DETERMINING THE SUITABILITY OF NATIVE GRASSES
FOR HIGHWAY REVEGETATION SOD

by

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ABSTRACT

In past years, the California Department of Transportation (Caltrans) has used hydroseeding, imprinting and drill seeding methods to revegetate highway construction sites with varying degrees of success. Ecological concerns have led researchers to consider using native species for revegetation as they are better suited to local environments, require less maintenance and do not pose a threat to adjacent ecosystems. In addition, the urgency for stabilizing areas of high erosion potential and that of establishing native plant cover quickly in order to prevent non-native plant and weed establishment, have led researchers to consider using native grass sod for highway revegetation.

Twenty-one species of native grasses were selected in order to determine their suitability for sod production. Grasses were grown in six growth chambers; each mimicking one of the climates of the six selected California ecoregions. Mixtures of varying species included either one rhizomatous species with three bunch grasses, one rhizomatous species and five bunch grasses, two rhizomatous species with three bunch grasses, or two rhizomatous species with five bunch grasses. The mixtures were grown and tested for yield, species composition and percent cover over time. At the end of the seven-month production cycle, a final harvest evaluated root architecture as well as sod strength.

Results varied between mixtures and from ecoregion to ecoregion. However, 18 of the 20 native species included in the sod mixtures seemed to be tolerant of sod production methods and became established. With few exceptions, total ground cover was similar between mixtures for each ecoregion. Root architectures for individual species varied, but they balanced each other such that there were few significant differences in total root mass between mixtures. Sod strength readings varied from ecoregion to ecoregion depending on sod composition. Mixtures with more species tended to have lower sod strength. Sod strength tended to increase as the percent composition of rhizomatous species increased. Mixtures with the rhizomatous species *Festuca rubra* tended to have greater sod strength than mixtures with other rhizomatous species.

INTRODUCTION

Literature Review

Nearly 6.2 million km of public roads exist in the United States (National Resource Council 1997) and ten percent of this total road length is in National Forests (Forman and Alexander 1998). Forman and Alexander (1998) reviewed the major ecological effects of roads and estimated that 15-20% of the United States is ecologically impacted by roads. While Forman and Alexander generally avoided “road-construction-related activities” for the purpose of their review, there are some major ecological effects due to road construction, which would conceivably increase the estimated area of the United States that is ecologically impacted by roads.

Ecological Impacts of Roads

Road construction contributes to erosion by changing slopes and altering normal hydrological patterns. After road construction, high levels of erosion can occur resulting in large amounts of sedimentation. Without pinpointing the source of this erosion and applying proper control measures, the resulting sediment can pollute streams and waterways (Grace 2000). This sediment pollution can negatively impact the spawning sites for key fish and disrupt aquatic plants and macro-invertebrates by increasing the turbidity of the water, filling deep pools and altering gravel beds (National Research Council 1997, Forman and Alexander 1998).

Swift (1984) identified roadside slopes as the source of 70% to 90% of total soil loss from road rights-of-way. Swift also recorded that soil loss was greatest during the first few months following construction. Swift (1985) later asserted that exposed soil should be revegetated quickly to mitigate this soil loss since vegetation stabilizes soil and reduces erosion. Further, Sullivan and Foote (1984) emphasized that the lack of established vegetative cover was a key factor leading to increased soil erosion from roadsides.

Road construction effects on plants, animals and streams are not limited to the disturbance during construction, but also include the pollution effects of traffic and road maintenance (Angold 1997) combined with increased runoff from road surfaces and the concentrated flows caused by road infrastructure (National Research Council 1997). Highway runoff has been shown to contain tire particles, heavy metals, petroleum products, salts, fertilizers, organic wastes (including herbicides) and bacteria (Detwyler 1971, Angold 1997, Forman and Alexander 1998). Petroleum products, salts and herbicides can damage roadside plants and pollute streams, killing fish and other aquatics (Forman and Alexander 1998). Fertilizers in runoff can increase plant growth near roadsides (Forman and Alexander 1998) and increase algae growth in wetlands and streams (Austin et al. 1996). Fertilizer and herbicide in runoff also have the potential to pollute ground water (National Research Council 1997, Forman and Alexander 1998).

Attempts to reduce the erosion of and sedimentation from roadsides after construction have been various. Multiple methods of slope stabilization have been employed with varying degrees of success. Various methods of revegetation with native and non-native species have also been utilized. (In this document *non-native* always indicates species not endemic to North America.) Established plant cover on roadsides exhibits the potential to reduce erosion and sedimentation while filtering the many pollutants often carried by runoff water. Thus, in addition to slope stabilization, revegetation is an essential tool for controlling and filtering sediment. In fact, Gross et al. (1991) demonstrated that sediment losses from even low density turfgrass plots were substantially less than those from bare soil plots in a simulated high precipitation event.

Sediment Control and Filtration

Slope Stabilization.

Gabion walls have been used to stabilize slopes disturbed by construction on very steep terrain (Landis et al. 2005). Other methods of slope stabilization have included stake and brush wattles, wood litter and debris, erosion mats (Grace 2000), spreading brush on exposed soil, erosion-resisting fabrics, natural filter strips or buffer strips (Swift 1985, Barling and Moore 1994), staked weed mulches, staked brush and litter mulches (Hursh 1938), straw, wood excelsior, jute fabric, coconut fiber blankets and coconut strand mats (Krenitsky et al. 1998). The main purpose of these methods of slope stabilization is to mitigate erosion by reducing the energy of falling raindrops and slowing the flow of water over the soil by increasing surface roughness (Morrow et al. 2006). Some of these methods of slope stabilization are meant to control erosion until vegetation can establish. However, the efficacy of some of these slope stabilization methods is minimal and some may actually hinder plant establishment (Landis et al. 2005).

Revegetation.

Revegetation also contributes to the stabilization of disturbed slopes and reduces erosion because the increase in surface roughness contributed by the vegetation reduces the energy of falling raindrops and slows runoff while increasing the infiltration of moisture into the soil (Beard and Green 1994, Morrow et al. 2006). This increase in infiltration can result in a delay of runoff initiation and an overall reduction in runoff volume (Krenitsky et al. 1998).

Sod strips along road contours, root clumps, grass seeding of non-native and/or native species (Grace 2000), hydromulch or hydroseeding (Grace 2000, Caltrans 2004, Landis et al. 2005), seeded erosion blankets (Landis et al. 2005), Kentucky bluegrass/tall fescue sod (Krenitsky et al. 1998) and native sod (Stone 2003, Caltrans 2004) have all been used to some degree in order to re-establish vegetation.

Direct seeding and hydroseeding are sometimes effective methods of establishing plant cover. However, on steep slopes, seeds may be washed away before they can germinate and establish (Caltrans 2004). Combining seeds with erosion control blankets may mitigate seed washing problems (Landis et al. 2005). Sod has shown promise both in reducing erosion and sedimentation and in quickly establishing vegetation, particularly on steep slopes (Krenitsky et al. 1998, Stone 2003, Caltrans 2004). Root clumps of honeysuckle were heavily utilized in the southeastern United States to revegetate roadside slopes, but they were unable to become established at all sites (Hursh 1938). Hursh concluded that too much confidence had been placed in the ability of one species in revegetation efforts. Accordingly, successful revegetation programs will most likely utilize a variety of species and a variety of establishment methods to control erosion and remove sedimentation.

Sediment Removal and Control. In addition to stabilizing soils and reducing the creation of sediment, established vegetation can also filter sediment from runoff water. Buffer strips of natural vegetation have been shown to protect streams from sediment pollution by slowing water flow and removing suspended solids (Clinnick 1985, Barling and Moore 1994). Sediment runoff from agricultural fields has been successfully controlled by planting vegetative filter strips (VFS). The efficacy of sod VFS for the reduction of sediment in runoff from agricultural fields has been demonstrated. Dillaha et al. (1989) showed that vegetative filter strips removed 53% to 98% of the sediment entering the VFS. Robinson et al. (1996) showed that VFS 3.0 m and 9.1 m in length removed 70% and 85% (respectively) of total sediment. Abu-Zreig et al. (2004) further contributed that the average sediment trapping capacity of a VFS was 84%. Although VFS length seems to be the greatest indication for the efficacy of sediment removal, Pearce et al. (1997) discovered that taller stubble on mowed VFS increased their sediment removal capacity.

In addition to sediment removal, sod may also reduce sedimentation by delaying runoff initiation. Krenitsky et al. (1998) found that sod comprised of Kentucky bluegrass or tall fescue installed on steep slopes successfully delayed the initiation of runoff compared to other stabilization methods (jute, excelsior, straw, coconut fiber and coconut strand) and bare soil. Sod also reduced the total volume of runoff by 61.0% while reducing soil sediment losses in comparison to bare soil. Stone (2003) discovered that native sod also prevented erosion and reduced sediment run-off compared to broadcast seeding covered by either a straw/coconut fiber mat or hydromulch when applied to steep slopes. In addition to sediment reduction and removal, VFS can also act as a filter, removing pollutants from runoff.

Vegetative Filtration. The use of grasses as vegetative filter strips to remove non-point source pollution, including herbicide and fertilizer residues, from run-off in agricultural crops is well documented. Dillaha et al. (1989) demonstrated that VFS removed 97% of the phosphorus and 78% of the nitrogen entering the VFS, though they conceded that this was an expected result as these products were sediment-bound. In their study, soluble nitrogen and phosphorus concentrations in runoff entering VFS were sufficient to cause increased growth of aquatic plants. However, they also demonstrated that the lengths of VFS used were moderately effective at removing soluble nitrogen and phosphorus. Daniels and Gilliam (1996) showed that VFS removed 60% to 90% of sediment and nearly 50% of nitrogen and phosphorus from runoff. Patty et al. (1997) found that VFS reduced soluble nitrate and phosphorus concentrations by 22% to 100%. Further, they concluded that VFS were effective at reducing concentrations of strongly adsorbed pesticides (diflufenican and lindane) carried in runoff water.

Mickelson and Baker (1993) showed that VFS 4.6 m and 9.1 m in length removed 35% and 59.5% of soluble atrazine from runoff. Arora et al. (1996) found that VFS retained 11% to 100% of atrazine, 16% to 100% of metolachlor and 8% to 100% of cyanazine, while Webster and Shaw (1996) showed that VFS reduced metolachlor concentrations by 55% to 74% and metribuzin by 50% to 76%. Rankins et al. (2001) added that VFS composed of various perennial grasses reduced fluometuron concentration in runoff by at least 46% compared to unfiltered runoff.

Vegetative filter strips can also absorb many pollutants carried in urban run-off (Rankins et al. 2001), including those produced from hard surfaces in urban areas (Schueler 1987) and from highway surfaces (Walsh et al. 1997). If properly constructed, VFS or bioswales are also effective at removing heavy metals (Yousef et al. 1985, Barrett et al. 2004).

Erosion Control with Turfgrass

Due to the fact that established turfgrass is effective for stabilizing soil and reducing erosion and sedimentation while increasing infiltration, it has been used widely in revegetation efforts (Barling and Moore 1994, Bugg et al. 1997, Krenitsky et al. 1998, Rankins et al. 2001, Abu-Zreig et al. 2004, Landis et al. 2004). The use of turfgrass to control erosion and reduce sedimentation and the pollution of waterways is well-documented (Hursh 1938, Swift 1985, Barling and Moore 1994, Rankins et al. 2001, Abu-Zreig et al. 2003). Gross et al. (1991) demonstrated that sediment losses from even low density turfgrass plots were substantially less than those from bare soil plots in a simulated high precipitation event. Others have shown that turfgrass decreases runoff by increasing the resistance to the flow of water while simultaneously increasing the infiltration of water into the soil (Beard and Green 1994, Krenitsky et al. 1998, Stone 2003, Morrow et al. 2006). However, the benefits of turfgrass are not limited to erosion control and sedimentation reduction.

Other Benefits of Turfgrass

In addition to erosion control and sediment reduction, turfgrass provides many other benefits. Turfgrass reduces dust, dissipates radiant heat and contributes to a cooling effect in urban areas (Beard and Johns 1985), while reducing noise and glare (Cook and Van Haverbeke 1971, Robinette 1972). This glare reduction enhances visibility on roads, which may lead to greater highway safety (Beard 1973). Established turf is capable of excluding many weeds (The word *weeds* in this document refers to native and non-native species that are considered to cause economic loss in agricultural systems.), including those responsible for human allergens (Beard and Green 1994).

Revegetation with Non-Native Species

Non-native species have been used extensively in revegetation projects. Landis et al. (2005) posited that non-native species were primarily used because they were inexpensive, readily available and easy to establish on disturbed sites. Wilson (1989) stated that non-native species were used for revegetation because they were able to stabilize and nitrify the soil (depending on the species). The difficulty of obtaining quality native seed in large quantities has also been documented (Lippett et al 1994, Stevenson et al. 1995), which may be another potential reason that non-native species are used so commonly for revegetation.

Prior Use of Non-Native Species

The prior use of non-native species in revegetation efforts and as vegetative filter strips is well-documented (Tyser and Worley 1992, Tyser et al. 1998, Landis et al. 2005, Rentch et al. 2005). Non-native species including Kentucky bluegrass (Tyser and Worley 1992, Krenitsky et al. 1998, Abu-Zreig et al. 2004), tall fescue (Krenitsky et al. 1998, Abu-Zreig 2004), orchard grass, Crabgrass, Bermuda grass, smooth brome, rye grass (Abu-Zreig et al. 2004), love grass, sericea lespedeza, bird's foot trefoil, crown vetch (Rentch et al. 2005) and common timothy (Tyser and Worley 1992) have all been used to some degree in revegetation efforts.

Potential Problems Associated with the Use of Non-Native Species. Aside from the fact that the sowing of non-native species along roadsides has altered the vegetation, these areas can be regarded as separate ecosystems due to the major changes in soil structure, fertility and hydrology incurred during construction (Forman and Alexander 1998). Roadside corridors are particularly susceptible to invasion by non-native species (Spellerberg 1998, Tyser et al. 1998). Many studies have shown that roads are a primary pathway for the spread of non-native species (Wilcox 1989, Tyser and Worley 1992, Greenberg et al. 1997, Spellerberg 1998, Tyser et al. 1998, Larson et al. 2001, Gelbard and Belnap 2003, Landis et al. 2005, Rentch et al. 2005).

Rentch et al. (2005) posited that the composition of species after revegetation was most likely to be influenced by the species initially planted during the revegetation phase of construction. They further asserted that non-native species should be preempted by the establishment of native ones. Since revegetating road construction sites with non-native species has shown the potential to compromise adjacent ecosystems, Bugg et al. (1997) asserted that the reestablishment of native species on roadsides could preclude the establishment of non-native ones. Gelbard and Belnap (2003) agreed, stressing that efforts to prevent and control non-native plant invasions should focus on roads.

Additionally, Tyser et al. (1998), citing other research (Wilson 1989, Jefferson et al. 1991), suggested that non-native species may be more susceptible to stress and may interfere with the recruitment and establishment of native species. Indeed, Wilson's data (1989) showed that the planting of introduced species resulted in the suppression of native species. Since roads are a primary pathway for non-native species (Greenberg et al. 1997), efforts to prevent and control non-native and invasive species should be concentrated on roads (Gelbard and Belnap 2003). Consequently, the use of native species for road construction revegetation is preferable to that of non-native species for both ecological and aesthetic reasons (Tyser et al. 1998).

In addition, the Federal Noxious Weed Act, enacted in 1975, mandates that species designated as "noxious" be controlled. The law requires that both private landowners and government agencies apply control measures for these noxious species. Several non-native species are listed as noxious weeds and by law must be controlled. Based on estimated losses due to non-native species considered to be weeds, Pimentel et al. (2000) estimated that the total annual cost of non-native weeds to the US agricultural economy was approximately $26.4 billion, including direct crop losses ($23.4 billion) and control costs ($3 billion). Many of these non-native species also inhabit disturbed soil along roads. The cost of controlling these species is immense. Pre-empting their establishment has great potential economic benefit for both government agencies and private landowners. Because of this, both the USDA Forest Service and the National Park Service have implemented policies to prevent the spread and establishment of non-native species and noxious weeds.

The National Forest Service policy on non-native species is demonstrated by the Invasive Species Executive Order issued in 1999. This Executive Order stipulates that the National Forest Service "…prevent the introduction of invasive species…" by monitoring and controlling invasive species, restoring habitat with native species, conducting appropriate research and promoting public education regarding non-native species. This Order also stipulates that the Forest Service not "…authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species…" (USDA, Forest Service 1999).

The National Park Service has also mandated that non-native species be controlled (National Park Service 1996). Non-native species in national parks can alter fire regimes, damage natural resources, alter water regimes, increase soil nitrogen levels, release toxic chemicals, harbor diseases and displace native species that are vital for herbivore consumption (National Park Service 1996). It is estimated that over seven million acres of National Park Service lands have been infested by non-native species. Millions of dollars are spent on non-native species management each year by the National Park Service. Because of this, the National Park Service (1996) has also mandated that native species (from a locally-collected seed source, if possible) be used for revegetation projects on National Park Service lands. Researchers have also recognized the potential ecological benefits of revegetating with native species.

Revegetation with Native Species

Ecological Implications. In addition to concerns about erosion and sedimentation, Tyser et al. (1998) cited the rapid establishment of non-native species (particularly noxious weeds) as grounds for prompt revegetation efforts after road construction. Plants near roads can grow rapidly because of disturbed soil, ample light and increased moisture at the road edge (Forman and Alexander 1998). Non-native species are typically adapted to highly disturbed sites such as those near a recently constructed or reconstructed road and can spread rapidly on these sites (Greenberg et al. 1997). Propagules may also be dispersed along roadways via road infrastructure (Wilcox 1989) and by vehicular traffic (National Research Council 1997, Forman and Alexander 1998). Re-establishing native vegetation may pre-empt the establishment of non-native species, which have the potential to spread into nearby native ecosystems (Pysek 1995).

Indeed, Booth et al. (2003) found that *Bromus tectorum* and *Taeniatherum caput-medusae*, two common non-native annual species, could be suppressed by the native, perennial grass *Elymus elymoides*, once the latter was established. This effect is mainly attributed to competitive mechanisms caused by similar phenology between the two species (Hironaka and Tisdale 1963), particularly that they are both capable of autumn germination (Hironaka and Sindelar 1973) and that *Elymus elymoides* is also very responsive to autumn precipitation (Coyne 1969). Booth et al. (2003) further hypothesized that the establishment of *E. elymoides* was a critical step in community rehabilitation in areas that are predominantly occupied by these annual species. This indicates that other native perennial species, once established, may be capable of suppressing non-native species and other weeds while facilitating native community restoration.

Tilman (1997) suggested that the establishment of seeded species was negatively correlated with initial species richness, indicating that more diverse communities are less susceptible to invasion. This is likely due to competitive interactions. Brown et al. (1998) conducted an experiment to determine the competitive interactions between species in erosion control seedings. Among their conclusions, they iterated that varying mixtures of native species used moisture more evenly and completely from the soil profile than did monostands. They asserted that this resource partitioning would enable a mixture of native species to compete more effectively with non-native species and weeds because the more varied the species mixture, the more likely that one of the native species would compete with one of the undesirable species present for the existing resources.

Further, Humphrey and Schupp (2002) suggested that native species are more suited to local environments than are non-native species and will, accordingly, require less maintenance than non-native species. Additionally, native species do not pose a threat to the biodiversity of adjacent plant communities (Berger 1993, Wilson and Gerry 1995, Grant et al. 2003). The establishment of native species on roadsides may also ameliorate the impacts of adjacent intensive agriculture programs on vertebrate populations such as nesting birds (Forman and Alexander 1998, Forman 2000).

Native Species Establishment. Though there are many perceivable benefits of using native species for revegetation, optimal methods to plant and establish these species must still be delineated. In 2002, Montalvo et al. suggested that long-term establishment on disturbed sites was influenced primarily by species, seed origin, planting methods, seedbed preparation, and soil. In their study, initial establishment was affected by the combination of seed origin and species with planting methods. Their findings also showed that establishment over two growing seasons was influenced by planting methods, seedbed preparation and soil properties. Additionally, Dyer and Rice (1997) concluded that seedlings of native species were more likely to establish successfully in a community of varied native species than in a community of annual weeds, suggesting that preventing annual weed establishment would enable native species to establish more effectively.

In order to use native grasses successfully for long-term roadside revegetation, the proper species must be selected. The within species genetic variance of native grass species and the importance of using a locally appropriate seed source has been well documented (Quinn and Ward 1969, Akeroyd 1994, Lippett et al. 1994, Millar and Libby 1994, Knapp and Rice 1996, Bugg et al. 1997, Montalvo et al. 2002, Landis et al. 2005). Seed of local provenance is more likely to be genetically adapted to the conditions of the site and, therefore, more likely to successfully establish. Seeding rate may also influence the successful establishment of native species; however, optimal seeding rates for native species are often not known.

Seeding Rates. Noting that optimal seeding rates for revegetation and ecological restoration projects are often not known, Burton et al. (2006) compared the establishment of mixtures of native species under different seeding rates ranging from 0 to 6000 pure live seed per square meter (PLS/m^2) on sites degraded through forestry operations or agricultural activities. They observed that higher sowing densities (3000 and 6000 PLS/m^2) did increase plant cover in the first year, but that lower rates (1500 PLS/m^2) produced comparable plant densities by year two. They concluded that lower seeding rates could be used if rapid results were not required, but that higher densities should be used if revegetation were more urgent. Higher seeding densities will likely facilitate the rapid establishment of native species on roadsides during the revegetation phase of construction.

Establishing Native Turfgrass

In addition to indications that coupling a locally appropriate seed source with appropriate seeding rates will increase the establishment success of native turfgrass, there are many potential methods of establishment that may also influence establishment success. Broadcast seeding, seeded erosion mats, hydroseeding, drill seeding, imprinting, plugging and sod are among the potential methods. All methods are moderately successful in establishing plant cover, but there are some advantages and drawbacks to each of these methods.

Broadcast seeding is inexpensive, but establishment is very slow and weeds tend to be prevalent (Beard and Green 1994). Landis et al. (2005) had minimal success with a fall hydroseeding of native species at one site because of minimal snow cover and highly-fluctuating temperature extremes, but, at another site, hydroseeding stabilized cut and fill slopes and aided in native species establishment. This indicates that hydroseeding may be a successful method of native species establishment depending on specific site characteristics. Hydroseeding is more expensive than broadcast seeding or drill seeding, but can be used on very steep slopes. Landis et al. (2005) also tested seeded erosion mats. Establishment success using this method was dependent upon the species planted.

In 2004, the California Department of Transportation (Caltrans) conducted a pilot study to determine the best management practices for revegetating highway construction sites using native grass species. Among the methods selected to establish native species were hydroseeding, imprinting, drill seeding, and plugging. Again, each method resulted in some plant cover, but there were also some potential drawbacks. Hydroseeding was very cost effective and provided good germination, but survivability into year two was less than that in drill seeded plots. Imprinting and drill seeding were successful, but the required use of large machinery precluded the use of these methods in small areas or on steep slopes. Additionally, drill seeding resulted in a non-natural look—despite repeated passes in varied directions, furrow rows left by the machinery remained visible. Imprinting was a successful method, but seeds that were not pressed into the soil were either eaten by birds or blown away. Plugging was an expensive and labor intensive method, but proved successful. However, the bare spaces between plugs allowed spaces for the recruitment of undesirable species and accelerated erosion before the planted species were able to fill in the gaps.

Lastly, Caltrans (2004) conducted limited experimentation with monostands of native grass sod. This sod showed promise for reducing erosion and potentially reducing weed seed recruitment, however more research was needed to determine which species would be best suited to sod production and establishment as well as to determine practicable methods of native sod production and installation. Stone (2003) showed that native sod installed on steep slopes was capable of reducing runoff and erosion in comparison to other methods of native species establishment. The installation of native sod shows promise as a future revegetation tool, particularly for areas with steep slopes and those with a large non-native seed bank.

Establishing Turfgrass with Sod.

There is a long history of using sod as a way to quickly establish turfgrass in home and commercial landscape settings (Beard and Rieke 1969). The two most common cool season species used for this application are two non-native species, Kentucky bluegrass (*Poa pratensis*) and tall fescue (*Festuca arundinacea*) (Beard and Rieke 1969). Generally, the sod is harvested and rolled with machinery (Beard and Rieke 1969), transported to the home landscape and then installed by hand. Though installing sod is labor intensive and initially more expensive (Hottenstein 1969), sod provides more immediate results and precludes the establishment of weeds in the landscape more effectively than does broadcast seeding (Beard and Rieke 1969). Despite the fact that sod has been used to quickly establish grass cover in lawns and commercial landscapes, its use as a revegetation tool has largely been uninvestigated, possibly due to the fact that it is labor-intensive to install and more expensive than other methods of revegetation.

With the advent of new technologies, sod can be installed mechanically. Dryland sodders (Brouwer Turf Equipment, Bucyrus Equipment Company) are specialized buckets that can be attached to front-end loaders. Using these dryland sodders, thick slabs of native sod can be harvested from one area and installed at another. However, transporting sod over long distances using this type of machinery is not practical since each slab must be harvested and installed separately. In addition, transplanting intact native sod from one location to another results in two disturbed locations rather than one. Because of this, producing and harvesting native sod is preferable to transplanting existing sod for ecological reasons.

Advances in technology that allow sod to be harvested with reinforcement materials in “big rolls” (Bucyrus Equipment Company) and installed mechanically with equipment such as the Brouwer turf installer (Brouwer Turf Equipment) could make the use of sod more affordable and practical as a roadside revegetation management tool. These “big rolls” can be harvested, transported on trucks and then installed mechanically. Harvesting and installing sod mechanically may render the commercial production and installation of native sod more feasible. Installing sod results in more immediate ground cover than do other methods of establishing turfgrass, which render it more aesthetically-pleasing. Additionally, sod covers up the existing seed bank, potentially reducing the likelihood of germination and establishment of weeds, while giving the sodded species a competitive advantage in establishment (Beard and Green 1994, Caltrans 2004). As a result, using sod as a revegetation tool potentially reduces the amount of chemical controls necessary to combat weed establishment.

Specific Applications to This Project

Considering that road construction sites are prone to erosion and to invasion by non-native species, rapid establishment of native vegetation is imperative. Native grass sod provides a method to rapidly establish native species while pre-empting weeds and non-native species, in addition to reducing erosion and controlling sedimentation. The use of sod in revegetation practices must be evaluated to determine whether or not it could be used as an effective management tool. By determining which native species are best suited to sod production, the use of native grass sod could be added to the existing methods of roadside revegetation. This study focused on the selection, establishment and harvest-ability of native sod species mixtures.

The overall goal of this study was to determine if native grass sod could be produced and harvested using commercial methods. If sod composed of grass species native to California can be commercially produced and harvested, native sod can then be utilized as another tool for revegetation efforts—particularly for sensitive areas such as those near streams, those that are prone to high erosion rates (such as steep slopes), and areas where the rapid establishment of non-native species reduces the effectiveness of revegetation efforts by other methods.

The state of California can be divided into six different ecoregions: Pacific Forest, Chaparral, California Grasslands, Intermountain Sagebrush, Sierran Forest and Great American Desert. In order to produce native sod successfully, the appropriate species must be selected for use in each of these six ecoregions. Selection of the proper species included evaluations of descriptions of the habitat in which they are generally found, their geographic distribution and typical elevational range (Hickman 1993). Evaluations also included potential native species' preferred soil moisture regimes (*Native Grass Database*) and rooting depth and descriptions (USDA, NRCS 2007).

By determining which species occurred most frequently across the selected ecoregions and ascertaining their habitat descriptions and growth characteristics, the species most suited to sod production and establishment on roadsides were selected. Not only must the selected species be adapted to a particular ecoregion, but they must also be adapted to potentially widely-varied sites within a particular ecoregion, since roads are constructed in a variety of habitat types with differing elevations, slopes, aspects and soil types (Appendix A).

Selecting species that are highly adaptable to a wide range of sites should ensure that the selected native species will persist in a number of varied sites after installation. However, the selected species must also tolerate sod production processes such as mowing, harvesting, transportation and installation. An evaluation of the percent species composition of each mixture will give an indication of how each species will perform under sod production conditions including mowing, irrigation and fertilization. Since roadside vegetation typically receives only natural moisture with no supplemental watering, the selected species must also be adapted to sites that may receive minimal precipitation.

Prior research suggests that a mixture of species is more appropriate than a monoculture for ecological and aesthetic reasons (Tyser et al. 1998). A mixture of species more closely resembles native vegetation and is, thus, more aesthetically pleasing (Bugg et al. 1997). Brown et al. (1998) also suggested that a variety of species with varied rooting depths and growth characteristics would be more likely to compete with existing weed species for resources.

Regular mowing is part of a typical sod production protocol (Youngner 1969). Mowing induces lateral branching or tillering and increases shoot density (Youngner 1969, Emmons 1995, Turgeon 1996). In this way, mowing encourages grass to spread basally and cover the ground more quickly. The growth characteristics of both individual species and species mixtures must be evaluated in order to determine whether or not they are suitable for sod production. Clipping yield will give an indication of mowing frequency requirements of the native species mixtures.

Some species of grasses have low "mowing quality" which causes shredding, reducing the aesthetic appeal of the turf (Emmons 1995). Though this reduction in aesthetic appeal may not be of major concern for roadside revegetation, shredding causes the wounds from mowing to heal more slowly which, in turn, may increase water loss from the turf and the occurrence of disease (Emmons 1995). The clipping percent dry weight will give an indication of the mowing quality of the sod. Species with greater percent dry weights will likely have lower mowing quality.

Additionally, some varieties specifically selected and developed for turfgrass applications are tolerant of very low mowing heights (Emmons 1995). However, native species may not be adapted to these conditions and should be mowed at the maximum recommended mowing height for turfgrasses of three inches (Emmons 1995).

Watering and fertilization are also typical components of a sod production system (Youngner 1969, Emmons 1995, Turgeon 1996). Native species may not require or even tolerate the same type of irrigation and fertilization regime as might be used to produce a tall fescue or Kentucky bluegrass sod.

Since the sod must be mechanically-harvestable to expedite its practical use, the selected combinations of species must produce tensile strength sufficient that the sod may be harvested and installed with machinery. Non-native turfgrass species such as tall fescue and Kentucky bluegrass are widely used for sod production because their roots result in sufficient sod tensile strength for mechanical harvesting (Beard and Rieke 1969). Huff (2003) suggested that the high tensile strength of Kentucky bluegrass sod is due to extensive rhizome production. Beard and Rieke (1969) suggested that "…rhizome or stolon development is the most critical factor in both sod strength and in the sod rooting capability." This indicates that rhizomatous species will likely have greater sod strength. In order to determine the strength of the sod, a tensile strength measurement will be taken on the sod produced from each mixture using a sod strength-testing device, constructed as described by Parish (1995). However, the number of native rhizomatous species is limited for the six selected California ecoregions. Therefore, a maximum of two rhizomatous species was included. Increasing percent composition of rhizomatous species may be linked to overall sod strength.

Another objective of this study is to determine the ecologically-appropriate number of species to include in the sod mixtures. There are two major ecological perspectives concerning community assembly and biodiversity: the niche-assembly perspective (Niche Theory) and the dispersal-assembly perspective (Unified Neutral Theory) (Hubbell 2001). The niche-assembly theory is based primarily on competitive interactions between plant species (Tilman 1997), while the dispersal-assembly theory is based primarily on dispersal (Hubbell 2001).

One well-known example of the niche-assembly perspective is Tilman's R* model (Tilman et al. 1997). This model assumes that in a homogenous environment, there is a single limiting resource; the species that can tolerate the lowest level of this resource will eventually dominate. However, this model also allows for the assumption that resources are not homogenously distributed and that there may be more than one limiting resource. Therefore, each species has a different R* value and a community can support as many species as there are different limiting resources, provided propagules are present (Tilman et al. 1997). In other words, the number of species in a community is dependent on the number of different niches present.

The dispersal-assembly perspective relies on the assumption that all species in a community are equal (Hubbell 2001). Because of this, community assembly is not determined by competition so much as by dispersal. When an individual dies, a space is created for recruitment. According to the dispersal-assembly perspective, the individual that recruits in the open space will depend on which species' propagule arrives there first (Hubbell 2001).

Though these two theories take different approaches, both have potentially-significant implications to this project. According to the dispersal-assembly perspective, the individual arriving in the gap first recruits. Therefore, circumventing random dispersal mechanisms through the installation of native sod has the potential of removing recruitment sites that could be inhabited by non-native species. Undoubtedly, over time individuals in the sod will die, opening up new gaps for recruitment. However, propagules from the native species are now present and will have an opportunity to occupy these gaps.

The niche-assembly theory also has application to this project. Tilman (1997) argues that more diverse communities are more resistant to invasion. Therefore, an increased number of species in the sod mixtures will increase the likelihood that one of the species will compete with each non-native species present at the installation site. Including a greater number of species in the revegetation sod may also lead to more rapid and complete ground cover as different species occupy different niches. Therefore, an assessment of total ground cover over time will be used to determine sod establishment.

Based on research by Brown et al. (1998), the inclusion of a greater number of species will also produce a more extensive root system as different species will likely have different root architecture. Because of this, including species with varied rooting depths in the sod mixtures should increase the likelihood that the sod will be able to successfully compete for soil moisture with non-native species present at installation sites. A measure of total root mass will be used to evaluate this hypothesis. In addition, root mass by depth as well as percent root mass by depth will be used to evaluate the root distribution of monostands and mixtures. Arguably, the containers may potentially alter the root architecture of the selected species, but large container sizes may mitigate these effects (NeSmith and Duval 1998).

Hypotheses

The presence of non-native species along roadsides poses an economic and ecological threat to adjacent ecosystems. Additionally, the pollution effects of erosion and sedimentation during construction and long-term road use thereafter have the potential to pollute streams, waterways and groundwater. Native sod may potentially aid in the reduction of erosion, the control of sedimentation and pollution and the management of non-native species.

Therefore, we hypothesize that:

1. All native species will tolerate current sod production methods.
2. The greater the number of species included in the sod, the more rapidly and completely the sod will cover the ground.
3. The inclusion of a greater number of species in the sod will produce a more extensive root system.
4. As the percent composition of rhizomatous species present in the sod increases, the sod strength will also increase.

MATERIALS AND METHODS

The timing of sod production in California was planned to coincide with the rainy winter months. Therefore, in order to mimic temperatures from each of the six ecoregions in the greenhouse, individual growth chambers were constructed. Accordingly, temperature and relative humidity settings for each chamber were determined from California climate data beginning in the month of September and continuing through the month of March.

Experimental Design

Eighteen five-gallon black plastic pots (30.5 cm in diameter and 35.5 cm in depth) were arranged in a completely randomized design for each chamber. Pots were filled with a soil mixture containing Canadian sphagnum peat moss, washed concrete sand, and loam soil in a 1:1:1 ratio by volume. AquaGro 2000 G wetting agent was blended in at a rate of 0.59 kg per cubic meter (one pound per cubic yard) of soil. Media was pasteurized with aerated steam at 80° C for 45 minutes. The soil level was 5 cm below the container rim in each pot.

For all ecoregions except the Great American Desert, there were six different mixtures with three replications of each in a completely randomized design. The six different mixtures for each ecoregion were as follows: Rhizomatous species X (RX) and three bunch grass species (3B) (i.e. RX3B); Rhizomatous species Y (RY) with the same three bunch grass species (i.e. RY3B); Rhizomatous species X (RX) with the first three bunch grass species, plus an additional two bunch grass species (5B) (i.e. RX5B);

Rhizomatous species Y (RY) with the same five bunch grass species (i.e. RY5B); Rhizomatous species X and Y (RXY) with the first three bunch grass species (i.e. RXY3B); and, lastly, Rhizomatous species X and Y (RXY) with all five bunch grass species (i.e. RXY5B) (Table 1).

Table 1. Mixtures of species included in the experimental design.

RX3B	**RY3B**	**RXY3B**
Rhizomatous (X)		Rhizomatous (X)
	Rhizomatous (Y)	Rhizomatous (Y)
Bunch (1)	Bunch (1)	Bunch (1)
Bunch (2)	Bunch (2)	Bunch (2)
Bunch (3)	Bunch (3)	Bunch (3)
4 Total Species	4 Total Species	5 Total Species
RX5B	**RY5B**	**RXY5B**
Rhizomatous (X)		Rhizomatous (X)
	Rhizomatous (Y)	Rhizomatous (Y)
Bunch (1)	Bunch (1)	Bunch (1)
Bunch (2)	Bunch (2)	Bunch (2)
Bunch (3)	Bunch (3)	Bunch (3)
Bunch (4)	Bunch (4)	Bunch (4)
Bunch (5)	Bunch (5)	Bunch (5)
6 Total Species	6 Total Species	7 Total Species

Only two mixtures, RX3B and RX5B, were planted for the Great American Desert ecoregion with nine replications rather than three in a completely randomized design. This was due to the fact that the RY species, *Pleuraphis rigida*, was eliminated from the study due to poor germination (Appendix B).

Planting and Establishment

The selected species for all ecoregions are listed below (Table 2). Nomenclature used in this document comes from the *Native Grass Database* (2001) furnished by Caltrans.

Table 2. Selected species for all ecoregions.

