GRASS ROOT PENETRATION IN TOSCO II PROCESSED OIL SHALE[1]

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Abstract.--Root penetration of several grass species was studied on TOSCO II processed oil shale in the Colony Shale Oil plots in Garfield County, Colorado. Substrate treatments examined included bare processed shale, six inches of soil over processed shale, 24 inches of soil over processed shale, and soil control. Species examined included Agropyron desertorum, Agropyron elongatum, Agropyron smithii, Agropyron riparium, Elymus junceus, and Sporobolus airoides. Results showed that roots had penetrated processed shale to the depths normal for grass roots. However, roots in processed shale were usually fewer in number but thicker so that biomass was equal to or greater than that of the same species, at the same depth, in the soil control. In the 6-inch soil over processed shale treatment, the roots in the uppermost processed shale (immediately beneath the soil) were the most numerous observed in any processed shale.

INTRODUCTION

This paper details the results of studies conducted for the purpose of documenting the penetration of plant roots in TOSCO II processed shale revegetation plots at the Colony Shale Oil Project, located in and around the Middle Fork of Parachute Creek in Garfield County, Colorado.

Work on revegetation of disturbances to be associated with development of the Colony Shale Oil Project began as early as 1965 (Bloch and Kilburn 1973). Between 1965 and 1973, several experimental revegetation plots were established in and around the Colony property. In these plots, variation in species planting, topsoil depths, and moisture regime were incorporated. Evaluation of the plot results has taken place over the years based on plant canopy cover and density (see Baker and Duffield 1973; Baker 1974, 1975, 1976; Buckner and Kline 1977; Merino and Kline 1978; Camp Dresser & McKee Inc. 1979).

Data from years 1977 through 1980 comprise a detailed body of quantitative information, the 1977 through 1979 portions of which have been used in an evaluation of trends in plant cover (Camp Dresser & McKee Inc. 1980).

Prior to the study reported here, nothing was known about the subsurface plant growth patterns in the Colony revegetation plots. It became important, as actual oil shale development neared, to have some information on the patterns of root penetration under different cultural conditions.

Studies reported here were designed to show patterns of root penetration as they vary with (1) presence or absence of topsoil, (2) thickness of topsoil in topsoil treatments, (3) individual species, (4) native versus introduced species, and (5) xeric (dry) versus mesic (relatively moist) growing conditions.

Root penetration is seldom studied; the major effort put forth on this subject in the western U.S. has been the work of the late Professor John Weaver of the University of Nebraska. Using this "monolith" method (Weaver and Darland 1949a, 1949b; Weaver and Voight 1950), he and his co-workers painstakingly excavated whole soil profiles and returned them to the laboratory for careful removal of soil from roots by hand washing. These very labor intensive studies provide the bulk of what is reliably known about root penetration of western plants.

The present study had more of a reconnaissance nature; excavation and separation of entire root systems was deemed unnecessarily labor intensive for the purpose of general patterns and extents of rooting among the varying species and treatments in the processed shale revegetation plots.

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The 1969 Box Plots, 1971 Species Plots, and 1972 Species Plots are in the valley of Middle Fork and East Middle Fork of Parachute Creek, at elevations of about 6,000 feet. The Plateau Plots are located on the top of the Roan Plateau, a short distance north of East Middle Fork of Parachute Creek, at an elevation of 8,000 feet.

METHODS

Species Selection

The following grass species occurring in the indicated plots and substrate treatments were selected for study of their root penetration:

Agropyron desertorum (Crested Wheatgrass)
- Plateau Plots
  - processed shale
  - 6 inches of soil over processed shale
- 1972 Plots
  - processed shale
  - 6 inches of soil over processed shale
  - 24 inches of soil over processed shale
- 1971 Plots
  - processed shale
- Box Plots
  - processed shale

Agropyron elongatum (Tall Wheatgrass)
- Plateau Plots
  - processed shale
  - 6 inches of soil over procesed shale
- 1971 Plots
  - processed shale
- Box Plots
  - processed shale

