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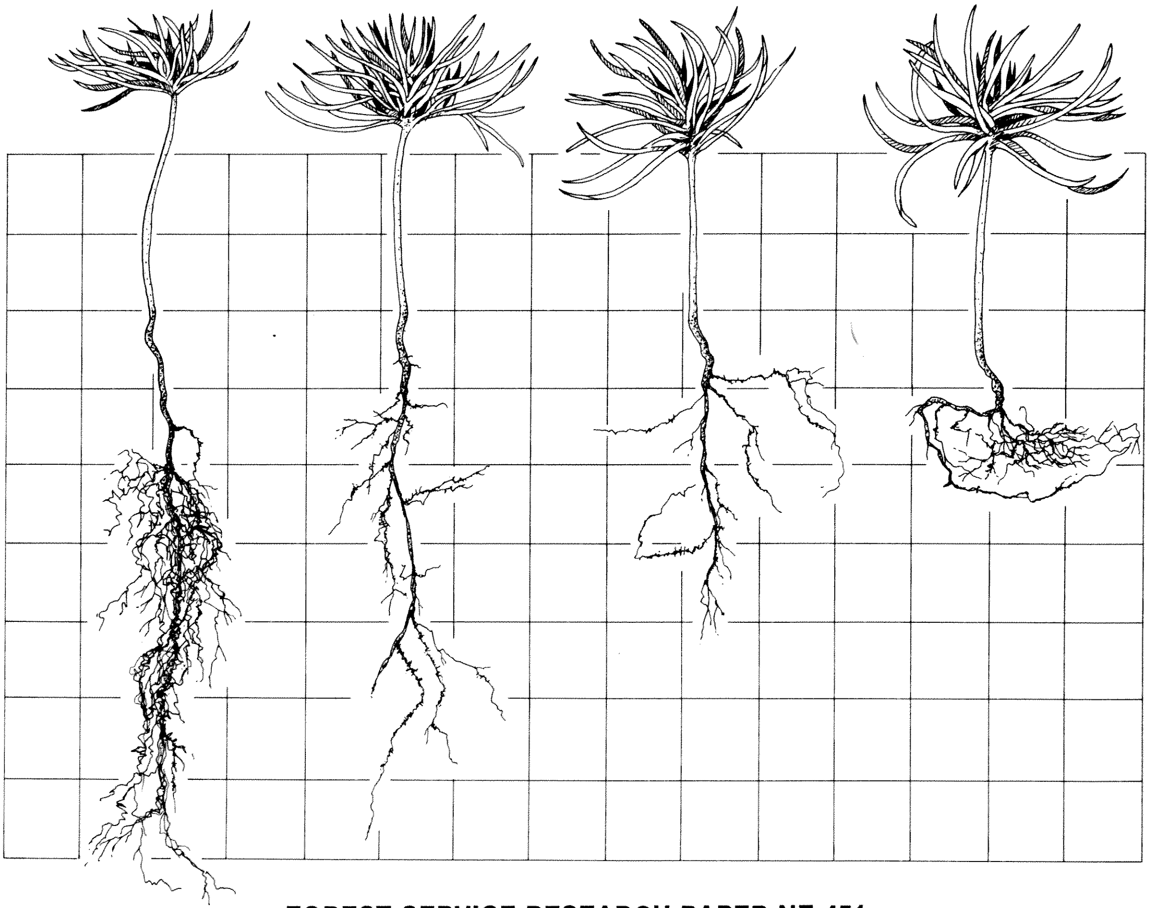
ESTABLISHMENT AND EARLY GROWTH OF CONIFERS ON COMPACT SOILS IN URBAN AREAS



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Abstract

A study of pitch pine, Austrian pine, and Norway spruce on two different urban soils compacted to bulk densities of 1.2, 1.4, 1.6, and 1.8 $g \cdot cm^{-3}$ and maintained at high water potentials showed that all three species could become established from seed at high soil bulk densities. Pitch pine was the most successful species in establishment. Only a silt loam soil, packed to a bulk density of 1.8 $g \cdot cm^{-3}$, significantly reduced establishment of all three species. A sandy loam soil, also packed to 1.8 $g \cdot cm^{-3}$, did not reduce establishment. Root penetration was restricted at a bulk density of 1.4 $g \cdot cm^{-3}$ on the silt loam and 1.6 $g \cdot cm^{-3}$ on the sandy loam; there was a strong interaction between bulk density and soil type. Measured soil resistance to penetration may be a better indicator than bulk density for predicting seedling performance.

