Root Distribution in 1- to 48-Year-Old Strip-mine Spoils in Southeastern Montana

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Abstract

A study was initiated in June 1976 at Colstrip, Montana, to determine root distribution to 1- to 48-year-old stripmine spoils and in undisturbed soils of the area. Root distribution was determined using three methods: (1) soil profile description, (2) root biomass, and (3) radioactive tracer (^{32}P). Results from all three methods showed that old spoils had substantially more roots below 100 cm than new spoils or undisturbed soils. Differences in root abundance were attributed to species composition. Old spoils were dominated by half-shrubs, while new spoils and undisturbed soils were dominated by grasses and forbs. Root biomass in the upper 100 cm of new spoils was 44% less than in undisturbed soils and 43% less than in old spoils. Maximum rooting depths of 15 important plant species were determined using the radioactive tracer method.

Roots are important in soil development (Hole and Nielsen 1970), soil water relations (Hillel and Talpaz 1976), and plant nutrient uptake; however, little attention is given to roots in current studies of stripmined land reclamation. Jones et al. (1975) related the rooting patterns of different forage grasses to organic matter accumulation in Eastern minesoils, but no reference to roots in Western minesoils was found in the literature. Instead, emphasis was usually placed on above-ground portions of plants (DePuit et al. 1978; Ries et al. 1975).

Potential applications of information on root systems in strip-mined lands include: (1) evaluation of reclamation success, (2) determination of the required depth of burial for toxic overburden material based on maximum rooting depth, and (3) identification of critical factors affecting root development. To provide needed information on plant root systems in spoils, a study was initiated in June 1976 at Colstrip, Montana, to determine root distribution in 1- to 48-year-old stripmine spoils and undisturbed soils of the surrounding area.

Methods

Study Area

The study area is located in the unglaciated portion of the Missouri Plateau in southeastern Montana near Colstrip, approximately 150 km east of Billings. Climate in the Colstrip area is semiarid with temperature extremes ranging from −36°C in winter to 42°C in summer. The area has a frost-free period of 120−140 days. Precipitation averages 40 cm, much of which occurs as rain in April, May, and June (NOAA n.d.). The area is characterized by valleys,

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rolling hills, and scattered sandstone and porcelanite outcrops. Soils have developed in sedimentary rocks, residuum, and colluvium consisting of sandstone, siltstone, and shale. Dominant soils in the area include Ustic Torriorthents, Borollic Camborthids, and Aridic Haploborolls. Natural vegetation is of the Eastern Montana Ponderosa Pine Savannah type (Payne 1973). Woodland vegetation is restricted to higher elevation, north-exposed and/or high relief sites, and consists of ponderosa pine (*Pinus ponderosa*) overstory and bluebunch wheatgrass (*Agropyron spicatum*), Idaho fescue (*Festuca idahoensis*), and little bluestem (*Schizachyrium scoparium*) understory. Grassland vegetation is characteristic of northern mixed prairie, with major species including western wheatgrass (*Agropyron smithii*), thickspike wheatgrass (*Agropyron dasystachyum*), green needlegrass (*Stipa viridula*), prairie Junegrass (*Koeleria cristata*), and needle-and-thread (*Stipa comata*). Degraded sites are dominated by increaser or invader plant species, chiefly big sagebrush (*Artemisia tridentata*), silver sagebrush (*A. cana*), and annual bromegrasses (*Bromus* spp.).

Mine spoils of two age classes are present in the study area: old (44 to 48 years old) and new (1 to 6 years old). Old spoils consist of excess sandy overburden deposited in nearly level platforms. Old spoils have been revegetated through natural succession and are dominated by half-shrubs, primarily false tarragon sagewort (*Artemisia dracunculus*). Other ungraded spoils in the Colstrip area have steeper slopes and higher clay content than the old spoils used in this study. New spoils were regraded, topsoiled, and seeded with introduced and native perennial grasses, biennial and perennial legumes, grains, and shrubs. The research sites on new spoils were dominated by perennial grasses and forbs: crested wheatgrass (*Agropyron cristatum*), smooth brome (*Bromus inermis*), tall wheatgrass (*Agropyron elongatum*), yellow sweetclover (*Melilotus officinalis*), and alfalfa (*Medicago sativa*). Research sites on native range were dominated by perennial grasses and forbs, needle-and-thread, western wheatgrass, purple prairie-clover (*Petalostemon purpureum*), and yellow sweetclover.

