients and nutrient sources – 6 pages

Standards for soil test interpretation – 2 pages

Homework.... Read these pages.

# Effects of Nursery Fertilization on Outplanting Performance

**David South**



# Outline

- How do we define “optimum” nutrition

Effects on .....

- seedling morphology
- survival
- root growth potential (RGP)
- short-term growth
- long-term growth

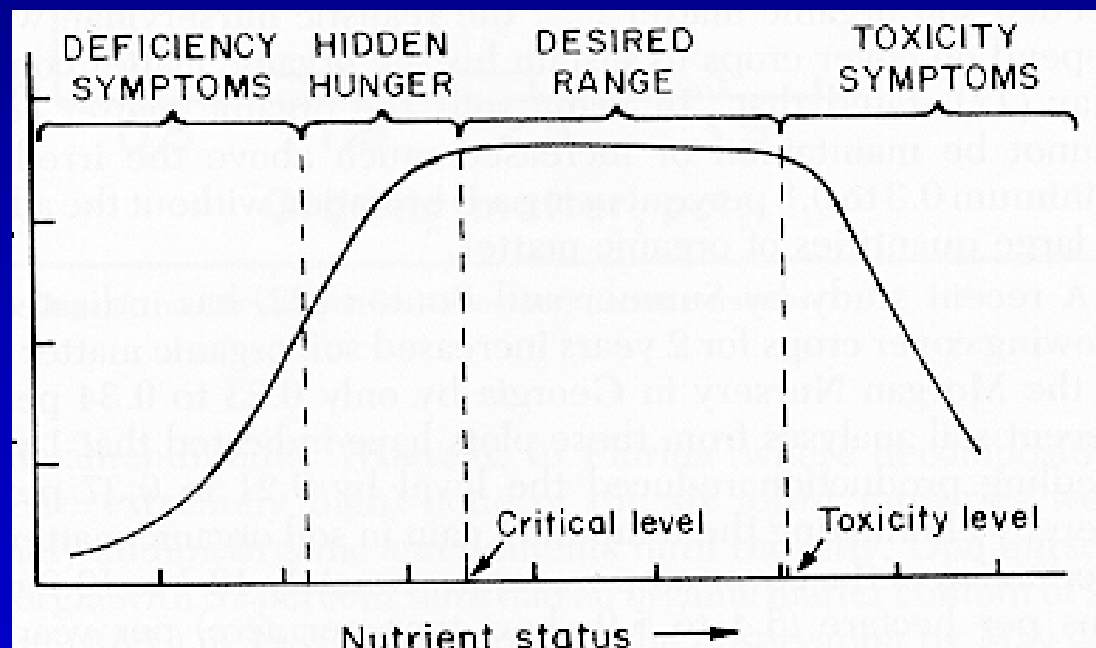
# How do we determine the “desired range” of nutrients?

Color?

Height?

Plantable  
seedlings?

Field growth?



# How do we determine the “desired range” of nutrients?

Color?

2616

A. V. Barker

**Table 1**

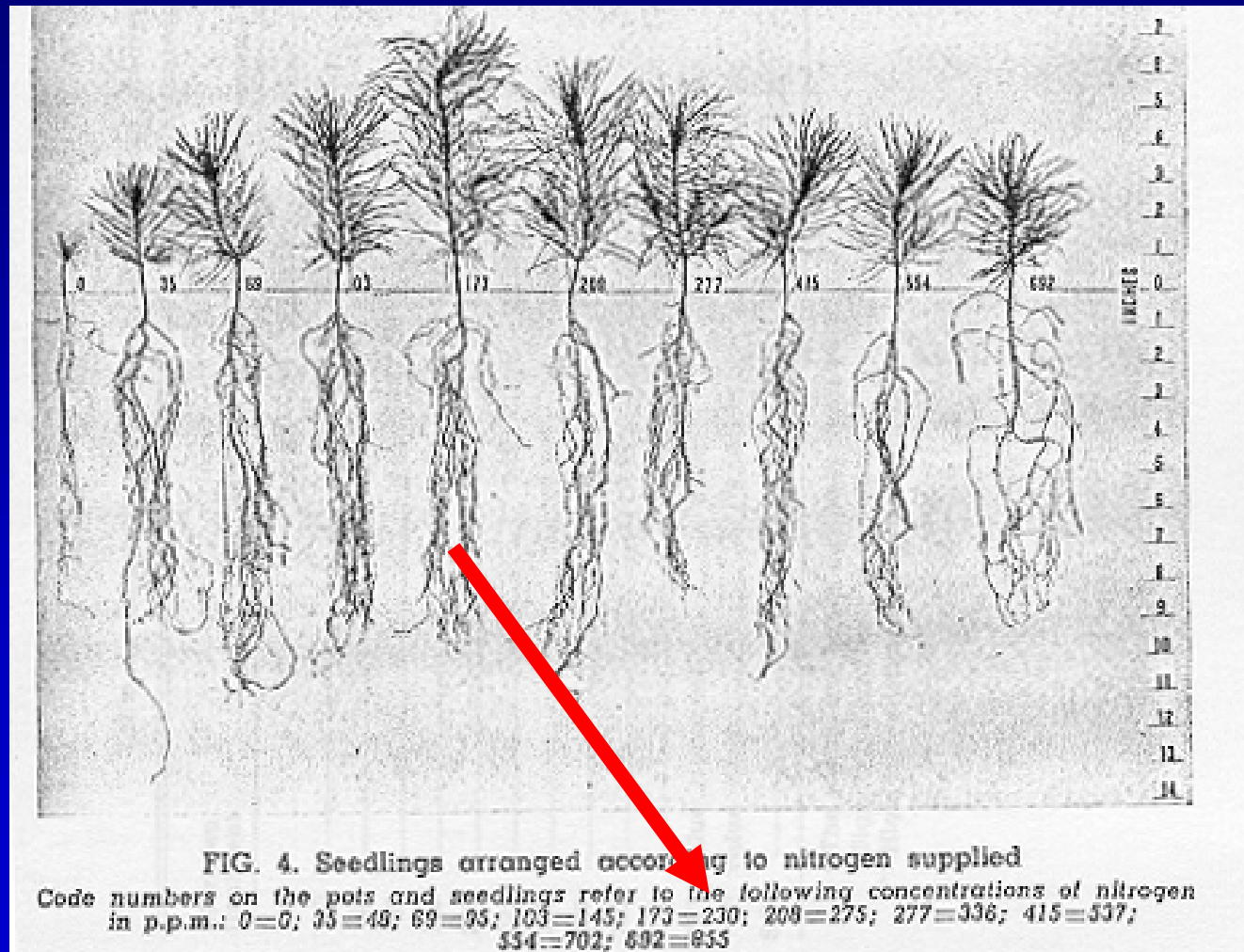
Munsell color of needles of white pine and loblolly pine at the end of one year of culture for nutrient loading

| Relative strength of nutrient solution | N concentration (mg L <sup>-1</sup> ) | Color chart designation <sup>2</sup> | Visual color <sup>3</sup> |
|----------------------------------------|---------------------------------------|--------------------------------------|---------------------------|
| <i>Loblolly pine</i>                   |                                       |                                      |                           |
| 0.0625                                 | 13                                    | 100% 5GY 6/6                         | light green               |
| 0.125                                  | 26                                    | 100% 5GY 6/10                        | light green               |
| 0.25                                   | 51                                    | 50% 5GY 7/10                         | light green               |
|                                        |                                       | 50% 5GY 6/8                          | light green               |
| 0.50                                   | 102                                   | 30% 5GY 7/10                         | light green               |
|                                        |                                       | 70% 7.5GY 4/6                        | dark green                |
| 1.0                                    | 205                                   | 20% 5GY 6/10                         | light green               |
|                                        |                                       | 80% 5GY 4/4                          | dark green                |
| 2.0                                    | 410                                   | 60% 5GY 4/4                          | dark green                |
|                                        |                                       | 40% 2. 5GY 8/10                      | yellow green              |

<sup>2</sup>% of leaves, page, value/chroma. <sup>3</sup>bottom to top down the column.

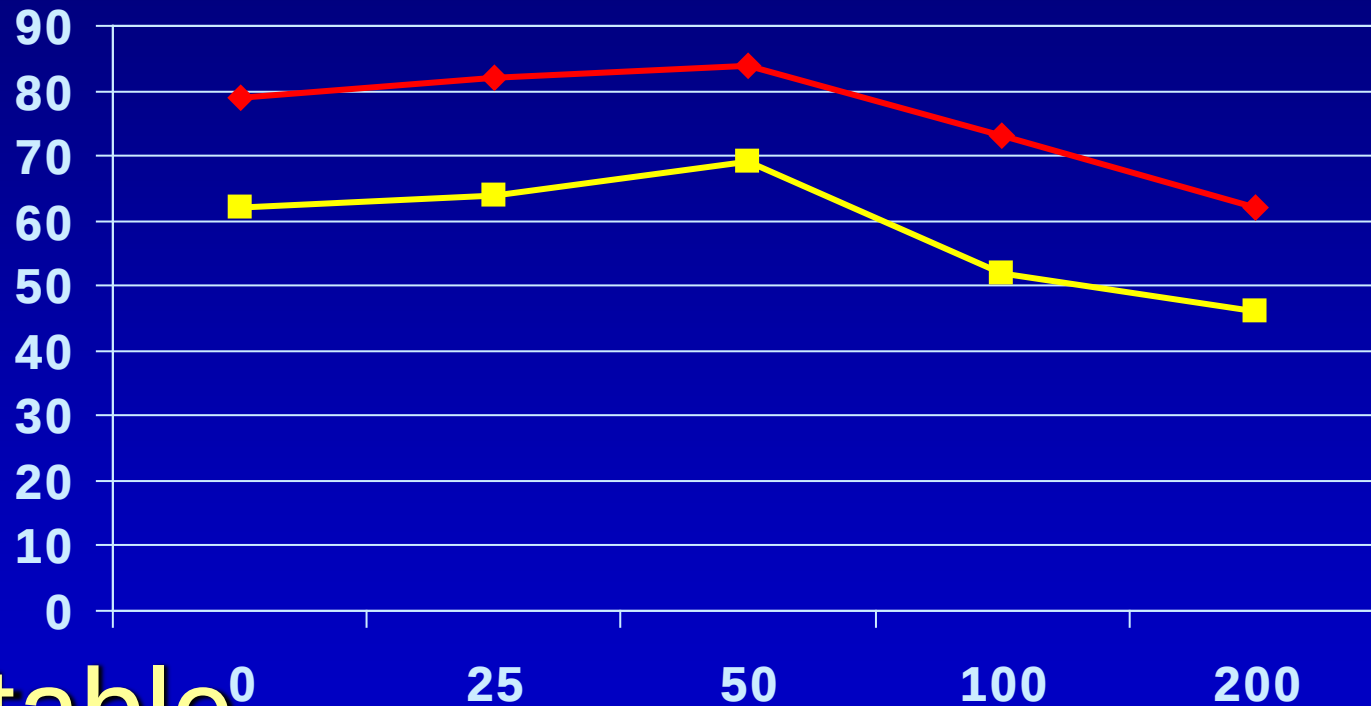
# How do we determine the “desired range” of nutrients?

Height?



# Sweetgum Rooted Cuttings

(Rieckermann et al. 1999: New Forests)



Plantable<sup>0</sup>  
seedlings?

—◆— % survival —■— % plantable



# Slow release fertilizer treatment on *Gmelina aborea* cuttings (Redell et al. 1999: New Forests)

- Nutricote per liter of Coir potting medium

- 0

- 2 g

- 10 g

- 15 g

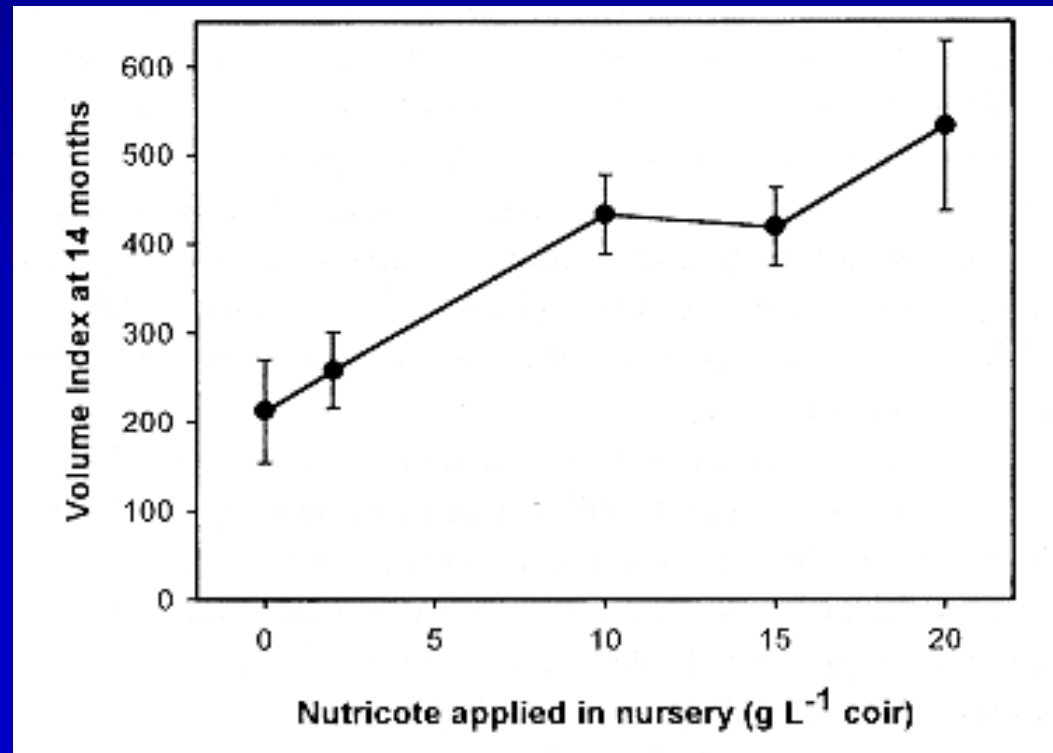
- 20 g

No effect on nursery height

No effect on field survival  
avg. 94.6%

# Slow release fertilizer treatment on *Gmelina aborea* cuttings (Redell et al. 1999: New Forests)

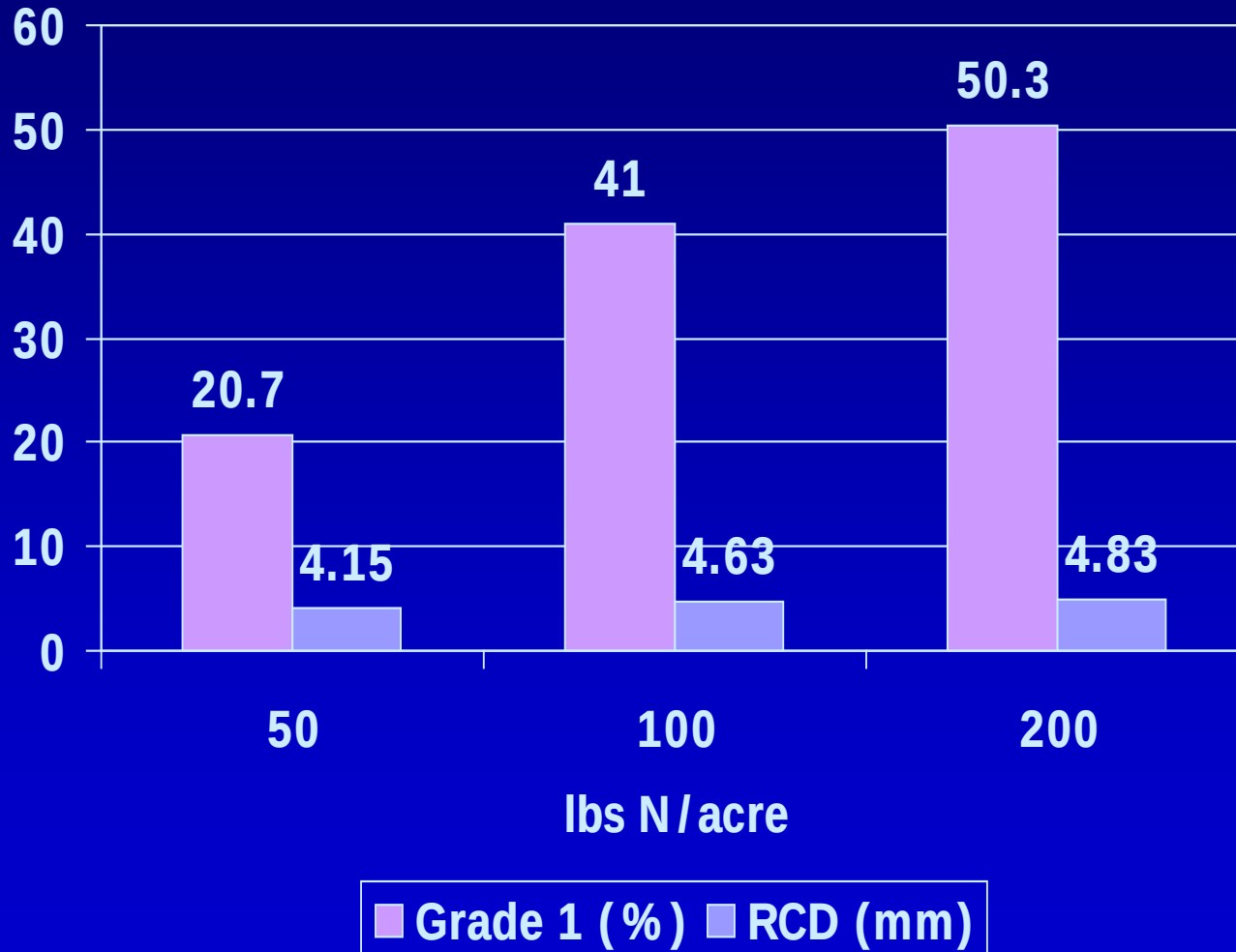
Field  
growth?



# Effect of Fertilization on seedling morphology

# Slash pine - Georgia

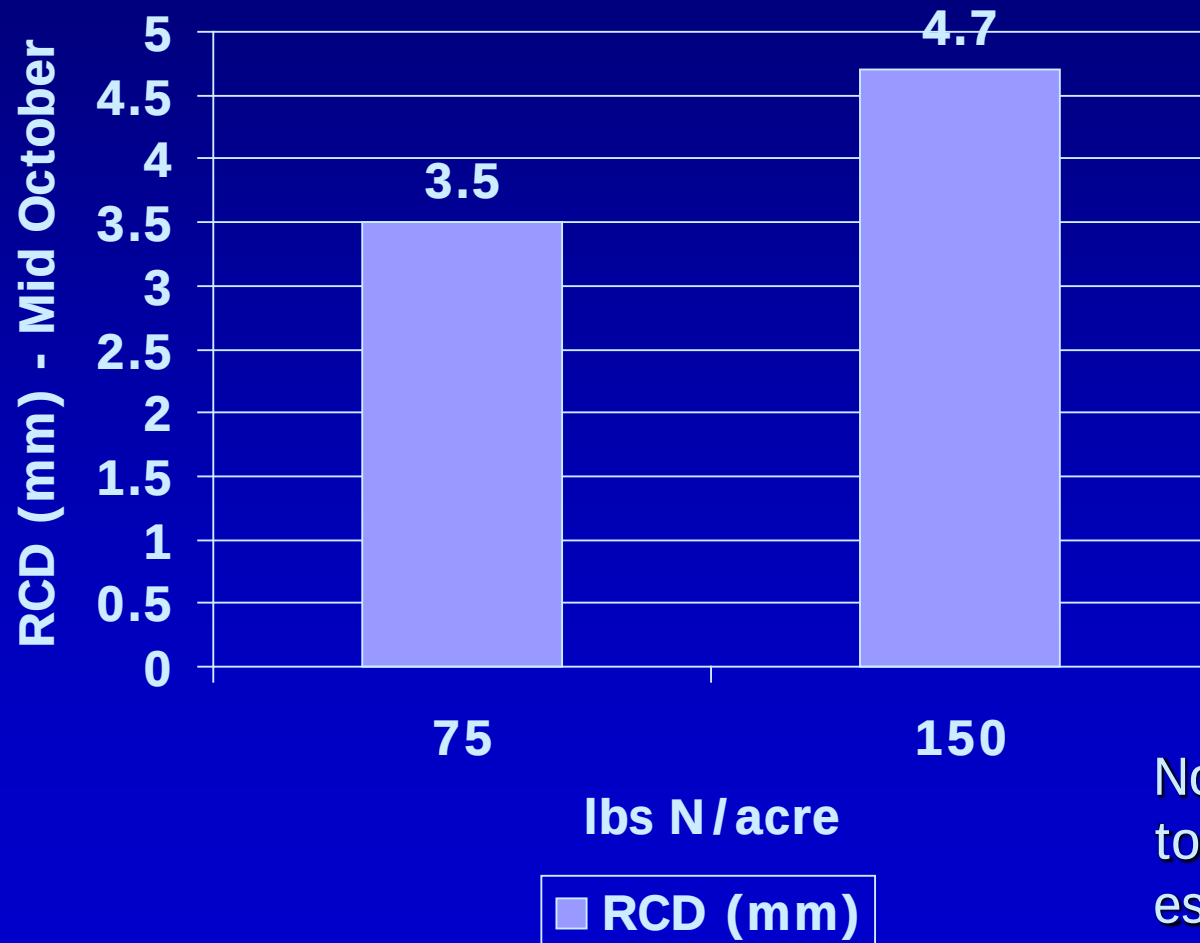
(Heser 2000: MS)



Although there is no statistical difference between 100 and 200 lbs N/acre, the trend for both diameter and grade 1 seedlings appears to be linear.

