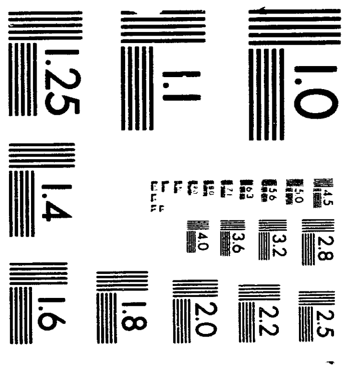

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# PLANT REESTABLISHMENT AFTER SOIL DISTURBANCE: EFFECTS OF SOILS, TREATMENT, AND TIME

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MASTER

## *Summary*


The Pacific Northwest Laboratory examined plant growth and establishment on 16 sites where severe land disturbance had taken place. The purpose of the study was to evaluate th relative effectiveness of the different methods in terms of their effects on establishment of native and alien plants. Disturbances ranged from 1 to 50 years in age. Revegetation using native plants had been attempted at 14 of the sites; the remainder were abandoned without any further management. Revegetation efforts variously included seeding, fertilizer application, mulching with various organic sources, compost application, application of Warden silt loam topsoil over sand and gravel soils, and moderate irrigation.

The greatest benefit was derived from seeding: without seeding, abandoned sites, especially on heavier soils, were covered with a near monoculture of cheatgrass (*Bromus tectorum*). Cheatgrass was found to be a strong competitor with most native grasses, especially Sandberg's bluegrass (*Poa sandbergii*). Cheatgrass is extremely prone to fire, and supports a generally depauperate vertebrate fauna. After 50 years of such a monoculture, cheatgrass in one of the Hanford Townsite old fields was found to be successfully invaded by the native grass sand dropseed (*Sporobolus cryptandrus*). Russian thistle (*Salsola kali*) increased in abundance with age of site disturbance at least over the first 5 years after disturbance. In contrast to cheatgrass, Russian thistle was not found to be a significant competitor with Sandberg's bluegrass.

The second greatest benefit was derived from moderate irrigation. Irrigation on the studied sites was limited to a maximum of 2.5 cm of water per month from April to July following seeding the previous October and November. Enhanced survival and growth were found among all native species on irrigated sites, including native forbs that were not introduced to the disturbed areas in the seeding mixes. Cheatgrass abundance and cover were lower on irrigated sites than on unirrigated sites. Russian thistle was more abundant on irrigated sites, but plants were smaller than on unirrigated sites.

Incorporation of compost at a rate of 25% by volume produced the third greatest benefit for seeded native plants. Pure compost seedbeds, however, were totally without cover of seeded species; only Russian thistle was able to colonize such sites.

Wood fiber or straw mulches were used at all revegetated sites. Different mulches had no apparent effect on Russian thistle growth. Wood fiber mulch on sands was generally more effective than straw in enhancing growth of seeded native grasses. In contrast, straw performed slightly better than wood fiber on loamy sand soils. Straw on silt loam sites had a less beneficial effect on native plants than did composts.

Loamy sands were the most difficult to revegetate with native plants. Silt loams, at least with the amendments used, produced the highest cover and density of seeded native species. Sandy soils produced intermediate success. Russian thistle density was highest on loamy sands; lowest on sands with wood fiber mulch and on silt loams.

Fertilizer use at rates up to 45 kg nitrogen/ha had minimal effects on the growth of reseeded native species. The greatest effects of fertilizer use were realized by Russian thistle.

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## *Introduction*

The U.S. Department of Energy's Hanford Site contains one of the few relatively undisturbed remnants of the shrub-steppe habitat in the state of Washington. However, a number of land disturbances have occurred on the Site since the advent of cultivation agriculture in the northwest. Areas of the Site located near sources of water, such as near the Columbia River, Rattlesnake Springs, Snively Springs, and artesian wells in the northwest corner of the Site, were cultivated from the turn of the century to 1943, when the local Eurasian population was displaced by the U. S. army for the Hanford Project (Chatters 1989).

Subsequent disturbances have resulted from nuclear-related operations at the Hanford Site. These disturbances have included construction, excavation, and materials/spoils disposal. Most disturbances were confined to the vicinity of the reactors along the Columbia River and within the 200 Areas of the central plateau; however, few areas of the Site remain totally unaffected today, as a result in part of the widespread groundwater monitoring network that has expanded over the years, road and power line construction, excavation of numerous gravel and soils borrow pits, and offroad vehicle traffic.

Most sites disturbed areas were left untreated with respect to reestablishment of a vegetative cover. Some areas, especially those associated with recent anthropogenic disturbances, were prepared and planted with various seed mixes, usually relying primarily on alien species. A few sites, especially those associated with the restoration program of the Basalt Waste Isolation Project (BWIP), were prepared and seeded with species of grasses and shrubs native to the Hanford Site.

Severe land disturbances at the Hanford Site will continue for some time as a result of environmental cleanup. Disturbance will result from direct effects of cleanup of buildings, roadways, and hazardous waste sites, and the construction of massive barriers over certain waste disposal sites. For the barriers program, mined silt loam soil from the McGee Ranch area will be used as the uppermost layer in the barrier (Wing and Gee 1990). Because of requirements likely to be made by the state of Washington, as well as requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the vegetation that must be established on these sites will be limited to species native to the Hanford Site.

A review of native versus alien plants in the shrub-steppe habitats of the lower Columbia River Plain has been presented by Brandt and Rickard (In Press). Even in relatively undisturbed habitats, the primary cover in the Plain is provided by the alien annual cheatgrass (*Bromus tectorum*), which has proven to be an exceptionally successful competitor with the native species (Billings 1990, Brandt et al. 1990). Cheatgrass has been reported to form monotypic climax communities in the shrub-steppe environment following soil disturbances (Daubenmire 1970). Both floral and faunal diversity in these monotypic communities are severely limited relative to the less-disturbed habitats (Brandt and Rickard In Press; Rickard and Schuler 1988). Habitats with high cheatgrass cover also are prone to wildfires, which are both more frequent and more severe than in the native bunchgrass communities (Billings 1990).

Reintroducing native species to disturbed areas of the Hanford Site has proven difficult (Brandt et al. 1992). Competition from alien weeds such as cheatgrass and Russian thistle

(*Salsola kali*) may play a role in limiting revegetation with native species; however, other potentially significant factors affecting revegetation success at least over the short term include soil physical properties, moisture availability, and extreme winter temperatures (Brandt et al. 1990, 1991, 1992).

A number of techniques have been used at Hanford to attempt to overcome some of the factors limiting establishment and growth of native vegetation. Between 1989 and 1991, the BWIP attempted to restore some 60 severely disturbed sites totaling over 32 ha to conditions that resemble the surrounding undisturbed habitat. In fall of 1991, 11 sites on the 200 Area Plateau were revegetated using Sandberg's bluegrass (*Poa sandbergii*), the most abundant and common native grass on the Columbia River Plateau (Brandt et al. 1990), and a combination of soil amendments and treatment options, including in four cases the surficial application of silt loam material excavated from a pit in the McGee Ranch area (Brandt et al. 1992). Amendments used on the restoration sites included compost, wood chips, and fertilizer either alone or in combination.

McGee Ranch soils (Warden silt loam) will be used as a surface cover on the proposed barriers over waste disposal sites. A single prototype barrier will be constructed in 1994 using materials and techniques currently thought to be the most probable elements of the final barrier design. The single prototype will be too small to allow experimental analysis of alternative methods of soil placement, seedbed preparation and amendment, and seed/propagule introduction. Consequently, information necessary to evaluate potential methods for introducing cover to these areas must be obtained from elsewhere. Westinghouse Hanford Company contracted with the Pacific Northwest Laboratory to obtain such information from existing disturbed sites on Hanford.

This report addresses the following objective using primarily the BWIP treatment sites:

> What are the relationships between soil and seed treatments, soil type, and disturbance history, and the establishment of native versus alien plant cover?

This report describes the methods used to revegetate sites, if any, presents the results of the evaluation, and provides a discussion of the relative effectiveness of the treatment options.

## *Methods*

Sites to be evaluated were selected to represent a diversity of soils and treatment options (Table 1), and also were distributed throughout most of the Hanford Site (Figure 1). All but three sites had been treated at a minimum by seeding with native species. One untreated site was located in old fields near the Hanford Townsite; a second site was a waterline right-of-way south of the 300 Area that was disturbed in 1990 by excavation and subsequent replacement of the soils. The third untreated site was located at the McGee Ranch area, and consisted of test plots for the barriers program.

Two estimates of plant establishment and growth were used: density and percentage cover. Density was estimated by counting all plants by species occurring within a 0.25-$m^2$ quadrat placed at 1-m intervals along a 10-m tape. Sampling intensity was controlled to provide a minimum of four transects per 0.1-ha site. Transects were established along the margins of 100-$m^2$ permanent plots at sites, where such plots had been established in past years. All sites were additionally sampled in two strata comprising the perimeter 50% of the area and the central 50%. The origin of the transect was located within each stratum by pacing a randomly generated number of steps from either a corner (starting transect) or the terminus of a previous transect. Field sampling was conducted during June and July 1993.

**Table 1.** Characteristics of Sites Evaluated for Vegetation Establishment.

| Site | Treatment | Year Remediated or Disturbed | Soil Type | Area Disturbed |
|---|---|---|---|---|
| Hanford Townsite Old Field | abandoned | 1943 | Rupert Sand | unk. |
| Horn Rapids | abandoned | 1990 | Rupert Sand | 10 ha |
| McGee | abandoned | 1990/1992 | Warden Silt Loam | 120 $m^2$ |
| Gable Mountain Borrow Pit | revegetated | 1991 | Warden Silt Loam | 1.5 ha |
| DB-1 | revegetated | 1989 | Rupert Sand | 0.25 ha |
| DC-15 | revegetated | 1988 | Rupert sand | 0.8 ha |
| DC-16 | revegetated | 1991 | Koehler Sand | 1.4 ha |
| DC-19 | revegetated | 1989 | Rupert Sand | 1.2 ha |
| DC-20 | revegetated | 1991 | Rupert Sand | 1.4 ha |
| DC-24 | revegetated | 1988 | Hezel Sand | 2.4 ha |
| DC-25 | revegetated | 1989 | Rupert Sand | 1.9 ha |
| DC-32 | revegetated | 1988 | Esquatzel Silt Loam | 2.3 ha |
| DC-33 | revegetated | 1988 | Rupert Sand | 2.3 ha |
| DC-7/8 | revegetated | 1991 | Burbank Loamy Sand | 0.43 ha |
| Exploratory Shaft Facility | revegetated | 1988 | Hezel Sand | 5.2 ha |
| RRL-7 | revegetated | 1991 | Warden Silt Loam | 0.25 ha |
| Trailer Village | revegetated | 1989 | Kiona Silt Loam | 1.3 ha |

Data were analyzed using nonparametric statistics based on ranks. The percentage cover and density data sets were non-normally distributed and, because of the patchy distribution of the vegetative cover in some areas, included a number of outliers. Both these attributes preclude analysis using parametric methods, but nonparametric rank-order methods are unaffected by such characteristics (Potvin and Roff 1993).