	California Grasslands	**Chaparral**	**Great American Desert**	**Intermountain Sagebrush**	**Pacific Forest**	**Sierran Forest**
Achantherum hymenoides			x			
Achnatherum occidentale				x		
Aristida purpurea			x			
Bromus carinatus	x	x			x	x
Elymus elymoides			x	x		x
Elymus glaucus	x	x			x	x
Elymus multisetus				x		
Elymus trachycaulus		x		x	x	x
Festuca idahoensis					x	
Festuca rubra	x	x			x	x
Hordeum brachyantherum						x
Koeleria macrantha		x	x	x	x	
Leymus cinereus				x		
Leymus condensatus			x			
Leymus triticoides	x			x		
Melica californica	x				x	
Muhlenbergia rigens						x
Nassella cernua	x		x			
Nassella lepida		x				
Nassella pulchra	x	x				

Pots were seeded at a rate of 5382 PLS/m^2 (500 PLS/ft^2). Each species was equally represented by dividing the seeding rate by the number of species to determine the rate for each species. Germination tests were performed on all seed lots prior to sowing to determine accurate seeding rates (Appendix B). The seeds of all species were mixed together and then sprinkled on the soil surface and covered with a 0.5 cm layer of soil. In addition to these mixtures, three replications of each individual species in each ecoregion were planted in tree tubes measuring 6.5 cm in diameter and 35.5 cm in depth. These monostands were also seeded at a rate of 5382 PLS/m^2 (500 PLS/ft^2). The soil was kept evenly moist until the seeds germinated.

Germinating dicot seeds and identified grass species not intentionally planted (mostly *Bromus tectorum*) were removed by hand as needed. Containers and tree tubes were checked daily and hand-watered to field capacity as needed. Pots and tree tubes were re-randomized at each harvest date.

Each mixture and monostand received two applications of granular fertilizer (Wil-Gro 16-16-16 7S, Wilbur-Ellis, San Francisco, California) at a rate of 4.9 g of elemental Nitrogen per square meter (1 pound per 1000 square feet), one at 60 DAP and the second at 120 DAP. Supplemental lighting (GE Multi-Vapor MVR1000/C/U, GE Lighting, General Electric Company, Cleveland, Ohio) was provided for eight hours per day from November 30, 2005 through April 10, 2006. The supplemental lighting was adjusted periodically to coincide with sunrise times such that it did not extend day length but rather supplemented natural light. The actual light levels of each chamber are shown below (Table 3).

Table 3. Average day and night photosynthetically active radiation level (μmol•m^{-2}•sec^{-1}) and standard deviation by month for each ecoregion.

	California Grasslands	
	Day PAR ± SD	Night PAR ± SD
Month 1	81.7 ± 85.1	4.7 ± 7.9
Month 2	110.5 ± 76.2	11.6 ± 14.5
Month 3	138.9 ± 90.0	5.0 ± 10.5
Month 4	179.9 ± 121.5	3.6 ± 8.4
Month 5	221.5 ± 170.8	4.0 ± 8.0
Month 6	345.2 ± 261.7	5.1 ± 9.3
Month 7	326.4 ± 275.0	6.3 ± 10.6

	Chaparral	
	Day PAR ± SD	Night PAR ± SD
Month 1	123.8 ± 93.0	1.7 ± 2.3
Month 2	111.7 ± 97.7	1.8 ± 1.9
Month 3	135.4 ± 71.3	1.0 ± 1.5
Month 4	183.9 ± 114.4	1.1 ± 1.6
Month 5	226.2 ± 157.5	1.1 ± 1.7
Month 6	227.0 ± 172.1	1.2 ± 2.3
Month 7	324.0 ± 293.6	1.1 ± 2.6

	Great American Desert	
	Day PAR ± SD	Night PAR ± SD
Month 1	143.5 ± 85.9	1.0 ± 1.5
Month 2	205.2 ± 139.2	0.9 ± 1.4
Month 3	214.2 ± 154.1	1.1 ± 2.0
Month 4	272.2 ± 254.7	1.3 ± 2.6
Month 5	291.9 ± 317.2	1.3 ± 2.9
Month 6	319.2 ± 343.1	1.2 ± 3.0
Month 7	268.9 ± 307.5	1.5 ± 3.1

	Intermountain Sagebrush	
	Day PAR ± SD	Night PAR ± SD
Month 1	134.2 ± 71.2	1.8 ± 1.6
Month 2	93.4 ± 75.0	14.0 ± 1.4
Month 3	166.4 ± 73.4	3.5 ± 1.6
Month 4	203.8 ± 134.3	2.0 ± 1.5
Month 5	245.7 ± 196.3	1.7 ± 2.7
Month 6	266.1 ± 207.5	3.9 ± 3.1
Month 7	322.3 ± 206.6	4.9 ± 3.4

	Pacific Forest	
	Day PAR ± SD	Night PAR ± SD
Month 1	134.2 ± 111.3	1.8 ± 3.0
Month 2	93.4 ± 112.9	14.0 ± 13.3
Month 3	166.4 ± 108.1	3.5 ± 7.6
Month 4	203.8 ± 106.2	2.0 ± 3.6
Month 5	245.7 ± 159.6	1.7 ± 2.9
Month 6	266.1 ± 192.3	3.9 ± 7.9
Month 7	322.3 ± 209.1	4.9 ± 9.3

	Sierran Forest	
	Day PAR ± SD	Night PAR ± SD
Month 1	83.1 ± 56.2	11.5 ± 13.8
Month 2	96.2 ± 44.6	4.8 ± 9.6
Month 3	120.7 ± 67.5	4.0 ± 8.2
Month 4	160.9 ± 115.0	3.6 ± 7.7
Month 5	199.8 ± 172.9	6.0 ± 9.3
Month 6	235.8 ± 187.8	5.9 ± 10.0
Month 7	274.5 ± 187.8	6.0 ± 9.5

Each mixture was grown for a period of 7 months. Planting and final harvest dates, respectively, for each ecoregion are as follows: Pacific Forest, October 21, 2005 and May 22, 2006; Chaparral, October 21, 2005 and May 24, 2006; California Grasslands, November 14, 2005 and June 14, 2006; Intermountain Sagebrush, November

28, 2005 and June 28, 2006; Sierran Forest, November 28, 2005 and June 30, 2006; and Great American Desert, February 3, 2006 and August 3, 2006.

Growth Chambers

In order to mimic the climates of the six selected California ecoregions in the greenhouse, six growth chambers were constructed. Each chamber was 1.5 x 1.8 x 0.9 m (5 x 6 x 3 feet) tall and was built with wood framing and corrugated polycarbonate. Horizontal air flow (HAF) fans (4WT46, Dayton Electronic Manufacturing Company, Niles, Illinois) were placed in each chamber to provide continuous air movement. Each chamber was also fitted with a heater bar (Ceramic Channel Strip Heater, 350 W, Tempco Electric Heater Corporation, Wood Dale, Illinois) which was placed in front of the HAF fan so that the heated air would be spread throughout the chamber.

Each chamber (except the Great American Desert ecoregion chamber) was equipped with a fogger system designed to increase relative humidity. Two ultrasonic foggers (The Mist Maker Model M0001, Mainland Mart Corporation, El Monte, California) were placed in five-gallon buckets filled with water. The foggers were placed in baskets buoyed up by Styrofoam rings, which kept the foggers at the appropriate water depth continuously, despite evaporation. The water buckets were refilled with tap water as needed. Periodic algae removal was also performed when required.

Two cooling fans were placed through the polycarbonate covering in diagonally-opposite corners of each chamber. These fans pulled air from the greenhouse into the chambers in order to cool the air when necessary due to a “double greenhouse effect” caused by the growth chambers' being inside of a greenhouse. All fans used were axial fans (4WT46, Dayton Electronic Manufacturing Company, Niles, Illinois) rated at 115 CFM.

Each chamber was also equipped with a line quantum sensor (Model LQS506, Apogee Instruments, Inc., Logan, Utah) to measure photosynthetically active radiation (PAR) and a relative humidity and temperature probe (HMP-45C, Campbell Scientific, Inc., Logan, Utah). These sensors provided input for the two dataloggers (CR-10X, Campbell Scientific, Inc., Logan, Utah) which were used to control the heating, cooling and humidification of the chambers.

Climate Control

To determine the climatic conditions of each of the six ecoregions, we obtained average minimum and maximum temperature and average relative humidity data from the Western Regional Climate Center for weather stations within each respective ecoregion for as many years as recorded. For each month, high and low temperatures as well as high and low relative humidities were averaged across all of the climate center stations within each ecoregion. These data were then used as settings for the growth chambers representing each ecoregion. Day and night temperature settings and actual mean day and night temperatures are displayed below for each ecoregion for each of the seven months (Table 4). Relative humidity settings and actual mean relative humidity data are displayed below for each ecoregion for each of the seven months (Table 5).

Table 4. Day and night temperature settings and actual mean day and night temperatures (°C) and standard deviations by month for each ecoregion.

California Grasslands

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	32	21.9 ± 3.19	14	15.1 ± 2.36
Month 2	26	23.5 ± 2.97	10	18.3 ± 3.78
Month 3	18	19.9 ± 3.39	6	13.5 ± 3.21
Month 4	13	19.2 ± 3.78	3	12.1 ± 2.25
Month 5	13	19.5 ± 3.57	3	12.4 ± 2.19
Month 6	16	21.0 ± 3.70	5	12.7 ± 2.22
Month 7	19	22.5 ± 2.84	6	17.0 ± 3.23

Chaparral

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	27	22.7 ± 3.44	12	14.1 ± 2.31
Month 2	25	20.7 ± 2.90	9	13.7 ± 2.52
Month 3	19	22.4 ± 3.30	6	17.9 ± 3.84
Month 4	16	20.6 ± 4.47	3	12.0 ± 2.26
Month 5	16	20.8 ± 4.41	4	11.9 ± 2.34
Month 6	17	21.3 ± 4.79	5	11.9 ± 1.90
Month 7	19	23.3 ± 5.38	6	13.8 ± 3.73

Great American Desert

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	31	25.5 ± 4.01	15	17.0 ± 2.88
Month 2	25	22.7 ± 3.12	9	12.7 ± 2.40
Month 3	18	19.6 ± 2.70	4	12.4 ± 2.22
Month 4	14	20.0 ± 3.53	0	12.2 ± 1.70
Month 5	14	21.5 ± 3.31	1	16.4 ± 3.83
Month 6	16	21.7 ± 4.15	2	14.2 ± 2.22
Month 7	18	23.5 ± 3.73	4	16.0 ± 2.20

Intermountain Sagebrush

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	27	21.8 ± 2.83	4	14.3 ± 2.80
Month 2	21	22.3 ± 2.20	-1	18.1 ± 4.20
Month 3	14	17.7 ± 2.75	-6	12.7 ± 2.15
Month 4	9	18.2 ± 3.65	-9	12.9 ± 2.10
Month 5	8	18.6 ± 3.19	-9	12.6 ± 1.78
Month 6	11	20.3 ± 3.34	-7	15.8 ± 3.79
Month 7	14	20.5 ± 3.64	-4	14.1 ± 2.19

Pacific Forest

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	22	20.2 ± 2.71	10	13.7 ± 2.17
Month 2	19	18.3 ± 2.39	8	13.4 ± 3.04
Month 3	15	21.0 ± 3.34	6	17.8 ± 3.42
Month 4	13	18.7 ± 4.10	4	11.4 ± 2.28
Month 5	13	18.5 ± 4.19	4	11.1 ± 2.30
Month 6	14	19.6 ± 3.75	5	11.4 ± 2.13
Month 7	15	21.2 ± 3.87	6	12.7 ± 3.71

Sierran Forest

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	25	21.4 ± 2.97	7	16.7 ± 2.50
Month 2	20	21.9 ± 2.75	3	18.1 ± 3.98
Month 3	12	17.7 ± 3.11	-1	12.5 ± 2.22
Month 4	8	18.5 ± 3.73	-4	12.5 ± 2.06
Month 5	8	19.1 ± 3.05	-4	12.9 ± 2.17
Month 6	10	20.9 ± 3.11	-3	15.9 ± 3.77
Month 7	11	21.3 ± 2.94	-1	14.6 ± 2.47

Table 5. Day and night relative humidity settings and actual mean day and night relative humidity (%) and standard deviations by month for each ecoregion.

California Grasslands

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	31	25.9 ± 6.58	65	39.3 ± 7.34
Month 2	39	29.4 ± 6.00	72	44.4 ± 11.50
Month 3	57	30.2 ± 6.60	81	39.6 ± 7.88
Month 4	64	28.9 ± 7.09	86	41.8 ± 6.30
Month 5	67	36.2 ± 9.99	86	48.9 ± 9.81
Month 6	56	37.0 ± 11.23	83	46.2 ± 11.38
Month 7	50	56.6 ± 8.99	80	70.3 ± 11.31

Chaparral

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	63	36.3 ± 12.16	85	47.9 ± 11.62
Month 2	61	26.6 ± 7.07	81	34.0 ± 7.55
Month 3	62	29.3 ± 6.18	79	46.0 ± 8.59
Month 4	63	24.1 ± 6.12	79	37.9 ± 6.55
Month 5	63	25.8 ± 6.48	80	41.0 ± 6.56
Month 6	63	33.2 ± 11.38	81	49.3 ± 10.43
Month 7	62	36.8 ± 14.00	81	49.8 ± 12.46

Great American Desert

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	N/A	21.8 ± 4.37	N/A	36.3 ± 11.07
Month 2	N/A	24.2 ± 5.74	N/A	35.7 ± 6.21
Month 3	N/A	32.1 ± 9.20	N/A	42.9 ± 10.52
Month 4	N/A	34.2 ± 9.78	N/A	44.8 ± 9.29
Month 5	N/A	50.2 ± 12.85	N/A	59.1 ± 15.29
Month 6	N/A	59.6 ± 11.07	N/A	77.5 ± 7.99
Month 7	N/A	57.4 ± 9.25	N/A	72.2 ± 7.67

Intermountain Sagebrush

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	25	22.9 ± 4.96	30	33.8 ± 8.45
Month 2	25	27.3 ± 5.71	30	41.9 ± 9.99
Month 3	25	27.0 ± 5.08	30	34.3 ± 6.22
Month 4	25	29.8 ± 6.90	30	37.3 ± 5.98
Month 5	25	37.0 ± 10.28	30	44.6 ± 9.81
Month 6	25	46.3 ± 14.38	30	49.5 ± 13.97
Month 7	25	59.0 ± 10.64	30	72.1 ± 9.37

Pacific Forest

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	60	39.1 ± 10.81	70	49.7 ± 9.80
Month 2	60	30.1 ± 7.63	70	38.8 ± 8.71
Month 3	60	33.6 ± 6.71	70	49.1 ± 8.53
Month 4	60	29.1 ± 7.13	70	42.6 ± 7.12
Month 5	60	31.6 ± 8.35	70	47.5 ± 6.89
Month 6	60	37.7 ± 11.29	70	53.0 ± 11.15
Month 7	60	42.7 ± 13.40	70	54.7 ± 11.98

Sierran Forest

	Day		Night	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	34	24.3 ± 4.76	42	38.4 ± 9.59
Month 2	42	29.8 ± 5.97	48	44.6 ± 9.82
Month 3	53	29.9 ± 6.47	60	39.3 ± 6.99
Month 4	56	32.6 ± 7.48	59	42.5 ± 6.52
Month 5	60	40.7 ± 10.46	58	50.1 ± 9.25
Month 6	59	48.1 ± 13.53	61	54.0 ± 13.12
Month 7	60	60.8 ± 8.06	61	72.4 ± 8.49

Measures of Growth and Development

Above-Ground Characteristics

In order to determine the growth characteristics of the selected species and to encourage more rapid ground cover, the grass was mowed to 3 inches above the soil surface at two-week intervals. The fresh weight of the removed clippings was recorded for each pot and each tree tube at each harvest date. These samples were then dried for 48 hours at 50°C and re-weighed to determine their percent dry weight. In this way, not only the growth of each species, but also the collective growth of each mixture of species could be analyzed.

Percent species composition and total ground cover were visually estimated at every harvest for each mixture of species, after each container was mowed to 3 inches. The tree tube monostands were used to aid in species identification for the purpose of these assessments. These assessments were not conducted at the first two harvests of the Pacific Forest and Chaparral ecoregions or at the first harvest of the California Grasslands ecoregion. *Festuca rubra* and *Festuca idahoensis* were extremely difficult to differentiate in the greenhouse and thus were pooled together for the purpose of percent composition by species for the Pacific Forest ecoregion when planted together. In the California Grasslands ecoregion, *Nassella pulchra* and *Nassella cernua* were also pooled because of difficulty distinguishing between the two species in the greenhouse.

Below-Ground Characteristics

To determine the below-ground characteristics of the species mixtures, an assessment of the root structure was conducted. Two 7.5 cm by 10.0 cm cores of soil profile were cut. Since the container edges redirected roots, the outside of the container was avoided and removed for all core samples. These samples were collected, bagged, labeled and stored intact at 5° C until they could be washed. Upon removal from cold storage, an assessment was conducted by removing the verdure (the above-ground remainder of stems after mowing) and bagging it separately. Then, since sod was harvested from the first 2.5 cm of the soil profile, the first 2.5 cm of the soil profile was demarcated as the first strata. The remainder of the soil profile was divided into 5.0 cm strata. Each of the 5.0 cm segments was washed with tap water to remove all soil and inert matter. A fine screen was used to prevent the loss of root material during washing. After washing, samples were individually dried for 48 hours at 50°C and the mass of each was recorded. An identical procedure was used to evaluate the rooting of the tree tube monostands with the exception that the entire soil profile was segmented rather than a core sample.

Sod Tensile Strength

In order to determine the tensile strength of the sod, we constructed a sod strength-testing device based on a plan developed by Parish (1995). The testing device consisted of a small table with two clamps. One of the clamps was fixed to the table but adjustable in two-inch increments to accommodate differing lengths of sod strips. The other clamp was in a fixed location, but rotated around an axis. The sod samples were clamped between these two clamps and a torque wrench was used to tear the sod. The maximum torque reading during the test was recorded for each pot. The readings from the torque wrench were in pound inches and so were divided by the distance from the movable clamp to its axis of rotation (6 inches) to convert to pounds of force. This reading was then converted to kilograms and divided by the width of the sod sample to convert to kilograms of force per centimeter width (kg/cm width).

Sod strength tests were conducted by removing the grass mixtures from the pots without disturbing the soil. Root structure was such that this was possible. A cardboard template was used to cut a 12.5 cm by 20.0 cm sample of sod from each container. Sod samples were 2.5 cm thick. Sod samples were then clamped in the sod strength testing device and the tear strength of each sample was recorded. The soil from the container was then set aside for the root distribution analysis. Identically-sized samples of native sod were also tested for sod strength. Six 12.5 cm by 20.0 cm samples of 1.9 cm thick drought-tolerant sod composed of *Poa compressa*, *Elymus trachycaulus*, *Elymus lanceolatus* and *Festuca idahoensis* (Bitterroot Turf Farms, Corvallis, Montana), which had been grown for three years, were assessed for comparison.

Statistical Analysis

All statistical analyses were performed using SAS (SAS Institute, Cary, NC). Repeated measurements were taken on each container for assessment of percent species composition, total cover, fresh weight and percent dry weight. The values of these measures at one harvest would likely be related to the values at the previous harvest(s).

Therefore, in order to account for this temporal autocorrelation, analyses were conducted using repeated measures statements with the PROC MIXED procedure as described by Littell (1997). Analysis of the data revealed that an autoregressive covariance structure accounted for the most autocorrelation based on Akaike Information Criterion (AIC) values. This autoregressive covariance structure accounts for both random differences between experimental units and the autocorrelation between repeated measurements taken on the same experimental unit over time or space.

Since roots at one depth of the soil profile are likely influenced by those at adjacent depths, repeated measures analysis was also used to analyze root mass by depth and percent root mass by depth since there is likely spatial autocorrelation within these measurements. Autoregressive covariance structure was used for root analyses. Sod strength analysis was conducted with analysis of variance (ANOVA) using PROC GLM. A linear regression for sod strength was fitted with percent rhizomatous species composition as the predicting variable using PROC REG.

RESULTS AND DISCUSSION

Since an identical sampling procedure and statistical analysis were used to assess each ecoregion and comparison between ecoregions was not the focus of this study, results from the six different ecoregions will be reported separately, but with identical formatting. Ecoregions are presented in alphabetical order.

California Grasslands

Selected Species

Table 6 lists the selected species for each sod composition for the California Grasslands ecoregion.

Table 6. Selected species for each sod composition for the California Grasslands ecoregion.

RX3B	**RY3B**	**RXY3B**
RX: *Leymus triticoides*		RX: *Leymus triticoides*
	RY: *Festuca rubra*	RY: *Festuca rubra*
B1: *Bromus carinatus*	B1: *Bromus carinatus*	B1: *Bromus carinatus*
B2: *Nassella pulchra*	B2: *Nassella pulchra*	B2: *Nassella pulchra*
B3: *Elymus glaucus*	B3: *Elymus glaucus*	B3: *Elymus glaucus*
RX5B	**RY5B**	**RXY5B**
RX: *Leymus triticoides*		RX: *Leymus triticoides*
	RY: *Festuca rubra*	RY: *Festuca rubra*
B1: *Bromus carinatus*	B1: *Bromus carinatus*	B1: *Bromus carinatus*
B2: *Nassella pulchra*	B2: *Nassella pulchra*	B2: *Nassella pulchra*
B3: *Elymus glaucus*	B3: *Elymus glaucus*	B3: *Elymus glaucus*
B4: *Nassella cernua*	B4: *Nassella cernua*	B4: *Nassella cernua*
B5: *Melica californica*	B5: *Melica californica*	B5: *Melica californica*

Clipping Fresh Weight

Mixtures. For clipping fresh weight, there was no significant DAP by sod composition interaction for the California Grasslands ecoregion (p = 0.9990). There was a significant DAP main effect (p < 0.0001), with peaks in clipping fresh weight from 44 to 98 DAP and at 171 DAP. The sod composition main effect was not significant for clipping fresh weight (p = 0.4046) (Figure 1).

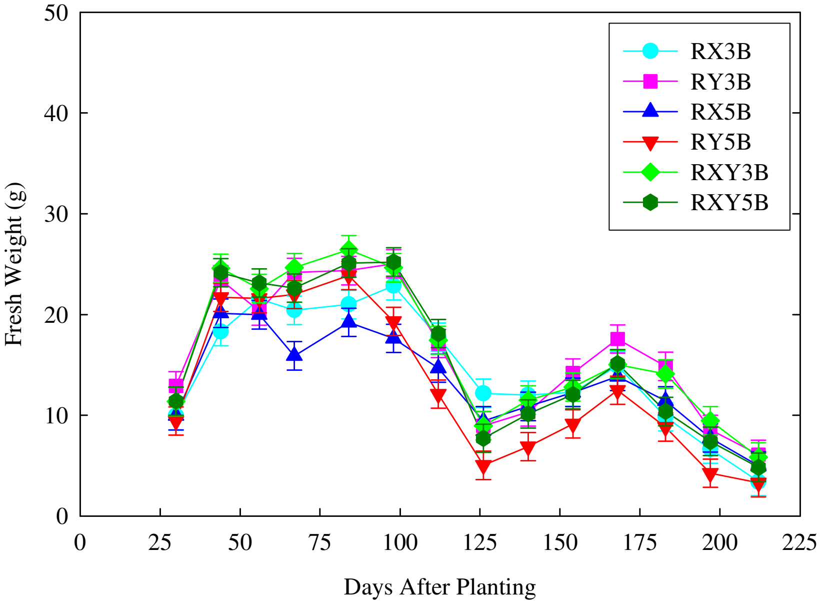

Figure 1. Effect of sod composition and days after planting on clipping fresh weight for the California Grasslands ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. There was a significant DAP by species interaction for clipping fresh weight for monostands (p < 0.0001). Most species tested had similar fresh weights throughout the experiment except *Bromus carinatus* and *Elymus glaucus* produced significantly higher fresh weight from 25-60 DAP, while *Festuca rubra* fresh weight was significantly higher at 170 DAP followed closely by *Bromus carinatus* (Figure 2).

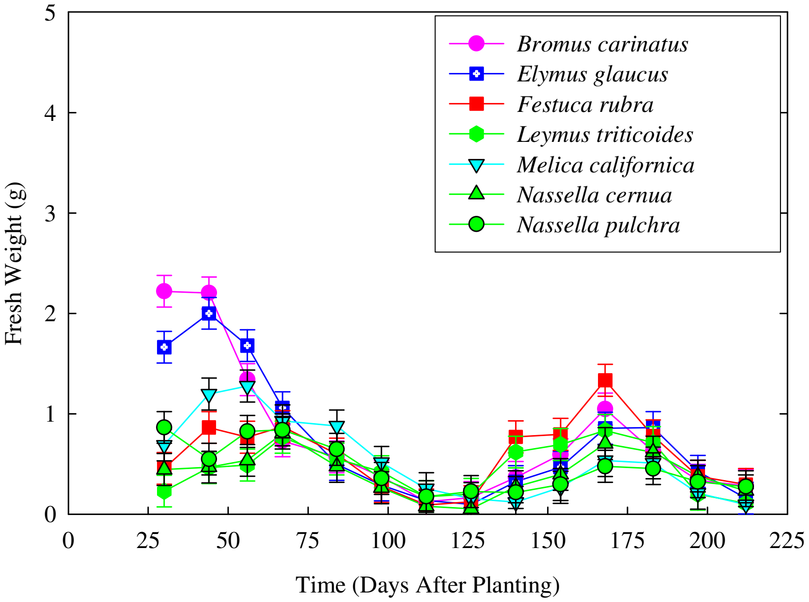

Figure 2. Effect of species and days after planting on clipping fresh weight for the California Grasslands ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Clipping Percent Dry Weight

Mixtures. There was no significant DAP by sod composition interaction for clipping percent dry weight for this ecoregion ($p = 0.5328$). The DAP main effect was significant ($p < 0.0001$), but the sod composition main effect was not significant for clipping percent dry weight ($p = 0.4747$). Clipping percent dry weight increased from an average minimum of 14.0% at 30 DAP to a maximum of 32.0% at 197 DAP. From 197 DAP to 212 DAP, percent dry weights decreased slightly to an average of 29.0% at the final harvest (Figure 3).

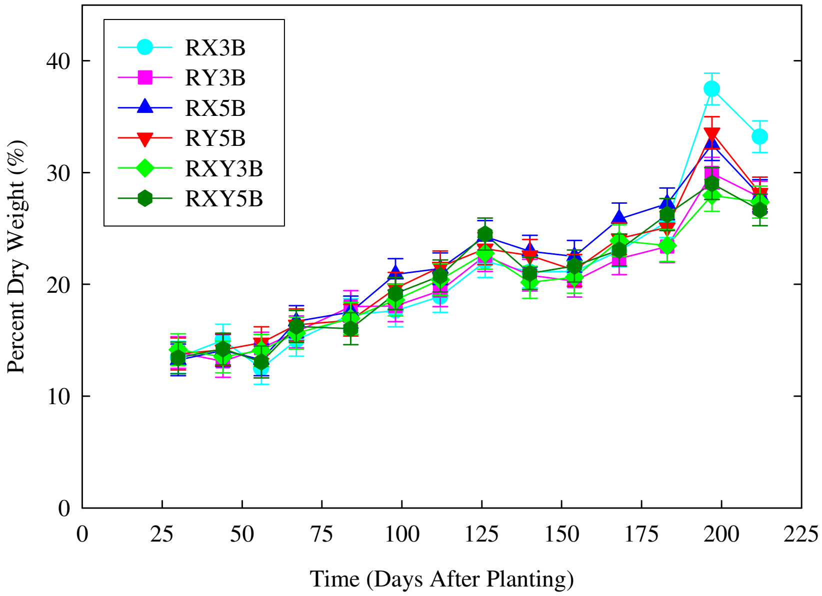

Figure 3. Effect of sod composition and days after planting on clipping percent dry weight for the California Grasslands ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. For clipping percent dry weight, the DAP by species interaction was not significant ($p = 0.8823$). The DAP and sod composition main effects were both significant ($p < 0.0001$ for both). When averaged over DAP, *Festuca rubra* and *Bromus carinatus* had significantly lower percent dry weights than the other five species, but were not significantly different from each other (Figure 4). *Nassella pulchra* had significantly greater percent dry weights than all other species. There were no significant differences in clipping percent dry weight for *Nassella cernua*, *Melica californica*, *Leymus triticoides* and *Elymus glaucus*.

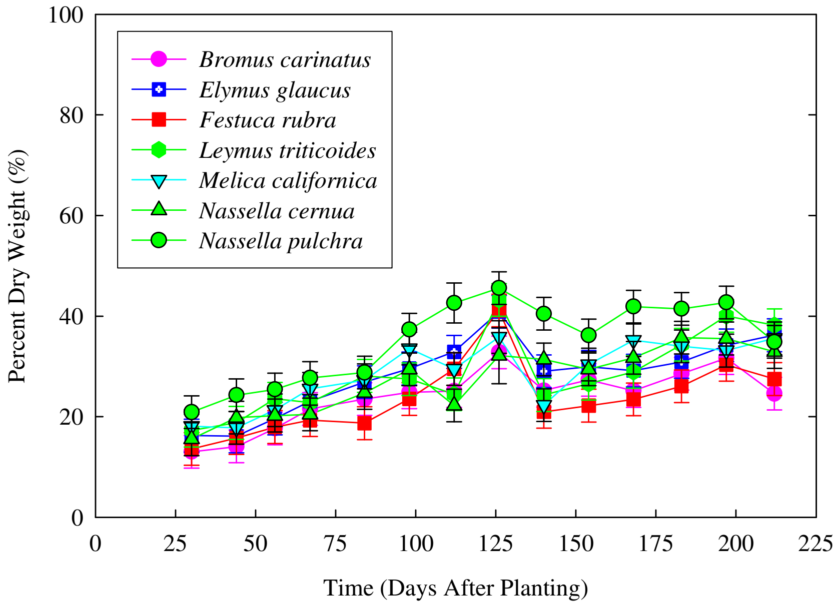

Figure 4. Effect of species and days after planting on clipping percent dry weight for the California Grasslands ecoregion monostands. Points represent estimates and error bars represent standard errors from the SAS MIXED model.

Total Ground Cover

There was no significant DAP by sod composition interaction for total ground cover (p = 0.1162). The DAP main effect was significant (p < 0.0001). The sod composition main effect was not significant (p = 0.4132). Total ground cover at the first harvest averaged 31.0%. From the first harvest up through 84 DAP, the total ground cover increased to 43.0%. From 84 to 112 DAP, the total ground cover increased to an average of 71.0%. Total ground cover increased from 71.0% to 77.0% between 112 and 154 DAP, where it remained constant until 197 DAP. Between 197 DAP and the final harvest, total ground cover decreased to an average of 72.0% (Figure 5).

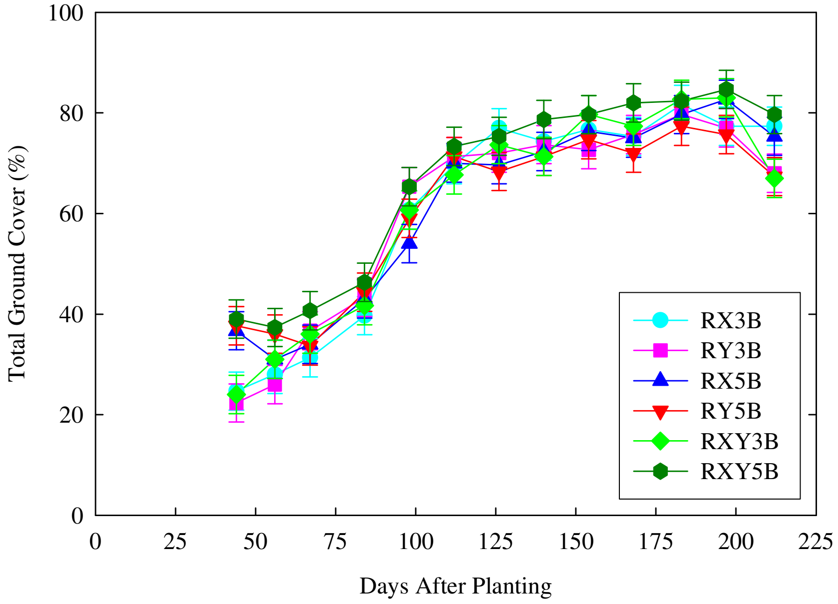

Figure 5. Effect of sod composition and days after planting on total ground cover for the California Grasslands ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Species Composition

Bromus carinatus had greater variation in percent composition between sod mixtures than any of the other species used in the mixtures. The DAP by sod composition interaction was significant for *Bromus carinatus* in the California Grasslands ecoregion (p = 0.0115). There were no significant differences in *B. carinatus* abundance between any of the mixtures from 44 to 84 DAP. From 98 to 212 DAP, RX3B mixtures contained the greatest percent *Bromus*, although *B. carinatus* composition for RX3B mixtures was not significantly different from every other mixture at all harvests. RY3B and RXY3B mixtures were only significantly different from one another at 112 DAP. These two mixtures contained greater percentages of *B. carinatus* than did the mixtures with five bunch grasses, although the differences were not significant at all harvests. The RY5B and RXY5B mixtures were not significantly different from one another at any point from 98 DAP through the final harvest. Both contained significantly less *B. carinatus* than did any other mixture at 197 DAP (Figure 6a).

At the final harvest, there were significant differences among mixtures for *B. carinatus* percent composition. The rhizomatous by bunch grass interaction was not significant ($p = 0.3094$). The rhizomatous main effect was significant ($p = 0.0315$). Mixtures containing rhizomatous species X contained significantly greater abundance of *Bromus* than did mixtures containing rhizomatous species Y and those containing both rhizomatous species. There was no significant difference in *B. carinatus* composition between mixtures containing rhizomatous species Y and those containing both rhizomatous species. The bunch grass main effect was also significant. Mixtures with three bunch grasses contained significantly greater abundance of *B. carinatus* than did mixtures containing five bunch grasses ($p = 0.0021$) at the final harvest.

For *Elymus glaucus*, there was a significant DAP by sod composition interaction ($p = 0.0058$). At 56 DAP, RX3B mixtures contained significantly greater amounts of *E. glaucus* than did any other mixtures. At 67 and 84 DAP, mixtures with three bunch grasses contained more *E. glaucus* than did mixtures with five bunchgrasses. At 168 and 212 DAP, the RX3B mixtures contained significantly more *E. glaucus* than did any other mixtures. At all other harvests, there were no significant differences in *E. glaucus* abundance between mixtures (Figure 6b).

At the final harvest, there was a significant rhizomatous by bunch grass interaction for percent composition of *E. glaucus* ($p = 0.0060$). RX3B mixtures contained significantly more *E. glaucus* than all other mixtures excepting RY5B mixtures. There were no significant differences in *E. glaucus* percentages among the remaining five mixtures.

For *Festuca rubra*, there was no significant DAP by sod composition interaction ($p = 0.1685$). The DAP main effect and the sod composition main effect were both significant ($p < 0.0001$ and $p = 0.0149$, respectfully). RY3B mixtures contained a significantly greater percentage of *F. rubra* than did the RXY5B mixtures and the RY5B mixtures, between which there was no significant difference. The percentage of *F. rubra* in the RY3B mixtures was not significantly greater than that in the RXY3B mixtures at the 5% level ($p = 0.0653$). There was also no difference between the RXY3B mixtures and the RXY5B mixtures at the 5% significance level ($p = 0.0567$) (Figure 6c).

There was no significant DAP by sod composition interaction for *Leymus triticoides* in the California Grasslands ecoregion ($p = 0.3053$). Both the DAP main effect and the sod composition main effect for this species were significant ($p < 0.0001$ and $p = 0.0129$, respectively). The RX3B mixtures contained 7.0% *L. triticoides* averaged over DAP which was significantly more than did the RX5B (6.4%), RXY3B (6.3%) and RXY5B mixtures (6.0%), among which there were no significant differences (Figure 6d).

