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GALE A. BUCHANAN, DIRECTOR
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The Southern Forest Nursery Soil Testing Program

A Review of the Work of the Program and its Support by the Auburn University Southern Forest Nursery Management Cooperative

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THE SOUTHERN FOREST NURSERY SOIL TESTING PROGRAM

DAVID B. SOUTH and C.B. DAVEY[1]

INTRODUCTION

IN 1980, a committee was established to address the problem of soil testing and interpretation for southern forest nurseries. Subsequently, a program has been developed primarily for the nurseries in the Southern Coastal Plain and involves (1) soil testing by a single lab; (2) soil fertility interpretation and suggestions for amendments; and (3) computer storage and retrieval of data. In 1982, 25 southern nurseries used the services of the Southern Forest Nursery Soil Testing Program.

At the 1980 Southern Nurseryman's Conference, the Nursery Technical Committee discussed the problems of soil testing and interpretation for forest nurseries in the South. Dr. John Mexal was appointed chairman of a committee to address this problem. The committee met at Raleigh, North Carolina, on June 23, 1981, and as a result, the Southern Forest Nursery Soil Testing Program was formed.

This program consists of three separate but integrated parts:

(1) Soil testing performed by A&L Agricultural Labs in Memphis, Tennessee.

(2) Soil fertility suggestions by C.B. Davey.

[1]Assistant Professor, Department of Forestry, and Director of the Auburn University Southern Forest Nursery Management Cooperative; and Carl Alvin Schenck Professor of Forestry and Soil Science, North Carolina State University, respectively.

(3) Soil data storage by the Auburn University Southern Forest Nursery Management Cooperative.

The program works as follows:

(A) The nurseryman takes soil samples from his nursery by block or unit. It is very important that the acreage and sampling code should remain the same from one sampling period until the next. This means that in 1990 the analysis from sample 1A will be comparable to the analysis from sample 1A in 1982. This is essential if balance sheets are to be made for each sampled area.

(B) The samples should be taken during the "cold" season (October to January) prior to the crop being sown. Taking samples after January increases the risk of late recommendations which may cause problems in ordering the correct fertilizers. To ensure sampling consistency, the same person should take and handle all soil samples.

(C) Each sample should be a composite of 25-30 cores taken at random. If there are visible differences in soils or nursery stock growth in a block, a separate sample should be taken from each uniform soil area.

(D) The cores should be taken with a soil probe tube and to a consistent depth of 15 centimeters (6 inches). The cores forming a single sample are collected in a clean plastic pail and mixed thoroughly. A half-liter (pint) sample is removed.

(E) The soil samples should be air-dried and sent to A & L Labs in Memphis, Tennessee. The results of the analyses are usually returned within 2 weeks. Copies of the analyses are sent to C.B. Davey and one copy to the Auburn Cooperative. Figure 1 illustrates an example of the soil report from A&L.

(F) For each soil sample, the nursery should fill out a History Data Form, figure 2. This form should include all the amendments (organic, fertilizer, lime) that have been applied since the previous soil test. The crop species grown for each year should be recorded and the next crop should be indicated. The soil texture of the area should also be included. One copy of this form is sent to C.B. Davey and one copy to the Auburn Cooperative.

(G) The soil analyses, history forms, and balance sheets are reviewed by C.B. Davey, who makes suggestions for amendments. These suggestions are sent directly to the nursery.

(H) The Auburn Cooperative will place the data from the soil analysis and history forms into the computer. This data bank will be utilized for two functions.

(1) For each nursery, balance sheets will be prepared for each soil sampling unit, figure 3. This information will aid the nursery-

REPORT NUMBER 169-9

A & L AGRICULTURAL LABORATORIES, INC.
[illegible]
411 N. THIRD ST., MEMPHIS, TN 38105 • (901) 527-2780

SEND TO: AUBURN U. (D.SOUTH)
DEPT. OF FORESTRY
AUBURN UNIVERSITY,
ALABAMA 36849

GROWER

SAMPLES SUBMITTED BY: DAVID SOUTH

DATE OF REPORT 06/21/82 PAGE 1

SOIL ANALYSIS REPORT

SAMPLE NUMBER	LAB NUMBER	ORGANIC MATTER % RATE	ORGANIC MATTER ENR lbs./A	PHOSPHORUS P1 (Weak Bray) ppm-P RATE	PHOSPHORUS P2 NaHCO3-P ppm-P RATE	POTASSIUM K ppm-K RATE	MAGNESIUM Mg ppm-Mg RATE	CALCIUM Ca ppm-Ca RATE	SODIUM Na ppm-Na RATE	pH SOIL pH	pH BUFFER pH	HYDROGEN H meq/100g	Cation Exchange Capacity C.E.C. meq/100g	PERCENT BASE SATURATION (COMPUTED) % K	% Mg	% Ca	% H	% Na
1L	4094	2.2	88 M	49VH	52 H	102 VH	39 L	250 L	35 M	5.2	6.90	1.0	3.0	8.7	10.8	41.7	33.3	5.1
2U	4095	1.5	74 L	60VH	61VH	96 VH	38 L	250 L	35 M	5.3	6.90	0.9	2.9	8.5	10.9	43.1	31.0	5.2
3	4096	1.3	70 L	36VH	39 M	100 VH	19VL	200 L	84VH	5.0	6.80	1._	3.0	8.5	5.3	33.3	40.0	12.2
4	4097	1.5	74 L	37VH	38 M	108 VH	28 L	250 L	101VH	5.1	6.80	1.3	3.5	7.9	6.7	35.7	37.1	12.5

(SEE EXPLANATION ON BACK)

SAMPLE NUMBER	NITRATE NO3 ppm-NO3-N RATE	SULFUR S ppm-S RATE	ZINC Zn ppm-Zn RATE	MANGANESE Mn ppm-Mn RATE	IRON Fe ppm-Fe RATE	COPPER Cu ppm-Cu RATE	BORON B ppm-B RATE	EXCESS LIME RATE	SOLUBLE SALTS mmhos/cm RATE	CHLORIDE Cl ppm-Cl RATE	MOLYBDENUM Mo ppm-Mo RATE	PARTICAL SIZE ANALYSIS % SAND	% SILT	% CLAY	SOIL TEXTURE
1L		8 M	1.3 L	20 M	50VH	1.9 H	.4 L	N	.4 L						
2U		12 M	1.2 L	12 M	26 H	2.4 H	.3VL	N	.4 L						
3		10 M	4.2 H	118VH	62VH	6.1VH	.8 M	N	.7 M						
4		21VH	3.7 H	108VH	74VH	6.1VH	1.0 M	L	.8 V						

This report applies only to the sample(s) tested. Samples are retained a maximum of thirty days after testing.

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R.L. LANGE BJL
BY

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), VERY HIGH (VH), AND NONE (N)
** ENR - ESTIMATED NITROGEN RELEASE
*** MULTIPLY THE RESULTS IN ppm BY 2 TO CONVERT TO LBS. PER ACRE OF THE ELEMENTAL FORM
**** MULTIPLY THE RESULTS IN ppm BY 4.6 TO CONVERT TO LBS. PER ACRE P_2O_5
***** MULTIPLY THE RESULTS IN ppm BY 2.4 TO CONVERT TO LBS. PER ACRE K_2O
MOST SOILS WEIGH TWO (2) MILLION POUNDS (DRY WEIGHT) FOR AN ACRE OF SOIL 6-2/3 INCHES DEEP.

Fig. 1. Example of soil analysis report.

SOUTHERN NURSERY SOIL MANAGEMENT HISTORY FORM

NURSERY:________________________ ADDRESS:________________________
COMPARTMENT (BLOCK):____________________ UNIT (S):________________________
SOIL TEXTURE:________________ % SAND:______ % SILT:______ % CLAY:______
NEXT CROP TO BE GROWN:____
CONDITION OF LAST CROP OF PINE SEEDLINGS
Chlorotic ☐ Stunted ☐ Below average ☐ Average ☐ Above average ☐
Other____

	DATE APPLIED	RATE APPLIED	DATE APPLIED	RATE APPLIED
Crop Grown[1]				
FERTILIZERS APPLIED				
Ammonium nitrate				
Ammonium sulfate				
Calcium nitrate				
Calcium sulfate (Gypsum)				
Magnesium sulfate (Epsom salt)				
Diammonium phosphate				
Nitrate of Soda-potash				
Potassium chloride (Muriate)				
Potassium nitrate				
Potassium sulfate				
Sulfate of Potash Magnesia				
Sulfur				
Superphosphate, normal				
Superphosphate, double				
Superphosphate, triple				
Urea				
Other				
MICRONUTRIENTS (list form)				
Boron				
Copper				
Manganese				
Zinc				
Iron				
LIME				
Calcite				
Dolomite				
ORGANIC MATTER				
Pine bark				
Hardwood bark				
Pine sawdust				
Hardwood sawdust				
Pine chips				
Hardwood chips				
Other				

1 If cover crop, include both winter and summer covercrop.

Is irrigation water high in calcium? No ☐ Yes ☐ High in sodium? No ☐ Yes ☐

Fig. 2. Soil management history form.

AUBURN UNIVERSITY SOUTHERN FOREST NURSERY MANAGEMENT COOPERATIVE
SOIL NUTRIENT BALANCE SHEET

NURSERY ST. REGIS ORGANIZATION ST REGIS PAP CO ADDRESS P. O. BOX 37 LEE, FL 32059
NURSERYMAN ALAN WEBB SOIL SAMPLE NO. E1 LABORATORY NO. 3007 SOIL SERIES NAME
COMPARTMENT E UNITS AREA IN UNIT . %SAND:SILT:CLAY . . . APPROX. BULK DENSITY

SOIL VARIABLE	OLD SOIL TEST 01/06/82	AMENDMENTS FIRST / /	AMENDMENTS SECOND / /	AMENDMENTS THIRD / /	REMOVED BY SEEDLINGS*	ADDITIONAL LOSSES OR GAINS	NEW SOIL TEST 12/07/82	COMMENTS
PH	6.00				.	-0.30	5.70	
% ORGANIC MATTER	1.40	S.DUST-1/4"			.	-0.25	1.40	
C.E.C. MEQ/100G	1.60				.	0.20	1.80	
NITROGEN LB/A	.		18-0-26 45	AMM. NITRATE 25	40.00	5.00	.	
PHOSPHORUS(P2) LB/A PPM	72.00	0-10-20 17			7.00	33.50	107.00	
POTASSIUM(K) LB/A PPM	10.00	0-10-20 66	18-0-26 54		38.00	-2.00	30.00	
MAGNESIUM(MG) LB/A PPM	42.00				2.50	-14.50	23.00	
CALCIUM(CA) LB/A PPM	200.00				9.00	9.00	200.00	
SODIUM(NA) LB/A PPM	.				0.80	27.80	27.00	
SULFUR(S) LB/A PPM	11.00		SULFUR 215		2.50	-106	10.00	
ZINC(ZN) LB/A PPM	1.90	FRIT 305G 0.4			0.20	0.00	1.90	
MANGANESE(MN) LB/A PPM	14.00	FRIT 305G 0.12			1.40	9.34	22.00	
IRON(FE) LB/A PPM	43.00	FRIT 305G 0.16			2.00	23.92	65.00	
COPPER(CU) LB/A PPM	1.70	FRIT 305G 0.04			0.10	-0.52	1.10	
BORON(B) LB/A PPM	0.40	FRIT 305G 0.04		SOLUBOR 1.8	0.10	-1.02	0.20	
% BASE SAT.-K	1.60				.	2.70	4.30	
% BASE SAT.-MG	20.80				.	-10.20	10.60	
% BASE SAT.-CA	62.50				.	-6.90	55.60	
% BASE SAT.-H	12.50				.	9.70	22.20	
% BASE SAT.-NA	.				.	6.50	6.50	

* IF AREA IS IN COVER CROPS OR FALLOW AND THE "REMOVED" COLUMN DOES NOT SHOW ZEROS, THEN ADD THE "REMOVED" COLUMN TO ADD. LOSSES OR GAINS

Fig. 3. Example of a soil nutrient balance sheet.

