no significant differences between the number of scions produced on the hedged trees (134) and on the heavily pruned trees (147). Any slight reduction in number of scions would be more than offset by the ease of collection from the shorter hedged trees. The suspected increase in graft incompatibility from severe hedging also was not a problem in this study.

However, since future clone banks should ideally serve both scion production needs for seed orchard establishment and strobilus and seed production needs for the breeding program, heavy pruning appears to be the best treatment in this study. The heavy pruning treatment not only produced the most scions but also had a minimal effect on the tree growth. Neither the hedging nor BAP treatment appears to have a useful role for scion multiplication in operational seed orchards or clone banks where breeding will also be conducted. Both practices drastically reduced growth, and it is doubtful that treated trees would recover sufficiently to compete with nontreated trees. Grafts subjected to the light and heavy pruning treatments had comparable height growth to the untreated trees, and recovery would only consist of crown expansion. We anticipate that pruned trees would recover sufficiently from scion multiplication efforts to achieve normal cone production. □

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New-Ground Syndrome: An Ectomycorrhizal Deficiency in Pine Nurseries[1]

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*ABSTRACT. In July 1986, stunted loblolly pine (*Pinus taeda *L.) seedlings were studied at a nursery in Union Springs, Alabama. Stunted seedlings were found only in seedbeds formed on* new ground *(soil having no history of producing a nursery crop of ectomycorrhizal tree seedlings). The stunted seedlings were either nonmycorrhizal or had extremely low levels of ectomycorrhizae, whereas nonstunted seedlings had a greater degree of ectomycorrhizal development. Stunted seedlings were deficient in phosphorus (0.07%), whereas nonstunted seedlings had sufficient phosphorus (0.15%). An application of phosphoric acid (H_3PO_4) to stunted seedlings increased shoot phosphorus and resulted in substantial growth improvement. The phosphorus application reduced the percentage of cull seedlings (root-collar diameter <3.2 mm) from 62% to 8%. This study also demonstrates that when a seedbed is formed on new ground, ectomycorrhizal deficiencies can occur even when ectomycorrhizal tree hosts are present in the immediate vicinity. The ectomycorrhizal deficiency in the seedlings observed in this study may have been related to restricted spore dispersal caused by insufficient rainfall that had occurred after spring fumigation.*

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Ectomycorrhizal deficiencies in conifer nurseries have been reported in the Pacific Northwest (Trappe and Strand 1969) and in the Lake States (Croghan et al. 1987). In the South, however, such deficiencies are uncommon, it has been suggested that wind dissemination of spores assures rapid ectomycorrhizal colonization of seedlings in southern nurseries (Cordell and Filer 1985). To date, the only published report of an ectomycorrhizal deficiency in loblolly pine (*Pinus taeda* L.) seedbeds is from the Ft. Towson Nursery in Oklahoma (Marx et al. 1978). Seedlings growing there in new ground appeared stunted and chlorotic and few had developed secondary needles three months after germination. (For this paper, *new ground* is defined as soil having no history of producing a nursery crop of ectomycorrhizal tree seedlings.) Examination of the root systems in late July revealed that less than 10% of the seedlings had ectomycorrhizae. At the end of the growing season, only 4% of the seedlings had attained a height of 15 cm. It was concluded that the mycorrhizal

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deficiency was caused by a lack of endogenous ectomycorrhizal inoculum in the soil. Marx et al. (1978) proposed that this lack resulted from there being no ectomycorrhizal hosts (e.g., *Pinus* or *Quercus*) in the immediate vicinity. In an effort to correct the problem, loblolly pines with abundant ectomycorrhizae were planted at various locations around the nursery, since sporocarps formed in association with such trees provide a source of windblown spores for natural inoculation.

Over the past 10 years the senior author has visited several nurseries where loblolly pine seedlings were growing in new ground. In most cases seedling growth was normal. However, at some locations, seedlings growing in new ground began to show signs of stunting in July. In these cases, considerable seedling variability was evident within seedbeds, with patches of large seedlings having a healthy appearance (Figure 1). Although stunted seedlings were usually not chlorotic, the cotyledons and tips of older needles would often be reddish-purple. This condition occurred despite the fact that the nurseries had species of pines or oaks or both in the immediate vicinity. No stunted seedlings were observed at these nurseries in seedbeds formed on *old ground* (that is, seedbeds formed with soil that had produced an ectomycorrhizal seedling crop within the last 5 years). Therefore, the term *new ground syndrome* was coined as a name for the problem just described.