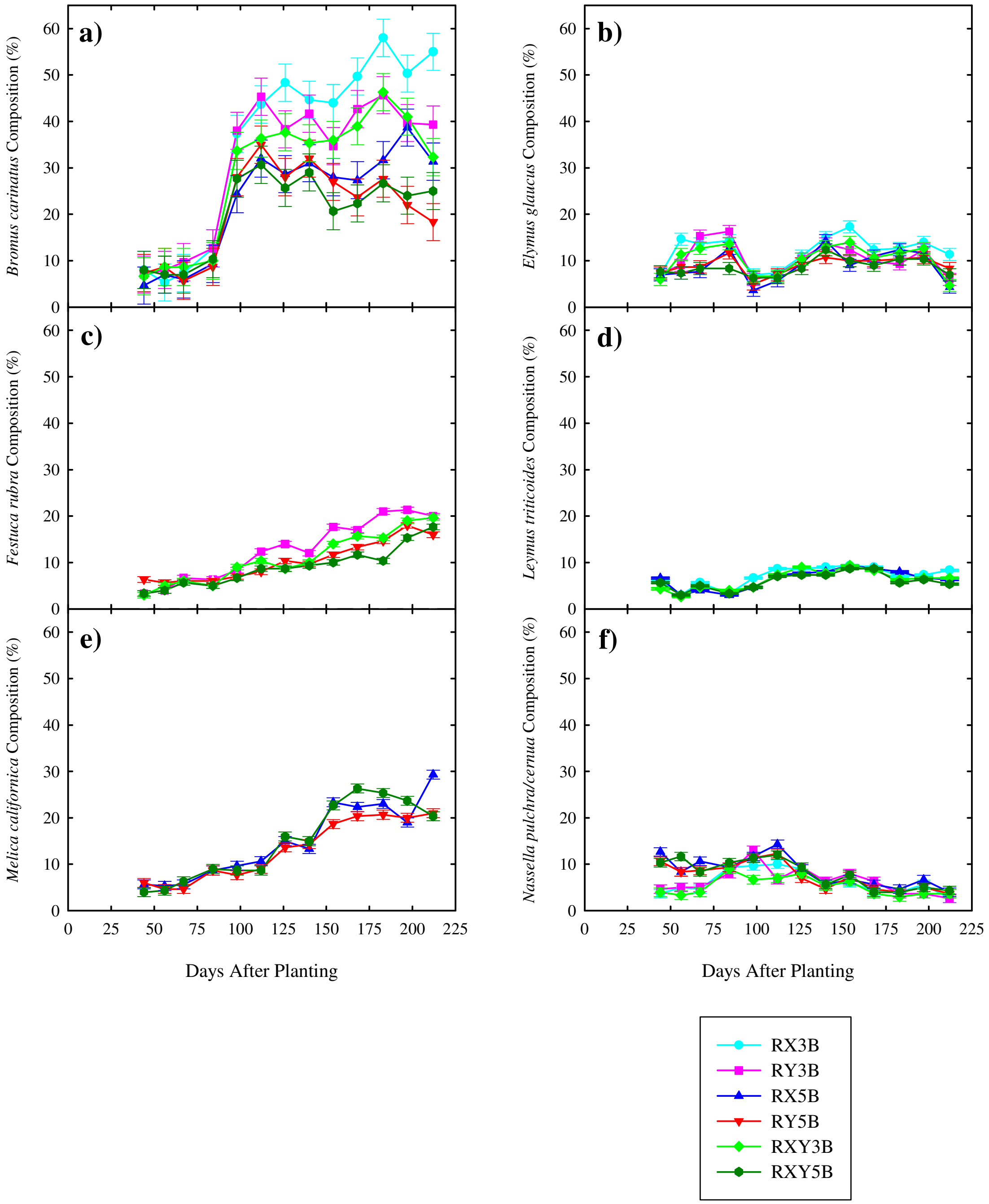

Figure 6. Effect of sod composition and days after planting on a) *Bromus carinatus*, b) *Elymus glaucus*, c) *Festuca rubra*, d) *Leymus triticoides*, e) *Melica californica* and f) *Nassella pulchra/cernua* percent composition for the California Grasslands ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

For mixtures containing *Melica californica*, there was not a significant DAP by sod composition interaction ($p = 0.2065$). There was a significant DAP main effect ($p < 0.0001$). The sod composition main effect was not significant for this species ($p = 0.4333$). Average *M. californica* composition increased linearly from 5.0% at 44 DAP to 23.0% at 212 DAP (Figure 6e).

There was a significant DAP by sod composition interaction for *Nassella pulchra/cernua* ($p < 0.0001$). From 44 through 67 DAP, mixtures with three bunch grasses had less *N. pulchra/cernua* than mixtures with five bunch grasses. However, from 126 DAP through the final harvest, there were no significant differences in *N. pulchra/cernua* composition between mixtures (Figure 6f).

Total Root Mass

For total root biomass, the rhizomatous by bunch grass interaction was not significant ($p = 0.4564$). There was a significant rhizomatous main effect ($p = 0.0186$). The bunch grass main effect was not significant ($p = 0.6893$). Mixtures with rhizomatous species X had significantly less total root biomass than did those with rhizomatous species Y and those with both rhizomatous species. There was not a significant difference between mixtures with rhizomatous species Y and those with both rhizomatous species for total root biomass.

Root Mass by Depth

Mixtures. For the California Grasslands ecoregion, the depth by sod composition interaction was not significant at the 5% level ($p = 0.0658$). The depth main effect was significant ($p < 0.0001$) with the shallowest section producing more dry root mass than all other depths. The sod composition main effect was not significant ($p = 0.4449$) (Figure 7).

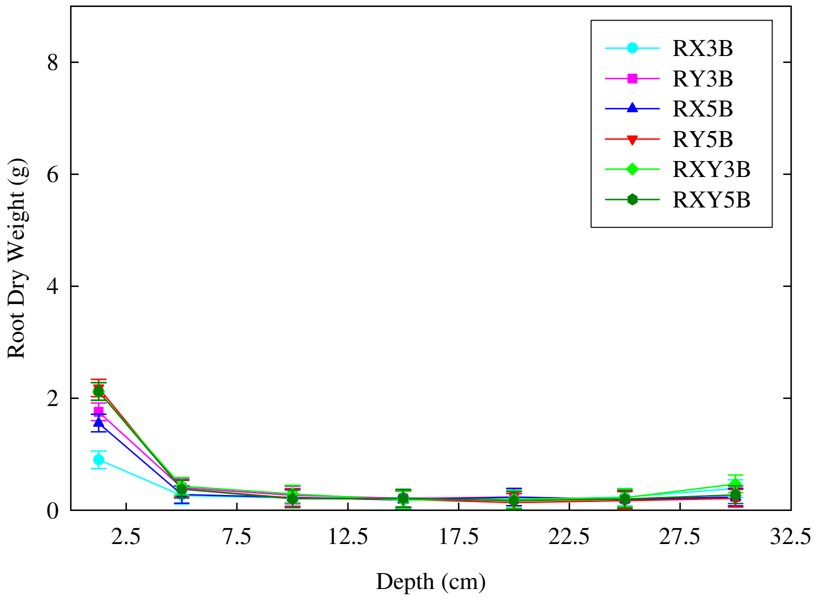

Figure 7. Effect of sod composition and depth on root mass for the California Grasslands ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

<u>Monostands</u>. The depth by species interaction for root mass was significant ($p < 0.0001$). *Festuca rubra* had significantly greater root mass than all other species from 0.0 – 7.5 cm, but was not significantly different from *Leymus triticoides*, *Melica californica*, *Nassella cernua* and *Nassella pulchra* beyond 7.5 cm. *Bromus carinatus* and *Elymus trachycaulus* never differed significantly from each other in root mass. These two species had the greatest root mass beyond 17.5 cm. *Bromus carinatus* had significantly

greater root biomass than did all other species, excepting *E. trachycaulus*, beyond 22.5 cm (Figure 8).

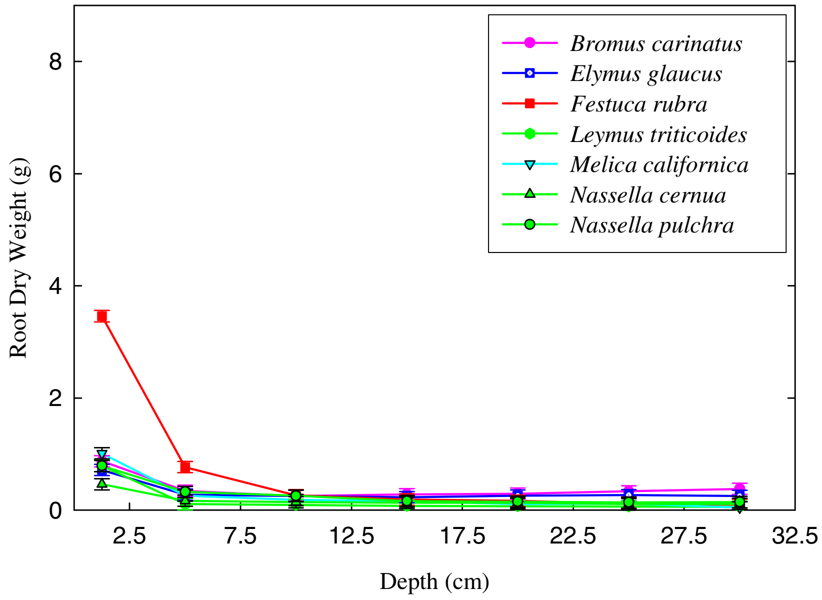

Figure 8. Effect of species and depth on root mass for the California Grasslands ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Root Mass by Depth

Mixtures. The depth by sod composition interaction for percent root mass was not significant at the 5% level ($p = 0.0702$). There was a significant depth main effect ($p < 0.0001$) with the shallowest depth containing the highest percentage of root mass. The sod composition main effect was not significant ($p = 1.0$) (Figure 9).

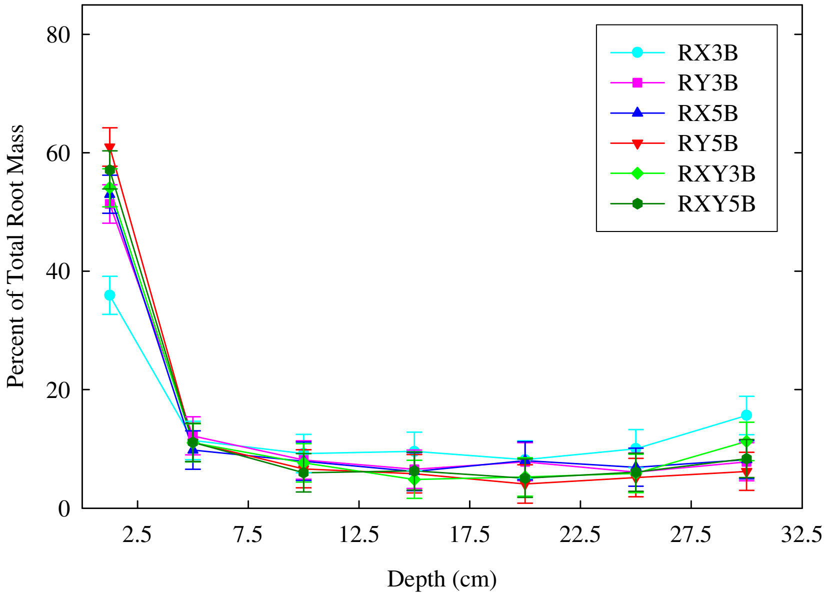

Figure 9. Effect of sod composition and depth on percent root mass for the California Grasslands ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The depth by species interaction was significant for percent root mass for monostands ($p < 0.0001$). From 0.0 – 7.5 cm, *Festuca rubra* had significantly greater percent root mass than did *Leymus triticoides*. Both of these species had significantly greater percentages than did all other species from 0.0 – 2.5 cm. However, beyond 7.5 cm these two species were not significantly different from each other and had the lowest percent root mass. *Melica californica* had the third-greatest percent root mass from 0.0 – 2.5 cm, having significantly greater percentages at this depth than did any of the four remaining species. *Nassella pulchra* had significantly greater percent root mass than did *Nassella cernua* from 0.0 – 2.5 cm. Beyond 2.5 cm, percent root mass of the two *Nassella* species was not significantly different. *Melica californica* was not significantly different from the *Nassella* species from 2.5 – 27.5 cm, but had significantly lower percentages beyond 27.5 cm. *Bromus carinatus* and *Elymus glaucus* percentages were not significantly different from each other at any point. These two species had significantly lower percentages from 0.0 – 2.5 cm than did any other species. Beyond 17.5 cm, these two species had the greatest percent root mass, having significantly greater percentages than all other species from 22.5 – 27.5 cm. Beyond 27.5 cm, these two species had significantly greater percentages than did all other species, excepting that *E. glaucus* percentages were not significantly different from those of *N. pulchra* (Figure 10).

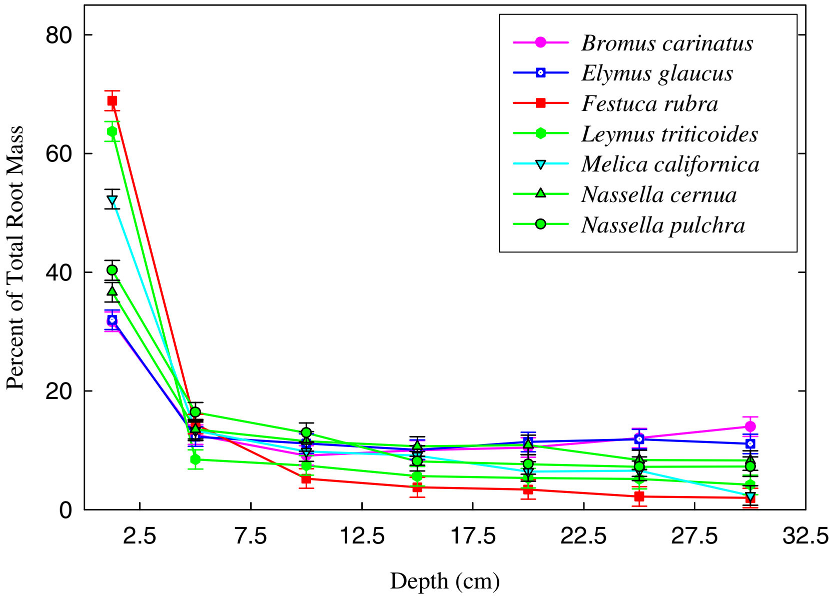

Figure 10. Effect of species and depth on percent root mass for the California Grasslands ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Sod Strength

There was a significant positive correlation between percent rhizomatous species composition and sod strength ($R^2 = 0.4324$, $p = 0.0018$) for the California Grasslands ecoregion. However, it is evident that mixtures with rhizomatous species X (*Leymus triticoides*) generally had lower sod strength than those containing rhizomatous species Y (*Festuca rubra*) (Figure 11).

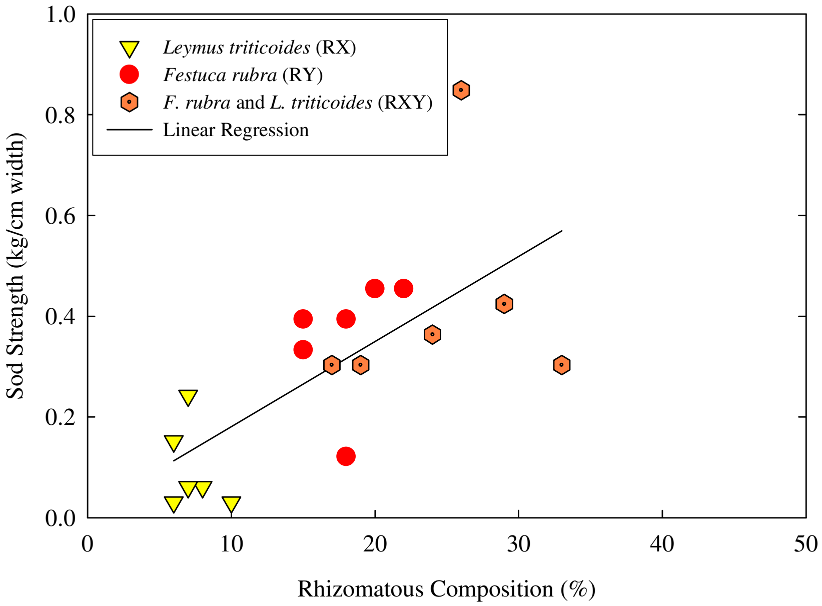

Figure 11. Correlation of percent rhizomatous species composition and sod strength for the California Grasslands ecoregion. Linear regression R^2=0.4324.

The rhizomatous by bunch grass species interaction was not significant (p = 0.1161). The rhizomatous species main effect was significant for the California Grasslands ecoregion (p = 0.0023). The bunch grass main effect was not significant (p = 0.1282). Mixtures containing rhizomatous species X (*Leymus triticoides*) had significantly lower sod strength that those containing both X and Y (p = 0.0010) and those containing rhizomatous species Y (*Festuca rubra*) (p = 0.0046). Mixtures containing rhizomatous species Y were not significantly different from those containing both X and Y (p = 0.4028) (Figure 12).

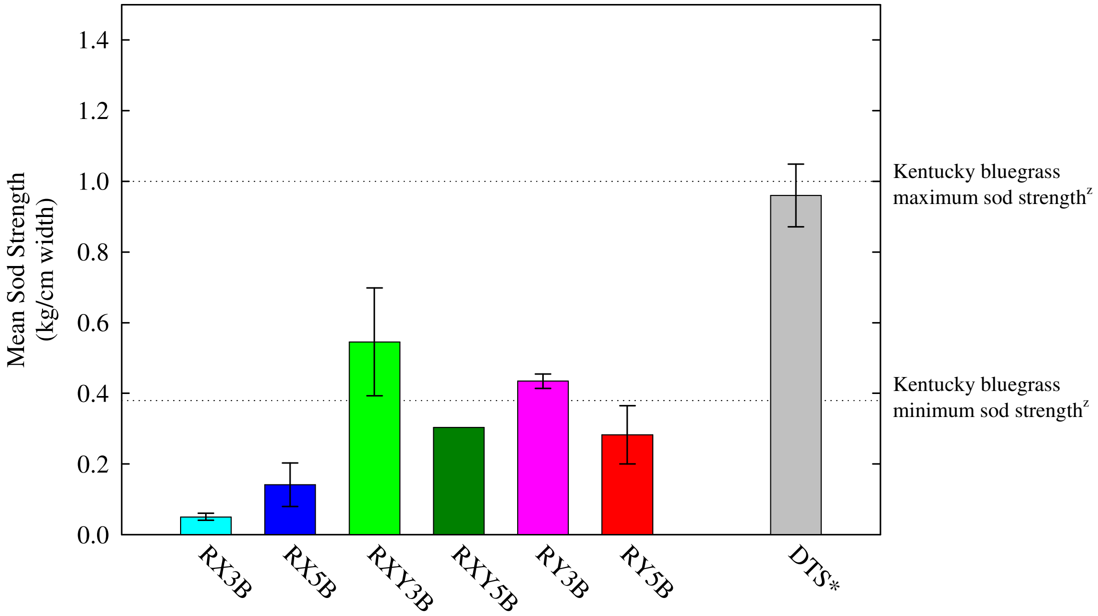

Figure 12. Effect of sod composition on sod strength for the California Grasslands ecoregion. Bars represent means and error bars represent standard errors. *Drought-tolerant sod (Bitterroot Turf Farms, Corvallis, Montana). [z]From Flanagan et al. 1993.

Discussion

Despite significant differences in clipping fresh weight and percent dry weight at specific times between monostands, the mixtures in the California Grasslands ecoregion did not differ significantly for these measures. Therefore, all mixtures will likely have similar mowing requirements and mowing quality.

Mixtures with more species did not have greater total ground cover, indicating that there were no differences in the rate of sod establishment. This also indicates that ground cover was not a contributing factor for sod strength in the California Grasslands ecoregion.

As the percent rhizomatous species composition increased, sod strength increased. This is evidence to support the hypothesis that greater rhizomatous species composition would result in greater sod strength. However, sod strength for mixtures containing *L. triticoides* as the single rhizomatous species was significantly less than that for mixtures with *F. rubra* as the single rhizomatous species and those with both rhizomatous species, indicating a positive correlation between sod strength and *F. rubra* composition. This could be an indication that *L. triticoides* produces less sod strength than does *F. rubra*. However, *L. triticoides* percent composition was generally less than that of *F. rubra,* even though they were seeded at the same rate. It is unclear whether sod strength would be similar for these two species if they were present in equal proportions. All mixtures in the California Grasslands ecoregion had lower sod strength than the Bitterroot Turf Farms drought-tolerant sod. Mixtures with the combination of *F. rubra* and three bunch grasses had comparable sod strength to that reported of Kentucky bluegrass as reported by Flanagan et al. (1993). Using a similar sod strength evaluation procedure, they reported tensile strengths for 1.9 cm thick Kentucky bluegrass sod between 0.38 and 1.0 kg/cm width at 8.5 months after planting.

Bromus carinatus composition varied between mixtures at times over the production cycle. Further, there were significant differences in *Bromus* composition at the final harvest; RX3B mixtures contained the most *B. carinatus*, but had the least sod strength. There does not appear to be a positive correlation between *B. carinatus* composition and sod strength. *Elymus glaucus* percent composition was significantly different between mixtures at the final harvest, but mixtures with greater *E. glaucus* composition had lower sod strength. *Elymus glaucus* composition is not positively correlated with sod strength. Despite significant differences between mixtures for *Nassella pulchra*, *Nassella cernua*, and *Melica californica* composition at specific times, by the final harvest, there were no significant differences between mixtures for the percent composition of these three species. The percent composition of these species is not likely a contributing factor to differences in sod strength, but the fact that all of these species persisted in the sod mixtures indicates that they will tolerate current sod production methods.

Despite differences in monostand root architecture, as indicated by differences in dry root mass and percent root mass by depth, there were no significant differences in dry root mass or in percent root mass by depth between mixtures. Though different species had different root architectures, they balanced each other in the mixtures such that there were no significant differences in total root mass between mixtures. This refutes the hypothesis that a greater number of species would result in a more extensive root system.

In the California Grasslands ecoregion, root mass in the first 2.5 cm does not correlate with sod strength, since there were significant differences in sod strength, but no corresponding differences in root mass between mixtures. Even though both *F. rubra* and *L. triticoides* partitioned more than 60% of their total root mass in the first 2.5 cm of the soil profile, *F. rubra* composition seems to be positively correlated with sod strength while *L. triticoides* composition does not. Additionally, *Melica californica* partitioned

52% of its total root mass in the first 2.5 cm, but *M. californica* composition does not correlate positively with sod strength. One possible explanation for this is that *M. californica* produces bulb-like roots, which would be of greater mass, but would not necessarily increase sod strength. Root mass may be one possible indication of sod strength, but sod strength is likely a product of at least root mass and species identity.

Chaparral

Selected Species

Table 7 lists the selected species for each sod composition for the Chaparral ecoregion.

Table 7. Selected species for each sod composition for the Chaparral ecoregion.

RX3B	**RX5B**	**RXY3B**
RX: *Elymus trachycaulus* B1: *Bromus carinatus* B2: *Nassella lepida* B3: *Koeleria macrantha*	RX: *Elymus trachycaulus* B1: *Bromus carinatus* B2: *Nassella lepida* B3: *Koeleria macrantha* B4: *Nassella pulchra* B5: *Elymus glaucus*	RX: *Elymus trachycaulus* RY: *Festuca rubra* B1: *Bromus carinatus* B2: *Nassella lepida* B3: *Koeleria macrantha*
RY3B	**RY5B**	**RXY5B**
RY: *Festuca rubra* B1: *Bromus carinatus* B2: *Nassella lepida* B3: *Koeleria macrantha*	RY: *Festuca rubra* B1: *Bromus carinatus* B2: *Nassella lepida* B3: *Koeleria macrantha* B4: *Nassella pulchra* B5: *Elymus glaucus*	RX: *Elymus trachycaulus* RY: *Festuca rubra* B1: *Bromus carinatus* B2: *Nassella lepida* B3: *Koeleria macrantha* B4: *Nassella pulchra* B5: *Elymus glaucus*

Clipping Fresh Weight

Mixtures. The DAP by sod composition interaction was not significant for the Chaparral ecoregion ($p = 0.7638$). There was a significant DAP main effect ($p < 0.0001$) with peaks of fresh weight at 60 and 175 DAP. The sod composition main effect was not significant at the 5% level ($p = 0.0825$) (Figure 13).

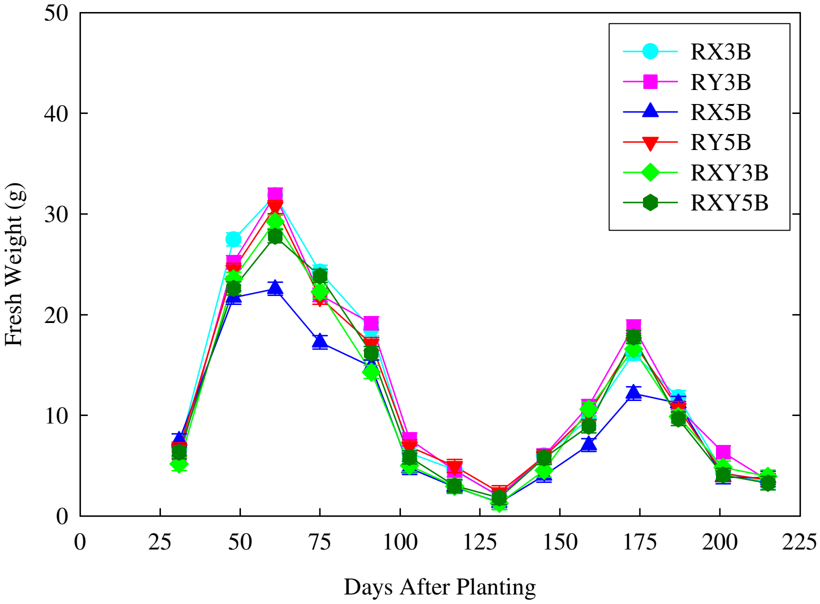

Figure 13. Effect of sod composition and days after planting on clipping fresh weight for the Chaparral ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The DAP by species interaction was significant for clipping fresh weight for monostands ($p < 0.0001$). At the first harvest, *Bromus carinatus* had significantly greater fresh weights than did any of the other species planted for this ecoregion. From 48 through 75 DAP, a peak in clipping fresh weight occurred. *Festuca rubra*, *Elymus glaucus* and *Elymus trachycaulus* had the greatest clipping fresh weight during this period. *Koeleria macrantha* had significantly lower fresh weights than did all other species from 48 through 75 DAP. A second peak occurred from 159 through 187 DAP where *E. glaucus*, *F. rubra* and *B. carinatus* had greater fresh weights than did the remaining four species (Figure 14).

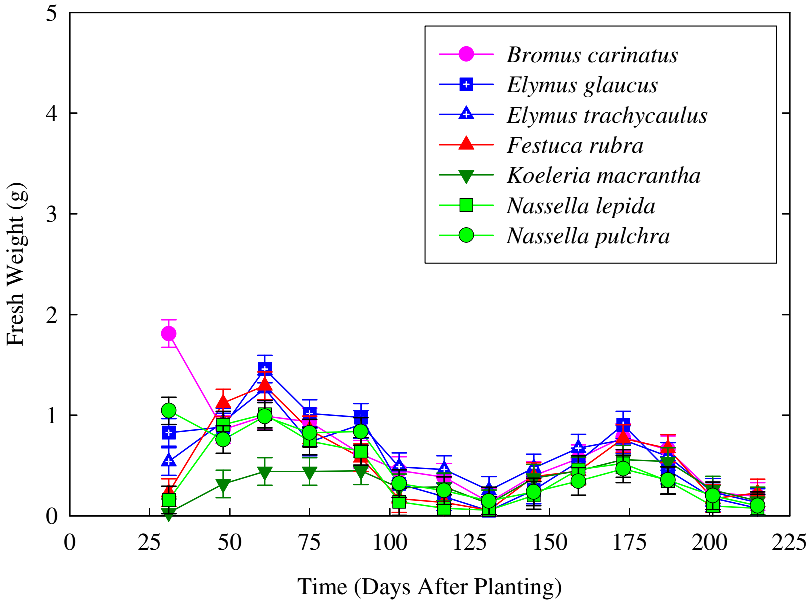

Figure 14. Effect of species and days after planting on clipping fresh weight for the Chaparral ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Clipping Percent Dry Weight

Mixtures. The DAP by sod composition interaction was not significant (p = 0.9226). There was a significant DAP main effect (p < 0.0001). The sod composition main effect was not significant (p = 0.8939). Average clipping percent dry weight at the first harvest was 15.0% and increased linearly until the final harvest percent dry weight average of 28.0% (Figure 15).

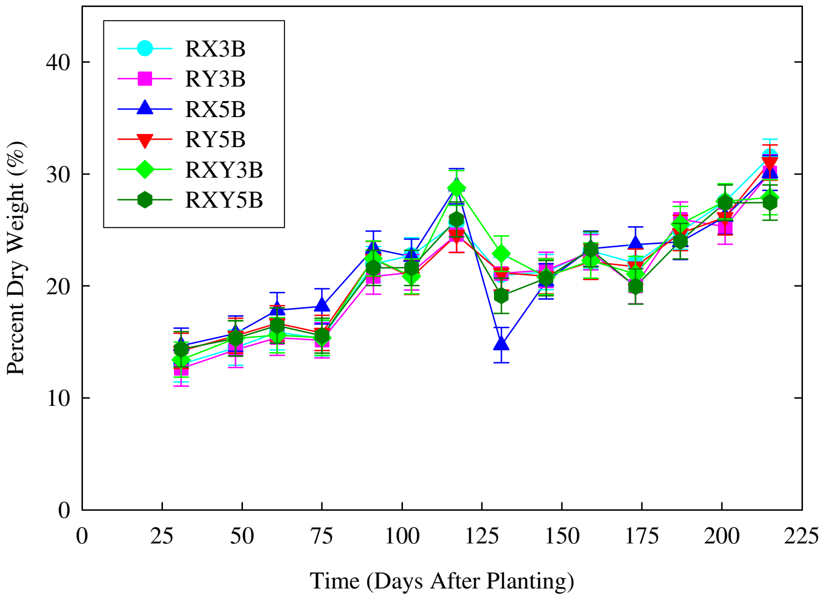

Figure 15. Effect of sod composition and days after planting on clipping percent dry weight for the Chaparral ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. There was no significant DAP by species interaction for clipping percent dry weight for monostands (p = 0.2540). Both the DAP and species main effects were significant (p < 0.0001 for both) (Figure 16). *Festuca rubra* had the lowest average percent dry weight (25.2%), which was not significantly different from *Koeleria macrantha* (26.0%) or *Bromus carinatus* (26.8%), and was also not different from *Elymus trachycaulus* (27.7%) at the 5% significance level (p = 0.0798). *Bromus carinatus* and *E. trachycaulus* percent dry weights were not significantly different from those of *Elymus glaucus* (28.1%). *Nassella lepida* and *Nassella pulchra* had the greatest percent dry weights in the Chaparral ecoregion (32.4% and 35.0%, respectively) and were not different from each other at the 5% significance level (p = 0.0795). Average clipping percent dry weights for both *Nassella* species were significantly greater than those of all other species.

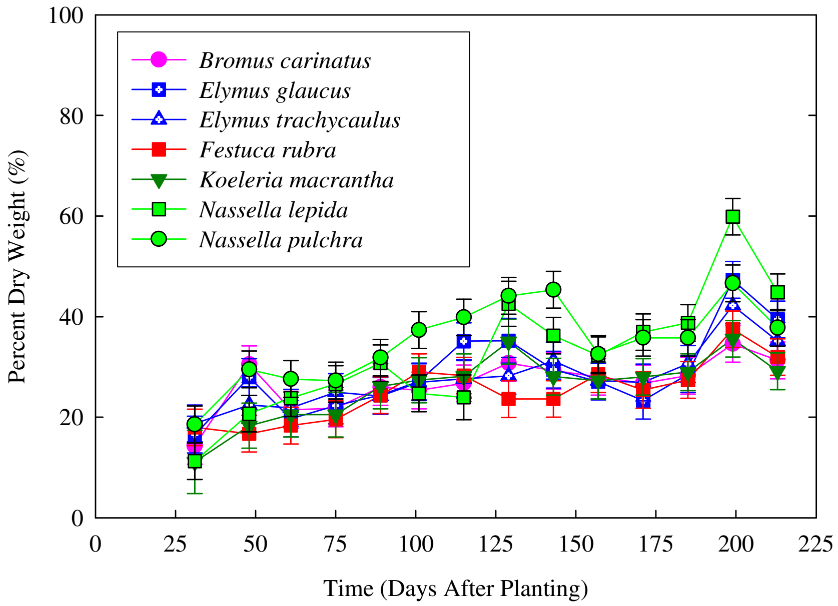

Figure 16. Effect of species and days after planting on clipping percent dry weight for the Chaparral ecoregion monostands. Points represent estimates and error bars represent standard errors from the SAS MIXED model.

Total Ground Cover

For total ground cover, there was a significant DAP by sod composition interaction (p = 0.0035) (Figure 17). There were no significant differences among mixtures from 61 to 103 DAP. From 117 to 159 DAP, RX3B mixtures had the greatest total cover, but total cover was only significantly greater than all other mixtures at 159 DAP. RY3B and RX5B mixtures were not significantly different from one another at any point between 117 and 159 DAP, but had greater total cover than did the RXY3B and RXY5B mixtures. The RXY3B and RXY5B mixtures were not significantly different from each other during this same period. The RY5B mixtures had the least total ground cover during this period, with total ground cover being significantly less than all other mixtures at 117 and at 159 DAP. From 173 DAP to the final harvest, there were no significant overall differences in total ground cover between the mixtures, although there were some differences between some mixtures at some harvests.

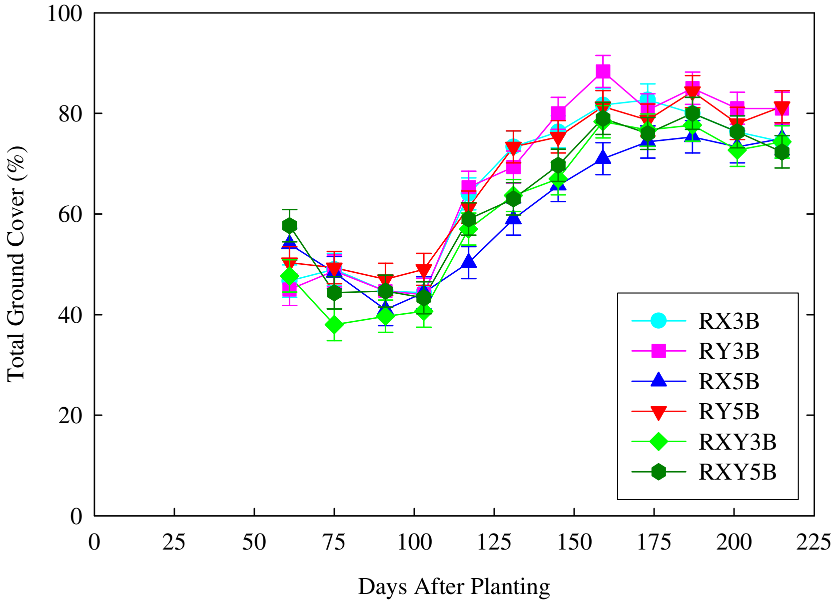

Figure 17. Effect of sod composition and days after planting on total ground cover for the Chaparral ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Species Composition

The percent composition of *Bromus carinatus* was also characterized by a significant DAP by sod composition interaction (p = 0.0426). Beginning at 117 DAP, *B. carinatus* composition for RX3B and RY3B mixtures increased dramatically, while

Bromus composition for the other mixtures only increased modestly. However, by the final harvest, there were no significant differences between mixtures (Figure 18a).

There was no significant DAP by sod composition interaction for *Elymus glaucus* composition ($p = 0.5455$). The DAP main effect was significant for this species ($p < 0.0001$). There was also a significant sod composition main effect ($p = 0.0453$). On average, RY5B mixtures contained significantly more *E. glaucus* than did the RX5B mixtures, but did not contain significantly more *E. glaucus* than the RXY5B mixtures at the 5% level ($p = 0.0518$) (Figure 18b). There was no significant difference in the average *E. glaucus* composition between the RX5B and the RXY5B mixtures.

For mixtures containing *Elymus trachycaulus*, there was no significant DAP by sod composition interaction ($p = 0.2808$). The DAP and the sod composition main effects were both significant ($p < 0.0001$ and $p = 0.0010$, respectively) (Figure 18c). Average *E. trachycaulus* composition was significantly greater for the RX3B mixtures than for all other mixtures containing this species.

For *Festuca rubra* composition, there was a significant DAP by sod composition interaction ($p = 0.0010$). This interaction is most likely explained by the changes in rank order between RXY3B and RY5B mixtures at 150 and 175 DAP and is, therefore, not likely of any practical importance (Figure 18d). Averaged over DAP, *F. rubra* was most abundant in RY3B mixtures. RXY3B and RY5B mixtures were not different from each other at all harvests, but had significantly greater proportions of *F. rubra* than did RXY5B. At the final harvest, there was a significant difference in *F. rubra* composition between mixtures.

At the final harvest, the rhizomatous by bunch grass interaction was not significant ($p = 0.7348$) for *Festuca rubra*. Mixtures containing three bunch grasses contained significantly more *F. rubra* than did mixtures containing five ($p = 0.0048$). Mixtures containing *F. rubra* as the only rhizomatous species (Y) had significantly more *F. rubra* than did those containing both rhizomatous species ($p = 0.0009$).

There was no significant DAP by sod composition interaction for the percent composition of *Koeleria macrantha* ($p = 0.1014$). The DAP main effect was significant ($p < 0.0001$), but the sod composition main effect was not ($p = 0.1639$). Average abundance of *K. macrantha* was 1.0% from 61 through 103 DAP. From 117 to 187 DAP, the abundance of *K. macrantha* increased linearly from an average of 1.3% to an average of 7.0% (Figure 18e). From 187 to 201 DAP, *K. macrantha* abundance decreased to an average of 5.5%, where it remained through the last harvest.

For *Nassella lepida*, the DAP by sod composition interaction of was not significant ($p = 0.2838$). There was a significant DAP main effect ($p < 0.0001$). The sod composition main effect was also significant for this species ($p < 0.0001$). On average, RX3B mixtures contained significantly more *N. lepida* than did any of the other mixtures. RY5B mixtures contained significantly greater percentages of this species than did the four remaining mixtures, among which, there were no significant differences in the abundance of *N. lepida* (Figure 18f).

