Competition between cheatgrass and two native species after fire: Implications from observations and measurements of root distribution

GRACIELA MELGOZA AND ROBERT S. NOWAK

Abstract

During 1987 and 1988, a study was conducted in northern Nevada to examine root growth of cheatgrass (Bromus tectorum L.) and 2 native species, needle-and-thread grass (Stipa comata Trin. & Rupr.) and rabbitbrush (Chrysothamnus viscidiflorus (Hook.) Nutt.), after fire. Profile wall maps were used to determine the distribution of roots in the soil profile for the 2 native species. Root morphology differed between the 2 species: needle-and-thread grass had a flabelliform root system, whereas rabbitbrush had a main tap root with 2-4 major lateral roots. Although total root biomass differed between the species, more than half the root biomass was in the top 0.2 m of soil for both needle-and-thread grass and rabbitbrush. Measurements of root length density were used to evaluate the interaction between root systems of cheatgrass and the native species. Root production of plots with only the native species was not significantly different from that of plots with both the native species and cheatgrass for the first 2 years after fire. Furthermore, root production of plots in a recently burned area was also not significantly different from that in an area burned 12 years prior to our study. Thus, root systems of these species rapidly occupied the belowground space and competed for soil resources after fire, and the presence of cheatgrass partially reduced the root systems of the native species.

Key Words: Chrysothamnus viscidiflorus, rabbitbrush, Stipa comata, needle-and-thread grass, root length density, root biomass

Roots are the primary structures that plants have to utilize belowground resources, but very little is known about how root growth responds after fires. Fire affects the availability of soil resources (Britton and Ralphs 1979). Burning converts plant biomass into ash, which releases nutrients (Raison 1979, Wright and Bailey 1982). Soil water is influenced by fire (Dunham 1966, Wright and Bailey 1982), increasing or decreasing the amount of water present in the soil (Anderson et al. 1970). Soil resources are also freed by the loss of fire-intolerant plants. Root growth and density are coupled to uptake of nutrients (Silberbush and Barber 1985, Caldwell and Richards 1986) and water (Caldwell 1976, Lascano and van Bavel 1984). Thus, root growth after fire may influence how plants exploit newly available nutrients and acquire sufficient moisture for enhanced shoot growth (Raison 1979, Hadley and Kieckhefer 1963).

Cheatgrass (Bromus tectorum L.) is well adapted to frequent fire and often dominates plant communities after fire (Young et al. 1969). The success of cheatgrass after fire has often been attributed to its capability to rapidly occupy the open spaces created by the removal of fire-intolerant plants (Stewart and Hull 1949, Kleinmedson and Smith 1964, Young et al. 1969, Young and Evans 1973, Thill et al. 1984). Recently, we found that cheatgrass also successfully competes for soil water with native species that survive the fire (Melgoza et al. 1990). This capability of cheatgrass to successfully compete with its neighbors may be related to differences in their capacities to extend root systems after fire. However, how roots of cheatgrass and established adult perennials compete for and exploit the soil resources available after fire in sagebrush (Artemisia tridentata Nutt.) ecosystems is unknown.

This study describes the distribution of roots for 2 native species: needle-and-thread grass (Stipa comata Trin. & Rupr.) and rabbitbrush (Chrysothamnus viscidiflorus (Hook.) Nutt.). It also investigates the spatial distribution of roots after fire for these 2 species and how competition with cheatgrass affects rooting characteristics. Finally, because results from a 2-year study after fire may not accurately predict changes that occur during extended periods of time after fire, we compared root production of a recently burned area with that from an area that burned 12 years prior to our study.

Methods

Study Area

The study plots were located in 2 adjacent areas: a 1-ha area that was naturally burned during late-summer 1986 and a 0.7-ha area that had not burned for at least 12 years. The recently burned study area probably resulted from an isolated lightning strike that was quickly extinguished because of accompanying rain and low fuel load. The second study area served as a "long-term reference" to compare rooting characteristics after an extended post-fire period of time with those during the first 2 years after a fire. Both areas were fenced to exclude grazing.