Agropyron smithii (Western Wheatgrass)
- Plateau Plots
  - processed shale
  - 6 inches of soil over processed shale
  - native soil
- 1971 Plots
  - processed shale

Agropyron riparium (Streambank Wheatgrass)
- Plateau Plots
  - processed shale
- 1972 Plots
  - processed shale
  - 6 inches of soil over processed shale
  - native soil

Elymus junceus (Russian Wildrye)
- Plateau Plots
  - processed shale
- 1972 Plots
  - processed shale

Sporobolus airoides (Alkali Sacaton)
- 1972 Plots
  - processed shale
  - 6 inches of soil over processed shale
  - native soil

Trench Excavation

For each of these 24 species/plot/treatment combinations, a trench was excavated in such a fashion so as to result in exposure of the root system of the subject plant on a flat vertical face at least 45 cm (18 in.) wide. Depth of excavation was determined by the processed shale treatments; in these treatments, excavation continued to a depth of 20 to 30 cm (8 to 12 in.) below the limit of procesed shale or to a depth of 115 cm (45 in.). The latter maximum depth was deemed satisfactory to observe virtually all the root systems of the subject grasses and keep the disturbed area associated with the trench and spoil to a minimum. Deeper excavation would have necessitated a substantially larger working trench and would have produced much more spoil.

Trenches were located after careful consideration of the location which not only have access to a good example of the subject species on the treatment, but also minimized adverse effects on the surrounding portions of the experimental plots. Spoil from the trenches was placed on plastic sheets for this purpose. Although some impact on the experimental plots from root studies was inevitable, effects were thought mainly to be cosmetic, and scientific value of the plots remained intact.

Emergent Root Count Sampling

Roots emerging from the trench wall within a 10 cm by 10 cm (4 in. by 4 in.) quadrat were counted at 15-cm (6-in.) intervals down the exposed profile. All visible roots were counted; roots branching beyond their point of emergence were counted as one root.

Root Biomass Sampling

Root biomass was also sampled at 15-cm (6-in.) depth increments; samples were removed using a soil bulk density tube measuring 35 mm (1.4 in.) inside diameter, and 130 mm (5.1 in.) in length with a volume of 125.1 cm^3. The bulk density tube was driven horizontally into the trench face at the prescribed intervals). Where possible, contents of three tube samples were composited at each depth. Severely rocky conditions in the subsoils sometimes allowed only two or even one properly filled tube sample to be recovered at a particular depth. Samples removed from bulk density tubes were placed in sealed plastic bags and returned to the laboratory and weighed to 0.1 g, then oven-dried (105°C, 24 hours), and weighed again to 0.1 g. The difference (moisture) was divided by the oven-dry weight to calculate soil moisture percentage for each sample. The oven-dry weights were also divided by field volume to derive field bulk density data.

After oven drying and weighing, the soil samples were immersed in water to which approximately 10 g per liter Calgon had been added as a dispersant. The samples were allowed to soak for two days with stirring twice each day. At the end of this period, the floating root material was removed and the soil which had settled was strained to remove non-floating roots. This process was laborious and tedious but is thought to have allowed rather complete recovery of the majority of roots. The finest end of the spectrum of root size was inevitably the least perfectly recovered, but the weight of material lost was probably not substantial. Separated root material was then oven-dried (105°C, 24 hours) and weighed to 0.1 mg.

RESULTS AND DISCUSSION

Root Penetration As Affected By Topsoil Depth

As these data are examined, it is necessary to keep in mind that this study was not designed to provide statistical proof for any conclusions. Rather, it was an exploratory study in which suggestions are sought using nothing more sophisticated than averages.