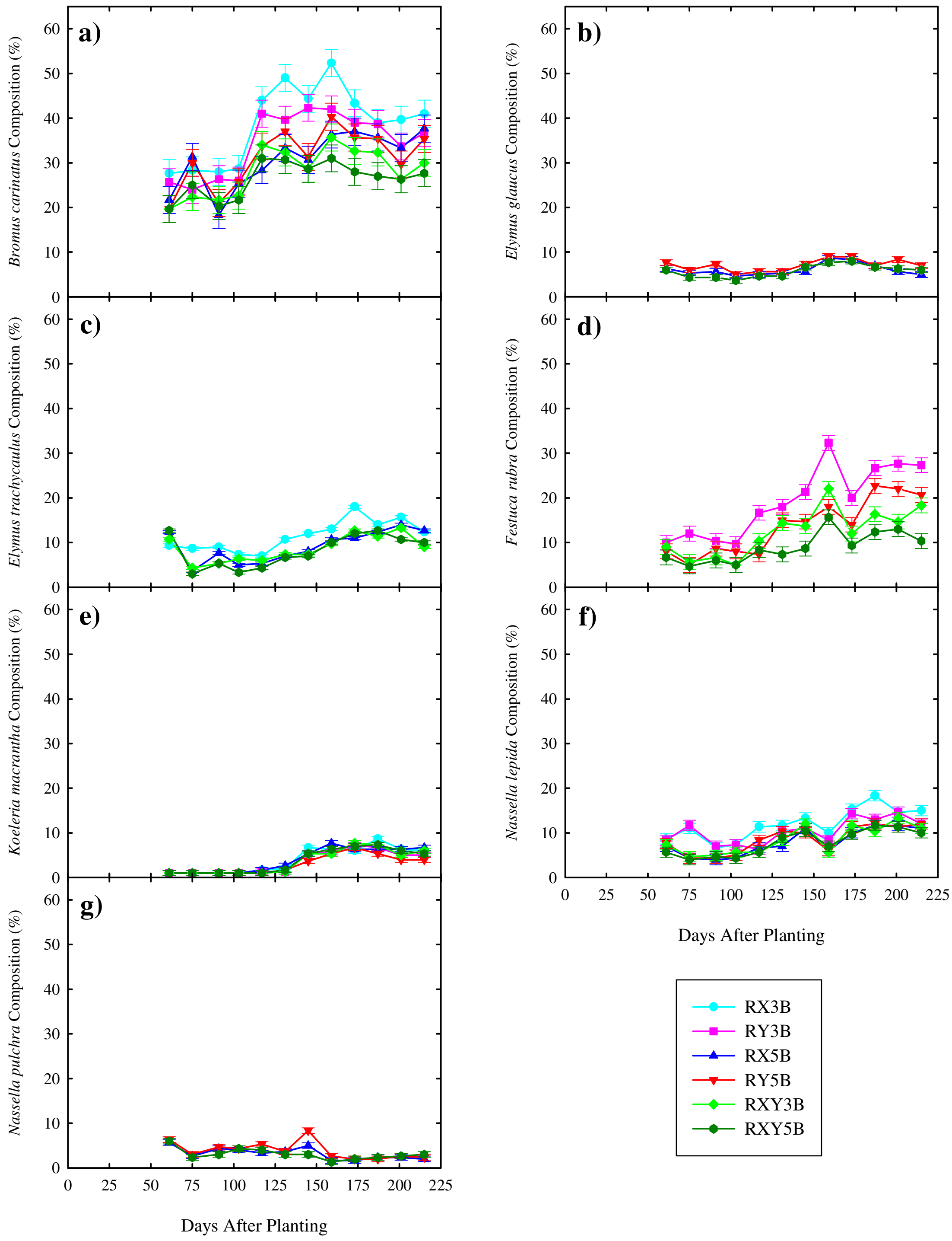

Figure 18. Effect of sod composition and days after planting on a) *Bromus carinatus*, b) *Elymus glaucus*, c) *Elymus trachycaulus*, d) *Festuca rubra*, e) *Koeleria macrantha*, f) *Nassella lepida*, and g) *Nassella pulchra* percent composition for the Chaparral ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

For *Nassella pulchra*, the DAP by sod composition interaction was significant ($p = 0.0200$). The only statistically significant difference occurred at 145 DAP, where the RY5B mixtures contained significantly greater percentages of *N. pulchra* than did the RX5B or RXY5B mixtures, which were not different from each other (Figure 18g).

Total Root Mass

There were no significant differences in total root mass between mixtures for the Chaparral ecoregion ($p = 0.2668$).

Root Mass by Depth

Mixtures. For the Chaparral ecoregion mixtures, the depth by sod composition interaction was significant ($p = 0.0006$). From 0.0 – 2.5 cm, RXY3B mixtures had significantly greater root mass than that of all other mixtures (Figure 19). There were no significant differences in root mass from 0.0 – 2.5 cm between RY3B and RX5B mixtures, but both of these mixtures had significantly greater root mass from 0.0 – 2.5 cm than did the remaining three mixtures, among which there were no significant differences. There were no significant differences in root mass between mixtures at any other depth.

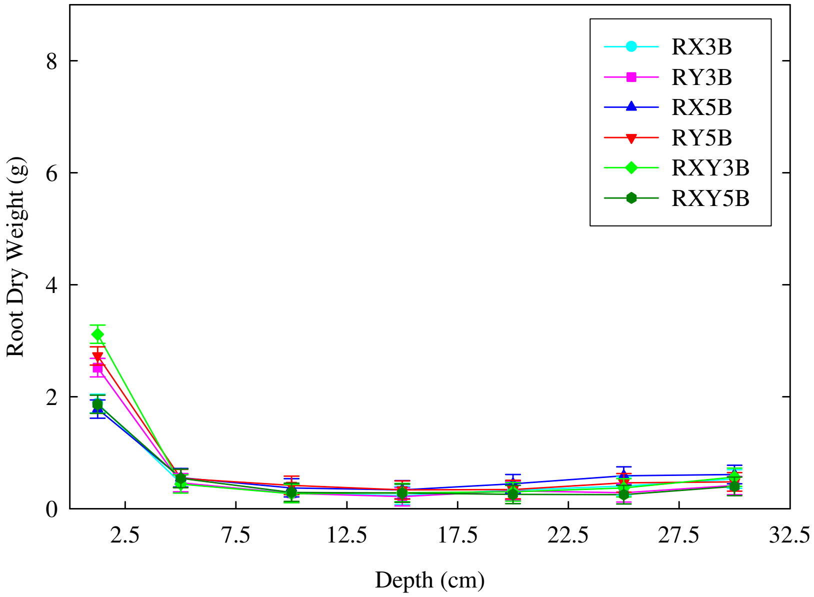

Figure 19. Effect of sod composition and depth on root mass for the Chaparral ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The depth by species interaction for the Chaparral monostand root mass was significant (p = 0.0002). From 0.0 – 7.5 cm, *Festuca rubra* had the greatest root biomass, having significantly greater biomass than that of all other species from 0.0 – 2.5 cm (Figure 20). *Koeleria macrantha* and *Bromus carinatus* were not significantly different from each other from 0.0 – 7.5 cm, but both had significantly greater root biomass than the remaining species from 0.0 – 2.5 cm. *Nassella pulchra* and *Nassella lepida* were not significantly different from each other. *Elymus glaucus* and *Elymus trachycaulus* were also not significantly different from one another in root biomass from 0.0 – 7.5 cm. Beyond 12.5 cm, there were no significant differences in root mass between species.

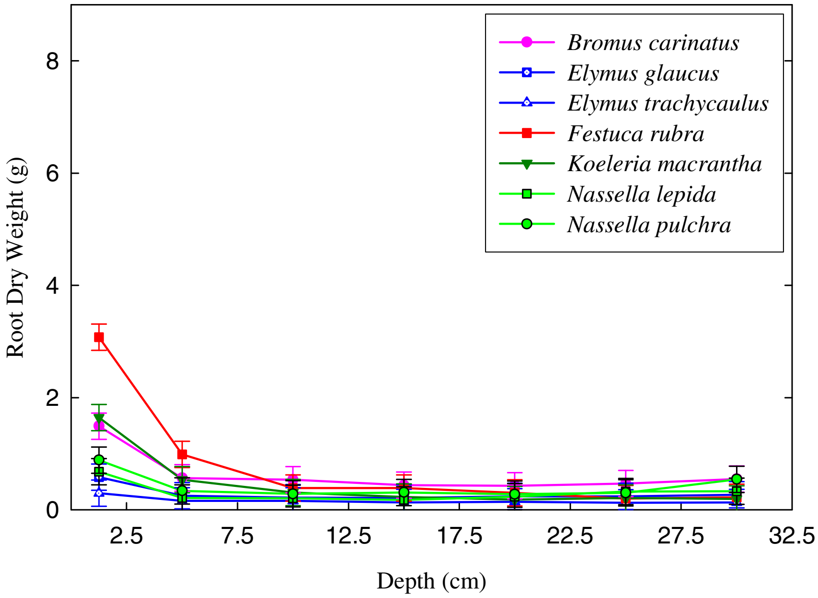

Figure 20. Effect of species and depth on root mass for the Chaparral ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Root Mass by Depth

Mixtures. There was a significant depth by sod composition interaction for percent root mass ($p < 0.0001$). From 0.0 – 2.5 cm, RXY3B, RY3B, and RY5B mixtures had the greatest percent root mass, but the lowest percent root mass from beyond 27.5 cm (Figure 21). Conversely, the RX3B and RX5B mixtures had the lowest percent root mass from 0.0 – 2.5 cm and the greatest percent root mass beyond 27.5 cm).

There were significant differences between mixtures for the percent root mass in the first 2.5 cm. The difference between mixtures with three bunch grasses and those with five was not significant at the 5% level ($p = 0.0805$). Mixtures containing rhizomatous species X (*E. trachycaulus*) had significantly lower percent root mass in the first 2.5 cm than did mixtures containing rhizomatous species Y (*F. rubra*) (p = 0.0048) and mixtures containing both rhizomatous species (p = 0.0063). There was not a significant difference in percent root mass in the first 2.5 cm between mixtures containing rhizomatous species Y and those containing both rhizomatous species (p = 0.8853).

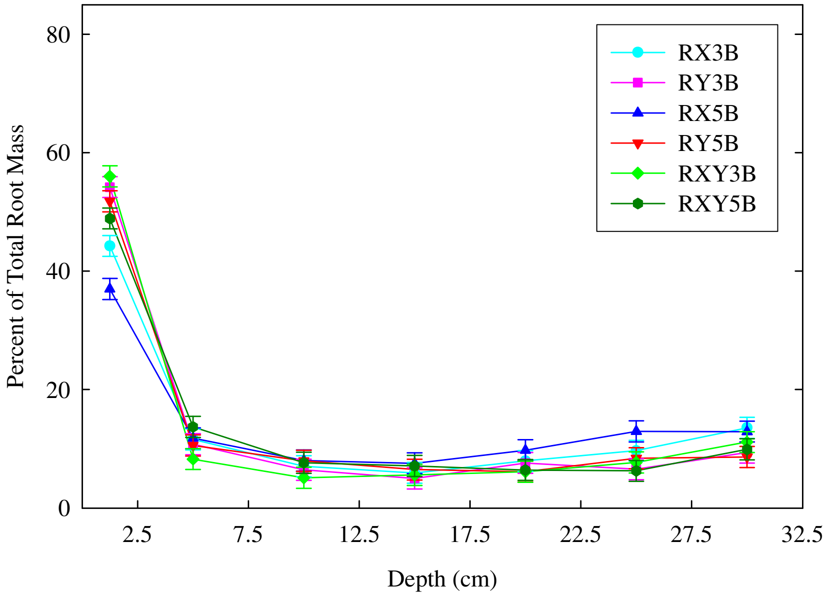

Figure 21. Effect of sod composition and depth on percent root mass for the Chaparral ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

<u>Monostands</u>. For percent root mass there was a significant depth by species interaction for Chaparral monostands (p < 0.0001). From 0.0 – 2.5 cm, *Festuca rubra* and *Koeleria macrantha* had significantly greater percent root mass than did the other five species (Figure 22). *Bromus carinatus* had significantly greater percentages than did *Elymus glaucus* and *Elymus trachycaulus*, but was not significantly different from

Nassella pulchra and *Nassella lepida*. The two *Nassella* species were not significantly different from the two *Elymus* species from 0.0 – 2.5 cm.

From 2.5 – 7.5 cm, *F. rubra* had significantly greater percent root mass than did all other species except *K. macrantha*. *Koeleria macrantha* was not significantly greater than any of the remaining five species except for *N. lepida*. *Nassella lepida* was not significantly different from the two *Elymus* species, *N. pulchra* or *B. carinatus*.

From 7.5 – 12.5 cm *E. trachycaulus* had significantly greater percent root mass than did *F. rubra* and both *Nassella* species, but was not different from the remaining three species. There were no significant differences among the six species excluding *E. trachycaulus* for percent root mass from 7.5 – 12.5 cm. From 12.5 – 17.5 cm, there were no significant differences in percentages among the seven species.

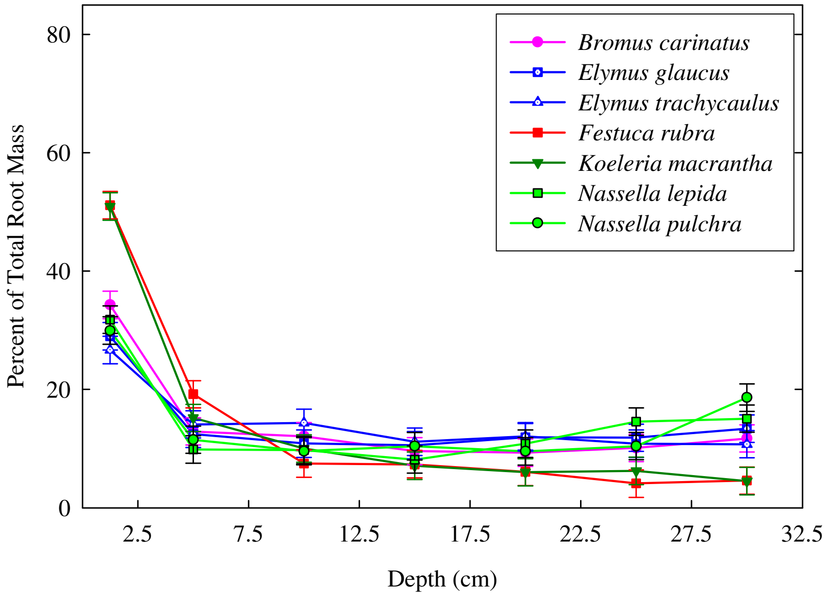

Figure 22. Effect of species and depth on percent root mass for the Chaparral ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Beyond 17.5 cm, there were no differences in percent root mass between the two *Elymus* species, the two *Nassella* species and *B. carinatus*, except beyond 27.5 cm where *N. pulchra* had significantly greater ratios than did both *Elymus* species and *B. carinatus*, but was not significantly different from *N. lepida*. *Koeleria macrantha* and *F. rubra* were not significantly different from each other beyond 17.5 cm and had the lowest percent root mass (Figure 22). Both of these species had significantly lower percentages than did all of the other five species beyond 27.5 cm.

Sod Strength

Sod strength was positively correlated with percent rhizomatous species composition for the Chaparral ecoregion ($R^2 = 0.5357$, $p = 0.0003$) (Figure 23).

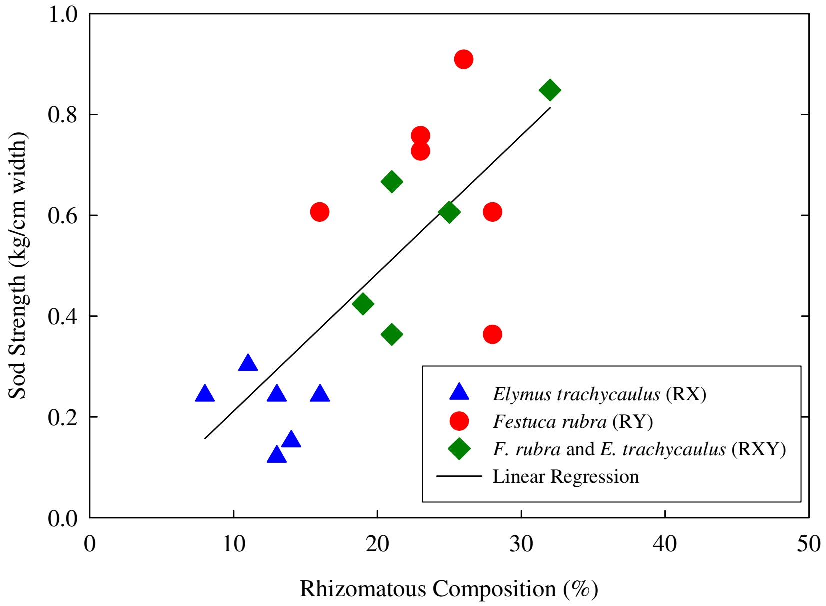

Figure 23. Correlation of percent rhizomatous species composition and sod strength for the Chaparral ecoregion. Linear regression $R^2 = 0.5357$.

The rhizomatous by bunch grass interaction for sod strength in the Chaparral ecoregion was not significant (p = 0.3128). There was a significant difference in sod strength due to rhizomatous species (p = 0.0006) (Figure 24). There was not a significant difference between mixtures with three bunch grasses and mixtures with five (p = 0.5217). Mixtures with rhizomatous species X (*Elymus trachycaulus*) had significantly lower sod strength than did those with both X and Y (p = 0.0003) and those with species Y (*Festuca rubra*) (p = 0.0012). There was no significant difference between mixtures with rhizomatous species Y and those with both X and Y (p = 0.4035).

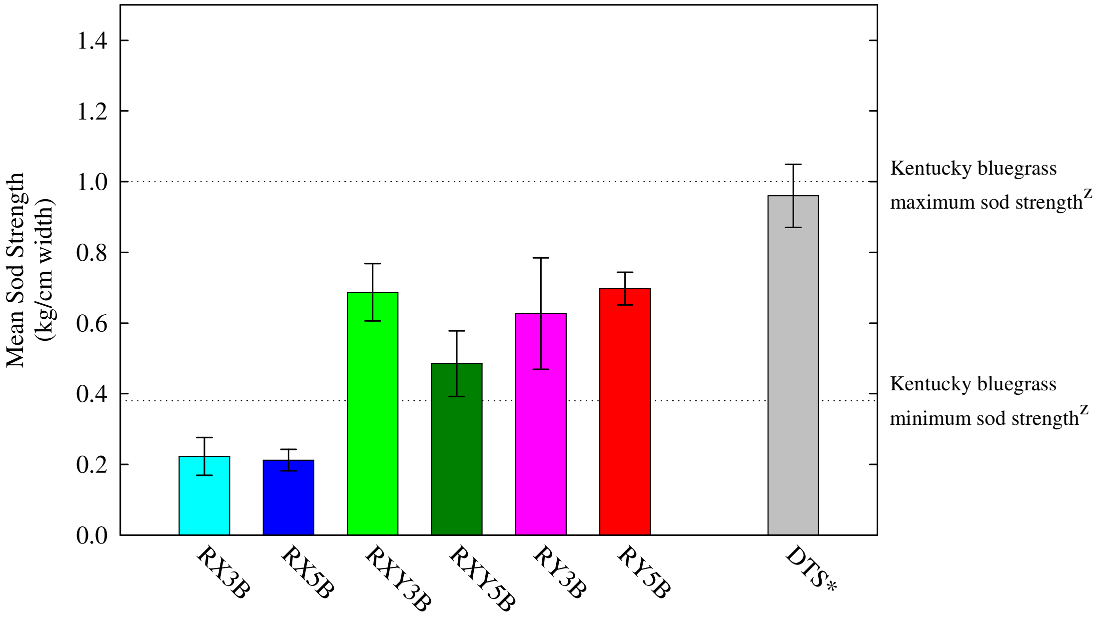

Figure 24. Effect of sod composition on sod strength for the Chaparral ecoregion. Bars represent means and error bars represent standard errors. *Drought-tolerant sod (Bitterroot Turf Farms, Corvallis, Montana). ^{z}From Flanagan et al. 1993.

Discussion

Despite significant differences in clipping fresh weight and percent dry weight at specific times between monostands, the Chaparral ecoregion mixtures did not differ significantly for these measures. Therefore, all mixtures will likely have similar mowing requirements and mowing quality. There were some differences between mixtures in total ground cover over the course of production. However, at the final harvest, there were no significant differences in ground cover between the mixtures. This indicates that there were no important differences between mixtures for total ground cover. The RY3B and RY5B mixtures covered the ground more quickly and, consequently, may reduce weed incidence. Sod does not establish more quickly or cover the ground more completely when a greater number of species are included.

Differences in *E. trachycaulus* and *F. rubra* abundance are explained by differences in initial seed proportions. Mixtures with fewer species contained significantly greater proportions of these two species because the initial seeded proportion was greater. Mixtures with *E. trachycaulus* as the single rhizomatous species had significantly lower sod strength than did those with *F. rubra* as the single rhizomatous species and those with both rhizomatous species. This indicates that *F. rubra* contributes more to sod strength than *E. trachycaulus*. Again, it is unclear whether similar percent compositions of these two rhizomatous species would produce similar sod strength. However, sod strength does increase as the percent rhizomatous species composition of the mixtures increases.

Bromus carinatus composition varied between mixtures over the production cycle; but, at the final harvest, there were no significant differences in *Bromus* abundance, indicating that *B. carinatus* composition was not correlated with sod strength. Despite some differences in composition at specific times, there were no differences in composition between mixtures for *Koeleria macrantha*, *Nassella pulchra* or *Elymus glaucus* at the final harvest; all of these species persisted in the mixtures despite low abundance and should not be eliminated from further studies. Since differences in the percent composition of *B. carinatus*, *K. macrantha*, *N. pulchra* and *E. glaucus* were not significant, these differences were not likely realized as differences in sod strength. RX3B and RY3B mixtures contained significantly more *Nassella lepida* than did the other four mixtures. This difference in *N. lepida* composition between RX3B mixtures and RY3B mixtures cannot be explained by initial seeding rates, but is more likely to be explained by competition effects. However, since RX3B mixtures had significantly lower sod strength than did RY3B mixtures, it is unlikely that *N. lepida* abundance was a major contributing factor for sod strength. All species persisted in the mixtures, even though some were less abundant, which affirms the hypothesis that these native species are tolerant of current sod production methods.

Total root mass did not differ between mixtures. Mixtures with more species did not have more extensive root systems than did mixtures with fewer species. Dry root mass and percent root mass varied significantly between monostands across depths, indicating that different species have different root architecture. Dry root mass and percent root mass in the first 2.5 cm was significantly less for mixtures with *E. trachycaulus* as the single rhizomatous species than it was for mixtures with *F. rubra* as the single rhizomatous species or for mixtures with both species. This information, coupled with the fact that *E. trachycaulus* had significantly less dry root mass and a significantly lower percentage of roots in the first 2.5 cm than did *F. rubra*, further supports idea that *F. rubra* contributes to sod strength more than *E. trachycaulus*. Mixtures with *F. rubra* had similar sod strength to the Kentucky bluegrass, but had slightly lower sod strength than the drought-tolerant sod (Figure 24). Mixtures with *E. trachycaulus* as the single rhizomatous species had lower sod strength than both the drought-tolerant sod and Kentucky bluegrass.

Great American Desert

Selected Species

Table 8 lists the selected species for each sod composition for the Great American Desert ecoregion.

Table 8. Selected species for each sod composition for the Great American Desert ecoregion.

RX3B
RX: *Leymus condensatus* B1: *Achantherum hymenoides* B2: *Elymus elymoides* B3: *Koeleria macrantha*
RX5B
RX: *Leymus condensatus* B1: *Achantherum hymenoides* B2: *Elymus elymoides* B3: *Koeleria macrantha* B4: *Nassella cernua* B5: *Aristida purpurea*

Clipping Fresh Weight

Mixtures. There was no significant DAP by sod composition interaction for clipping fresh weight in the Great American Desert ecoregion ($p = 0.7150$). The DAP main effect was significant ($p < 0.0001$) with peaks of growth at 60 and 175 DAP (Figure 25). The sod composition main effect was not significant ($p = 0.3290$).

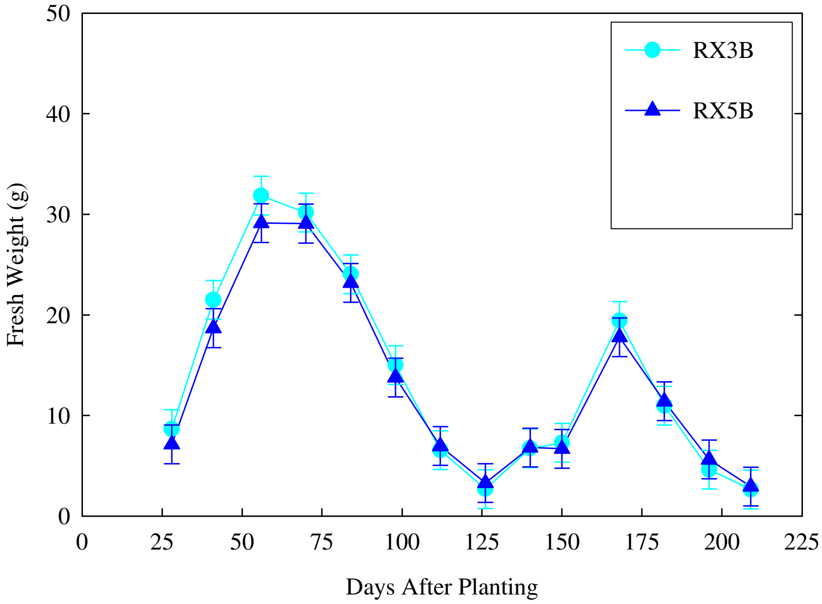

Figure 25. Effect of sod composition and days after planting on clipping fresh weight for the Great American Desert ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The DAP by species interaction was significant for monostands in the Great American Desert ecoregion ($p < 0.0001$). Clipping fresh weights of *Elymus elymoides* and *Leymus condensatus* only differed significantly from each other at 182 DAP (Figure 26). These two species had greater fresh weights than all other species. From 28 through 126 DAP, Nassella cernua had greater fresh weights than *Koeleria* *macrantha*. However, beyond 126 DAP, *K. macrantha* fresh weights were greater than those of *N. cernua*. Initially, *Aristida purpurea* had lower fresh weights, but beyond 126 DAP, fresh weights of this species were comparable to those of *E. elymoides* and *L. condensatus*. *Achnatherum hymenoides* had the lowest fresh weights across all harvests.

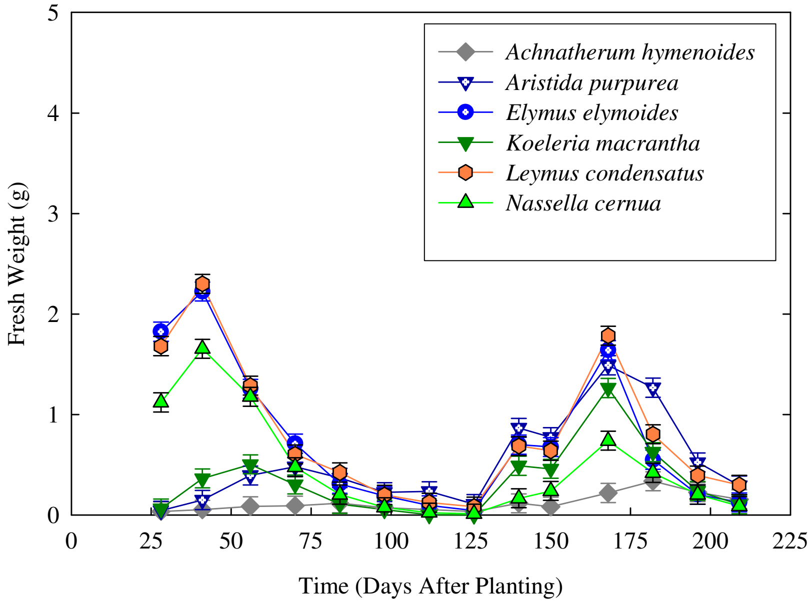

Figure 26. Effect of species and days after planting on clipping fresh weight for the Great American Desert ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Clipping Percent Dry Weight

Mixtures. The DAP by sod composition interaction was not significant for clipping percent dry weight (p = 0.9800). The DAP main effect was significant (p < 0.0001). The sod composition main effect was not significant (p = 0.1561). Percent dry weight at the first harvest averaged 14.0% (Figure 27). Average clipping percent dry weight increased in a linear fashion over time until the final harvest where it reached a maximum of 33.0%.

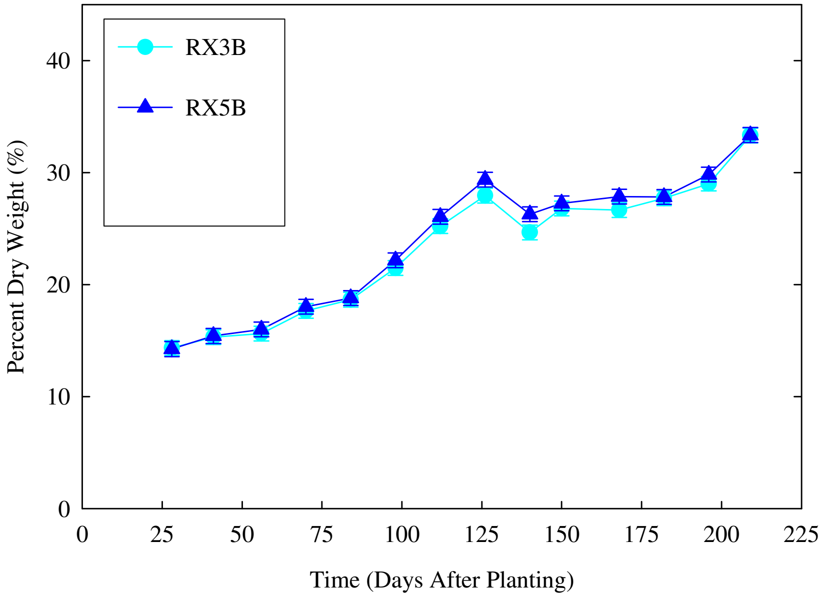

Figure 27. Effect of sod composition and days after planting on clipping percent dry weight for the Great American Desert ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. There was significant DAP by species interaction for clipping percent dry weight for monostands ($p < 0.0001$). The percent dry weights of *Elymus elymoides* and *Leymus condensatus* were not significantly different from each other at any harvest and percent dry weight gradually increased (18% to 30%) as DAP increased (Figure 28). For all other species, there was not a consistent or meaningful trend in percent dry weight.

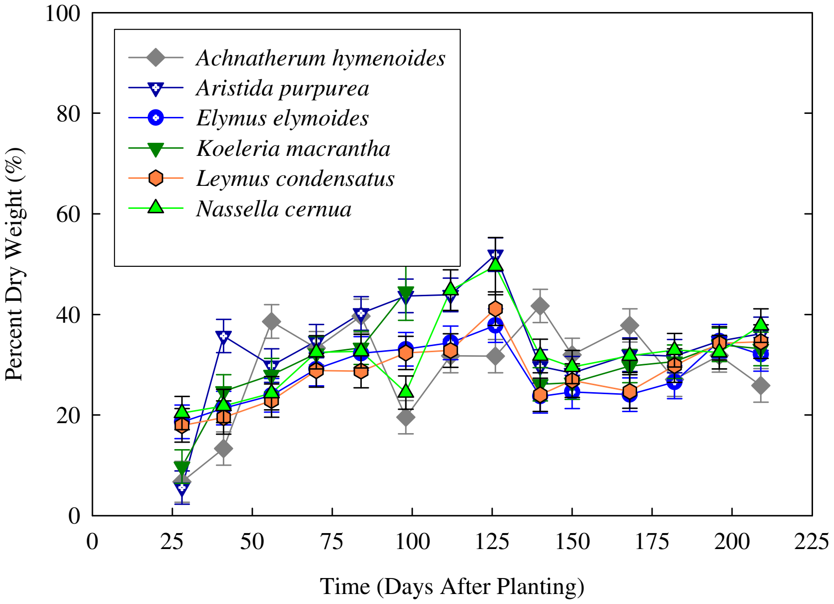

Figure 28. Effect of species and days after planting on clipping percent dry weight for the Great American Desert ecoregion monostands. Points represent estimates and error bars represent standard errors from the SAS MIXED model.

Total Ground Cover

For total ground cover in the Great American Desert ecoregion, there was no significant interaction of DAP and sod composition (p = 0.1990). Both the DAP main effect (p < 0.0001) and the sod composition main effect were significant (p = 0.0102). On average, RX5B mixtures (59.7%) had greater total ground cover than RX3B mixtures (56.7%) (Figure 29).

Total ground cover was significantly greater for RX5B mixtures at the final harvest than it was for RX3B mixtures (p = 0.0190).

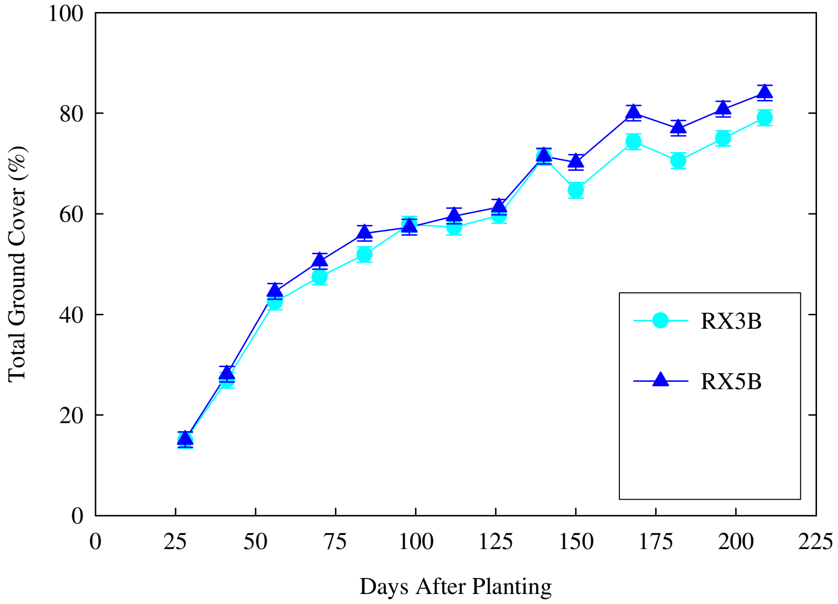

Figure 29. Effect of sod composition and days after planting on total ground cover for the Great American Desert ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Species Composition

For *Achnatherum hymenoides*, the DAP by sod composition interaction was not significant at the 5% level (p = 0.0804). Although both the DAP main effect (p < 0.0001) and the sod composition main effect (p = 0.0338) were significant for *A. hymenoides*, the averages were within a unit of discernable measurement (1.87% and 1.74%) (Figure 30a).

Average *Aristida purpurea* percent composition was significantly greater than zero (p < 0.0001). *Aristida purpurea* abundance averaged 1.1% at the first harvest. From the first harvest until 56 DAP, *A. purpurea* composition increased to 4.0%. From 56 DAP through the final harvest, average *A. purpurea* abundance ranged between 4.0% and 5.0% (Figure 30b).

There was a statistically significant DAP by sod composition interaction for *Elymus elymoides* ($p < 0.0001$). RX3B mixtures contained a significantly greater abundance of *E. elymoides* than did RX5B mixtures at every harvest except those at 168 and 182 DAP, where differences were not significant (Figure 30c).

For *Koeleria macrantha*, the DAP by sod composition interaction was significant ($p < 0.0001$). For the first two harvests, there was no significant difference in *K. macrantha* composition between the two mixtures (Figure 30d). From 56 DAP through the final harvest, RX3B mixtures had significantly greater proportions of *K. macrantha* than did RX5B mixtures.

For *Leymus condensatus*, there was a significant DAP by sod composition interaction ($p < 0.0001$). RX3B mixtures contained significantly greater percentages of *L. condensatus* than did the RX5B mixtures at all but the first harvest (Figure 30e).

Average *Nassella cernua* percent composition was significantly greater than zero ($p < 0.0001$). *Nassella cernua* percent composition averaged 3.4% at the first harvest thereafter increasing to 20.0% by 70 DAP and gradually increased to 24% by 196 DAP (Figure 30f). Percent composition of this species markedly increased to 33.8% at 182 DAP and 31.1% at the final harvest.

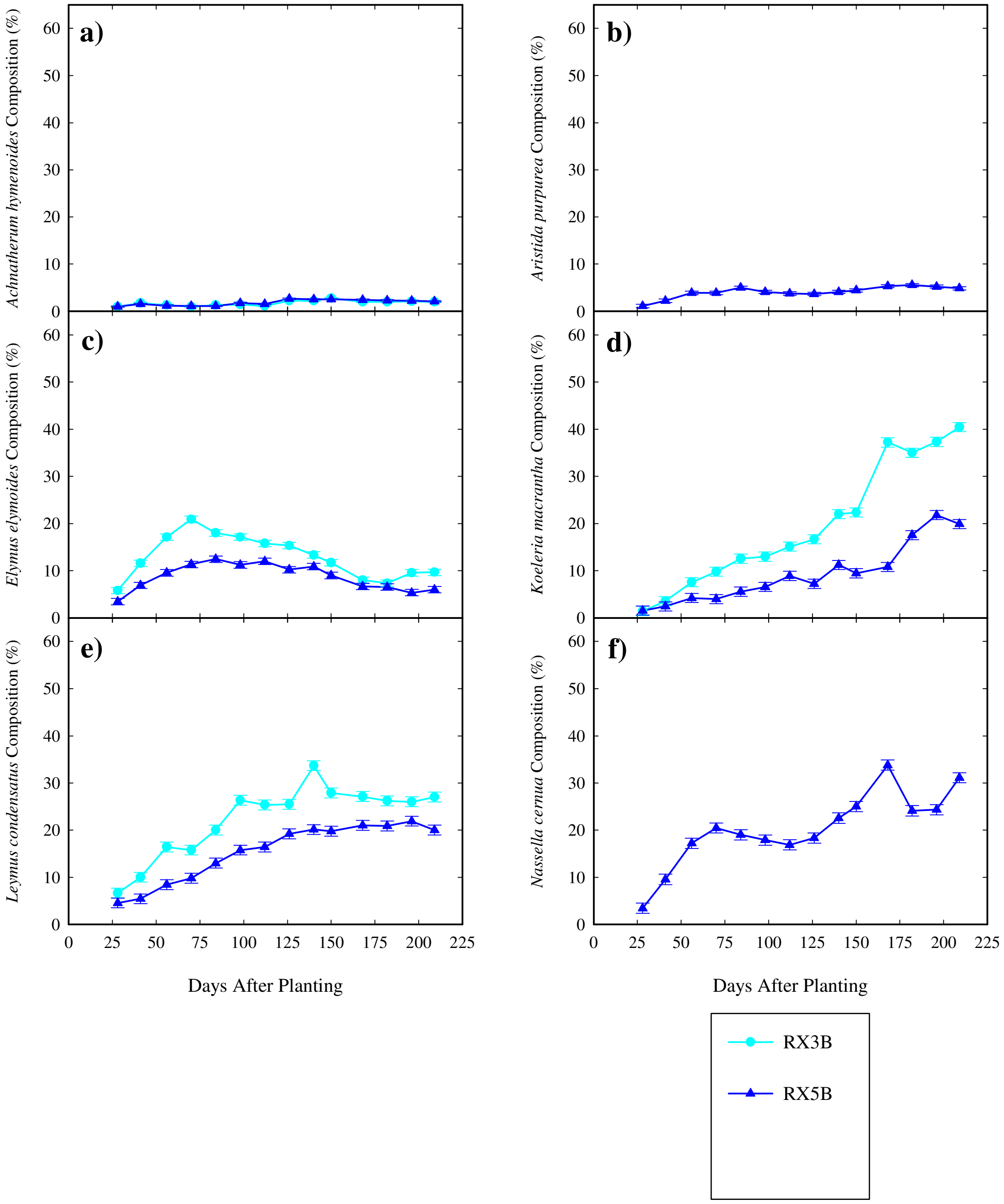

Figure 30. Effect of sod composition and days after planting on a) *Achnatherum hymenoides*, b) *Aristida purpurea*, c) *Elymus elymoides*, d) *Koeleria macrantha*, e) *Leymus condensatus*, f) *Nassella cernua* percent composition for Great American Desert ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

Total Root Mass

For the Great American Desert ecoregion, there were no significant differences between mixtures in total root mass (p = 0.2525).