The objectives of this study were to characterize the growth, mineral nutrition, and ectomycorrhizal condition of stunted seedlings growing in new ground at the Inverness Nursery located at Union Springs, Alabama, and to determine the extent to which stunted seedlings respond to the addition of phosphoric acid.

MATERIALS AND METHODS

Nursery Soil Management

In January 1984, the sudy site at the nursery was supporting a 23-year-old pine plantation. That timber stand was harvested during the summer of 1984, and stump removal began in August. Land leveling was completed in early July the next year, and millet (*Panicum ramosum* L.) was sown as a cover crop on July 15. Phosphorus levels of soil samples taken that November ranged from 11 ppm to 15 ppm. The soil was fumigated on March 15, 1986 with methyl bromide (448 kg/ha) containing 2% chloropicrin. Before sowing pine seed, the soil received 224 kg/ha of triple superphosphate and 112 kg/ha of potassium chloride. Loblolly pine seeds were treated with the fungicide triadimefon (Bayleton) at 12.5 g of active ingredient (ai) per 10 kg of seed.

Seeds were sown with a vacuum precision sower on April 9, and the area was treated with the herbicide oxyfluorfen (Goal) at 0.56 kg ai/ha. Postemergence applications of oxyfluorfen at 0.56 kg ai/ha were applied on June 13 and August 15. In addition, the herbicide sethoxydim (Poast) was applied on June 13 and July 9 to control grasses. Foliar applications of triadimefon (0.14 kg ai/ha) were applied on May 5, May 12, and June 5 to control fusiform rust, caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirae f. sp. *fusiforme* Birdsall and Snow. Seedlings were fertilized with ammonium nitrate (100 kg/ha) on May 21 and July 8 and with ammonium sulfate (168 kg/ha) on June 12 and again on July 23. Rainfall at the nursery in February (107 mm) and March (185 mm) was above normal, but rainfall in April (18 mm), May (69 mm), and June (71 mm) was 98 mm, 34 mm, and 39 mm below normal (National Oceanic and Atmospheric Administration 1987).

Sampling of Seedlings in New Seedbeds

On July 29, 1986, a total of five sample locations was selected on two adjacent nursery beds that contained stunted seedlings. Each sample location was within 2 m of an area containing healthy seedlings. At each location, a sample of stunted and a sample of healthy seedlings were collected, a total of ten samples. Seedlings were carefully excavated from the soil to re-

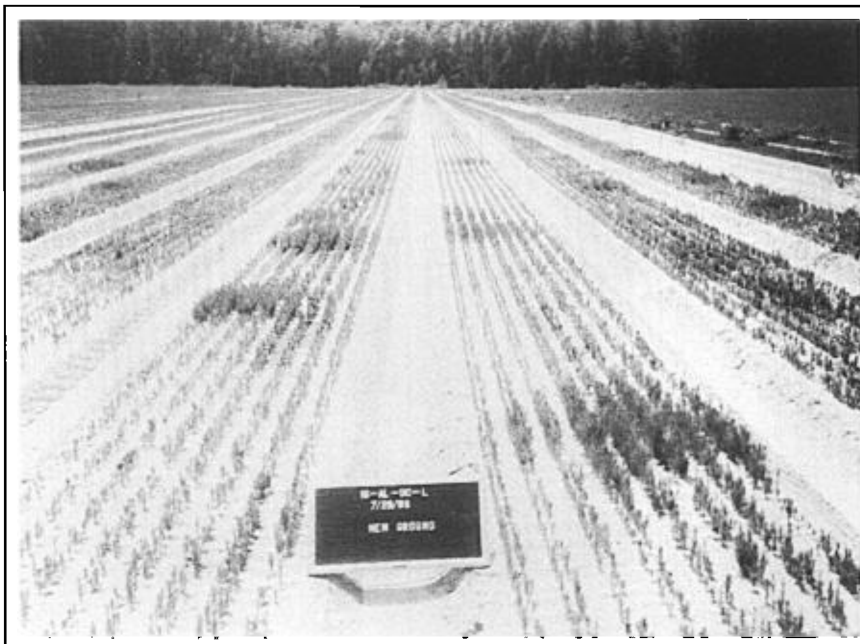

Figure 1. Ectomycorrhizal deficiency symptoms in new ground at the Inverness Nursery at Union Springs, Alabama in 1986. (Note the proximity of the mixed stand of pines, oaks, and hardwoods in background).