INTRODUCTION

THERE HAS BEEN INCREASING PRESSURE to use forest lands in and near urban centers to provide amenities for people. Forest vegetation within cities is often collectively referred to as the urban forest. Andresen (1978) distinguishes inner-city forests from adjacent surrounding forests by calling the latter urbanizing forests. The difference is important because different forest management practices may be needed in each area to moderate the impact of people on the forest.

Human use of the forest for amenity purposes, such as recreation, has a variety of impacts. Under light initial use, the impact is small; natural processes can restore the site to original conditions. Near urban centers, continued and heavier use is the rule, and additional impacts appear. It is difficult to quantify the degree of impact near urban centers because there are few, if any, undisturbed areas which can be examined to define initial conditions. Isolated high-use areas, such as recreation sites in wilderness areas, can be used to gain some insight into the problem. A recent article (Frissell 1978) defined five condition classes and possible management actions to restore wilderness area campsites. One of the first significant conditions to develop with continued use is soil compaction. As use intensifies, soils become more compacted, the site deteriorates, erosion increases, and trees begin to die. As site conditions worsen, rehabilitation becomes more difficult.

While it is ofen mentioned that compacted soil is common in urban areas, few investigations have been made to determine accurately the extent of the problem. One of the few pieces of quantitative information that documents the degree of soil compaction in metropolitan areas comes from a survey of soils located in the Washington, D.C. area (Patterson 1976). Compaction of several different soils resulted in an increase in bulk density from a range of 1.30 to 1.60 $g{\cdot}cm^{-3}$ to a range of 1.70 to 2.20 $g{\cdot}cm^{-3}$. Even this small amount of information clearly indicates the potential for serious soil compaction problems in urban areas.

Although we speak of certain urban soils as compacted, the term is qualitative. Compaction alone does not describe accurately the effect of compacted soils on vegetation. Associated with the compaction process are changes in total pore space, distribution of pore sizes, and resistance to penetration that may affect tree establishment and growth.

Although there are several descriptions of the effect of compact soils on trees and roots (Meinecke 1929; McQuilkin 1935; Lutz et al. 1937; Youngberg 1959), there have been relatively few quantitative investigations from which specific recommendations can be made. To date, several coniferous tree species have been used for most studies in the western United States (Forristall and Gessel 1955; Minore et al. 1969) and loblolly pine (*Pinus taeda*) has been used for most studies in the Southeast (Pomeroy 1949; Perry 1964; Foil and Ralston 1967; Hatchell 1970; Duffy and McClurkin 1974). Little work has been done with deciduous tree species except by Korstian (1927) and Broadfoot and Bonner (1966). The highly variable and sometimes conflicting results illustrate the need for research conducted under more controlled conditions.

There is an inverse relationship between the total porosity of a soil and its bulk density. The use of total porosity as an index of soil compaction is similar to the use of bulk density. However, since most movement of air and water takes place in the soil macropores, the distribution of pore sizes is of more interest than the total porosity. In general, soil aeration does not become limiting until the macroporosity is reduced to less than about 10 percent (Baver et al. 1972). In addition, a direct influence of pore size on the physical resistance which a soil offers a growing root has been suggested (Wiersum 1957).

The resistance of soil to penetration by a probing instrument (Penetrometer) is an integrated index of several soil properties including texture, structure, density, consistency, moisture content, and degree of compaction. It is an index of soil strength under the conditions of the measurement (Baver et al. 1972). Although the amount of penetration per unit force applied to a given soil will vary with the shape and kind of penetrometer used (Baver et al. 1972), the pattern of resistance to penetration is not affected. Also, penetrometer measurements have been shown to be highly correlated with standard laboratory determinations of soil strength (Taylor and Burnett 1964). Soil moisture appears to be the dominant factor influencing the strength of a given soil. There is a rapid increase in resistance with decreasing moisture (Eavis 1972).