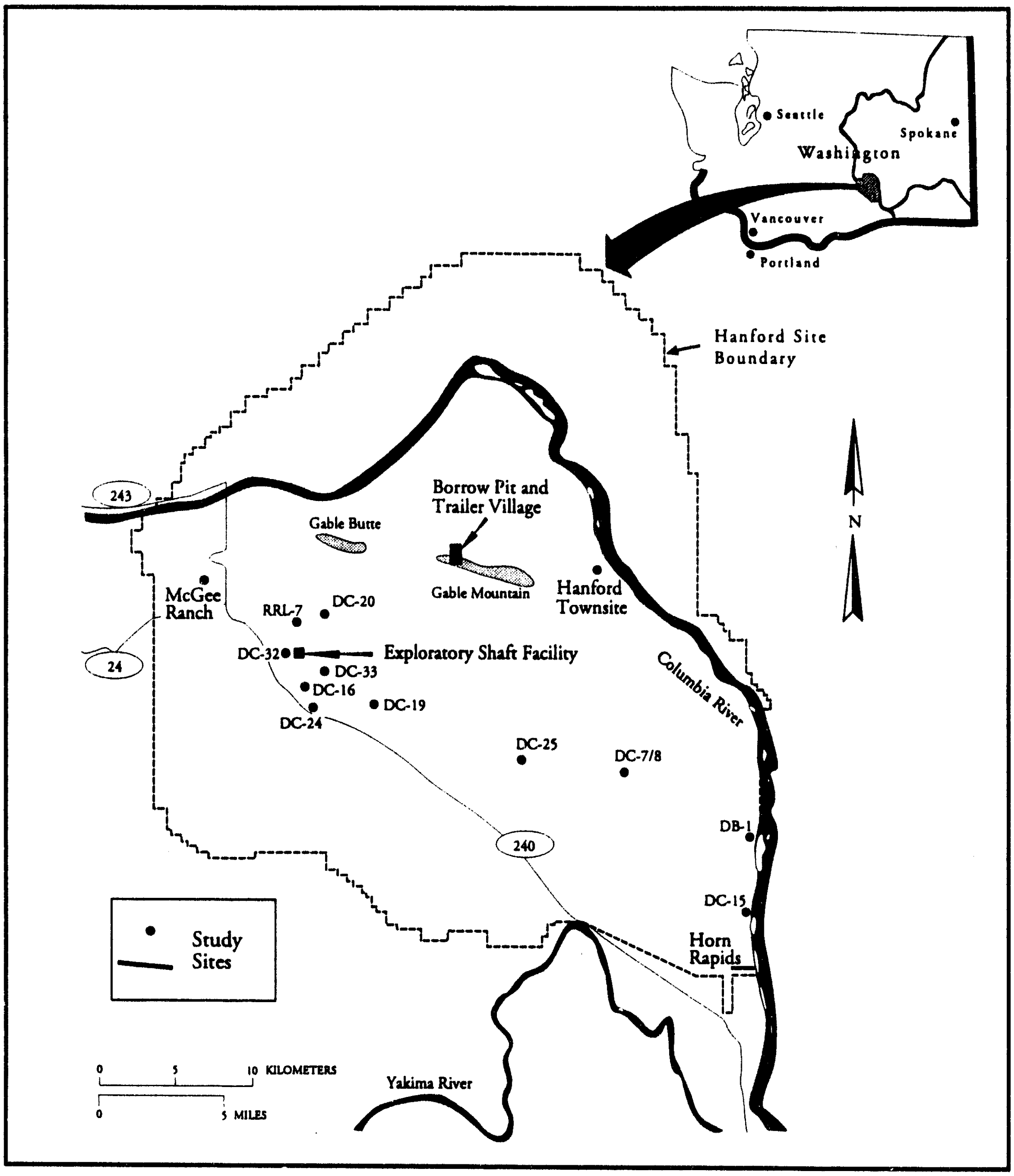



**Figure 1.** Location of Plant Reestablishment Study Sites on the Hanford Site.

Revegetated sites differed in the texture of soils found at each site and in treatments (Table 3), as well as in when each site was revegetated. Because these variables were not all applied in an experimental treatment, and because all variables were not completely crossed (matched), a single analysis of variance cannot be applied to elucidated the effect of treatment A in the presence of treatments B, C, and D. Instead, treatments were examined on an individual basis. Combinations of treatments were examined using plots and nonparametric tests where possible.

## *Results*

Revegetation had been attempted at 13 of the sites examined (Table 2); the remaining three sites were abandoned after disturbance. The Hanford Townsite old field was formerly an agricultural field south of the Town that was regularly plowed prior to 1943, when it was abandoned. The Horn Rapids site consisted of a water line right-of-way from the Columbia River to the new agricultural fields located north and west of the City of Richland. The portion of the right-of-way that was surveyed lay between the river and Stevens Drive. The McGee Ranch sites comprised two gravel admix test plots approximately 6 by 10 m that were cleared of vegetation and tilled to incorporate the admix. A summary of the relevant revegetation methods that were examined in this report are given in Table 3.

Revegetated sites differed significantly from sites that had been abandoned without revegetation in a number of plant characteristics. Abandoned sites supported significantly higher densities of cheatgrass and native forbs, and lower densities of Sandberg's bluegrass and perennial grasses than did revegetated sites (Figure 2 and Table 4). The principal perennial grass found on the abandoned old fields was sand dropseed (*Sporobolus cryptandrus*), which seems to be effectively competing with cheatgrass, at least in a few areas. The McGee Ranch sites lacked any native grasses; the sandy soils of the Horn Rapids site included Indian ricegrass (*Oryzopsis hymenoides*), the only native grass present.

Percentage cover also differed greatly between abandoned and revegetated sites (Table 5). Abandoned sites had significantly higher cover of cheatgrass and native forbs and lower cover by Russian thistle, Sandberg's bluegrass, and shrubs (Figure 3). Russian thistle was not significantly lower in abundance on abandoned sites than on revegetated sites, but it did not reach the same stature as on revegetated sites, where plant density overall was quite a bit lower than on the Hanford Townsite and the McGee sites.

Cheatgrass density was significantly correlated with the age of the disturbance (Spearman rank correlation between year of disturbance and density: $r_s = -0.291$, $P = 0.004$), with older sites supporting higher densities of cheatgrass than younger sites (Figure 4). Limiting the analysis to sites where revegetation had been attempted did not greatly decrease the relationship ($r_s = -0.280$, $P = 0.01$): older sites still supported higher densities of cheatgrass than did younger sites despite revegetation (Figure 5). However, revegetated sites supported less cheatgrass than expected based on the regression of all sites (analysis of covariance using rank-transformed data: $F = 5.46$, degrees of freedom = 2/96, $P = 0.006$). For example, the regression equation for all sites predicted a density of 581 cheatgrass plants per 0.25 $m^2$, while the prediction from the revegetated sites alone was 508 plants per 0.25 $m^2$.

## Table 2. Revegetation Methods Used at Study Sites.

| Location | Seedbed Treatment | Seeding Method | Species Seeded | Seeding/Planting Rate |
|---|---|---|---|---|
| Gable Mountain Borrow Pit | 6-in. McGee Ranch soil with 25% compost by volume. Follow with cultivator or harrow. | Brillion seeder | *Poa sandbergii* | 13 kg/ha |
| | | | *Melilotus alba* | 1.5 kg/ha |
| DB-1 | Remove gravel cover in 1988; seed in fall 1989. | Deep furrow drill grass, plant tubeling shrubs | *Poa sandbergii* | 2.2 kg/ha |
| | | | *Chrysothamnus nauseosus* | 914 clumps/ha |
| DC-15 | Remove gravel cover and seed in 1988. | Deep furrow drill grass, plant tubeling shrubs | *Poa sandbergii* | 4.5 kg/ha |
| | | | *Artemisia tridentata* | 939 clumps/ha |
| | | | *Chrysothamnus nauseosus* | 198 clumps/ha |
| | | | *C. viscidiflorus* | 198 clumps/ha |
| | | | *Grayia spinosa* | 89 clumps/ha |
| DC-16 | 3-in. compost disked into existing seedbed. | Brillion seeder | *Poa sandbergii* | 11.5 kg/ha |
| | | | *Sitanion hystrix* | 2.7 kg/ha |
| | | | *Melilotus alba* | 1.3 kg/ha |
| DC-19 | Remove gravel cover in 1988; seed in fall 1989. | Deep furrow drill grass, plant tubeling shrubs | *Oryzopsis hymenoides* | 9 kg/ha |
| | | | *Artemisia tridentata* | 25 clumps/ha |
| | | | *Chrysothamnus nauseosus* | 395 clumps/ha |
| | | | *C. viscidiflorus* | 99 clumps/ha |
| DC-20 | 15:30:15 fertilizer applied at 45 kg N/ha disked into existing seedbed. Follow with cultivator or harrow. | Brillion seeder | *Poa sandbergii* | 11.5 kg/ha |
| | | | *Sitanion hystrix* | 2.7 kg/ha |
| | | | *Melilotus alba* | 1.3 kg/ha |
| DC-24 | Remove gravel cover in 1988; seed in fall 1988. | Deep furrow drill grass, plant tubeling shrubs | *Poa sandbergii* | 3.3 kg/ha |
| | | | *Sitanion hystrix* | 2.2 kg/ha |
| | | | *Artemisia tridentata* | 939 clumps/ha |
| | | | *Chrysothamnus nauseosus* | 198 clumps/ha |
| | | | *C. viscidiflorus* | 198 clumps/ha |
| | | | *Grayia spinosa* | 89 clumps/ha |
| DC-25 | Remove gravel cover in 1988; seed in fall 1989. | Deep furrow drill grass | *Agropyron dasystachyum* | 6.7 kg/ha |
| | | | *Oryzopsis hymenoides* | 2.2 kg/ha |
| DC-32 | Remove gravel cover in 1988; seed in fall 1988. | Deep furrow drill grass, plant tubeling shrubs | *Poa sandbergii* | 3.3 kg/ha |
| | | | *Sitanion hystrix* | 2.2 kg/ha |
| | | | *Artemisia tridentata* | 939 clumps/ha |
| | | | *Chrysothamnus nauseosus* | 198 clumps/ha |
| | | | *C. viscidiflorus* | 198 clumps/ha |
| | | | *Grayia spinosa* | 89 clumps/ha |
| DC-33 | Remove gravel cover in 1988; seed in fall 1988. | Deep furrow drill grass, plant tubeling shrubs | *Poa sandbergii* | 3.3 kg/ha |
| | | | *Sitanion hystrix* | 2.2 kg/ha |
| | | | *Artemisia tridentata* | 939 clumps/ha |
| | | | *Chrysothamnus nauseosus* | 198 clumps/ha |
| | | | *C. viscidiflorus* | 198 clumps/ha |
| | | | *Grayia spinosa* | 89 clumps/ha |
| Trailer Village | Irrigate 2.5 cm/mo. for April to July following seeding. | Rangeland drill grass, broadcast shrub seed | *Poa sandbergii* | 3.4 kg/ha |
| | | | *Stipa comata* | 2.2 kg/ha |
| | | | *Oryzopsis hymenoides* | 3.4 kg/ha |
| | | | *Artemisia tridentata* | 0.28 kg//ha |
| | | | *Chrysothamnus nauseosus* | 0.14 kg/ha |
| | | | *C. viscidiflorus* | 0.14 kg/ha |