# Loblolly pine - Georgia

(Kormanik et al. 1999: GTR SRS-25)



No undercutting and no top-pruning. RCD estimated from regression lines.

# Loblolly - Virginia

(Dierauf 1991: VDF OR #94)

|        | 1 X Rate       | 2 X Rate       | Extra cost per M |
|--------|----------------|----------------|------------------|
| ■ 1981 | 270 lbs N/acre | 540 lbs N/acre | 11 cent more     |
| ■ 1982 | 270 lbs N/acre | 540 lbs N/acre | 11 cents more    |
| ■ 1983 | 300 lbs N/acre | 600 lbs N/acre | 12 cents more    |
| ■ 1984 | 250 lbs N/acre | 500 lbs N/acre | 10 cents more    |
| ■ 1985 | 270 lbs N/acre | 540 lbs N/acre | 11 cents more    |

- 0.5 inch of sawdust
- 1 inch of sawdust
- 1.5 inch of sawdust

- top pruning in all years (2 times or 3 times)
- no top pruning included in 1983, 1984, 1985

# Loblolly - Virginia

(Dierauf 1991: VDF OR #94)

Figure 2. Top length at lifting, 1981 study.

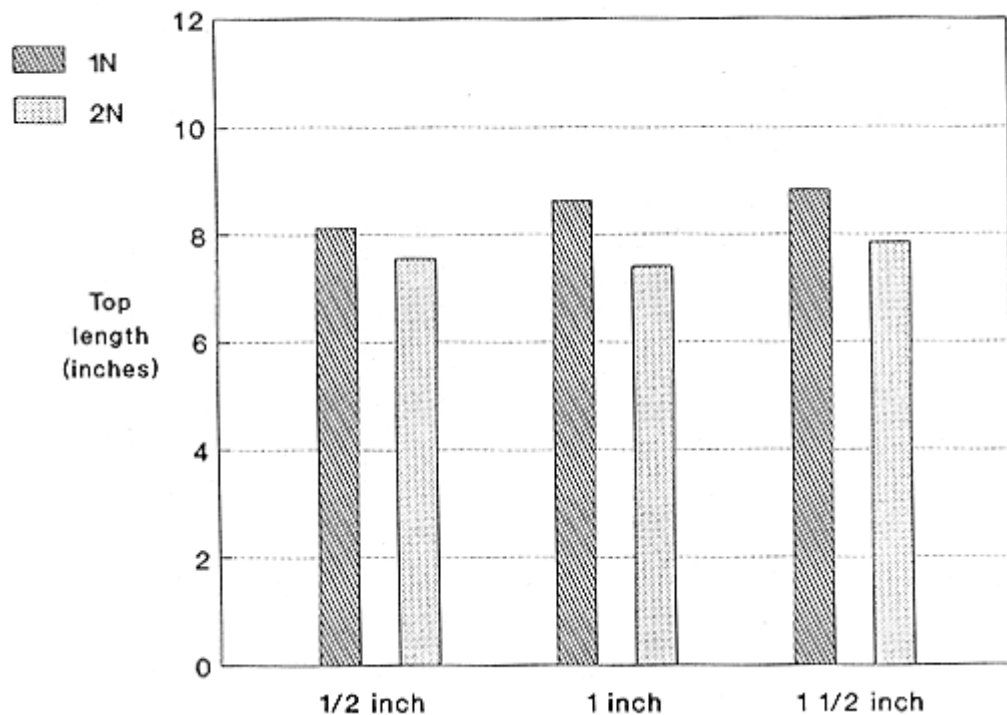
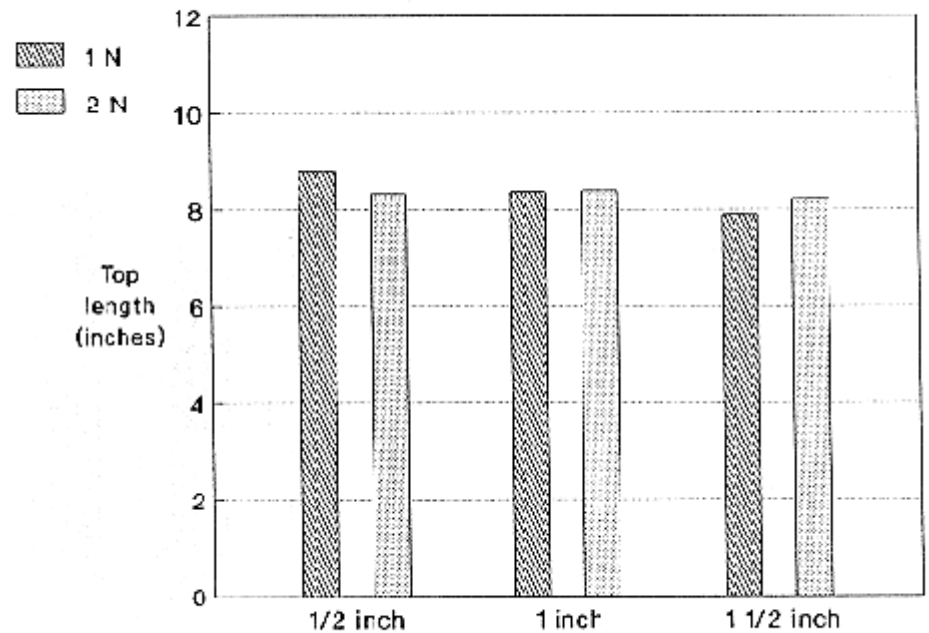


Figure 4. Top length at lifting, 1982 study.





# Loblolly - Virginia

(Dierauf 1991: VDF OR #94)

Figure 6. Top length at lifting, 1983 study.

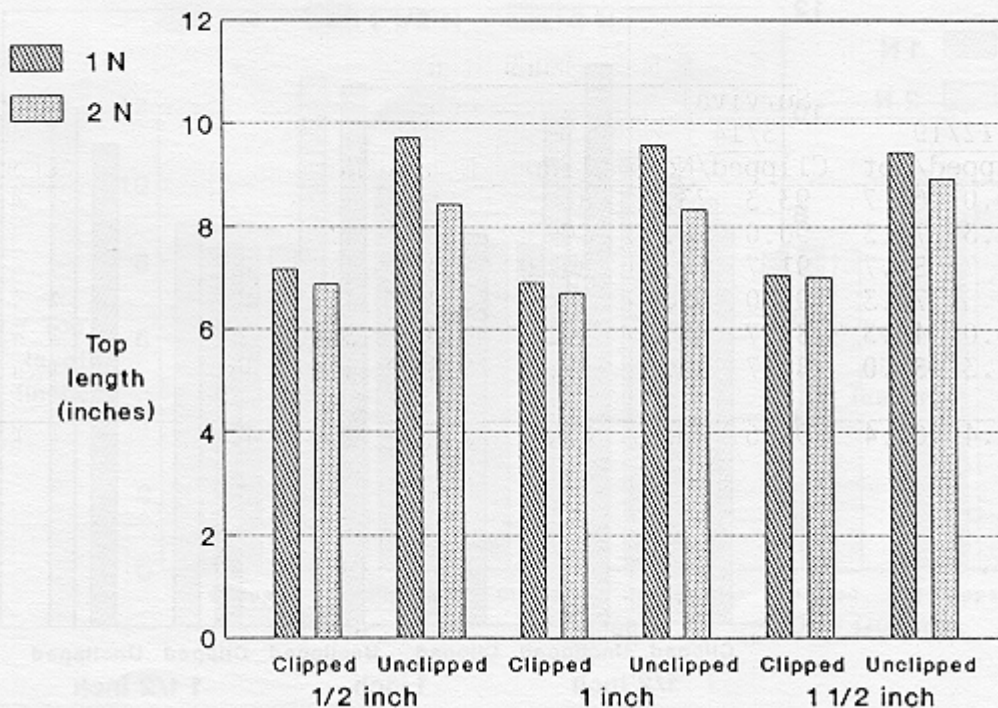
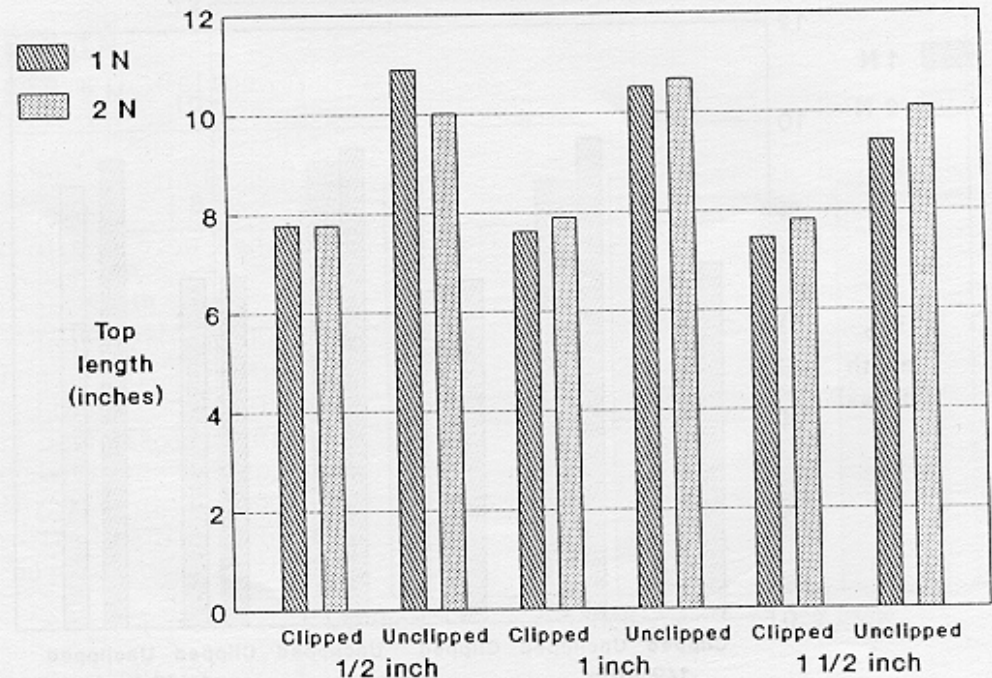


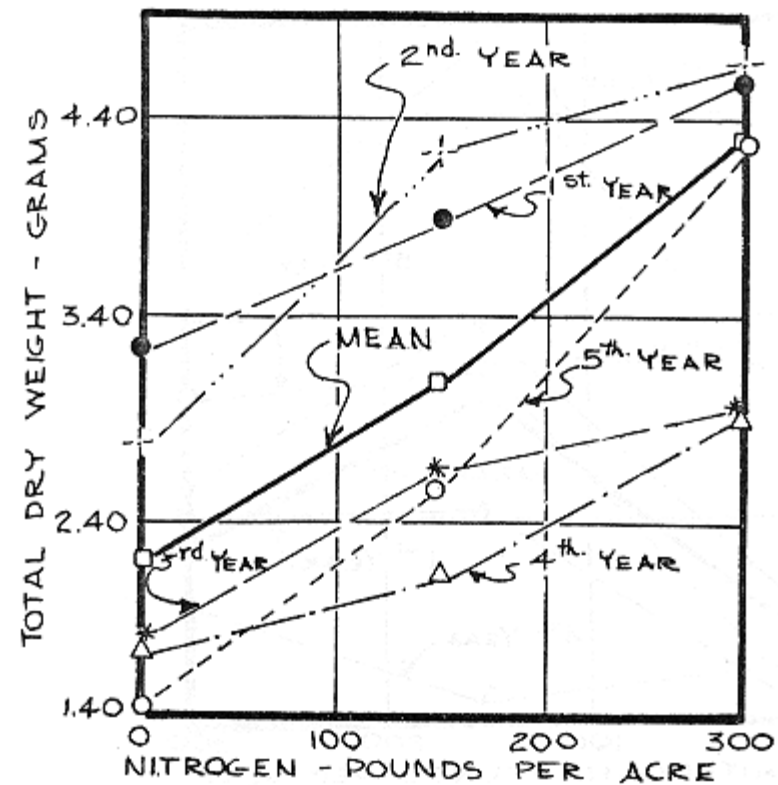
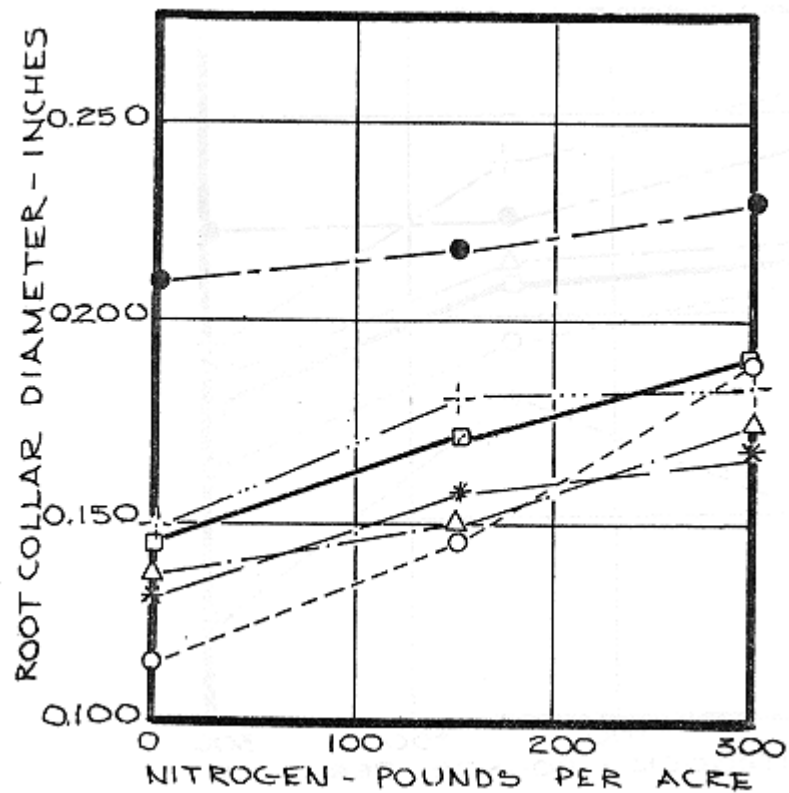
Figure 8. Top length at lifting, 1984 study.





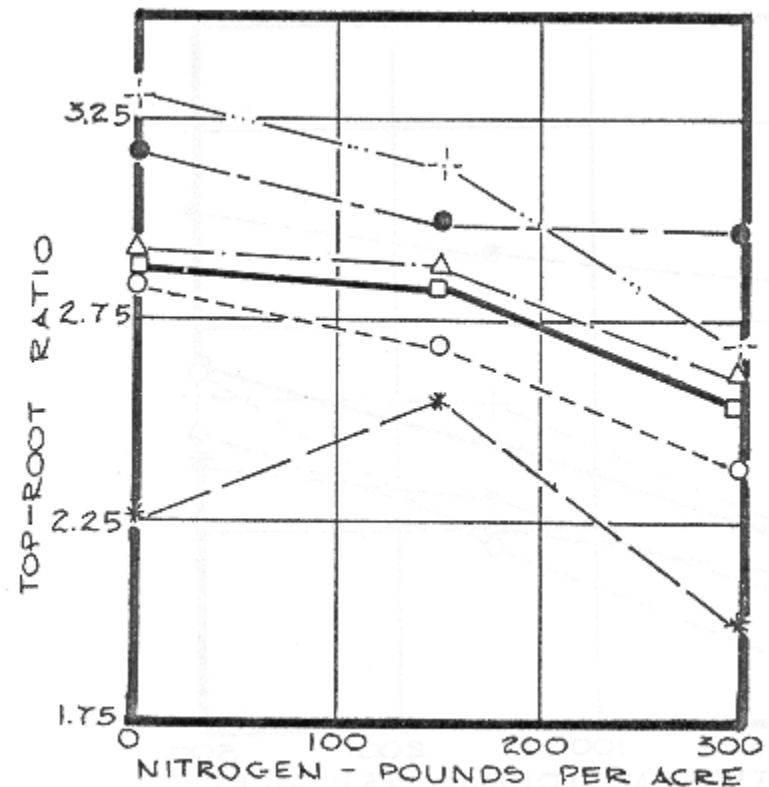
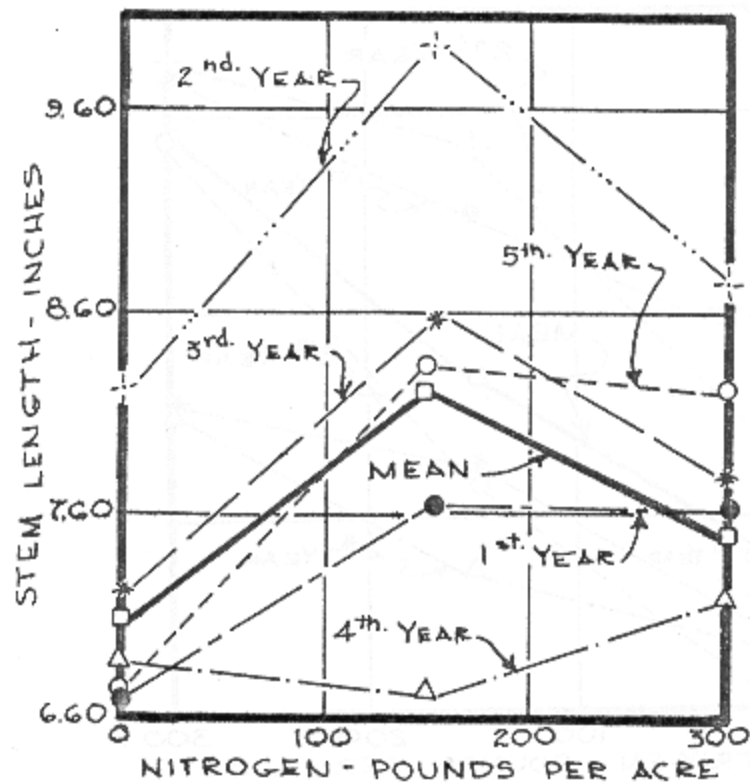
# Loblolly - Mississippi

(Switzer 1962: PhD)



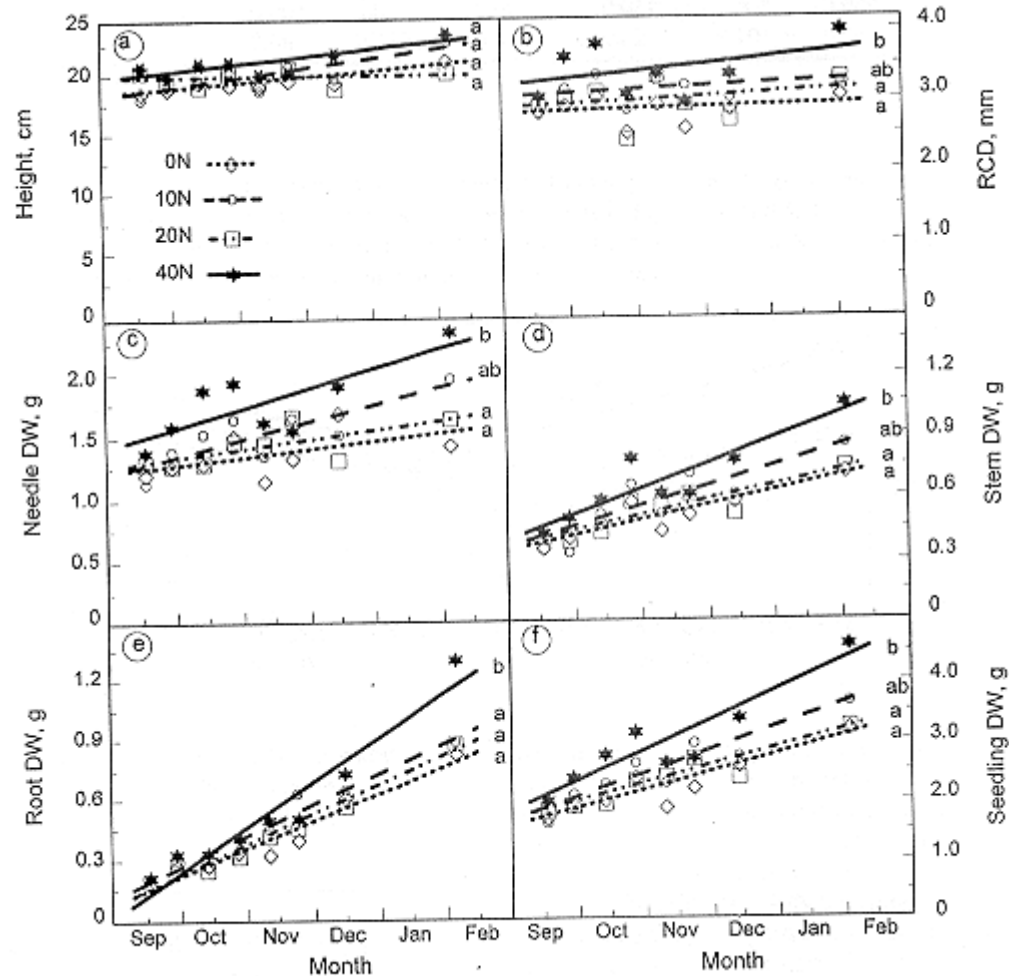
# Loblolly - Mississippi

(Switzer 1962: PhD)



# Loblolly - Georgia

(Sung et al. 1997: CJFR 27)



# Summary

Some of the old beliefs about the effect on N fertilization on seedling morphology were developed under greenhouse and hydroponic systems.