Urban site rehabilitation on compacted soils often includes tree planting. The plants considered are usually nursery stock which is several years old and a few meters tall. The process used to select trees is given in a theoretical example by Rex (1976). Planting larger trees is labor-intensive and may well not be economically feasible for forest tracts surrounding cities. Consequently, alternative methods of urban forest establishment are needed, and direct seeding is one method that should be evaluated.

This study was conducted to evaluate the effects of two highly compacted urban soils on the establishment and early growth of several tree species grown from seed. The species chosen are either native or widely planted in the urbanized Northeast.

MATERIALS AND METHODS

Two medium-textured soils (silt loam and sandy loam) found in the Northeast urban corridor were used in this study. The silt loam was taken from an area classified as a poorly drained variant of the Nixon soil series and the sandy loam was taken from an area classified as part of the Lakewood soil series. Both soils were analyzed for physical and chemical properties:

Property	*Silt loam*	*Sandy loam*
Texture (%)		
Sand	22	66
Silt	64	26
Clay	14	8
pH	4.0	4.3
Organic matter (% dry weight)	7.52	3.60
Total nitrogen (% dry weight)	0.2090	0.0825
Available nutrients (ppm)		
Phosphorous	10	33
Potassium	30	18
Magnesium	20	16
Calcium	0.75	1.00

Cast acrylic tubes were used as growing containers. The tubes were 22.5 cm (8.9 inches) in length and had an inside diameter of 6.35 cm (2.5 inches). A perforated plate was secured to the bottom of each tube to allow for drainage.

Samples from each soil type were packed into individual containers to give four levels of bulk density: 1.2, 1.4, 1.6, and 1.8 $g \cdot cm^{-3}$. The soil was compacted in 1-cm (0.4-inch) increments in an attempt to create a soil column of uniform density. The total height of each soil column was 15.0 cm (5.9 inches).

Laboratory determinations of distribution of pore sizes, amount of water retained at ⅓ bar tension, and resistance of the soil to penetration at this moisture content were made for each combination of soil type-bulk density treatment (Table 1). Total porosity was separated into macro- and micro-porosity on the basis of the pore size that would hold water

Table 1.—Distribution of pore sizes and resistance to penetration of two soil types at different bulk densities

Bulk density	Pore Size		Resistance to penetration
	Macro	Micro	
$g \cdot cm^{-3}$	%		*bar*
	SILT LOAM		
1.2	24.2	30.5	1.4
1.4	19.0	28.2	2.5
1.6	16.8	22.8	4.7
1.8	14.6	17.5	9.4
	SANDY LOAM		
1.2	41.2	13.5	0.6
1.4	28.9	18.3	1.2
1.6	23.7	15.9	2.4
1.8	18.6	13.5	3.7

Macropores were defined as pores that would not retain water at ⅓ bar tension. Micropores retained water at ⅓ bar tension.

under ⅓ bar tension. Resistance of the soil to penetration was determined with a hand-held penetrometer at the low levels of compaction and with a Proctor[1] penetrometer at the high levels.

The genera *Picea* and *Pinus* are the most often planted conifers in the urban Northeast (Gerhold et al. 1975). Stratified seeds of pitch pine (*Pinus rigida* Mill.), Austrian pine (*Pinus nigra* Arnold), and Norway spruce (*Picea abies* (L.) Karst) were obtained from a state nursery, soaked in water for 24 hours, and treated with a fungicide solution to control damping off. For each species, 20 seeds were then sowed on top of the appropriate compacted soil column and covered with a thin layer of sphagnum moss to prevent desiccation and to offer further protection from damping off.