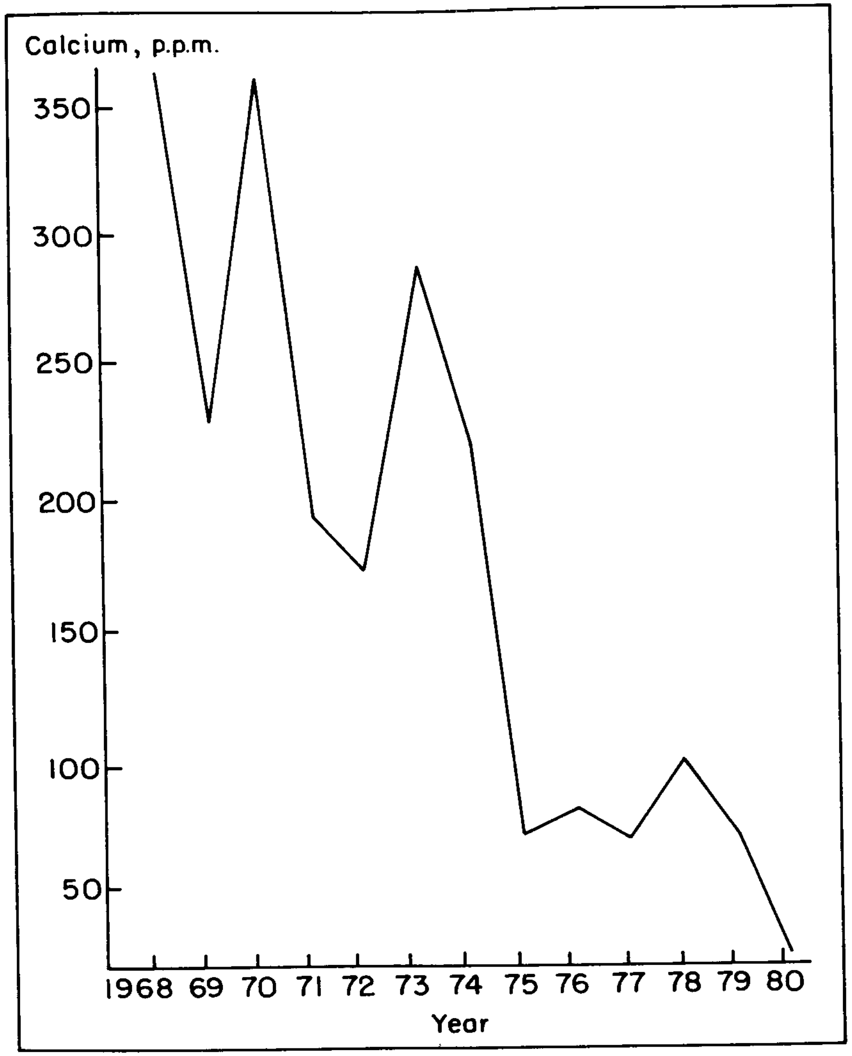

Fig. 4. History of soil calcium for one compartment in a southern forest tree nursery.

man in determining how his soil management practices have affected soil fertility. The balance sheet should help avoid large fluctuations in soil factors which may result in reduced productivity. For example, figure 4 indicates the change in calcium over a 13-year period from one block in a forest nursery. This type of fluctuation is undesirable and could have been avoided by the use of a balance sheet.

(2) The data bank will be used to combine analyses from nurseries with similar soil textures. By comparing data among nurseries with similar textures, it can be more readily determined what is "normal" and what is "out-of-line." This method of comparison has already benefited several nurseries by defining soil fertility problems which were causing decreases in seedling productivity. This publication presents some preliminary data which illustrate how southern forest nurseries will benefit from this program.

MATERIALS AND METHODS

Soil samples were collected from several nurseries by the Auburn Cooperative between 1977 and 1980. Most of the samples were collected in conjunction with pre- and postemergence herbicide experiments and, therefore, were usually collected from April until June (after the preplant fertilizer application). Samples were not representative of the entire nursery, but were only representative of an area of 1 hectare (2.5 acres) or less. Four soil samples were collected from each herbicide test area. Soil texture was determined by the hydrometer method at the Auburn Department of Forestry. Chemical analysis was performed by A & L Laboratories in Memphis, Tennessee, on a composite sample from each nursery. Phosphorus was extracted with the Weak Bray and Strong Bray methods. Calcium, magnesium, potassium, sodium, and sulfur were extracted with 1M ammonium acetate. Zinc, manganese, iron, and copper were extracted with 0.1N hydrochloric acid. Boron was extracted with boiling water. Organic matter was determined with a modified Walkley-Black method. Soil pH value was determined using a 1:1 ratio of water to soil. Correlations between soil texture and chemical analyses were determined with the aid of the Statistical Analysis System, table 1. When significant correlations occurred, nurseries were separated into three soil texture groups. Twenty-five nurseries were in Group A (more than 75 percent sand); 12 nurseries were in Group B (between 75 percent and 50 percent sand); and 8 nurseries were in Group C (less than 50 percent sand). Median, minimum, and maximum values for each soil group were determined for each variable, table 2.

TABLE 1. A&L CORRELATION COEFFICIENTS AND PROBABILITIES OF A GREATER R VALUE[1]

	OM	pH	CEC	Sand	Silt	Clay
OM	1.00000 0.0000	0.01033 0.9476	0.30024 0.0504	-0.28438 0.0583	0.23548 0.1194	0.33392 0.0250
pH	0.01033 0.9476	1.00000 0.0000	0.23727 0.1255	0.05741 0.7146	-0.07246 0.6442	-0.00130 0.9934
CEC	0.30024 0.0504	0.23727 0.1255	1.00000 0.0000	-0.86540 0.0001	0.83231 0.0001	0.71183 0.0001
P1[2]	0.10734 0.4933	-0.03572 0.8201	-0.25102 0.1044	0.26579 0.0850	-0.32230 0.0350	-0.02036 0.8969
P2[2]	0.18884 0.2252	0.01310 0.9336	-0.16841 0.2803	0.19638 0.2069	-0.26954 0.0805	0.07793 0.6194
K	0.49984 0.0006	0.06338 0.6864	0.59714 0.0001	-0.58231 0.0001	0.46514 0.0015	0.74002 0.0001
Mg	0.26241 0.0853	0.41512 0.0056	0.90644 0.0001	-0.63875 0.0001	0.57178 0.0001	0.62557 0.0001
Ca	0.28687 0.0590	0.45628 0.0021	0.95673 0.0001	-0.76855 0.0001	0.75126 0.0001	0.56787 0.0001
SO_4-S	0.23049 0.1277	-0.23377 0.1314	0.26704 0.0834	-0.38207 0.0096	-0.41512 0.0046	0.15955 0.2951
Zn	0.09941 0.5159	0.05338 0.7339	0.11572 0.4599	-0.09373 0.5403	0.08294 0.5880	0.09622 0.5295
Mn	0.21060 0.1659	0.06587 0.6747	0.45290 0.0023	-0.54081 0.0001	0.44549 0.0022	0.63822 0.0001
Fe	0.17975 0.2374	0.03123 0.8424	0.40074 0.0077	-0.41553 0.0045	0.48765 0.0007	0.07949 0.6037
Cu	0.01151 0.9402	-0.00212 0.9892	0.15335 0.3262	-0.25148 0.0956	0.25747 0.0877	0.15051 0.3237
B	0.34443 0.0205	-0.10497 0.5029	0.52361 0.0003	-0.65993 0.0001	0.62467 0.0001	0.55740 0.0001
Pct. base sat. K	0.22594 0.1452	-0.18127 0.2247	-0.37186 0.0141	0.28649 0.0625	-0.33783 0.0267	-0.05445 0.7288
Pct. base sat. Mg.	0.08858 0.5722	0.39372 0.0090	-0.07555 0.6301	0.26844 0.0818	-0.32492 0.0335	-0.03400 0.8286
Pct. base sat. Ca.	-0.09059 0.5635	0.84911 0.0001	0.29692 0.0532	-0.08882 0.5711	0.11157 0.4763	-0.00402 0.9796
Pct. of CEC H	-0.03017 0.8477	-0.97419 0.0001	-0.14431 0.3559	-0.12947 0.4080	0.15536 0.3198	0.02163 0.8905
H meq/100g	0.19112 0.2196	-0.57571 0.0001	0.55013 0.0001	-0.71499 0.0001	0.72185 0.0001	0.49259 0.0008

[1]The top value is the linear correlation coefficient and the bottom value is the probability of a greater correlation coefficient.
[2]The P1 value is obtained using the Weak Bray extractant while the P2 is the Strong Bray value.

TABLE 2. MEDIAN, MINIMUM, AND MAXIMUM VALUES FOR SOIL CHARACTERISTICS FROM 45 SOUTHERN FOREST NURSERIES

Variable	Group A Sands + loamy sands (25 nurseries)			Group B Sandy loams + sandy clay loams (12 nurseries)			Group C Loams + silt loams (8 nurseries)		
	Median	*Min.*	*Max.*	*Median*	*Min.*	*Max.*	*Median*	*Min.*	*Max.*
pH	5.7	5.2	6.0	5.6	4.5	6.1	5.7	4.6	6.4
CEC	1.7	1.1	2.8	2.8	1.9	3.5	4.8	4.0	9.2
Pct. OM	1.6	0.7	2.8	1.6	0.9	3.4	1.9	1.3	3.0
Pct. sand	83	76	95	66	55	71	38	15	49
Pct. silt	8	2	15	21	23	28	46	37	67
Pct. clay	7	1	12	14	11	25	17	7	23
				p.p.m.					
P1	76	27	167	67	40	136	48	28	114
P2	92	36	186	87	46	166	79	38	138
K	58	20	126	103	47	136	111	68	138
Mg	40	15	85	55	25	90	82	35	250
Ca	200	100	300	300	100	400	550	300	1200
Mn	25	4	144	132	26	278	108	63	260
SO_4-S	14	5	60	16.5	5.0	50.0	33	13	100
Fe	47	13	102	45	24	105	84	43	217
Cu	0.7	0.4	2.3	0.8	0.5	4.3	0.9	0.5	2.4
Zn	2.2	1.1	11.4	4.4	1.9	29.4	3.4	1.6	4.7
B	0.4	0.3	1.4	1.2	0.9	1.8	1.2	0.9	2.5
				base saturation					
Pct. K	8.3	3.3	17.0	8.8	6.3	12.9	5.0	3.2	8.8
Pct. Mg	19.8	8.9	27.2	17.6	11.0	21.4	15.4	10.6	22.6
Pct. Ca	53.6	35.7	62.5	48.1	26.3	62.5	58.5	31.3	65.2
Pct. H	21.4	12.5	35.3	23.3	14.3	57.9	20.0	8.7	54.2

RESULTS AND DISCUSSION

Of the 45 nurseries sampled, 38 were located in the Coastal Plain, figure 5. Nurseries in this geographic province tended to have soil textures that were sands, loamy sands, and sandy loams. The three nurseries in the Mississippi Alluvial Valley had silt loam textures and were among the finest textured soils sampled. The remaining nurseries were located in the Ridge and Valley, Lower Plateau, and Piedmont provinces and were normally located on alluvial terrace soils. One nursery in the Valley and Ridge province in Alabama was not located on a river terrace. However, in 1980 and 1981, the entire nursery was covered with approximately 25 centimeters (10 inches) of river terrace soil which was moved to the nursery site. The original soil contained 54 percent sand and the new soil 77 percent sand.