Root Mass by Depth

Mixtures. For Great American Desert ecoregion, the depth by sod composition interaction was not significant for root mass (p = 0.1787). The depth main effect was significant (p < 0.0001) with the greatest dry root mass occurring from 0.0 - 2.5 cm (Figure 31). There was not a significant sod composition main effect (p = 0.3625).

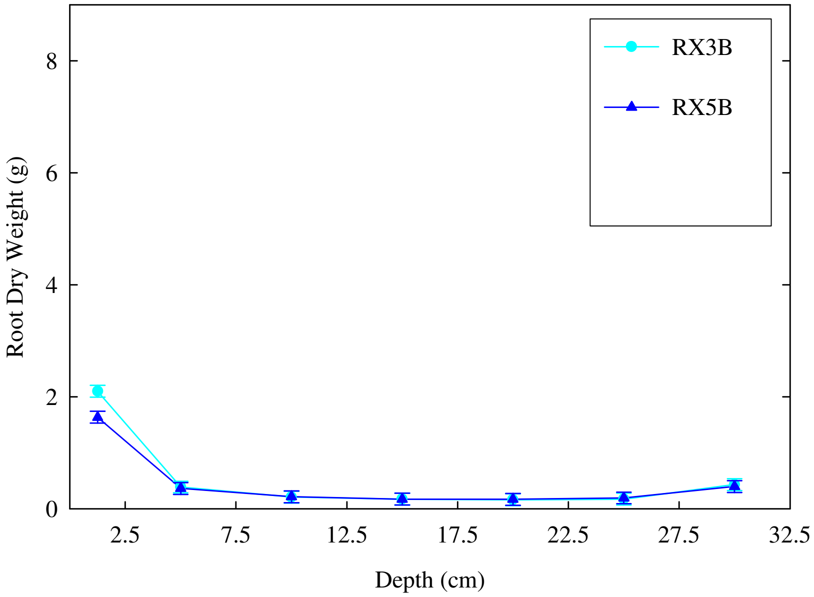

Figure 31. Effect of sod composition and depth on root mass for the Great American Desert ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. There was a significant depth by species interaction for the root mass of monostands ($p < 0.0001$). *Koeleria macrantha* had the greatest root mass, having significantly greater root mass than that of all other species from 0.0 – 2.5 cm (Figure 32). *Koeleria macrantha* was followed by *Nassella cernua*, *Elymus elymoides*, and *Leymus condensatus* in statistically significant descending root mass order. All species had significantly diminished root mass beyond 7.5 cm *Achnatherum hymenoides* root mass did not vary significantly across depths ($p = 0.9999$).

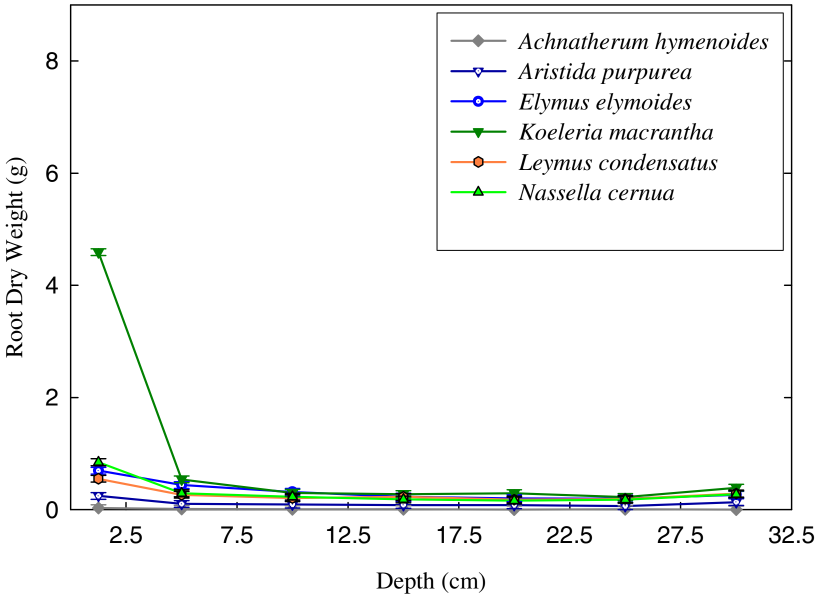

Figure 32. Effect of species and depth on root mass for the Great American Desert ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Root Mass by Depth

Mixtures. The depth by sod composition interaction was significant for percent root mass for the Great American Desert ecoregion ($p = 0.0294$). RX3B mixtures had significantly greater percent root mass from 0.0 – 2.5 cm than did RX5B mixtures (Figure 33). However, from 2.5 – 32.5 cm percent root mass of the two mixtures was similar.

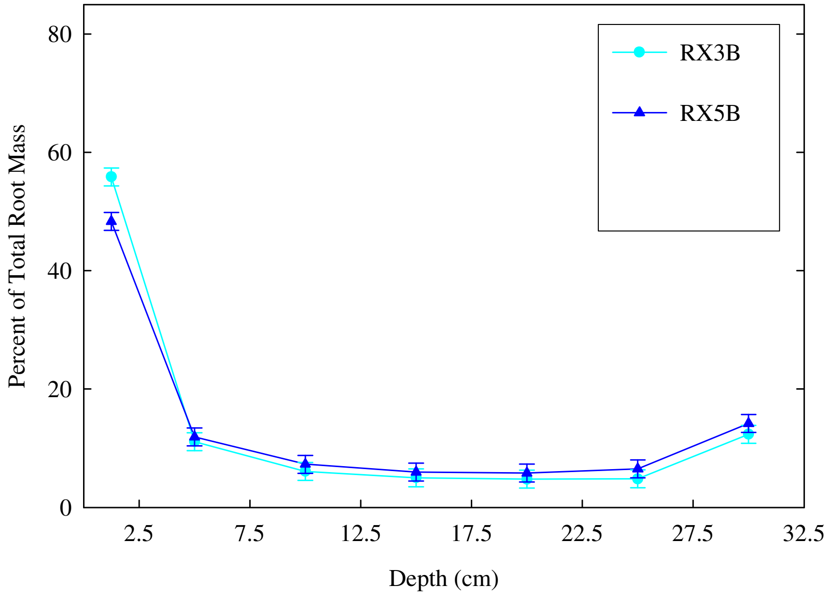

Figure 33. Effect of sod composition and depth on percent root mass for the Great American Desert ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The species by depth interaction for percent root mass was significant for Great American Desert monostands ($p < 0.0001$). *Koeleria macrantha* had significantly greater percent root mass from 0.0 – 2.5 cm than any other species (Figure 34). However, beyond 2.5 cm, *K. macrantha* had the lowest percent root mass. *Nassella cernua* had significantly greater percent root mass from 0.0 – 2.5 cm, than did *Aristida purpurea*, *Elymus elymoides* and *Leymus condensatus*, among which there were no significant differences. Beyond 2.5 cm, there were no significant differences in percent root mass between these four species. *Achnatherum hymenoides* percent root mass was not significantly different from those of *N. cernua* and *A. purpurea* from 0.0 – 2.5 cm. From 2.5 – 12.5 cm and from 22.5 – 27.5 cm, *A. hymenoides* had the greatest percent root mass, but from 17.5 – 22.5 cm and beyond 27.5 cm had the lowest percent root mass.

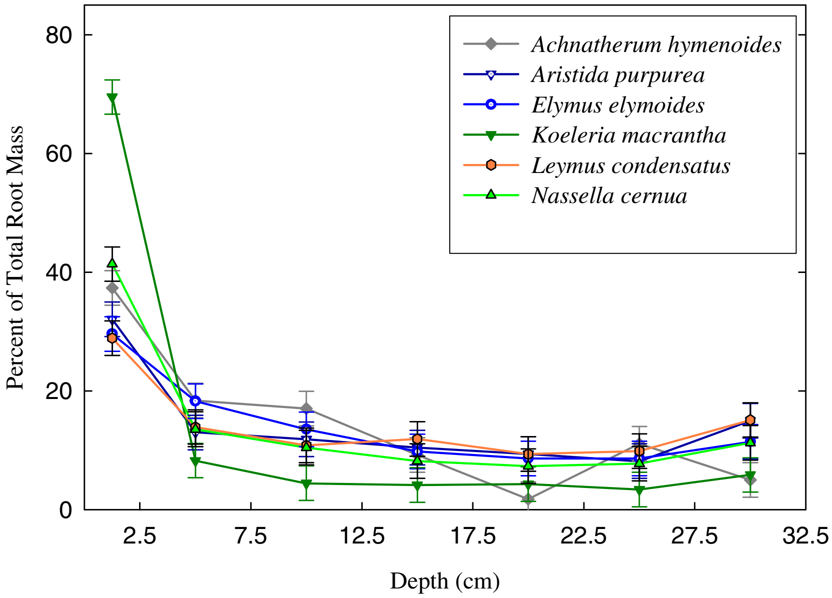

Figure 34. Effect of species and depth on percent root mass for the Great American Desert ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Sod Strength

The correlation between sod strength and percent rhizomatous species composition was not significant for the Great American Desert ecoregion ($R^2 = 0.0610$, $p = 0.1662$) (Figure 35). Sod strength for RX3B mixtures was significantly greater than that for RX5B mixtures in the Great American Desert ecoregion ($p = 0.0168$) (Figure 36).

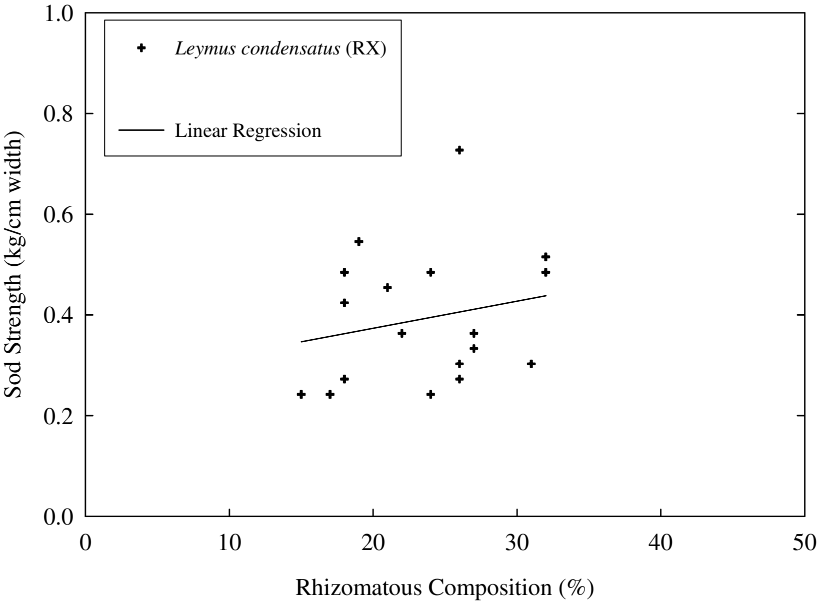

Figure 35. Correlation of percent rhizomatous species composition and sod strength for the Great American Desert ecoregion. Linear regression $R^2 = 0.0610$.

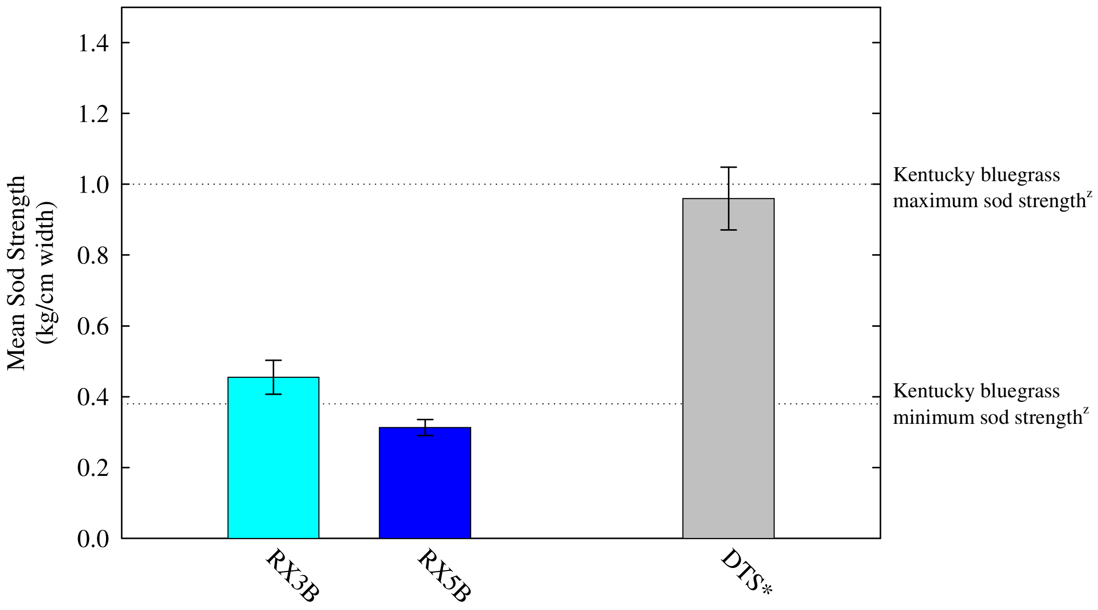

Figure 36. Effect of sod composition on sod strength for the Great American Desert ecoregion. Bars represent means and error bars represent standard errors. *Drought-tolerant sod (Bitterroot Turf Farms, Corvallis, Montana). [z]From Flanagan et al. 1993.

Discussion

Differences in clipping fresh weight and percent dry weight for monostands indicate differences in the growth rates of different species. These differences balanced each other such that there were no significant differences in clipping weights between mixtures. Therefore, the mowing requirements and mowing quality of mixtures in the Great American Desert ecoregion will likely be similar.

There were no differences between mixtures in the rate of sod establishment as evidenced by total ground cover. However, at the final harvest, RX5B mixtures had significantly greater total ground cover than did RX3B mixtures. This could be construed as evidence, albeit weak, to support the hypothesis that there is a positive correlation between increasing number of species and total ground cover. However, it is more likely that this difference in total ground cover is explained by species identity rather than the number of species present, since *Nassella cernua* was only included in the five bunch grass mixtures and comprised nearly 30% of the total ground cover in those mixtures.

RX3B mixtures contained greater percentages of *Leymus condensatus*, *Elymus elymoides* and *Koeleria macrantha* than did RX5B mixtures. This can be explained by initial seeding rates. *Achnatherum hymenoides* germinated at very low percentages and comprised less than 2.0% of the average total ground cover. This was likely due to the fact that the emerging radicles of the cold-stratified seeds were damaged during planting. *A. hymenoides* should be excluded from further studies, unless a fall planting of *A. hymenoides* could be followed by a spring planting of the remainder of the species, such that they germinated at the same time. This shows that some native species will not tolerate current sod production methods and should not be utilized.

Total root mass did not differ significantly between the two mixtures which refutes the hypothesis that a greater number of species will produce a more extensive root system. However, RX3B mixtures had greater sod strength and greater root mass and percent root mass in the first 2.5 cm than did RX5B mixtures, which indicates a correlation between, root mass in the first 2.5 cm and sod strength. This, coupled with the fact that *Koeleria macrantha* had greater root mass in the first 2.5 cm than all other species and partitioned over 65% of its total root mass in the first 2.5 cm, indicates that *K. macrantha* may contribute to sod strength more than the other species in the Great American Desert ecoregion. RX3B mixtures produced sod strength within the Kentucky bluegrass range (Figure 36). Neither RX3B nor RX5B mixtures produced as strong of sod as the Bitterroot Turf Farms drought-tolerant sod. There was not a significant correlation between percent rhizomatous species composition and sod strength for the Great American Desert ecoregion.

Intermountain Sagebrush

Selected Species

Table 9 lists the selected species for each sod composition for the Intermountain Sagebrush ecoregion.

Table 9. Selected species for each sod composition for the Intermountain Sagebrush ecoregion.

RX3B	**RX5B**	**RXY3B**
RX: *Leymus triticoides* B1: *Elymus elymoides* B2: *Koeleria macrantha* B3: *Leymus cinereus*	RX: *Leymus triticoides* B1: *Elymus elymoides* B2: *Koeleria macrantha* B3: *Leymus cinereus* B4: *Achnatherum occidentale* B5: *Elymus multisetus*	RX: *Leymus triticoides* RY: *Elymus trachycaulus* B1: *Elymus elymoides* B2: *Koeleria macrantha* B3: *Leymus cinereus*
RY3B	**RY5B**	**RXY5B**
RY: *Elymus trachycaulus* B1: *Elymus elymoides* B2: *Koeleria macrantha* B3: *Leymus cinereus*	RY: *Elymus trachycaulus* B1: *Elymus elymoides* B2: *Koeleria macrantha* B3: *Leymus cinereus* B4: *Achnatherum occidentale* B5: *Elymus multisetus*	RX: *Leymus triticoides* RY: *Elymus trachycaulus* B1: *Elymus elymoides* B2: *Koeleria macrantha* B3: *Leymus cinereus* B4: *Achnatherum occidentale* B5: *Elymus multisetus*

Clipping Fresh Weight

Mixtures. There was a significant DAP by sod composition interaction for clipping fresh weight in the Intermountain Sagebrush ecoregion ($p = 0.0234$). This interaction was due to the fact that the RX5B mixtures had lower fresh weights than all other mixtures only from 86 through 114 DAP (Figure 37). From 170 DAP through the final harvest, there were no significant differences among mixtures for clipping fresh weight.

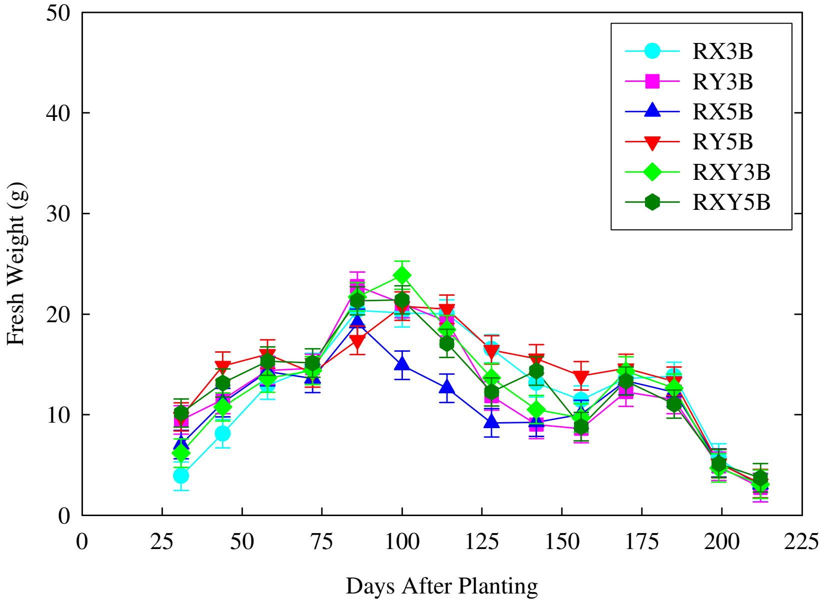

Figure 37. Effect of sod composition and days after planting on clipping fresh weight for the Intermountain Sagebrush ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The DAP by species interaction was significant for monostands in the Intermountain Sagebrush ecoregion ($p < 0.0001$). There were numerous changes in rank order of fresh weight between the species (Figure 38). *Elymus multisetus* produced consistently high fresh weights while *Achnatherum occidentale* produced consistently low fresh weights.

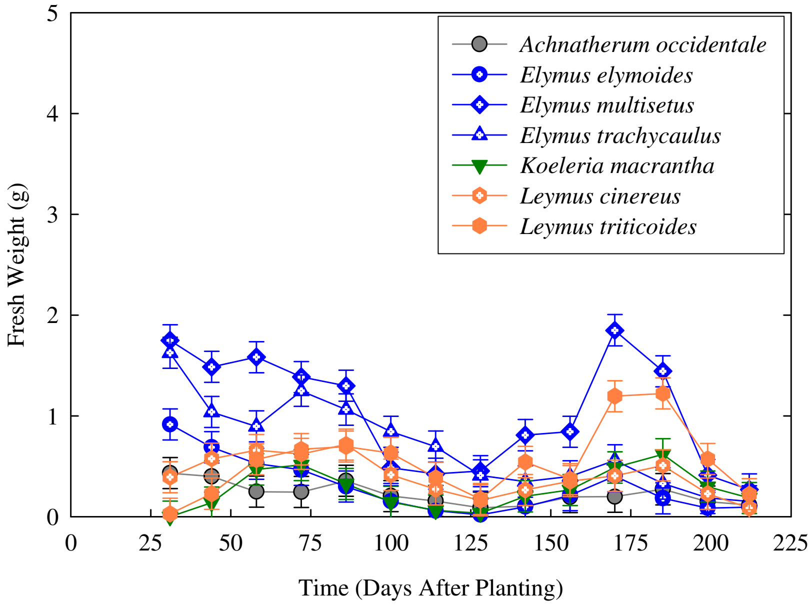

Figure 38. Effect of species and days after planting on clipping fresh weight for the Intermountain Sagebrush ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

<u>Clipping Percent Dry Weight</u>

<u>Mixtures</u>. The DAP by sod composition interaction was significant for clipping percent dry weight for the Intermountain Sagebrush ecoregion (p = 0.0021). At 44 DAP, the percent dry weight of RX3B mixtures was not significantly different from that of the RX5B mixtures, but was significantly less than that of the other four mixtures (Figure 39). Other than this difference, the mixtures were not significantly different from one another from the first harvest until 114 DAP.

Percent dry weight was similar for all mixtures for the remainder of the experiment with the exception of lower percent dry weights in the RY5B mixture from 114 to 185 DAP and the RXY5B mixture at 142 DAP

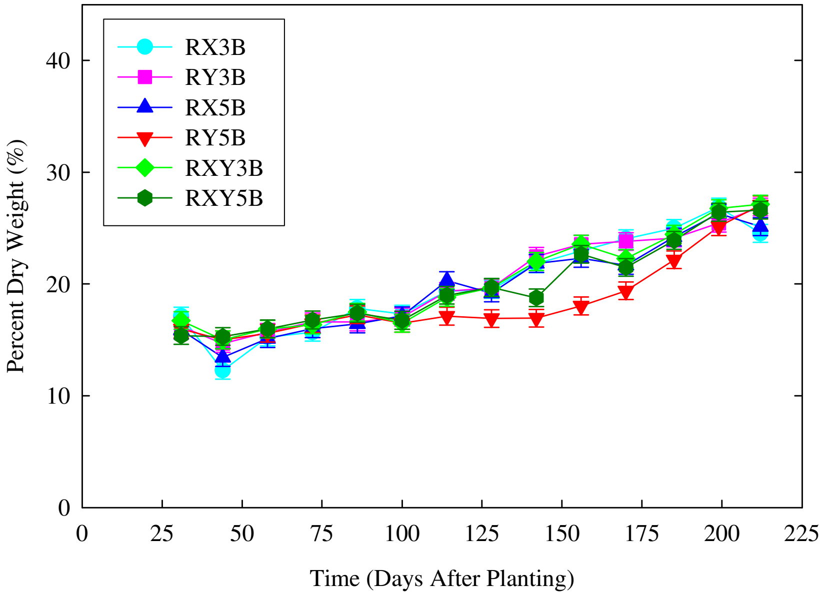

Figure 39. Effect of sod composition and days after planting on clipping percent dry weight for the Intermountain Sagebrush ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The DAP by species interaction for clipping percent dry weight for monostands was not significant ($p = 0.2784$). The DAP main effect was significant ($p < 0.0001$) with a gradual increase in percent dry weight over time. The species main effect was not significant ($p = 0.1129$) (Figure 40).

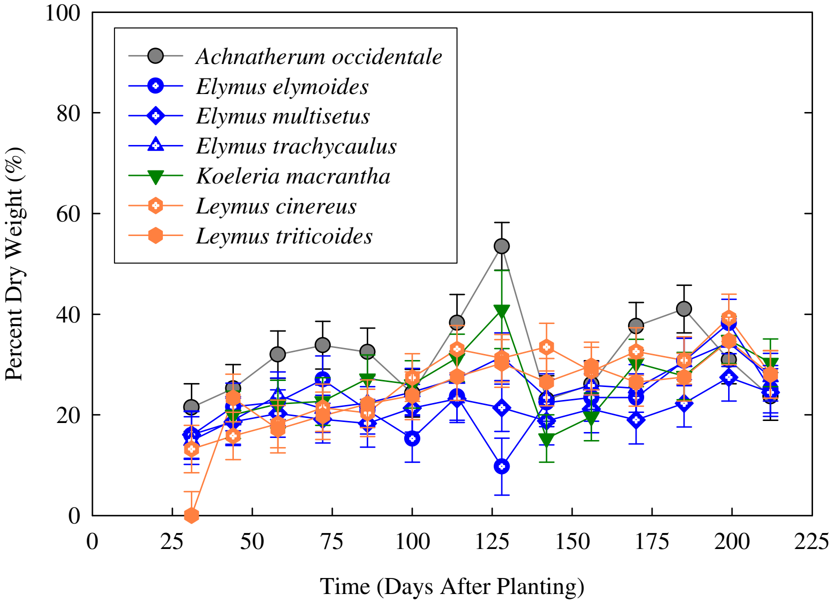

Figure 40. Effect of species and days after planting on clipping percent dry weight for the Intermountain Sagebrush ecoregion monostands. Points represent estimates and error bars represent standard errors from the SAS MIXED model.

Total Ground Cover

There was a significant DAP by sod composition interaction for total ground cover ($p < 0.0001$). Minor variations in total ground cover occurred early on, but major differences were present beginning at 100 DAP (Figure 41). RX3B mixtures had the statistically greatest ground cover for most of the remaining experiment, followed by the two RXY mixtures. The RX5B mixtures and the two RY mixtures consistently had the lowest ground cover after 100 DAP.

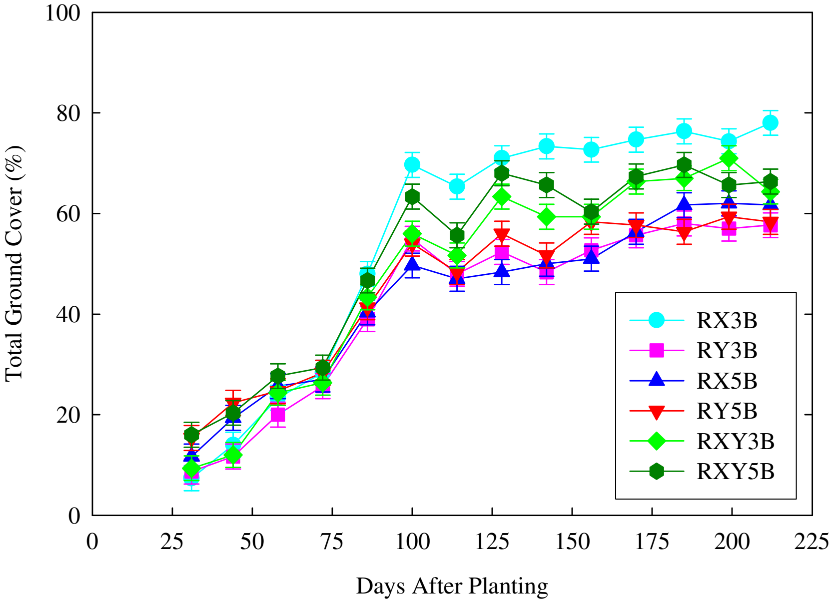

Figure 41. Effect of sod composition and days after planting on total ground cover for the Intermountain Sagebrush ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

At the final harvest, there was a significant rhizomatous by bunch grass interaction for total ground cover (p = 0.0343). There was significantly more total ground cover in RX3B mixtures than in any of the other five mixtures, among which there were no significant differences.

Percent Species Composition

For *Achnatherum occidentale*, there was no significant interaction between DAP and sod composition (p = 0.9467). The DAP main effect was significant (p < 0.0001). There were no significant differences in *A. occidentale* composition among mixtures (p = 0.9144). Average percent compositions for *A. occidentale* were 3.0% at 31 DAP, increasing to a maximum of 8.0% at 100 DAP before falling back to 3.0% at the final harvest (Figure 42a).

For *Elymus elymoides*, the DAP by sod composition interaction was significant (p = 0.0136). The RX3B mixtures contained the most *E. elymoides* over the growth period; however, these mixtures only contained significantly greater percentages of *E. elymoides* than all other mixtures from 72 through 100 DAP (Figure 42b).

The DAP by sod composition interaction was not significant for *Elymus multisetus* (p = 0.3811). The DAP main effect was significant (p < 0.0001). There were no significant differences in *E. multisetus* composition among mixtures (p = 0.1119). Average percent composition of *E. multisetus* was 2.5% for the first four harvests (Figure 42c). From 72 DAP until 185 DAP, average *E. multisetus* percentages increased to 10.6%. From 185 DAP until the final harvest, *E. multisetus* percent composition decreased slightly to 9.5%.

There was a significant DAP by sod composition interaction for *Elymus trachycaulus* (p = 0.0017). All mixtures had similar *E. trachycaulus* composition (about 8%) throughout the experiment except RY3B mixtures contained significantly greater percentages at 86, 100 and 185 DAP (Figure 42d).

There was a significant interaction of DAP by sod composition for *Koeleria macrantha* in the Intermountain Sage ecoregion (p = 0.0026). From the first harvest through 86 DAP, there were no significant differences in *K. macrantha* composition among mixtures (Figure 42e). From 86 DAP until the final harvest, mixtures with only three bunch grasses (RX3B, RY3B, and RXY3B) contained more *K. macrantha* than mixtures with five bunch grasses. The RX3B mixtures consistently had the highest *K. macrantha* composition.

For *Leymus cinereus*, the DAP by sod composition interaction was significant ($p < 0.0001$). For this species, there were no significant differences among mixtures from 31 through 72 DAP (Figure 42f). From 86 DAP through the final harvest, RX3B mixtures contained significantly greater percentages of *L. cinereus* than did any other mixture, except at 185 DAP. During this same period RXY3B mixtures contained the second-greatest proportions of *L. cinereus*, having significantly greater percentages than all of the remaining four mixtures only from 128 through 156 DAP. RX5B mixtures contained the least *L. cinereus* at 100 DAP, but *L. cinereus* composition in this mixture increased linearly over time and had the third-greatest proportion of *L. cinereus* by the final harvest.

For *Leymus triticoides*, there was a significant DAP by sod composition interaction in the Intermountain Sagebrush ecoregion ($p = 0.0009$). RX3B mixtures contained significantly greater percentages of *L. triticoides* than did all other mixtures from 72 to 185 DAP and at final harvest (Figure 42g). The remaining three mixtures were not significantly different from one another except from 72 to 100 DAP and from 156 DAP through the final harvest.

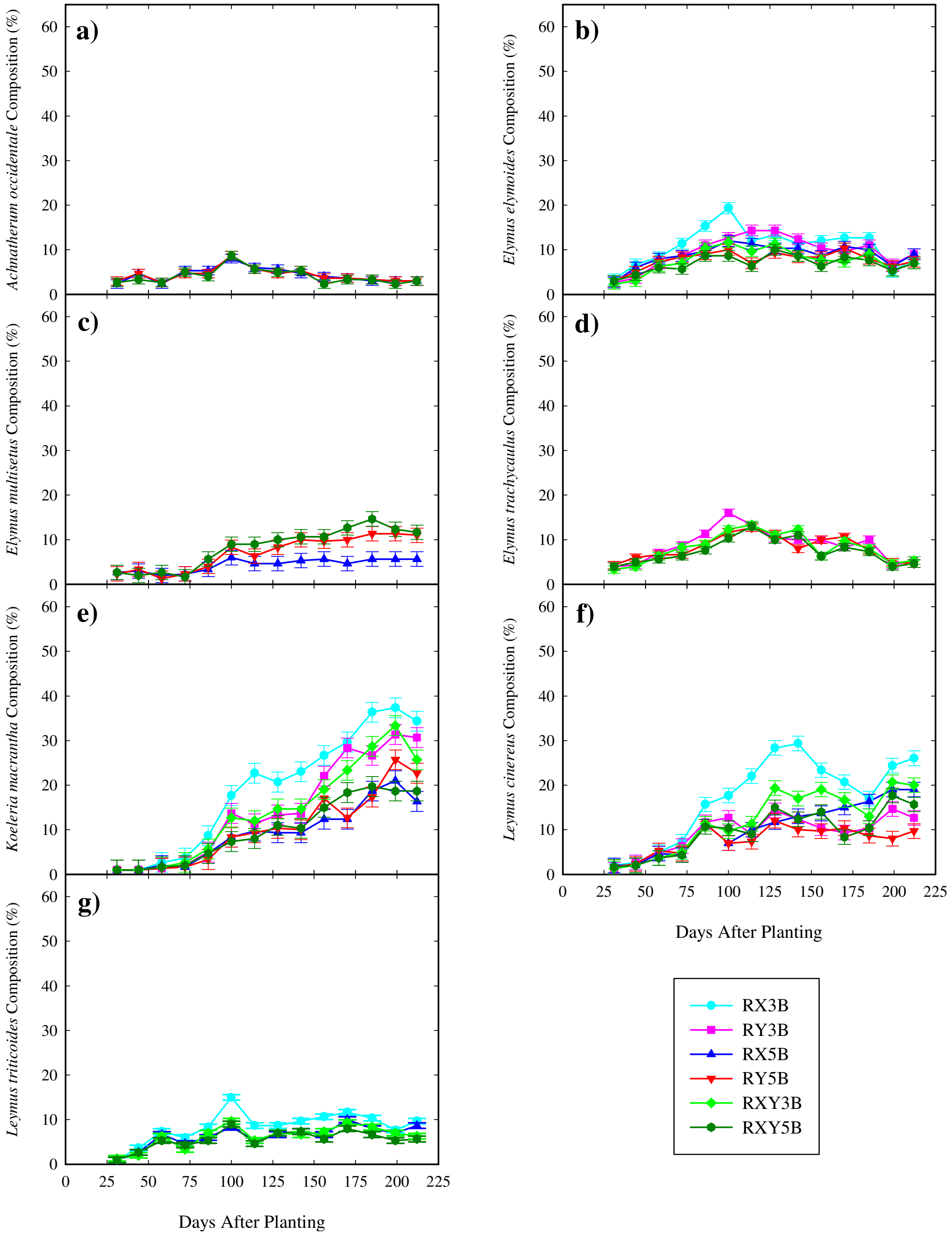

Figure 42. Effect of sod composition and days after planting on a) *Achnatherum occidentale*, b) *Elymus elymoides*, c) *Elymus multisetus*, d) *Elymus trachycaulus*, e) *Koeleria macrantha*, f) *Leymus cinereus*, and g) *Leymus triticoides* percent composition for the Intermountain Sagebrush ecoregion. Bars represent means and error bars represent standard errors from the SAS MIXED model.

Total Root Mass

For the Intermountain Sagebrush ecoregion there were no significant differences in total root mass between mixtures ($p = 0.2058$).

Root Mass by Depth

Mixtures. The depth by sod composition interaction was not significant for root mass for mixtures in the Intermountain Sagebrush ecoregion ($p = 0.9979$). There was a significant depth main effect ($p < 0.0001$) with the most dry root mass occurring from 0.0 – 2.5 cm depth (Figure 43). The sod composition main effect was not significant ($p = 0.2534$).