## Table 2. Revegetation Methods Used at Surveyed Sites (cont.).

| Location | Seedbed Treatment | Seeding Method | Species Seeded | Seeding/Planting Rate |
|---|---|---|---|---|
| Exploratory Shaft Facility | Irrigate 2.5 cm/mo. for April to July following seeding, fertilize with 34 kg N/ha. | Rangeland drill grass, broadcast shrub seed | *Poa sandbergii*<br>*Sitanion hystrix*<br>*Artemisia tridentata*<br>*Chrysothamnus nauseosus*<br>*C. viscidiflorus* | 4.5 kg/ha<br>2.2 kg/ha<br>0.28 kg//ha<br>0.14 kg/ha<br>0.14 kg/ha |
| RRL-7 | 6-in. McGee Ranch soil with 5% wood chips by volume and 15:30:15 fertilizer applied at 84 kg N/ha. Follow with cultivator or harrow. | Brillion seeder | *Poa sandbergii*<br>*Sitanion hystrix*<br>*Melilotus alba* | 11.5 kg/ha<br>5.4 kg/ha<br>1.3 kg/ha |
| DC-7/8 (west half of pad) | Remove gravel in 1988; seeding attempted in 1989 and failed; compost added at 15% rate in 1990 on EAST HALF of the site; broadcast a 15:30:15 fertilizer at 20 kg N/ha to WEST HALF of pad area in 1991. | Brillion seeder (WEST HALF) | *Poa sandbergii*<br>*Stipa comata*<br>*Sitanion hystrix*<br>*Melilotus alba*<br>(WEST HALF) | 11.5 kg/ha<br>2.7 kg/ha<br>2.7 kg/ha<br>1.3 kg/ha<br>(WEST HALF) |

## Table 3. Summary of Revegetation Methods at Revegetated Sites.

| Site | Water? | Topsoil Amendment? | Fertilizer? | Organic Materials? |
|---|---|---|---|---|
| Gable Mountain Borrow Pit | no | topsoil | none | compost |
| DB-1 | no | none | none | straw |
| DC-15 | no | none | none | straw |
| DC-16 | no | none | none | compost topdressing |
| DC-19 | no | none | none | straw |
| DC-20 | no | none | yes | wood fiber |
| DC-24 | no | none | none | straw |
| DC-25 | no | none | none | straw |
| DC-32 | no | none | none | straw |
| DC-33 | no | none | none | straw |
| DC-7/8 | no | none | yes | wood fiber |
| Exploratory Shaft Facility | yes | none | yes | straw |
| RRL-7 | no | topsoil | yes | wood fiber |
| Trailer Village | yes | none | none | straw |

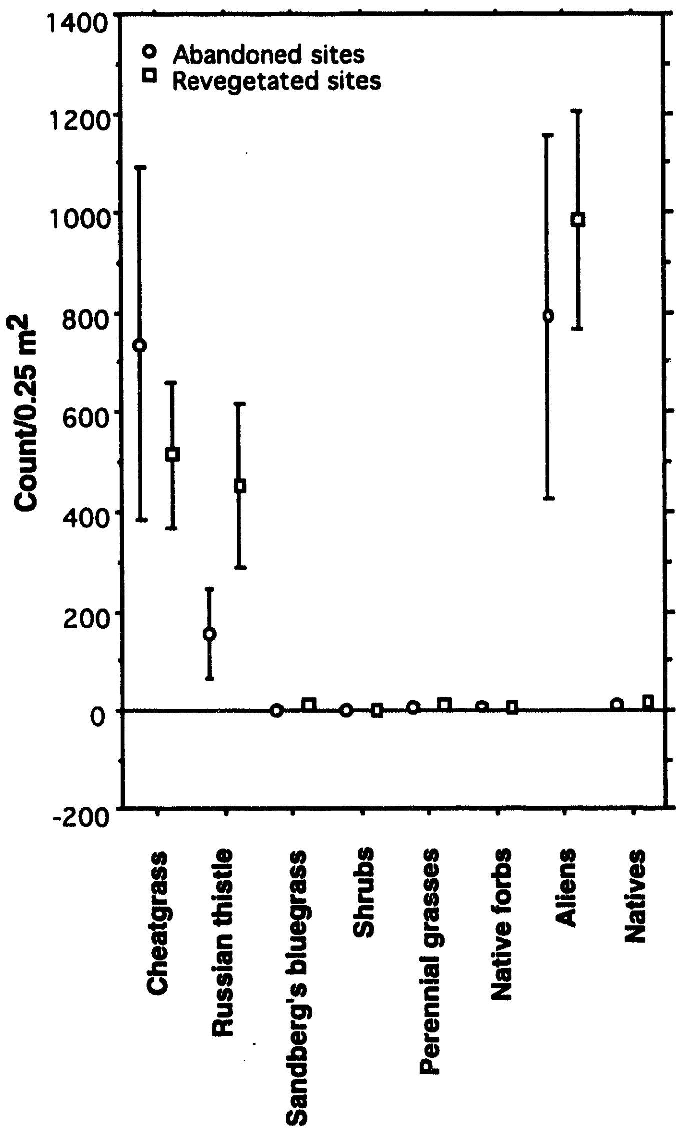



**Figure 2.** Density of Species and Species Groups on Abandoned and Revegetated Sites. Bars indicate 95% parametric confidence intervals.

**Table 4.** Nonparametric Mann-Whitney U Comparisons of Plant Density on Abandoned and Revegetated Sites.

| Species | U statistic | P-value | Abandoned vs. Revegetated Means |
|---|---|---|---|
| Cheatgrass | 993 | 0.04 | > |
| Russian thistle | 944.5 | 0.10 | ≤ |
| Sandberg's bluegrass | 1030 | 0.006 | < |
| Shrubs | 849.5 | 0.25 | = |
| Perennial grasses | 951.5 | 0.07 | ≤ |
| Native forbs | 1062 | 0.003 | > |
| Aliens | 822.5 | 0.6 | = |
| Natives | 764.5 | 1.0 | = |

**Table 5.** Nonparametric Mann-Whitney U Comparisons of Plant Cover on Abandoned and Revegetated Sites.

| Species | U statistic | P-value | Abandoned vs. Revegetated Means |
|---|---|---|---|
| Cheatgrass | 1063.5 | 0.007 | > |
| Russian thistle | 1070 | 0.006 | < |
| Sandberg's bluegrass | 933 | 0.06 | ≤ |
| Shrubs | 1007 | 0.005 | < |
| Perennial grasses | 871 | 0.3 | = |
| Native forbs | 953 | 0.05 | > |
| Aliens | 880.5 | 0.3 | = |
| Natives | 814 | 0.6 | = |