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tain the fine lateral roots and associated ectomycorrhizal roots. Soil samples were also collected from both healthy and stunted areas (for a total of 10 samples). Techniques used for chemical analyses of soil were as previously reported (South and Davey 1983).

Five seedlings were randomly selected from each of the ten seedling samples and were assessed for presence of ectomycorrhizae according to the methods of Trappe (1983) as modified by Grand and Harvey (1986). On July 30, the percentage of ectomycorrhizal roots was estimated by carefully scanning the entire root system of each seedling under a stereo microscope at 10–40 × magnification.

The ectomycorrhizal status of each seedling fell into one of the following classes:

Class 1 = 0–24% of short roots ectomycorrhizal
Class 2 = 25–49% of short roots ectomycorrhizal
Class 3 = 50–74% of short roots ectomycorrhizal
Class 4 = 75–100% of short roots ectomycorrhizal

The remainder of the sampled seedlings (87–174 seedlings per sample location) were oven-dried at 70°C to a constant weight, after which the weights of roots and shoots were determined. In addition, foliage from randomly selected seedlings within each sample location was ground in a Wiley mill. Both foliage and soil samples were analyzed by standard procedures (Boyer and South 1985). Differences between seedlings from stunted and healthy areas were evaluated using paired t-tests (SAS 1982).

Phosphorus Fertilization Study

A phosphorus fertilization study was established on July 29, 1986, in part of the study area containing uniformly stunted seedlings. Fertilization treatments (phosphoric acid fertilization and a control) were established with five replicate plots for each treatment; plot size was 1 m by 1.2 m.

Table 1. Chemical analysis of soil containing stunted or healthy loblolly pine seedlings from the nursery at Union Springs, Alabama.

	O.M (%)	Ca	P	K	Mg	S	pH
		ppm					
Stunted	2.8	94.0	19.2	33.4	30.6	41.1	4 76
Healthy	1.5	82.0	21.6	29.0	31.0	49.8	4 78
$P < T$[1]	0.12	0.37	0.43	0.49	0.54	0.48	0.75

[1] Probability of a greater *T* value. Paired t-test.

Table 2. Foliar nutrient levels and dry weights of stunted and healthy loblolly pine seedlings from the nursery at Union Springs, Alabama.

	Foliar nutrients						Dry weight	
	N	P	S	K	Mg	Ca	Shoot	Root
	(%)						(mg)	
Stunted	2.3	0.07	0.09	1.23	0.15	0.34	173	32
Healthy	2.2	0.15	0.09	1.08	0.11	0.32	576	105
$P > T$[1]	0.270	0.001	0.648	0.004	0.007	0.140	0.003	0.001

[1] Probability of a greater *T* value. Paired t-test.

Phosphorus fertilization was accomplished by applying dilute (3% w/w) H_3PO_4 at a rate of 18.3 g of phosphorus/m^2. Three weeks after treatment, sample seedlings were removed from each plot and used to determine heights, shoot dry weight, and root dry weight. Foliar mineral concentrations were determined, as previously described. Seedling data were subjected to analysis of variance (SAS 1982).