The belief that extra N produces unbalanced seedlings is not supported by data collected under nursery conditions.

In most cases with pine, top-pruning and undercutting will alter the root/weight ratio more than extra N.



Effect of Fertilization  
on survival

# Liquid Fertilization - 1937

(Wilde et al. 1940: JOF)

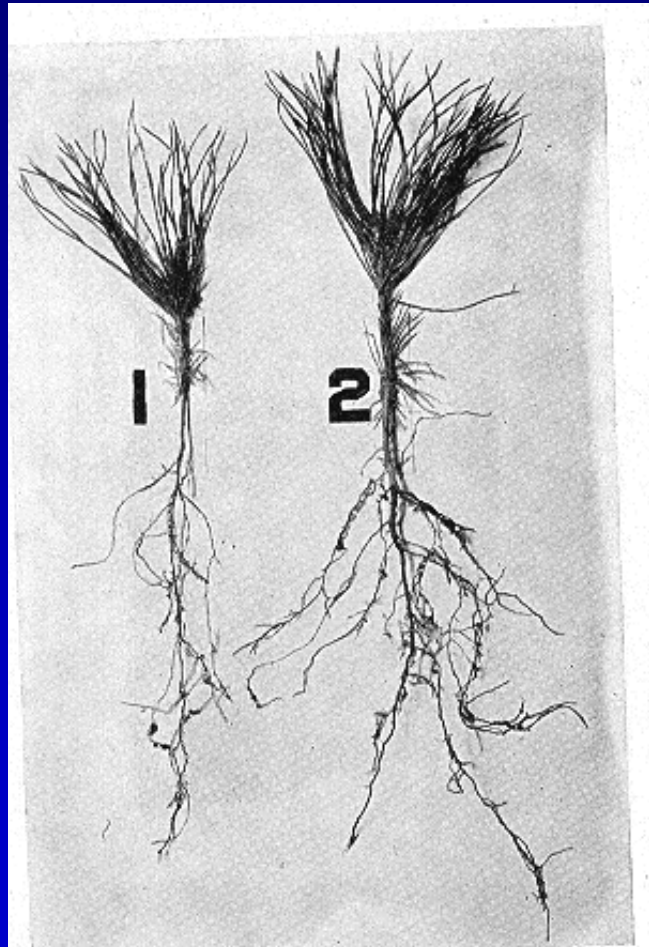


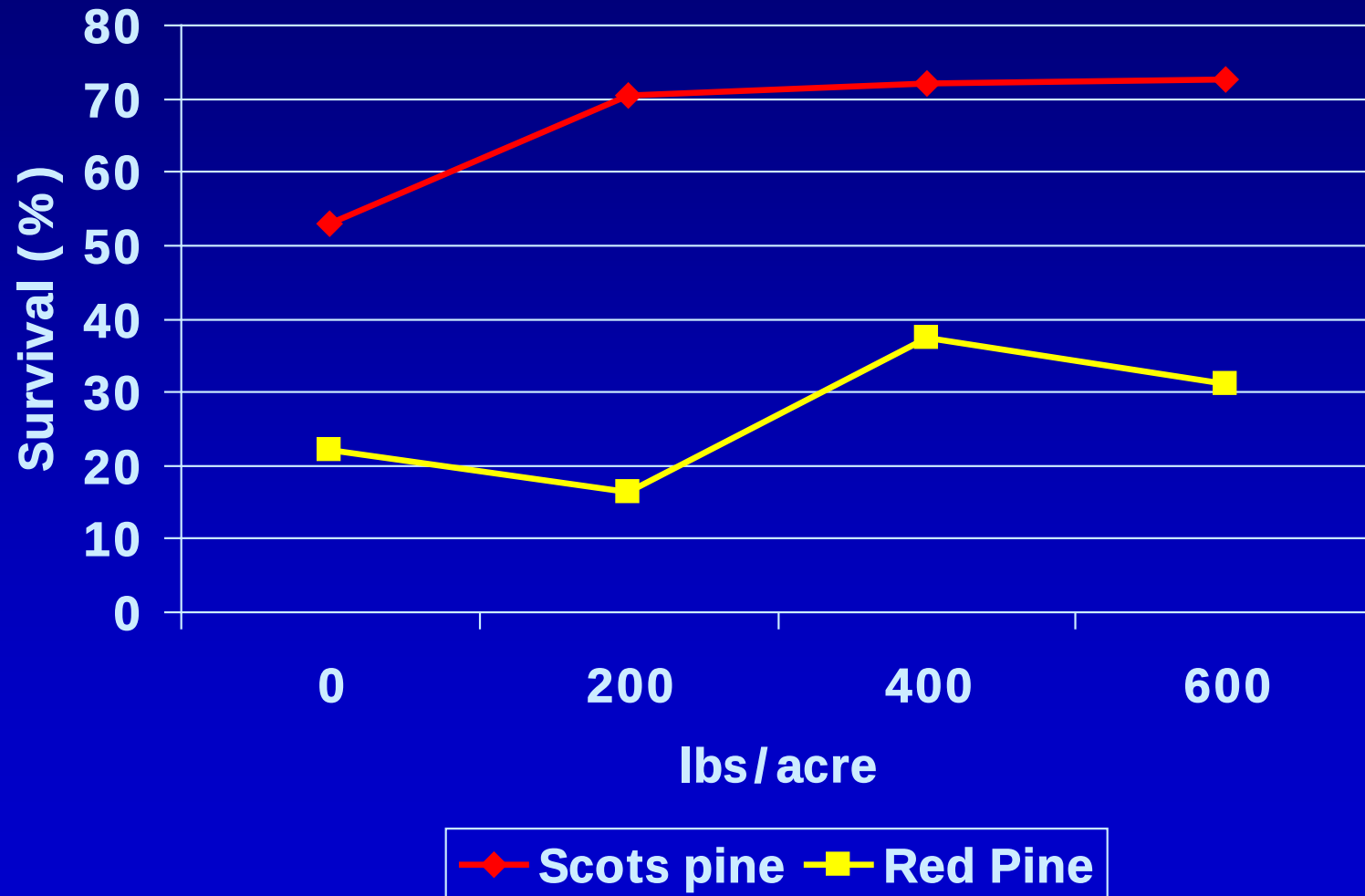
Fig. 1.—Effect of liquid fertilizer upon the growth of two-year old Scotch pine seedlings: (1) Check; (2) 600 pounds per acre of 11-48 ammonium phosphate and 13-0-44 potassium nitrate, applied in equal portions.

# Liquid Fertilization - 1937

(Wilde et al. 1940: JOF)

| 13-0-44 | Top  | Root | Top/root | Weight |
|---------|------|------|----------|--------|
| 11-48-0 | inch | inch |          | (g)    |
| Check   | 2.4  | 5.0  | 0.47     | 0.48   |
| 200 lbs | 2.7  | 5.2  | 0.52     | 0.83   |
| 400 lbs | 3.1  | 5.1  | 0.61     | 1.09   |
| 600 lbs | 2.8  | 5.5  | 0.52     | 1.34   |

# Liquid Fertilization - 1937 (Wilde et al. 1940: JOF)





# Longleaf Fertilization (greenhouse) (Allen and Maki 1954: Soil Sci.)



# Longleaf - Fall Fertilization (nursery) (Hinesley and Maki 1980: SJAF)

- Pre sowing  
250 lbs N  
80 lbs K  
2000 lbs of dolomitic limestone

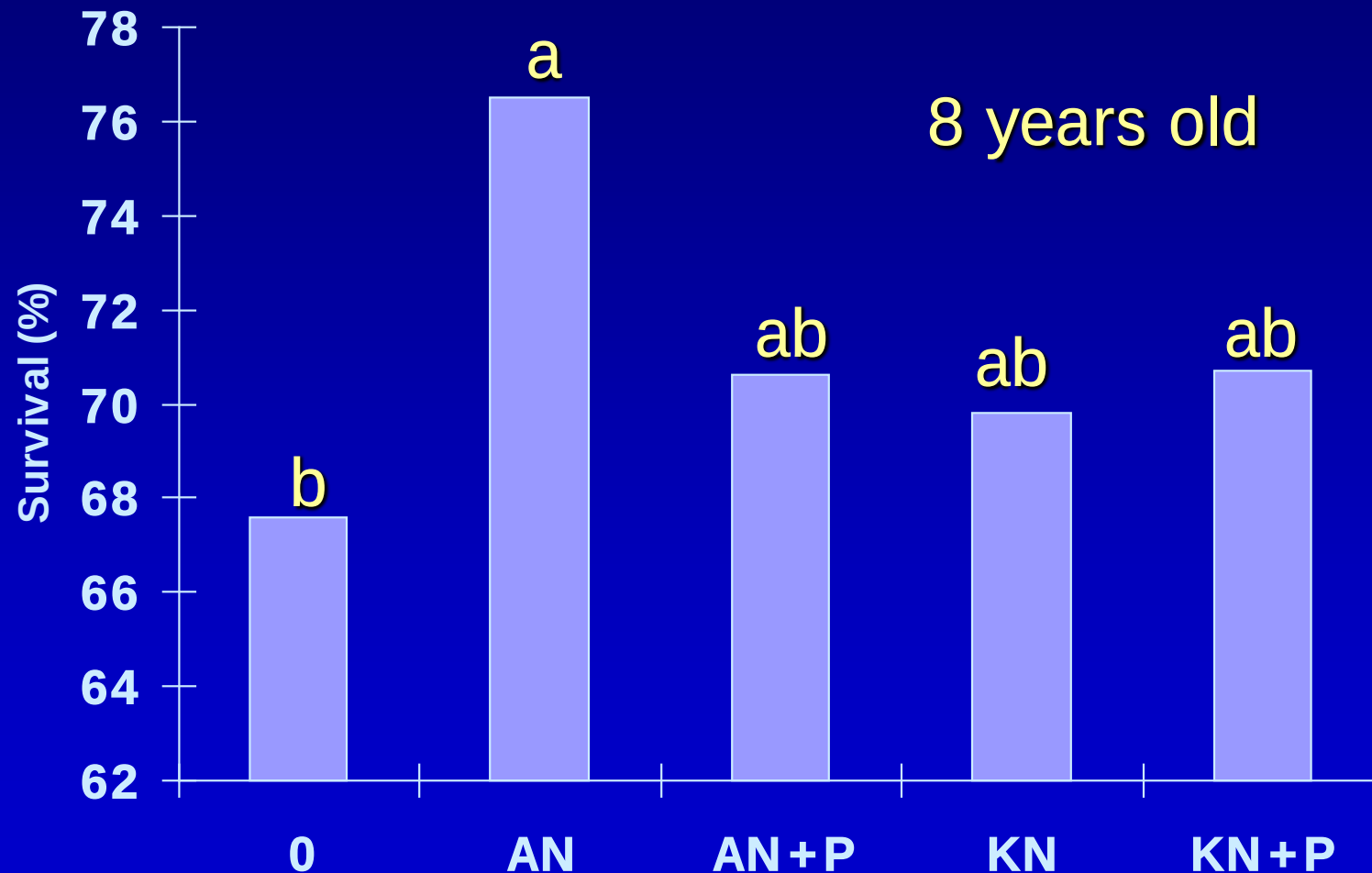
- Ammonium nitrate 100 lbs N/acre  
350 lbs N/acre total

## ■ Fall treatments

150 lbs N or 300 lbs N/acre  
(AN or KNitrate) plus dolomitic limestone

350 : 500 : 650 lbs N/acre

# Longleaf - Fall Fertilization (nursery) (Hinesley and Maki 1980: SJAF)



# Loblolly - Georgia

(Sung et al. 1997: CJFR 27)

## Fall nitrogen fertilization and the biology of *Pinus taeda* seedling development

S.S. Sung, C.C. Black, T.L. Kormanik, S.J. Zarnoch, P.P. Kormanik, and P.A. Counce

**Abstract:** In mid-September when stems and roots of nursery-grown loblolly pine (*Pinus taeda* L.) seedlings are actively accumulating dry weight (DW), we gave 10, 20, or 40 kg NH<sub>4</sub>NO<sub>3</sub> ha<sup>-1</sup> (10N, 20N, 40N) and applied seedlings meeting 100 cm<sup>3</sup> N (10N) were the controls. The temporal patterns of seedling growth, nutrient concentrations, and sugar-metabolizing enzyme activities were determined during that fall and winter to assess the dynamics of seedling vigor. The 40N-treated seedlings had significantly fewer calli and greater first-order lateral root numbers, root collar diameter, DW of stems, roots, and roots and N concentration (percentage of DW) and content (milligrams per seedling) than controls and the 10N-treated seedlings. However, the temporal patterns of DW allocation, sugar metabolism, or the concentrations of P, K, Mg, and Ca were not affected by fall N fertilization. These results test the hypothesis that most plant morphological and biochemical processes, e.g., particularly in stem and root DW growth or in stem and root anatomy and physiology, were not altered by human-made changes such as fall N fertilization. Fall N fertilization near 40 kg N ha<sup>-1</sup> is a beneficial treatment because it decreased the number of calli and increased seedling N concentrations and DW without causing nutrient imbalances or detectably disturbing seedling development.

**Résumé:** À la fin-septembre, lorsque la tige et les racines des semis de pin à croûtes (*Pinus taeda* L.) cultivés en pépinière accumulent activement du poids sec, une application additionnelle de 10, 20 ou 40 kg NH<sub>4</sub>NO<sub>3</sub> ha<sup>-1</sup> (10N, 20N, 40N) a été effectuée. Les semis ne recevant pas de N additionnel (10N) ont servi de témoins. Les patrons temporels de croissance des semis, les concentrations en nutriments et l'activité enzymatique relative au métabolisme des sucres ont été documentés durant l'automne et l'hiver afin d'évaluer la dynamique de la vigueur des semis. Les semis traités avec 40 N ont obtenu significativement moins de callosités et un plus grand nombre de racines latérales de premier ordre, un diamètre au collet plus élevé, une masse sèche des racines, de la tige et des racines plus élevée et une concentration plus élevée de poids sec et un contenu foliaire (milligrammes par semis) et N plus élevés que les témoins ainsi que ceux traités à 10N. Toutefois, les patrons temporels d'allocation de biomasse, le métabolisme des sucres ou les concentrations de P, K, Mg ou Ca n'ont pas été affectés par la fertilisation automnale d'azote. Ces résultats concordent avec l'hypothèse que les processus morphologiques et biochimiques de base des plantes, par ex., physiologie des racines, croissance des racines, physiologie des tiges et de la photosynthèse dans la tige et les racines, ne sont pas altérés par les changements apportés par les humains, tels que fertilisation automnale d'azote. La fertilisation automnale d'azote de l'ordre de 40 kg N ha<sup>-1</sup> est un traitement bénéfique car elle diminue le nombre de callosités et accroît la concentration en N du semis ainsi que le poids sec sans causer de déséquilibres nutritifs ni perturber le développement des semis de façon perceptible. (Traduit par la Rédaction)

### Introduction

The success of artificial forest regeneration commonly is assessed by seedling survival rate on a natural forest site and by stem growth after the first few growing seasons (Grossnickle and Folk 1993). At lifting, attempts have been made to identify key characteristics of nursery seedlings that are responsible for their field performance. Loblolly pine (*Pinus taeda* Mill.) seedlings with greater first-order lateral root numbers or lifting survived better and added more height after two growing

seasons (Hatchell and Muse 1990). Seedling needle N concentrations or lifting were reported to be positively correlated with height and volume growth of loblolly pine (*Pinus taeda* L.) 3 years after transplanting (Switzer and Nelson 1963; Larson et al. 1988). In seedling production of several coniferous species, a fall N application has been reported to increase needle N contents and enhance field performance of transplanted seedlings (Hansley and Maki 1989; van den Driessche 1992; Margolis and Waring 1996b). Several morphological, physiological, and biochemical traits of loblolly pine

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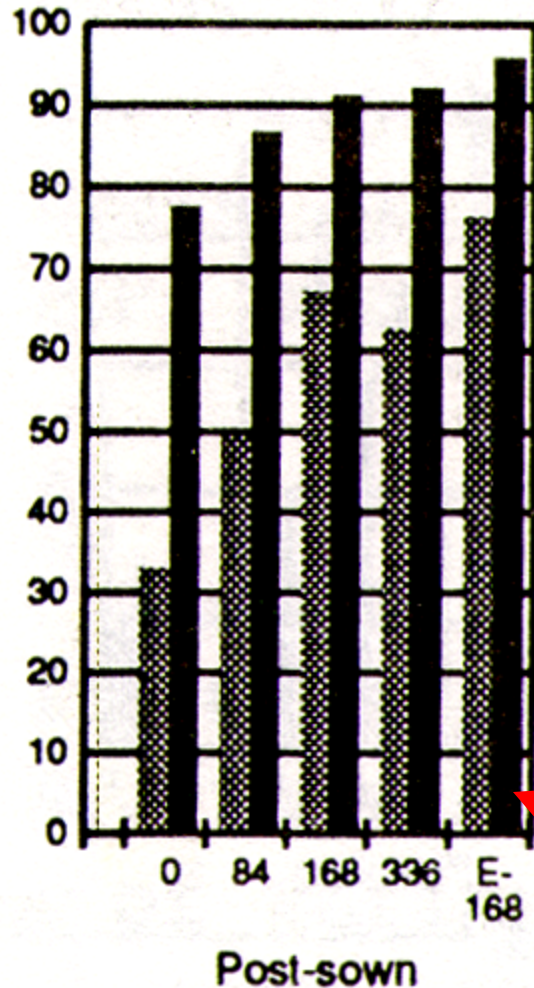
S.S. Sung<sup>1</sup> and P.P. Kormanik, Institute of Tree-Ring Biology, U.S. Department of Agriculture Forest Service, Southern Research Station, 320 Green Street, Athens, GA 30602, U.S.A.  
C.C. Black, Department of Wood Science and Biotechnology, Life Sciences Building, University of Georgia, Athens, GA 30602, U.S.A.  
T.L. Kormanik, Department of Crop and Soil Sciences, Plant Sciences Building, University of Georgia, Athens, GA 30602, U.S.A.  
S.J. Zarnoch, Research Section, U.S. Department of Agriculture Forest Service, Southern Research Station, P.O. Box 2040, Asheville, NC 28802, U.S.A.  
P.A. Counce, Southeast Research and Extension Center, University of Arkansas, P.O. Box 48, Keiser, AR 72261, U.S.A.

<sup>1</sup> Author to whom all correspondence should be addressed.

Although no field performance study was established, it is probable that the seedlings fertilized with 137 lbs of N/acre (May-Sept.) "will survive and grow better than the controls" that were fertilized with only 96 lbs of N/acre (May-Aug.).