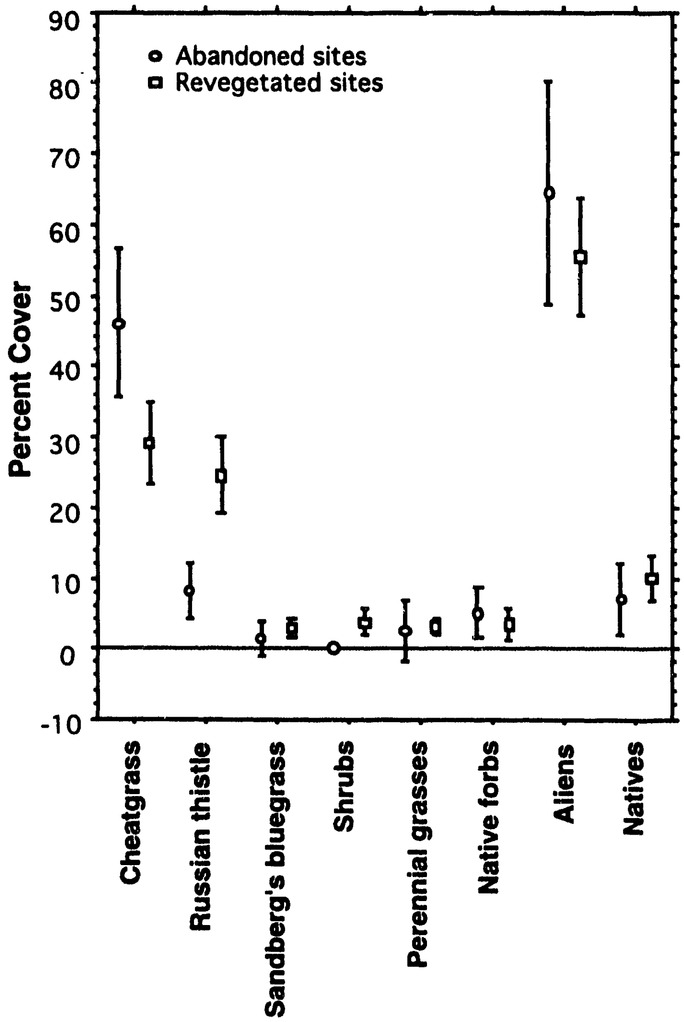
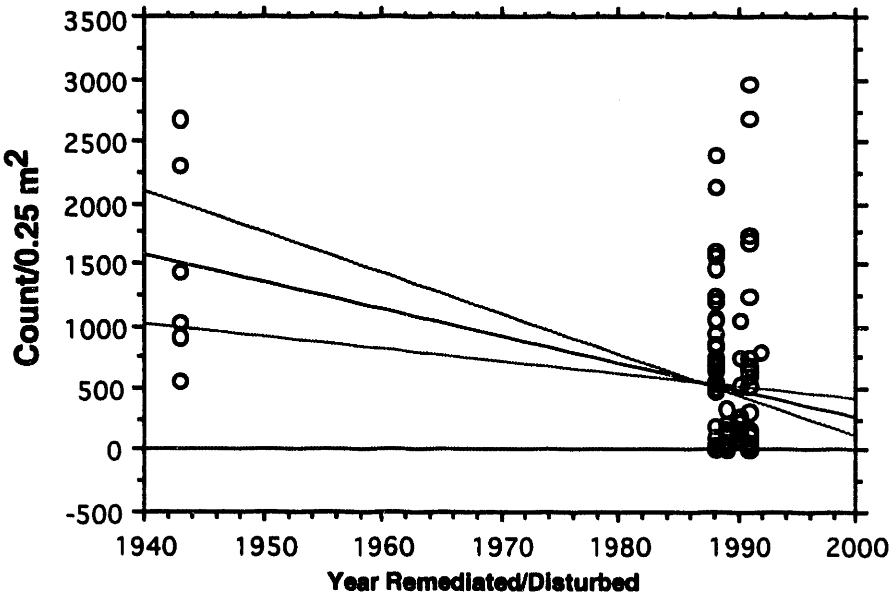
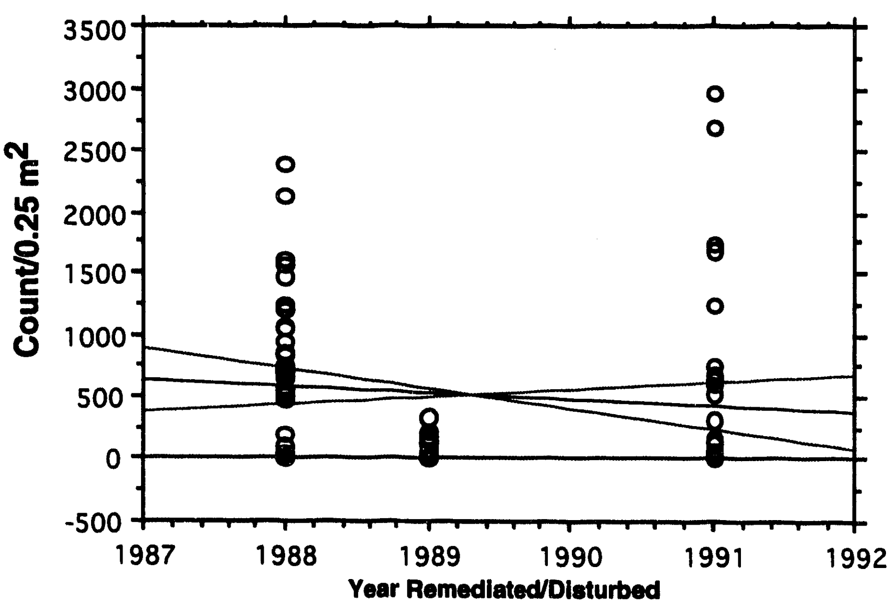



**Figure 3.** Percent Cover of Species and Species Groups on Abandoned and Revegetated Sites. Bars indicate 95% parametric confidence intervals.




BRTE D = 43366.562 - 21.549 * YEAR REMEDIATED/DISTURBED; $R^2$ = .125

**Figure 4.** Density of Cheatgrass Versus Year of Last Disturbance for all Study Sites. Solid line shows least-squares regression (equation below); shaded lines show 95% parametric confidence intervals on the slope.




BRTE D = 103590.005 - 51.815 * YEAR REMEDIATED/DISTURBED; $R^2$ =.011

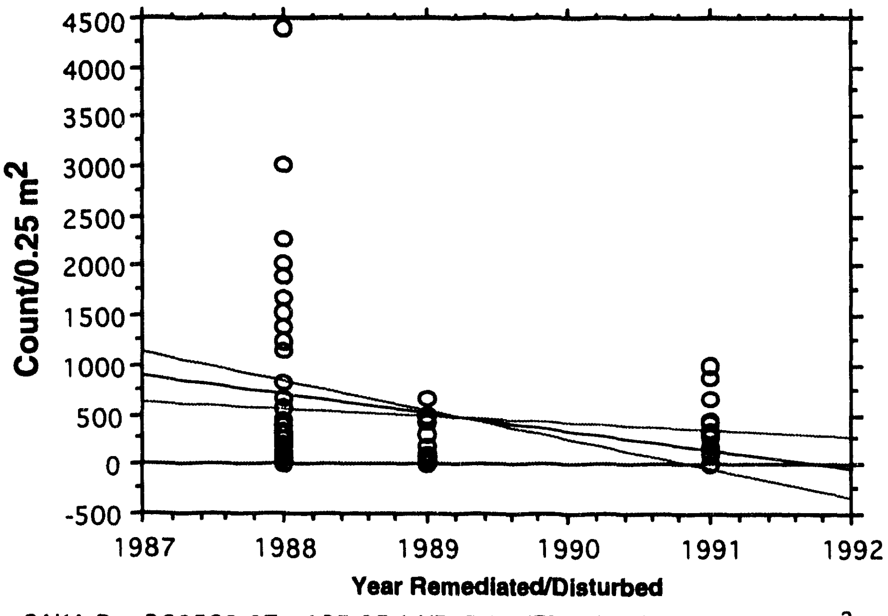
**Figure 5.** Density of Cheatgrass Versus Year of Last Disturbance for Revegetated Sites Only. Rest as in Figure 4.

Russian thistle density increased with time since disturbance on the revegetated sites (Spearman rank correlation between year of disturbance and density: $r_s$ = -0.408, P = 0.0003). Density of Russian thistle was extremely sporadic on the older revegetation sites, with a range from 0 to nearly 4500 plants per 0.25-$m^2$ plot (Figure 6). The Hanford Townsite plots supported very little cover by Russian thistle (Figure 7).

Limiting analysis to revegetation sites, Russian thistle density bore no significant relationship to the density of Sandberg's bluegrass ($r_s$ = -0.069, P = 0.5), whereas cheatgrass density was negatively correlated with Sandberg's bluegrass density ($r_s$ = -0.210, P = 0.06). The plot of cheatgrass versus Sandberg's bluegrass densities indicates an log-linear relationship between these plants (Figure 8), with a rapid elimination of Sandberg's bluegrass in favor of cheatgrass at a density of >500 cheatgrass plants per 0.25 $m^2$.

Irrigation of disturbed sites after seeding significantly influenced the resulting plant cover and density (Table 6). Irrigation of the seeded sites resulted in significantly enhanced establishment and growth of all native plants (Figure 9) including native forbs, which were not included in the seeding mixes on these sites. Alien weeds were in general unaffected by irrigation; however, cheatgrass abundance and cover were lower on the irrigated sites than on the unirrigated sites.

Inorganic fertilizers incorporated into the seedbed before seeding significantly enhanced the resulting cover and density of Sandberg's bluegrass and native perennial grasses in general, but did not significantly affect any cover of other species (Table 7 and Figure 10). Densities of cheatgrass, Sandberg's bluegrass, shrubs, and native grasses in general were higher on fertilized than on unfertilized sites, but the differences for cheatgrass and shrubs were only marginally significant (P < 0.1, Table 7).




SAKA D = 368568.87 - 185.05 * YEAR REMEDIATED/DISTURBED; $R^2$ = .113

**Figure 6.** Density of Russian Thistle Versus Year of Last Disturbance for Revegetated Sites Only. Rest as in Figure 4.

