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ROOT PROFILES OF SOME NATIVE AND EXOTIC PLANT SPECIES IN SOUTHEASTERN IDAHO*

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REYNOLDS T. D. and FRALEY L., JR *Root profiles of some native and exotic plant species in southeastern Idaho*. ENVIRONMENTAL AND EXPERIMENTAL BOTANY 29, 241–248, 1989.—Root depth and lateral spread were determined for five plant species using radiotracer techniques. Depth data only were collected from two additional species. Big sagebrush (*Artemisia tridentata*), the deepest rooted species examined, had roots extending to a depth of 225 cm. Roots of Great Basin wildrye (*Leymus cinereus*), the deepest rooted grass, were detected to 200 cm. The maximum lateral spread of both of these species was 100 cm and occurred at a depth of 40 cm.

INTRODUCTION

OVER 1000 toxic waste disposal sites exist in the United States. Many of these are shallow land burial sites where a variety of chemical, biological, and/or nuclear waste materials are stored in pits or trenches covered with a mantle of soil. Maintaining the integrity of the soil covering over wastes is a primary concern for the long-term isolation of toxic materials from the environment.

Low-level radioactive waste materials are interred at the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex on the Idaho National Engineering Laboratory (INEL) in southeastern Idaho. Preserving the shielding capacity of the soil cover over waste buried at the SDA is integral to the waste management program to meet federal standards for the disposal of low-level waste.[25] These regulations require that following a century of institutional maintenance, monitoring and control, waste be effectively isolated from the environment for at least 500 years.[26]

Because the action of water and wind can erode soils and compromise waste management strategies, vegetation has been planted over portions of the SDA to stabilize the soil. An auxiliary benefit of vegetation growing on the trench cover is the withdrawal of moisture from the soil via evapotranspiration. Because potential evapotranspiration exceeds precipitation in arid areas, it is theoretically possible for plants to prevent water from percolating through the waste zone and carrying contaminants into ground water.[1]

Although plants growing on shallow land waste burial sites can be beneficial, they may also have negative impacts. The most obvious is the possibility that deep rooted plants will contact buried wastes or contaminated soils and translocate contaminants to the above-ground plant tissue where they could be dispersed by various biotic and abiotic events.

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Recently McKenzie *et al.*[17,18] and Kennedy *et al.*[13] identified the importance of considering biotic transport mechanisms in developing radioactive waste management strategies. Listed among the mechanisms were plant and animal intrusion which, coupled with active physical transport, rivaled the agricultural human intrusion scenario[25] in ultimate radionuclide dose to man.[13] Although burrow characteristics and some consequences of small mammal intrusion have been determined on the INEL,[3,4,21] completed studies on plants and plant processes on the SDA are few. Arthur[2] detected above background concentrations of radionuclides in the shoots of crested wheatgrass (*Agropyron cristatum*) and Russian thistle (*Salsola kali*) growing on the SDA and concluded that roots of these plants had encountered and translocated underground contaminants.

Nearly 400 native and exotic plant species occur on the INEL.[12] These include over 100 genera representing 57 families, which range from pioneer and early successional annuals to perennial climax species. After the loss of institutional maintenance and control of waste management areas on the INEL, some of these species will likely invade and become significant seral or terminal members of the floristic community at the SDA. Although root depths for about 70 plant species occurring on the INEL have been determined elsewhere, no root depth studies have been conducted under the climatic and edaphic conditions specific to the INEL. The objective of this study was to determine the root depths and lateral spread of some native and introduced plant species growing on the INEL.

MATERIALS AND METHODS

The INEL is an energy research and development reservation administered by the U.S. Department of Energy. The INEL occupies 2305 km^2 of sagebrush (*Artemisia* spp.)-dominated shrub-steppe rangeland on the Snake River Plain approximately 50 km west of Idaho Falls, Bonneville Co., Idaho. The soil catena is primarily aeolian sandy loam and loess derived from silicic volcanic and paleozoic rocks from the surrounding mountains.[19] The climate is characterized by hot, dry summers and cold winters with low total precipitation. The mean annual temperature is 5.6°C. Maximum and minimum temperatures recorded on site are 39°C and −44°C respectively. Annual precipitation averages 22.4 cm (range: 11.4–36.6 cm), with more than 35% usually falling from April to June. The frost-free period is about 90 days.