Poor site

Survival  
(%)



# Loblolly - Texas

(Barber et al. 1991: BSSRC)

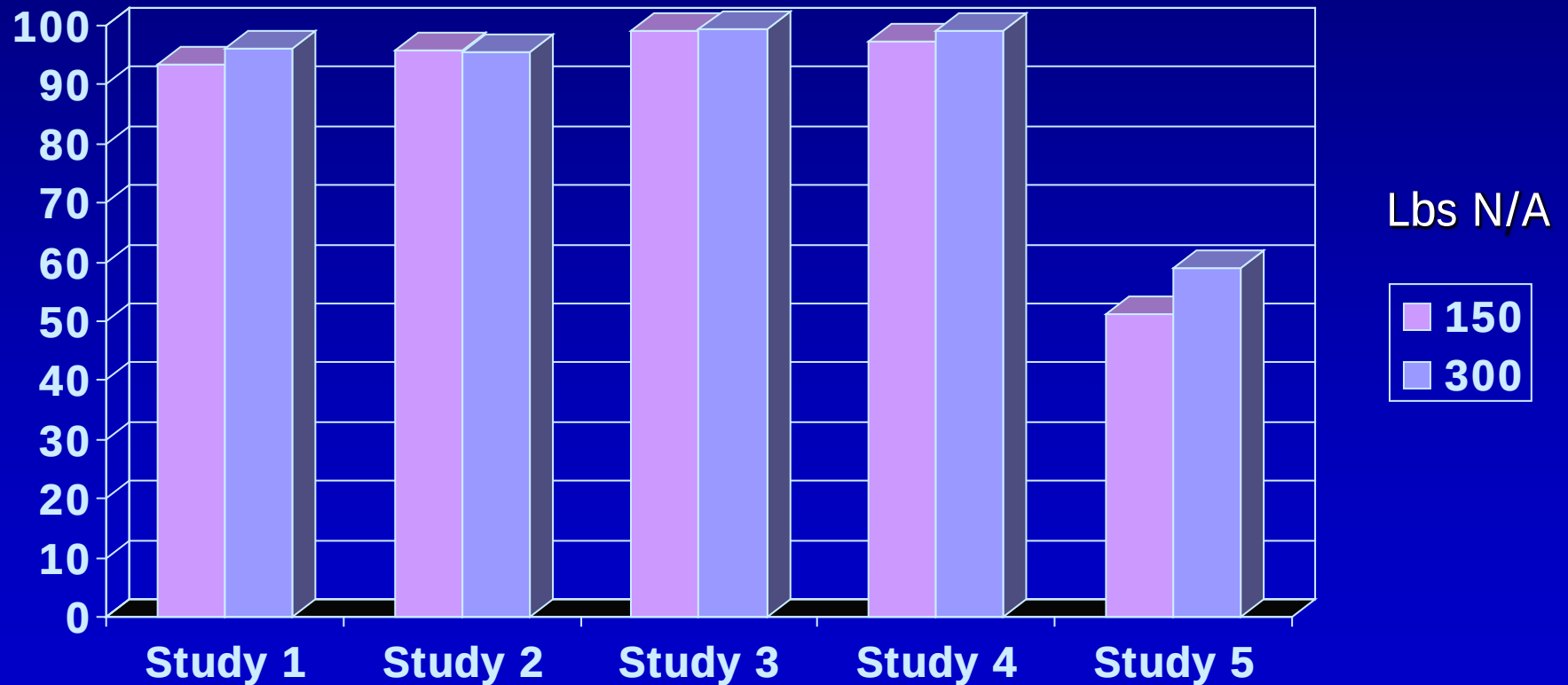
Post-sowing fertilization significantly increased survival on the poor site but had no effect on the good site. Pre-sowing fertilization had little effect on survival at both sites.

Weed control

# Loblolly - Mississippi

(Switzer 1962: Phd)

Age 3 survival (%)



# Loblolly - Virginia

(Dierauf 1991: VDF OR #94)

|        | 1 X Rate       | 2 X Rate       | Extra cost per M |
|--------|----------------|----------------|------------------|
| ■ 1981 | 270 lbs N/acre | 540 lbs N/acre | 11 cent more     |
| ■ 1982 | 270 lbs N/acre | 540 lbs N/acre | 11 cents more    |
| ■ 1983 | 300 lbs N/acre | 600 lbs N/acre | 12 cents more    |
| ■ 1984 | 250 lbs N/acre | 500 lbs N/acre | 10 cents more    |
| ■ 1985 | 270 lbs N/acre | 540 lbs N/acre | 11 cents more    |

- 0.5 inch of sawdust
- 1 inch of sawdust
- 1.5 inch of sawdust

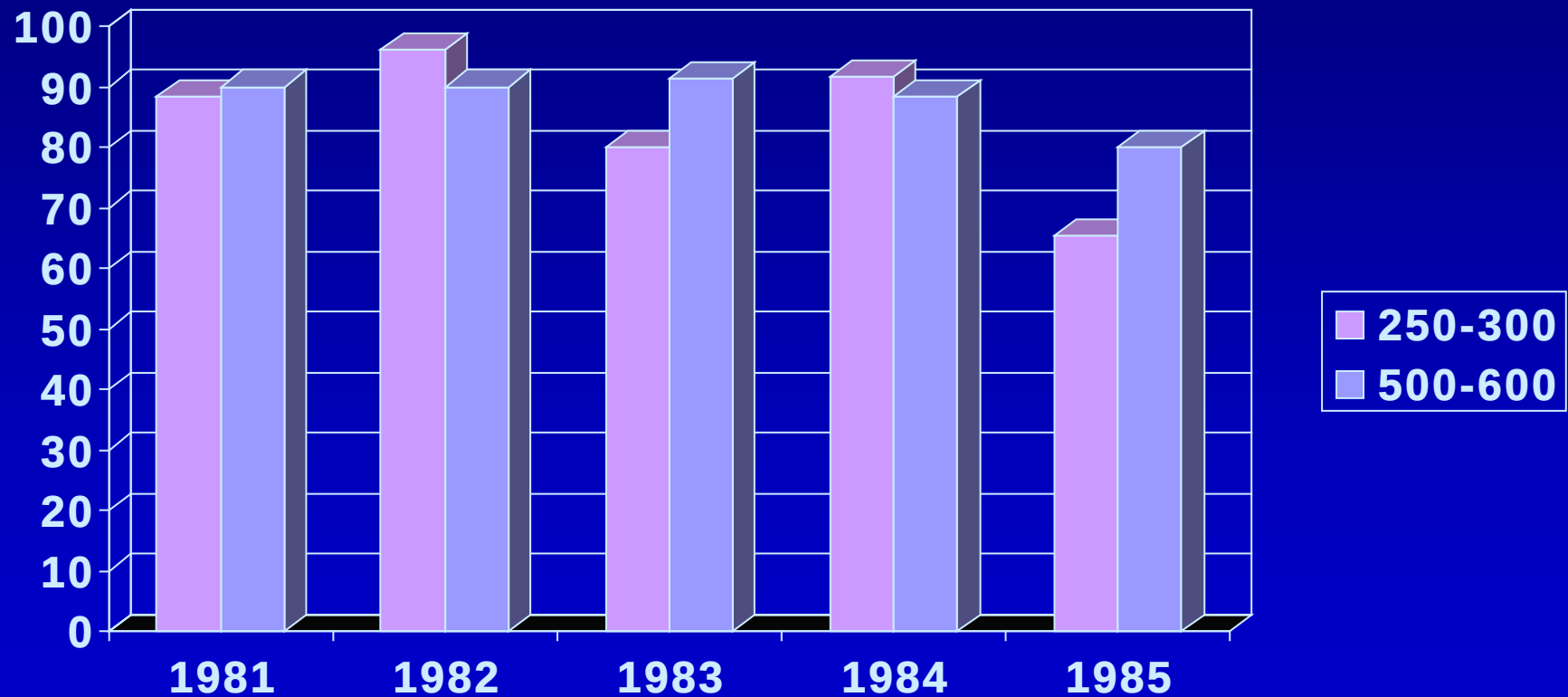
- top pruning in all years (2 times or 3 times)
- no top pruning included as a treatment in 1983, 1984, 1985

# Loblolly - Virginia

(Dierauf 1991: VDF OR #94)

Age 3 survival (%)

December planting: fresh planting: 0.5 inch sawdust

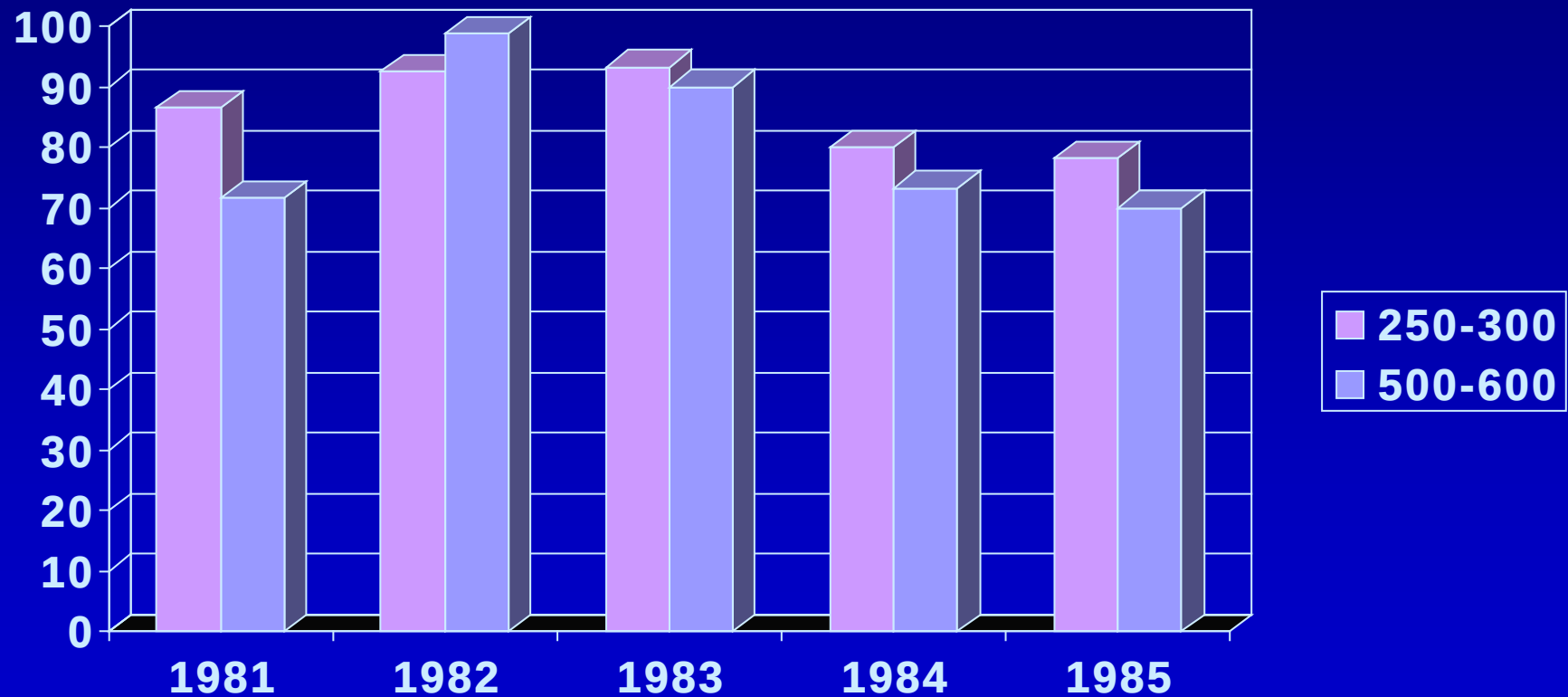




# Loblolly - Virginia

(Dierauf 1991: VDF OR #94)

Age 3 survival (%)      March planting: Stored 2-3 months: 0.5 inch sawdust



# Fall applied nitrogen and slash pine

(Irwin et al. 1998: SJAF)

- Fall treatments

- Control

- 150 lbs ammonium nitrate - Nov 15                      50 lbs N/acre
- 150 lbs ammonium nitrate - Nov 15                      150 lbs N/acre
  - 150 lbs ammonium nitrate - Nov 29
  - 150 lbs ammonium nitrate - Dec 13

# Fall applied nitrogen and slash pine

(Irwin et al. 1998: SJAF)

| Variable | Nitrogen per acre |         |         |
|----------|-------------------|---------|---------|
|          | 181 lbs           | 231 lbs | 331 lbs |
| RCD      | 5.1               | 4.9     | 5.2     |
| Ht       | 27                | 26      | 26      |
| Shoot wt | 4.5               | 3.9     | 4.4     |
| Root wt  | 1.6               | 1.4     | 1.5     |

# Fall applied nitrogen and slash pine

(Irwin et al. 1998: SJAF)

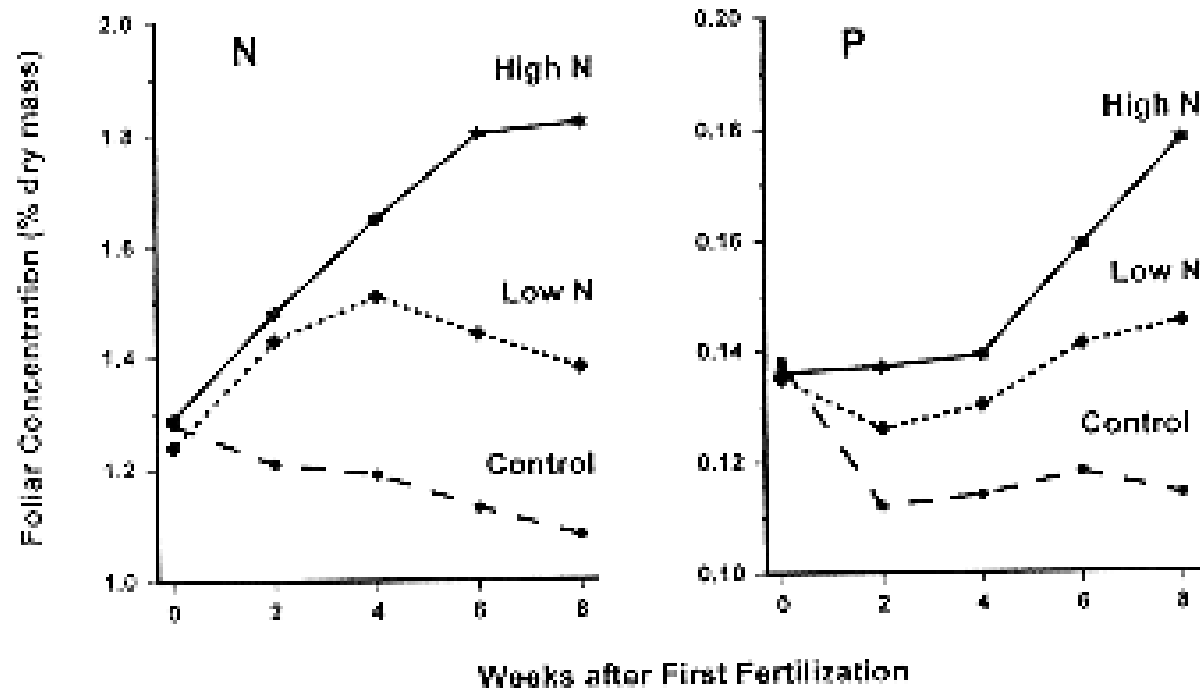


Figure 1. Foliar N and P concentrations during the 8 wk sampling period as affected by soil application of N only: low N—one application 57 kg N/ha on November 15, 1989; high N—three applications at 57 kg N/ha on November 15 and 29, and December 13.

# Fall applied nitrogen and slash pine

(Irwin et al. 1998: SJAF)

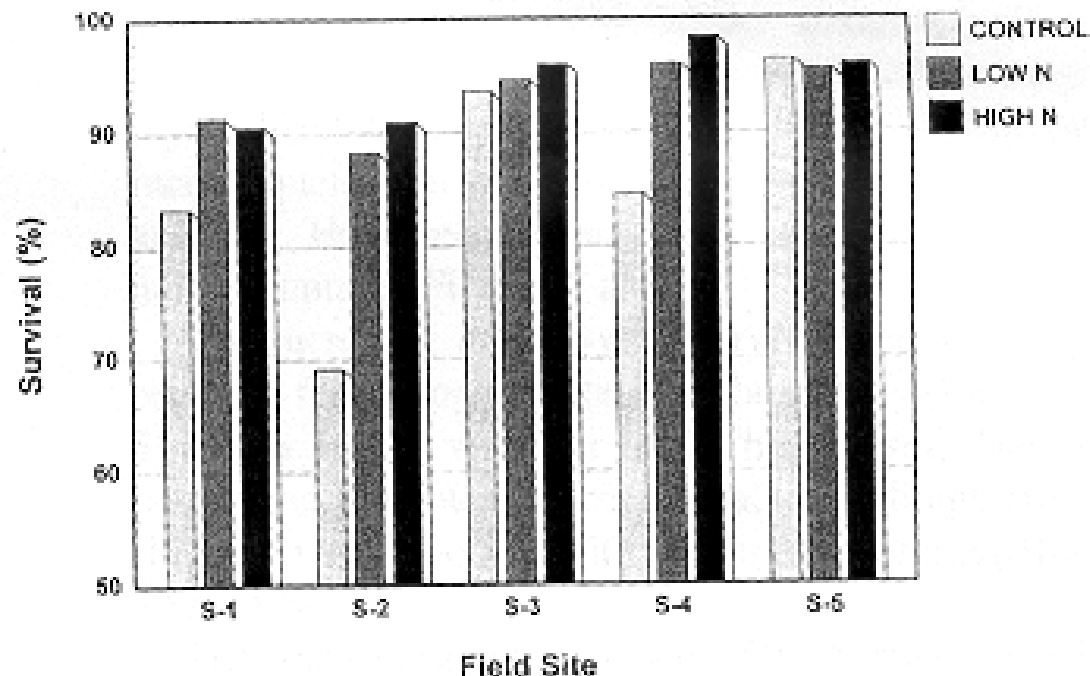
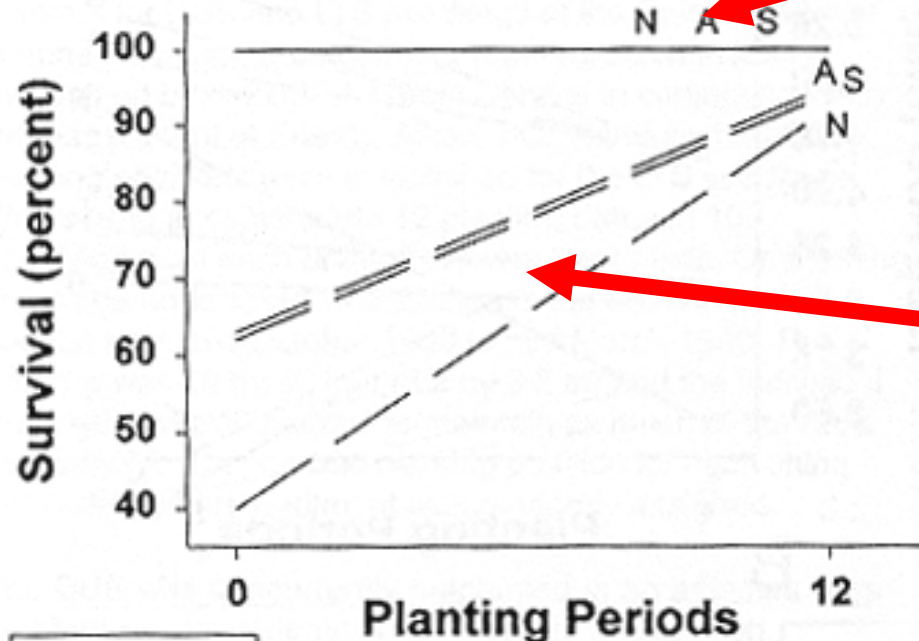


Figure 4. First-year survival of fertilized and unfertilized slash pine seedlings. Mean contrasts among treatments showed that survival of the N-fertilized seedlings, excluding site 5, was significantly higher than unfertilized ( $P < 0.0001$ ).

# Loblolly pine - Georgia

(Kormanik et al. 1999: GTR SRS-25)

Block 1: 75 Lb N/acre  
No undercutting  
Easy to plant due  
to small roots.  
“well balanced”  
seedlings



Block 2: 150 Lb N/acre  
No undercutting  
Difficult to hand plant  
properly due to large lateral  
roots. Seedlings were  
poorly balanced.  
They were not  
“morphologically improved”  
due to high seedbed density  
(24-26/sq ft)

Seedlings grown in raised beds at Athens, GA.