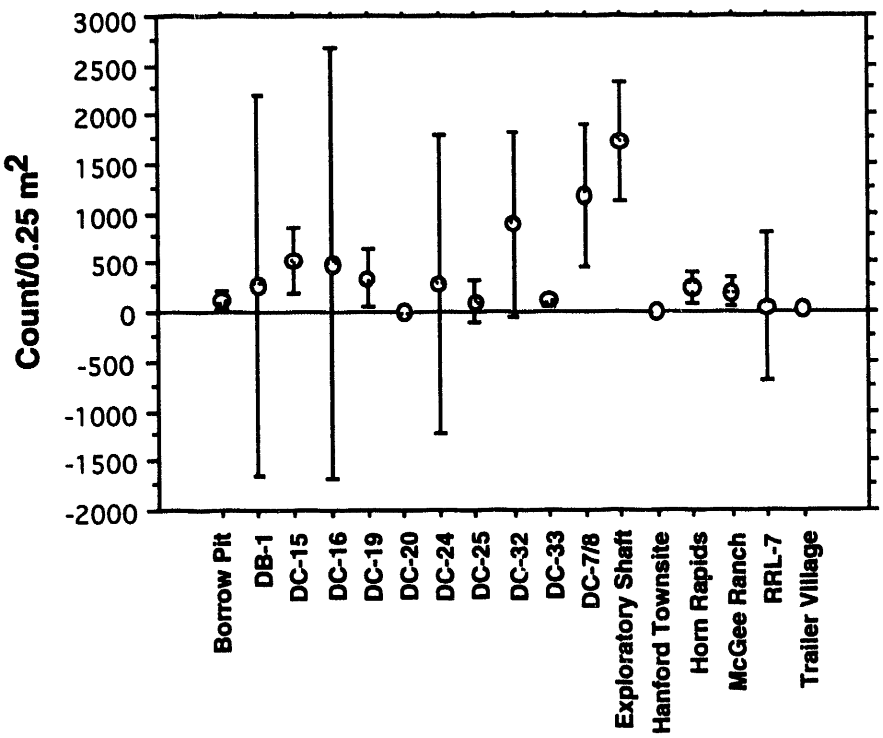
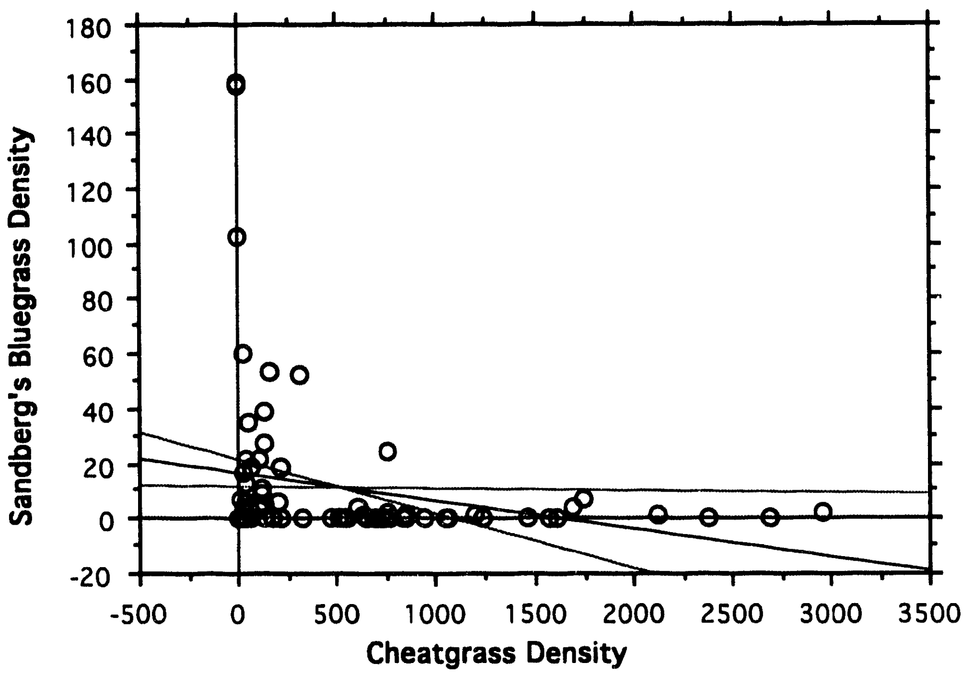



**Figure 7.** Average Density of Russian Thistle on Evaluation Sites. Bars indicate 95% parametric confidence interval.




POSA Density = 16.628 - .01 * BRTE Density; $R^2$ = .056

**Figure 8.** Density of Cheatgrass Versus Sandberg's Bluegrass on Revegetated Sites. Rest as in Figure 4.

**Table 6.** Nonparametric Mann-Whitney U Comparisons of Plant Cover and Density on Revegetated Sites According to Irrigation Treatment.

| Species | U statistic | P-value | Irrigated vs. Unirrigated |
|---|---|---|---|
| **Percent Cover** | | | |
| Cheatgrass | 627 | 0.04 | < |
| Russian thistle | 560.5 | 0.2 | = |
| Sandberg's bluegrass | 797.5 | <0.0001 | > |
| Shrubs | 584.5 | 0.06 | > |
| Perennial grasses | 794.5 | <0.0001 | > |
| Native forbs | 528.5 | 0.3 | = |
| Aliens | 482.5 | 0.8 | = |
| Natives | 686 | 0.004 | > |
| **Density** | | | |
| Cheatgrass | 588 | 0.1 | ≤ |
| Russian thistle | 615 | 0.05 | > |
| Sandberg's bluegrass | 731.5 | 0.0002 | > |
| Shrubs | 551 | 0.1 | ≥ |
| Perennial grasses | 724 | 0.0004 | > |
| Native forbs | 590.5 | 0.06 | > |
| Aliens | 488.5 | 0.7 | = |
| Natives | 698.5 | 0.002 | > |

**Table 7.** Nonparametric Mann-Whitney U Comparisons of Plant Cover and Density on Revegetated Sites According to Fertilizer Treatment.

| Species | U statistic | P-value | Fertilized vs. Unfertilized |
|---|---|---|---|
| **Percent Cover** | | | |
| Cheatgrass | 697 | 0.2 | = |
| Russian thistle | 629.5 | 0.6 | = |
| Sandberg's bluegrass | 757 | 0.02 | > |
| Shrubs | 603 | 0.7 | = |
| Perennial grasses | 736.5 | 0.04 | > |
| Native forbs | 715.5 | 0.07 | ≤ |
| Aliens | 615 | 0.7 | = |
| Natives | 610 | 0.7 | = |
| **Density** | | | |
| Cheatgrass | 721.5 | 0.1 | ≥ |
| Russian thistle | 647.5 | 0.4 | = |
| Sandberg's bluegrass | 810.5 | 0.004 | > |
| Shrubs | 671.5 | 0.1 | ≥ |
| Perennial grasses | 790.5 | 0.01 | > |
| Native forbs | 621.5 | 0.6 | = |
| Aliens | 642 | 0.5 | = |
| Natives | 729.5 | 0.09 | ≥ |

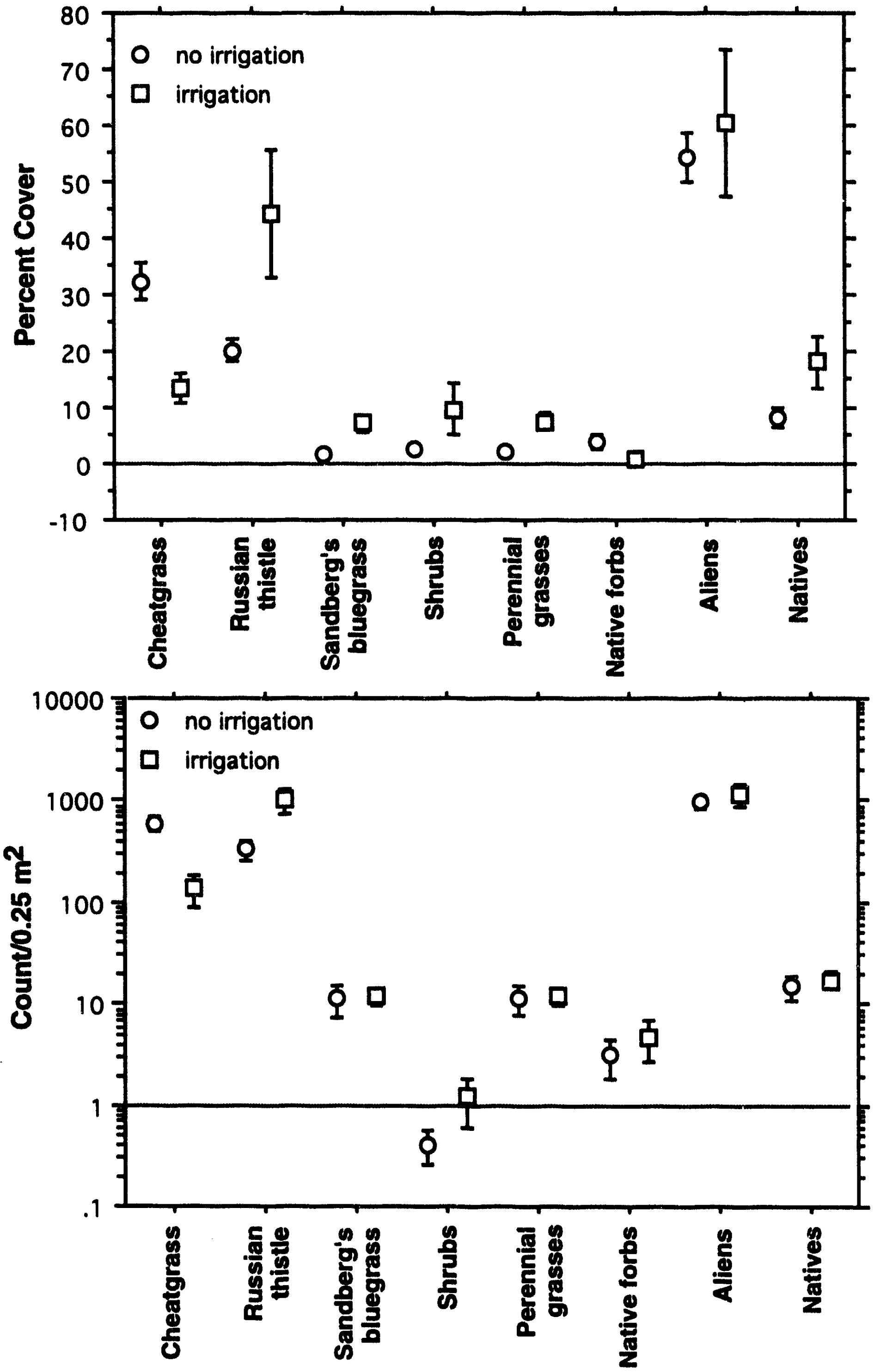



**Figure 9.** Effects of Irrigation on Percent Cover (upper) and Density (lower) of Various Plants on Revegetation Sites. Bars indicate one standard error of the mean.