Rooting profile data were obtained indirectly by radiotracer techniques during the summers of 1984 and 1985. Root depth and lateral spread of mostly mature plants in a representative climax sagebrush-dominated community were determined in undisturbed soil in 1984. Depth data only were collected in two different disturbed soils in 1985. In 1984, two procedures were used to examine roots in soil adjacent to a large (*ca* 3 × 9 × 180 m) trench. One method involved spiking the soil with a radioactive tracer and subsequently examining the plant for above background levels of activity.[7,10] For the other method, above-ground portions of the plant were inoculated with the tracer solution and the soil containing plant roots was examined.

The first technique used an injection system[16] to introduce radioactive phosphorus, as orthophosphate in aqueous solution ($^{32}PO_4^{3-}$) at various depths into holes drilled into the bulk soil beyond the face of the trench. A power drill with a 1.25 cm diameter bit and extensions was used to auger 12 holes horizontally up to 2 m into one vertical wall of the trench. These injection holes were arranged in six pairs. Members of each pair were separated by a distance of 1.0 m. The uppermost pair of holes was drilled 40 cm below the soil surface. Successive pairs were drilled at 30–40 cm depth intervals 3 m to the right of the closest member of the previously drilled pair. A 3 m interval between pairs was selected because it was $\geqslant 2\times$ the reported spread of big sagebrush.[8,23,24] The result was a stair-step arrangement of pairs of holes descending to a depth of 190 cm. The sampling site was 3.5 × 24 m. This was the total area above the injection holes plus a 1.5 m boundary strip. A map was drawn which superimposed all the perennial plants and many of the annuals growing on the sampling site on the injection holes. This illustrated the horizontal relationship between the plants and the injection holes. Knowledge of this relationship allowed us to determine the mini-

mum rooting depths of plants growing directly above the injection holes, and also measure the lateral spread at different depths of many plants growing between injection holes.

The ^{32}P solution (*ca* 100 kBq/ml = 3 μCi/ml)[8] was introduced into the drilled holes by plastic tubing attached to the injection device. This injection tube was first inserted to the terminus of the hole and then slowly withdrawn. As it was withdrawn, 10 ml aliquots of the ^{32}P solution were injected at 30 cm intervals at distances of 200, 170, 140, 110, 80, and 50 cm from the face of the trench. Soil was then lightly tamped into the holes.

Two weeks after the ^{32}P injections were completed, two samples (leaf, meristem, and/or apical tissue) were collected from all perennial and many annual plants in the sampling area. Control samples were collected within 30 m of the study areas from four plants of each test species. Activity was determined by counting each sample twice for 4 min with a gross beta detector and plastic phosphor scintillation counting system (Model 4MB.02PP/3M, Bicron Corporation, Newbury, OH).* One-tailed *t*-tests[28] were used to compare activity values between control and experimental samples. The level of significance was $P \leqslant 0.05$. Our interpretation of significant results was conservative. That is, although it was possible for a plant growing over an injection site to translocate radiotracer from a neighboring site, we recorded depth and distances only to the nearest injection.

Radionuclide solutions were administered to above-ground plant tissues of two species: squirreltail bottlebrush (*Elymus elymoides*) and big sagebrush (*Artemisia tridentata*). For squirreltail bottlebrush, the tips of several leaf blades were severed and the cut ends of the blades still attached to the plant were inserted into a small vial containing about 3.7 MBq (100 μCi) of either ^{32}P or ^{86}Rb solution. To prevent tipping, the vial was taped inside a 10 ml beaker which was held stationary with a burette lamp. Leaves accumulated the radiotracer solution over a minimum of 24 hr.

For big sagebrush, five 6-mm diameter holes were drilled 6 mm into the larger stems. Each hole was inoculated with 100 μl of ^{32}P or ^{86}Rb solution (18.5 MBq/plant; 500 μCi). Additional water was added to fill the hole. Tape was placed over the hole to prevent evaporation or biotransport by insects. After 6 or 7 days, soil cores were taken on 25 and 50 cm radii (sagebrush) or 20 and 40 cm radii (squirreltail). Except where rocks prevented it, two cores were taken on both radii for each species to a depth of 2.0 m. Soil aliquots to be counted for radioactivity were removed at 25 cm depth intervals. Control samples were collected within 30 m of the sampling site. For plants inoculated with ^{32}P, soil samples were fired at 500°C, leached with sulfuric acid, filtered, and counted with a liquid scintillation counter (Model 3385, Packard Instrument Co., Downers Grove, IL) for Cerenkov radiation. Samples from soil cores taken near plants inoculated with ^{86}Rb were placed in a plastic bottle and counted on an 8 × 8 cm NaI(Tl) well detector (Beckman Gamma Model 310, Beckman Instrument Co., Fullerton, CA). A one-tailed *t*-test[28] ($P \leqslant 0.05$) was used to compare counting results between control and experimental samples.

