ROOT DEVELOPMENT OF SIX-YEAR-OLD PONDEROSA PINE ESTABLISHED ON RECLAIMED MINE SOILS[1]

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The root systems of five ponderosa pine seedlings established on a 1981 research plot at Colstrip, Montana, were excavated using water pressure. An estimate of soil volume accessed was made from root tip location data that were collected during excavation. Shoot and root growth characteristics were measured. Ratios of these variables to each other and per unit soil volume describe the root system, distribution, and the relationship between the shoot and root for each seedling.

INTRODUCTION

Reforestation research conducted by the University of Montana School of Forestry, in cooperation with Western Energy Company at Colstrip, has resulted in establishment of young ponderosa pine plantations on a variety of reclaimed mine soils and sites.[3] These studies identified local seed trees whose progeny can avoid or withstand water stress when outplanted on regraded mine soils, providing the Western Energy Company with a tested seed source for future plantings. However, the mechanisms of drought resistance have not been identified. These mechanisms can be expressed phenotypically in a variety of ways: low shoot:root ratios (Ladiges 1974), increased leaf diffusion resistance (Kaufmann 1968), fewer stomata per unit surface area (Knauf and Bilan 1974), smaller needles with deeper stomatal pits, and deeper root systems with wider ranging laterals (van Buijtenan et al. 1976, Cannell et al. 1978).

Root egress and adequate root systems development for long-term survival of planted trees are undoubtedly important. Near Colstrip, Richardson (1981) found one-year-old natural seedlings with root:shoot length ratios as large as 16:1. Stout (1980) found lateral roots of mature pine that extended as far as 15 meters. These observations indicate that root factors can be a principal means of drought avoidance. That this rapid root elongation and root system development are key to successful seedling establishment on regraded mine soils was hypothesized and tested during the summer of 1986.

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[3]See "Studies to determine how to re-establish ponderosa pine on mine soils in Eastern Montana" by George M. Blake, in these proceedings.

OBJECTIVES

The objectives were to excavate established seedlings on reclaimed mine soils and describe crown and root growth patterns as measured by root dry weight, shoot dry weight, total root length, and shoot length. The extent of the seedling root system "in situ" was measured to estimate the soil volume accessed. Ratios of these variables to each other and per unit soil volume are used to describe the root system, distribution, and the relationship between shoot and root for each seedling.

METHODS

Root systems of five six-year-old ponderosa pine seedlings were washed free of the soil using a modification of Weaver's technique (Bohm 1979). The excavation utilized water under pressure to remove soil particles from the roots. The seedlings were established as part of the 1981 progeny test at Colstrip. Three seedlings were from family L-15 and two were from family S-5.

Prior to excavation of each seedling, shoot characteristics were noted and soil profile descriptions were made. Soil samples were taken at intervals along the initial trench wall until at least one spoil sample was taken. The crowns were then clipped five centimeters above ground level and bagged. A wooden frame was affixed to the seedling stem to support the root system during excavation and as an aid to measurement of root distribution.

Excavation started from the downslope sidewall of a backhoed trench, approximately 0.5 meter from the seedling, and ended at the farthest extension of the seedling's root system. Water was supplied from a 500-gallon portable tank equipped with a

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small pump. Water pressure was adjusted with nozzles.

Excavation of the seedling root system proceeded upslope. Beginning at the soil surface, water was sprayed sequentially so that vertically oriented layers of the soil were washed away and the roots exposed. Grass roots and plants were discarded. When the tip of a root was exposed, its position in the soil was located by measuring vertical distance to the surface, horizontal distance to the stem, and the degree of the offset angle. As excavation and location proceeded, the roots freed from the soil were clipped and bagged. When the entire seedling root system had been removed, the sample was washed and frozen for transport.

In the laboratory, root samples were thawed, cleaned of extraneous matter and stored in a 15-20% alcohol solution. Total root length of each sample was estimated using a simplified version of Newman's line intercept method (Tennant 1975). A two centimeter grid was used. Dry weight biomass of root and shoot samples were measured to the nearest 0.1 gram.

Soil horizons at each seedling location were sampled for laboratory analysis. Bulk density was estimated using core samples of known volume. Texture was determined by the hydrometer method. In addition, clod samples of extremely compacted soil were collected from selected horizons. Bulk density of these samples was determined by the clod method for comparison with other estimates.

Field data of root tip locations were converted to XYZ coordinates and separated into five centimeter depth intervals for each seedling. These data were graphed as scatter plots and the area for each five centimeter interval determined. Soil volume accessed was estimated by integration of these areas.