Soil characteristics of the recently burned and long-term reference areas were similar. We dug 2 soil pits, one in each study area. Soils were classified as coarse-loamy, mixed, mesic, Xerolitic Hapludolls. Soils were very deep (depth to bedrock exceeded 2 m) and well drained with 15-25% surficial coarse fragments. The study areas were on a remnant summit of a fan piedmont, and parent material was alluvium from nearby granitic mountains. Average slope was 2% with a west-southwest aspect. Soils also have been mapped to the same unit, which belongs to the Bedell series (Baumer 1983).

Vegetative characteristics of the adjacent study areas were also similar. Both areas were in the middle of a sagebrush-bunchgrass community. Sagebrush, rabbitbrush, needle-and-thread, horsebrush (Tetradymia canescens DC.), squirreltail (Sitanion hystrix (Nutt.) J.G. Smith), and the introduced species cheatgrass were the dominant species in the community. Average precipitation was estimated to be 250 mm (Evans and Young 1977). Measurements were taken during 1987 and 1988, which had 95% and 50% of estimated normal precipitation, respectively. The study areas (39°51'N, 119°48'W) were 35 km north of Reno, Nevada at 1,570 m elevation.
Target Species

Two native species that are relatively resistant to fires in late summer, rabbitbrush, and needle-and-thread grass (Young 1983), were selected to determine the effects of fire and cheatgrass competition on root growth and density. Rabbitbrush is a perennial, undesirable shrub and needle-and-thread grass is a perennial, desirable bunchgrass. At the beginning of the study, we selected plants that were similar in size based upon measurements of basal area. Sixteen target individuals of each species in the recently burned area were selected with stratified random technique to assure adequate size and spatial interdispersion (Hurlbert 1984).

Eight target individuals of each species in the long-term reference area were selected using the same technique. These target individuals were the same ones used for soil water measurements in Melgoza et al. (1990).

In order to determine the short-term effects of cheatgrass competition on root growth after fire, we established plots with and without cheatgrass. All plants within a 1.0-m radius around target individuals in the recently burned area (plots without cheatgrass) were removed with a hoe during fall 1986. Many of the plants removed from the burned area appeared to be dead, but were removed to insure a uniform competitive environment among plots. During the next 2 years, cheatgrass as well as seedlings of other plants were removed as needed from the plots. Plots of target individuals with cheatgrass were established in an analogous manner: all plants except cheatgrass were removed during fall 1986 and as needed during the next 2 years.

The long-term reference area provided information on what may occur at 12 years after fire. Vegetation in the long-term reference area was not altered. Thus, these plots served as an extended time reference for rooting characteristics in a competitive environment many years after fire rather than as a strict experimental control for the treatments in the recently burned area.

Root Observations

Direct root observations of the 2 native species were made during 1987. Trenches about 2-m deep and 5-m long were dug about 0.2 m from 2 individuals of each target species to provide access for root excavation. The soil on the trench wall was carefully removed by hand to uncover the root systems of individual rabbitbrush and needle-and-thread plants. Although fine roots were lost in the process, profile wall maps of the root systems provided information about root form and underground distribution of biomass of larger roots. Root form and distribution was recorded to 0.6-m soil depth, and root biomass at 0.1-m depth increments was clipped, oven-dried, and weighed.

Root Growth and Density

Root length density was determined by destructive sampling. Soil cores were taken with a 35-mm diameter auger at 2 locations: the edge of the target plant canopy and 0.5 m away from the edge. We made 2 assumptions when we selected these locations. First, the volume of soil below the canopy of the plant represents soil that is probably dominated by the plant (Caldwell and Richards 1986, Manning and Barbour 1988). Second, the volume of soil at 0.5-m distance represents a soil resource that was probably dominated by another plant but became available after the removal of that other plant by fire. These assumptions were verified by our profile wall maps.

Soil cores were taken from each plot at the end of each growing season (July 1987 and August 1988). Root cores were taken at the following depth increments: 0.0-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, 0.9-1.1, and 1.1-1.4 m depth. Samples were washed free from soils using a hydropneumatic root washer (Gillison's Variety Fabrication Inc., Benzie County, Michigan) (Smucker et al. 1982). Organic material was manually removed from samples. Live and dead roots were differentiated by a staining technique (Ward et al. 1978). Root length was measured with a Comair root length scanner (Commonwealth Aircraft Corporation Limited, Melbourne, Australia).