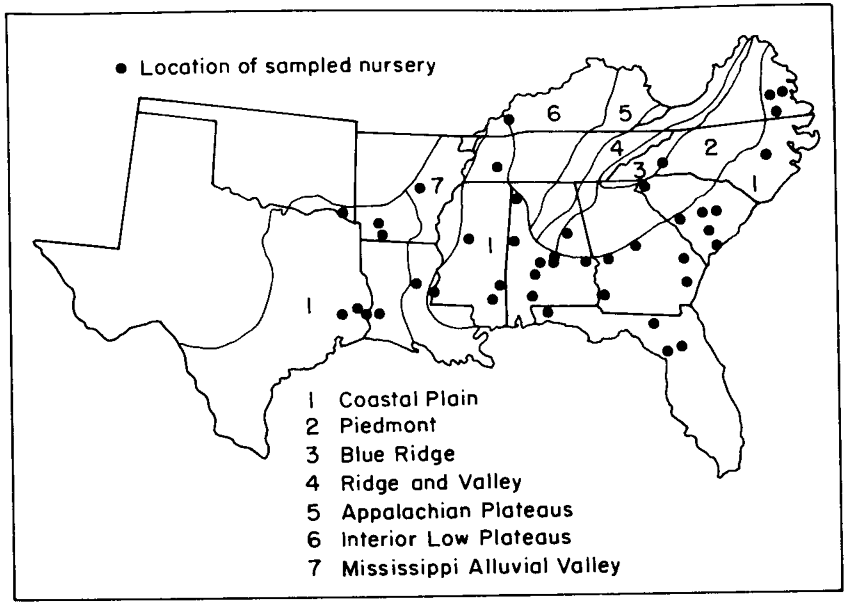

Fig. 5. Physiographic Division of the Southeastern States.

A coarse textured soil is desirable for pine nurseries because it allows seedbed preparation, lifting, and other work to be carried out sooner under wetter condition than for fine textured soils. For pine nurseries, many authors suggest soil texture having no less than 75 percent sand *(1, 4, 17, 25, 26)*. Only 25 of the nurseries had textures which met this requirement.

It is apparent that many nurseries established before 1960 had finer soil texture than those established later, figure 6. This trend is, in part, because of the increased usage of mechanical harvesting after 1960. With hand lifting, soil texture was of little importance; however, mechanical harvesters perform better on loamy sands or sands. Of the 18 nurseries established after 1960, 14 had textures with more than 75 percent sand. This fact has management implications in that the coarser textured soils will have a lower nutrient holding capacity and, therefore, monitoring essential elements is of more importance on these soils.

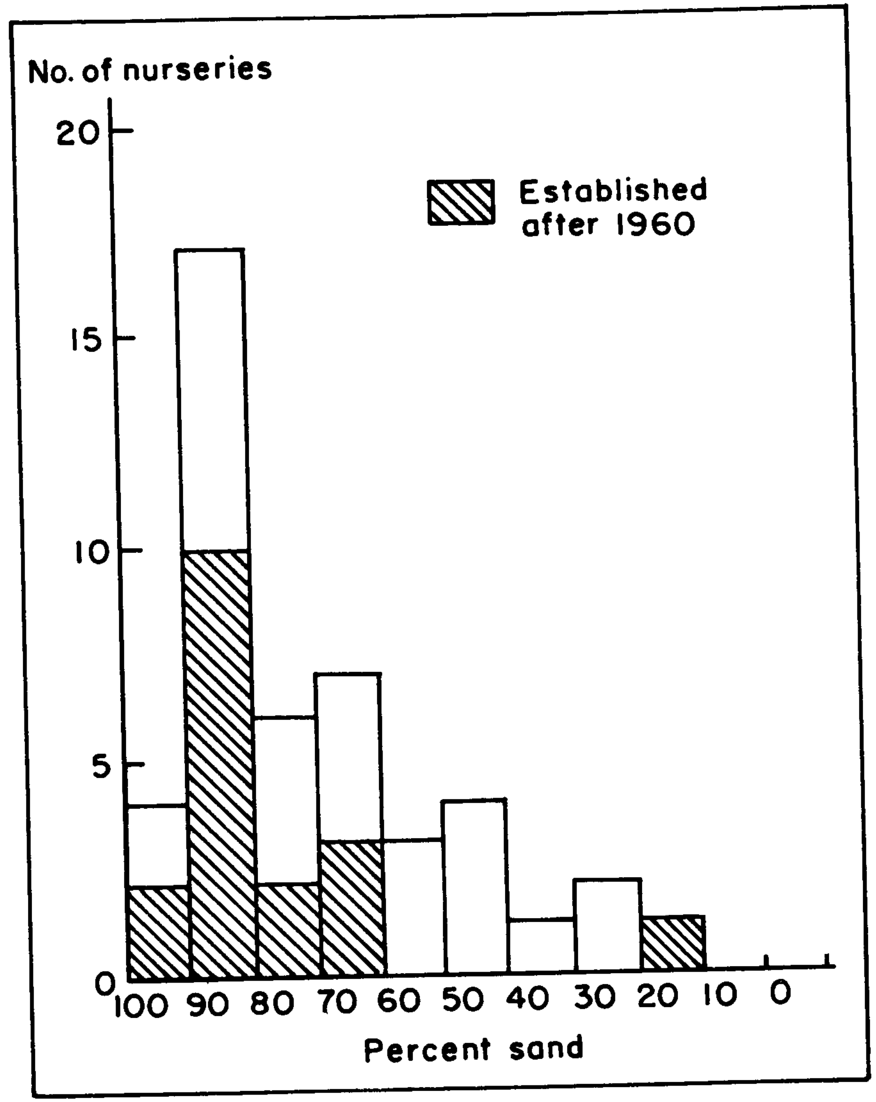

Fig. 6. Percent sand for 45 southern forest nurseries.

Soil Acidity

The hydrogen ion activity of the soil, expressed as the pH value, is perhaps the most important chemical property. Soil acidity not only influences the availability of elements but also has a direct influence on the microbial population of the soil. The forest nurseryman is well aware of the influences of the soil acidity on seedling growth and can change the pH value with either lime, acid-forming fertilizers, or sulfur applications.

Many of the nurserymen have kept soil acidity in pine nurseries in the South between pH 5.0 and 6.0, figure 7, and this range is

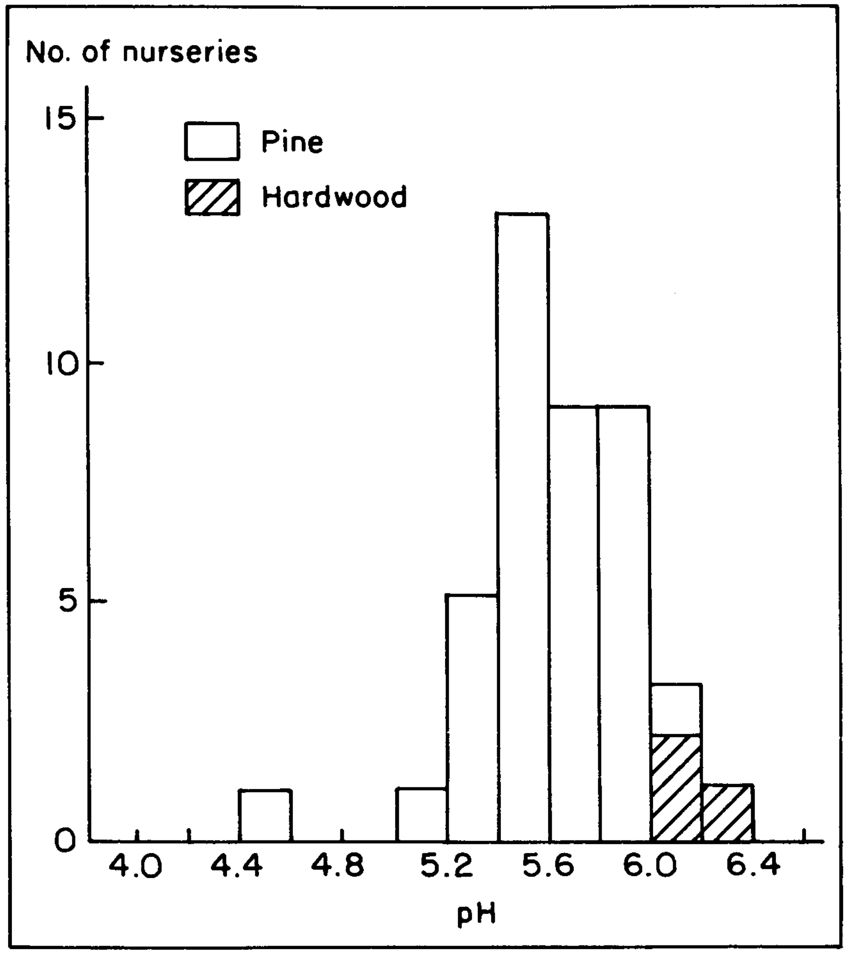

Fig. 7. Soil acidity for 45 southern forest nurseries.

optimum for most tree species *(26)*. However, because conditions for growth of some pathogens are more favorable at a higher pH value, the senior author recommends a level between pH 5.0 and 5.5 for loblolly pine. Nutrients may become less available in soils with soil acidity levels below pH 5.0. The three hardwood nurseries were more alkaline, with pH levels between 6.2 and 6.4. However, some hardwood species can grow well at pH levels as low as 4.5 *(20, 8)*. The assumption that pH 6.2 is the optimum acidity level for hardwood growth is based on natural bottomland hardwood stands and **not** on studies from the nursery *(20)*.

Figure 8 indicates the history of one compartment at a nursery in the South which has alkaline irrigation water that is well buffered with calcium. Between 1955 and 1966 the primary source of fertilizer nitrogen was ammonium nitrate. Because of the calcium level in irrigation water, the pH value steadily rose until it reached a maximum of 6.6 in 1966. In 1967 the nursery began applying ammonium sulfate and sulfur to increase soil acidity. This practice was continued and eventually the pH value was lowered to the desired level of 5.5 in 1975.

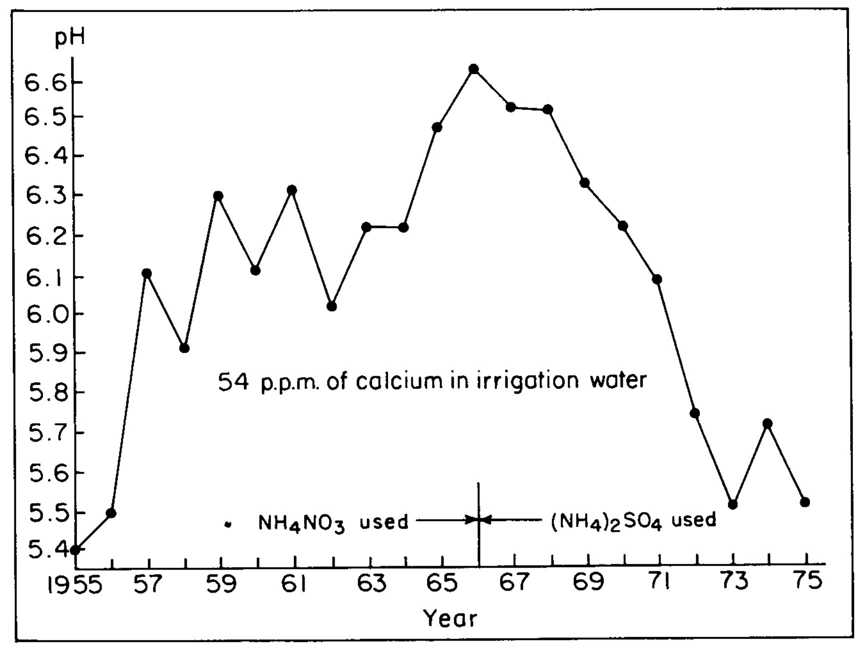

Fig. 8. History of soil acidity for one compartment in a southern forest tree nursery as affected by nitrogen source.