Experimental Design

Twelve study sites were selected in the area surrounding Colstrip: four each on old spoils, new spoils, and undisturbed soils. Root distribution was characterized using three methods: (1) standard soil profile descriptions (Soil Survey Staff 1975), (2) root biomass, and (3) radioactive tracer (^{32}P).

Size and abundance of roots were included in standard soil profile descriptions made by experienced soil scientists (Soil Survey Staff 1975) in August 1976. Root biomass was measured using fifteen 1,000 cm^3 soil samples that were collected on September 15, 1976, from each soil profile at three depths: 5−15, 45−55, and 95−105 cm. Samples were hand-washed over a 30 mesh (1 mm) sieve until roots were relatively free of soil. Roots were oven-dried at 60°C to a constant weight, weighed, then oven-dried at 600°C for 24 hours, and reweighed. Root biomass values were reported on an ash-free basis.

Root distribution was estimated *in situ* by injecting plant available ^{32}P into the soil and monitoring radioactivity in above-ground portions of plants during the 1976 and 1977 growing seasons (Fox and Lipps 1964). Radiophosphorus injections were made at six depths (15, 46, 76, 107, 137, and 183 cm) in separate holes at each site on June 11, 1976. Since a few plants had taken up ^{32}P from 183 cm in 1976, a deeper ^{32}P injection depth (214 cm) was added when injections were made the second year on April 6, 1977. Three replicate ^{32}P injections were made in 1977 at each depth on the site from each soil group shown to have the greatest root biomass. The remaining sites received a single ^{32}P injection at each depth as in 1976.

Three aluminum access tubes were installed in each study plot. A neutron probe was used to measure water content at monthly intervals to a depth of 240 cm from June 9, 1976, to July 31, 1977.

Results and Discussion

Profile Description

Most plant roots described were fine (1 to 2 mm) in each soil profile (Soil Survey Staff 1975). Table 1 shows the distribution and abundance of fine roots in old and new spoils, and in undisturbed soils. Fine plant roots were equally abundant in the upper 10 cm of spoils and undisturbed soils. Root abundance decreased between 10 and 50 cm, especially in new spoils. Few fine roots were observed between 50 and 100 cm in new spoils and undisturbed soils, while in old spoils fine roots were common at this depth. Old spoils had more fine roots below 100 cm than did undisturbed soils and new spoils.

The lower quantity in new spoils compared to undisturbed soils, both of which were dominated by grasses and forbs, was probably due to the relatively short time that new spoils had been vegetated. The abundance of roots at lower soil depths in old spoils may have been due to the dominance of deep-rooted half shrubs.

Table 1. Abundance of fine (1-2 mm in diameter) roots in mine soils and native soils of Colstrip study area (Soil Survey Staff, 1975).

Depth (cm)	Native soils	Old spoils	New spoils
0−10	C−M	C−M	C−M
10−50	C	C	F−C
50−100	F	F−C	F
>100	−	F−C	−

M: Many, >100 roots dm^{-2}
C: Common, 10−100 roots dm^{-2}
F: Few, <1-roots $d.^{-2}$

Biomass

Root biomass at three soil depths is shown in Table 2. These data were similar to those obtained from the soil profile descriptions. Root biomass was less in new spoils than in old spoils, particularly at the 45−55 and 95−105 cm depth intervals. Root biomass in the upper 100 cm of new mine soils was 44% less than in undisturbed soils and 43% less than in old mine soils. A gradual increase in root biomass during the first

Table 2. Root biomass (kg/m^3) at three depths in old and new minesoils and native soils near Colstrip, Montana.