Presence Versus Absence of Topsoil

Examination of table 1 reveals that the grasses rooted in processed shale alone tended to have fewer emergent roots than in topsoil or topsoil over processed shale treatments at corresponding depths. The exceptions to this general trend are mainly found in the Box Plots where rooting was very abundant. The processed shale in the Box Plots was qualitatively the easiest of any processed shale to excavate and was the most moist. The Box Plots are also the oldest plots, suggesting that time elapsed might have affected root number.

By contrast, there is a tendency for root biomass in the processed shale treatments to equal or exceed that of topsoil treatments (table 2). As g/dm^3 values totaled for all sampled depths within a profile, the 14 processed shale profiles averaged 9.45 grams, the three native soil profiles averaged 6.83 grams, and the seven topdressed profiles averaged 8.87 grams.

In terms of rooting depth, there seems to be no substantial difference between processed shale and topsoil treatments. Generally, there is not a very large portion of the total root number or biomass below about 50 cm (18 in.), although in alkali sacaton and western wheatgrass, major rooting extends a bit deeper. The actual maximum depth of penetration of the last fractions of a percent of a given root system was not and could not be determined during this study. It is likely, based on the extensive excavation/washing studies of Weaver (1920, 1930, 1958a) that there were a few very small roots penetrating to 150 or 200 cm (5 to 6.5 ft) or deeper. However, as shown by Weaver's studies, the root systems of upland grasses are typically most densely developed in the upper soil, mainly the upper 45 to 75 cm (1.5 to 2.5 ft). It is in this upper soil zone that these dryland species have their water absorptive capacity concentrated, apparently in order to maximize access to soil moisture provided by limited precipitation.

Of the 24 profiles examined, 17 had 90 percent of the profile root biomass in the upper 50 cm (18 in.) and 23 had 90 percent of the profile root biomass in the upper 65 cm (24 in.), regardless of presence or absence of topsoil. Thus, the presence or absence of topsoil has not affected the basic distribution of roots. Increased root number accompanies the presence of topsoil; root biomass is unaffected or slightly less in topsoil treatments.

Depth of Topsoil

The four species which were observed on six inches of soil over processed shale and on thicker topsoil treatment (either 24 inches or native soil) were crested wheatgrass, streambank wheatgrass, western wheatgrass, and alkali sacaton. Of these species, crested wheatgrass and western wheatgrass had more emergent roots on topsoil (table 1) than on the 6-inch soil treatments, while for the other two species, the opposite was true. As regards root biomass, streambank wheatgrass and alkali sacaton had values much greater for the 6-inch soil treatment than the thick topsoil treatments. For crested wheatgrass and western wheatgrass, root biomass values were approximately equal for both treatments.

Total Rooting Depth

In nearly all cases, rooting at the lowest sampled profile depths approached zero. The major exception to this was western wheatgrass which showed substantial rooting at the bottom of many of the examined profiles. However, as discussed below, western wheatgrass still had the highest average root biomass per profile of any of the examined species.

Data in tables 1 and 2 suggest that highest root numbers occur on the treatments with topsoil involved and highest root biomass occurs on the treatments with processed shale involved. Highest root number and biomass together occurred on the 6-inch soil over processed shale treatment.

Root Penetration of Native Versus Introduced Species

Of the six plant species observed in this study, three are introduced, namely crested wheatgrass, tall wheatgrass, and Russian wildrye. The remaining three were native species, namely streambank wheatgrass, western wheatgrass, and alkali sacaton.

Rooting patterns vary by both species and treatment, and no general all-encompassing patterns of native versus introduced species are discernible. Even considering only one treatment at a time, the variability fails to segregate native from introduced species. Over all treatments, western wheatgrass (native) has fewest roots and greatest biomass and tall wheatgrass (introduced) and Russian wildrye (introduced) have the most roots and second and third greatest biomass values. These comparisons may be misleading since tall wheatgrass and Russian wildrye were not examined in all treatments.

If species performance within individual treatments is examined it can be seen that on processed shale, streambank wheatgrass, western wheatgrass, and alkali sacaton (all natives) have the fewest roots per profile. Streambank wheatgrass and alkali sacaton have the lowest root biomass per profile while tall wheatgrass (introduced) and western wheatgrass have the highest biomass per profile values.