RESULTS

Although no difference in extractable soil phosphorus was observed between soil containing healthy versus stunted seedlings (Table 1), substantial differences were apparent in concentrations of foliar phosphorus (Table 2). The average foliar phosphorus concentration in healthy seedlings (0.15%) was double that for stunted seedlings (0.07%). Furthermore, large differences in the degree of ectomycorrhizal colonization were observed between healthy and stunted seedlings (Figure 2). The ectomycorrhizae appeared to be formed by *Thelephora terrestris* (Ehrh.) Fr. Sixty-eight percent of the stunted seedlings were judged to fit into ectomycorrhizal colonization class 1

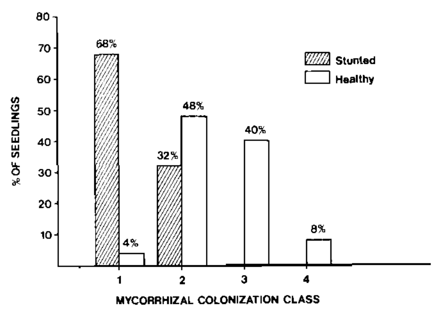

Figure 2. The ectomycorrhizal status of loblolly pine seedlings growing in new ground at the Inverness Nursery at Union Springs, Alabama on July 29, 1986. The percentage of ectomycorrhizal short roots was greater on healthy seedlings than for stunted seedlings ($P < T < 0.001$). *Percentage of short roots ectomycorrhizal: Class 1 = 0–24%; Class 2 = 25–49%; Class 3 = 50–74%; Class 4 = 75–100%.*

(0–25%); no stunted seedlings exhibited greater than a class 2 level of ectomycorrhizal colonization (25–49%). The majority (88%) of seedlings from the healthy plots had mycorrhizal colonization levels between 25% and 74%; 8% had ectomycorrhizal levels greater than 74%, placing them in class 4, the highest class.

Soil from two plots containing stunted seedling exhibited above-average levels of organic matter (3.1% and 4.7%). However, seedlings from these plots contained

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more than 2.2% foliar nitrogen and showed no signs of nitrogen chlorosis.

Phosphorus fertilization increased the height, the shoot and root weights, and the foliar phosphorus concentrations of stunted seedlings (Table 3). Three weeks after treatment, seedlings provided with available phosphorus were 50% heavier, 14% taller, and had more than 4 times the amount of foliar phosphorus as untreated seedlings. This growth advantage increased with time. By November 26, treated seedlings were 200% heavier, 28% taller, and 32% larger in diameter. The phosphorus treatment reduced the percentage of cull seedlings with root-collar diameters of less than 3.2 mm from 62% for untreated seedlings to only 8%.

DISCUSSION

Although no significant differences in soil fertility levels existed between the plots of healthy and stunted seedlings, the foliar phosphorus concentration of the stunted seedlings was only half that of the healthy seedlings. The stunted seedlings were not chlorotic but did exhibit signs of phosphorus deficiency: the cotyledons and tips of older primary needles were sometimes reddish-purple in color. The addition of phosphoric acid dramatically increased the concentration of phosphorus in the foliage, which, in turn, increased seedling growth.

A number of studies have demonstrated the role of ectomycorrhizae in phosphorus uptake by the host (Mitchell et al. 1984; Reid et al. 1983; Hart et al. 1980; Harley 1969; Stone 1950). Reid et al. (1983) reported the same foliar phosphorus concentrations in 8-month-old nonmycorrhizal (0.07%) and mycorrhizal (0.15%) loblolly pine seedlings that we observed in stunted and healthy seedlings, respectively. Apparently, stunted seedlings in the present study were experiencing phosphorus deficiency that was associated with the lack of ectomycorrhizae.

Except for the absence of chlorosis in the seedlings in the present study, the ectomycorrhizal deficiency of these seedlings was similar to that observed in the seedlings at the Ft. Towson Nursery (Marx et al. 1978). At the Ft. Towson Nursery, a lack of ectomycorrhizal host plants in the immediate vicinity was cited as the likely reason for the absence of inoculum. However, at the Inverness Nursery, the seedbeds were surrounded by a stand of pines and oaks. Furthermore, similar mycorrhizal deficiencies in new ground have been observed at the following other nurseries located near stands of pine or oak or both: Red Bay and Selma, Alabama; Munson, Florida; Natchez, Mississippi; Morganton, North Carolina; Salem, South Carolina; and Sussex, Virginia. Therefore, it is clear that ectomycorrhizal deficiencies at southern pine nurseries are not limited to sites lacking in ectomycorrhizal hosts.