Although we could differentiate between live and dead roots, we could not reliably differentiate among species. Thus, we assumed that roots were from the plants that were present in the 1-m diameter plots. For example, live roots in soil cores from plots without cheatgrass in the recently burned area were undoubtedly from the target individual of that plot. For soil cores from plots with cheatgrass, roots were from both the target individual and cheatgrass.

Statistical Analyses

Data were analyzed using split-plot types of analysis of variance (ANOVA). We had 2 dependent variables: root length density at each depth increment and root length density for the 1.4-m deep soil profile. Whole-plot treatments had 3 levels: recently burned area without cheatgrass, recently burned area with cheatgrass.

Fig. 1. Root biomass distribution for 2 rabbitbrush plants (left frame) and 2 needle-and-thread grass plants (right frame). Root systems were excavated by hand from a trench dug 0.2 m away from each individual. Note the different x-axis scales for the 2 species.
Excavations for root observations were stopped when the silic- cemented horizon was reached (at about 0.6 m depth) because it became very difficult to track roots. Below 0.6 m, roots were few and very fragile. More than 50% of the total root biomass for both species was distributed in the upper 0.2 m of soil depth (Fig. 1).

### Root Length Density

Three interaction terms and 3 subplot factors were significant from the split-split-split plot ANOVA of root length density data for individual depth increments from plots with rabbitbrush plants as the target individual (Table 1). From the mean comparisons for the Location*Depth interaction term, root length densities near the edge of the target plant's canopy were significantly greater than those 0.5 m away from the edge only for the 0.0-0.3 m depth increments (Table 2a). Root length densities for the 5 depth increments below 0.3 m were not significantly different between loca-

### Results

**Root Observations**

The root system of rabbitbrush was characterized by a main tap root at least 0.6 m deep, with some major, secondary roots extended laterally over 0.6 m and many fine roots. Needle-and-thread grass had a flabelliform root system, about 0.5-m wide.
Table 3. Mean comparisons for root length density (cm cm\(^{-3}\)) from individual depth increments for plants with needle-and-thread grass as the target individual.

<table>
<thead>
<tr>
<th>Depth increment</th>
<th>0.0-0.3 m</th>
<th>0.3-0.5 m</th>
<th>0.5-0.7 m</th>
<th>0.7-0.9 m</th>
<th>0.9-1.1 m</th>
<th>1.1-1.4 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1987</td>
<td>7.1c</td>
<td>3.5b</td>
<td>3.2b</td>
<td>2.2ab</td>
<td>1.7ab</td>
<td>0.6a</td>
</tr>
<tr>
<td>Year 1988</td>
<td>13.8d</td>
<td>10.6c</td>
<td>6.7b</td>
<td>6.1ab</td>
<td>8.0b</td>
<td>4.4a</td>
</tr>
</tbody>
</table>

(b) Depth increment subplot factor

<table>
<thead>
<tr>
<th>Depth increment</th>
<th>0.0-0.3 m</th>
<th>0.3-0.5 m</th>
<th>0.5-0.7 m</th>
<th>0.7-0.9 m</th>
<th>0.9-1.1 m</th>
<th>1.1-1.4 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>10.5d</td>
<td>7.0c</td>
<td>4.9b</td>
<td>4.9b</td>
<td>4.1b</td>
<td>2.5a</td>
</tr>
<tr>
<td>1988</td>
<td>3.0a</td>
<td>8.3b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean comparisons were made with an LSD test; means within a row that have the same letter did not differ significantly (p > 0.05).

Only 1 interaction term and 2 subplot factors were significant (Table 1). As with rabbitbrush plots, the significant Year*Depth interaction term (Table 3a) confounded the significant Depth subplot factor (Table 3b): the grouping of means for individual depth increments differed between years. Root length density in 1988 was significantly greater than that in 1987 (Table 3c).