In 1985 most of the root depth sampling was of mature plants growing in disturbed soil on the banks of an earthen canal excavated and abandoned prior to 1920 (B. Smaltz, Unpublished). Because the canal banks were approximately 2 m above grade, we were sampling roots growing in about 2 m of historically disturbed soil. Additional sampling for the grasses basin wildrye (*Leymus cinereus*) and standard crested wheatgrass (*Agropyron desertorum*) was conducted in an area that had been disturbed to a depth of about 50 cm by disking and drilling in 1960 (C. Hammond, pers. comm.). In both areas a 4- or, occasionally, 5-cm diameter bucket auger was used to core a vertical hole to a predetermined depth (25, 100, 150, 200, 225 or 250 cm) near a chosen plant. Approximately 100 ml of water were poured into the hole to stimulate root activity. Within 24 hr 5 ml of a $^{32}PO_4^{3-}$ solution with a concentration of 150 kBq/ml (5 μCi/ml) was introduced into the bottom of the hole via the injection system described by LOEWENSTEIN.[16] Holes were then backfilled with the original soil. Sixteen days after

* Use of trade names and supplies does not imply endorsement of commercial products.

the introduction of the radiotracer, two samples of leafy, meristem, or apical material were clipped from the crown of each subject plant. The collective activity in these tissues was counted with the gross beta, plastic phosphor scintillation system. Control samples were collected within 30 m of the experimental sites. Comparisons for each species at each depth were made with a one-tailed t-test[28] ($P \leqslant 0.05$).

Standard sedimentation techniques[5] were used to determine the particle size distribution for the soils in which roots were examined. Soil classification follows DUNN *et al.*[9] Nomenclature for plants follows HITCHCOCK and CRONQUIST[11] except for perennial members of the tribe Triticeae, which follows BARKWORTH *et al.*[6]

RESULTS AND DISCUSSION

Undisturbed soils in the area of the trench where root depths were determined in 1984 were predominately clayey silt. Disturbed soils comprising the earthen canal bank and the other area examined in 1985 were classified as loam and clay loam, respectively.

Root depths were documented for seven plant species: two native perennial shrubs (big sagebrush and green rabbitbrush—*Chrysothamnus viciflorus*), one native annual forb (birdbeak—*Cordylanthus ramosus*), and one exotic and three native perennial grasses (crested wheatgrass, basin wildrye, squirreltail bottle brush, and Indian ricegrass—*Oryzopsis hymenoides*). Some data on lateral root spread were collected for all species except Indian ricegrass and crested wheatgrass.

About 25% of the nearly 250 plant samples collected and analyzed had radiation levels significantly greater than background. Differences in horizontal and vertical root extension between the disturbed and undisturbed soils were generally slight for all plant species we examined (Table 1). Hence, for each species we illustrate the composite root profiles based on all individual plants sampled from both kinds of soils (Fig. 1). Rather than averages or other indices of central tendency, figures present the maximum lateral spread that we determined at any one depth. Because of the design of our sampling, this value is most likely conservative for many depths.

Roots of big sagebrush were detected to 225 cm below ground level in the undisturbed soil. This was the deepest root penetration of any of the seven species examined. In disturbed soil, big sagebrush roots were found at a depth of 200 cm, but not at 250 cm. KLEPPER *et al.*[15] found roots of this species as deep as 250 cm during excavations of disturbed soils in Washington. Other investigators have generally found Wyoming big sagebrush roots shallower than 183 cm.[22–24] We recorded the maximum lateral spread of 100 cm at a depth of 40 cm (Fig. 1). TABLER[24] and STURGES[23] hand excavated sagebrush roots in Wyoming at 2900 m and 730 m elevation, respectively. Both recorded a maximum lateral spread of 152 cm.

Green rabbitbrush roots were found at 190 cm and 100 cm in undisturbed and disturbed soils, respectively. Although roots of the congener *C. nauseosus* were found at depths of 240 cm in disturbed soils in Washington,[14] KLEPPER *et al.*[15] found roots of green rabbitbrush no deeper than 160 cm. We recorded the maximum lateral spread of 40 cm at a depth of 80 cm (Fig. 1). We could find no additional information on roots of this species for comparison.