Because the cation exchange capacity (CEC) of the above nursery was high (12 meq per 100 grams), the change in pH value took place gradually. The amount of sulfur required to increase the soil acidity varies with the cation exchange capacity of the soil. The higher the cation exchange capacity the greater the amount of sulfur required. The cation exchange capacity for most of the nurseries in the South is below 5 meq per 100 grams, figure 9. In Florida nurseries, 448 kilograms per hectare (400 pounds per acre) of sulfur have been used in March before planting loblolly pine and up to 224 kilograms per hectare (200 pounds per acre) have been applied directly to the seedlings *(13)*. Sulfur applications of more than 1,600 kilograms per hectare (1,429 pounds per acre) have reduced survival of red pine in Ontario *(15)*.

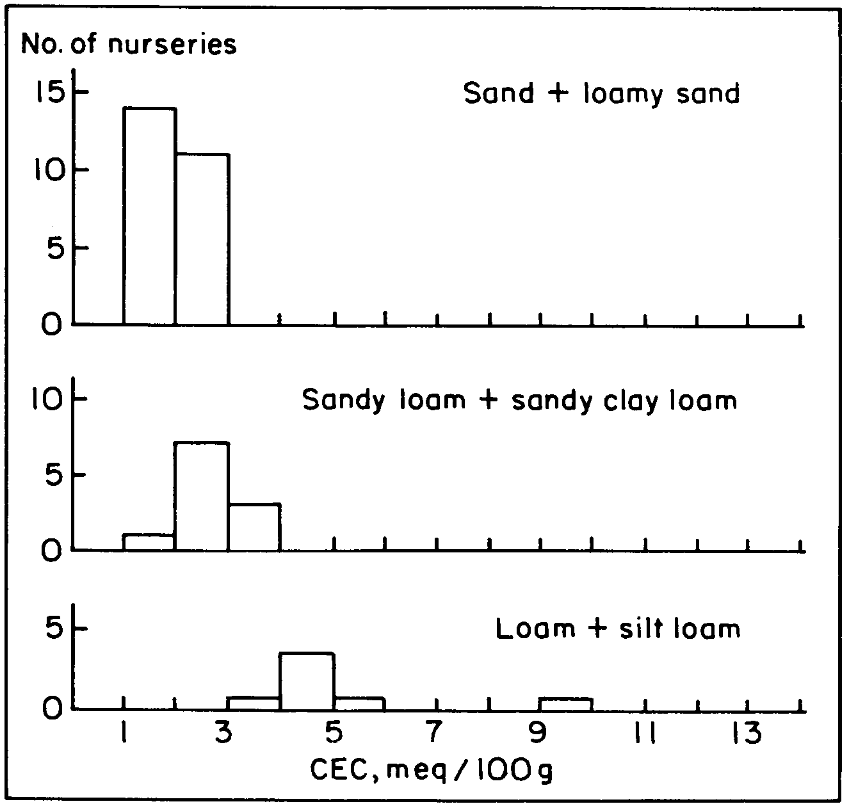

Fig. 9. Cation exchange capacity for 45 southern forest nurseries.

Organic Matter

A&L Labs normally determines the percent organic matter content by the Walkley-Black method. However, the results from A&L are consistently higher than those from other labs *(16)*. Table 3 indicates the organic matter values reported by A&L Labs are about 25 percent higher than those from Auburn (Auburn uses a Leco Carbon Analyzer). This difference is attributable to the extra heating of the sample by A&L in their variation of the basic method.

Incorporation of organic matter in the soil usually improves physical and chemical properties *(4)*. Organic levels are often correlated with soil texture. The more clay and silt in the soil, the higher the organic matter content. This is a result of less macropores in a fine textured soil which favors slower decomposition of organic matter.

Organic matter maintenance is considered basic to good soil management programs. In the 1950's and early 1960's, organic matter amendments were a routine practice in most forest nurseries in the South, with sawdust being one of the primary sources. However, today less than two-thirds of the southern nurseries routinely add organic amendments. With the A&L analysis, 2 percent organic matter is considered to be the minimum desired level for southern nurseries. However, over two-thirds of the nurseries sampled had organic levels below 2.0 percent, figure 10. In the Pacific Northwest, 19 of 20 Douglas-fir nurseries routinely apply organic amendments for each rotation *(24)*.

It seems ironic that in the Northwest (where the decomposition rates are much lower than in the South) such emphasis is placed on

TABLE 3. REGRESSIONS OF AUBURN SOIL LAB ANALYSIS ON A&L SOIL ANALYSIS OF 45 NURSERY SOILS

Auburn soil test		Intercept		A&L soil test	R^2
Organic matter	=	NS[1]	+	.8 (OM)	.56
pH	=	1.35	+	.745 (pH)	.56
CEC	=	1.18	+	1.283 (CEC)	.75
P[2]	=	NS	+	.62 (p Weak Bray)	.44
P	=	NS	+	.58 (p-$NaHCO_3$-p)	.45
K	=	NS	+	.71 (K)	.63
Mg	=	NS	+	.94 (Mg)	.75
Ca	=	NS	+	1.13 (Ca)	.83
Fe	=	9.6	+	.356 (Fe)	.72
Mn	=	NS	+	.80 (Mn)	.93
SO_4-S	=	9.3	+	.25 (SO_4-S)	.40
Cu	=	NS	+	.88 (Cu)	.59
Zn	=	1.24	+	.23 (Zn)	.26
B	=	NS	+	.165 (B)	.49

[1]NS = intercept not significantly different from zero.
[2]Auburn soils lab uses Double Acid Extraction.

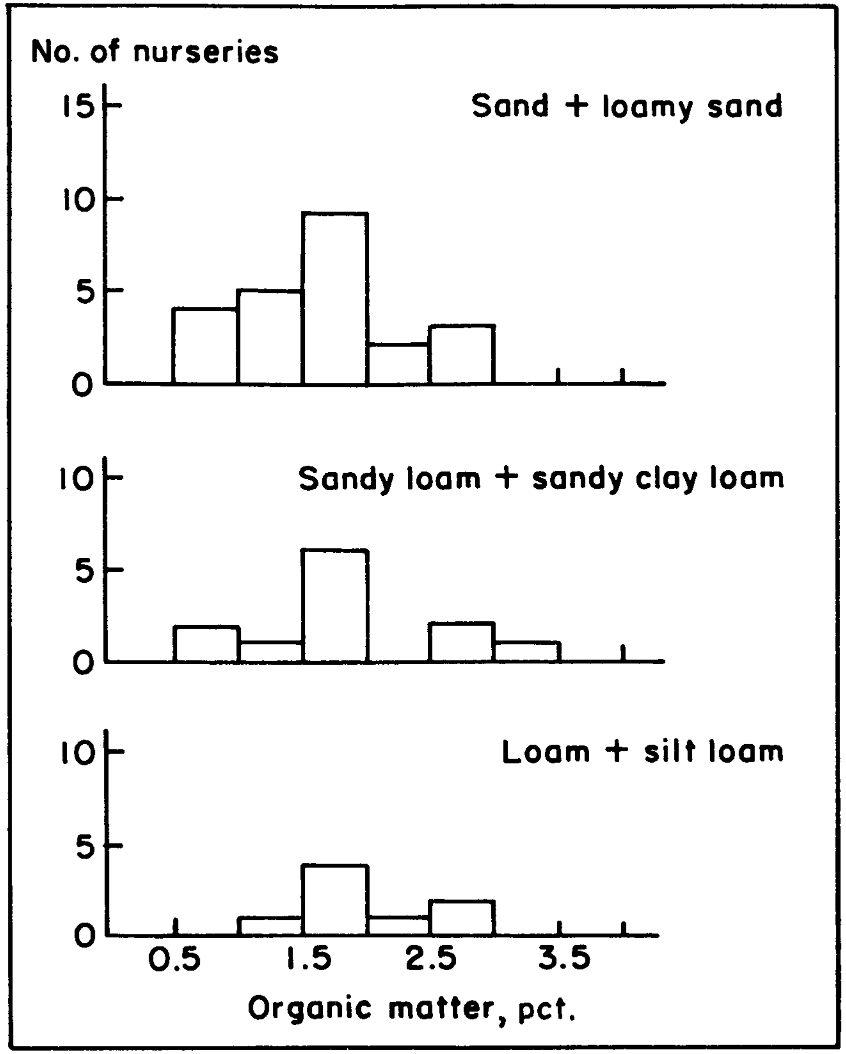

Fig. 10. Organic matter content for 45 southern forest nurseries.

organic amendments. Whereas, in Florida (where decomposition rates are extremely high) none of the six forest nurseries were routinely adding organic amendments until recently. One nursery in Georgia with 87 percent sand had an organic matter content of 2.8 percent (A&L) in 1981. This supports the observation by May *(11)* that "organic matter content of 1.5 to 2.5 percent can be developed and maintained in sands and loamy sands..."

Organic matter provides numerous benefits to soil management, including increased water-holding capacity; improved soil physical properties; increased cation exchange capacity; a source for nutrients such as nitrogen and phosphorus; a regulator of micronutrients, such as manganese, boron, copper, zinc, and iron; reduction in toxicity of certain herbicides; favors mycorrhizal development; and suppression of certain pathogens. It is possible for a nurseryman to grow good seedlings with soil having a low organic matter content; however, he cannot afford to make mistakes in fertilizer application, irrigation, pesticide application, management of microbial populations, or management of soil physical properties. Organic matter provides a buffer against such mistakes. Some nurserymen say they can't afford to grow seedlings without this buffer. Other nurserymen say they can't afford to spend money for it.

It is doubtful that the use of cover crops will substantially increase soil organic matter levels. This is supported by several experts in forest soils. Stone *(19)* stated that, "It is now appreciated that organic matter content will not be built up by green manures as is commonly employed unless the initial level is very low. Even their frequent inclusion will not prevent a decline in organic matter under most circumstances." Allison *(3)* stated that "It is now well established that green manures have a negligible effect on total soil organic matter levels if cultivation is continued, although they do replenish the supply of active, rapidly decomposing organic matter." Davey and Krause *(7)* stated that "Cover crops, catch crops, and green manures are very beneficial in nursery management, but current wisdom indicates that they will not suffice for the total needed soil organic matter . . . the realistic nurseryman will not depend on cover crops to sustain his soil organic matter content." May *(12)* stated that "In many soils the organic matter content cannot be maintained or increased much above the irreducible minimum 0.3 to 0.8 percent using a 1:1 rotation without the addition of large quantities of organic matter."

A recent study by Sumner and Bouton *(22)* has indicated that growing cover crops for 2 years increased soil organic matter levels at the Morgan Nursery in Georgia by only 0.23 to 0.34 percent. Recent soil analyses from these plots have indicated that 1 year of seedling production reduced the level by 0.21 to 0.37 percent, thereby eliminating the temporary gain in soil organic matter. The production of the cover crop was approximately 12.1 to 13.2 metric tons per hectare (5.4 to 5.9 short tons per acre) per year. The addition of 45 metric tons per hectare (20 short tons per acre) of sawdust can effectively increase soil organic matter levels by 1.5

percent. The amount of lignin contained in sawdust and/or pine bark greatly exceeds that contained in cover crops such as corn or sorghum. Pine bark is reported to have between 31 and 50 percent lignin, and sawdust is reported to have 27 to 30 percent lignin. Corn can contain 15 percent lignin and sorghum-sudangrass between 5 and 14 percent lignin depending on the stage of development. Therefore, the maximum amount of lignin added in a 2-year cover crop of sorghum-sudangrass would be 3.8 metric tons per hectare. The minimum amount of lignin added in a 2.5-centimeter addition of sawdust or bark would be 12 metric tons per hectare. Lignin is a desirable organic amendment because of its slow decomposition rate. It degrades slower than starch, carbohydrates, cellulose, and hemicellulose. In addition, lignin is the source of the substances that provide for the increase in cation exchange capacity.