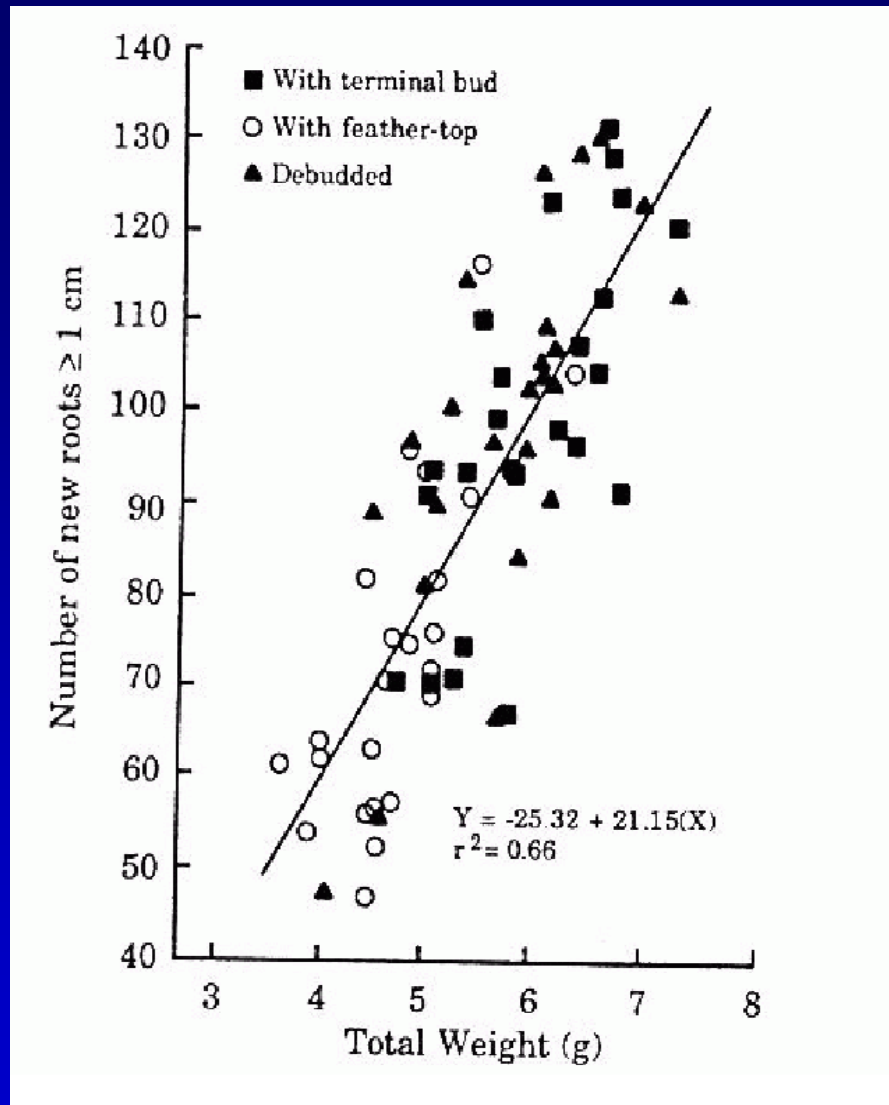
# Summary

When seedling survival is high, there will be little or no fertilizer effect.

However, when grown at operational nurseries and planted on adverse sites, extra N in the nursery can sometimes increase survival by producing seedlings that are no taller but have larger root systems than N deficient seedlings.

# Effect of N Fertilization on RGP



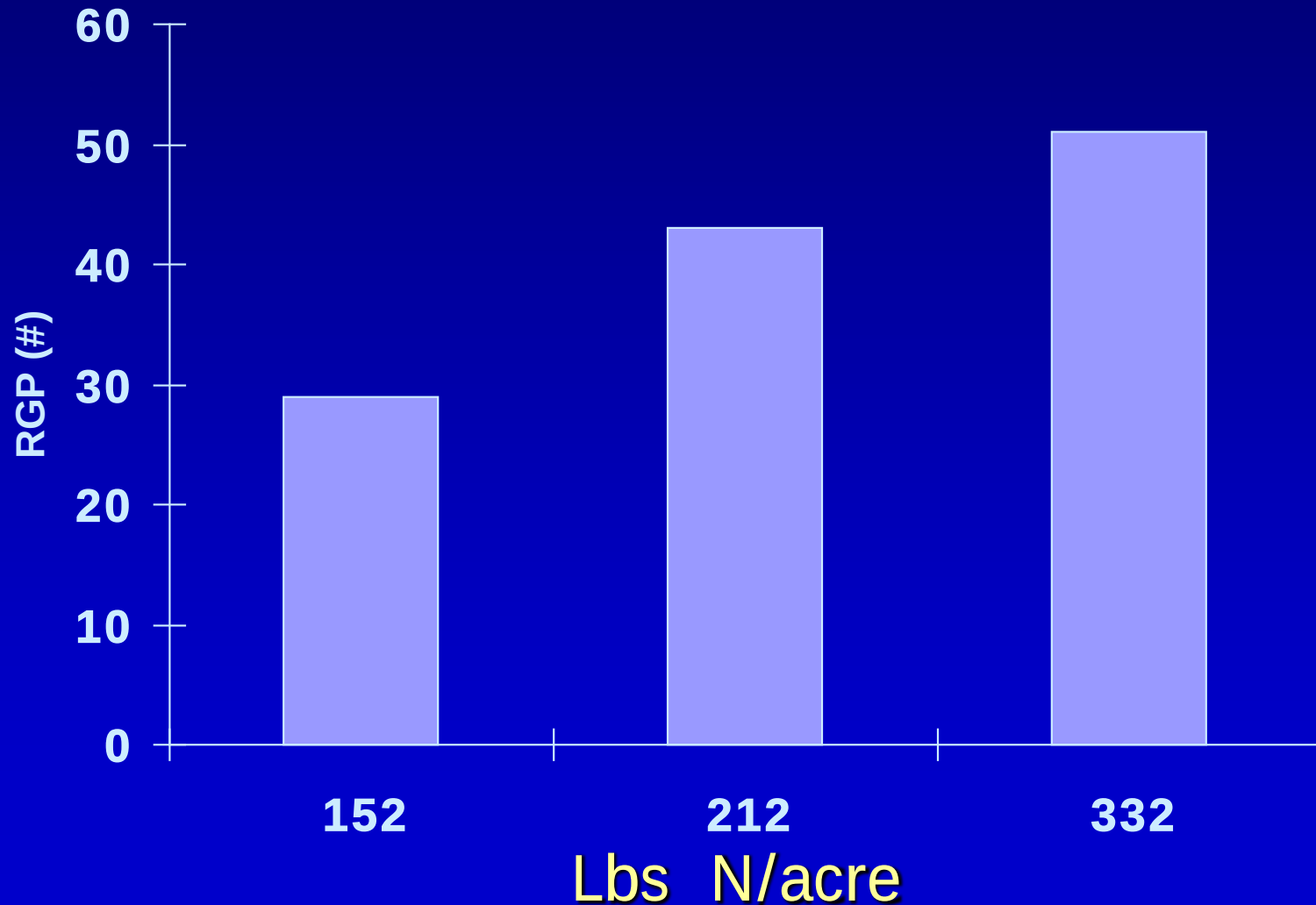


Williams, South and Glover 1988 CJFR

Loblolly pine - Fall Fertilization (containers)  
(Williams and South 1994: 8th BSSRC)

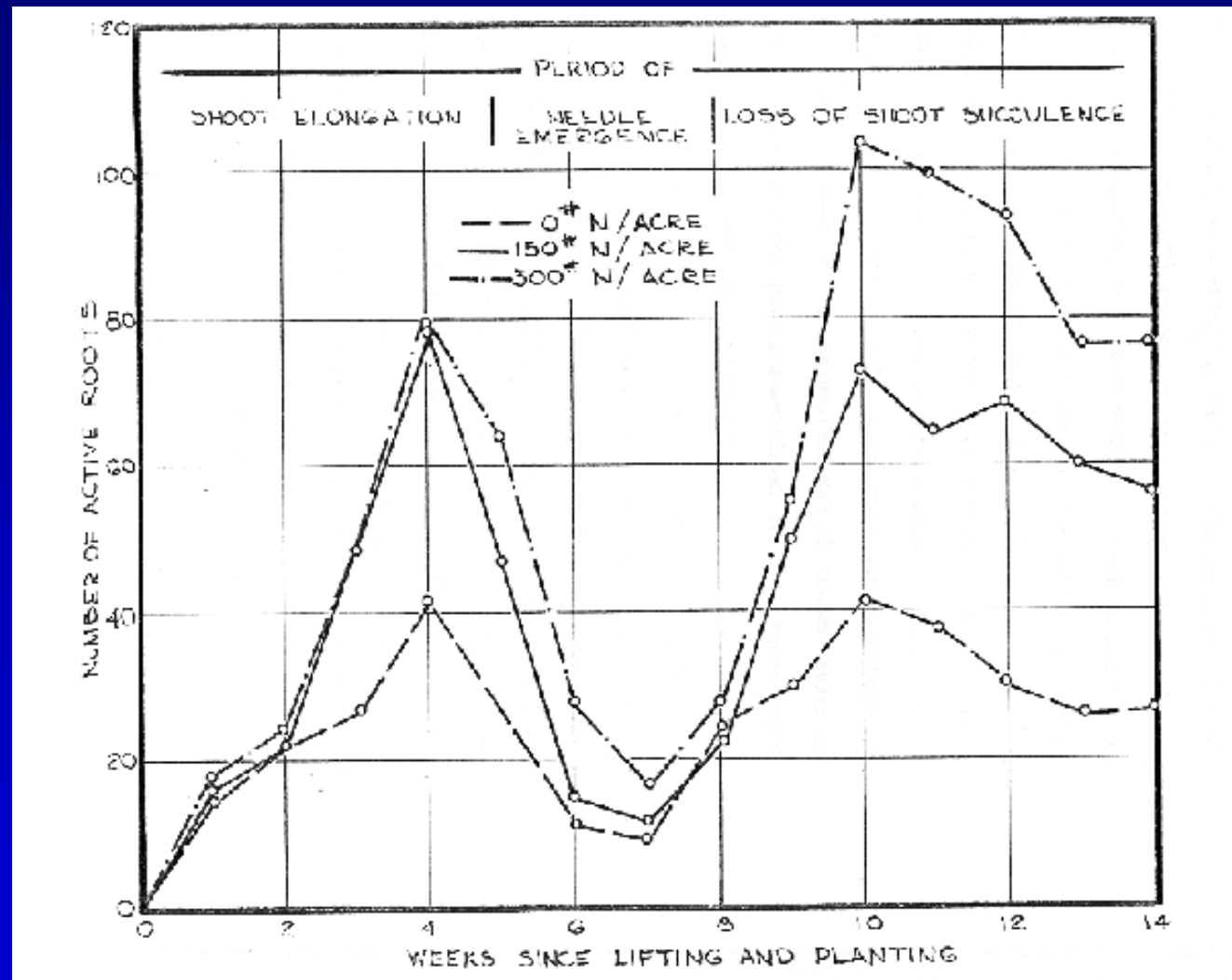
- Growing season N  
152 lbs N/acre      20-20-20      and 15-30-15
- Fall treatments  
control  
60 lbs N/acre      (DAP)  
180 lbs N/acre      (DAP)

# Loblolly pine - Fall Fertilization (containers) (Williams and South 1994: 8th BSSRC)



# Loblolly - Mississippi

(Switzer 1962: Phd)



# Summary

If the environmental conditions are good and seedling survival is high, then there will be little or no differences in survival among fertilizer treatments.

However, when conditions are stressful and seedling mortality is moderate, those seedlings that have higher root-growth will likely survive better than seedlings that are deficient in N at time of outplanting. In some cases “deficient” means levels below 1.4% N in December.

# Effect of Fertilization on short-term growth



**FIG. 3.** First-year height of a seedling from the high nitrogen fertilization regime, approximately 6.5 mm in root collar diameter, and planted on a site receiving herbaceous weed control. The measurement standard is 3.2 ft.



 PAPER

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NURSERIES & ORCHARDS

**Nutrient Loaded**  
for increased early root and shoot growth

TreePack

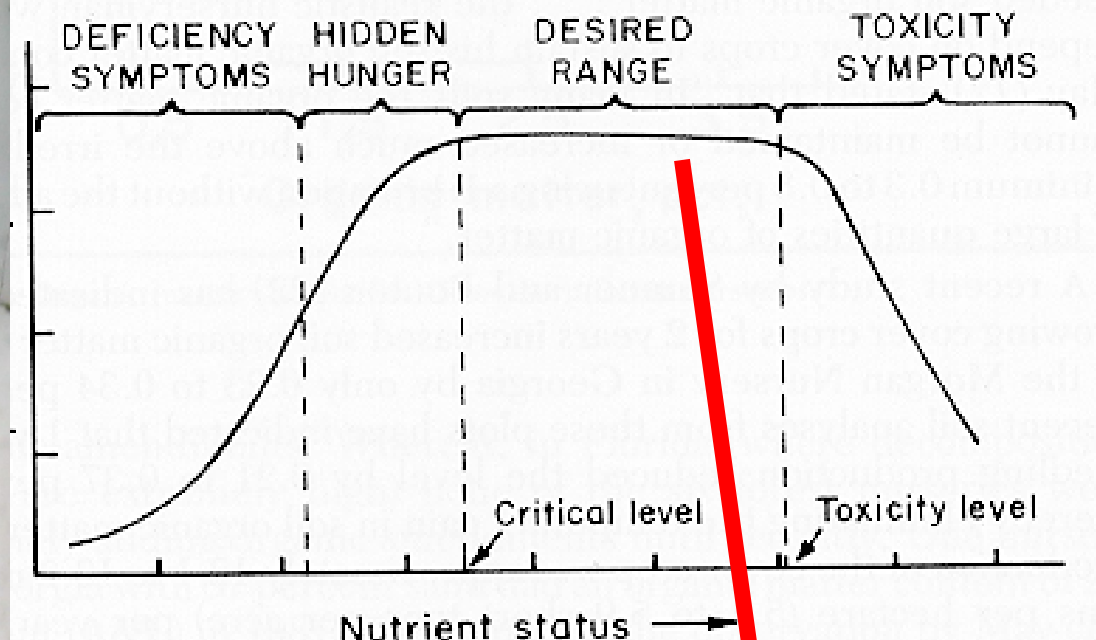
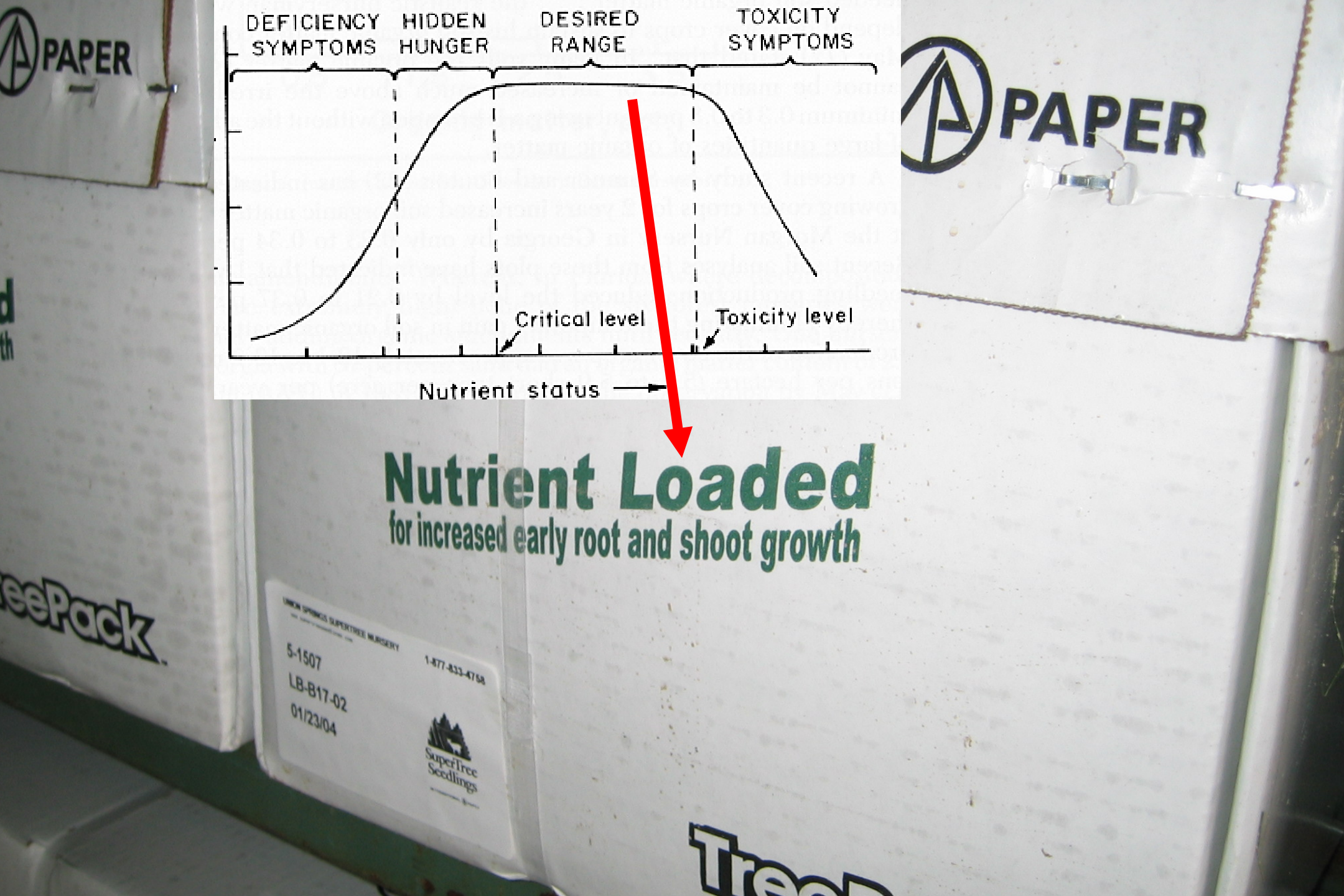
UNION SPRINGS SUPERTREE NURSERY  
1-877-833-4758

5-1507  
LB-B17-02  
01/23/04

  
SuperTree  
Seedlings

Tree





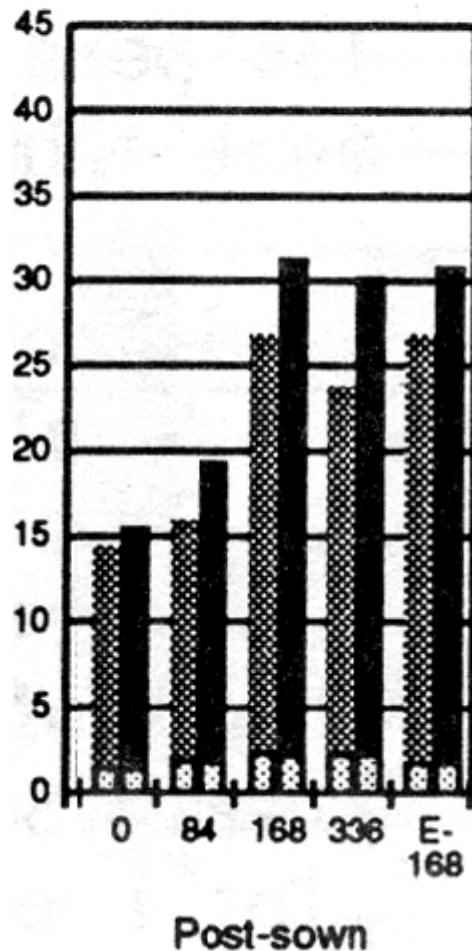
**Nutrient Loaded**  
for increased early root and shoot growth

UNION SPRINGS SUPERTREE NURSERY  
5-1507  
LB-B17-02  
01/23/04  
1-877-833-4758  
SuperTree Seedlings

Tree



## Volume Index (cc)



## Loblolly - Texas (Barber et al. 1991: BSSRC)

Post-sowing fertilization had a positive impact on first-year size of the seedlings: however, use of initial seedling size as a covariate reduced statistical significance in most cases.