On the 6 inches of soil over processed shale treatments, total root numbers are higher for all species tested, as mentioned previously. Tall wheatgrass (introduced) and streambank wheatgrass (native) have the highest root number values while both have moderate root biomass values. Crested wheatgrass (introduced) and alkali sacaton (native) on the 6-inch soil treatment both had moderate root biomass values.

On the 24 inches of soil or native soil treatments, crested wheatgrass (introduced) had the highest number of roots per profile, but a fairly low profile root biomass. Western wheatgrass (native) had a moderate number of roots per profile on native soil but had by far the highest root biomass per profile. Streambank wheatgrass (native) and alkali sacaton (native) had low profile root count values and low profile root biomass values.

As for trends over all treatments, western wheatgrass (native) had the lowest average root count per profile and by far the highest root biomass per profile of species examined in all three treatments. Of the other three species examined in all treatments, crested wheatgrass (introduced), streambank wheatgrass (native), and alkali sacaton (native) had more moderate root count and biomass values.

If average root number per profile is compared for all treatments, introduced species have the highest values. However, since number of observations per treatment and species vary, the validity of this conclusion would be questionable.

One other conclusion regarding native/introduced species may be suggested by the data in tables 1 and 2. It appears that native species are tending to have greater root biomass than introduced species on the six inches of soil over processed shale treatment.

Root Penetration in Mesic Versus Xeric Sites

To arrive at a comparison of root penetration as affected by general moisture regime, the plots were arranged along an assumed moisture gradient, from wettest to driest as follows: Plateau Plots, 1971 Plots, Box Plots, and 1972 Plots. The Plateau Plots were assumed to be the moistest because they are some 2,000 feet (610 m) higher in elevation and are located in mountain shrub vegetation which clearly reflects moister conditions than the sagebrush-Indian ricegrass characterizing the area where the other plots are located. Of the low elevation plots, the 1971 Plots are doubtless the wettest because they are located very close to the foot of the steep north-facing slope in East Middle Fork Canyon and receive frequent shade not only from the slope but also an overhanging cottonwood tree. The Box Plots are located in the bottom of Upper Middle Fork Canyon with no particular protection and no south-facing aspect. The 1972 Plots are located on the south-facing slopes along the north side of East Middle Fork Canyon and have probably the most severe exposure of any of the plots.

Upon review of the root count data of table 1, it can be seen that for each of the five species occurring in the Plateau and other plots, the root count values are consistently lower in the Plateau Plot samples. As regards root biomass (table 2), introduced species tend to have higher biomass in the drier plots, while native species had higher values in the moister plots.

Total root count and total root biomass per profile show that the moistest plots (Plateau and 1971 plots) have fewest emergent roots and the most root biomass. Again, however, the reality of this conclusion may be questioned because not all species occur in all plots.

With regard to patterns of rooting depths, all the wheatgrasses showed denser rooting higher in the profile in the moister plots. In the drier plots, rooting was concentrated deeper in the profile although total depth of rooting was not substantially different. In Russian wildrye, this pattern was reversed.

General Discussion

Examination of bulk density data showed that processed shale is often denser in the upper levels than topsoil, probably mainly because of organic matter incorporated in the surface topsoil material. At moderate depth, the soil material typically has higher bulk density than processed shale, while at greater depth, the processed shale is sometimes very compact with values approaching those for native soil of the same depths.

Percent soil moisture data showed a tendency for processed shale to have higher moisture content than soil, except sometimes in surface soils where organic content probably is responsible for higher moisture retention capacity. The biological meaning of these figures is not known because without 15-bar moisture percentage data for each sample, it is not known how much of the moisture is available. In general, however, processed shale has a uniform fine texture in the fine silt and clay range and would be expected to have greater moisture retention capacity and also a higher 15-bar (permanent wilting) percentage. This means that the higher moisture percentage of the processed shale may not necessarily represent greater available moisture. However, especially at greater depth, the difference between moisture contents of processed shale and soil (C horizon material) becomes large and would suggest the presence of more available moisture in the processed shale, despite its probable higher permanent wilting percentage.