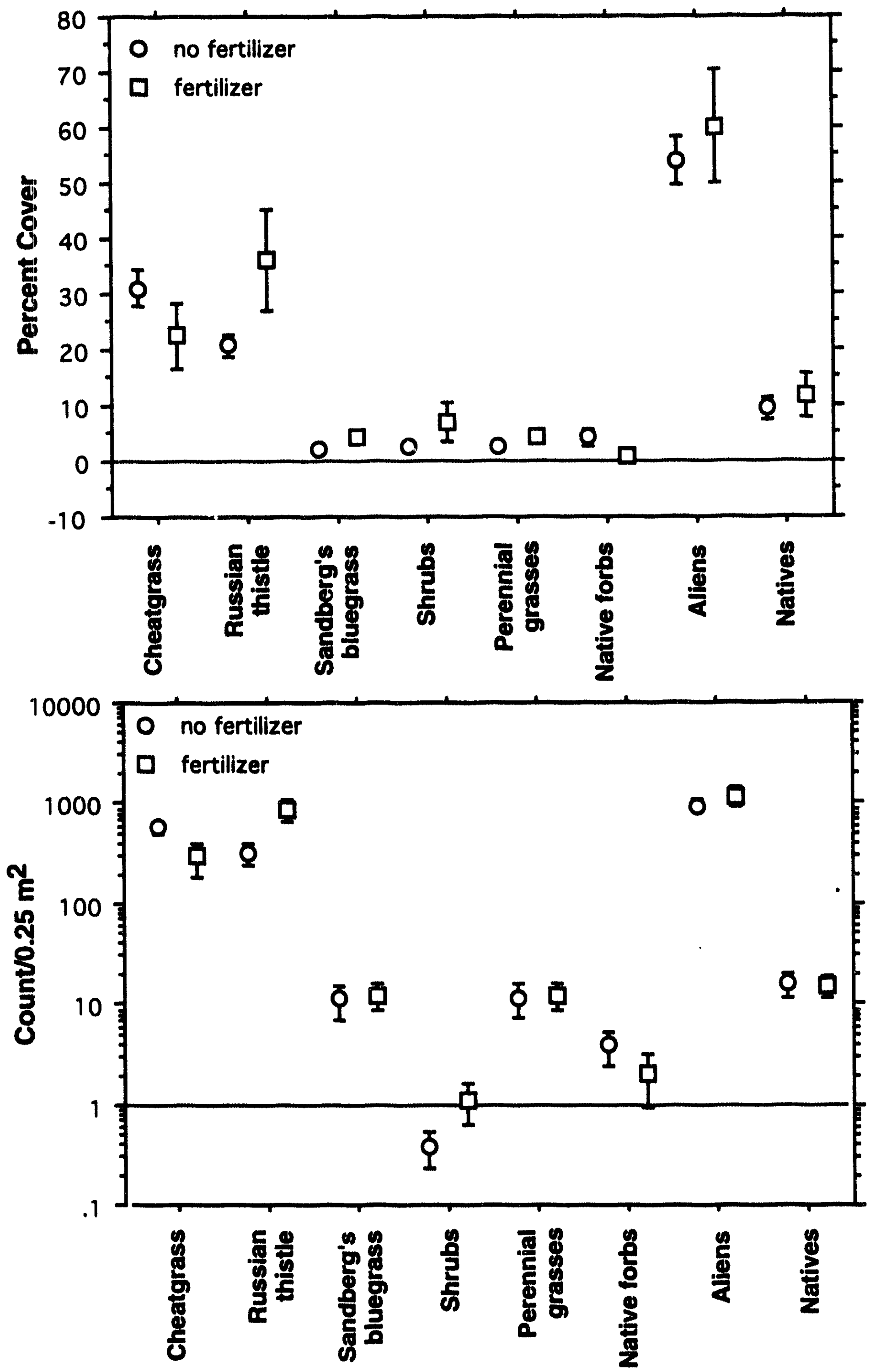



**Figure 10.** Effects of Fertilizer on Percent Cover (upper) and Density (lower) of Various Plants on Revegetation Sites. Bars indicate one standard error of the mean.

Organic amendments used on the revegetated sites included straw, wood fiber, and compost. Composts were either applied as a 6-cm topdressing, or were mixed with Warden silt loam from a pit at the McGee Ranch area and spread as an artificial topsoil. Consequently, topsoiling alone was not examined as its own treatment. However, one BWIP site not examined in the present study (RRL-10) received a topsoiling of McGee Ranch pit material in 1990 without any further amendment. Plant establishment on this site in 1991 was almost nonexistent (Brandt et al. 1992), suggesting that topsoiling with mined Warden silt loam alone provides an insufficient base for establishing a rapid plant cover.

Significant differences among amendments were found for Russian thistle, Sandberg's bluegrass, shrubs, perennial grasses, and native species in general, in terms of percent cover (Table 8). No significant differences were found for shrub density among the amendments (Table 8), although there were differences in the density of native forbs, which were not included in any seeding mix. The highest densities of Russian thistle were found in areas that received a pure compost topdressing and those where straw was incorporated into the seedbed (Figure 11). The lowest densities were found in the sites where compost and wood fiber were mixed with Warden silt loam. Sandberg's bluegrass density (Figure 11) and cover (Figure 12) were highest in the sites where compost was incorporated into the soil and were lowest in pure compost. The same relationship held for perennial grasses and native species in general. Shrub density and cover were highest in the sites where straw or wood fiber alone was used as a mulch. Native forbs were found only on the oldest revegetation sites, which were the sites with straw mulch. Because native forbs were not included in seeding mixes, they could only appear on revegetation sites through seed immigration.

**Table 8.** Nonparametric Kruskal-Wallis Comparisons of Plant Cover and Density on Revegetated Sites According to Organic Additives to the Seedbed.

| Species | H statistic | P-value |
|---|---|---|
| **Percent Cover** | | |
| Cheatgrass | 4.53 | 0.3 |
| Russian thistle | 17.9 | 0.001 |
| Sandberg's bluegrass | 14.2 | 0.007 |
| Shrubs | 10.1 | 0.04 |
| Perennial grasses | 12.8 | 0.01 |
| Native forbs | 5.19 | 0.3 |
| Aliens | 7.13 | 0.1 |
| Natives | 9.63 | 0.05 |
| **Density** | | |
| Cheatgrass | 6.02 | 0.2 |
| Russian thistle | 15.0 | 0.005 |
| Sandberg's bluegrass | 15.4 | 0.004 |
| Shrubs | 2.96 | 0.6 |
| Perennial grasses | 13.2 | 0.01 |
| Native forbs | 20.1 | 0.0005 |
| Aliens | 6.09 | 0.2 |
| Natives | 8.77 | 0.07 |

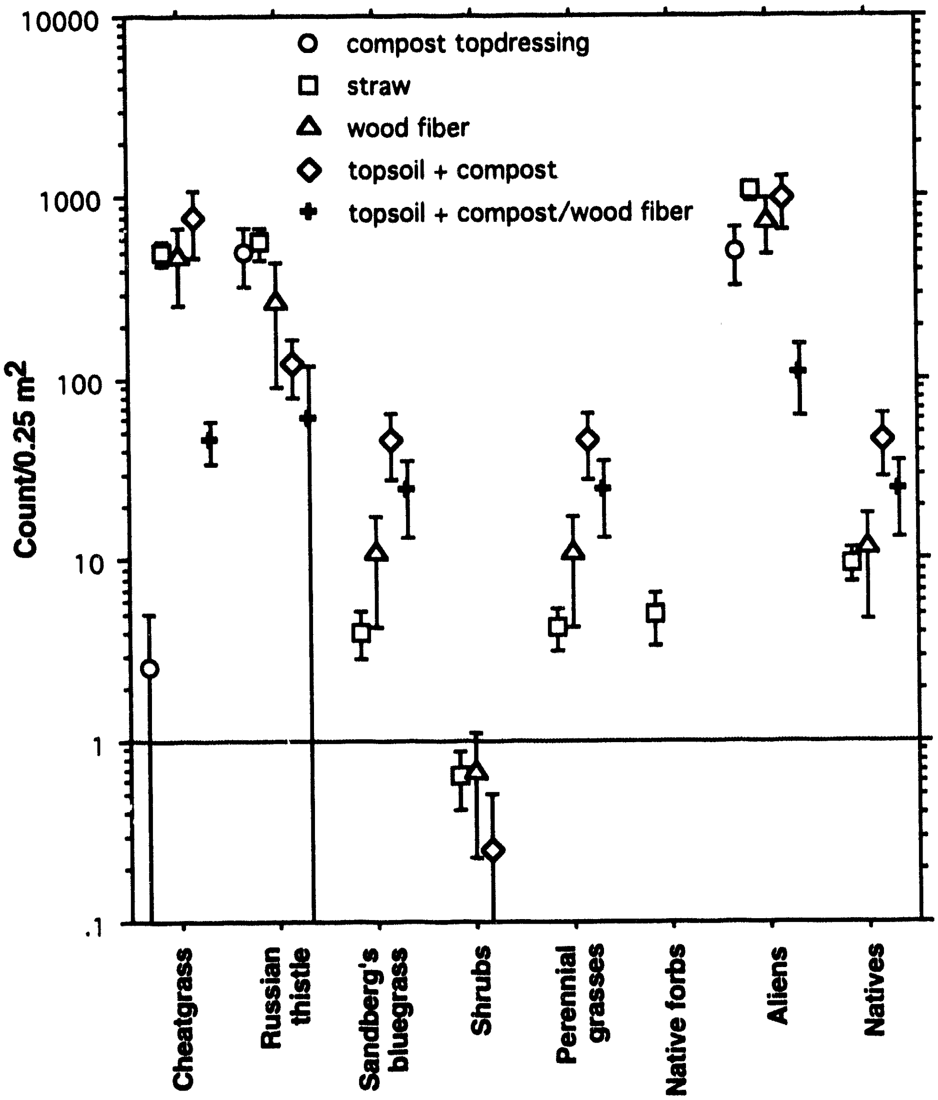



**Figure 11.** Effects of Seedbed Amendments on Density of Various Plants on Revegetation Sites. Bars indicate one standard error of the mean.

Comparing amendments to topsoiled sites alone, no significant differences were found between compost alone and compost with wood fiber in terms of effects on cover or density of Sandberg's bluegrass, cheatgrass, or Russian thistle (Mann-Whitney U tests, $1.0 > P > 0.3$).