Soil Nutrients

A generalized response of seedling growth, as affected by nutrient level, is indicated by figure 11. The forest nurseryman should not wait until he sees a deficiency symptom before deciding to fertilize nor should he keep his seedlings in the hidden hunger area of the curve. Although no distinct deficiency will be noted, productivity will be reduced. However, the nurseryman should not overfertilize to the degree where other nutrients become unavailable or toxic symptoms occur. It is the goal of the Southern Forest Nursery Soil Testing Program to help keep the nurseryman's soil fertility in the area where maximum productivity will be achieved at the least cost.

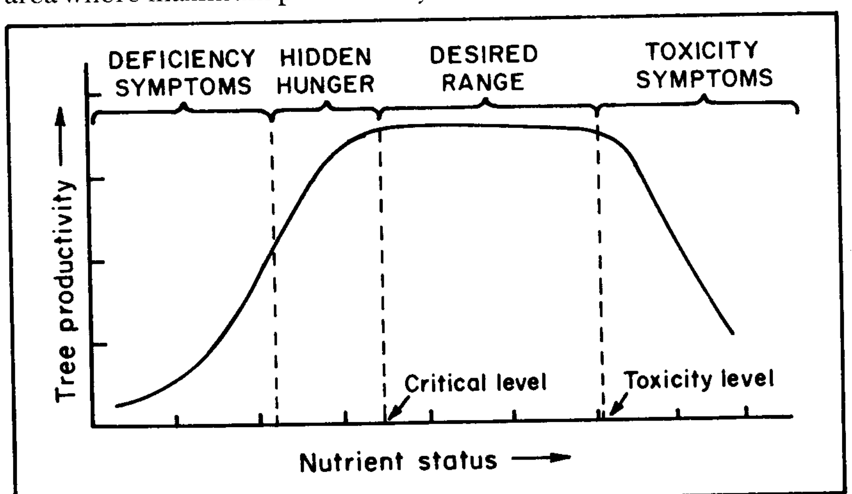

Fig. 11. Relationship between tree productivity and nutrient status.

Nitrogen

Nitrogen is the nutrient which most frequently limits plant growth, and it is needed in greatest quantities for production of tree seedlings. Scientists have been unable to develop a reliable test to determine the nitrogen supplying capacity of soils. There are several reasons for this. First, a majority of the nitrogen is stored in soil organic matter. The rate of nitrogen release is affected by the amount of soil organic matter, the carbon/nitrogen ratio of the organic matter, the soil temperature, supply of other nutrients, soil moisture, and length of growing season. These and other factors make it impractical to predict the amount of nitrogen that will be supplied by the soil in one growing season. Second, most forest nurseries are low in organic matter content and vary little in their capacity to supply nitrogen. Therefore, nitrogen recommendations are based primarily on the crop to be grown.

The estimated nitrogen return (ENR) as reported by A&L Laboratories is an attempt to estimate the amount of nitrogen available from decomposition of organic matter. This figure is computed directly from the soil organic matter. The assumption is, the higher the organic matter in the soil, the higher the carbon/nitrogen ratio. For soils having 3 percent organic matter, 116 kilograms per hectare (104 pounds per acre) of nitrogen is estimated to be released through the growing season. However, soils with 1 percent organic matter would be calculated to release as much as 72 kilograms per hectare (64 pounds per acre) of nitrogen. On fields where the organic matter level is lower than 1 percent, some preplant nitrogen is suggested. Otherwise, it is more efficient to apply all the nitrogen as summer topdressings. Where preplant nitrogen is used, 56 kilograms per hectare (50 pounds per acre) of nitrogen should be applied preplant, with additional topdressings during the summer totaling 140 kilograms per hectare (125 pounds per acre). Where no preplant nitrogen is applied, a total of 170 kilograms per hectare (150 pounds per acre) of nitrogen during the growing season should be sufficient except when excessive leaching is caused by major storms.

If organic amendments have to be applied directly ahead of the seedling crop, then additional nitrogen may be required. The additional nitrogen will be needed to meet the demand of the increased microbial population. The amount of additional nitrogen required is dependent on the amount and kind of material applied. A material with a low carbon/nitrogen ratio (e.g. 15/1) may not require any additional nitrogen. Composted materials normally have low carbon/nitrogen ratios and do not require additional nitrogen. Fresh materials such as hardwood sawdust, pine sawdust, and pine bark have high carbon/nitrogen ratios and will require additional nitrogen. The amount of nitrogen applied will vary depending on whether the material is from xylem or bark, or from conifers or hardwoods *(2)*. The amount required can even depend on species. However, in general, hardwood sawdust will require about twice as much nitrogen as pine sawdust and about four times as much as pine bark. The specific amount required will vary with environmental conditions, but under controlled conditions, Allison found that for every 100 grams (dry weight) of hardwood sawdust, 1.2 grams (1.2 percent) of nitrogen was required for decomposition. Loblolly pine sawdust required 0.6 gram (0.6 percent) of nitrogen, but loblolly pine bark required only half this amount. Therefore, if 40,000 kilograms per hectare of fresh hardwood sawdust were applied prior to a seedling crop, then approximately 480 kilograms per hectare of additional nitrogen would be required. If 40,000 kilograms per hectare of pine bark were applied, then only 120 kilograms per hectare of nitrogen would be needed. Half of the additional nitrogen requirement should be applied pre-plant and the remainder as sidedressings.

If the pH value is high, the soil sulfur test is low, or concentrated fertilizers are used, then some or all of the nitrogen should be applied as ammonium sulfate. Otherwise, ammonium nitrate can be used. Light applications of nitrogen during the growing season are recommended to prevent summer chlorosis in loblolly pine *(5)*. The application rate should range from 22 to 33 kilograms per hectare (20 to 30 pounds per acre) of nitrogen per application. Therefore, five to seven applications of nitrogen would be required when applying 170 kilograms per hectare (150 pounds per acre) of nitrogen during the growing season. The first application of nitrogen is usually applied 6 weeks after seeding.

Phosphorus

The level of available phosphorus (Weak Bray) is not strongly correlated with soil texture, table 1. For loblolly, the minimum desired level of phosphorus using Weak Bray extraction is 40 p.p.m. (25 p.p.m. if a Double-Acid extraction is used). For hardwood seedlings, Kormanic *(8)* has recommended soil phosphorus levels of 75 to 100 p.p.m. using Weak Bray. Too high a level of phosphorus can be undesirable. Our analysis indicated that four nurseries had phosphorus levels greater than 120 p.p.m. (Weak Bray), figure 12. By using our previous records at Auburn University, we found that these nurseries were high in phosphorus because of management

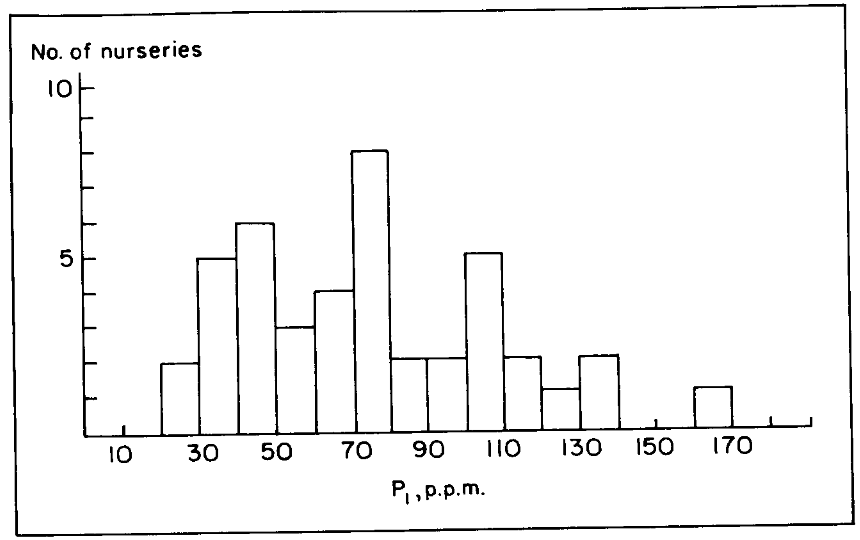

Fig. 12. Soil phosphorus (Weak Bray) for 45 southern forest nurseries.

practices. In the late 1950s, these nurseries had lower phosphorus levels. However the practice in those days was to apply 1,100 kilograms per hectare (1,000 pounds per acre) of superphosphate.

Phosphorus does not leach through the soil but becomes incorporated in organic matter and forms compounds with calcium, iron, and aluminum. These conditions release phosphorus slowly. It is doubtful whether much of the phosphorus in a topdressing of superphosphate ever becomes available to the current season's crop because of phosphorus immobility and fixation in the soil. Where needed, phosphorus should be applied preplant. If a topdressing of phosphorus is needed, ammonium phosphate should be used. Crops require much smaller quantities of phosphorus than nitrogen and potassium. One crop of pine seedlings would usually remove less than 8 kilograms per hectare (7 pounds per acre) of phosphorus. Therefore, under continuous fertilization, soil content of phosphorus has increased at some forest nurseries to high levels. Extremely high phosphorus levels are undesirable because of potential decreases in the availability of iron, zinc, and copper.

In addition, Youngberg *(27)* suggests that when the ratio between phosphorus and potassium becomes out of line, seedlings may have problems in hardening-off in the fall. Figure 13 indicates the phosphorus/potassium ratio of the sampled nurseries. According to Youngberg, nurseries with twice as much phosphorus as potassium may have hardening-off problems and this helps explain why some

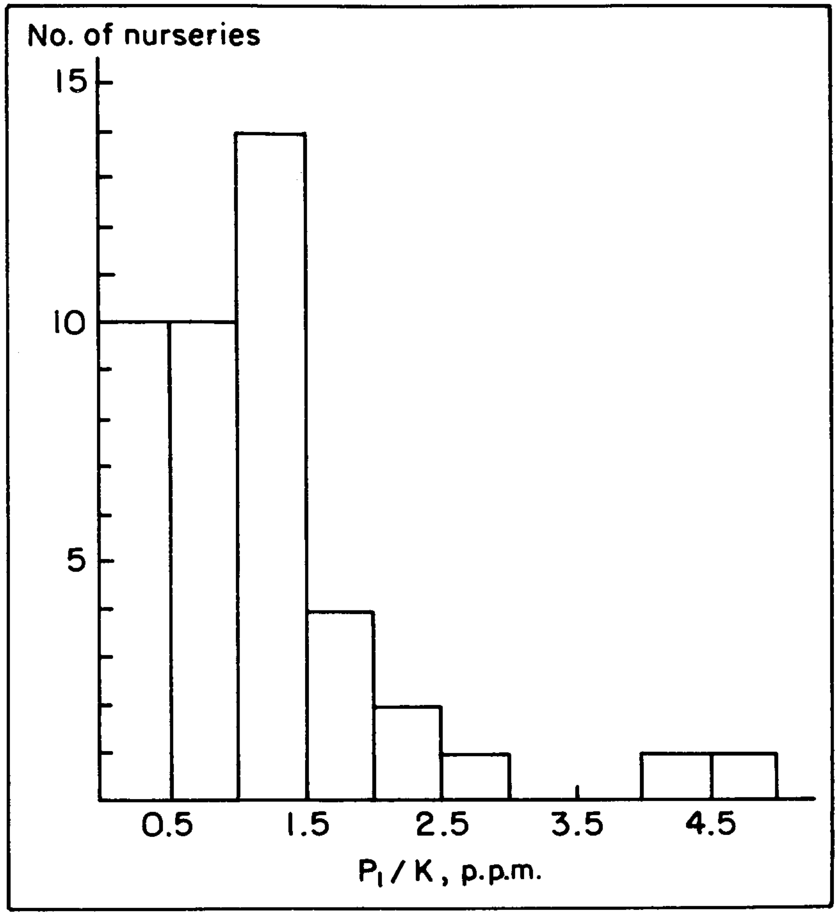

Fig. 13. The soil phosphorus/potassium ratio for 45 southern forest nurseries.

nurseries have had this trouble. This may also explain some of the responses observed after late applications of phosphorus. In 1982, two nurseries reported that seedlings fertilized with diammonium phosphate were delayed in hardening-off and also broke bud earlier in the spring. At one nursery, seedlings that were fertilized with 140 kilograms per hectare (125 pounds per acre) of diammonium phosphate on September 24 broke bud early the following spring and produced 15 centimeters (6 inches) of growth by March 9. Research needs to be conducted to confirm the role phosphorus plays in the dormancy of loblolly pine seedlings.