CONCLUSIONS

Results of these root penetration studies showed no dramatic differences between rooting patterns of species or substrate treatments. This was to be expected since the grass species chosen for study were among those which had been the most successful in the plots, implying successful establishment of their root systems.

The success of grasses on processed shale and on soil over processed shale treatments in these test plots does not apparently relate to primary rooting in native substrate material below the processed shale layer. Although in some cases roots do penetrate so deep as to enter such substrate, the overall rooting patterns are typical of grasses (see Weaver 1920, 1930; Weaver and Darland 1949b) with over 90 percent of root number and biomass within the upper 30 to 45 cm (12 to 18 in.).

Bulk density data suggest that high compaction is not a problem in TOSCO II processed shale. There seems to be no physical impedence to root or moisture penetration in processed shale. There is a recurring pattern of an inverse relationship between emergent root number and root biomass. Generally, in processed shale treatments, fewer emergent roots were observable but more root biomass was present, especially when compared for the same species in the same plot.

The reason for this inverse relation is not known but two explanations seem plausible. First, the roots in processed shale may be primarily larger roots having sufficient absorptive capacity without abundant fine development because of greater profile moisture content. Second, adverse effects of processed shale salt content may be minimized by minimizing root surface area. Thus, roots in processed shale have a lower surface area to volume ratio than roots in native soil. These reasons could be complementary in that more abundant moisture could make up for loss of absorptive capacity which concurrently reduces salt stress. It is known that under saline conditions, the root systems of crop plants are dwarfed (Buckman and Brady 1969). Further, it has been observed that under salinity stress, the roots of wheat are thinner and less branched, and the cell walls are thicker (Udovenko et al. 1975). All of the above suggests that the decrease in root branching and possibly the increased biomass (due to thicker cell walls) observed in processed shale represent response to the high salt content of the processed shale.

In the treatments with topsoil overlying processed shale, the density of rooting in the uppermost processed shale was typically much higher than was observed in any other processed shale.

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Table 1. -- Emergent root count data,
Colony Shale Oil Revegetation Plots,
November 1980

Species: *Agropyron desertorum* (Crested Wheatgrass)
Substrate: Processed Shale

Plot:	Plateau	1972(E)	1971	Box Plots
Depth (cm)	No. of emergent roots per 100 cm^2 (Percent of Profile)			
0-10	[1] 77 (59.2%)	52 (38.0%)	83 (29.2%)	142 (53.8%)
15-25	42 (32.3%)	36 (26.3%)	61 (21.5%)	85 (32.2%)
30-40	7 (5.4%)	24 (17.5%)	48 (16.9%)	22 (8.3%)
45-55	[2] 1 (0.8%)	25 (18.2%)	51 (18.0%)	12 (4.5%)
60-70	3 (2.3%)	0 (0%)	26 (9.2%)	2 (0.8%)
75-85	-	-	15 (5.2%)	1 (0.3%)
90-100	-	-	-	0 (0%)
105-115	-	-	-	0 (0%)
Profile Total	130	137	284	264

Species: *Agropyron desertorum* (Crested Wheatgrass)

Substrate:	6" Soil over Shale		24" Soil over Shale
Plot:	Plateau	1972W	1972E
Depth (cm)	No. of emergent roots per 100 cm^2 (Percent of Profile)		
0-10	86 (44.6%)	78 (28.5%)	93 (27.7%)
15-25	83 (43.0%)	92 (33.6%)	86 (25.5%)
30-40	19 (9.8%)	59 (21.6%)	108 (32.0%)
45-55	2 (1.0%)	28 (10.3%)	48 (14.2%)
60-70	3 (1.6%)	13 (4.8%)	2 (0.6%)
75-85	-	1 (0.4%)	0 (0%)
90-100	-	1 (0.4%)	0 (0%)
105-115	-	1 (0.4%)	0 (0%)
Profile Total	193	273	337