Soil texture was generally confounded with organic amendments in the sites examined, such that compost treatments were not incorporated into all soils, for example, and wood fiber alone was not used on any of the silt loam soils. Broad analyses of soil differences were performed by combining texture and organic amendment into a single variable and analyzing with a Kruskal-Wallis nonparametric test. Significant heterogeneity among the texture-treatment groups was found in terms of percent cover for all species except the combined native species group (Table 9). The differences among groups was marginally significant for

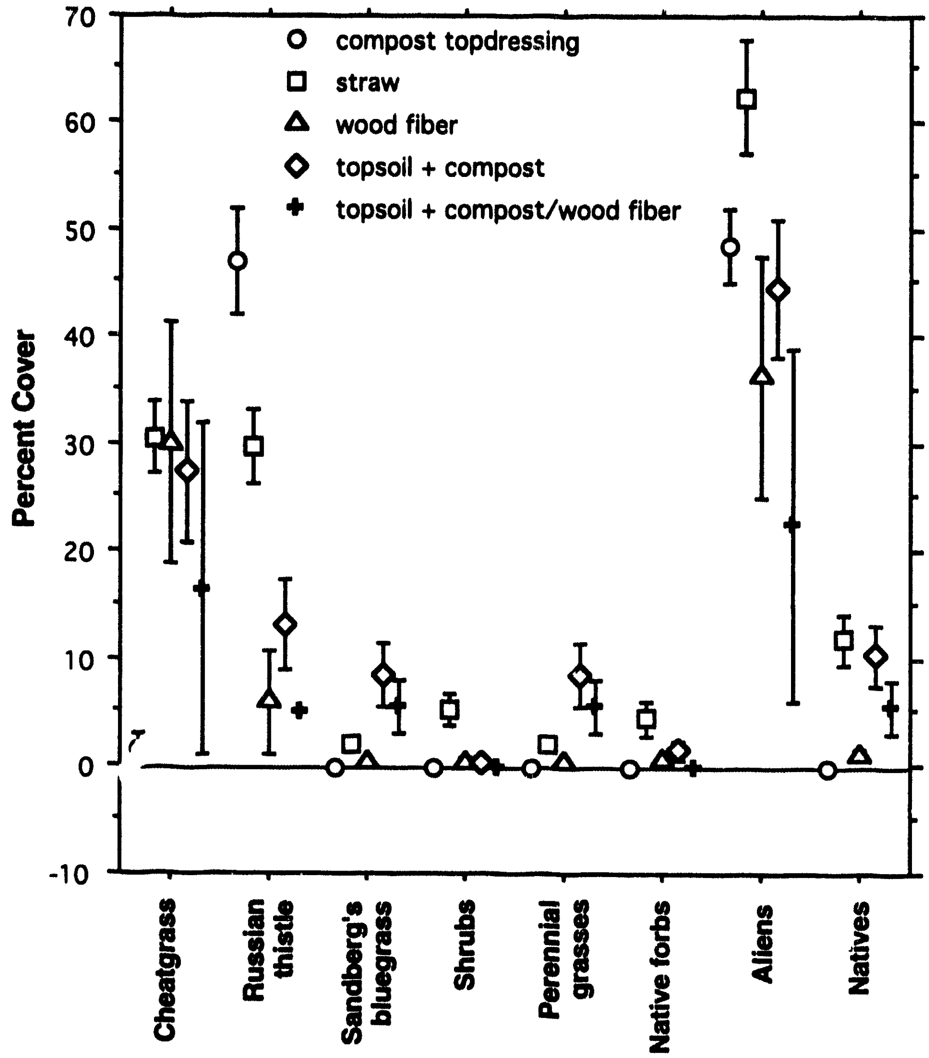



**Figure 12.** Effects of Seedbed Amendments on Percent Cover of Various Plants on Revegetation Sites. Barseindicate one standard error of the mean.

the native species. All species except shrubs showed wide variability among texture-treatment groups in terms of density.

The compost topdressing site supported no cover of native plants (see Figures 13 and 14), but did support a high cover by Russian thistle. Very little cheatgrass was found on this medium.

Cheatgrass density and cover were highest on loamy sands with straw amendments versus sands or silt loams with straw. The latter supported the least cheatgrass of the three soils. Wood fiber mulch in loamy sand produced a lower cover of cheatgrass than did straw mulch in the same soil texture. Among the silt loam soils, compost admix without wood fiber produced a higher density and cover of cheatgrass than did the other treatments on silt loams.

**Table 9.** Nonparametric Kruskal-Wallis Comparisons of Plant Cover and Density on Revegetated Sites According to Organic Additives to the Seedbed.

| Species | H statistic | P-value |
|---|---|---|
| **Percent Cover** | | |
| Cheatgrass | 21.6 | 0.003 |
| Russian thistle | 44.7 | <0.0001 |
| Sandberg's bluegrass | 29.4 | 0.0001 |
| Shrubs | 14.6 | 0.04 |
| Perennial grasses | 28.1 | 0.0002 |
| Native forbs | 17.9 | 0.01 |
| Aliens | 35.5 | <0.0001 |
| Natives | 13.2 | 0.07 |
| **Density** | | |
| Cheatgrass | 21.0 | 0.004 |
| Russian thistle | 34.8 | <0.0001 |
| Sandberg's bluegrass | 30.9 | <0.0001 |
| Shrubs | 6.22 | 0.5 |
| Perennial grasses | 27.0 | 0.0003 |
| Native forbs | 27.5 | 0.0003 |
| Aliens | 29.8 | 0.0001 |
| Natives | 18.9 | 0.009 |

Russian thistle was least abundant and had the lowest cover on the silt loam soils, with the greatest cover on the loamy sand sites. Use of a wood fiber mulch on sandy soils, however, produced the least density and cover of Russian thistle compared to any other texture-treatment group.

Sandberg's bluegrass and perennial :asses in general were most abundant and had the greatest cover on the silt loam soils and the lowest occurrence on loamy sand soils (except for the sand/compost topdressing mix, where they were absent). The highest abundance of Sandberg's bluegrass was obtained with compost admix to mined soil among both the silt loam soils and over all soils. The silt loam site that received straw only supported less Sandberg's bluegrass than did the other silt loams, and the same density as did sands with wood fiber mulch. Wood fiber mulch produced a slightly higher density of Sandberg's bluegrass in sands versus straw mulch, but the reverse was found in loamy sand soils.

Shrub abundance and cover were relatively low on all soils.

In general, alien species were most abundant on loamy sands regardless of treatment, were least abundant on silt loams, and were most abundant on loamy sands. Wood fiber resulted in a lower abundance of alien species than did straw when used as a mulch. Wood fiber also apparently limited the growth of some native species on loamy sands. In contrast, wood fiber outperformed straw in terms of benefit to seeded native plants on sands. Straw was not used on silt loam sites, so no comparison was available.

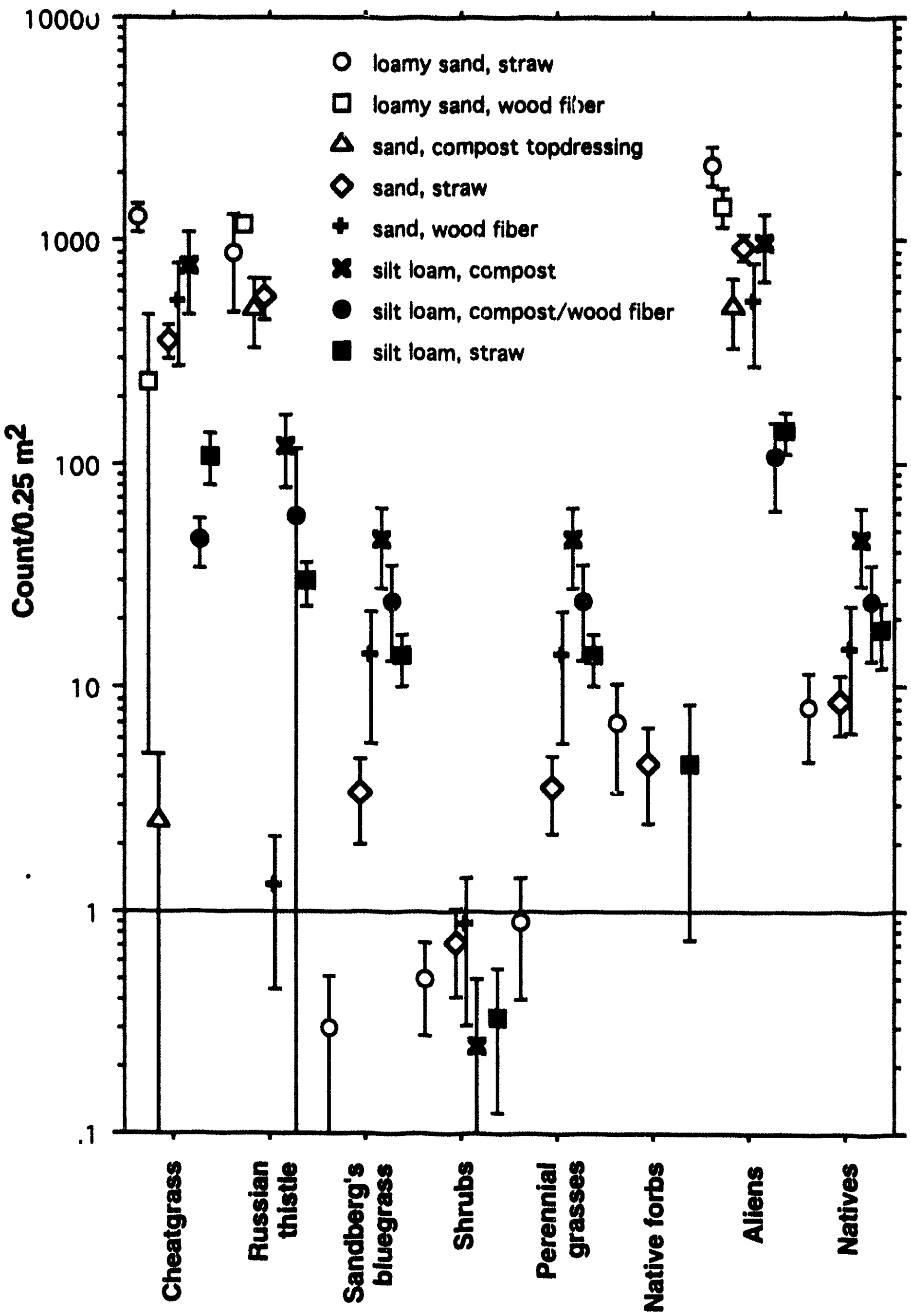



**Figure 13.** Effects of Seedbed Amendments and Soil Texture on Density of Various Plants on Revegetation Sites. Bars indicate one standard error of the mean.