# Extra Nursery study - Loblolly

(Blake and South 1990: Highlights)

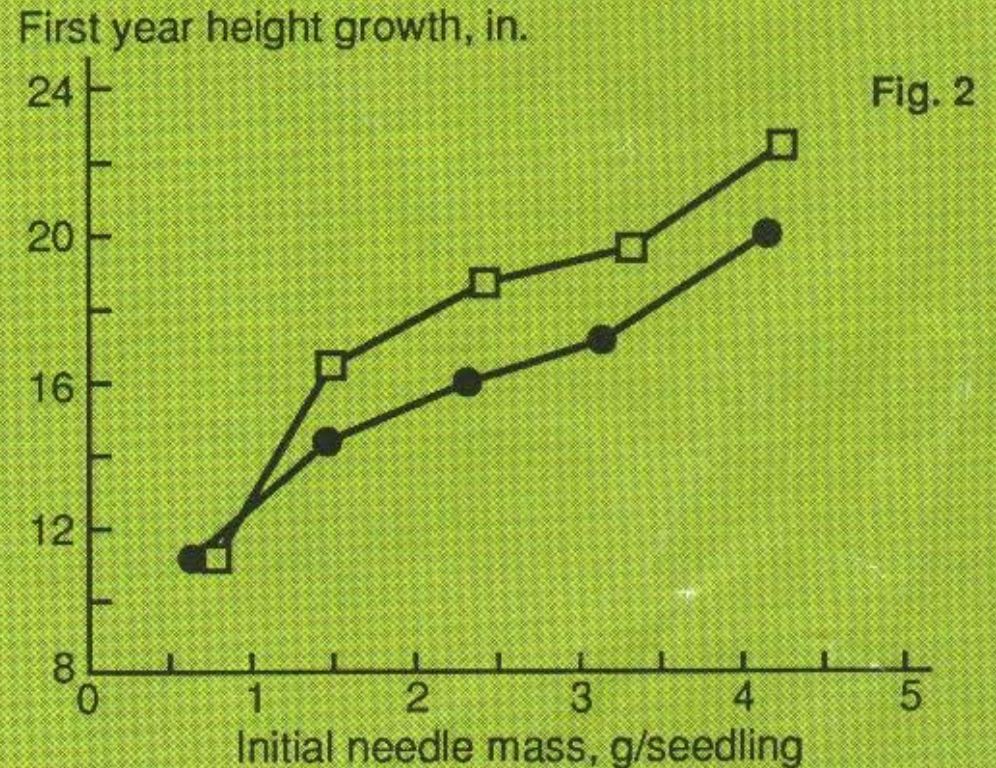
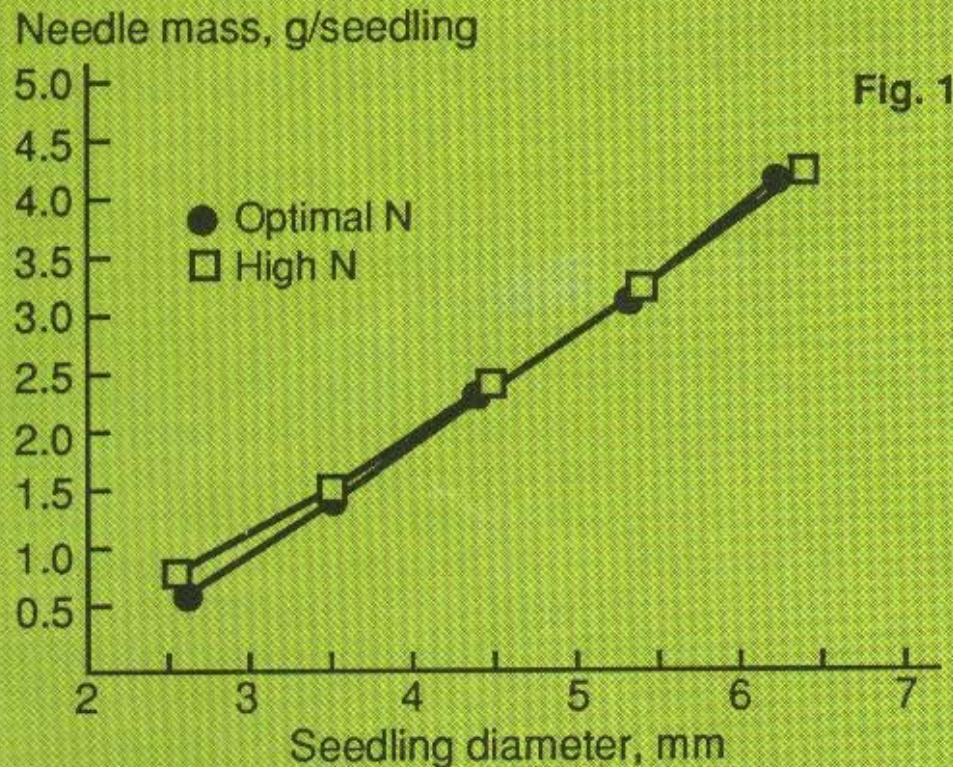
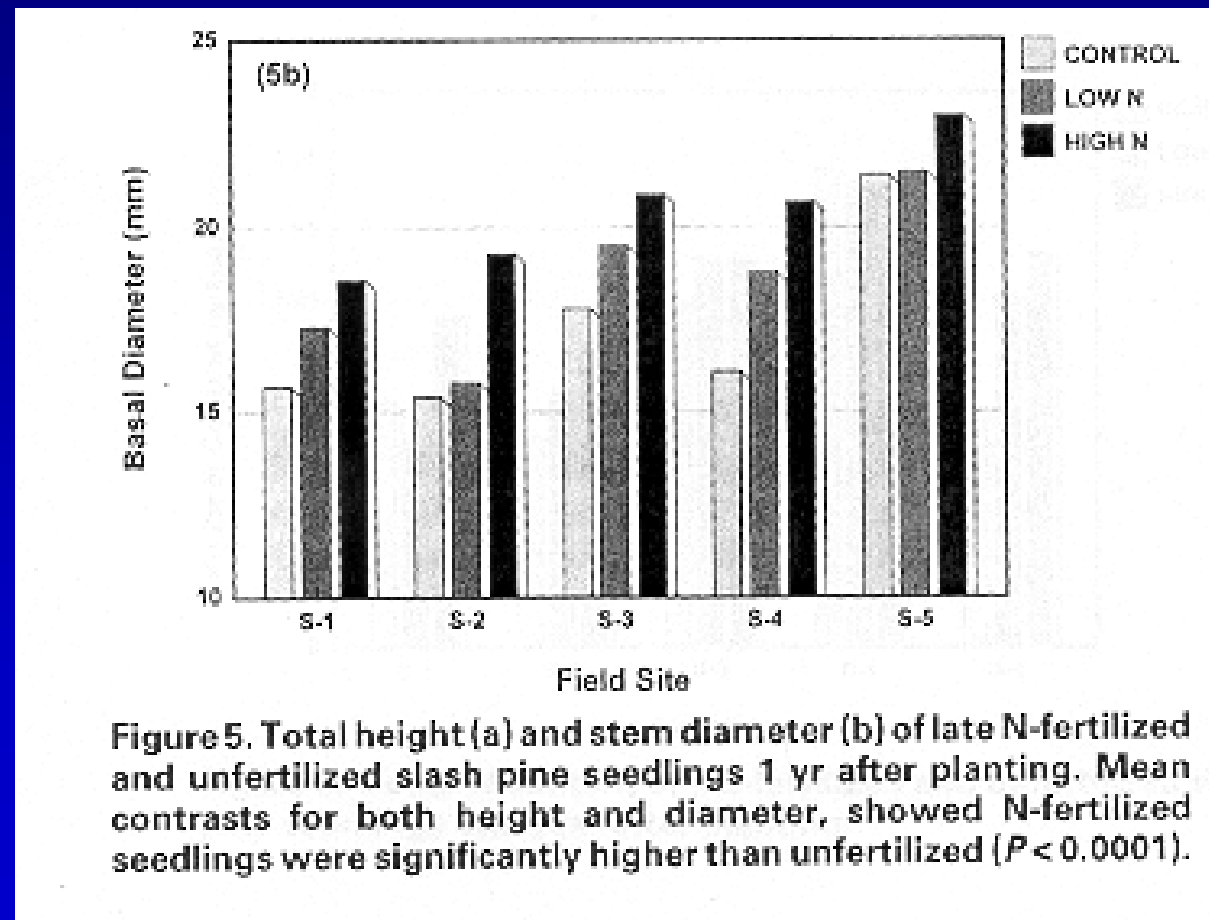


FIG. 1. Average relationships between needle mass of weight and seedling diameter at outplanting for two nursery nitrogen regimes: a nitrogen fertilization rate adequate for seedling development (Optimal N) and a rate 50% greater than needed for best nursery growth (High N). FIG. 2. Average relationship among first-year growth after planting in the field, needle mass or weight, and previous nursery N regime.



# Fall applied nitrogen and slash pine

(Irwin et al. 1998: SJAF)



# 20 Nursery study - Loblolly

(Larsen et al. 1988: SJAF)

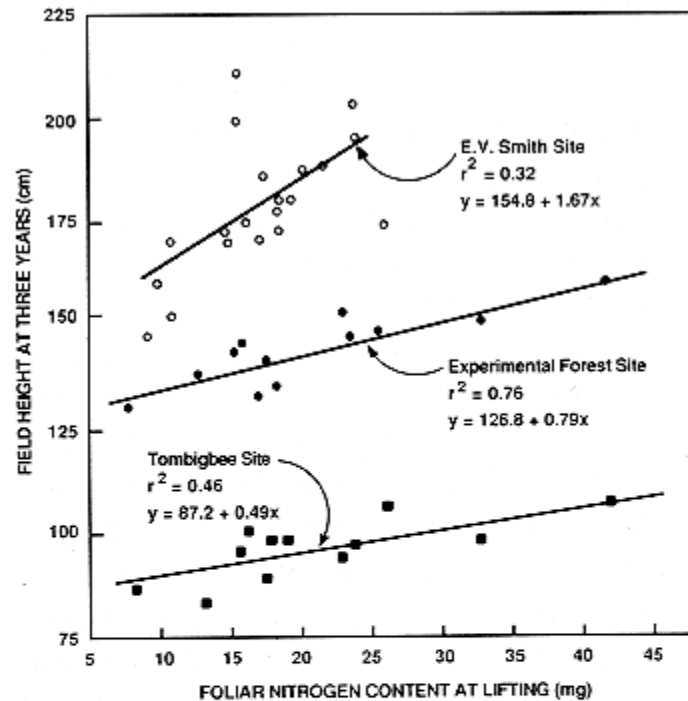


Figure 1. The relationship between third-year field height and foliar nitrogen content (mg/seedling) at lifting for the E. V. Smith Research Center site in Macon County, AL, the Experimental Forest site in Oktibbeha County, MS, and the Tombigbee site in Lowndes County, MS. (Solid symbols from 1957 outplantings by Switzer and Nelson 1963.)

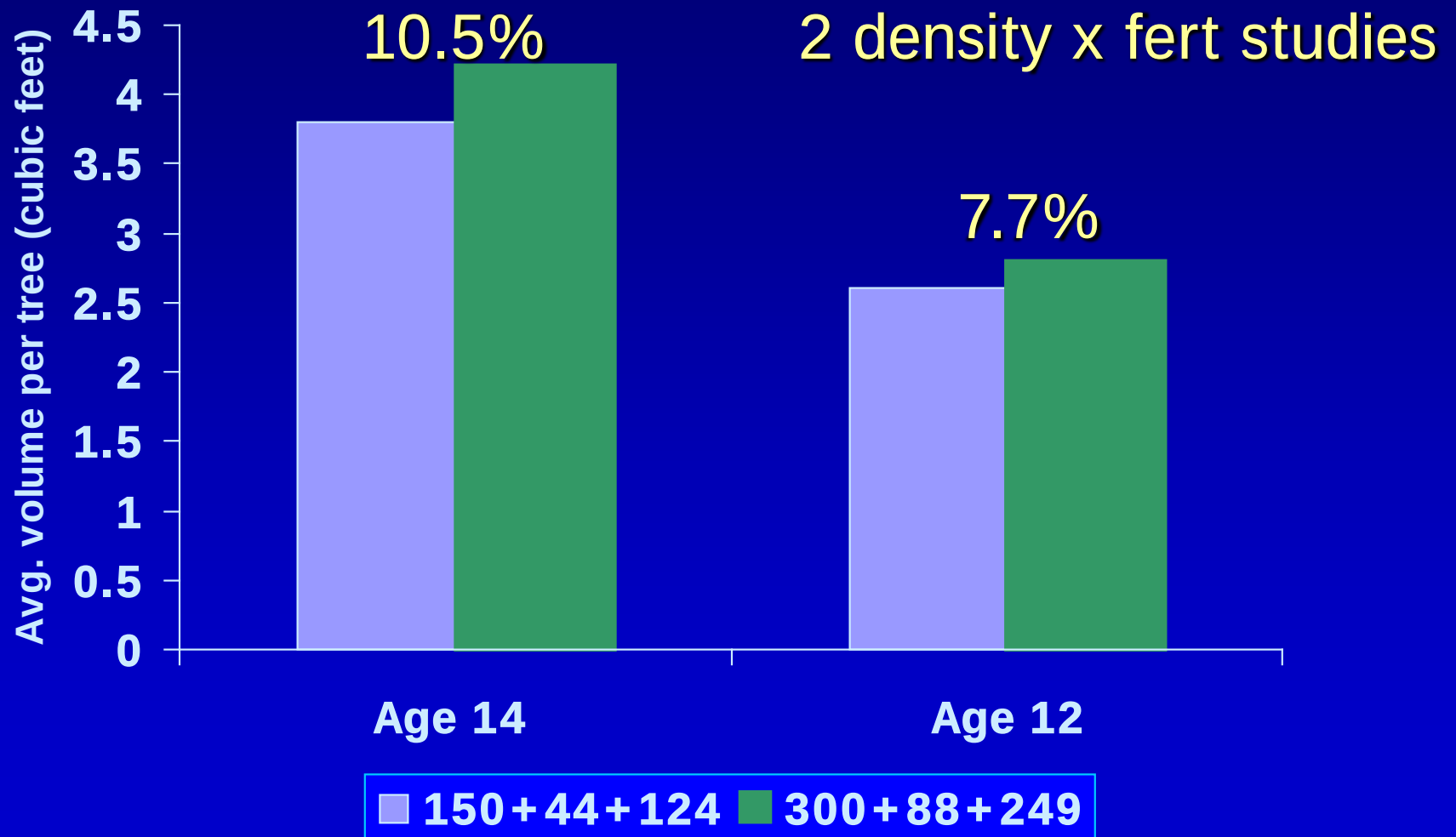
# Summary

Applying extra N in the nursery in the nursery can increase early growth on some sites. This early growth can sometimes be attributed to simply producing seedlings with larger RCD, larger roots and more foliage. Dr. Lee Allen says “Resources grow leaves.... Leaves grow trees.”

However, in some cases, extra growth appears to be related just to increases in nitrogen concentrations in the foliage. This suggests that early growth may be a function of both more leaves and higher foliar N.

# Effect of Fertilization on Long-term growth

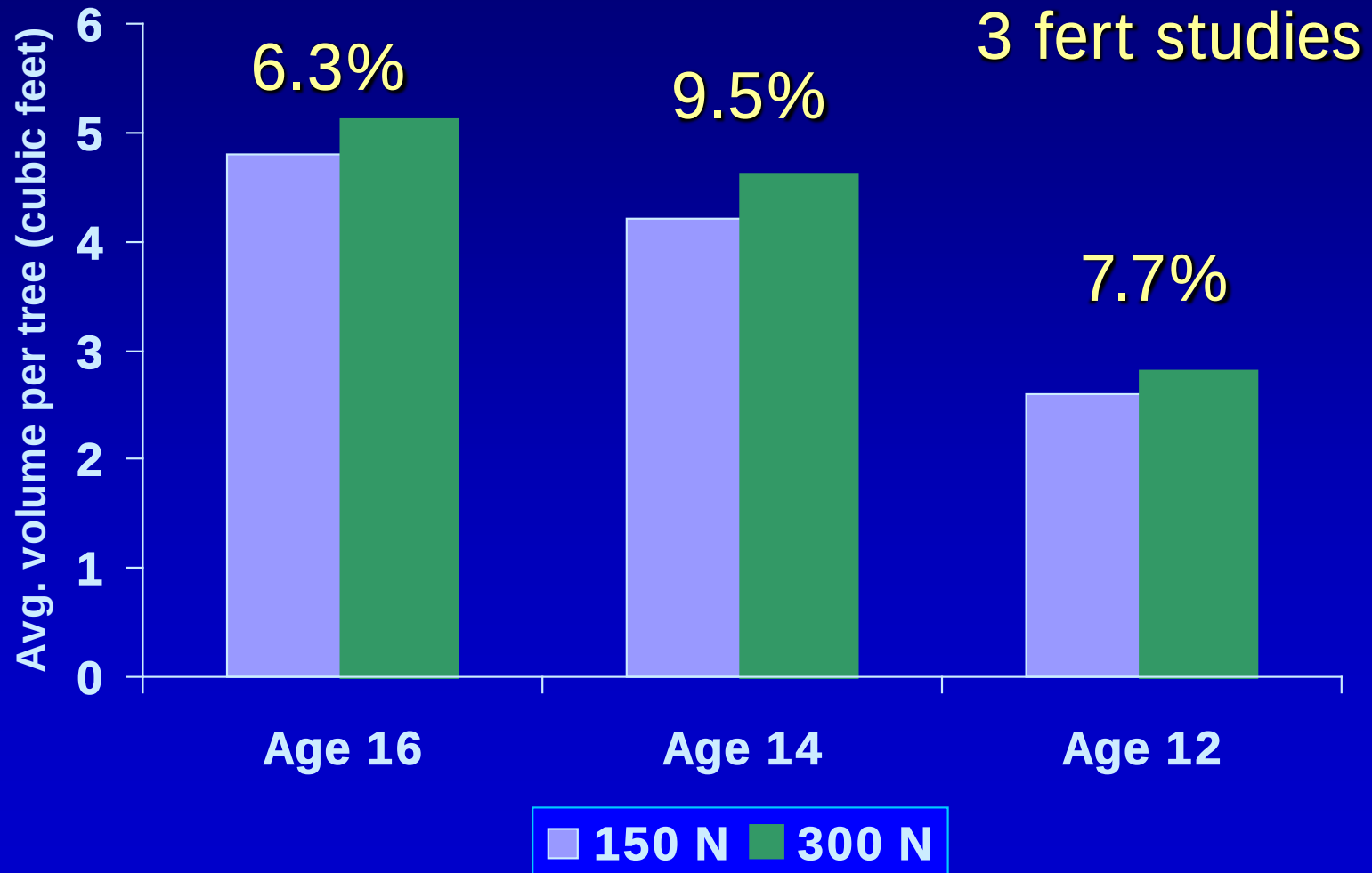
# Loblolly - Fertilization (nursery) (Autry 1972: MS thesis)





# Loblolly - Fertilization (nursery)

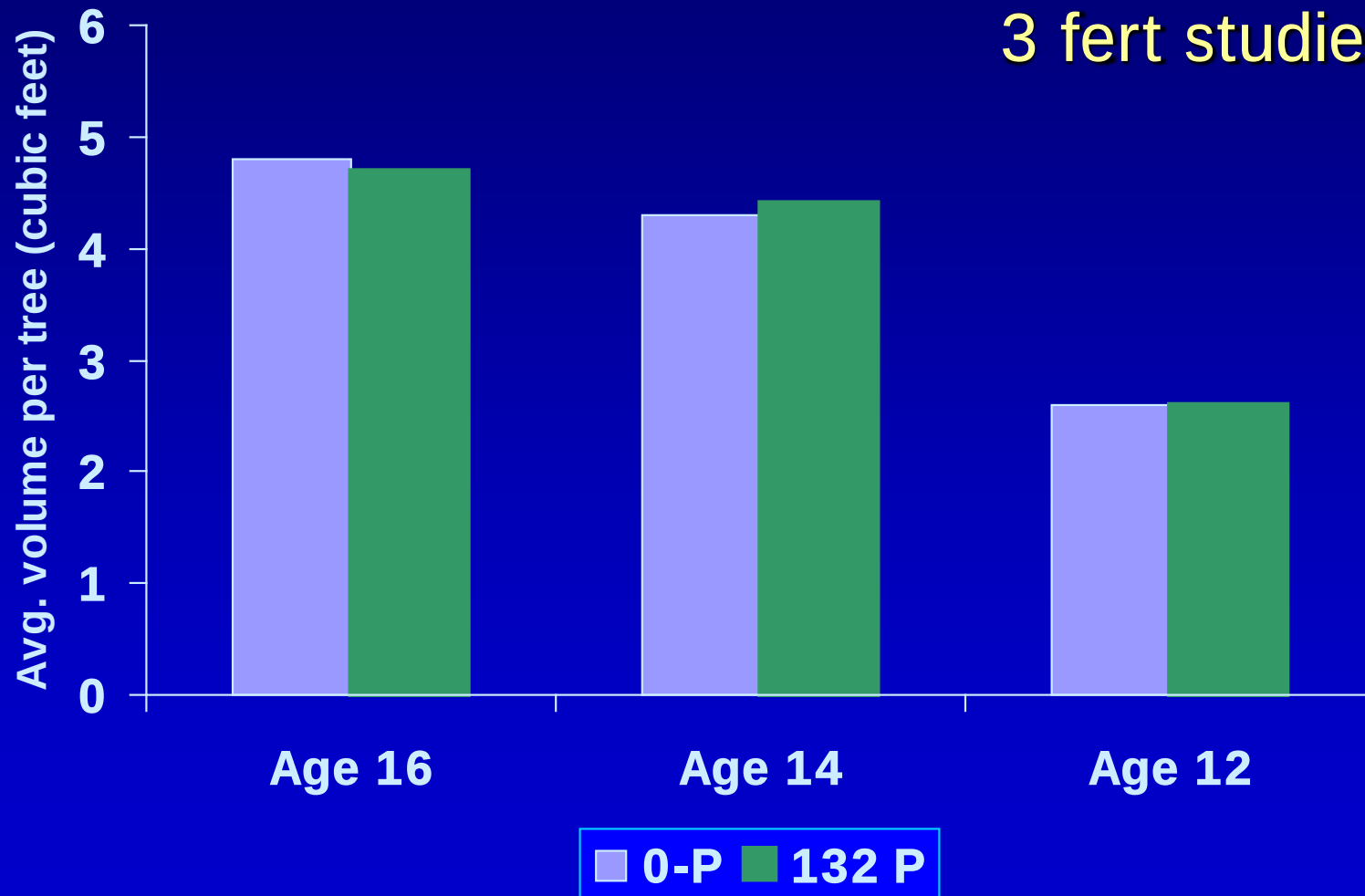
(Autry 1972: MS thesis)