The containers were placed on a greenhouse bench in a randomized complete block design with 24 treatment combinations and 4 replications. Soil-water availability in each container was maintained near ⅓ bar of tension for the duration of the study (October to February). Natural day length was extended by artificial light for 4 hours at the end of each day. Ambient air temperatures in the greenhouse varied between 16° and 34°C (60° and 94°F), and the relative humidity ranged from 26 to 98 percent.

After 1 month, the percentage of radicles that successfully penetrated the soil was recorded for each container. The number of seedlings was then reduced to one per container. These seedlings were allowed to grow for an additional 3 months at which time they were harvested by carefully washing the soil from the roots.

RESULTS

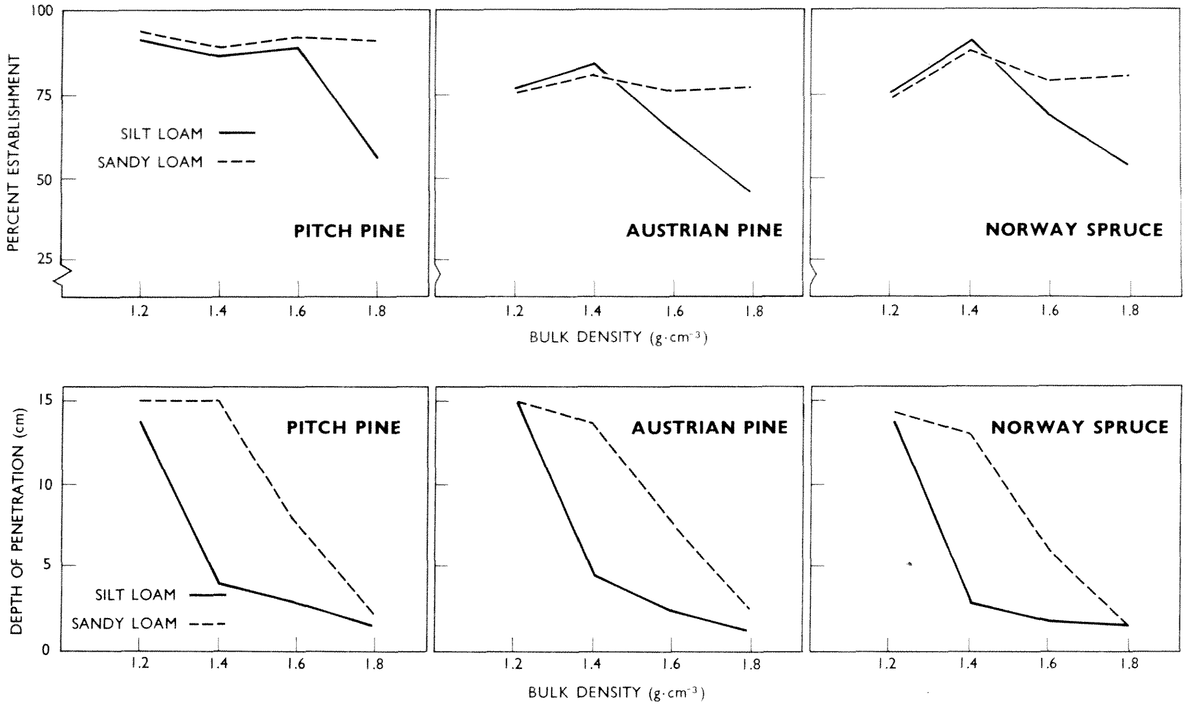
All data were subject to analysis of variance. The arcsine transformation (Zar 1974) was applied to percent establishment responses for purposes of statistical analysis. To make specific comparisons between certain treatment means, the honestly significant difference (hsd) multiple comparison procedure was used (Steel and Torrie 1960). All responses were reported as statistically significant at the $p < .05$ level.