There are various cultural practices that can affect the formation of ectomycorrhizae in new ground. For example, land leveling can affect the distribution of inoculum. Often, the topsoil is removed and stockpiled before grading takes place. However, uniform replacement of the topsoil is not always possible and sometimes sandy subsoil, devoid of ectomycorrhizal inoculum, will be brought to the surface. If this sterile soil does not become inoculated with ectomycorrhizal spores (or vegetative inoculum), seedling growth can be affected.

Soil fumigation can also have a negative impact on ectomycorrhizal colonization of seedlings (Trappe et al. 1984, Molina and Trappe 1984). In the southern United States, fumigation with methyl bromide-chloropicrin is a common practice that usually increases growth of southern pines. However, fumigation may delay formation of ectomycorrhizae for several weeks (Danielson and Davey 1969, Dixon et al. 1981) and sometimes can reduce development of seedlings growing in new ground (Marx et al. 1978). Apparently, in older seedbeds, rapid colonization of seedlings growing in fumigated soil occurs from sources of ectomycorrhizal inoculum that have escaped the fumigation because they resided deep enough in the soil. Rapid colonization of seedlings prevents the severe stunting that occurs when there is an excessive delay in inoculation.

Nursery managers who want to fumigate with methyl bromide-chloropicrin for diseases but also wish to avoid ectomycorrhizal deficiencies in seedbeds formed on new ground should consider fall fumigation. If the nursery manager must fumiage new ground in the spring, then fumigants containing 2% chloropicrin should be used rather than those containing

Table 3. Foliar nutrient levels, dry weights, and morphology of loblolly pine seedlings after treatment with H_3PO_4.

	Three weeks after treatment									Seventeen weeks after treatment				
	Foliar nutrients						Shoot weight	Root weight	Height (mm)	Shoot weight	Root weight	Height	Diameter	Culls[2] (%)
	N	P	S	K	Mg	Ca								
	(%)						(mg)		(mm)	(mg)		(mm)		
H_3PO_4	2.3	0.25	0.13	0.97	0.08	0.23	221	47	90	2,150	730	199	4.1	8
Control	2.3	0.08	0.10	1.02	0.11	0.28	148	31	79	1,040	400	155	3.1	62
$P > F$[1]	0.629	0.001	0.001	0.085	0.001	0.019	0.007	0.062	0.044	0.001	0.001	0.001	0.001	0.001

[1] Probability of a greater *F* value.
[2] A cull is a seedling with a root-collar diameter less than 3.2 mm.

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33% chloropicrin. This is because residual levels of chloropicrin can continue to delay ectomycorrhizal recolonization for 2 to 3 weeks after the plastic tarp has been removed (Pers. comm. Don Marx).

Although the fungicide triadimefon is effective in reducing fusiform rust, it can also inhibit ectomycorrhizae (South and Kelley 1982, Marx and Cordell 1986). However, poor develpment of ectomycorrhizae on seedlings growing in new ground is not consistently associated with either triadimefon or fumigation. For example, at nurseries in Virginia, North Carolina, and South Carolina, an ectomycorrhizal deficiency was observed in new ground that had not been treated with triadimefon. At Sussex, Virginia, seedlings grown in nonfumigated seedbeds exhibited ectomycorrhizal deficiencies. Nevertheless, fumigation practices could exacerbate any marginal ectomycorrhizal deficiency that may be present in new ground.

Environmental factors could explain why ectomycorrhizal deficiencies may occur in new ground during one year but not another. For example, at the Inverness Nursery in 1984, 21 million seedlings were produced on new ground that was formerly pasture land. Although fumigation, fungicide, and fertilization practices were similar to those used in 1986, no obvious signs of ectomycorrhizal deficiency occurred in 1984. However, the difference in rainfall following fumigation may have affected the availability of *Thelephora terrestris* spores for reinoculation (Trappe 1977). April rainfall in 1984 was 72 mm as compared to only 18 mm in 1986. It is possible that in 1986, the paucity of rainfall after the March fumigation limited fruiting body production and spore dispersal and resulted in the ectomycorrhizal deficiency.