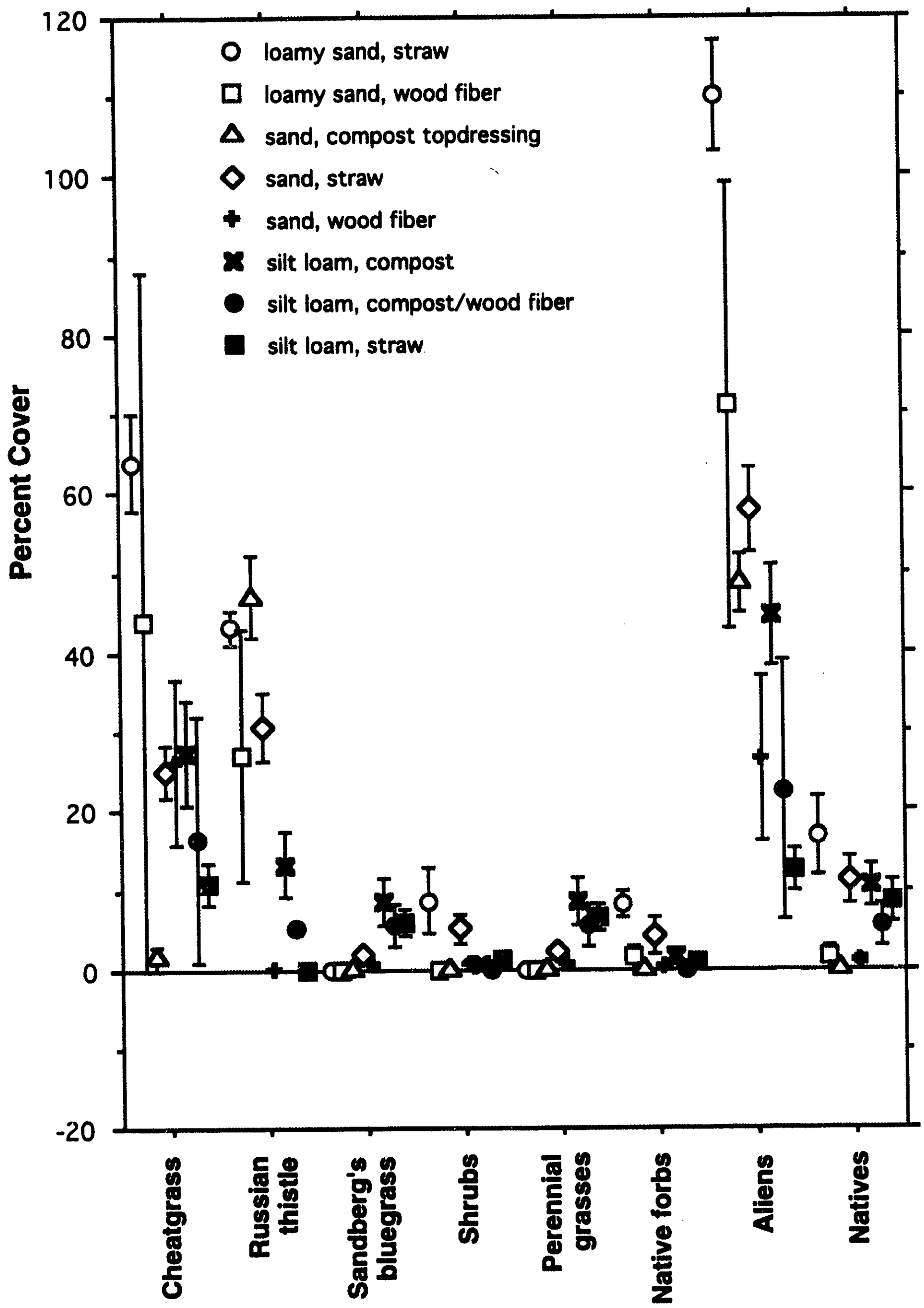



**Figure 14.** Effects of Seedbed Amendments and Soil Texture on Percent Cover of Various Plants on Revegetation Sites. Bars indicate one standard error of the mean.

## *Discussion*

Reseeding disturbed areas, especially on the heavier soils, using seeds of native plants significantly enhanced the establishment of native bunchgrasses, especially Sandberg's bluegrass, at the expense of cheatgrass. Revegetated sites on average supported less cheatgrass than would have been expected without any revegetation effort at all. Furthermore, without seeding, Sandberg's bluegrass was unable to establish on any of the sites examined. The only native grass that was found to establish within a cheatgrass sward was sand dropseed, which was found to be displacing cheatgrass at the Hanford Townsite old field site under unmanipulated conditions. This displacement was far from complete, however, and had required at least 50 years to be accomplished. The only other documented cased of a cheatgrass monoculture being successfully invaded by a native bunchgrass was in Idaho and involved bottlebrush squirreltail (*Sitanion hystrix*) (Hironaka and Tisdale 1963).

Cheatgrass has not replaced Sandberg's bluegrass after servere land disturbance in some specific microhabitats on Hanford, however. Rickard (1975) observed that the banks of railroad cuts on the Site had cheatgrass-only communities on south-facing slopes and predominantly Sandberg's bluegrass communities on north-facing slopes. Edaphic conditions differing between these microhabitats are insolation, surface soil temperatures, and evapotranspiration, with the lowest evapotranspiration and temperature on the north-facing slopes. The direct effects of temperature and insolation in these microhabitats may be less significant in terms of plant competition than is the difference in evapotranspiration. Based on their studies of water usage by cheatgrass and Sandberg's bluegrass in test chambers, Link et al. (1990) concluded that water stress would not account for the differences between the communities on north- and south-facing slopes; however, their studies were based on experiments in soils deeper than those present on the railroad cuts and did not examine competition for water or quantity and quality of seed set. They found that cheatgrass had deeper roots than Sandberg's bluegrass in deep soils, and that water stress developed earlier in Sandberg's bluegrass than in cheatgrass in such soils, since cheatgrass was able to make use of deeper water. In contrast to the Link et al. experiment, soils of railroad cuts are quite shallow, thus eliminating any advantage of cheatgrass's deeper roots. In shallow soils, Sandberg's bluegrass may be capable of outcompeting cheatgrass by depleting water in the surface horizon. These observations suggest that cheatgrass may be outcompeted by Sandberg's bluegrass under certain circumstances, especially in shallow soils.

In general, cheatgrass cover and abundance increased with the age of the disturbance, as did Russian thistle density, at least on recently (within 5 years) disturbed sites. Cheatgrass abundance showed a significant negative relationship with Sandberg's bluegrass abundance, which may be attributed to the outcome of competition between these species for water and nutrients (Billings 1990; Daubenmire 1970). In contrast, Russian thistle density showed no significant relationship with Sandberg's bluegrass abundance, indicating that these species are not competitors for the same resources. Russian thistle is a summer annual able to take advantage of the sparse and sporadic summer moisture. Sandberg's bluegrass and cheatgrass are both fall-spring species that grow and set seed before the onset of summer temperatures. Russian thistle's primary period of growth and water use is therefore after Sandberg's bluegrass has set seed. Also, dead Russian thistle plants may provide suitable microclimates that aid in the establishment of Sandberg's bluegrass.

Aside from seeding, the greatest single aid in revegetation was irrigation. The application of water on the few sites where water was used was minimal, being limited to a maximum addition of 2.5 cm/mo for April through July. The actual method was to add sufficient water at the start of each month to make the previous month's total precipitation reach 2.5 cm. The months actually supplemented were therefore March through June. Irrigation strongly enhanced native plants at the expense of cheatgrass. Russian thistle cover was relatively unaffected by irrigation.

The one-time application of inorganic fertilizers applied at low rates had a limited effect on seeded native species, improving their cover and density slightly over those of nonfertilized sites. Russian thistle abundance and cover increased with fertilizer application, but not significantly so. Cheatgrass showed a variable, but generally negative, response to fertilization, at least under the conditions in which fertilizers were used on the BWIP sites. More extensive and massive fertilizer applications may produce the opposite results, with the slower-growing native grasses obtaining the least benefit and the alien annual weeds benefiting the most. Experimental additions of 100 kg N/ha/yr for 5 years in disturbed shrub-steppe lands in Colorado produced stands of alien weeds after 5 years, in contrast to the native communities that developed on unfertilized controls (McLendon and Redente 1991). The application rates used in the McLendon and Redente study were over twice the rate of the maximum usage in the Hanford areas that were examined in the present study, and no Hanford area received more than a single application.

The soil amendment with the greatest benefit to seeded native species was compost; however, compost alone as a seedbed produced a dismal cover of primarily Russian thistle. Wood fiber mulch that had been applied as a top cover after seeding apparently allowed a higher density of Sandberg's bluegrass to establish than did a straw mulch cover. The difference in effectiveness of these two mulches may be a result of the apparent decreased erodability of soils covered with wood fiber versus the straw. Sandberg's bluegrass is a very short-statured grass with very slow growth. Consequently, this species is prone to burial by wind-blown soils (Brandt et al. 1992).

In terms of cost ranking, topsoiling was by far the most costly portion of the revegetation, based on BWIP experience, followed by seedbed preparation and revegetation with native species, compost incorporation, irrigation, and inorganic fertilizer. Topsoiling may be required despite its cost on sites without suitable soil cover. Seedbed preparation and revegetation is required to prevent takeover of the site by alien species. Irrigation, where water is available, is the least expensive activity with the greatest single positive benefit.

The most difficult soil texture to revegetate was loamy sand. These soils supported the highest cover of alien species and the lowest cover of seeded natives. Sandy soils were intermediate, with silt loams performing the best, at least with the additives and amendments that were used.

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