The most important aspect of these ANOVA’s was the lack of significance for any term involving the whole-plot Treatment factor (Table 1). Because the root measurements for plots with cheatgrass included roots of both the target individual and cheatgrass, we expected that treatment to have significantly greater root length density. Root length densities for individual depth increments within each treatment overlapped for both species throughout the soil profile, especially in 1987 (Fig. 2). Although differences among treatments in 1988 were larger than those in 1987, especially for plots with needle-and-thread grass as target individuals, the 3-way interaction term Treatment*Year*Depth was not significant for plots with either species as target individuals (Table 1).

Because the P value for the Treatment*Year*Depth from the ANOVA for needle-and-thread grass plots was low, we computed root length density for the entire 1.4-m-deep soil profile in order to integrate the 6 depth increments. Data were analyzed with a split-split plot ANOVA (Table 4a). For plots with rabbitbrush plants as target individuals, the Year*Location interaction term (Table 4b) confounded the significant Location subplot factor (Table 4c). Locations were not significantly different in 1987, but were significantly different in 1988. For plots with either native species as target individuals, the root length density for the soil profile in 1987 was significantly less than that in 1988 (Table 4d). However, all ANOVA terms that involved the whole-plot Treatment factor were not significant, even though mean root length density for the soil profile of plots with cheatgrass in the recently burned area tended to be slightly greater than that of other plots in 1988 (Fig. 3).

In order to focus only on the plots from the recently burned area, we reran the ANOVA’s without data from the long-term

---

Fig. 2. Root length density at different depth increments for plots with rabbitbrush (Chvi) as the target individual (left frames) and plots with needle-and-thread grass (Stco) as the target individual (right frames). Upper frames are means from 1987, and lower frames are means from 1988. Solid lines are plots in the recently burned area without competition; dash-dot-dot lines are plots in the recently burned area with cheatgrass competition; and dashed lines are plots in the long-term reference area. Error bars are standard errors of the mean. At any 1 depth, treatment means within any 1 frame were not significantly different (see Table 1a).
Fig. 3. Root length density for the entire soil profile from rabbitbrush (Chvi) plots (left frames) and needle-and-thread grass (Stco) plots (right frames) in 1987 (upper frames) and 1988 (lower frames). Open bars are plots in the recently burned area without competition; diagonal bars are plots in the recently burned area with cheatgrass competition; and crosshatch bars are plots in the long-term reference area. For each pair of bars, the left bar is mean root length density for soil cores taken at the edge of the target individual, and the right bar is that taken 0.5 m away from the edge of the canopy. Error bars are standard errors of the mean. With the exception of a significant Location effect in 1988 for rabbitbrush, means within a frame were not significantly different (see Table 2a).

reference area. Most of the significant terms in Tables 1 and 4a were again significant, and all the terms involving Treatment were, again, not significant (results not shown). We next removed the 1987 measurements from our data set and analyzed the data with split-plot types of ANOVA’s, but all the ANOVA terms involving Treatment were still not significant.

Discussion

The roots system of cheatgrass and the native species compete. Evidence to support this statement is based upon the lack of statistical significance for any ANOVA terms that involved the whole-plot Treatment factor. If cheatgrass roots were not affecting root growth of the established perennial plants after fire, then the combined root length densities of the target species plus cheatgrass in plots with both species should have been greater than the root length densities of plots with only the target species. We also expected that this would be especially striking at 0.5 m from the edge of the target individuals. However, root length density of plots in the recently-burned area with only the target species were nearly identical to the combined root length density of plots with both the target species and cheatgrass in 1987 (Figs. 2 and 3). Small differences in mean root length density existed in 1988, but were not significant. We cannot unequivocally conclude from our data whether cheatgrass or the native species is the better competitor: we have evidence that cheatgrass reduces root length densities of the native species (relative to monocultures of the native species), but we do not know to what extent the native species reduce root length densities of cheatgrass (relative to cheatgrass monocultures). None-the-less, productivity and water status of both rabbitbrush and needle-and-thread grass were also adversely affected by cheatgrass (Melgoza et al. 1990). Because plants depend on their root systems to exploit the soil space around them, the results from our 2 studies suggest that the root system of cheatgrass utilized soil resources that otherwise would have been used by the native plants. Similar results were noted for competition between bluebunch wheatgrass and cheatgrass in growth chamber studies (Harris 1967).