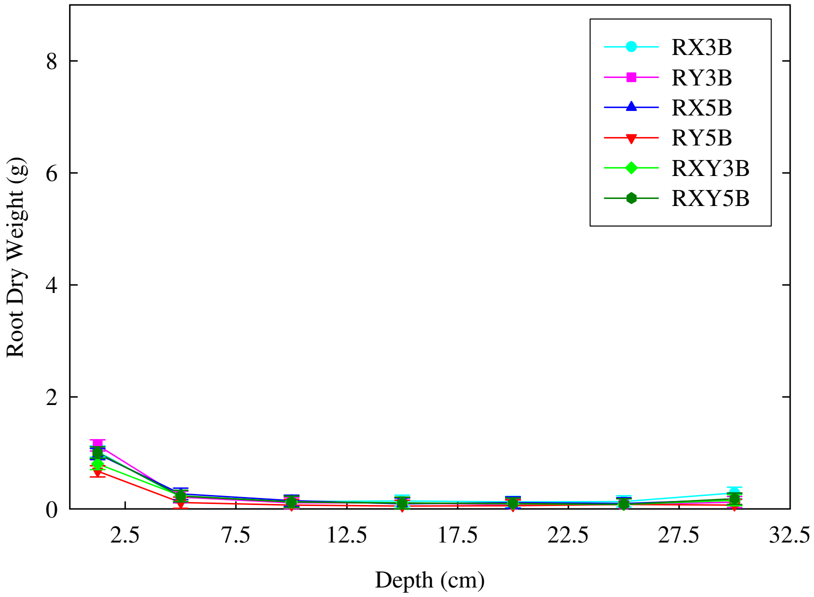

Figure 43. Effect of sod composition and depth on root mass for the Intermountain Sagebrush ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. There was a significant depth by species interaction for root mass of the monostands ($p < 0.0001$). *Koeleria macrantha* had significantly greater root mass from 0.0 – 2.5 cm than did any other species (Figure 44). *Leymus triticoides* had significantly greater root mass from 0.0 – 2.5 cm than did *Elymus multisetus* and *Leymus cinereus*. Beyond 2.5 cm, there were no significant differences in root mass amongst these four species, except beyond 27.5 cm where *L. cinereus* had significantly greater root mass than did *E. multisetus*.

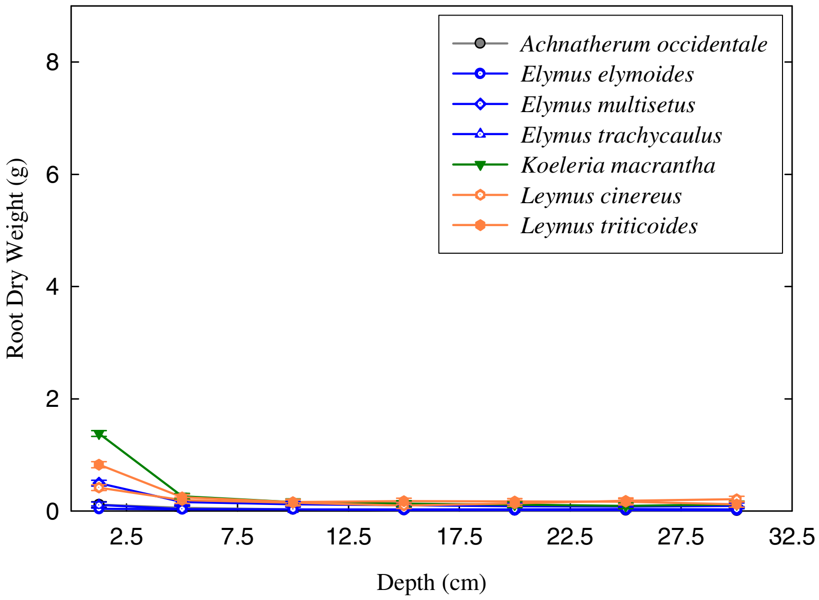

Figure 44. Effect of species and depth on root mass for the Intermountain Sagebrush ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

The root masses of *Achnatherum occidentale*, *Elymus elymoides* and *Elymus trachycaulus* were never significantly different from each other. These three species had significantly lower root masses than did the other four species from 0.0 – 2.5 cm. Root mass of *A. occidentale*, *E. elymoides*, or *E. trachycaulus* did not differ significantly across depths (p = 0.8261, p = 0.9999, and p = 0.9144, respectively) (Figure 44).

Percent Root Mass by Depth

Mixtures. There was no significant depth by sod composition interaction for root ratios (p = 0.6164). There was a significant depth main effect (p < 0.0001) with significantly more percent root mass in the first 2.5 cm (Figure 45). The sod composition main effect was not significant (p = 1.0) (Figure 45).

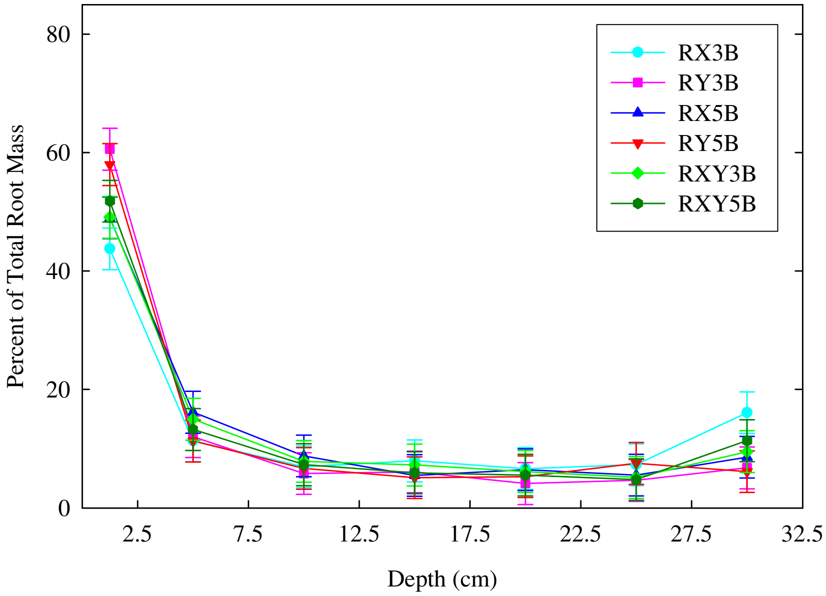

Figure 45. Effect of sod composition and depth on percent root mass for the Intermountain Sagebrush ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The depth by species interaction was significant for percent root mass for the Intermountain Sagebrush ecoregion ($p < 0.0001$). *Koeleria macrantha* had significantly greater percent root mass from 0.0 – 2.5 cm than did any other species; but, from 2.5 – 12.5 cm, *K. macrantha* had the lowest percentages (Figure 46). *Achnatherum occidentale*, *Leymus triticoides* and *Elymus multisetus* had significantly greater percentages from 0.0 – 2.5 cm than did the remaining three species. From 2.5 – 7.5 cm *A. occidentale* had significantly greater percent root mass than did all other species except for *Elymus elymoides*. *Elymus elymoides* did not follow the usual trend, but invested a larger percentage of root mass from 2.5 to 12.5 cm than from 0.0 – 2.5 cm. Similarly, *Leymus cinereus* invested a significantly higher percent of root mass beyond 27.5 cm than all other species.

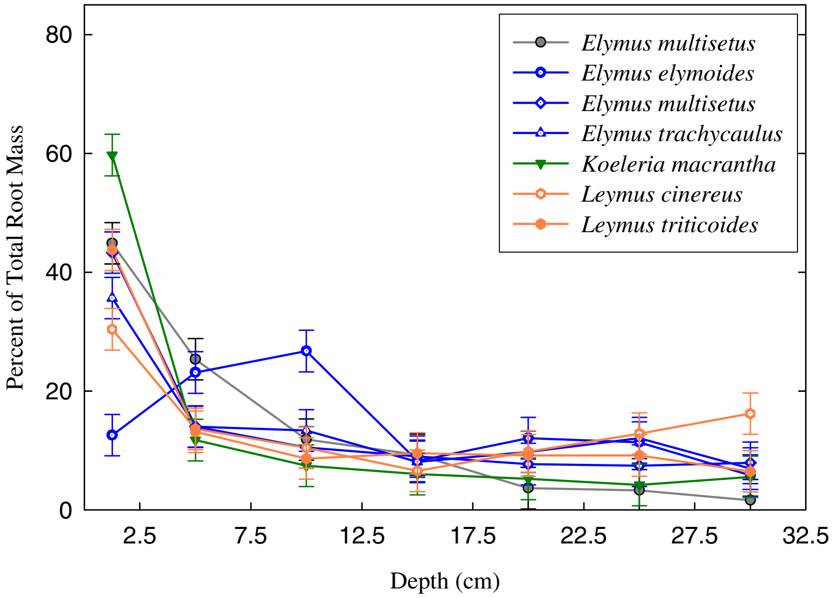

Figure 46. Effect of species and depth on percent root mass for the Intermountain Sagebrush ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Sod Strength

The correlation between percent rhizomatous species composition and sod strength was not significant for the Intermountain Sagebrush ecoregion (R^2 = -0.0614, p = 0.8985) (Figure 47).

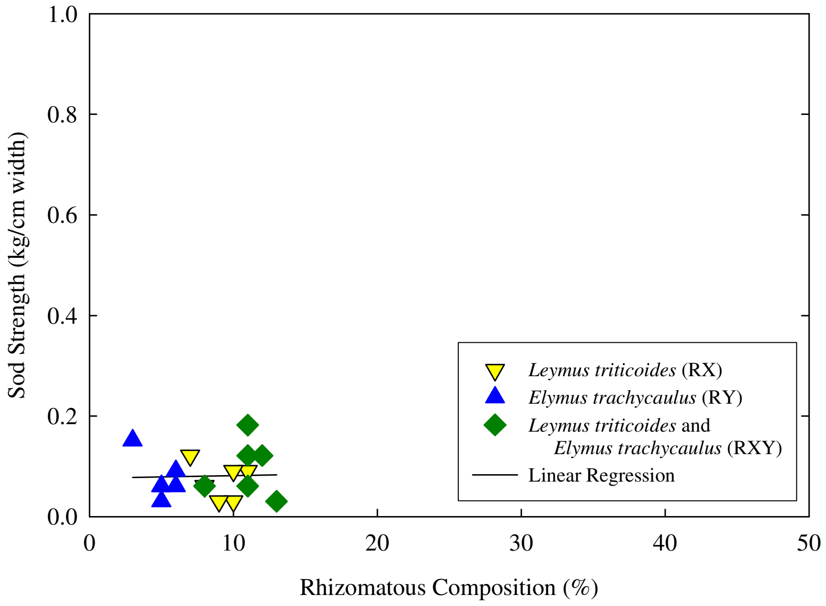

Figure 47. Correlation of percent rhizomatous species composition and sod strength for the Intermountain Sagebrush ecoregion. Linear regression R^2 = -0.0614.

The rhizomatous by bunch grass interaction was not significant for the Intermountain Sagebrush ecoregion (p = 0.9385). There was no significant main effect due to rhizomatous species (p = 0.6499). The bunch grass main effect was also not significant (p = 0.3985). Sod strength averaged 0.08 kg per cm width of sod (Figure 48).

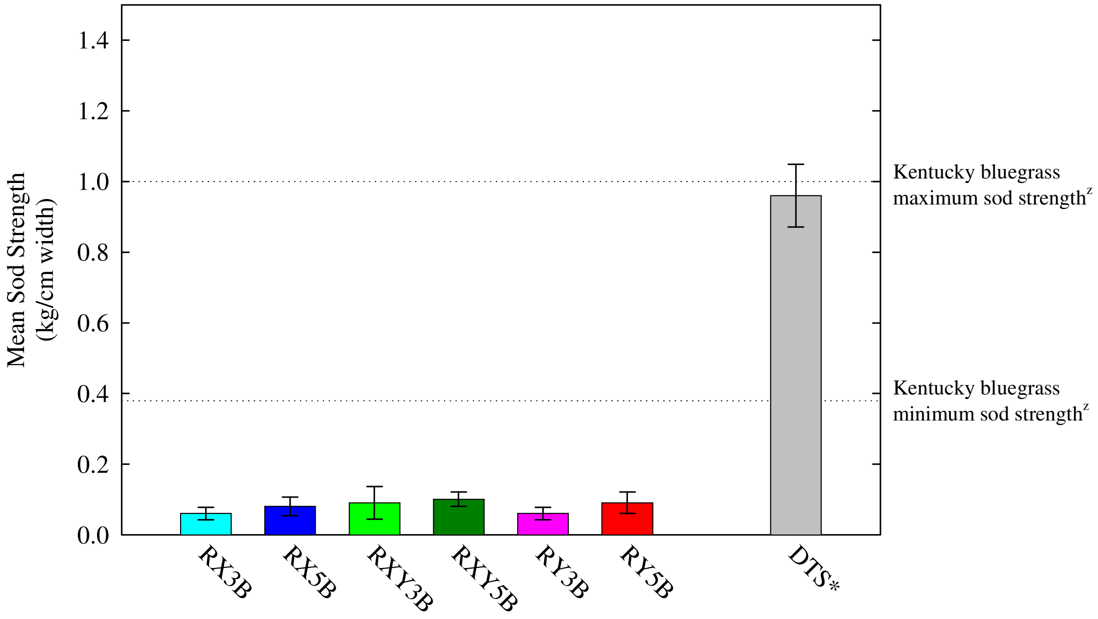

Figure 48. Effect of sod composition on sod strength for the Intermountain Sagebrush ecoregion. Bars represent means and error bars represent standard errors. *Drought-tolerant sod (Bitterroot Turf Farms, Corvallis, Montana). ^{z}From Flanagan et al. 1993.

Discussion

Differences in clipping fresh weight and percent dry weight for monostands at different times contributed to differences in clipping fresh weight between mixtures. The most important difference in clipping fresh weight occurred from 100 to 142 DAP where RX5B mixtures had significantly lower fresh weights than did all other mixtures. During this period, *Achnatherum occidentale* and *Elymus trachycaulus* started to decline in both the mixtures and the monostands. Observationally, these species were developing root rots from being too wet. A possible explanation for this is that ecotypes of *A. occidentale* and *E. trachycaulus* from the Intermountain Sagebrush ecoregion will not tolerate irrigation. This is evidence against our hypothesis that all native species will tolerate current sod production methods. However, root rot may not be as prevalent in field-grown situations and these species should be investigated further under field conditions.

The decline in composition of *A. occidentale* and *E. trachycaulus* caused a corresponding decrease in total cover, which was likely correlated with the decrease in clipping weight. At the final harvest, there were significant differences in total ground cover, with RX3B mixtures having significantly greater total ground cover than all other mixtures. This is direct evidence that including more species in sod mixtures does not increase total ground cover or the rate at which the sod establishes. In addition, RX3B mixtures did not have significantly different sod strength than did any other mixtures. This indicates that total ground cover was not positively correlated with sod strength in the Intermountain Sagebrush ecoregion.

There were significant differences in percent species composition among mixtures for *Leymus triticoides*, *E. trachycaulus*, *Elymus elymoides*, *Koeleria macrantha* and *Leymus cinereus* over the production cycle. At the final harvest, *L. triticoides* was more abundant in mixtures where it was the single rhizomatous species than in mixtures where both rhizomatous species were included. Mixtures with three bunch grasses had significantly greater percentages of *K. macrantha* and *L. cinereus* than did those with five. All of this can be justified through initial differences in seeding rate proportions. However, differences in seeding rates do not explain why mixtures with *L. triticoides* as the single rhizomatous species had significantly more *L. cinereus* than did mixtures with *E. trachycaulus* as the single rhizomatous species. Differences in species composition did not affect sod strength for the Intermountain Sagebrush ecoregion. In this ecoregion, increased percent rhizomatous species composition did not result in greater sod strength. However, percent rhizomatous species composition was minimal for all mixtures.

Despite significant differences in root architecture among monostands as manifest by differences in root mass and percent root mass by depth, mixtures were not significantly different from each other in root mass or percent root mass across the soil profile. Total root mass was also not different between mixtures. The inclusion of more species does not result in a more extensive root system. The fact that there were no differences in root mass and percent root mass by depth or total root mass between mixtures may also help to explain why there were no significant differences in sod strength. In this ecoregion, sod strength was not correlated with percent rhizomatous species composition, although the percent composition of all rhizomatous species was low. All Intermountain Sagebrush ecoregion mixtures had lower sod strength than Kentucky bluegrass and the Bitterroot Turf Farms drought-tolerant sod (Figure 48).

Pacific Forest

Selected Species

Table 10 lists the selected species for each sod composition for the Pacific Forest ecoregion.

Table 10. Selected species for each sod composition for the Pacific Forest ecoregion.

RX3B	**RY3B**	**RXY3B**
RX: *Festuca rubra*		RX: *Festuca rubra*
	RY: *Elymus trachycaulus*	RY: *Elymus trachycaulus*
B1: *Bromus carinatus*	B1: *Bromus carinatus*	B1: *Bromus carinatus*
B2: *Festuca idahoensis*	B2: *Festuca idahoensis*	B2: *Festuca idahoensis*
B3: *Elymus glaucus*	B3: *Elymus glaucus*	B3: *Elymus glaucus*
RX5B	**RY5B**	**RXY5B**
RX: *Festuca rubra*		RX: *Festuca rubra*
	RY: *Elymus trachycaulus*	RY: *Elymus trachycaulus*
B1: *Bromus carinatus*	B1: *Bromus carinatus*	B1: *Bromus carinatus*
B2: *Festuca idahoensis*	B2: *Festuca idahoensis*	B2: *Festuca idahoensis*
B3: *Elymus glaucus*	B3: *Elymus glaucus*	B3: *Elymus glaucus*
B4: *Koeleria macrantha*	B4: *Koeleria macrantha*	B4: *Koeleria macrantha*
B5: *Melica californica*	B5: *Melica californica*	B5: *Melica californica*

Clipping Fresh Weight

Mixtures. The interaction between days after planting (DAP) and sod composition was not significant ($p = 0.4883$) for clipping fresh weight. There was no significant sod composition main effect ($p = 0.3929$). The DAP main effect was significant ($p < 0.0001$) with peaks of growth at 75 and 175 DAP (Figure 49).

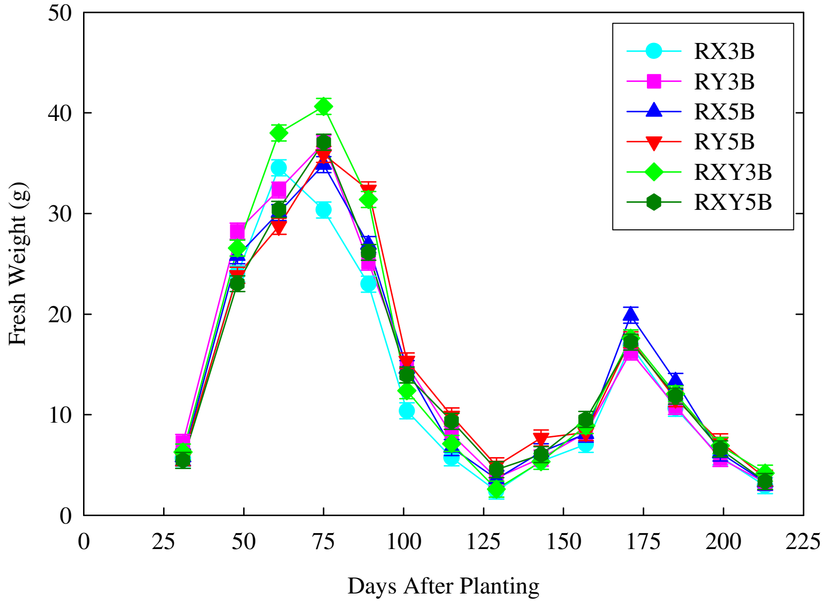

Figure 49. Effect of sod composition and days after planting on clipping fresh weight for the Pacific Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. There was a significant DAP by species interaction for clipping fresh weight for monostands ($p < 0.0001$). There were two major peaks in clipping fresh weight. At the first peak (48 DAP), *Bromus carinatus*, *Elymus trachycaulus* and *Elymus glaucus* had significantly greater fresh weights than did the remaining four species (Figure 50). *Koeleria macrantha* had significantly lower fresh weights during this period than all other species. From 157 through 185 DAP, *Festuca idahoensis* and *Festuca rubra* had the greatest fresh weights. *Melica californica* had significantly lower clipping fresh weights than did all other species during this period.

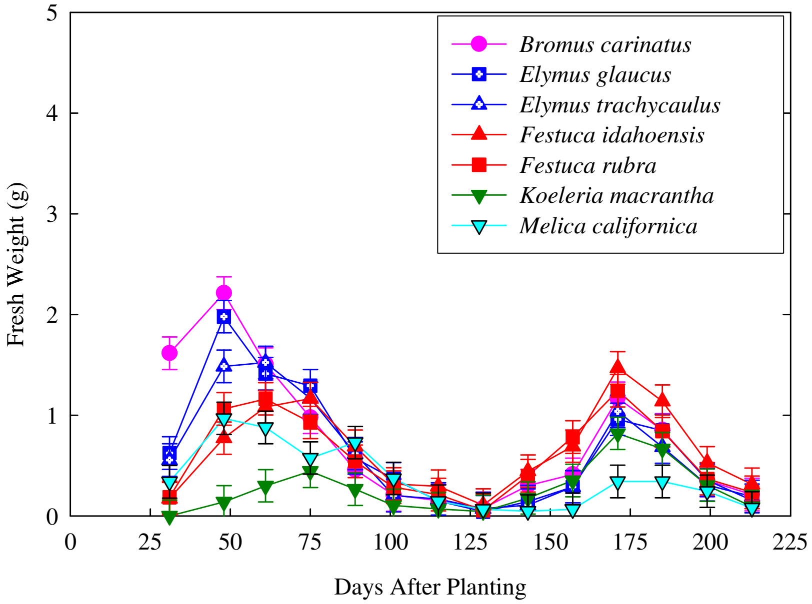

Figure 50. Effect of species and days after planting on clipping fresh weight for the Pacific Forest ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Clipping Percent Dry Weight

Mixtures. The sod composition by DAP interaction for clipping percent dry weight was not significant (p = 0.6071). The sod composition main effect was also not significant (p = 0.8535). There was a significant DAP main effect (p < 0.0001). Clipping percent dry weights ranged from a minimum of 15.0% at 31 DAP to a maximum of 33.0% at 213 DAP (Figure 51).

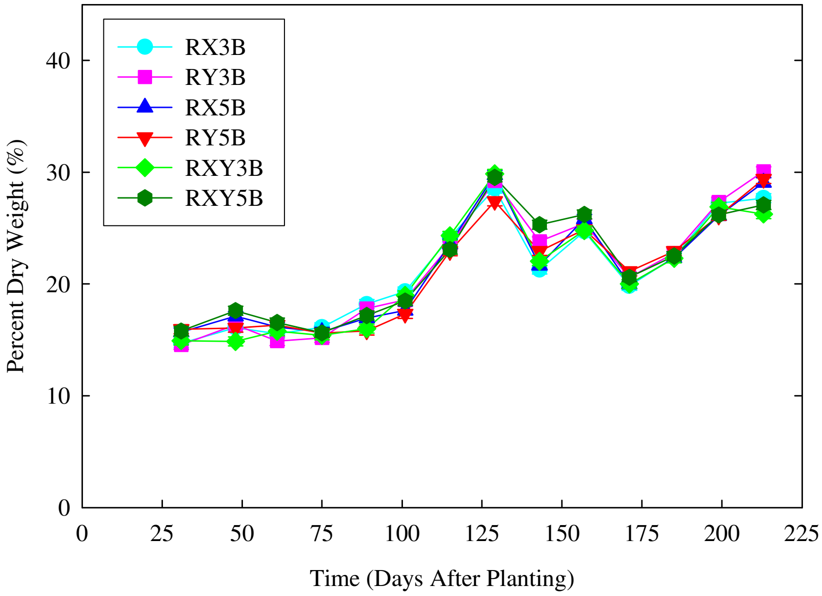

Figure 51. Effect of sod composition and days after planting on clipping percent dry weight for the Pacific Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

<u>Monostands</u>. The DAP by species interaction was not significant for clipping percent dry weight for the Pacific Forest ecoregion ($p = 0.9643$). The DAP main effect and the species main effect were both significant ($p < 0.0001$ and $p = 0.0019$, respectively). Excluding the first harvest because of missing data for *Koeleria macrantha*, *Melica californica* had significantly greater percent dry weights than did all other species excluding *Elymus glaucus* (Figure 52).

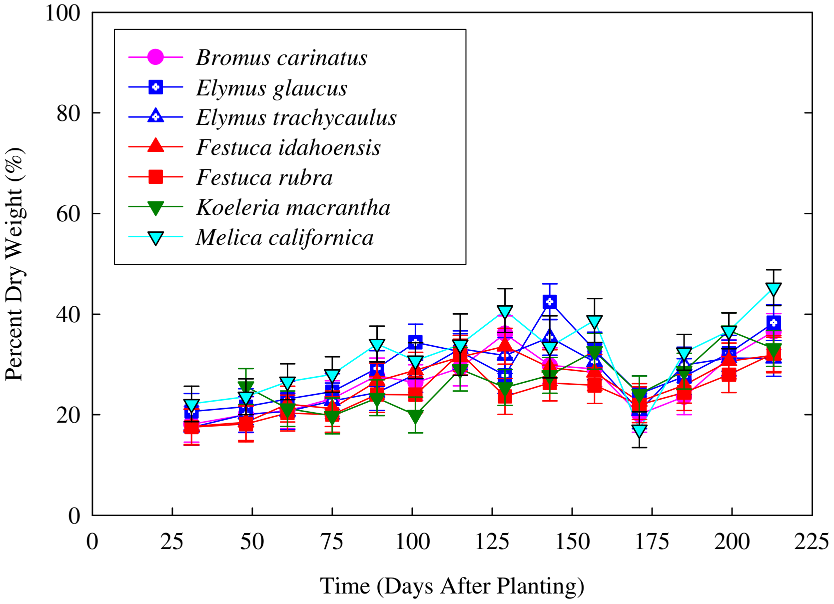

Figure 52. Effect of species and days after planting on clipping percent dry weight for the Pacific Forest ecoregion monostands. Points represent estimates and error bars represent standard errors from the SAS MIXED model.

Total Ground Cover

There was not a significant DAP by sod composition interaction (p = 0.8557) for total ground cover. There was a significant DAP main effect for total ground cover (p < 0.0001), but the sod composition main effect was not significant (p = 0.2738). Average total ground cover of all mixtures was 47.0% from 61 to 101 DAP, thereafter increasing linearly over time for all mixtures until 157 DAP where it peaked at 85.0% (Figure 53). From 157 DAP until the final harvest, total ground cover decreased to 82.0%.

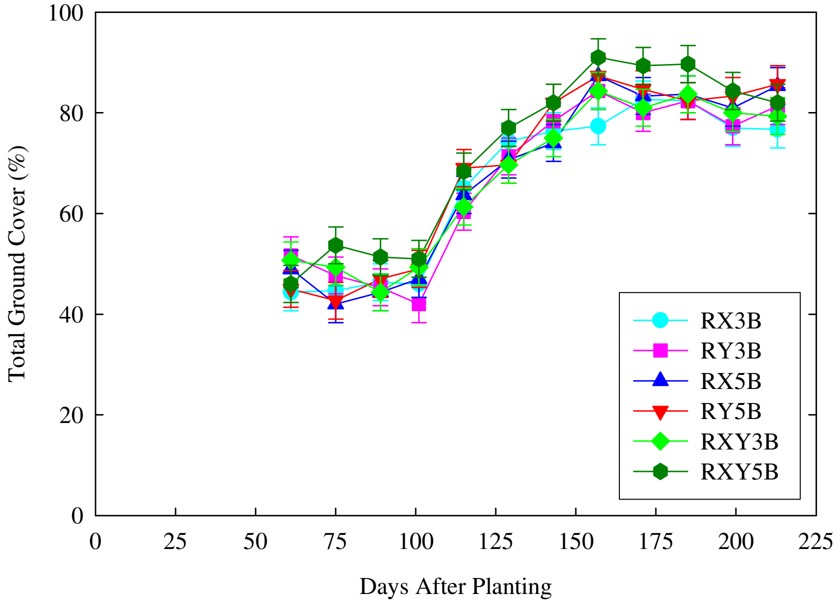

Figure 53. Effect of sod composition and days after planting on total ground cover for the Pacific Forest ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Species Composition

For *Bromus carinatus*, the DAP by sod composition interaction was not significant (p = 0.4896) There was a significant DAP main effect (p < 0.0001). There was also a significant sod composition main effect (p = 0.0346). The RX3B mixtures had significantly greater percentages of *B. carinatus* than did RX5B, RY5B,or RXY5B mixtures (Figure 54a). For RX3B and RY3B mixtures, *B. carinatus* composition was 24.0% at the first evaluation and increased until 143 DAP where it reached 45.0% before declining slightly to 35.0% at the final harvest. The other four mixtures contained 18.0% *B. carinatus*, on average, at 61 DAP. For these four mixtures, average *B. carinatus* composition increased to a maximum of 36.0% at final harvest. Averaged over DAP, *B.*

carinatus composition was significantly greater in mixtures with three bunch grasses than in mixtures with five ($p = 0.0035$).

There was a significant DAP by sod composition interaction for *Elymus glaucus* ($p < 0.0001$). Although at a few particular harvests percent composition of *E. glaucus* was higher for one mixture over another, *E. glaucus* composition was between 5.0% and 10.0% for the entire growth period, no matter the sod composition (Figure 54b).

For *Elymus trachycaulus*, the DAP by sod composition interaction was not significant ($p = 0.3866$). The DAP main effect was significant ($p < 0.0001$). The sod composition main effect was not significant for *E. trachycaulus* ($p = 0.5886$). *Elymus trachycaulus* percent composition was at a maximum at the first harvest, declined, and then rebounded for the final harvest (Figure 54c).

For *Festuca rubra/idahoensis* the DAP by sod composition interaction was not a significant ($p = 0.3912$). The DAP main effect was significant ($p < 0.0001$). The sod composition main effect was not significant ($p = 0.1093$). Average *F. rubra/idahoensis* was between 10.0% and 12.0% from 61 through 101 DAP, increasing to 27.0% by 143 DAP (Figure 54d). From 157 DAP through the final harvest, average *F. rubra/idahoensis* composition ranged between 29.0% and 34.0%.

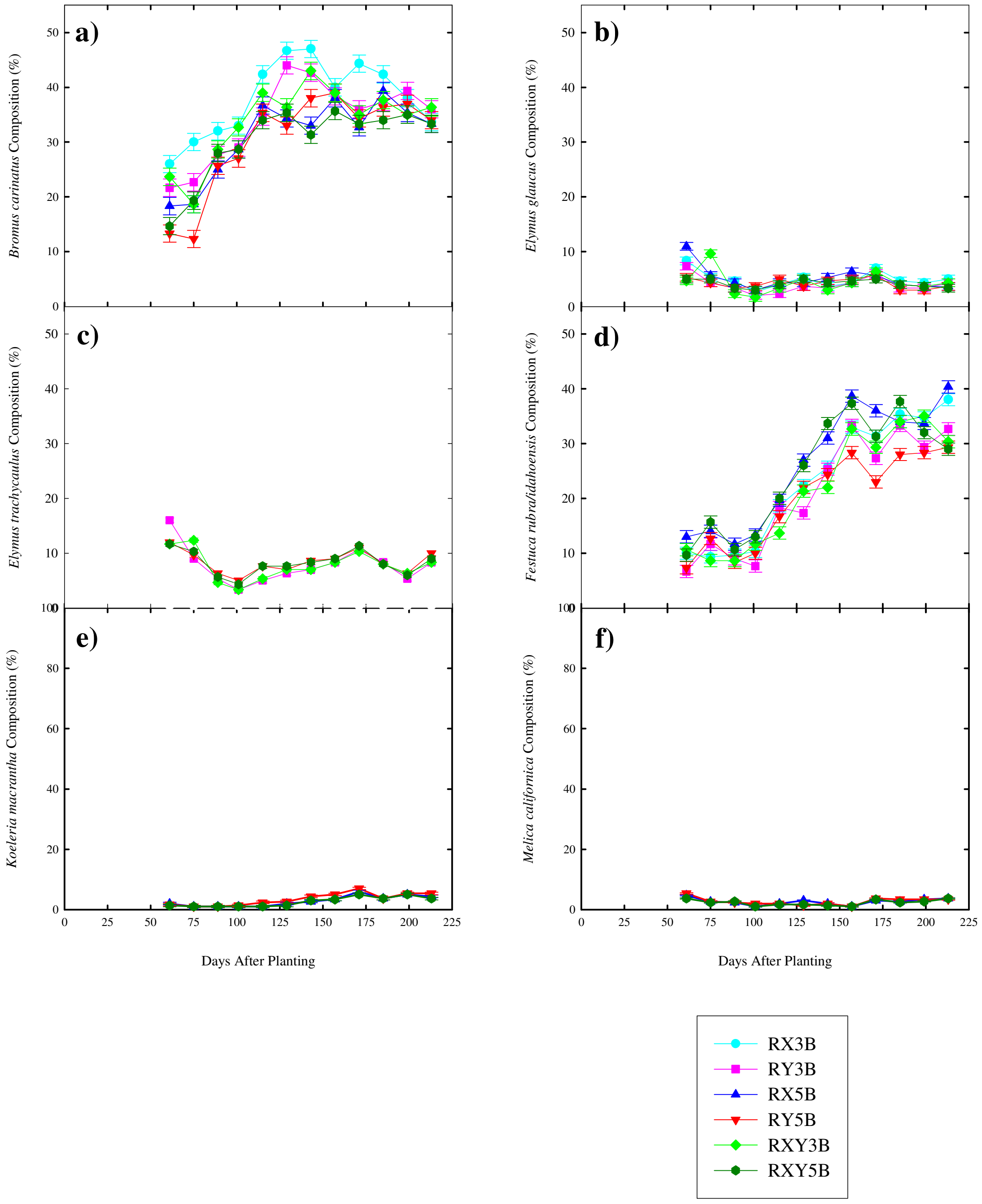

Figure 54. Effect of sod composition and days after planting on a) *Bromus carinatus*, b) *Elymus glaucus*, c) *Elymus trachycaulus*, d) *Festuca rubra/idahoensis*, e) *Koeleria macrantha* and f) *Melica californica* percent composition for the Pacific Forest ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

The DAP by sod composition interaction was not significant for *Koeleria macrantha* composition ($p = 0.5860$). The DAP main effect was significant ($p < 0.0001$). There was not a significant sod composition main effect for *K. macrantha* ($p = 0.3676$). *Koeleria macrantha* comprised 1.0% to 2.0% of the ground cover from 61 to 129 DAP, but increased in cover to 4.0% or 5.0% from 145 DAP to the final harvest (Figure 54e).

There was no significant DAP by sod composition interaction for *Melica californica* ($p = 0.9686$). There was a significant DAP main effect ($p < 0.0001$). The sod composition main effect for *Melica californica* was not significant ($p = 0.3760$). *Melica californica* comprised only 5.0% of the overall cover, but persisted in the mixtures at constant percentages over the seven months (Figure 54f).

Total Root Mass

There were no significant differences between mixtures for total root mass in the Pacific Forest ecoregion ($p = 0.2412$).

Root Mass by Depth

Mixtures. For the Pacific Forest ecoregion, the depth by sod composition interaction was not significant ($p = 0.1393$). There was a significant depth main effect ($p < 0.0001$) with the majority of root mass occurring in the first 2.5 cm (Figure 55). The sod composition main effect was not significant ($p = 0.6124$). The mixtures with both rhizomatous species had significantly greater root mass from 0.0 – 2.5 cm than did the mixtures with a single rhizomatous species ($p < 0.0001$). Differences in root mass from

0.0 – 2.5 cm between mixtures with rhizomatous species X and those with rhizomatous species Y were not significant at the 5% level ($p = 0.0513$).

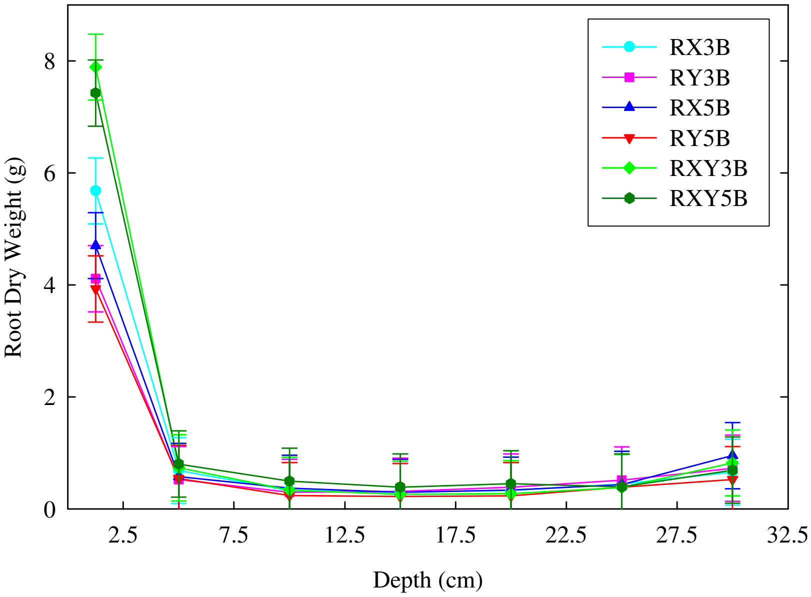

Figure 55. Effect of sod composition and depth on dry root mass for the Pacific Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

<u>Monostands</u>. There was a significant depth by species interaction for monostand root mass ($p < 0.0001$). *Festuca idahoensis* had significantly greater root mass from 0.0 – 12.5 cm than did all other species, except from 7.5 – 12.5 cm where *F. idahoensis* was not significantly different from *Festuca rubra* (Figure 56). *Festuca rubra* had the second-greatest root mass from 0.0 – 12.5 cm, with significantly greater root mass from 0.0 – 2.5 cm than the remaining five species. Of the remaining five species, *Koeleria macrantha* had significantly greater root biomass from 0.0 – 2.5 cm than did *Bromus carinatus* and *Melica californica*, which were not different from each other. *Elymus*

glaucus had lower root mass still and *Elymus trachycaulus* had the least root mass. Beyond 12.5 cm there were no differences between species for root biomass by depth.