Seedling establishment

The percent establishment of pitch pine seedlings was significantly greater than either Austrian pine or Norway spruce when averaged over soil type and bulk density; pitch pine establishment was 85 percent, Norway spruce was 76 percent, and Austrian pine was 72 percent. While there was a significant effect of bulk density and soil type on percent establishment, closer examination of the interaction of these two factors revealed that for each species only the response at a bulk density of 1.8 $g \cdot cm^{-3}$ on the silt loam was significantly different from the other soil type-bulk density treatment combinations (Fig. 1, upper). Although there appeared to be a tendency for pitch pine to become established more successfully at a bulk density of 1.6 $g \cdot cm^{-3}$ on the silt loam, this relationship was not statistically significant. Similarly, the observed tendency for Austrian pine and Norway spruce to attain optimum establishment at a bulk density of 1.4 $g \cdot cm^{-3}$ was not statistically significant.

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 1.—(*upper*) Effect of bulk density and soil type on the establishment of pitch pine, Austrian pine, and Norway spruce seedlings. (*lower*) Effect of bulk density and soil type on the maximum depth of root penetration of pitch pine, Austrian pine, and Norway spruce seedlings. The 95 percent hsd for comparison of bulk density treatment means = 2.415; for the soil type, treatment means = 1.832.



Depth of root penetration

Pitch pine and Austrian pine generally penetrated to a greater depth than Norway spruce on both soil types and at most bulk densities. Average depth of penetration for pitch pine was 7.7 cm, Austrian pine was 7.8 cm, and Norway spruce was 6.9 cm. There was no significant difference between the two pines in their average depth of root penetration.

As with establishment responses, there was a significant interaction between soil type and bulk density in their effect on depth of root penetration (Fig. 1, lower). The silt loam packed to a bulk density of 1.4 $g \cdot cm^{-3}$ markedly reduced the depth of root penetration for all three species. The depth of penetration on the sandy loam was not significantly reduced until a bulk density of 1.6 $g \cdot cm^{-3}$ was reached. Increasing the bulk density of the sandy loam to 1.8 $g \cdot cm^{-3}$ again resulted in a significant reduction in the depth of penetration for all three species. Although there were further reductions in the depth of root penetration on the silt loam at bulk densities above 1.4 $g \cdot cm^{-3}$, the largest reduction was clearly associated with an increase in bulk density from 1.2 to 1.4 $g \cdot cm^{-3}$. Figures 2 and 3 illustrate the effect of increasing bulk density on the growth of Austrian pine on the silt loam and sandy loam soils.

Resistance to penetration

Because soil resistance to penetration (soil strength) was confounded with the two soil types, it could not be formally incorporated in the analysis as an independent variable. Even without statistical analysis, however, the data suggest an additional interpretation of the results of this study.

In Table 2, establishment and root penetration data are arranged by values of resistance to penetration rather than by soil type and bulk density. Establishment appeared to be relatively consistent at resistance to penetration values of 4.7 bar or less. However, increas-