Distribution of roots in the belowground space is important because root length density is closely related to uptake of water (Caldwell 1976, Lascano and van Bavel 1984) and nutrients (Silverbush and Baker 1985, Caldwell and Richards 1986). Water is the limiting factor in desert communities (Fowler 1986, Smith and Nowak 1990), and frequently water is present in limited amounts and space. Species growing together can avoid competition to some extent by having active roots at different depths, but root length density of all species in our study was greatest in the upper 0.5 m of soil, suggesting considerable root competition. Cheatgrass is very effective in removing soil water from the upper levels early in the spring (Cline et al. 1977, Melgoza et al. 1990), and competition between cheatgrass and native species in the upper soil layers...
Table 4. Split-split plot analysis of variance (ANOVA) and mean comparisons for root length density (cm cm⁻²) for the 1.4 m deep soil profile.

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Chvi plots</th>
<th>Stco plots</th>
<th>P values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>2</td>
<td>0.343</td>
<td>0.526</td>
<td></td>
</tr>
<tr>
<td>Treatment*Year</td>
<td>2</td>
<td>0.589</td>
<td>0.677</td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>1</td>
<td>0.010</td>
<td>0.373</td>
<td></td>
</tr>
<tr>
<td>Treatment*Location</td>
<td>2</td>
<td>0.703</td>
<td>0.650</td>
<td></td>
</tr>
<tr>
<td>Year*Location</td>
<td>1</td>
<td>0.001</td>
<td>0.733</td>
<td></td>
</tr>
<tr>
<td>Treatment<em>Year</em>Plot</td>
<td>42</td>
<td>0.652</td>
<td>0.757</td>
<td></td>
</tr>
</tbody>
</table>

Total                  | 95  |            |            |          |

--- (b) Mean comparisons for locations by year (Year*Location interaction term)

<table>
<thead>
<tr>
<th>Year</th>
<th>Canopy edge from 0.5 m from edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>Chvi plots: 3.0a^3; Stco plots: 3.8a</td>
</tr>
<tr>
<td>1988</td>
<td>11.4b; 6.5a</td>
</tr>
</tbody>
</table>

--- (c) Mean comparisons for Location subplot factor

<table>
<thead>
<tr>
<th>Year</th>
<th>Chvi plots: 3.4a; Stco plots: 3.2a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>9.0b</td>
</tr>
<tr>
<td>1988</td>
<td>8.4b</td>
</tr>
</tbody>
</table>

--- (d) Mean comparisons for Year subplot factor

<table>
<thead>
<tr>
<th>Year</th>
<th>Chvi plots: 3.4a; Stco plots: 3.2a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>9.0b</td>
</tr>
<tr>
<td>1988</td>
<td>8.4b</td>
</tr>
</tbody>
</table>

Sources of variation: Treatment = whole-plot treatments of presence/absence of cheatgrass in recently-burned area and long-term reference; Year = 1987/1988; Location = edge or canopy/0.5 m from edge; Plot = experimental unit.

Degrees of freedom

Differences between plotters with rabbitbrush (Chvi) as the target individual and ANOVA from plots with needle-and-thread grass (Stco) as the target individual.

Mean comparisons were made with a L.S.D. test; means within a row that have the same letter did not differ significantly (P>0.05).


CALL FOR SPECIAL SESSIONS

1992 ANNUAL MEETING
FEBRUARY 9-14, 1992
SPOKANE, WASHINGTON

To better accommodate diverse program needs at annual meetings, meeting organizers have been directed to conduct a call for special sessions (symposia, workshops, or others) similar to the call for volunteer papers.

Proposals should include:

- Session title and type (symposium, workshop etc...)
- Statement of objectives and intended audience
- Number of hours required
- Number of attendees anticipated
- Name, address and phone number of organizer
- Sponsoring group (if applicable)

Submit to:
Linda H. Hardesty
Program Co-chair
Department of Natural Resource Sciences
Washington State University
Pullman, WA 99164-6410

Proposal deadline is April 1, 1991