# Loblolly - Fertilization (nursery)

(Autry 1972: MS thesis)

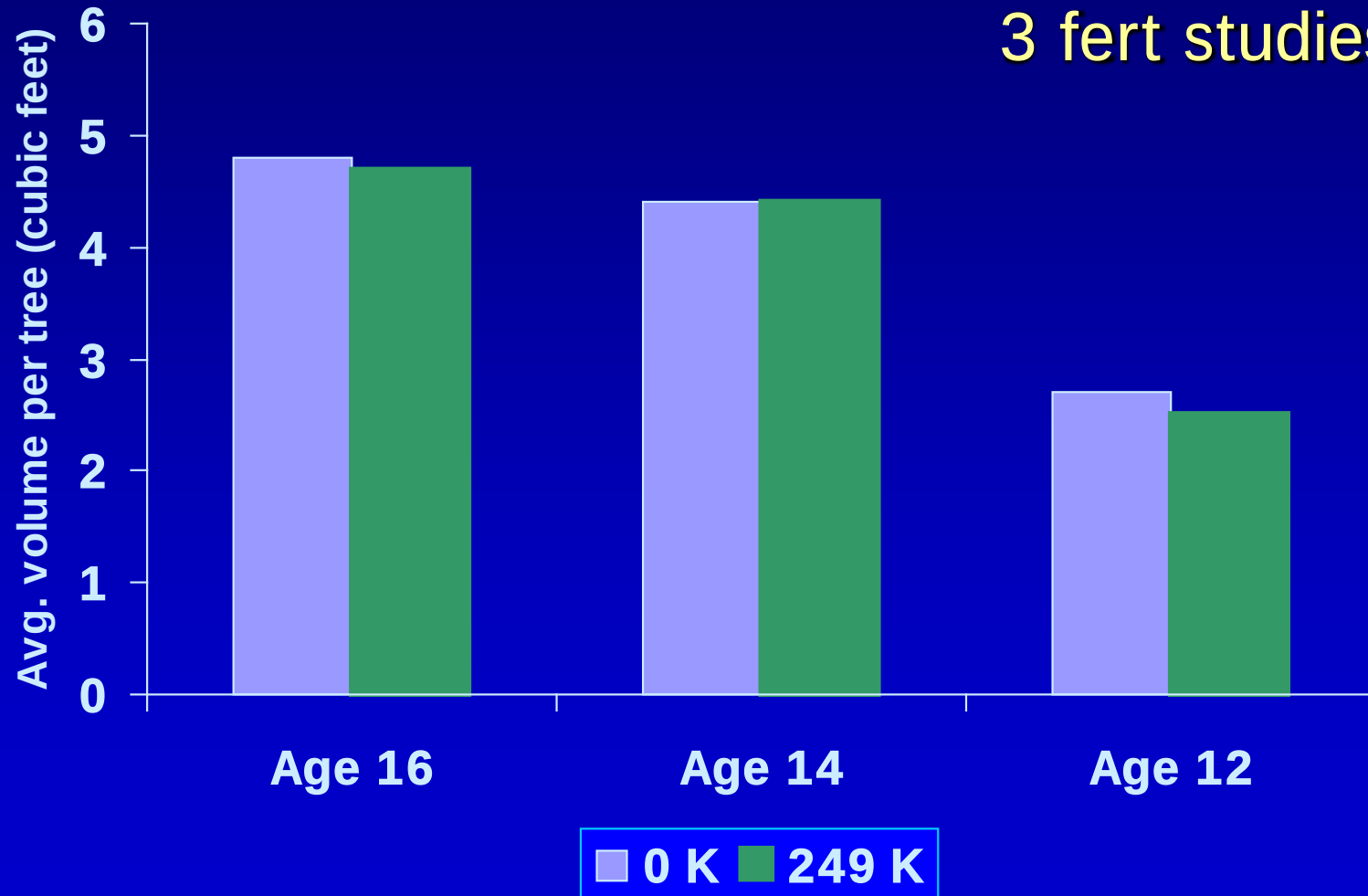
3 fert studies



# Loblolly - Fertilization (nursery)

(Autry 1972: MS thesis)

3 fert studies



# Loblolly - Fertilization (nursery)

## (Autry 1972: MS thesis)

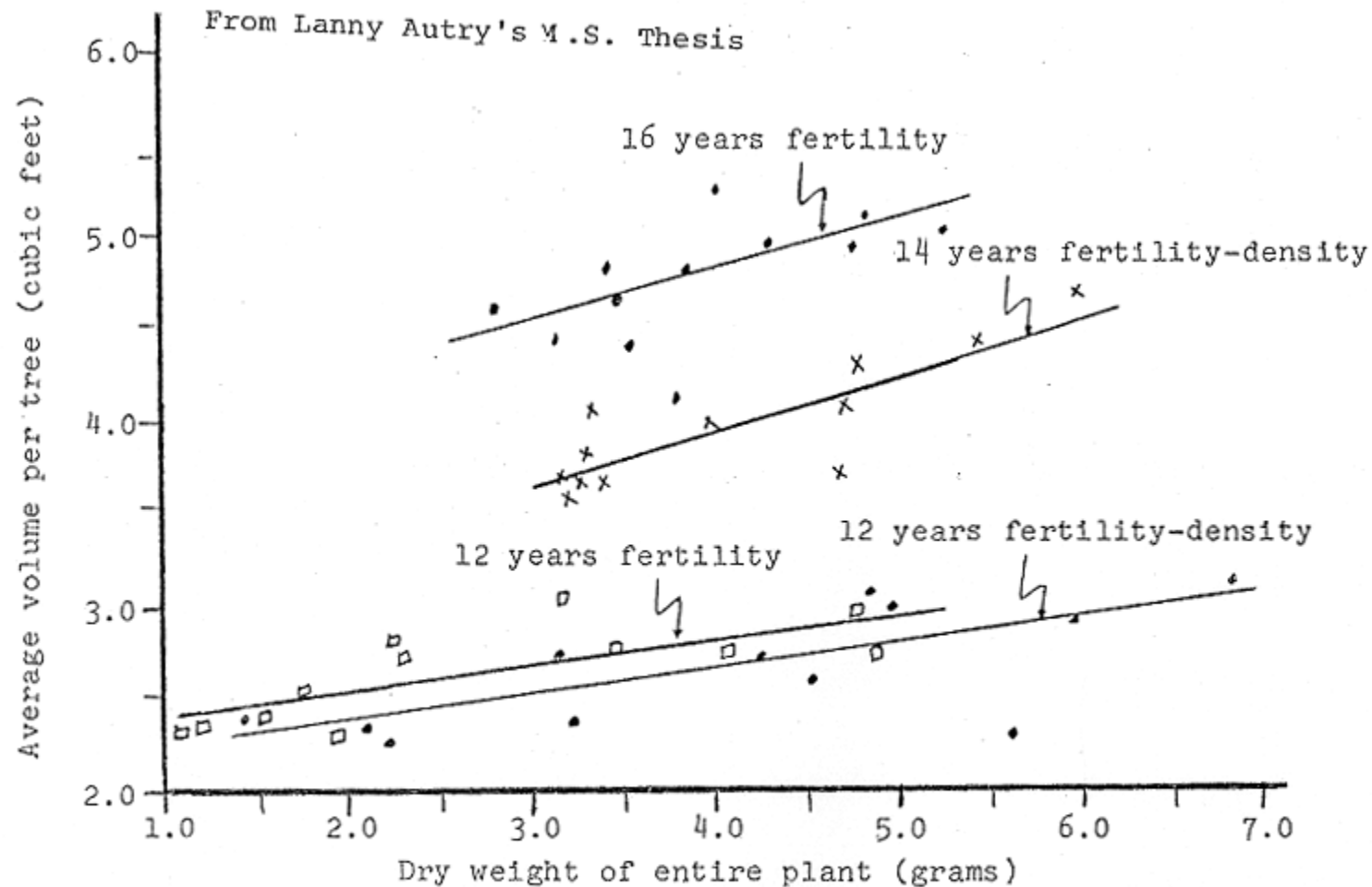
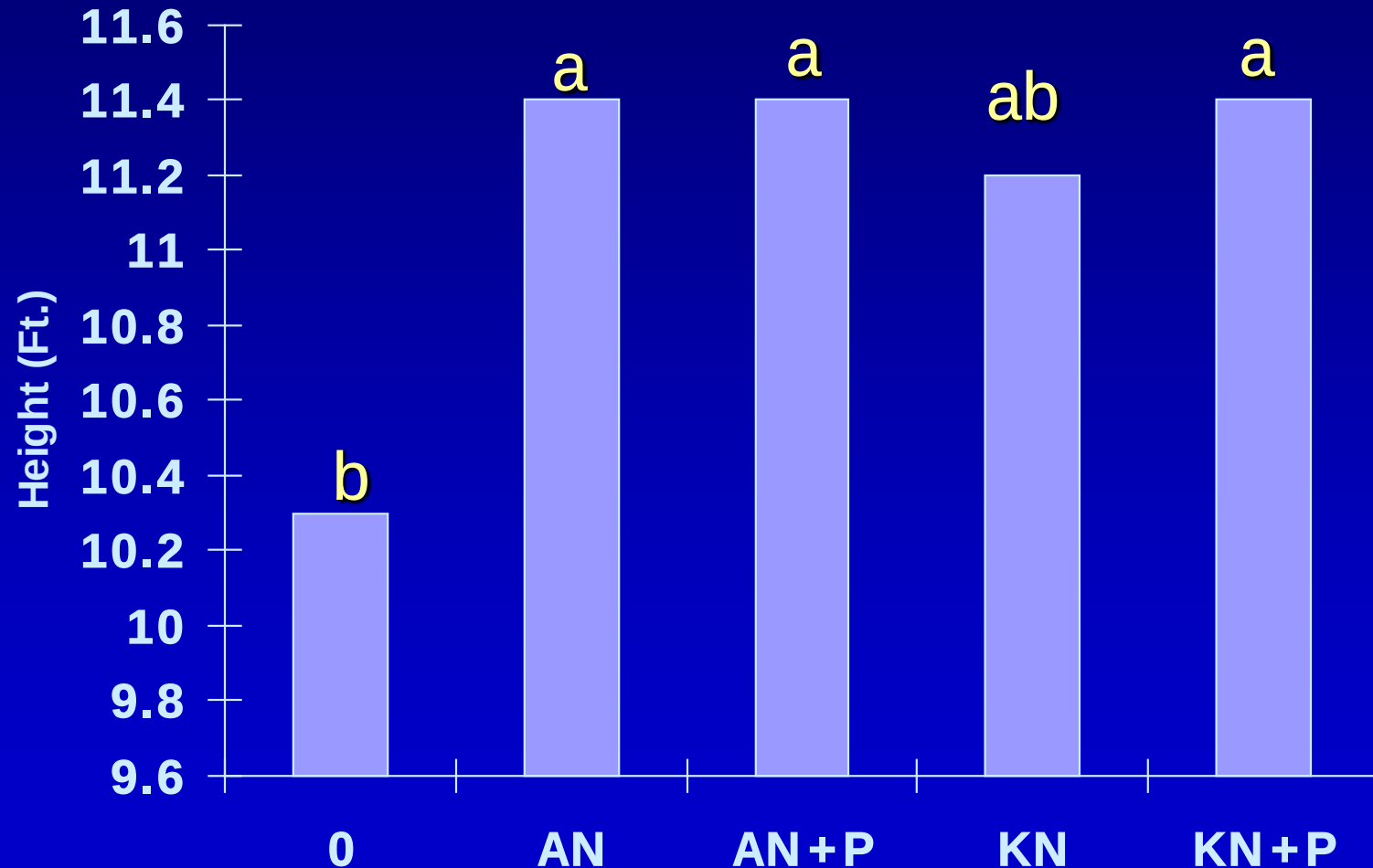


Figure 4. The relation of total dry weight of the seedlings at lifting to average volume per tree at the end of the indicated field seasons.

# Longleaf - Fall Fertilization (nursery) (Hinesley and Maki 1980: SJAF)

8 years old



# Loblolly - Virginia

(Dierauf and Chandler 1995: VDF OR #121)

|         | RCD | Top  | Density |
|---------|-----|------|---------|
|         | mm  | Inch | #/sq ft |
| 150 lbs | 5.1 | 9.8  | 18.4    |
| 300 lbs | 5.3 | 10.1 | 18.8    |
| 450 lbs | 5.1 | 8.9  | 18.6    |

# Loblolly - Virginia

(Dierauf and Chandler 1995: VDF OR #121)

Age 7 data      N.S.

| N rate  | Survival | DBH  | HT   | D*D*Ht |      |
|---------|----------|------|------|--------|------|
|         | %        | Inch | Ft   |        |      |
| 150 lbs | 88.8     | 3.8  | 20.2 | 2.025  |      |
| 300 lbs | 85.6     | 3.9  | 20.7 | 2.186  | 7.9% |
| 450 lbs | 90.6     | 4.0  | 20.8 | 2.197  | 8.5% |



# Summary

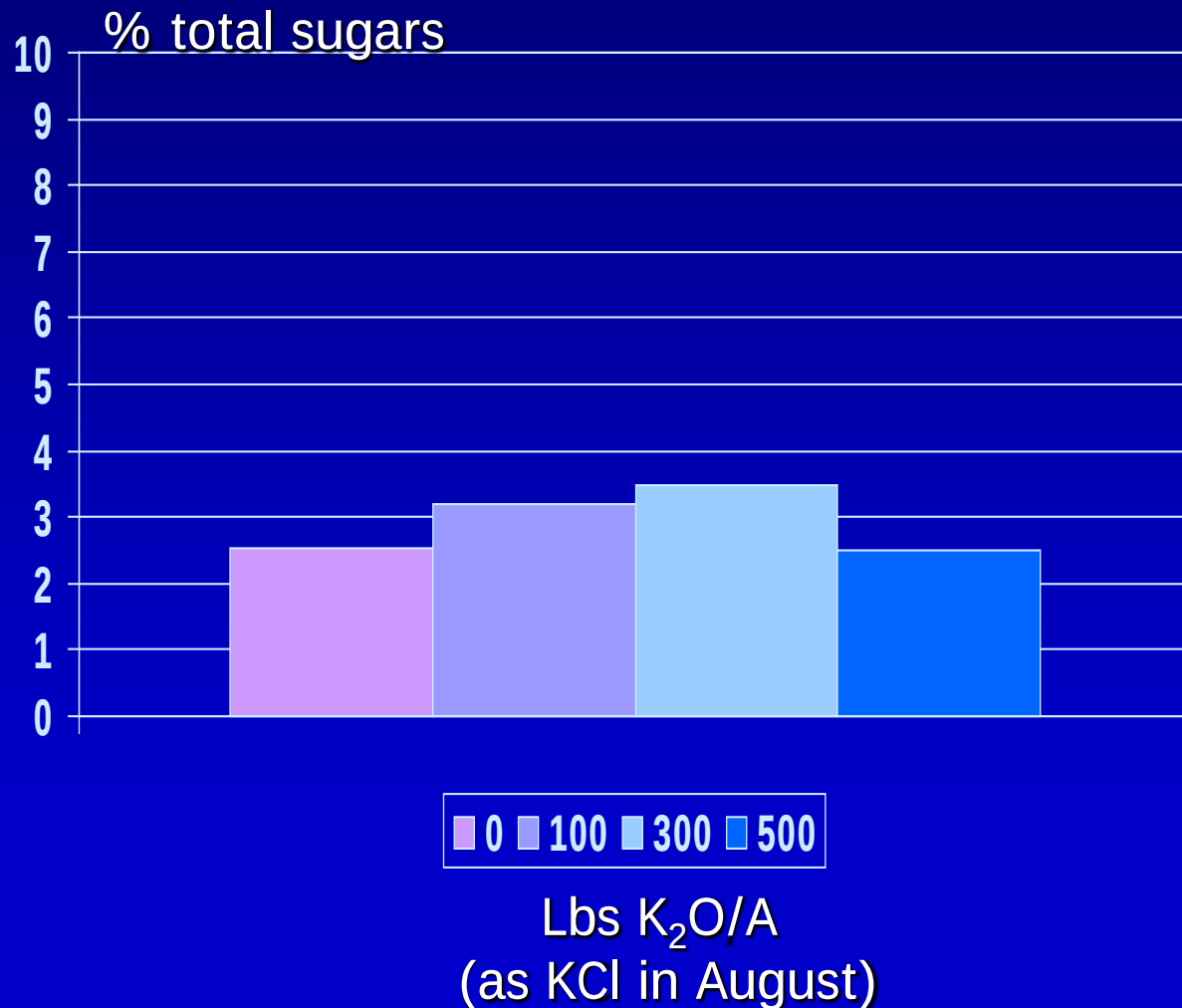
On some sites, extra N in the nursery can increase tree volume 7 to 16 years after planting. This long-term effect is likely not due to a persistent “treatment effect” but due instead to simply getting the trees “up and going” sooner.

No long-term benefit should be expected in situations where extra N (applied in the nursery) does not improve early growth in the field.

Extra K Fertilization in the  
nursery has little benefit for  
Survival and Early Growth

# White spruce - Wisconsin

(Kopitke 1941: JOF)



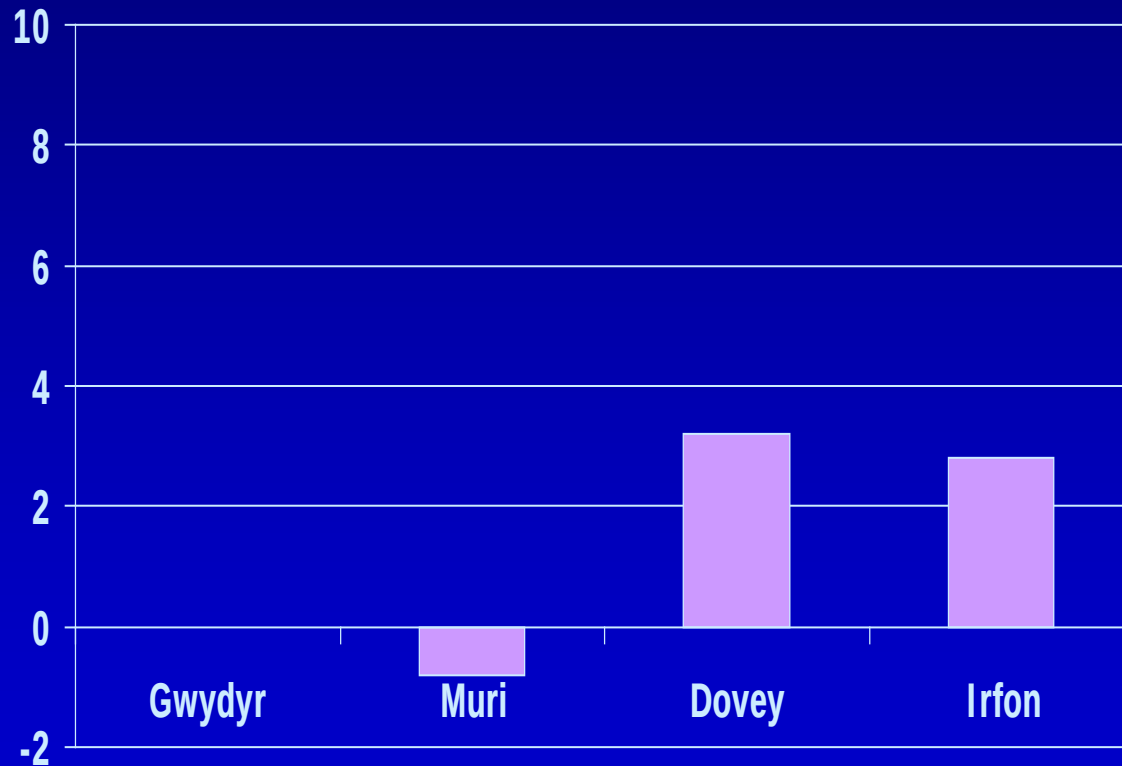
“Timely correction of potash deficiency are recommended as a prerequisite for production of frost resistant nursery stock.”