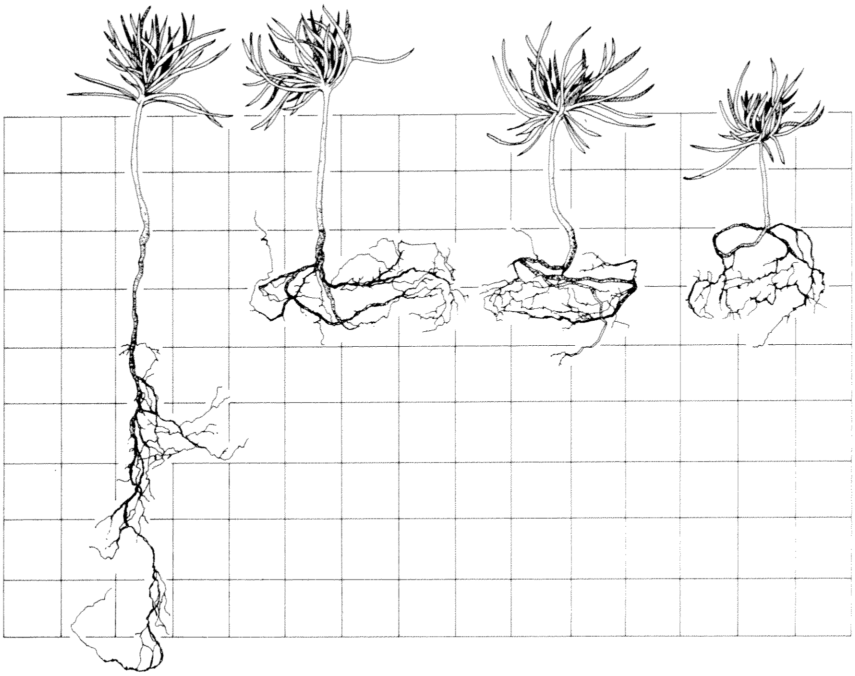


Figure 2.—Effect of bulk density at 1.2, 1.4, 1.6, and 1.8 g·cm^{-3} on Austrian pine seedling growth on a silt loam soil (2 cm grid).

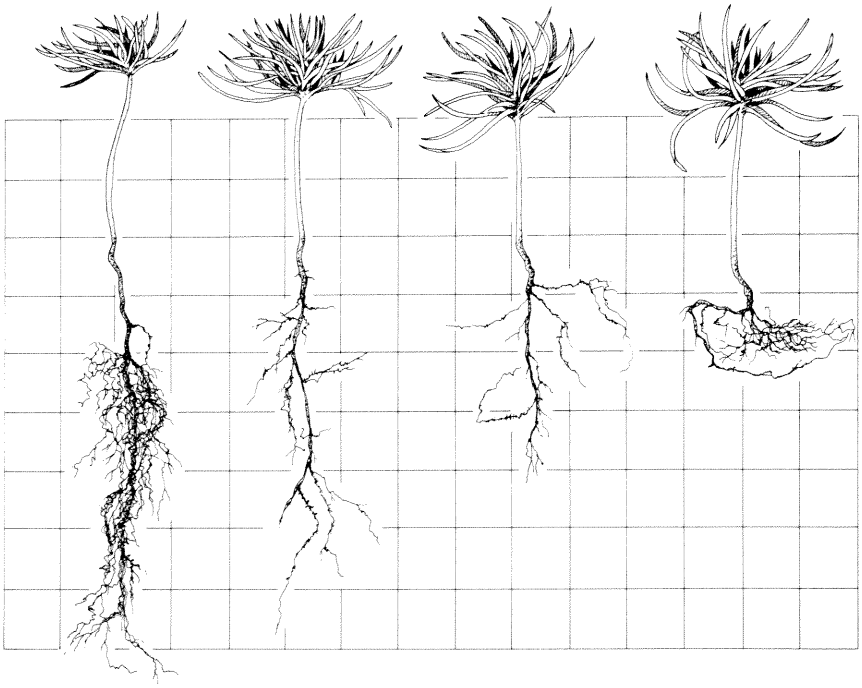


Figure 3.—Effect of bulk density at 1.2, 1.4, 1.6, and 1.8 g·cm^{-3} on Austrian pine seedling growth on sandy loam soil (2 cm grid).

Table 2.—Percent establishment and depth of root penetration of three forest tree species at different soil penetrabilities

Resistance to penetration (bar)	Pitch pine	Austrian pine	Norway spruce
	ESTABLISHMENT *(percent)*		
0.6	92.5	75.0	73.6
1.2	87.5	79.8	87.5
1.4	91.2	76.7	75.0
2.4	90.0	75.0	77.8
2.5	86.2	83.4	91.5
3.7	88.7	76.7	79.1
4.7	87.5	63.3	68.0
9.4	56.3	45.0	53.4
	ROOT PENETRATION *(cm)*		
0.6	15.0	16.0	14.3
1.2	15.0	13.7	13.0
1.4	13.6	15.0	13.8
2.4	7.6	7.7	6.2
2.5	3.9	4.6	2.8
3.7	2.2	2.6	1.6
4.7	2.8	2.5	1.5
9.4	1.4	1.2	1.5

ing the resistance to penetration from 4.7 to 9.4 bar resulted in reduced establishment for all three species. Once established, further root penetration was consistently restricted at values between 1.4 and 2.4 bar or more.