Species: *Agropyron elongatum* (Tall Wheatgrass)

Substrate:	Processed Shale			6" Soil Over Shale
Plot:	Plateau	1971	Box Plots	Plateau
Depth (cm)	No. of emergent roots per 100 cm^2 (Percent of Profile)			
0-10	34 (37.4%)	33 (25.2%)	90 (25.0%)	135 (47.3%)
15-25	34 (37.4%)	35 (26.7%)	113 (31.4%)	56 (19.6%)
30-40	18 (19.7%)	51 (38.9%)	95 (26.4%)	65 (22.7%)
45-55	4 (4.4%)	2 (1.5%)	31 (8.6%)	11 (3.8%)
60-70	1 (1.1%)	10 (7.7%)	16 (4.4%)	19 (6.6%)
75-85	-	-	13 (3.6%)	-
90-100	-	-	2 (0.6%)	-
105-115	-	-	0 (0%)	-
Profile Total	91	131	360	286

Species: *Agropyron riparium* (Streambank Wheatgrass)

Substrate:	Processed Shale		6" Soil Over Shale	Native Soil
Plot:	Plateau	1972W	1972W	1972E
Depth (cm)	No. of emergent roots per 100 cm^2 (Percent of Profile)			
0-10	28 (35.9%)	70 (32.7%)	90 (33.3%)	38 (19.4%)
15-25	30 (38.5%)	57 (26.6%)	88 (32.6%)	65 (33.1%)
30-40	15 (19.2%)	41 (19.2%)	49 (18.1%)	74 (37.7%)
45-55	3 (3.8%)	31 (14.5%)	29 (10.7%)	3 (1.5%)
60-70	2 (2.6%)	15 (7.0%)	5 (1.9%)	5 (2.6%)
75-85	-	0 (0%)	4 (1.5%)	5 (2.6%)
90-100	-	0 (0%)	4 (1.5%)	6 (3.1%)
105-115	-	0 (0%)	1 (0.4%)	-
Profile Total	78	214	270	196

Species: *Agropyron smithii* (Western Wheatgrass)

Substrate:	Processed Shale		6" Soil Over Shale	Native Soil
Plot:	Plateau	1971	Plateau	Plateau
Depth (cm)	No. of emergent roots per 100 cm^2 (Percent of Profile)			
0-10	34 (45.9%)	82 (49.4%)	123 (60.8%)	130 (51.4%)
15-25	26 (35.2%)	32 (19.3%)	69 (34.2%)	84 (33.2%)
30-40	6 (8.1%)	20 (12.0%)	1 (0.5%)	25 (9.9%)
45-55	8 (10.8%)	9 (5.4%)	9 (4.5%)	14 (5.5%)
60-70	-	22 (13.3%)	-	-
75-85	-	1 (0.6%)	-	-
90-100	-	-	-	-
105-115	-	-	-	-
Profile Total	74	165	182	253

Species: *Elymus junceus* (Russian Wildrye)
Substrate: Processed Shale

Plot:	Plateau	1972W
Depth (cm)	No. of emergent roots per 100 cm^2 (Percent of Profile)	
0-10	57 (36.1%)	130 (51.0%)
15-25	30 (19.0%)	61 (23.9%)
30-40	20 (12.7%)	32 (12.5%)
45-55	16 (10.1%)	20 (7.8%)
60-70	0 (0%)	10 (3.9%)
75-85	25 (15.8%)	2 (0.9%)
90-100	10 (6.3%)	-
105-115	-	-
Profile Total	158	255

Species: *Sporobolus airoides* (Alkali Sacaton)