		Depth (cm)		
Soil group	Site/Age	5−15	45−55	95−105
Native soils	Chinook−1	3.59	.56	.04
	Yamac−2	1.57	.00	.00
	Kobar−4	2.01	.29	.17
	Reidel−6	4.29	.06	.00
	Chinook−8	3.35	.48	.19
	Mean	2.96	.28	.08
Old Mine-soils	1928−5	3.36	.74	.63
	1928−7	2.18	.09	.04
	1928−9	1.68	.12	.05
	1929−10	2.94	.61	.17
	1948−3	3.30	.27	.13
	Mean	2.69	.37	.20
New mine-soils	1969−14	1.66	.38	.10
	1970−15	1.74	.11	.13
	1972−13	2.23	.10	.02
	1973−12	1.45	.06	.04
	1975−11	1.23	.01	.00
	Mean	1.66	.13	.06

6 years after reseeding occurred in the new spoils. Root biomass in 4- to 6-year-old spoils is only slightly less than in undisturbed soils.

Root biomass data were fit to a logarithmic function relating root biomass to soil depth:

$$W(Z) = W(O)e^{-\alpha Z}$$

where W(Z) is root weight at depth Z, W(O) is root weight at depth zero, and α is the slope of the line. Slopes (α) for old spoils, new spoils, and undisturbed soils were −.0258, −.0377, and −.0374, respectively. A comparison of these slopes showed that root biomass decreased less with soil depth in old spoils than in new spoils and undisturbed soils. The fact that new spoils and undisturbed soils had nearly identical slopes supported the premise that root distribution was mainly a function of vegetation type.

Root biomass values at 45−55 and 95−105 cm in new spoils and undisturbed soils were highly correlated with water use during the period from April 4 to June 5, 1977, suggesting that grasses and forbs obtained a substantial amount of soil water from these soil depths during that time period. Similar correlations for old spoils were not statistically significant. Correlations of water use with root biomass at 5−15 cm were not significant for old spoils, new spoils or undisturbed soils, indicating that factors other than root biomass such as evaporation, ratio of conducting roots to feeder roots, or other factors influenced water use near the soil surface.

Radioactive Tracer (^{32}P)

The total number of radioactive plants growing within 1 m of ^{32}P injection holes are presented in Table 3. On June 26, radioactivity was detected only in plants growing above ^{32}P injections at 15, 46, and 76 cm in the soil profiles. More plants had taken up ^{32}P from 76 cm in undisturbed soils and new spoils than in old spoils. This trend suggests that grasses and forbs, which dominated new spoils and undisturbed soils, had more active roots deeper in the soil early in the growing season than the dominant vegetation on old spoils (half-shrubs and annual grasses).

The total number of radioactive plants detected on new spoils, undisturbed soils, and old spoils increased from June 26 to July 15 (Table 3). Most of the additional plants on new spoils and undisturbed soils were growing above ^{32}P injections in the upper 76 cm while many of the additional plants on old spoils were taking up ^{32}P from 107 and 137 cm. This pattern of ^{32}P uptake indicated that roots below 76 cm in old spoils became active later in the growing season, while plant roots in new spoils and undisturbed soils did not.

Near the end of the growing season, from July 15 to August 9, the total number of radioactive plants detected on old spoils and undisturbed soils decreased while the number on new spoils increased. In general, plants obtaining ^{32}P from the upper 76 cm decreased, while the number obtaining ^{32}P below 76 cm increased between July 15 and August 9. The decrease in ^{32}P uptake from the upper 76 cm probably resulted from a depletion of water and reduced nutrient availability from these depths. As a result, deep roots, below 76 cm, became more important in supplying water and nutrients for plant growth. Although less than 5% of all roots occurred below 76 cm in these soils, deep roots were apparently extremely important for plant growth late in the growing season.

Table 3. Total number of radioactive plants detected in 1976 at Colstrip study area.