Basin wildrye roots were deeper than all other species except big sagebrush. Roots were detected at all depths examined up to and including 200 cm on the shallowly disturbed area. Roots were not detected below 160 cm in undisturbed soils. The maximum lateral spread of 100 cm was recorded at a depth of 40 cm. Published data on the root profile of this species are lacking for comparison. WEAVER[27] reported roots of the congener *L. (Elymus) canadensis* in Nebraska loess extending to 56 cm, with a lateral spread of 51 cm.

Squirreltail bottlebrush roots were detected only to a depth of 100 cm, but this species may actually have deeper roots. Because of subsurface basalt, we were unable to sample for roots of this species at depths greater than 100 cm. The 40 cm maximum lateral root extension was recorded at depths of 25, 50, 60, and 100 cm (Fig. 1). Although this species is often associated with early and mid-serial stages of secondary succession, it was not present on the disturbed study sites. No literature accounts addressing squirreltail root profiles were found for comparison.

Table 1. Lateral root spread (cm) at various depths, determined by radiotracer of some native and exotic semi-arid land plant species in undisturbed (U) and disturbed (D) soils on the Idaho National Engineering Laboratory

Root depth (cm)	Plant species*													
	ARTR		CHVI2		LECI		ELEL		CORA		ORHY		AGDE	
	U	D	U	D	U	D	U	D	U	D	U	D	U	D
25	50†	P‡	—§	P	—	P	40	—	—	—	—	P	—	P
40	100	—	20	—	100	—	—	—	80	—	—	—	—	—
50	50	—	—	—	—	—	40†	—	—	—	—	—	—	—
60	—	—	—	—	—	—	40†	—	—	—	—	—	—	—
65	50†	—	—	P	—	—	—	—	—	—	—	—	—	—
75	25†	—	—	—	—	—	—	—	—	—	—	—	—	—
80	71	—	40	—	60	—	—	—	50	—	—	—	—	—
100	25	—	—	P	—	P	40†	—	—	—	—	P	—	P
105	50	—	—	—	—	—	—	—	50	—	—	—	—	—
130	45	—	—	—	—	—	—	—	—	—	—	—	—	—
150	—	P	—	N‖	—	P	—	—	—	—	—	P	—	P
160	86	—	30	—	P	—	—	—	36	—	—	—	—	—
190	N	—	30	—	—	—	—	—	N	—	—	—	—	—
200	50†	P	N	P	—	P	—	—	—	—	—	N	—	N
225	25†	—	—	—	—	—	—	—	—	—	—	N	—	—
250	—	N	—	N	—	N	—	—	—	—	—	—	—	N

* Abbreviations follow the scheme of ASHERIN (1973): ARTR = *Artemisia tridentata*, CHVI2 = *Chrysothamous vicidiflorus*, LECI = *Leymus cinereus*, ELEL = *Elymus elymoides*, ORHY = *Oryzopsis hymenoides*, CORA- = *Cordylanthus ramosus*, AGDE = *Agropyron desertorum*.

† Depths determined using ^{86}Rb; all others determined with ^{32}P.

‡ P = Roots present at this depth, but lateral spread not determined.

§ — = Rooting not examined at this depth.

‖ N = Rooting examined, but none found at this depth.

No published accounts regarding roots were found for birdbeak. We recorded roots at a maximum depth of 160 cm, with the maximum lateral spread of 80 cm found beneath the soil surface (Fig. 1).

Roots of Indian ricegrass and standard crested wheatgrass were both found to depths of 150 cm in disturbed soils. This was slightly deeper than the 122 cm reported for the former species,[15] and slightly shallower than the 183 cm reported for the latter (Foxx and Tierney, Unpublished). Lateral spread was not determined for either of these species.

With the exception of basin wildrye, shrubs generally had deeper roots than grasses or forbs. For both shrub species, roots were found at slightly greater depths in the undisturbed soil than in the disturbed soil of the canal bank. We had anticipated deeper roots in the disturbed soil. ANDERSON *et al.*[1] reported that sagebrush, wildrye, and crested wheatgrass had roots as deep as 2.2 m (the deepest they could measure) within 2 years of transplanting in disturbed soils. Because rooting depth is thought to be limited by the depth of the wetting front,[20] our depth data for disturbed and undisturbed soils most likely were related to soil moisture differences between the study areas brought about by differences in physical characteristics. During construction, the canal bank soils had been compacted and shaped to reduce infiltration and erosion, and likely promoted runoff. Hence, lower soil moisture was probable. Although we did not quantify soil moisture content, we did note much drier soil conditions on the canal bank while we were hand augering injection holes.