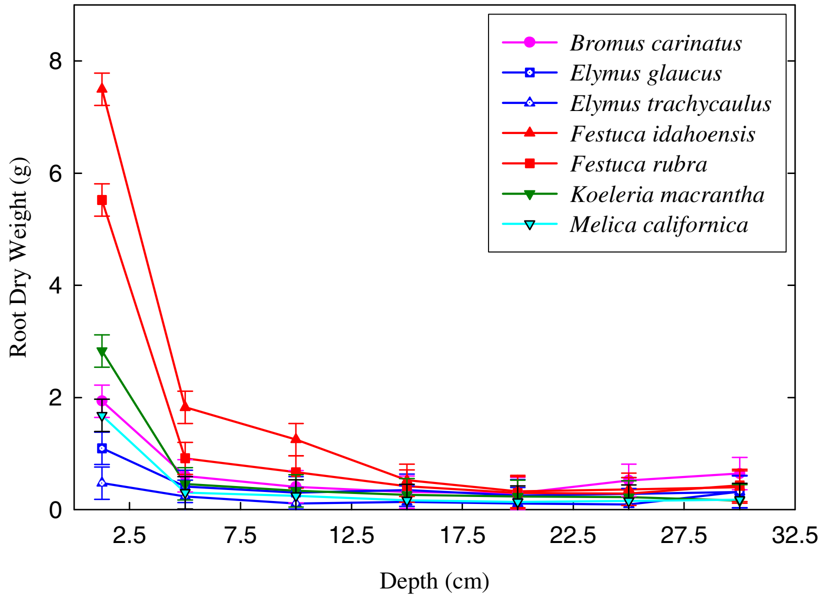

Figure 56. Effect of species and depth on dry root mass for the Pacific Forest ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

<u>Percent Root Mass by Depth</u>

<u>Mixtures</u>. The depth by sod composition interaction was not significant for percent root mass for mixtures ($p = 0.9838$). There was a significant depth main effect ($p < 0.0001$) with a significantly greater percentage of root mass in the first 2.5 cm than any other depth (Figure 57). The sod composition main effect was not significant ($p = 1.0$).

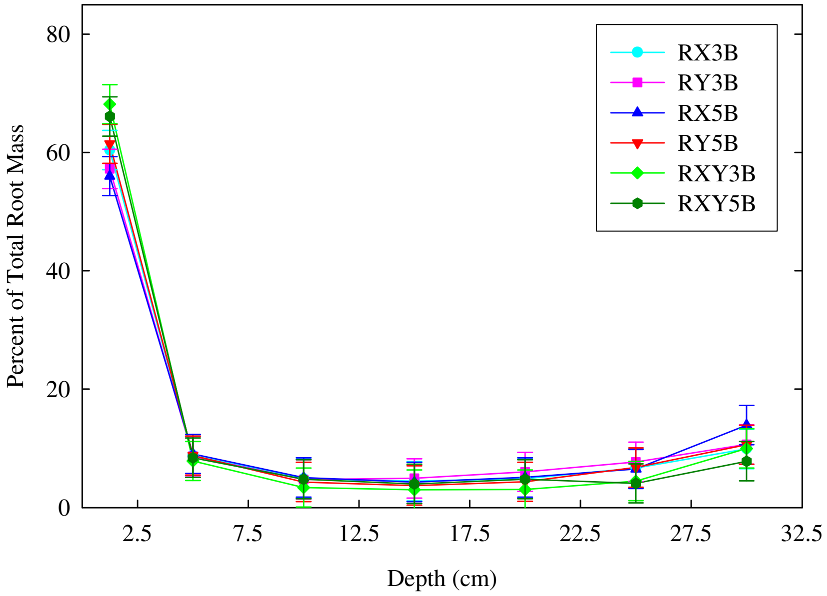

Figure 57. Effect of sod composition and depth on percent root mass for the Pacific Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. The depth by species interaction was significant for monostands of the Pacific Forest ecoregion ($p < 0.0001$). From 0.0 – 2.5 cm, *Festuca idahoensis*, *Festuca rubra*, *Koeleria macrantha* and *Melica californica* had significantly greater percent root mass than did *Bromus carinatus*, *Elymus glaucus* and *Elymus trachycaulus* (Figure 58). From 2.5 – 27.5 cm *B. carinatus* had significantly greater percent root mass than did both *Festuca* species, but was not significantly different from any other species. In contrast to the other species, *E. trachycaulus* invested a significantly greater percent of its root mass below 27.5 cm than from 12.5 – 27.5 cm.

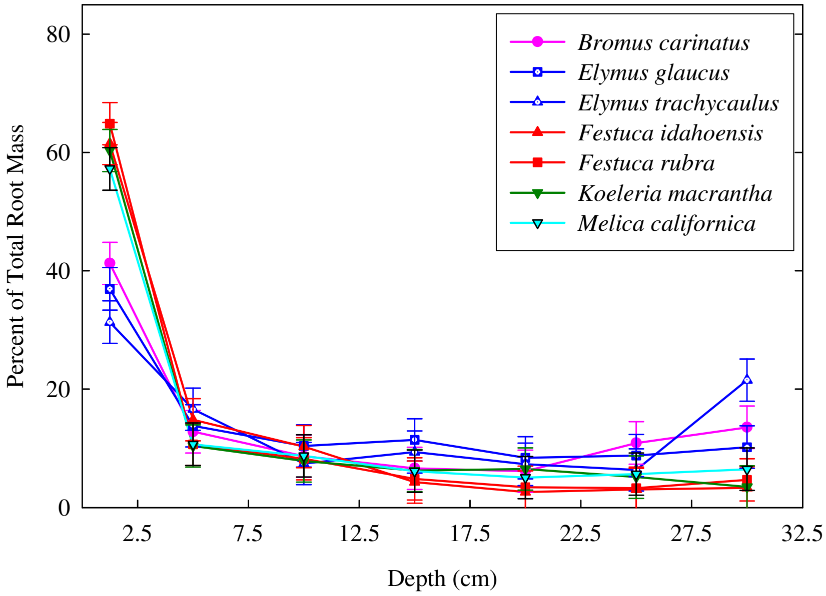

Figure 58. Effect of species and depth on percent root mass for the Pacific Forest ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Sod Strength

For the Pacific Forest ecoregion the correlation between percent rhizomatous species composition and sod strength was not significant ($R^2 = 0.0492$, $p = 0.1893$). Since *Festuca rubra* and *Festuca idahoensis* had to be pooled, the rhizomatous species data was confounded. Therefore, *F. idahoensis* was also included with *Elymus trachycaulus* in calculating percent rhizomatous species composition to avoid biasing the data (Figure 59).

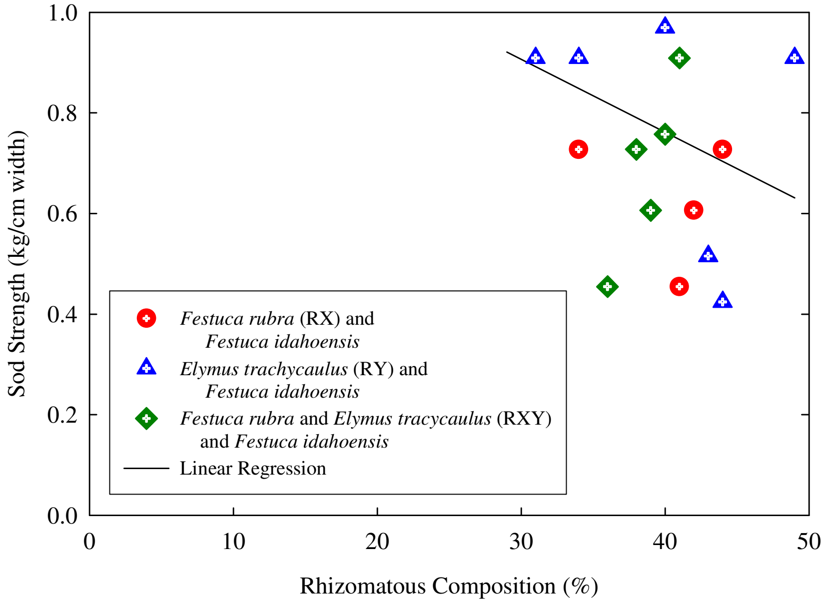

Figure 59. Correlation of percent rhizomatous species composition and sod strength for the Pacific Forest ecoregion. Linear regression $R^2 = 0.0492$.

For the Pacific Forest ecoregion the rhizomatous by bunch grass interaction was not significant for sod strength ($p = 0.5529$). There were no significant sod strength differences between mixtures with regard to the rhizomatous species present ($p = 0.9583$). There were also no significant sod strength differences between mixtures containing three bunch grasses and those containing five ($p = 0.1399$) (Figure 60).

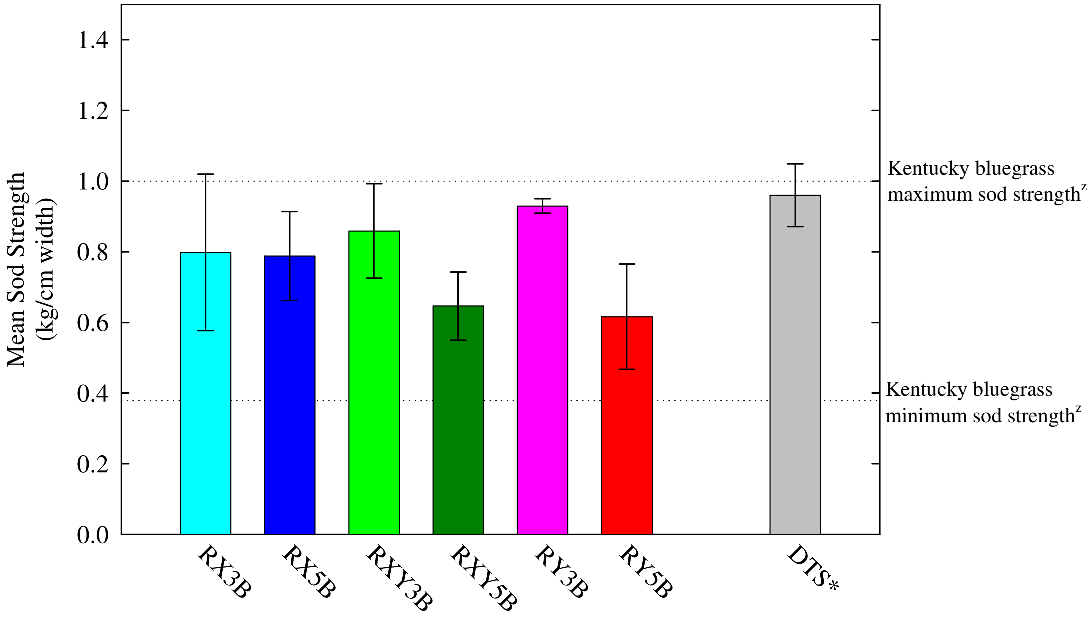

Figure 60. Effect of sod composition on sod strength for the Pacific Forest ecoregion. Points represent means and error bars represent standard errors. *Drought-tolerant sod (Bitterroot Turf Farms, Corvallis, Montana). ^{z}From Flanagan et al. 1993.

Discussion

Although there were significant differences in clipping fresh weight and percent dry weight for monostands, the species in the mixtures balanced each other such that there were no significant differences in clipping fresh weight or percent dry weight between mixtures. This indicates that the mixtures chosen would require similarly frequent mowing and would be similar in their mowing quality.

There were also no significant differences in total ground cover between mixtures, which indicates no difference in the rate at which the sod established. For the Pacific Forest ecoregion, we refute the hypothesis that including more species results in more rapid or more complete ground cover.

Mixtures with three bunch grasses had significantly more *Bromus carinatus* than did those with five bunch grasses because these mixtures were seeded with a greater proportion of this species. There were no significant differences in percent composition between mixtures for any of the remaining species. Although *Elymus glaucus*, *Koeleria macrantha* and *Melica californica* did not comprise a great percentage of the total cover, they persisted in the mixtures over the production cycle. These species add to the overall diversity in the sod mixtures and may be more adapted to some installation sites. Consequently, these species should not be removed from the sod mixtures in future studies because of the short growing cycle in our experiment. All of the native species selected for use in this ecoregion were tolerant of current sod production methods.

Despite differences between monostands for total root mass, dry root mass by depth and percent root mass by depth, these rooting characteristics equilibrated in the mixtures such that there were no differences between mixtures in the Pacific Forest ecoregion. Therefore, including more species in sod mixtures does not result in a more extensive root system.

There were also no differences in sod strength between mixtures. The fact that there were no significant differences in root architecture, ground cover or biomass production likely explains why there were no significant differences in sod strength. There were also no significant differences in species composition, aside from significant differences between mixtures for *B. carinatus*. The significant differences in composition for this species do not translate into significant differences in sod strength. For this ecoregion, sod strength was not positively correlated with the percent rhizomatous species composition. One possible explanation for this is that *Festuca idahoensis* may also be contributing to sod strength, despite its bunch grass habit. Sod strength measurements for all mixtures in the Pacific Forest ecoregion were similar to both the Bitterroot Turf Farms drought-tolerant sod and Kentucky bluegrass (Figure 60).

Sierran Forest

Selected Species

Table 11 lists the selected species for each sod composition for the Sierran Forest ecoregion.

Table 11. Selected species for each sod composition for the Sierran Forest ecoregion.

RX3B	**RY3B**	**RXY3B**
RX: *Festuca rubra*		RX: *Festuca rubra*
	RY: *Elymus trachycaulus*	RY: *Elymus trachycaulus*
B1: *Muhlenbergia rigens*	B1: *Muhlenbergia rigens*	B1: *Muhlenbergia rigens*
B2: *Hordeum brachyantherum*	B2: *Hordeum brachyantherum*	B2: *Hordeum brachyantherum*
B3: *Elymus elymoides*	B3: *Elymus elymoides*	B3: *Elymus elymoides*
RX5B	**RY5B**	**RXY5B**
RX: *Festuca rubra*		RX: *Festuca rubra*
	RY: *Elymus trachycaulus*	RY: *Elymus trachycaulus*
B1: *Muhlenbergia rigens*	B1: *Muhlenbergia rigens*	B1: *Muhlenbergia rigens*
B2: *Hordeum brachyantherum*	B2: *Hordeum brachyantherum*	B2: *Hordeum brachyantherum*
B3: *Elymus elymoides*	B3: *Elymus elymoides*	B3: *Elymus elymoides*
B4: *Bromus carinatus*	B4: *Bromus carinatus*	B4: *Bromus carinatus*
B5: *Elymus glaucus*	B5: *Elymus glaucus*	B5: *Elymus glaucus*

Clipping Fresh Weight

Mixtures. In the Sierran Forest ecoregion, there was a significant DAP by sod composition interaction for clipping fresh weight (p = 0.0001). Early fresh weight production (31 to 100 DAP) was significantly lower in the RX3B mixture than all other mixtures (Figure 61). The trend reversed from 100 to 175 DAP, where the RX3B mixtures had significantly greater fresh weights, than all other mixtures. The fresh weight of all other mixtures fluctuated inconsistently with significant differences occurring sporadically over the production cycle. There were no significant differences among mixtures for clipping fresh weight for the final three harvests.

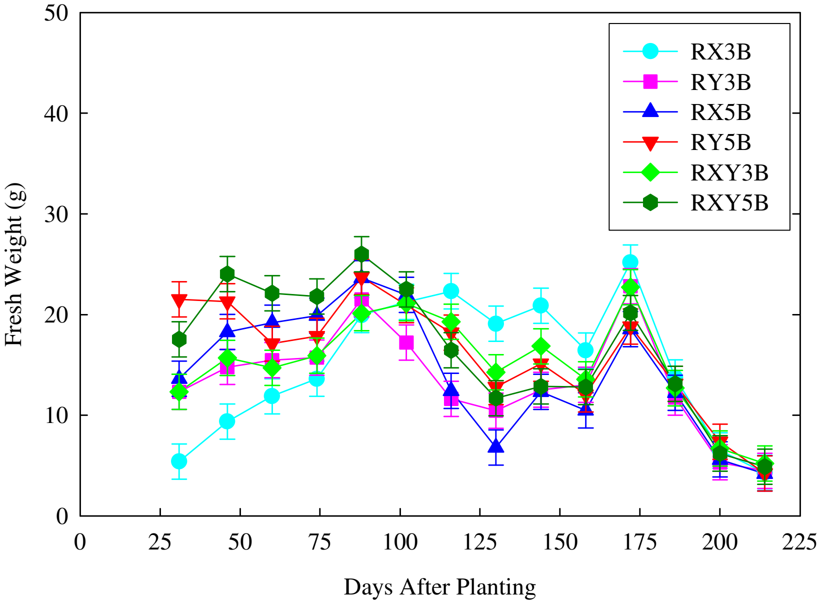

Figure 61. Effect of sod composition and days after planting on clipping fresh weight for the Sierran Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

<u>Monostands</u>. There was a significant DAP by species interaction for clipping fresh weight for monostands ($p < 0.0001$). From 31 through 74 DAP, there were many changes in rank order of fresh weight (Figure 62). *Bromus carinatus* and *Elymus trachycaulus* had significantly greater fresh weights than all other species at the first harvest. *Elymus glaucus* had significantly greater fresh weights than *Elymus elymoides*. *Hordeum brachyantherum* and *Festuca rubra* were not significantly different from each other, but had significantly greater fresh weights than *Muhlenbergia rigens*.

Beyond 74 DAP, *F. rubra* tended to have the greatest clipping fresh weight, followed by *H. brachyantherum*, *E. elymoides*, *E. glaucus*, *B. carinatus* and *E. trachycaulus*. *Muhlenbergia rigens* had significantly lower fresh weights than any other species through 100 DAP. Beyond 100 DAP, *M. rigens* fresh weights were comparable to those of *B. carinatus* and all three species of *Elymus*.

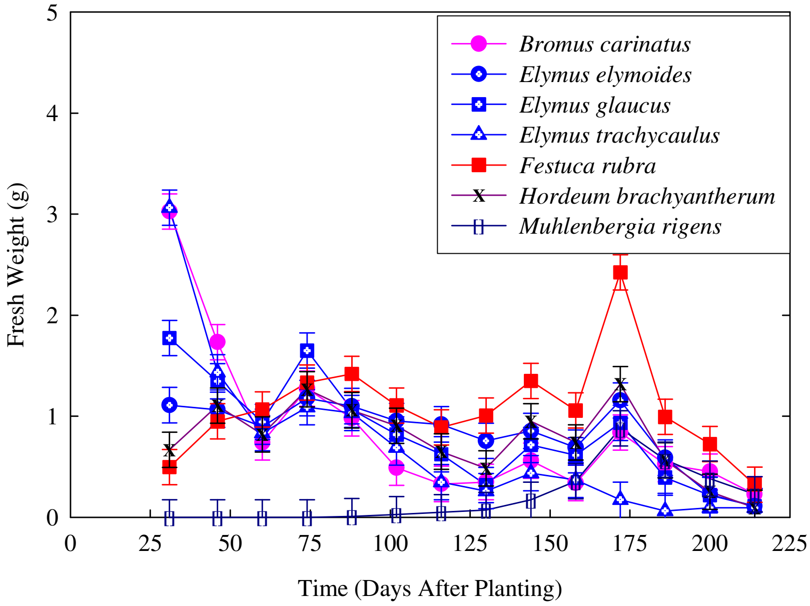

Figure 62. Effect of species and days after planting on clipping fresh weight for the Sierran Forest ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Clipping Percent Dry Weight

Mixtures. For clipping percent dry weight, the DAP by sod composition interaction was significant ($p < 0.0001$). From the first harvest until 102 DAP, mixtures with three bunch grasses had greater clipping percent dry weight than those with five bunch grasses. After 102 DAP, the order reversed (Figure 63).

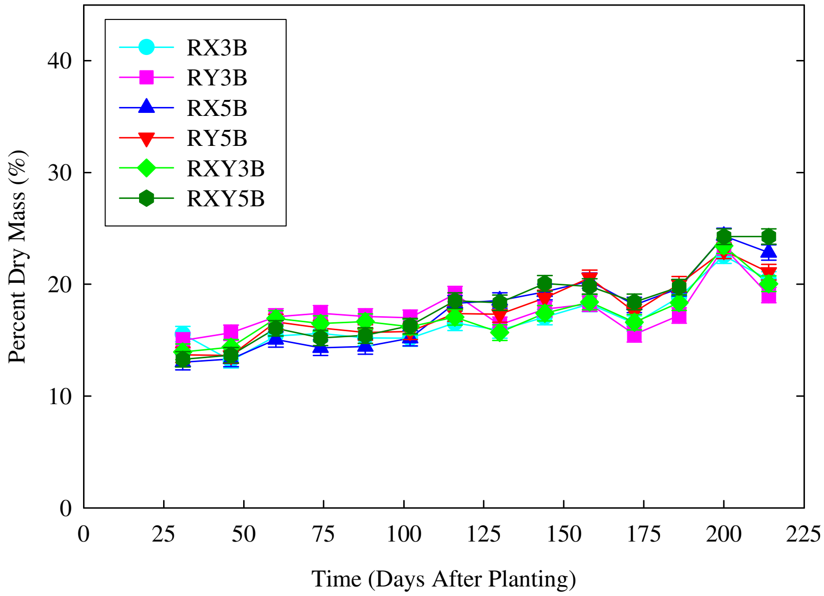

Figure 63. Effect of sod composition and days after planting on clippings percent dry weight for the Sierran Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

Monostands. For the Sierran Forest ecoregion monostands, the species by DAP interaction was not significant ($p = 0.9978$). The DAP main effect was significant ($p < 0.0001$). The species main effect was not significant ($p = 0.1255$). Excluding the percent dry weight of *Muhlenbergia rigens* for the first four harvests due to missing data (because no seeds had germinated), percent dry weight increased from an average of 14.9% at the first harvest to an average of 30.1% at the final harvest (Figure 64).

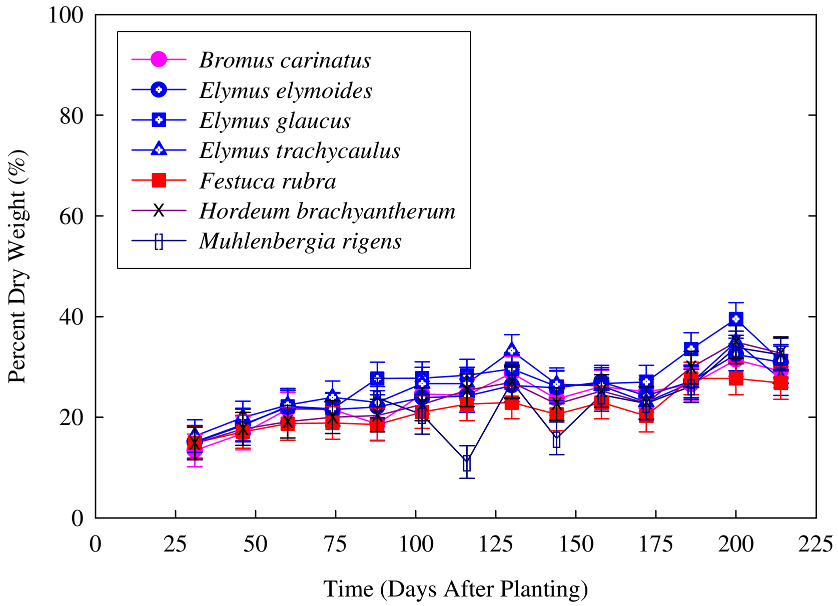

Figure 64. Effect of species and days after planting on clipping percent dry weight for the Sierran Forest ecoregion monostands. Points represent estimates and error bars represent standard errors from the SAS MIXED model.

Total Ground Cover

For total ground cover, the DAP by sod composition interaction was significant for the Sierran Forest ecoregion ($p < 0.0001$). Ground cover of all mixtures linearly increased up until 100 DAP where ground cover percentages plateaued (Figure 65). Mixtures with five bunch grasses attained significantly higher ground cover percentages than mixtures with only three bunch grasses. After 100 DAP, RXY5B and RY5B mixtures had the greatest total ground cover for most of the remaining growth period, followed closely by RX5B mixtures. RY3B mixtures consistently had significantly less total ground cover than all other mixtures after 100 DAP. Mixtures with five bunch grasses were similar in ground cover throughout the experiment, while the ground cover rank of mixtures with three bunch grasses fluctuated throughout the growing period.

For total ground cover at the final harvest, there was a significant rhizomatous by bunch grass interaction ($p = 0.0011$). Aside from the fact that there was no significant difference in ground cover between RX3B and RX5B mixtures, mixtures with five bunch grasses had greater ground cover than those with three bunch grasses.

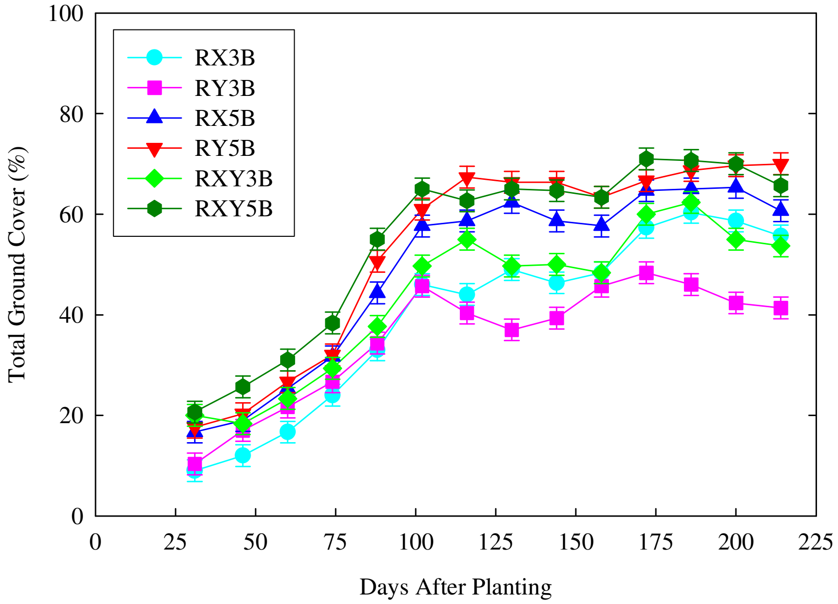

Figure 65. Effect of sod composition and days after planting on total ground cover for the Sierran Forest ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Species Composition

For *Bromus carinatus* in the Sierran Forest ecoregion, the DAP by sod composition interaction was significant ($p < 0.0001$). There were no significant differences in *B. carinatus* composition between mixtures until 116 DAP (Figure 66a). From 116 DAP through the final harvest, RY5B mixtures contained significantly greater percentages of *B. carinatus* than did the other two mixtures. From 116 through 158 DAP, RX5B mixtures contained similar percentages of *B. carinatus* to those of RXY5B mixtures except at 144 DAP. However, from 172 DAP through the final harvest, RXY5B mixtures contained more *B. carinatus* than did RX5B mixtures with significant differences at all but 186 DAP.

For *Elymus elymoides*, the DAP by sod composition interaction was significant ($p < 0.0001$). *Elymus elymoides* composition exceeded 10% for the RY3B mixtures at 74, 88, 158, 172, and 200 DAP and the RXY3B mixtures at 102 and 116 DAP (Figure 66b). At these particular evaluations, the *E. elymoides* composition was significantly higher for these mixtures than that of the other mixtures.

The DAP by sod composition interaction was not significant for *Elymus glaucus* ($p = 0.1249$). There was a significant DAP main effect ($p < 0.0001$). The sod composition main effect was not significant for *E. glaucus* percent composition ($p = 0.4742$). Average *E. glaucus* percentages remained near 4.5% until 102 DAP (Figure 66c). From 102 to 144 DAP, *E. glaucus* composition increased to 8.7%. From 144 to 158 DAP, average percent composition of this species decreased to 4.5% where it remained through the final harvest.

The DAP by sod composition interaction for *Elymus trachycaulus* was significant for the Sierran Forest ecoregion ($p = 0.0009$). *E. trachycaulus* percent composition was similar for all mixtures, except that the RY3B mixtures had significantly higher *E* *trachycaulus* percent covers than all other mixtures at 102 DAP and from 158 through 186 DAP (Figure 66d).

For *Festuca rubra*, there was a significant DAP by sod composition interaction for the Sierran Forest ecoregion ($p = 0.0007$). RX3B mixtures contained the greatest proportions of *F. rubra*, with significantly more *F. rubra* than all other mixtures at 88 DAP and from 116 through 186 DAP (Figure 66e). RXY3B mixtures contained the second-greatest abundance of *F. rubra*, with significantly greater proportions than the remaining two mixtures at 116 DAP and from 186 DAP through the final harvest. RX5B mixtures contained less *F. rubra* than RXY3B mixtures, while RXY5B mixtures contained the least *F. rubra*. *Festuca rubra* abundance for RX5B mixtures was significantly greater than that of RXY5B mixtures at 130, 172, 200, and 214 DAP. There was a significant DAP by sod composition interaction for *Hordeum brachyantherum* in the Sierran Forest ecoregion ($p < 0.0001$). For *H. brachyantherum*, there were no significant differences in composition between the mixtures with five bunch grass species at any harvest during the growth period (Figure 66f). Mixtures with three bunch grasses had significantly greater percentages of *H. brachyantherum* than mixtures with five bunch grasses from 88 DAP onward. RY3B mixtures contained significantly greater percentages of *H. brachyantherum* than did any other mixtures at 172, 200 and 214 DAP. *Hordeum brachyantherum* composition was significantly greater for RX3B mixtures than for RXY3B mixtures at 130, 158, 200 and 214 DAP, but was significantly less than RXY3B mixtures at 186 DAP.

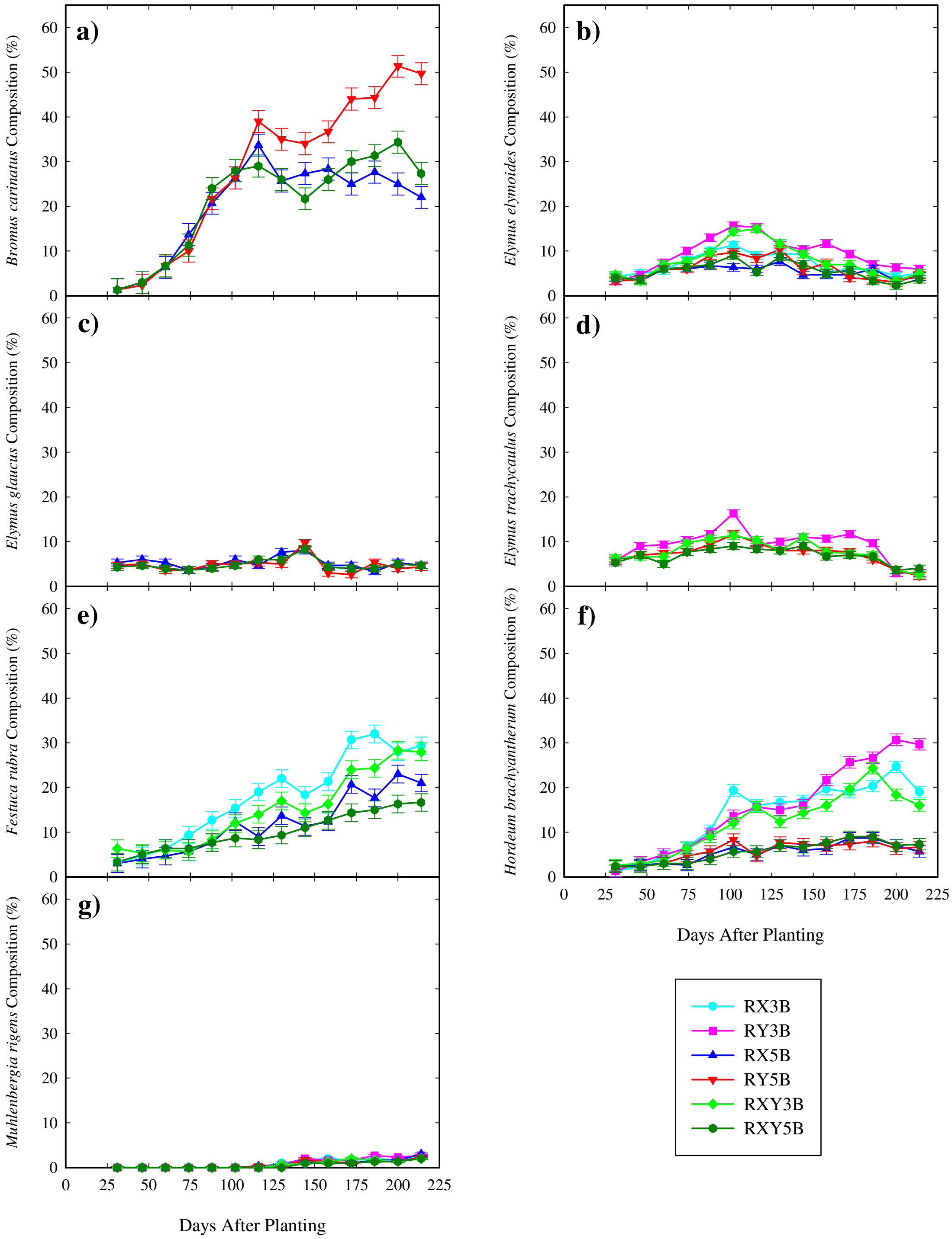

Figure 66. Effect of sod composition and DAP on a) *Bromus carinatus*, b) *Elymus elymoides*, c) *Elymus glaucus*, d) *Elymus trachycaulus*, e) *Festuca rubra*, f) *Hordeum brachyantherum*, and g) *Muhlenbergia rigens* percent composition for the Sierran Forest ecoregion. Points represent means and error bars represent standard errors from the SAS MIXED model.

The DAP by sod composition interaction was not significant for *Muhlenbergia rigens* ($p = 0.1848$). There was a significant DAP main effect ($p < 0.0001$). The sod composition main effect was not significant at the 5% level ($p = 0.0912$). Average *M. rigens* percent composition was 0.0% until 130 DAP, when it reached 1.0% (Figure 66g). From 130 DAP until the final harvest, average *M. rigens* composition increased from 1.0% to 2.4%. Mixtures with three bunch grasses contained significantly greater proportions of *M. rigens* than did those with five ($p = 0.0377$). Mixtures with a single rhizomatous species contained significantly greater *M. rigens* abundance than those with both ($p = 0.0311$).

Total Root Mass

The rhizomatous by bunch grass interaction was not significant for total root mass ($p = 0.6569$). Mixtures containing rhizomatous species Y had significantly less total root mass than did mixtures containing rhizomatous species X ($p = 0.0072$) and mixtures containing both rhizomatous species ($p = 0.0004$), between which there was no significant difference in total root biomass ($p = 0.1435$).

Root Mass by Depth

Mixtures. There was a significant depth by sod composition interaction for root mass ($p < 0.0001$). RXY3B mixtures had significantly greater root mass from 0.0 – 2.5 cm than did any other mixture (Figure 67). RXY5B mixtures were not significantly different from RX5B mixtures in root mass, but both had significantly greater root mass from 0.0 – 2.5 cm than did RX3B mixtures. RX3B mixtures had significantly greater root mass from 0.0 – 2.5 cm than did RY3B and RY5B mixtures, between which there was no significant difference in root mass. There were no significant differences between mixtures for root mass by depth at any other depth.

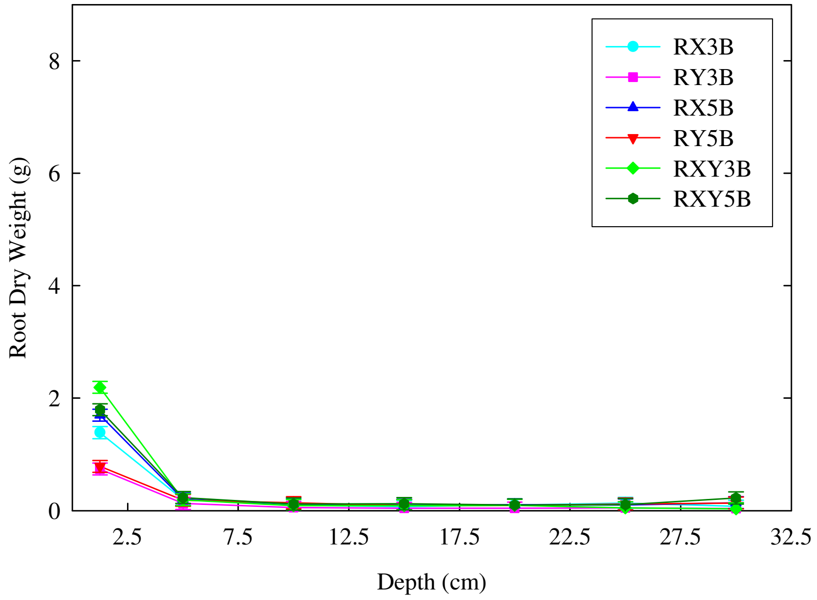

Figure 67. Effect of sod composition and depth on root mass for the Sierran Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

At the final harvest, the rhizomatous by bunch grass interaction was not significant for the root mass in the first 2.5 cm (p = 0.4596). The rhizomatous main effect was significant (p = 0.0027). There was not a significant bunch grass main effect (p = 0.9526). The root mass in the first 2.5 cm of mixtures containing rhizomatous species X (*Festuca rubra*) was not significantly different from that of mixtures containing both rhizomatous species (p = 0.1302), but both of these mixtures had significantly greater root mass in the first 2.5 cm than did mixtures containing rhizomatous species Y (*Elymus trachycaulus*) at the final harvest. The root mass in the first 2.5 cm was not significantly different between mixtures with three and mixtures with five bunch grasses ($p = 0.9526$).