^{32}P	Native soils			Old spoils			New spoils		
Injection	Date								
depth (cm)	6/26	7/15	8/9	6/26	7/15	8/9	6/26	7/15	8/9
15	4	5	6	4	6	3	5	6	5
46	4	7	5	4	4	2	2	6	4
76	4	5	2	1	6	4	4	4	3
107					4	2			2
137		1	2		4	3			1
183		1							2

The total radioactive plants on three soil groups were similar: new spoils had 44, old spoils 46, and undisturbed soils 46. This was unexpected since other measures of root abundance showed new spoils to have less roots than old spoils and undisturbed soils. The relative distribution of roots obtained by the ^{32}P uptake method concurs with data from the other two methods, however. The percentage of radioactive plants which obtained ^{32}P from below 76 cm in old spoils, new spoils, and undisturbed soils was 25.3, 12.8, and 8.7% respectively, indicating that deep roots were most abundant in old spoils.

The results obtained in 1977 concur with those collected during the 1976 growing season. There were no significant differences between the number of radioactive plants or root distribution. However, plants appeared to take up ^{32}P from lower soil depths in 1976 than in 1977. Less precipitation occurred in spring 1977 than in spring 1976; thus, differences in precipitation could have influenced root activity during the 2 years.

Maximum detectable rooting depths were determined for 15 plant species in the Colstrip area during the 2-year ^{32}P investigation (Table 4). Generally, plants found on both undisturbed soils and mine soils had greater rooting depths in undisturbed soils. However, because old spoils were dominated by deep rooting plant species, in particular false tarragon sagewort, there was a greater abundance of roots in the lower depths of old spoils compared to new spoils and undisturbed soils. Of the 180 radioactive plants monitored during this investigation, less than 10% took up ^{32}P from below 107 cm.

Summary and Conclusions

Three methods were used to characterize root distribution: (1) standard soil profile description, (2) root biomass, and (3) radioactive tracer (^{32}P). Results from all methods indicated that

Table 4. Maximum detectable rooting depths of important species in the Colstrip study area.

Plant species	Depth (cm)
Crested wheatgrass (*Agropyron cristatum*)	76
Thickspike wheatgrass (*Agropyron dasystachyum*)	46
Tall wheatgrass (*Agropyron elongatum*)	183
Western wheatgrass (*Agropyron smithii*)	107
Slender wheatgrass (*Agropyron trachycaulum*)	107
Western ragweed (*Ambrosia psilostachya*)	137
False Tarragon Sagewort (*Artemisia dracunculus*)	137
Blue grama (*Bouteloua gracilis*)	76
Smooth brome (*Bromus inermis*)	76
Prairie sandreed (*Calamovilfa longifolia*)	46
Prairie junegrass (*Koeleria cristata*)	76
Alfalfa (*Medicago sativa*)	76
Yellow sweetclover (*Melilotus officinalis*)	137
Purple prairie-clover (*Petalostemon purpureum*)	76
Needle and thread (*Stipa comata*)	183

old spoils had more roots below approximately 100 cm than new spoils or undisturbed soils. These differences were attributed to differences in species composition. Old spoils were dominated by half-shrubs while new spoils and undisturbed soils were dominated by grasses and forbs. The soil profile description and root biomass methods showed that plant roots were less abundant in new spoils below soil depths of 10 cm than they were in old spoils or undisturbed soils. In addition, root biomass in the upper 100 cm of new spoils was 43% less in undisturbed soils and 40% less than in old spoils. It appears that at least 5 years will be required for root abundance to approach pre-mining levels in the Colstrip area.

Range plants in the Colstrip area commonly have roots deeper than 100 cm while some species have roots as deep as 183 cm. Roots below 76 cm are extremely important in providing water and nutrients for plant growth late in the growing season even though they comprise 5% or less of total root biomass. Reclamation programs and policies should, therefore, be aimed at building soils which provide at least a 2 m root zone free of toxic overburden and compacted layers.

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