Nursery mangers who wish to assure a supply of inoculum in new ground should consider applying spores of *Pisolithus tinctorius* (Pers.) Coker & Couch just before or soon after sowing (Marx et al. 1978, Marx and Bell 1985). In addition to being relatively inexpensive, about 43¢/1000 seedlings (Cordell et al. 1987), there can be several other advantages to using spores for newly established seedbeds (Marx et al. 1979).

Although preplant applications of phosphorus were applied to new ground at the Inverness Nursery (49 kg P/ha) and Ft. Towson Nursery (104 kg P/ha), the resulting soil phosphorus levels were less than 30 ppm. Therefore, when the level of soil phosphorus in new ground is low—e.g. <45 ppm (Weak Bray)—at time of sowing and artificial inoculation is not used, nursery managers should consider applying phosphorus soon after germination. Although phosphoric acid was used in this study, it can cost about $2.60/kg of phosphorus. On the other hand, diammonium phosphate may cost only $1/kg of phosphorus (assuming the nitrogen has a value of $0.50/kg). Diammonium phosphate can be used instead of ammonium nitrate or ammonium sulfate when applying the first few topdressings to seedbeds. To be most effective, diammonium phosphate applications should begin in early June. Applications would not be as effective if delayed until July when visual symptoms of ectomycorrhizal deficiencies usually appear. As this study shows, ensuring that nonmycorrhizal seedlings receive enough phosphorus can greatly improve their growth and can reduce the production of culls. □

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Diameter-Distribution Yield-Prediction System for Unthinned Loblolly and Slash Pine Plantations on Non-Old-Fields in East Texas

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*ABSTRACT. Procedures and methods for a diameter-distribution yield-prediction system for young (4–20 years old) unthinned loblolly (*Pinus taeda *L.) and slash pine (*Pinus elliotti *Englem.) plantations on non-old-fields in East Texas are presented. Average height and number of trees are predictors of minimum diameter, arithmetic mean diameter, and quadratic mean diameter. The three measures of diameter are then used to determine the parameters of a Weibull probability density function. After obtaining the function, the number of trees by diameter class can be calculated, and by using individual tree content equations, expected yield by diameter class can be computed. An evaluation of the system indicated that on the average, loblolly pine plantation yields were underestimated by 5.3% and slash pine plantation yields were underestimated by 8.1%. Computer programs written in FORTRAN and BASIC are available from the author for the diameter-distribution yield-prediction system.*

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By the mid-1990s, when the conversion of about 3 million acres of forested land in East Texas from mixed pine-hardwood timber to planted loblolly and slash pine trees is completed, approximately 25% of East Texas forestland will be in pine plantations. The efficient use of these plantations requires comprehensive and accurate estimates of per-acre yields. If per-acre yields can be described on a diamter-class basis, the plantation manager can assign different stumpage prices to different size-classes and obtain more precise estimates of stumpage income at various points during a rotation.

Yield estimates by diameter classes for planted loblolly and slash pine in East Texas have been developed in three southwide or West Gulf Region studies (Dell et al. 1979, Feduccia et al. 1979, Amateis et al. 1984, and Burkhart et al. 1987). However, the three data sets included only 4–11 observations (1–3% of the total of the study observations) that were made in East Texas.

To provide yield information more applicable to loblolly and slash pine plantations in East Texas, the East Texas Pine Plantation Research Project (ETPPRP) was initiated in 1982 by the School of Forestry at Stephen F. Austin State University and participating forest industries[1] (Lenhart et al. 1985). Initial results of ETPPRP stand structure and yield research have been reported by Lenhart (1987). An updated diameter-distribution yield-prediction system is presented in this paper.

PERMANENT PLOT MEASUREMENTS

A total of 173 permanent plots of the ETPPRP are located in loblolly pine plantations and 79 in slash pine plantations throughout East Texas. The loblolly and slash pine plots are in 24 and 12 counties, respectively. Each plot was randomly located in a different plantation. A plot consists of 2 subplots—one for model development and the other for model evaluation—separated by a 60-ft-wide buffer zone. Each subplot is square and has 10,000 ft^2 of sample area. Every planted pine within a subplot is tagged and numbered. Initial measurement of planted pines within each subplot occurred during installation in 1982–1984, and the second measurement was completed in

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