Potassium

Potassium levels were significantly correlated with soil textures, table 1. The authors suggest a minimum of 90 p.p.m. of potassium. Of the 45 sample nurseries, 26 had less than this minimum level, figure 14. This suggests that of the major nutrients, potassium may be the one most often neglected. The ratio of potassium to other cations may indicate whether potassium may be deficient. The

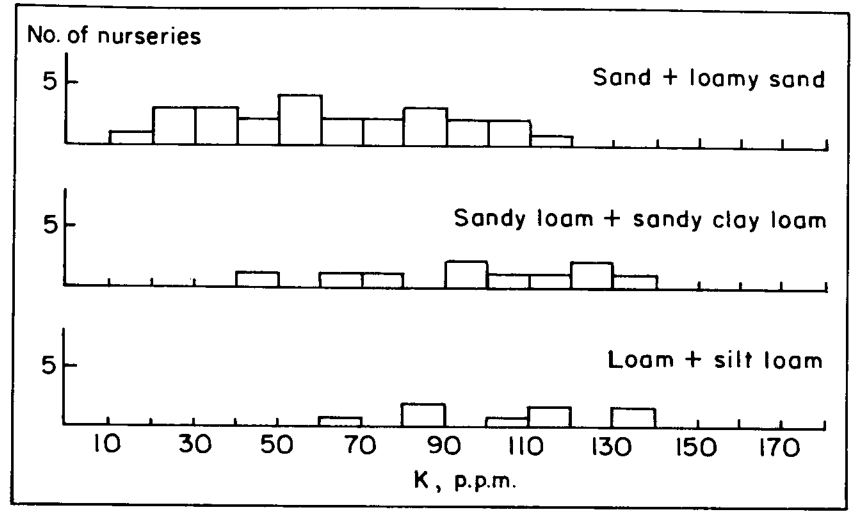

Fig. 14. Soil potassium for 45 southern forest nurseries.

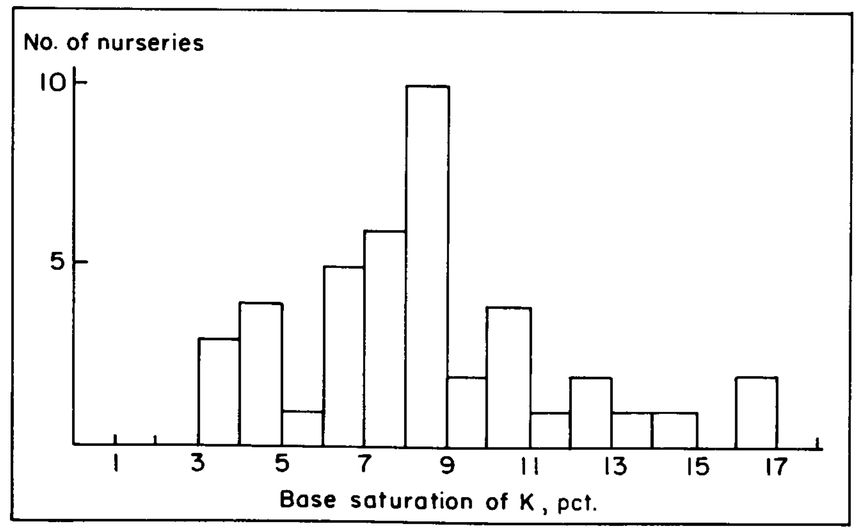

Fig. 15. The base saturation of potassium for 45 southern forest nurseries.

percent base saturation for potassium should be greater than 5 percent, figure 15. A crop of loblolly pine seedlings can remove up to 100 kilograms per hectare (90 pounds per acre) of potassium. Leaching of potassium in sandy soils is a common occurrence and potassium topdressings may be required even during the growing seasons at some nurseries where leaching is great. However, use of more potassium than is needed may cause magnesium deficiencies, especially on sandy soils.

Calcium

Calcium is positively correlated with the silt and clay content, table 1, and therefore, the absolute amounts will vary with texture, figure 16. For sands and loamy sands, at least 200 p.p.m. of calcium is recommended. However, the absolute amount of exchangeable calcium present is frequently not so important to plant nutrition as the amount present in relation to the quantities and kinds of other cations present. Figure 17 shows the percent base saturation of calcium for the 45 nurseries sampled. This distribution suggests that

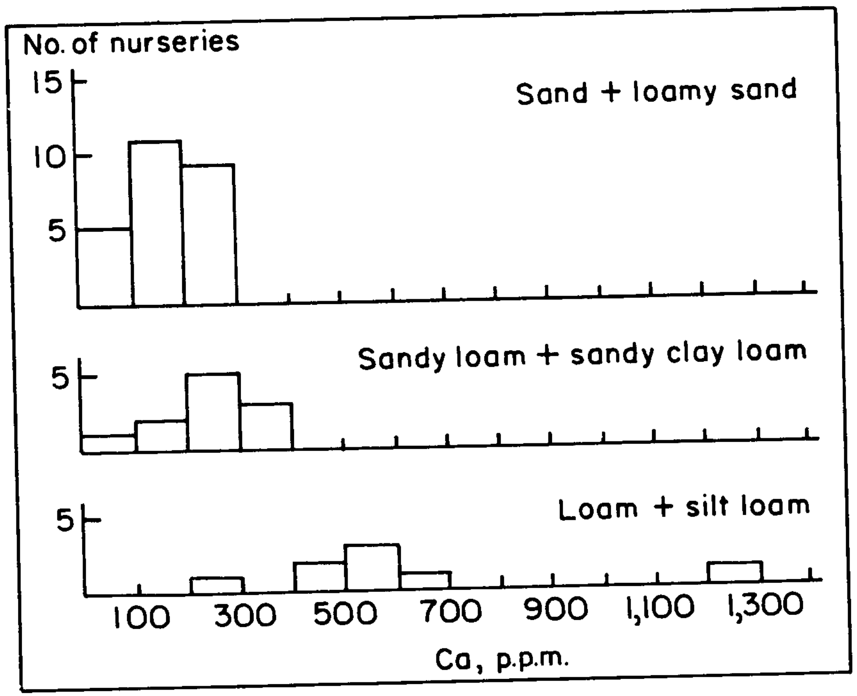

Fig. 16. Soil calcium for 45 southern forest nurseries.

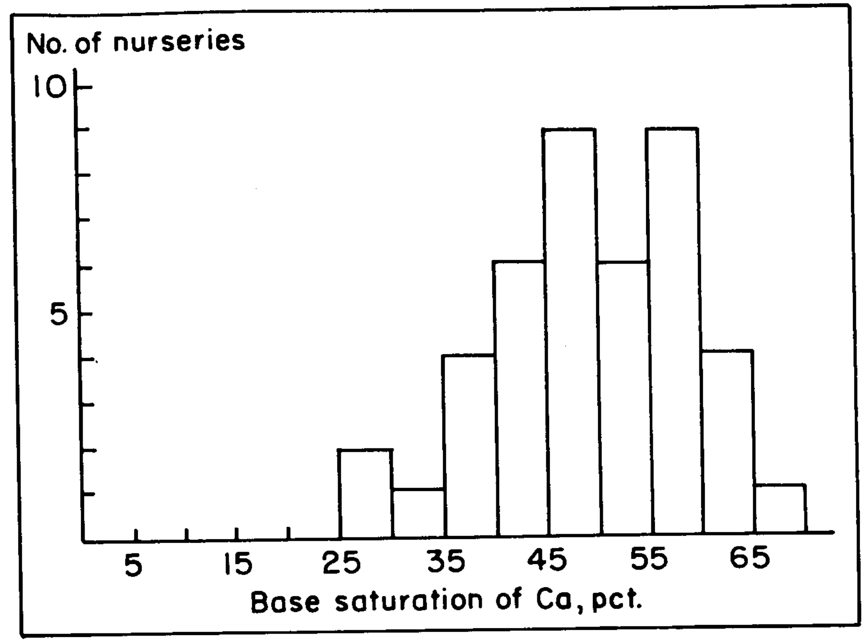

Fig. 17. The base saturation of calcium for 45 southern forest nurseries.

nurseries with less than 40 percent base saturation of calcium are either too acid or too low in calcium.

When an increase in the pH value is desired, dolomitic or calcitic limestone can be used. When an increase in pH value is not desired, calcium sulfate (gypsum) can be applied. Low calcium levels are undesirable in a conifer nursery since deficiencies can result in serious injury to meristematic regions (*6, 9, 21*).

Magnesium

Magnesium is correlated with silt and clay content, table 1 and figure 18. The recommendation for nursery soils with more than 75 percent sand is at least 25 p.p.m.; for those with sandy loams, at least 35 p.p.m. Loams and silt loams should have at least 40 p.p.m. The percent base saturation for magnesium should be between 10 and 25 percent, figure 19. As a general rule, if the soil test indicates that the p.p.m. of exchangeable potassium to exchangeable magnesium ratio is more than 3:1, then a magnesium deficiency could occur. Magnesium is important in chlorophyll formation. Magnesium deficiency yields a needle color similar to nitrogen deficiency (*9*).

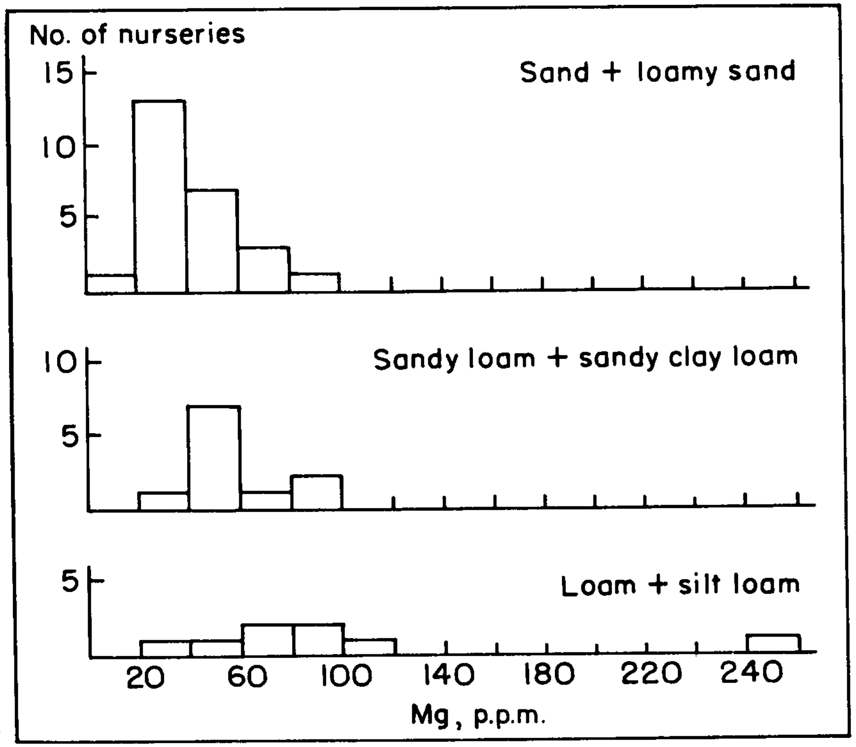

Fig. 18. Soil magnesium for 45 southern forest nurseries.