DISCUSSION AND CONCLUSIONS

Our results indicate that several common northeastern tree species may, under certain conditions, be successfully established on compacted soils. Only a bulk density of 1.8 $g{\cdot}cm^{-3}$ on a silt loam soil significantly reduced establishment. On a sandy loam soil, there was establishment even at a bulk density of 1.8 $g{\cdot}cm^{-3}$. Root penetration, however, was markedly reduced at a bulk density of 1.4 $g{\cdot}cm^{-3}$ on the silt loam and at 1.6 $g{\cdot}cm^{-3}$ on the sandy loam. Consequently, successful germination and establishment does not necessarily mean long-term survival. Trees that become established but develop shallow root systems may be less able to survive periods of moisture stress.

Forristall and Gessel (1955) and Minore et al. (1969) have reported bulk density values critical to the establishment and growth of trees. Pomeroy's (1949) study showed that establishment was poorer on soils with a greater clay fraction, and Foil and Ralston (1967) reported that tree root growth was negatively correlated with bulk density.

Although it is difficult to compare the results of other studies due to the differences in experimental conditions, it can be concluded that tree establishment and root growth were generally restricted at soil bulk densities between 1.25 and 1.60 $g{\cdot}cm^{-3}$. There was some difference among species and only rare success at bulk densities of 1.6 $g{\cdot}cm^{-3}$. In our study, tree establishment was unaffected by bulk density up to 1.6 or 1.8 $g{\cdot}cm^{-3}$, depending on the soil. Root growth was restricted at bulk densities of 1.4 or 1.6 $g{\cdot}cm^{-3}$, as has been reported for western species. Although there was slight indication that pitch pine responded best to the compact soils, large differences between species such as those reported by Minore et al. (1969) and Forristall and Gessel (1955) were not observed.

Although soil bulk density is commonly used as an index of soil compaction, characterizing a compact soil by its resistance to penetration, or some alternate expression of soil strength, may lead to a better understanding of the interaction of a growing root with its soil physical environment. As a growing root penetrates a soil, it displaces and compresses the surrounding soil. The soil resists deformation and the root must develop a pressure to overcome this resistance. Our results showed significantly reduced establishment at resistances greater than 4.7 bar, which suggests that tree roots can penetrate a soil with this resistance during establishment. The rate of root growth is also reduced as soil strength increases (Taylor and Gardner 1963). In our study, root growth decreased significantly when soil strength increased from 1.4 to 2.4 bar.

Three of the most frequently cited explanations for poor root growth in compact soils are: (1) insufficient aeration, (2) soil pores too small for roots to enter, and (3) a critical bulk density exceeded. However, the literature indicates that none of these explanations can fully account for reduced root growth on compacted soils because: (a) roots are unable to penetrate some highly compacted, coarse-textured soils where aeration is adequate, (b) plant roots can enter a nonporous substance if it is not too rigid (Taylor and Gardner 1960), and (c) many studies indicate that critical bulk density values are subject to wide variation because of strong interactions among bulk density, soil type, and moisture content. Results of this study appear to substantiate conclusions (a) and (c).

Additional conclusions can be inferred from the results of this investigation:

- Trees can successfully revegetate urban areas where soil compaction is a significant factor provided soil moisture is readily available.
- Establishment from seed can take place on soils with a bulk density up to 1.8 $g \cdot cm^{-3}$. Root penetration is restricted at lower bulk densities.
- The three species studied seemed to respond similarly to compact soil. The establishment of pitch pine was slightly better than Austrian pine and Norway spruce.
- Soil bulk density, while a valuable aid in interpreting soil conditions, may not be the best indicator of the effects of compact soils on tree establishment and growth.
- A measure of soil strength, such as resistance to penetration, may be a significant variable for determining soil compaction problems. Seedling establishment was uniform on soils where penetrability was less than 4.7 bar, but root penetration was reduced when penetrability exceeded the range of 1.4 to 2.4 bar. Penetrability values vary with soil moisture so these limits may be different at soil moisture tensions other than ⅓ bar.

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