(no freeze tests conducted on whole seedlings)

# Sitka spruce - UK

(Benzian 1974: Forestry)

Increase in 1st yr growth (cm)



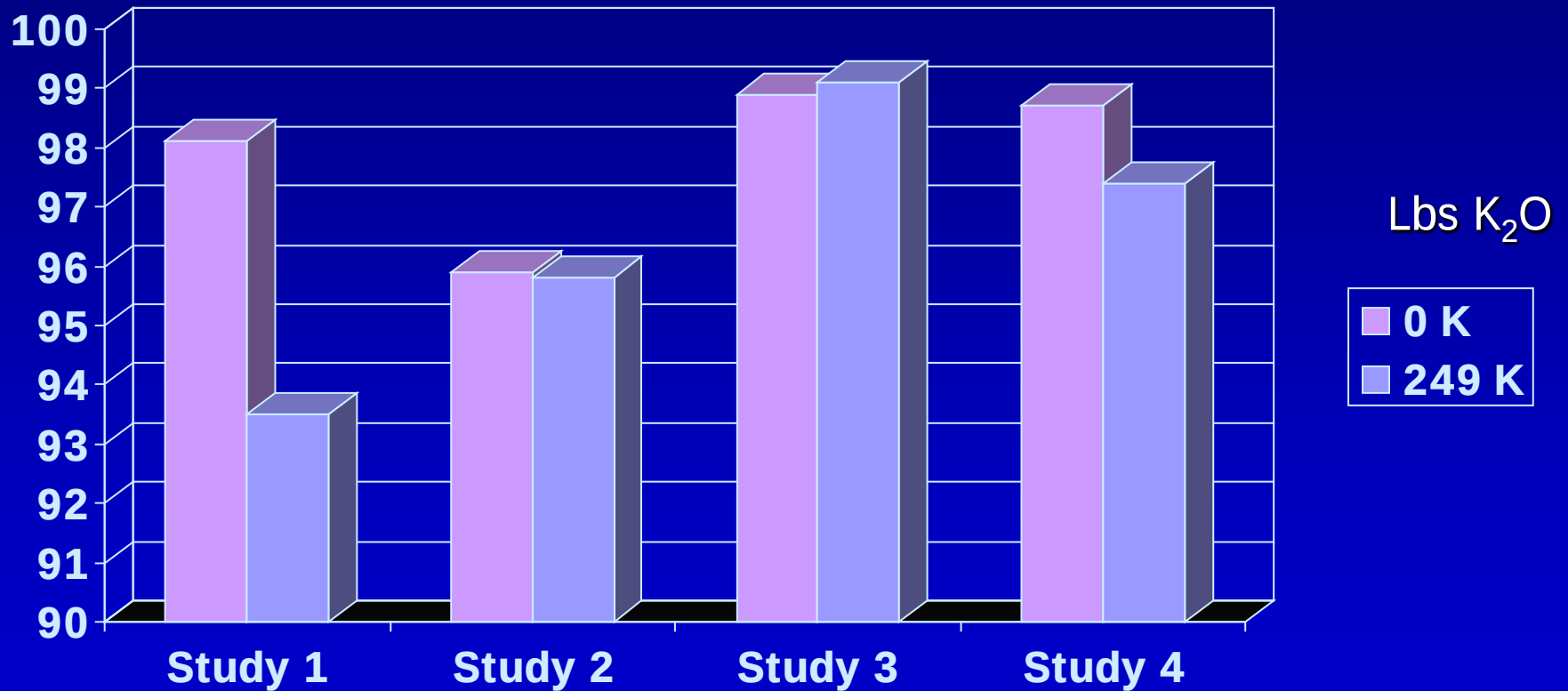
125 Lbs K/A (as K<sub>2</sub>SO<sub>4</sub> in September)

“In the few experiments which tested late-season potassium in the nursery, K concentrations were increased from deficiency to barely sufficiency level: growth in the forest was increased in 2 of the 4 experiments. The extra K had no effect on frost damage.”

# Loblolly - Mississippi

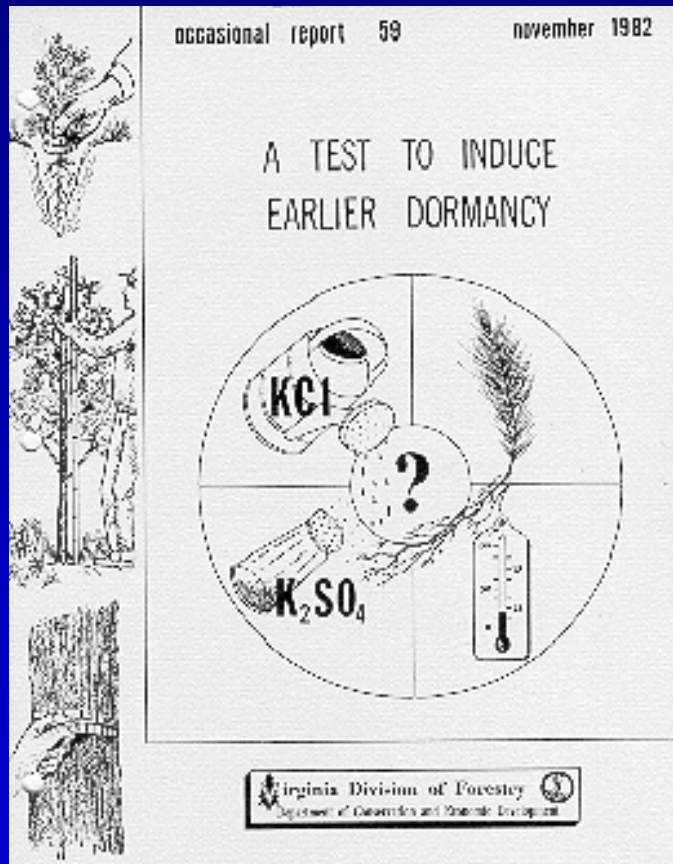
(Switzer 1962: Phd)

Age 3 survival (%)



# Loblolly - Virginia

(Dierauf 1982: VDF OR #59)

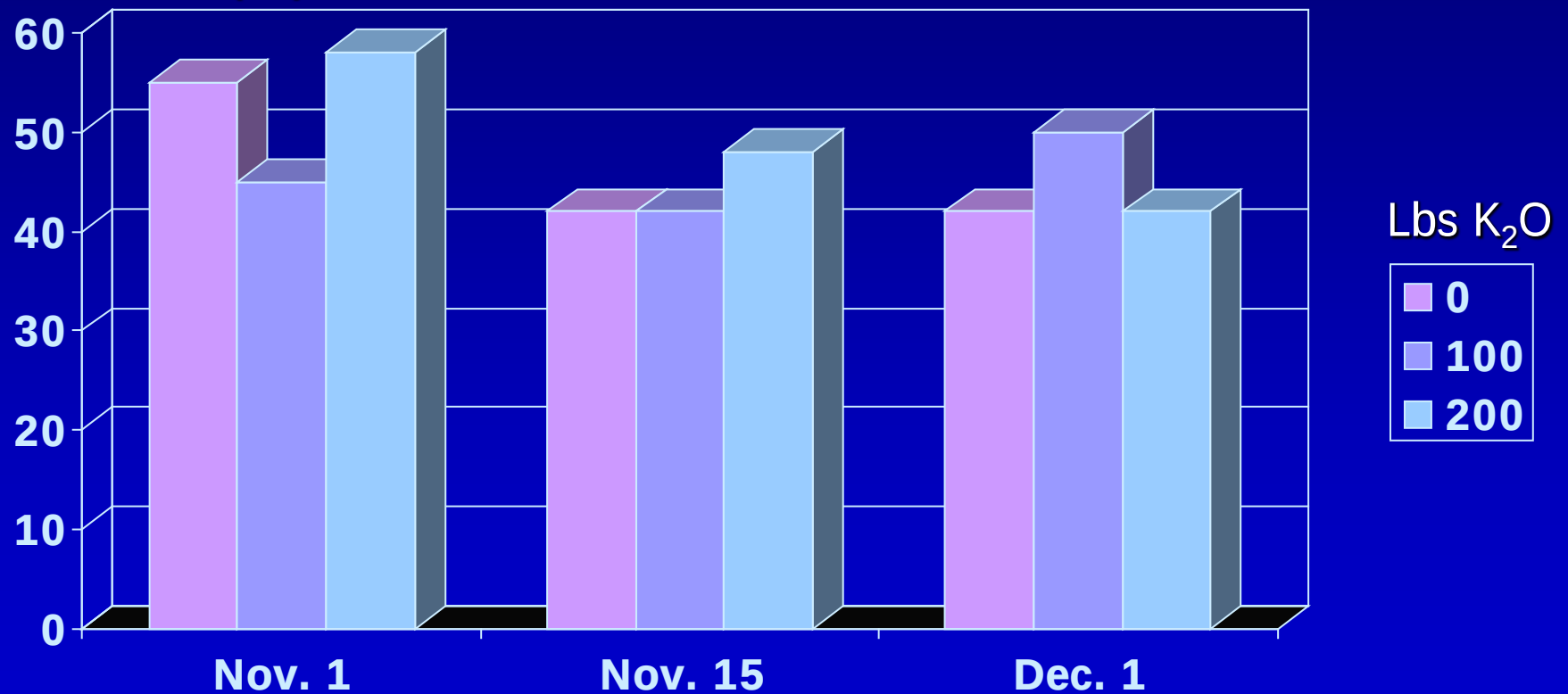


Potassium fertilizer applied in mid-September had the reverse effect of what we expected. But we were only looking at one aspect: whether potash would cause seedlings to become dormant earlier in the fall

# Loblolly - Virginia

(Dierauf 1982: VDF OR #59)

Age 3 survival (%)



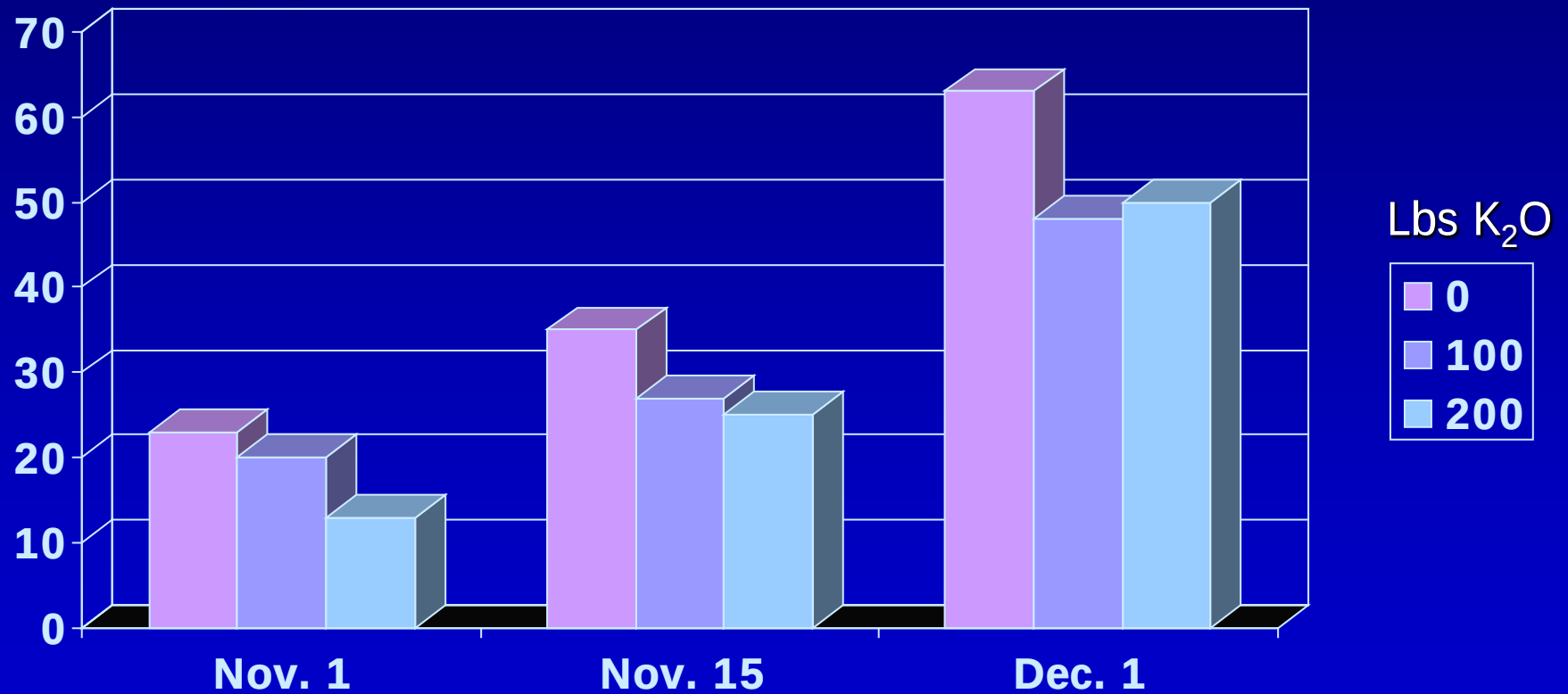
Lifting Date - no storage



# Loblolly - Virginia

(Dierauf 1982: VDF OR #59)

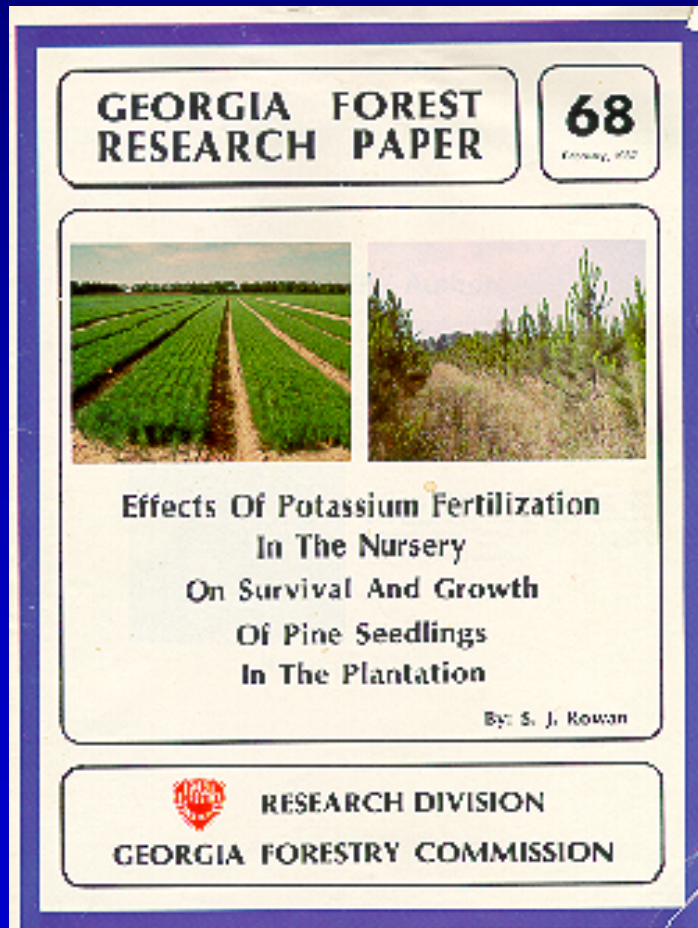
Age 3 survival (%)



Lifting Date - 2 week storage

# Loblolly - Georgia

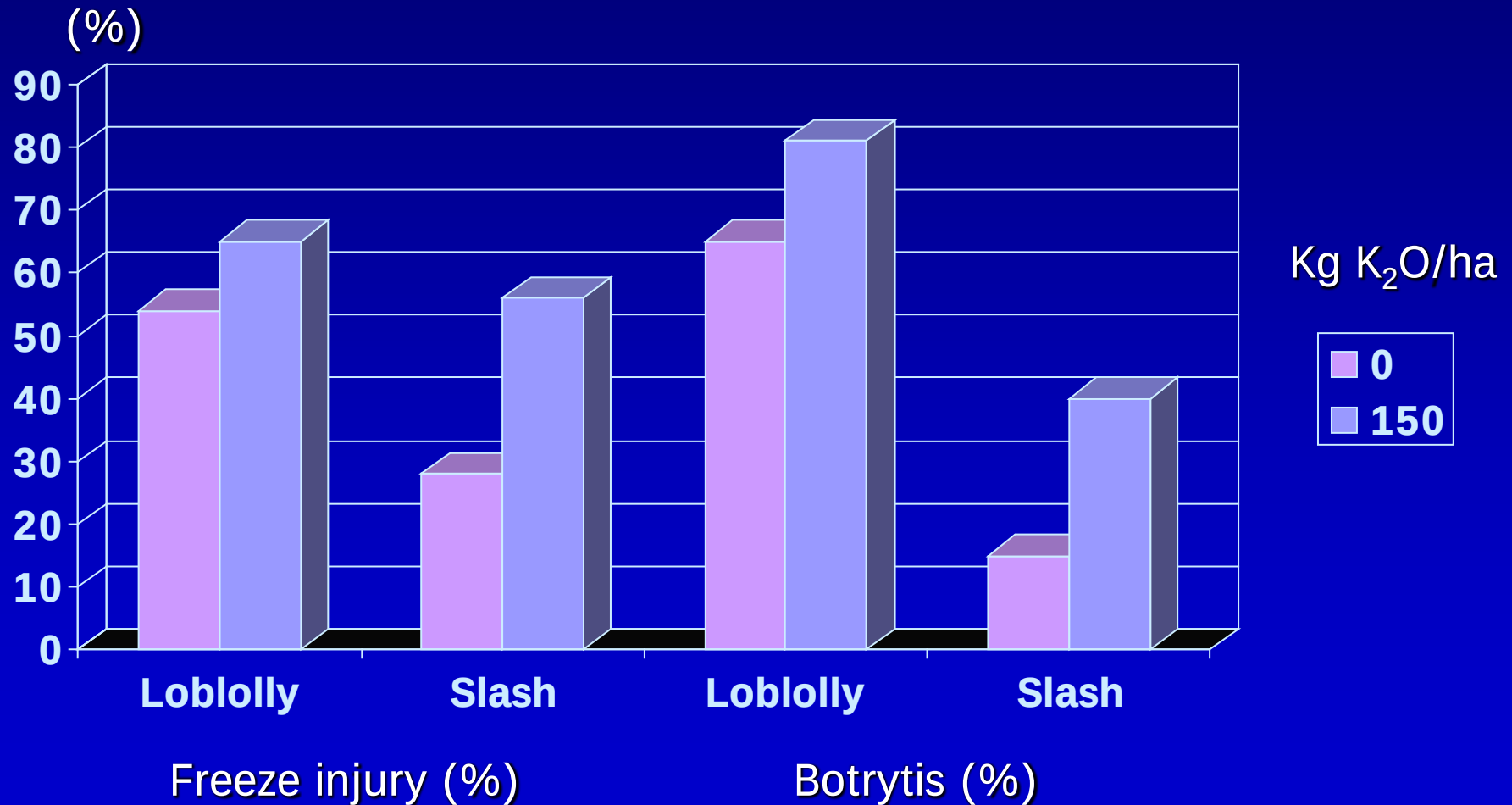
(Rowan 1987: GFC #68)



Potassium source, rate, frequency, nor date of application affected winter bud formation, resistance to artificial freezing temperatures, or seedling size in the nursery. Seedling growth, survival and disease in outplantings were not affected

# Loblolly - Slash - Alabama

(South et al. 1993: SAFJ#166)



# Summary

K should be applied to avoid a deficiency. However, for the southern pines, there is no evidence that providing extra K to seedlings increases freeze resistance or promotes the formation of terminal buds.



Regeneration foresters will become increasingly interested in improving early field growth by planting seedlings that are not deficient in N

# A very cheep investment in improving seedling quality

- When managers apply 300 lbs of N per acre/yr (operational now at some nurseries), the extra cost of fertilizers will amount to only 4 cents per outplanted acre!!!!!!