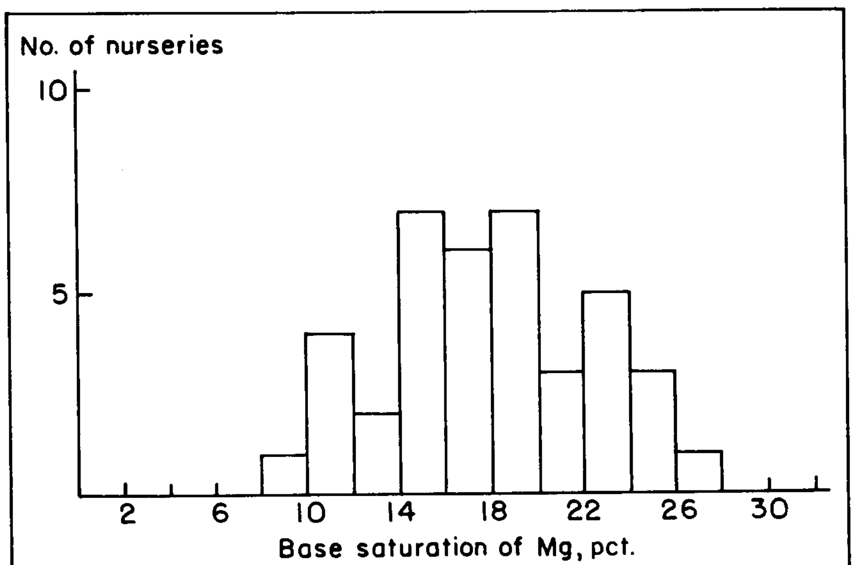

Fig. 19. The base saturation of magnesium for 45 southern forest nurseries.

Sodium

Sodium is not an essential element. However, the sodium level in the soil can greatly affect the production of quality seedlings. Problems may arise if the exchangeable sodium in the soil exceeds 10 percent. By testing irrigation water, the Auburn Cooperative identified three nurseries that had high sodium adsorption ratios, figure 20. Irrigation water with a sodium adsorption ratio of 3:5 indicates slight to medium hazard. Values above 5 indicate that problems with soil permeability are likely to occur, especially for fine textured soils. One of these nurseries was having difficulty producing loblolly seedlings. When the soil was tested, up to 21 percent exchangeable sodium was reported. This was causing problems with soil structure and was probably causing a nutrient imbalance. Now that the problem has been identified, steps have been

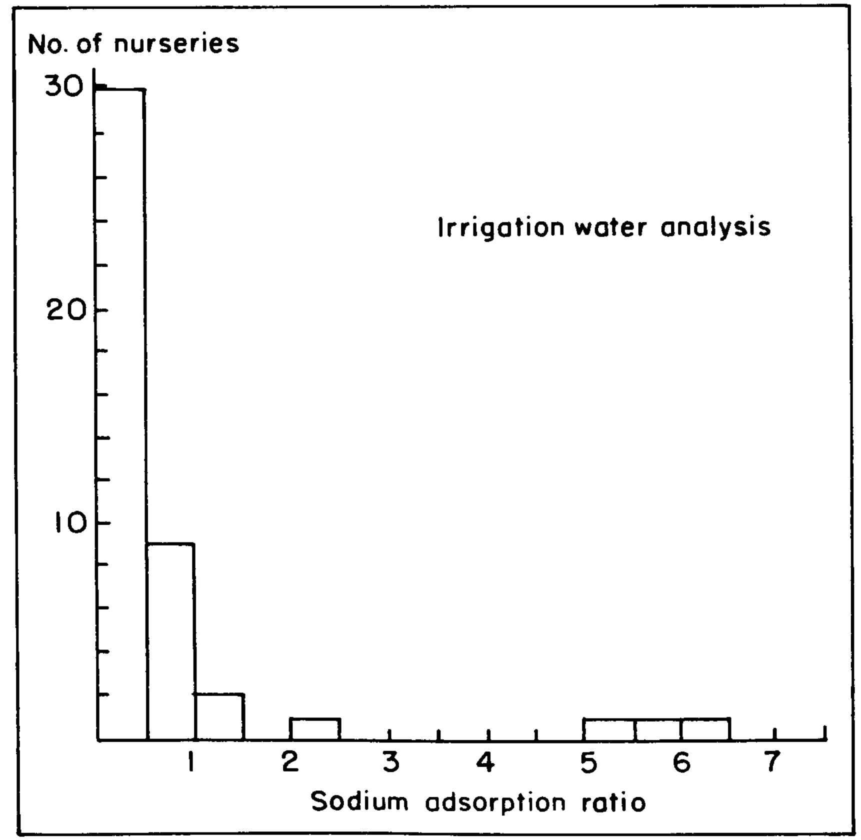

Fig. 20. The sodium absorption ratio of irrigation water from 45 southern forest nurseries.

taken to remedy the situation. Calcium sulfate additions helped in reducing the sodium adsorption ratio in the soil. Up to 780 kilograms per hectare (700 pounds per acre) of gypsum were applied directly to the seedlings. Sodium usually does not need to be monitored except at those nurseries with a high sodium adsorption ratio in their irrigation water.

Sulfur

Sulfur is essential for efficient nitrogen utilization by the plant. In the past, when sulfur containing fertilizers were used, sulfur was normally added in sufficient amounts to avoid deficiencies. However, with today's use of highly concentrated fertilizers and leaching losses from irrigation, sulfur deficiencies can and have occurred in forest nurseries. Sulfur deficiencies have been documented for at least three southern nurseries *(10, 14, 20)*. Response of loblolly pine seedlings at the Ft. Towson nursery in Oklahoma was dramatic *(14)*. For the present, the authors recommend maintaining at least 10 p.p.m. of sulfur, figure 21. The ratio of nitrogen to sulfur in the plant

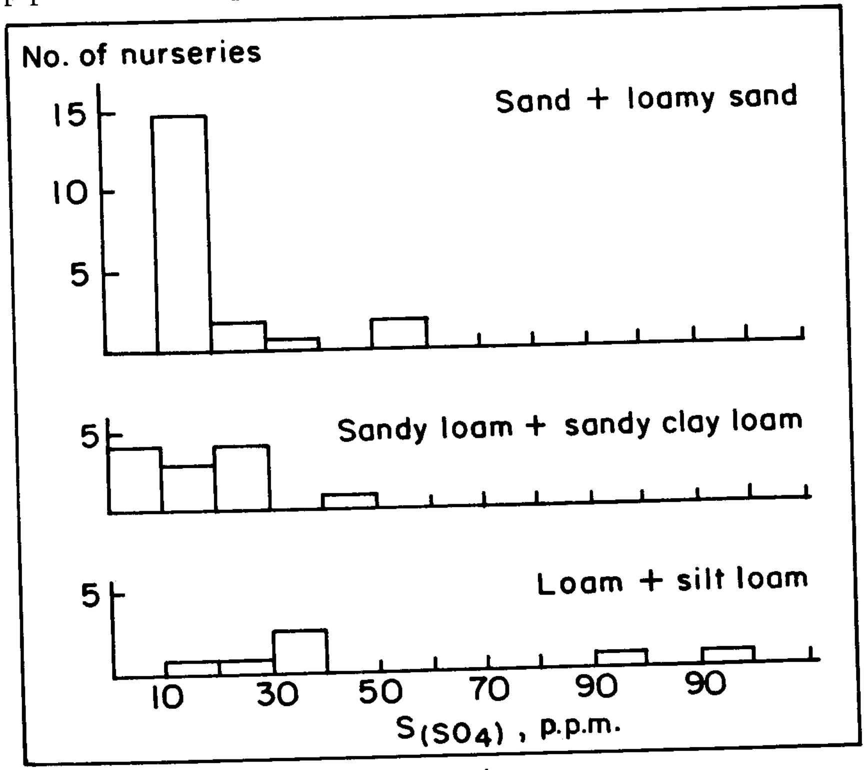

Fig. 21. Soil sulfur for 45 southern forest nurseries.

tissue may be a better indicator of sulfur requirement. On the average, loblolly seedlings require approximately 1 kilogram of available sulfur for each 15 kilograms of available nitrogen. Because most sulfur-containing fertilizers are highly soluble and the sulfate portion is subject to leaching, the best way of building sulfur reserves in soils is by maintaining an adequate organic matter content. Where organic sulfur reserves are not maintained, ammonium sulfate or other sulfur containing fertilizers will need to be applied.

Iron

Deficiency of iron is one of the most common and conspicuous micronutrient deficiencies of trees and occurs chiefly on alkaline and calcareous soils where absorption is inhibited. This is the main reason why loblolly pine does not grow well above pH 6. Iron chlorosis occurring after heavy applications of nitrogen or during hot weather is known as nitrate-induced chlorosis or heat-induced chlorosis. High levels of phosphorus can tie up iron by forming insoluble iron-phosphate compounds. Soil analysis for iron is probably only useful if a low level is indicated, figure 22. A soil test with medium or high levels of iron is almost meaningless since the iron may not be in an available form. Much of the iron in the leaves occurs in the chloroplasts where it plays a role in the synthesis of chloroplast proteins. Iron is relatively immobile and, therefore,

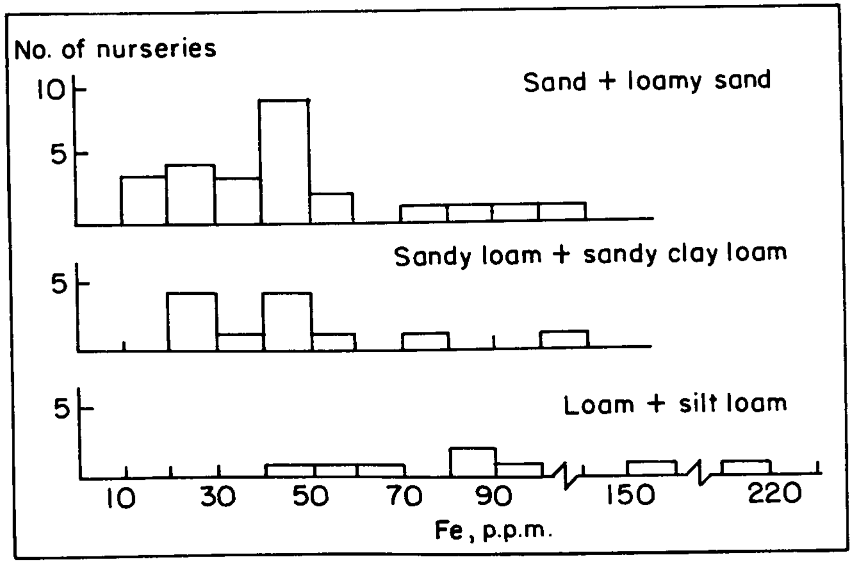

Fig. 22. Soil iron for 45 southern forest nurseries.

chlorosis develops first in the terminal needles. Iron chlorosis is usually corrected by either acidifying the soil with sulfur, or with the application of iron-chelates. The iron-chelates produce favorable results more quickly.

Manganese

Plants can use manganese over and over; therefore, only small amounts are required. The authors suggest a minimum level of 5 p.p.m. None of the nurseries sampled had less than 7 p.p.m. of manganese, figure 23. This element is also essential for the synthesis of chlorophyll and may also affect the availability of iron. For this reason, the symptoms of manganese deficiency are easily confused with iron chlorosis.