OBSERVATIONS AND RESULTS

Excavation of the seedlings began July 10, after budset, and was completed August 6. For each seedling, approximately 1.5 m^3 of soil was washed away using 350 gallons of water per day over a period of five days.

Each plot had three basic soil layers: topsoil, subsoil and spoil. The topsoil averaged 20-30 centimeters depth with loamy texture and low bulk density (1.1 g/cm^3). The subsoil/spoil interface averaged 50-70 centimeters depth. The subsoil had a sandy loam to clay loam texture with bulk densities averaging 1.3 g/cm^3. Clod samples were from this layer, and bulk density estimates using this method ranged from 1.77 to 1.87 g/cm^3, with an average of 1.83 g/cm^3. The spoil had a fractured rock component which the other horizons lacked. Texture was clay loam and bulk density was 1.4 g/cm^3.

Shoot heights for seedlings in family L-15 were 39, 47 and 52 centimeters, with depth of tap roots 94, 109 and 108 centimeters respectively. Shoot heights for seedlings in family S-5 were 52 and 64 centimeters, with depth of tap roots 89 and 90 centimeters respectively. This results in shoot:root length ratios for family L-15 of 0.40, 0.43 and 0.48; and ratios for family S-5 of 0.58 and 0.71. Shoot dry weights ranged from 30.8 grams to 113.5 grams and averaged 69.3 grams.

Soil volumes accessed for L-15 seedlings were 0.13, 0.18 and 0.25 m^3, while those for S-5 seedlings were 0.26 and 0.31 m^3. Total root lengths ranged from 143.9 meters to 292.0 meters, with an average length of 227.3 meters. Root dry weights were 13.0, 29.6 and 30.7 grams for the L-15 seedlings, and 25.5 and 34.4 grams for the S-5 seedlings.

The ratio of root biomass per unit soil volume describes the root system density. These ratios were 100, 123 and 164 g/m^3 for the L-16 seedlings, and 82 and 132 g/m^3 for the S-5 seedlings. Root length per unit soil volume describes the degree of system branching. These ratios are 894, 1107 and 1351 m/m^3 for family L-15, and 755 and 1123 m/m^3 for family S-5. The shoot:root biomass ratios for family L-15 were 2.14, 2.37 and 3.13; for family S-5, they were 1.73 and 3.30.

The root systems of all seedlings were well developed, with tap roots extending into the spoil to depths over one meter and laterals egressing from the seedling plug to lengths (straight line) over one meter. All seedling root systems had extensive mycorrhizal associations. The generalized root form was that of a flattened spheroid with laterals extending outward in the topsoil. The form narrowed through the subsoil and branched more upon entering the spoil. The majority of active root tips were in the spoil. Localized areas of soil compaction did not impede root growth and development. Soil layer interfaces had little to no effect on root growth.

CONCLUSIONS

Results of the study are summarized in Table 1. In 1985, family L-15 had 64% survival, while family S-5 had 45% survival. The sample size limits inferences concerning shoot and root growth. Interpretation of growth measurements reflect individual seedling response. For example, the largest seedling, S-5 #2, had the greatest shoot height, shoot weight, root weight and total root length. However, some trends were observed. The shoot:root length indexes and soil volume accessed were smaller for the L-15 seedlings than the S-5 seedlings. Personal observation during excavation indicated that the L-15 seedlings seemed to have deeper, more compact root systems. Conclusions concerning the mechanism of drought resistance and its genetic control can not be made at this time with these limited observations. The trends and the diversity of the root and shoot measurements for the sample strongly suggest a need for further research.

Table 1.--Growth characteristics and shoot:root relationships of six-year-old ponderosa pine outplanted on reclaimed mine soils at Colstrip.

Characteristic	Seedling Identification L-15 #1	L-15 #2	L-15 #3	S-5 #1	S-5 #2	Mean
Shoot height (cm)	39	47	52	52	64	51
Shoot weight (g)	30.8	65.6	92.7	44.1	113.5	69.3
Deepest root (cm)	97	109	108	89	90	99
Root weight (g)	13.0	30.7	29.6	25.5	34.4	26.6
Soil volume accessed (m^3)	0.13	0.25	0.18	0.31	0.26	0.23
Total root length (m)	143.9	223.3	243.3	234.0	292.0	227.3
Shoot:root biomass	2.37	2.14	3.13	1.73	3.30	2.53
Shoot:root length	0.40	0.43	0.48	0.58	0.71	0.52
Root weight: unit soil (g/m^3)	100	123	164	82	132	120
Root length: unit soil (m/m^3)	1107	894	1352	755	1123	1046
Longest lateral (cm)	84	74*	103	90*	81*	
Spoil depth (cm)	69	59	69	60	57	63

*Broken lateral root tip.

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