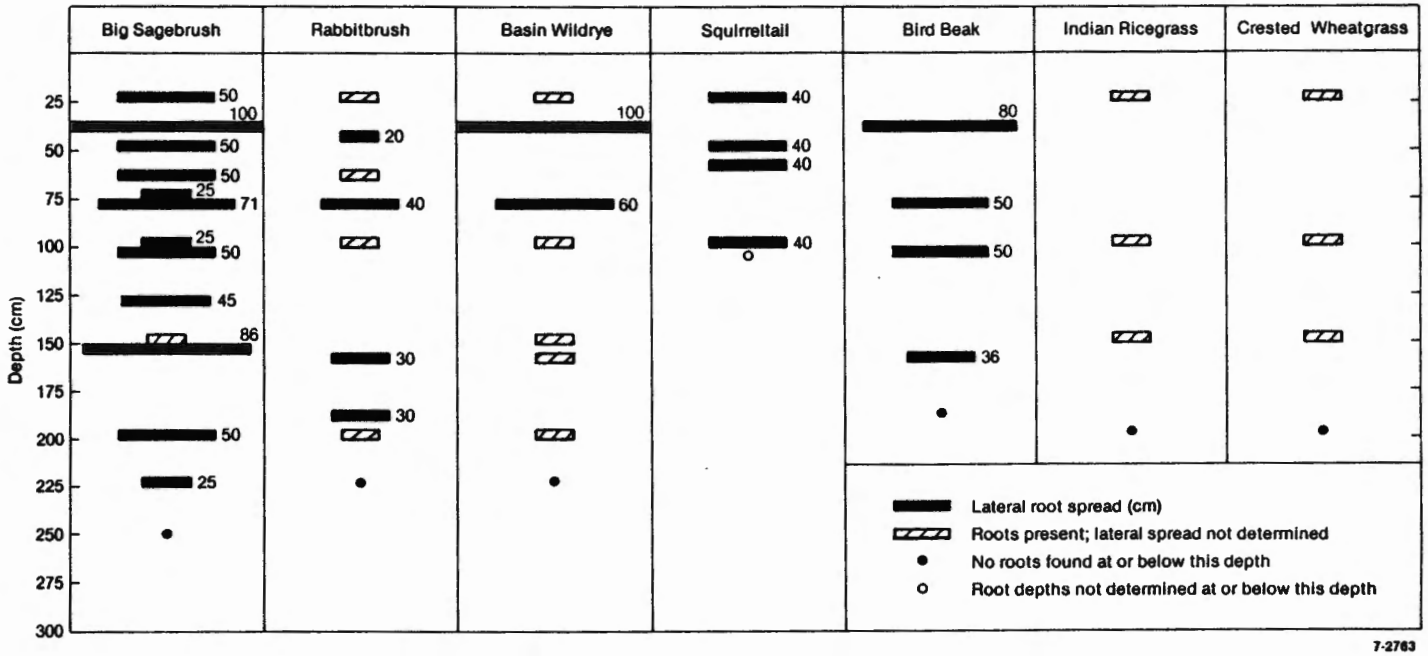

FIG. 1. Root depth and lateral spread (cm): composite profiles from disturbed and undisturbed sampling areas for seven plant species on the Idaho National Engineering Laboratory.

Whether the species we examined will have more extensive root systems in disturbed soils that are used to cover toxic waste materials is unknown. Contouring and some soil compaction has been performed at the Subsurface Disposal Area at the INEL. These practices may control the depth of the wetting front and, hence, the concomitant rooting depths. ANDERSON *et al.*[1] indicated that a 1.4 m soil cover was adequate to store the maximum annual precipitation occurring during the non-growing months (October–May) at the INEL. However, soil depressions which allow abnormal snow or rain accumulation, near surface basalt flows resulting in lateral water movement to adjacent areas, and extraordinary precipitation events may confound normal soil recharge dynamics and result in deeper percolation. Our data show that in certain situations, several plant species indeed send roots deeper than 1.4 m. Consequently, although a 1.4 m soil cover may generally prevent water percolation into waste zones at the SDA, that soil thickness alone may not be enough to reliably and consistently prevent root intrusion.

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