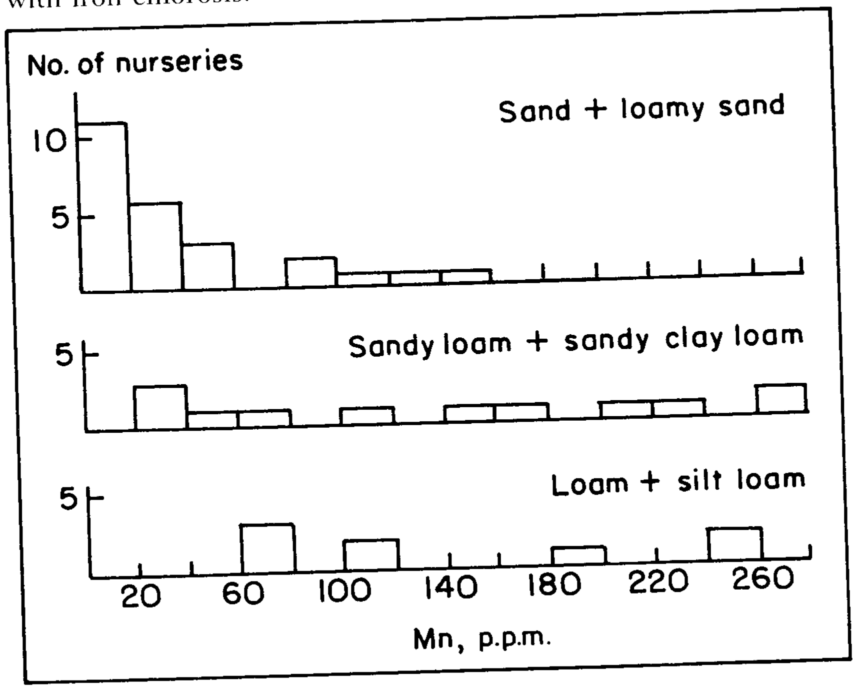

Fig. 23. Soil manganese for 45 southern forest nurseries.

Zinc

Zinc is essential for the transformation of carbohydrates and for regulation of the consumption of sugar. The authors suggest a minimum level of 1 p.p.m. for zinc. The lowest level of zinc for the nurseries sampled was 1.1 p.p.m., figure 24. However, in 1981 three nurseries had levels as low as 0.7 p.p.m. Those nurseries with

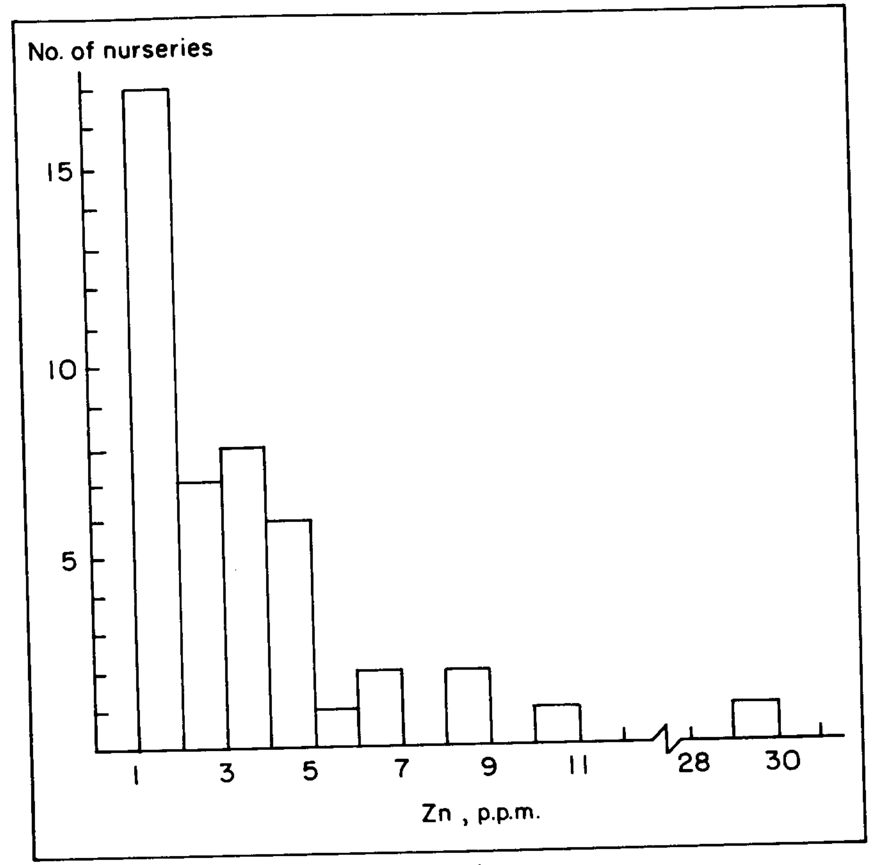

Fig. 24. Soil zinc for 45 southern forest nurseries.

sandy, easily leached soils with very high phosphorus levels are subject to zinc deficiency. Heavy applications of phosphate to the soil or soils with high levels of phosphates are often low in available zinc. It has been found that fumigation of soils low in zinc can result in increased plant uptake of zinc (*23*).

Copper

Copper plays an important role in plant growth as an enzyme activator. The authors suggest a minimum level of 0.8 p.p.m. Of the 45 nurseries sampled, 19 had less than this level, figure 25. On sandy soils containing little organic matter, copper generally becomes less available to plants as the pH value increases. High levels of phosphorus in the soil can reduce the uptake of copper by the seedling. The nursery with 4 p.p.m. of copper in figure 25 is high because of the frequent use of bordeaux mixture as a fungicide.

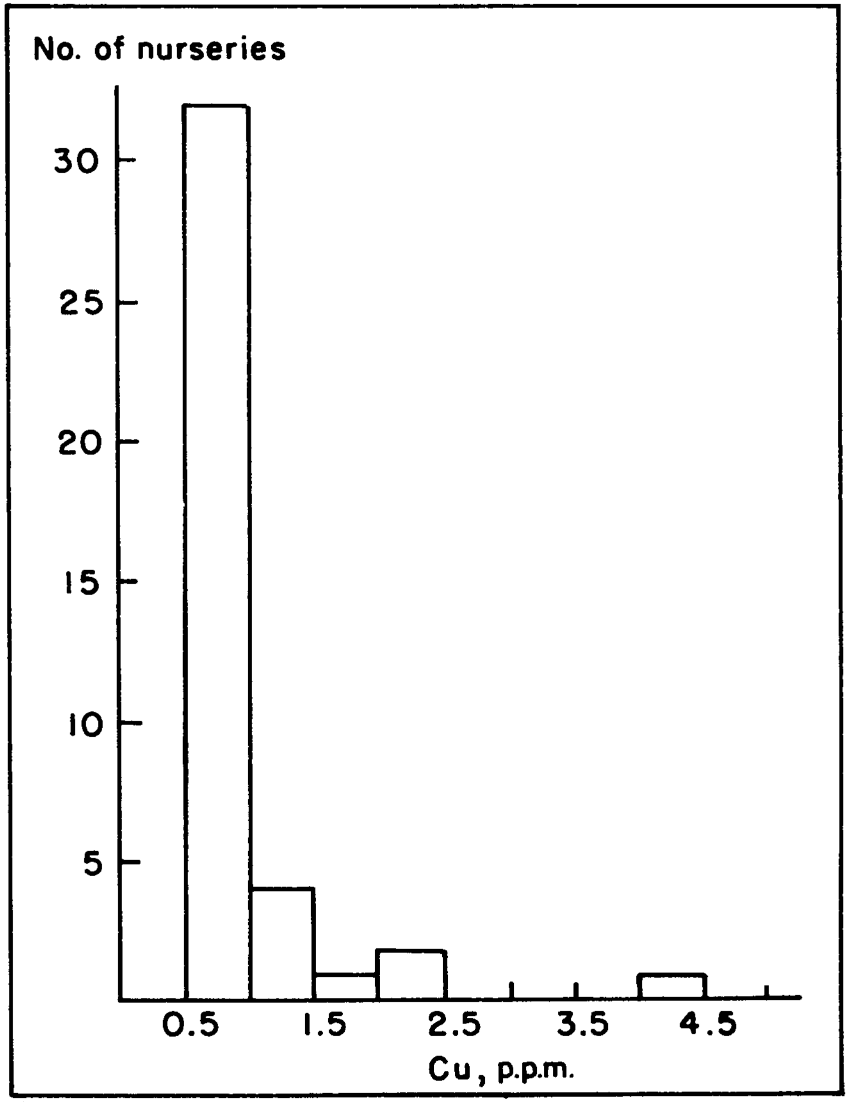

Fig. 25. Soil copper for 45 southern forest nurseries.

Boron

A recent paper in the Southern Journal of Applied Forestry by Stone *et al.* *(18)* pointed out the importance of monitoring the boron level in sandy nurseries. In a sandy soil, organic matter is the sole means of boron retention. This points out the importance of maintaining an adequate level of organic matter. In addition, soil acidity above pH 6.0, in conjunction with a high calcium level, resulted in

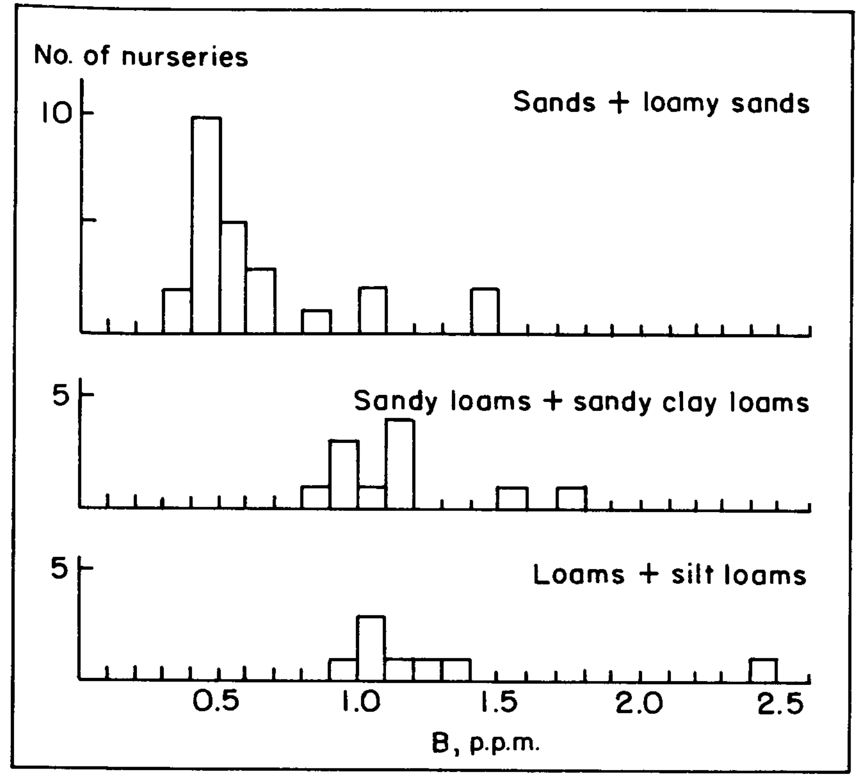

Fig. 26. Soil boron for 45 southern forest nurseries.

less available boron. The lowest level of boron reported by A&L Labs for the St. Regis nursery in Florida was 0.2 p.p.m., figure 26. Several other nurseries had soils with boron levels this low in 1981. The authors suggest maintaining the level of boron above 0.3 p.p.m. Excessive boron is highly toxic and application rates should be small, especially in sandy soils with low organic matter. Slight toxicity symptoms have been observed with application rates as low as 5 kilograms per hectare (4.5 pounds per acre). Boron deficiency causes serious injury and death of the apical meristem and is well illustrated in the paper by Stone *et al.* *(18)*.

CONCLUSION

Thus far, 25 southern nurseries have used the services of the Southern Forest Nursery Soil Testing Program. Although we have only just begun, several nurseries have already improved their seedling production as a result of this program. The primary goal of this soil testing program is to provide the nurseryman with help so he can avoid imbalances in soil nutrients as well as avoid dramatic fluctuations in nutrient levels. It is hoped that with this program nursery soil productivity will be maximized throughout the South.

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