Substrate:	Processed Shale	6" Soil Over Shale	Native Soil
Plot:	1972E	1972W	1972E
Depth (cm)	No. of emergent roots per 100 cm^2 (Percent of Profile)		
0-10	87 (64.1%)	26 (11.0%)	25 (13.4%)
15-25	26 (19.1%)	83 (35.1%)	65 (34.9%)
30-40	0 (0%)	33 (13.9%)	15 (8.1%)
45-55	1 (0.7%)	34 (14.3%)	29 (15.6%)
60-70	12 (8.8%)	36 (15.2%)	20 (10.8%)
75-85	1 (0.7%)	20 (8.4%)	32 (17.2%)
90-100	9 (6.6%)	3 (1.3%)	
105-115	0 (0%)	2 (0.8%)	
Profile Total	136	237	186

[1] Processed oil shale

[2] Soil or subsoil

Table 2. -- Root biomass data, Colony Shale Oil Revegetation Plots, November 1980

Species: *Agropyron desertorum* (Crested Wheatgrass)
Substrate: Processed Shale

Plot:	Plateau	1972(E)	1971	Box Plots
Depth (cm)	g oven-dry roots per dm^3 soil (Percent of Profile)			
5	[1] 5.54 (71.0%)	9.76 (82.1%)	4.87 (67.8%)	3.01 (56.1%)
15	1.48 (19.0%)	0.64 (5.4%)	0.93 (13.0%)	1.60 (29.9%)
30	0.45 (5.8%)	0.98 (8.2%)	0.65 (9.1%)	0.55 (10.3%)
45	0.03 (0.4%)	0.25 (2.1%)	0.38 (5.3%)	0.15 (2.8%)
60	[2] 0.09 (0.2%)	0.26 (2.2%)	0.16 (2.2%)	0.05 (0.9%)
75	0.20 (2.6%)	–	0.19 (2.6%)	<0.01 (0%)
90	–	–	–	<0.01 (0%)
105	–	–	–	–
Profile Total	7.79	11.89	7.18	5.36

Species: *Agropyron desertorum* (Crested Wheatgrass)

Substrate:	6" Soil Over Shale		24" Soil Over Shale
Plot:	Plateau	1972W	1972E
Depth (cm)	g oven-dry roots per dm^3 soil (Percent of Profile)		
5	5.29 (73.4%)	3.11 (49.4%)	3.86 (66.8%)
15	1.43 (19.9%)	1.46 (23.2%)	0.44 (7.6%)
30	0.28 (3.9%)	0.72 (11.5%)	0.75 (13.0%)
45	<0.01 (–)	0.23 (3.7%)	0.63 (10.9%)
60	0.15 (2.1%)	0.56 (8.9%)	0.10 (1.7%)
75	0.05 (0.7%)	0.11 (1.8%)	0 (0%)
90	–	0.08 (1.3%)	0 (0%)
105	–	0.01 (0.2%)	0 (0%)
Profile Total	7.20	6.28	5.78

Species: *Agropyron elongatum* (Tall Wheatgrass)

Substrate:	Processed Shale			6" Soil Over Shale
Plot:	Plateau	1971	Box Plots	Plateau
Depth (cm)	g oven-dry roots per dm^3 soil (Percent of Profile)			
5	2.78 (33.2%)	20.95 (91.2%)	6.22 (50.7%)	3.54 (39.8%)
15	1.57 (18.8%)	1.17 (5.1%)	3.16 (25.8%)	1.98 (22.2%)
30	0.82 (9.8%)	0.69 (3.0%)	1.61 (13.1%)	1.07 (12.0%)
45	1.14 (13.6%)	0.08 (0.3%)	0.56 (4.6%)	0.93 (10.4%)
60	2.02 (24.1%)	<0.01 (0%)	0.15 (1.2%)	1.13 (12.7%)
75	0.04 (0.5%)	0.10 (0.4%)	0.51 (4.2%)	0.26 (2.9%)
90	–	–	0.02 (0.2%)	–
105	–	–	0.02 (0.2%)	–
Profile Total	8.37	22.99	12.25	8.91

Species: *Agropyron riparium* (Streambank Wheatgrass)

Substrate:	Processed Shale		6" Soil Over Shale	Native Soil
Plot:	Plateau	1972W	1972W	1972
Depth (cm)	g oven-dry roots per dm^3 soil (Percent of Profile)			
5	2.82 (50.9%)	2.16 (64.9%)	6.12 (66.9%)	1.66 (54.3%)
15	0.91 (16.4%)	0.51 (15.3%)	0.39 (4.3%)	0.57 (18.6%)
30	0.77 (13.9%)	0.29 (8.7%)	1.27 (13.9%)	0.26 (8.5%)
45	0.11 (2.0%)	0.09 (2.7%)	0.93 (10.2%)	0.20 (6.5%)
60	0.93 (16.8%)	0.11 (3.3%)	0.35 (3.8%)	0.05 (1.6%)
75	–	0.10 (3.0%)	0.03 (0.3%)	0.32 (10.5%)
90	–	0.01 (0.3%)	0.03 (0.3%)	–
105	–	0.06 (1.8%)	0.03 (0.3%)	–
Profile Total	5.54	3.33	9.15	3.06

Species: *Agropyron smithii* (Western Wheatgrass)

Substrate:	Processed Shale		6" Soil Over Shale	Native Soil
Plot:	Plateau	1971	Plateau	Plateau
Depth (cm)	g oven-dry roots per dm^3 soil (Percent of Profile)			
5	9.75 (64.1%)	9.47 (73.8%)	6.69 (58.4%)	6.93 (57.6%)
15	2.28 (15.0%)	2.71 (21.1%)	2.05 (17.9%)	0.73 (6.1%)
30	2.14 (14.1%)	0.28 (2.2%)	1.98 (17.3%)	2.90 (24.1%)
45	0.90 (5.9%)	0.27 (2.1%)	0.42 (3.7%)	1.27 (10.6%)
60	0.13 (0.9%)	0.05 (0.4%)	0.31 (2.7%)	0.25 (2.1%)
75	–	0.05 (0.4%)	–	–
90	–	–	–	–
105	–	–	–	–
Profile Total	15.20	12.83	11.45	12.03

Species: *Elymus junceus* (Russian Wildrye)
Substrate: Processed Shale

Plot:	Plateau	1972W
Depth (cm)	g oven-dry roots per dm^3 soil (Percent of Profile)	
5	3.87 (50.7%)	6.46 (72.8%)
15	0.84 (11.0%)	1.25 (14.1%)
30	0.38 (5.0%)	0.58 (6.5%)
45	0.37 (4.9%)	0.34 (3.8%)
60	0.18 (2.4%)	0.03 (0.3%)
75	0.09 (1.2%)	0.08 (0.9%)
90	1.89 (24.8%)	0.12 (1.4%)
105	–	0.02 (0.2%)
Profile Total	7.62	8.88

Species: *Sporobolus airoides* (Alkali Sacaton)

Substrate:	Processed Shale	6" Soil Over Shale	Native Soil
Plot:	1972E	1972W	1972E
Depth (cm)	g oven-dry roots per dm^3 soil (Percent of Profile)		
5	2.76 (92.1%)	8.12 (60.8%)	2.55 (47.1%)
15	0.03 (1.0%)	2.15 (16.1%)	1.84 (34.0%)
30	0 (0.0%)	1.08 (8.1%)	0.21 (3.9%)
45	0.01 (0.3%)	0.77 (5.8%)	0.22 (4.1%)
60	0.10 (3.3%)	0.39 (2.9%)	0.59 (10.9%)
75	0.02 (0.7%)	0.37 (2.8%)	–
90	0.04 (1.3%)	0.44 (3.3%)	–
105	0.04 (1.3%)	0.03 (0.2%)	–
Profile Total	3.00	13.35	5.41

[1] Processed oil shale

[2] Soil or subsoil