Monostands. For the Sierran Forest monostands, there was a significant depth by species interaction ($p < 0.0001$). From 0.0 – 7.5 cm, root mass by depth had a rank order, from greatest to least, of *Hordeum brachyantherum*, *Festuca rubra*, *Bromus carinatus*, *Elymus glaucus*, *Elymus elymoides*, *Elymus trachycaulus* and *Muhlenbergia rigens* (Figure 68). From 0.0 – 2.5 cm *H. brachyantherum* had significantly greater root mass than any other species and *F. rubra* had greater root mass than the remaining five species. *Bromus carinatus* had significantly greater root mass from 0.0 – 2.5 cm than did *E. glaucus* and *E. elymoides*, between which there was no significant difference. *Elymus trachycaulus* and *M. rigens* were not significantly different from each other and had significantly lower root mass from 0.0 – 2.5 cm than did any other species.

Beyond 7.5 cm, there was a shift in the rank order. *Bromus carinatus* had the greatest root mass, having significantly greater root mass than all other species beyond 22.5 cm. The remaining six species in order of greatest root mass to least were *H. brachyantherum*, *F. rubra*, *E. glaucus*, *E. elymoides*, *E. trachycaulus* and *M. rigens*. The root mass did not differ significantly from depth to depth for *E. trachycaulus* and *M. rigens* ($p = 0.9998$ and $p = 0.9989$, respectively).

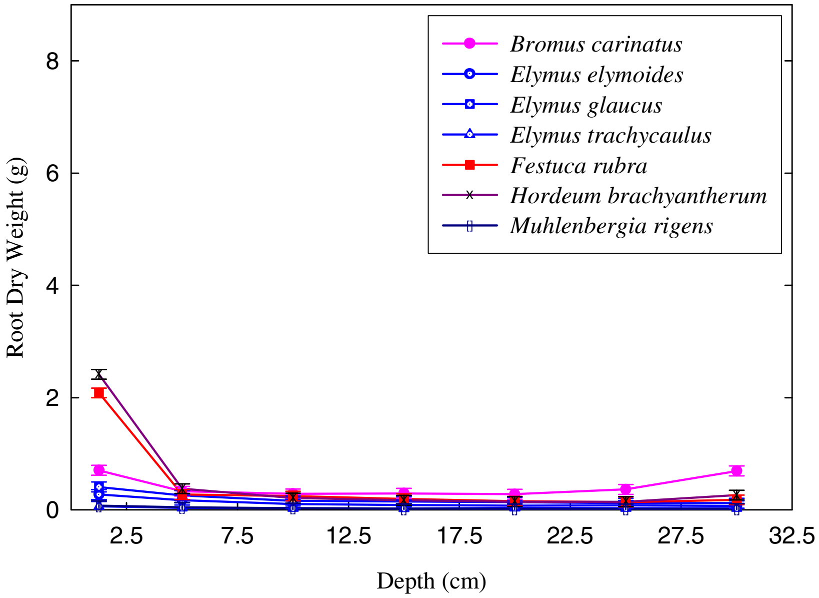

Figure 68. Effect of species and depth on root biomass for the Sierran Forest ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Percent Root Mass by Depth

Mixtures. For the Sierran Forest ecoregion, the depth by sod composition interaction for percent root mass was significant ($p < 0.0001$). The greatest differences between mixtures occurred from 0.0 – 2.5 cm (Figure 69). RXY3B mixtures had significantly greater percent root mass from 0.0 – 2.5 cm than any other mixture. RX5B mixture percent root masses were not significantly different at this depth than those of RX3B and RXY5B mixtures, but were significantly greater than those of the RY3B mixture. RX3B, RXY5B and RY3B mixtures were not significantly different from each other. RY5B mixtures had significantly lower percentages than did all other mixtures.

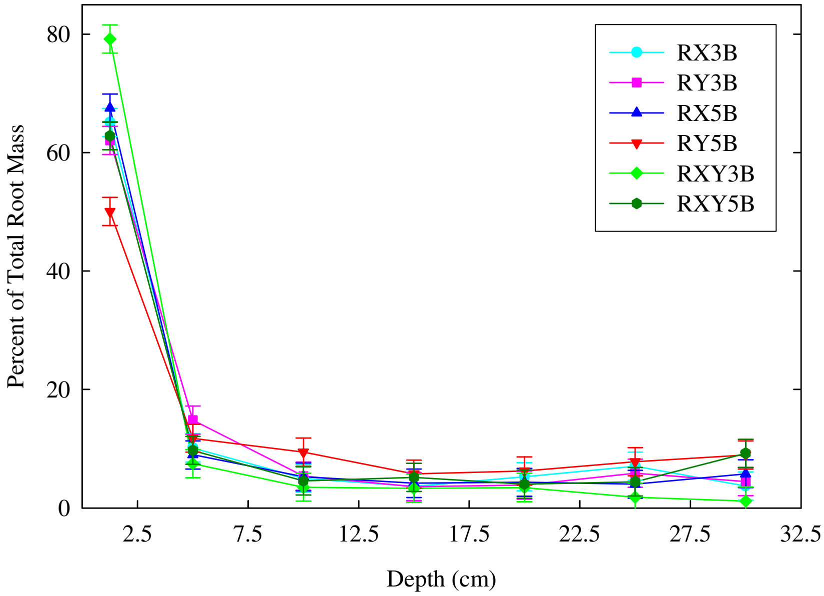

Figure 69. Effect of sod composition and depth on percent root mass for the Sierran Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

There was not a significant rhizomatous by bunch grass interaction for percent root mass in the first 2.5 cm (p = 0.2207). The rhizomatous main effect was significant (p = 0.0417), while the bunch grass main effect was not significant at the 5% level (p = 0.0686). The percent root mass in the first 2.5 cm for mixtures containing both rhizomatous species was significantly greater than that of mixtures containing only rhizomatous species Y (*Elymus trachycaulus*) (p = 0.0151), but was not significantly different from that of mixtures containing rhizomatous species X (*Festuca rubra*) (p = 0.3890). Percent root mass in the first 2.5 cm of mixtures containing rhizomatous species X were not different from those of mixtures containing rhizomatous species Y at the 5% significance level (p = 0.0766). The percent root mass in the first 2.5 cm of mixtures containing three bunch grasses did not differ from that of mixtures containing five bunch grasses at the 5% significance level (p = 0.0686).

Monostands. The depth by species interaction for percent root mass was significant for the Sierran Forest monostands (p < 0.0001). *Hordeum brachyantherum* and *Festuca rubra* were never significantly different from each other, but had significantly greater percent root mass than all other species from 0.0 – 2.5 cm (Figure 70). Beyond 2.5 cm, these two species had the lowest percentages, having significantly lower percent root mass than all other species from 12.5 – 17.5 cm and from 22.5 – 27.5 cm. The remaining species more uniformly partitioned their root mass across depths, with the exception that only *Bromus carinatus* partitioned a significantly greater percentage of root mass beyond 27.5 cm.

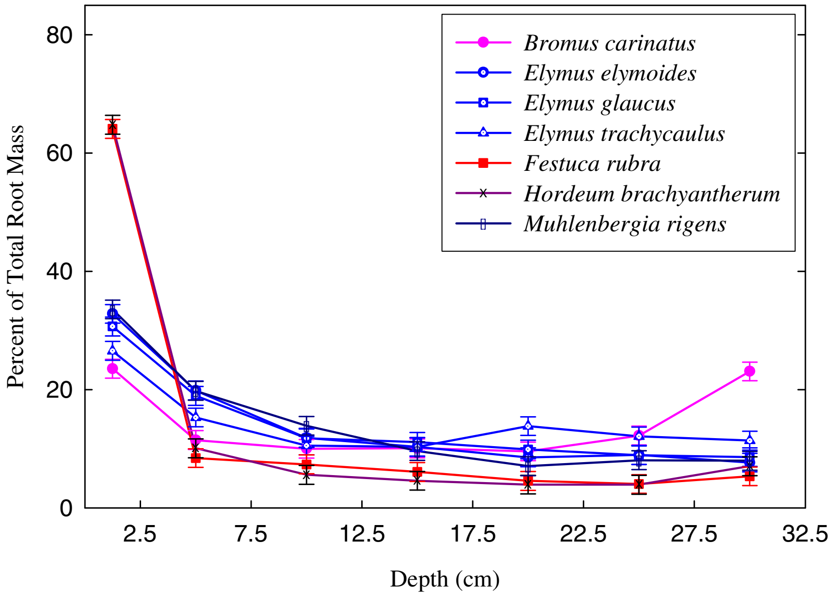

Figure 70. Effect of species and depth on percent root mass for the Sierran Forest ecoregion monostands. Points represent means and error bars represent standard errors from the SAS MIXED model.

Sod Strength

For the Sierran Forest ecoregion there was a significant positive correlation between percent rhizomatous species composition and sod strength ($R^2 = 0.5994$, $p < 0.0001$) (Figure 71).

The rhizomatous by bunch grass species interaction was not significant ($p = 0.1027$). Both the rhizomatous and bunch grass main effects were significant ($p < 0.0001$ and $p = 0.0073$, respectively). Mixtures containing three bunch grasses had significantly greater sod strength than those containing five (Figure 72).

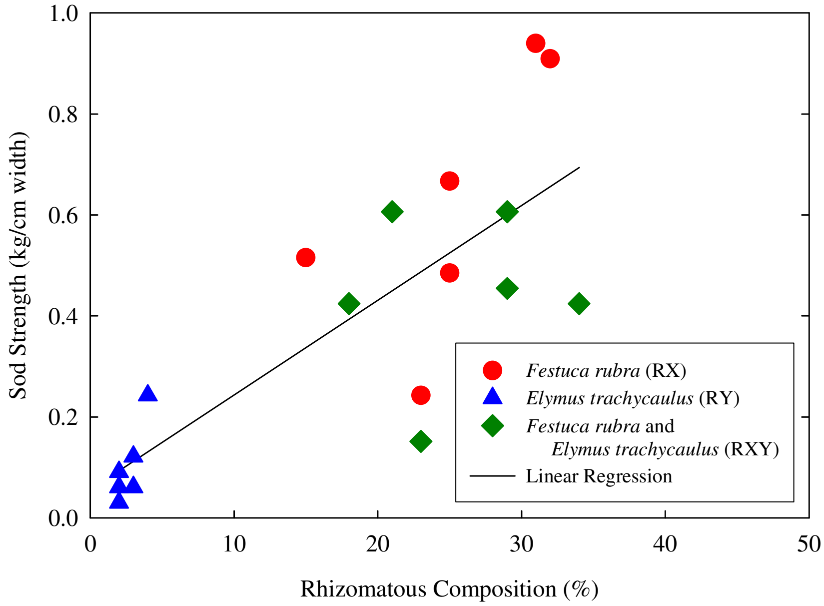

Figure 71. Correlation of percent rhizomatous species composition and sod strength for the Sierran Forest ecoregion. Linear regression $R^2 = .5994$.

Mixtures with rhizomatous species X (*Festuca rubra*) had significantly greater sod strength than did those with both X and Y ($p = 0.0408$). In turn, mixtures with both rhizomatous species had significantly greater sod strength than did those with rhizomatous species Y (*Elymus trachycaulus*). However, sod strength for the RX5B mixtures was not significantly different from that of mixtures containing both rhizomatous species.

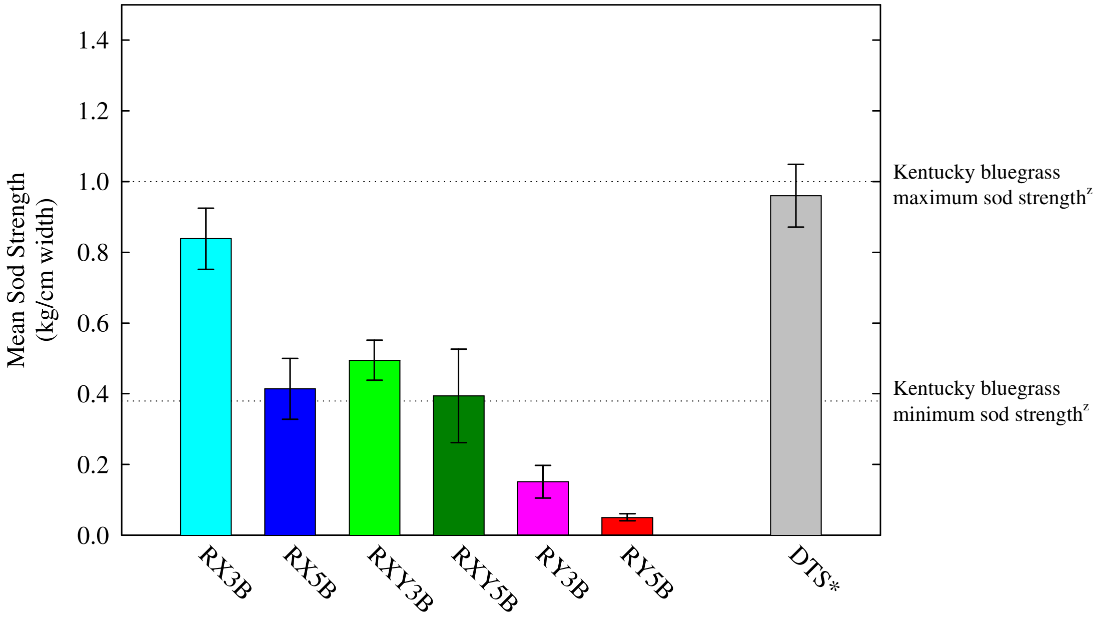

Figure 72. Effect of sod composition on sod strength for the Sierran Forest ecoregion. Points represent means and error bars represent standard errors. *Drought-tolerant sod (Bitterroot Turf Farms, Corvallis, Montana). ^{z}From Flanagan et al. 1993.

Discussion

Differences in clipping fresh weight and percent dry weight between monostands translated into differences in clipping fresh weight and percent dry weight for mixtures at some harvests. However, by the final harvest, there were no differences in clipping fresh weight or percent dry weight. Initially, there may be some differences in the required mowing frequency and the mowing quality of mixtures, but they would likely diminish as the sod develops and would not be sufficient justification for selecting one mixture over another.

Mixtures with three bunch grasses had significantly greater sod strength than did those with five. However, mixtures with five bunch grasses had greater total ground cover than did mixtures with three bunch grasses. Therefore, in the Sierran Forest ecoregion, sod strength is not positively correlated with total ground cover. This is likely because *Muhlenbergia rigens* is a warm season species and did not germinate and start to establish until 150 DAP and thereafter comprised less than 3.0% of the average total ground cover. Consequently, mixtures with fewer species had more bare ground because a greater proportion of their initial seeding rate was comprised of *M. rigens*, which did not perform well. Despite the fact that *M. rigens* is a widely-distributed species, if sod is produced under cool-season conditions it is unlikely that *M. rigens* will establish sufficiently to warrant its inclusion in further studies. This refutes the hypothesis that all native species will tolerate sod production methods. All other species were persistent in the mixtures and should not be excluded from further experimentation.

Over the production cycle, mixtures with a fewer total number of species developed increasingly greater *Festuca rubra* abundance, likely because of initial seed proportions. Initial seeding proportions were also likely the reason that there was more *Elymus trachycaulus* and more *Elymus elymoides* in mixtures with fewer species. Mixtures with fewer species also contained increasingly greater percentages of *Hordeum brachyantherum* for the same reason. There were no differences in *M. rigens* composition between mixtures. *Bromus carinatus* was only included in mixtures with five bunch grass species and was most abundant in RY5B mixtures. There were no significant differences in *Elymus glaucus* composition between mixtures.

There is a strong positive correlation between the percent rhizomatous species composition and sod strength. Mixtures with *F. rubra* as the single rhizomatous species had significantly greater sod strength than did mixtures with both rhizomatous species; mixtures with both rhizomatous species had significantly greater sod strength than mixtures with *E. trachycaulus* as the single rhizomatous species. In addition, there is a positive correlation between *F. rubra* composition and sod strength because mixtures with fewer total species had significantly greater proportions of *F. rubra* and correspondingly greater sod strength. Mixtures with *F. rubra* had sod strength within the range of Kentucky bluegrass, while those with *E. trachycaulus* had lower sod strength than Kentucky bluegrass (Figure 72). Only the RX3B mixtures had sod strength that was similar to the Bitterroot Turf Farms drought-tolerant sod.

There also seems to be a positive correlation between *H. brachyantherum* composition and sod strength, as mixtures with more *H. brachyantherum* had greater sod strength. Both *F. rubra* and *H. brachyantherum* seem to be contributing to sod strength since mixtures without *F. rubra* had increasingly greater sod strength as *H. brachyantherum* composition increased. However, without *F. rubra* sod strength was always significantly less than when *F. rubra* was included whether *H. brachyantherum* was present or not. Neither *E. elymoides* composition nor *E. trachycaulus* composition seem to be positively correlated with sod strength.

Mixtures with five bunch grasses had lower sod strength than those with three bunch grasses. Mixtures with five bunch grasses included *B. carinatus*. In addition, sod strength among five bunch grass mixtures seemed to decrease with increasing abundance of *B. carinatus*. This indicates that there may actually be a negative correlation between *B. carinatus* composition and sod strength. However, *B. carinatus* is a widely adapted species that performed well and should not be excluded from further studies. Perhaps decreasing the proportion of *B. carinatus* seed in the mixtures will allow the inclusion of this species without greatly compromising sod strength.

Species partitioned their total root mass differently across the soil profile as evidenced by differences in root mass and percent root mass by depth for monostands. These differences in root architecture were manifest in the mixtures as well. Total root mass was greater for mixtures with *F. rubra* as the single rhizomatous species and when both rhizomatous species were included as compared to when *E. trachycaulus* was included as the single rhizomatous species. Sod strength and root mass in the first 2.5 cm may not be positively correlated since mixtures with greater root mass and percent root mass in the first 2.5 cm did not always have greater sod strength. Including more species does not result in a more extensive root system.

CONCLUSIONS

Overall Conclusions

Though this experiment was not designed to make comparisons between ecoregions, a few general conclusions seem to be evident.

Despite the fact that total root mass did not increase with increasing species number, individual species did exhibit different root structures as evidenced by differences in root mass and percent root mass by depth for different monostands. For example, *Bromus carinatus* generally had increased root mass beyond 27.5 cm, indicating that this species would have rooted even deeper if the containers had allowed for such. Other species (*Festuca rubra*, *Festuca idahoensis* and *Koeleria macrantha*) allocated more than 50% of their root mass in the first 2.5 cm centimeters of the soil profile. It is unclear whether or not this variation in root architecture between species would actually make the sod more capable of competing with undesirable species as Brown and colleagues (1998) suggested. Further experimentation would be required to make this determination.

Including a greater number of species did not seem to contribute to differences in the speed of establishment or in total ground cover. However, for ecological and aesthetic reasons, several species should be included in the sod mixtures to increase environmental versatility. Sod strength generally decreased as the number of species increased—likely because the seeded proportion of the species contributing the most to sod strength decreased. Planting a greater proportion of rhizomatous species that seem to have greater sod strength, particularly *Festuca rubra*, while including smaller proportions of other well-adapted species should maximize sod strength but also provide the added benefit of having several different species in the sod mixtures.

Although the rhizomatous species *Elymus trachycaulus*, *Leymus triticoides* and *Leymus condensatus* did not seem to contribute a great deal to sod strength, they were persistent in the mixtures. If given more time, these species might develop greater sod strength. Beard and Rieke (1969) suggested that some species may take up to two years to develop sufficient sod strength for harvest. Regardless of their contribution to sod strength, these species should not be removed from future studies as they performed well and will contribute to the overall diversity and environmental versatility of the sod. Additionally, these species may have contributed more sod strength if they had been present in greater quantities.

Species like *Melica californica* (in the California Grasslands ecoregion) and *Bromus carinatus* (in all but the Intermountain Sagebrush and Great American Desert ecoregions) performed very well, comprising rather large percentages of the total ground cover. However, it seems that these species contributed very little sod strength. By planting smaller portions of these species that performed very well but did not necessarily produce strong sod, sod strength can be maximized while including other well-adapted species.

Warm-season species may be more difficult to include in sod mixtures, especially if the sod is produced under cool season conditions. *Muhlenbergia rigen*s did not perform well under these conditions. However, *Aristida purpurea* performed well despite being a warm season species. This could be due to the fact that the Great American Desert ecoregion temperature settings were warmer than those for the Sierran Forest ecoregion. Alternatively, it may be due to differences in temperature requirements among warm season species. Including warm season species is possible if they are capable of germinating and establishing despite cooler temperatures or if sod will be produced under warmer conditions.

Although some species did not comprise more than 10% of the total ground cover, they should not be excluded from future studies as they were persistent despite lower abundance and may be better-adapted to some installation sites. Overall, only two of the twenty species assessed (*Muhlenbergia rigens* and *Achnatherum hymenoides*) do not seem to be tolerant of current sod production methods.

Mixtures with *Festuca rubra* tended to produce sod with strength comparable to Kentucky bluegrass, which had been grown for a similar length of time (Flanagan 1993). Bitterroot Turf Farms (Corvallis, Montana) drought-tolerant sod had greater sod strength than the majority of the native sod mixtures tested. This is explained by the fact that the Bitterroot Turf Farms sod had been grown for three years, while the native sod mixtures tested here had only been grown for seven months. Native sod mixtures with *F. rubra* tend to produce sufficient tensile strength for mechanical harvesting within a relatively short amount of time. Sod mixtures including other rhizomatous species (*E. trachycaulus*, *L. triticoides* and *L. condensatus*) may develop sufficient sod strength for mechanical harvesting over time, but a reduced production time will reduce the cost of the sod and make its use more feasible. Further, these species may behave differently in field-grown situations than in the greenhouse and, consequently, should not be removed from further studies.

There was a significant positive correlation between the percent rhizomatous species composition and sod strength when data from all ecoregions was included ($R^2 = 0.5957$, $p < 0.0001$). Mixtures tended to have greater sod strength as the percent rhizomatous species composition increased, particularly if the composition of *Festuca rubra* increased (Figure 73). However, it seems that *Festuca idahoensis* must have also contributed to sod strength because in the Pacific Forest ecoregion there were no significant differences in sod strength between mixtures that had both *F. rubra* and *F. idahoensis* and those that had only *F. idahoensis*. This difference cannot likely be explained by the presence of *E. trachycaulus* because in all other ecoregions, mixtures containing *E. trachycaulus* had low sod strength—especially when *E. trachycaulus* was present in similarly small percentages. This provides some evidence that sod strength may not be determined solely by rhizomes or stolons as Beard and Rieke (1969) and Huff (2003) suggested. Rather, sod strength seems to be determined by a combination of several factors potentially including total ground cover, percent rhizomatous species composition, rooting characteristics and species identity.

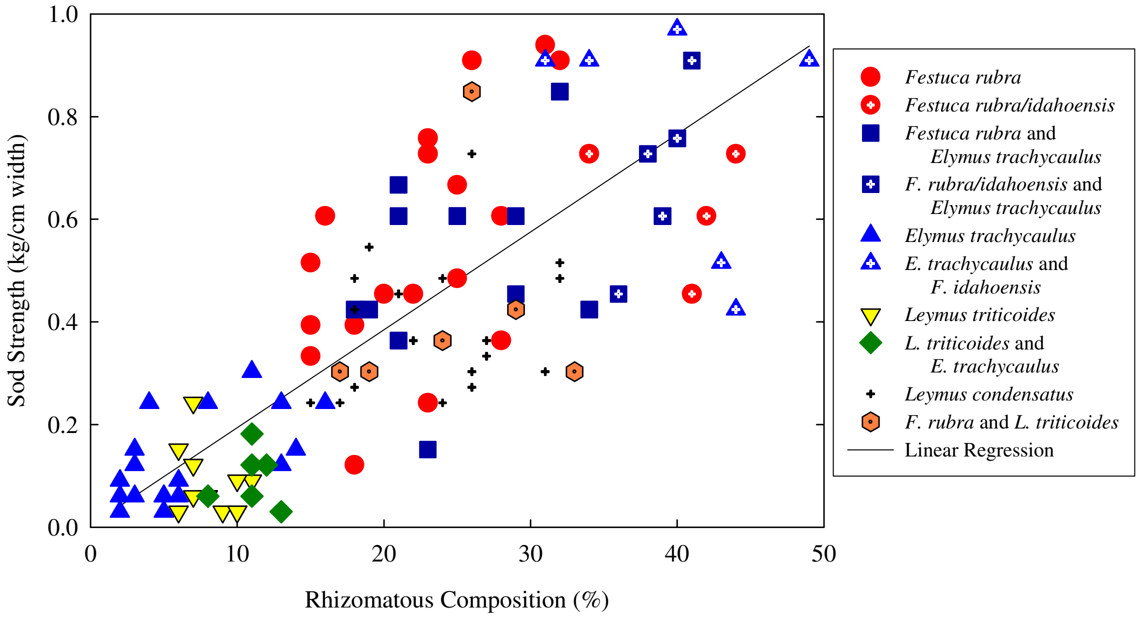

Figure 73. Correlation of percent rhizomatous species composition and sod strength for all six ecoregions. Different rhizomatous species and combinations of rhizomatous species are indicated with different symbols. Symbols with a white crosshair represent data from the Pacific Forest ecoregion where percent rhizomatous species composition data was confounded with the percent composition of *Festuca idahoensis*. Therefore, these data also include the percent composition of *F. idahoensis*. Linear regression R^2 = .5957.

APPENDICES

APPENDIX A

SPECIES SELECTION

Introduction

Using maps provided by Caltrans, the counties in California comprising each of the six selected ecoregions were determined. Each county in each ecoregion was queried using the *Native Grass Database* (2001) in order to determine which species were present. The query was limited to perennial grasses. After compiling lists for each county, the lists were merged and the frequency of each species was recorded for each ecoregion. With this methodology, the most widespread species were delineated. Each species was also evaluated for its elevational range, typical habitat type, soil moisture requirements (USDA, NRCS 2007, Hickman 2003), season of growth (Lavin and Siebert 2005) and commercial seed availability (S&S Seeds, Carpenteria, California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California). Some species were eliminated because they occurred in very few counties within an ecoregion, others because their habitat description seemed to preclude their use over a wide variety of sites. For example, a species that inhabits elevations from 0-10 m would likely be unsuitable for most highway construction sites.

In an attempt to closely mimic the community composition of each ecoregion, a query was also conducted to determine the ratio of warm and cool season species within the counties of each ecoregion. Even though all species present in an ecoregion cannot be included in revegetation efforts, a mixture with an appropriate ratio of cool season and warm season species is desirable. In the Pacific Forest, Chaparral, California Grasslands, and Intermountain Sage ecoregions, the ratio of warm season species to cool season species was small enough to preclude using any warm season grasses. For the Sierran Forest ecoregion, one warm season species was included. In the Great American Desert ecoregion, two warm season species were included. Seed sources for warm season species are very limited and many warm-season species native to California prefer moist or wet sites.

Because seed of local origin is more likely to be successful, every effort was made to find a seed source from a county within the desired ecoregion. Sources of native seed are limited. If a seed source for the desired ecoregion could not be found, another species, for which a local source was available, was substituted. If substituting another species was not practicable, either seed from a source outside the desired ecoregion or commercially grown seed was used. Despite their being a suitable selection in all other ways, some species were eliminated solely because a seed source could not be secured.

The *Native Grass Database* (2001) contains 303 species of grasses. In the initial query, the only limitation was that the “longevity” field was limited to “perennial” in order to eliminate all annual grass species. This query resulted in 234 species and sub-species of perennial grasses native to California (Table A.1). This list was then coupled with the more specific data about each species to create lists of potential species for each ecoregion.

Table A.1. List of 234 native perennial species and sub-species obtained from the *Native Grass Database*. Botanical and common names are included.

Species	Common Name	Species	Common Name
Achnatherum coronatum	Giant Stipa	*Glyceria occidentalis*	Western Mannagrass
Achnatherum hymenoides	Indian Ricegrass	*Glyceria striata*	Fowl Mannagrass
Achnatherum latiglume		*Hesperostipa comata*	Needle-and-Thread
Achnatherum lettermanii	Letterman's Needlegrass	*Hesperostipa comata* ssp. Comata	
Achnatherum nelsonii	Columbia Stipa	*Hesperostipa comata* ssp. Intermedia	
Achnatherum nevadense		*Heteropogon contortus*	Black Spear Grass
Achnatherum occidentale	Western Stipa	*Hierochloe occidentalis*	California Sweetgrass
Achnatherum occidentale ssp. californicum	California Stipa	*Hierochloe odorata*	Vanilla Grass
Achnatherum occidentale ssp. occidentale	Western Stipa	*Hordeum arizonicum*	Arizona Foxtail
Achnatherum occidentale ssp. pubescens	Elmer Stipa	*Hordeum brachyantherum*	Meadow Barley
Achnatherum parishii	Giant Stipa	*Hordeum brachyantherum ssp. brachyantherum*	
Achnatherum pinetorum	Pine Stipa	*Hordeum brachyantherum ssp. Californicum*	
Achnatherum speciosum	Desert Needlegrass	*Hordeum jubatum*	Foxtail Barley
Achnatherum stillmanii	Stillman's Stipa	*Imperata brevifolia*	Satintail
Achnatherum therberianum	Therber's Stipa	*Koeleria macrantha*	Prairie Junegrass
Achnatherum webberi	Webber's Ricegrass	*Leersia oryzoides*	Rice Cutgrass
Agrostis blasdalei	Blasdale's Bentgrass	*Leymus cinereus*	Great Basin Wildrye
Agrostis densiflora	Coastal Bluff Bentgrass	*Leymus condensatus*	Giant Wildrye
Agrostis hallii	Hall's Redtop	*Leymus mollis*	American Dunegrass
Agrostis hooveri	Hoover's Bentgrass	*Leymus multiflorus x*	Beardless Wildrye
Agrostis humilis	Mountain Bentgrass	*Leymus pacificus*	
Agrostis idahoensis	Idaho Bentgrass	*Leymus salinus*	Salina Wildrye
Agrostis oregonensis	Oregon Redtop	*Leymus triticoides*	Beardless Wildrye
Agrostis pallens	Dune Bentgrass, Thin Grass	*Leymus vancouverensis x*	

Species	**Common Name**		**Species**	**Common Name**
Agrostis scabra	Ticklegrass		*Lycurus phleoides*	Wolftail
Agrostis thurberiana	Therber's Bentgrass		*Melica aristata*	Awned Melic
Agrostis variabilis	Mountain Bentgrass		*Melica bulbosa*	Big Oniongrass
Alopecurus aequalis	Short-Awn Foxtail		*Melica californica*	California Melic
Alopecurus geniculatus	Water Foxtail		*Melica frutescens*	Oniongrass
Andropogon glomeratus var. scabriglumis	Bushy Beardgrass		*Melica fugax*	Little Oniongrass
Aristida californica var. californica	California Three-Awn		*Melica geyeri*	Geyer Oniongrass
Aristida divaricata	Poverty Three-Awn		*Melica harfordii*	Harford Melic
Aristida purpurea	Purple Three-Awn		*Melica imperfecta*	Small-Flowered Melic
Aristida purpurea var. fendleriana	Fendler's Three-Awn		*Melica spectabilis*	Purple Oniongrass
Aristida purpurea var. longiseta	Red Three-Awn		*Melica stricta*	Nodding Melic
Aristida purpurea var. nealleyi	Nealley Three-Awn		*Melica subulata*	Alaska Oniongrass
Aristida purpurea var. parishii	Parish Three-Awn		*Melica torreyana*	Torrey Melic
Aristida purpurea var. purpurea	Purple Three-Awn		*Monanthochloe littoralis*	Shoregrass
Aristida purpurea var. wrightii	Wright Three-Awn		*Muhlenbergia andina*	Foxtail Muhly
Aristida ternipes var. hamulosa	Spreading Three-Awn		*Muhlenbergia arsenei*	Tough Muhly
Blepharidachne kingii	King's Eyelash Grass		*Muhlenbergia asperifolia*	Scratchgrass
Bothriochloa barbinodis	Cane Beardgrass		*Muhlenbergia californica*	California Muhly
Bouteloua curtipendula	Side-Oats Grams		*Muhlenbergia jonesii*	
Bouteloua eriopoda	Black Grama		*Muhlenbergia mexicana*	
Bouteloua gracilis	Blue Grama		*Muhlenbergia montana*	Mountain Muhly
Bouteloua trifida	Red Grama		*Muhlenbergia pauciflora*	Few-Flowered Muhly
Bromus anomalus			*Muhlenbergia richardsonis*	Mat Muhly
Bromus carinatus	California Brome		*Muhlenbergia rigens*	Deergrass
Bromus carinatus var. carinatus	California Brome		*Muhlenbergia utilis*	Aparejograss

Species	**Common Name**
Bromus carinatus var. maritimus	
Bromus ciliatis	Fringed Brome
Bromus grandis	
Bromus laevipes	Woodland Brome, Chinook Brome
Bromus orcuttianus	Orcutt's Brome
Bromus suksdorfii	Suksdorf's Brome
Bromus vulgaris	Narrow-Flowered Brome
Calamagrostis bolanderi	Bolander's Reedgrass
Calamagrostis breweri	Brewer's Reedgrass
Calamagrostis canadensis	Bluejoint Reedgrass
Calamagrostis foliosa	Leafy Reedgrass
Calamagrostis koelerioides	
Calamagrostis nutkaensis	Pacific Reedgrass
Calamagrostis ophitidis	Serpentine Reedgrass
Calamagrostis purpurascens	Purple Reedgrass
Calamagrostis rubescens	Pine Grass
Calamagrostis strica	
Calamagrostis strica ssp. Inexpansa	Therber's Reedgrass
Calamagrostis strica ssp. Stricta	
Cinna bolanderi	Bolander's Woodreed
Cinna latifolia	Drooping Woodreed
Danthonia californica	California Oatgrass
Danthonia californica var. americana	
Danthonia californica var. californica	California Oatgrass
Danthonia intermedia	Timber Oatgrass
Danthonia unispicata	Onespike Oatgrass

Species	**Common Name**
Nassella cernua	Nodding Needlegrass
Nassella lepida	Foothill Needlegrass
Nassella pulchra	Purple Needlegrass
Panicum acuminatum	
Panicum acuminatum var. acuminatum	Geyser's Panicum
Panicum acuminatum var. lindheimerii	
Panicum hirticaule	
Panicum oligosanthes var. scribnerianum	
Panicum urvilleanum	
Pascopyrum smithii	Western Wheatgrass
Paspalum distichum	Knotgrass
Phalaris arundinacea	Reed Canarygrass
Phalaris californica	California Canarygrass
Phleum alpinum	Alpine Timothy
Phragmites australis	Common Reed
Piptatherum micranthum	Smallflower Ricegrass
Pleuraphis jamesii	Galleta
Pleuraphis rigida	Wooly Galleta, Big Galleta
Pleuropogon refractus	Nodding Semaphore Grass
Poa atropurpurea	San Bernardino Bluegrass
Poa confinis	Beach Bluegrass
Poa cusickii	Cusick's Bluegrass
Poa douglasii	Sand-Dune Bluegrass
Poa fendleriana ssp. Fendleriana	Muttongrass
Poa glauca ssp. Rupicola	Timberline Bluegrass
Poa keckii	

Species	**Common Name**	**Species**	**Common Name**
Deschampsia atropurpurea	Mountain Hairgrass	*Poa Kelloggii*	
Deschampsia cespitosa	Tufted Hairgrass	*Poa leptocoma* ssp. Leptocoma	Bog Bluegrass
Deschampsia cespitosa ssp. cespitosa		*Poa lettermanii*	
Deschampsia cespitosa ssp. Holciformis		*Poa macrantha*	Large Flowered Sand Dune Bluegrass
Deschampsia elongata	Slender Hairgrass	*Poa napensis*	Napa Bluegrass
Distichlis spicata	Saltgrass	*Poa pattersonii*	Patterson's Bluegrass
Elymus californicus		*Poa piperi*	Piper's Bluegrass
Elymus elymoides	Squirreltail	*Poa pringlei*	
Elymus elymoides ssp. brevifolius		*Poa rhizomata*	Timber Bluegrass
Elymus elymoides ssp. Californicus		*Poa secunda*	Pine Bluegrass
Elymus elymoides ssp. Elymoides		*Poa secunda* ssp. Juncifolia	
Elymus elymoides ssp. Hordeoides		*Poa secunda* ssp. Secunda	One-Sided Bluegrass
Elymus glaucus	Blue Wildrye	*Poa sierrae*	
Elymus glaucus ssp. glaucus		*Poa stebbinsii*	
Elymus glaucus ssp. jepsonii		*Poa tenerrima*	Delicate Bluegrass
Elymus glaucus ssp. Virescens		*Poa unilateralis*	Ocean-Bluff Bluegrass
Elymus lanceolatus	Thickspike Wheatgrass	*Poa wheeleri*	Wheeler Bluegrass
Elymus multisetus	Big Squirreltail	*Pseudoroegneria spicata*	Bluebunch Wheatgrass
Elymus scribneri	Scribner's Wheatgrass	*Ptilagrostis kingii*	King's Ricegrass
Elymus sierrus		*Puccinellia howellii*	Howell's Alkaligrass
Elymus stebbinsii	Stebbin's Wheatgrass	*Puccinellia lemmonii*	Lemmon's Alkaligrass
Elymus trachycaulus	Slender Wheatgrass	*Puccinellia nutkaensis*	Alaska Alkaligrass
Elymus trachycaulus ssp. Subsecundus		*Puccinellia nuttalliana*	Nuttall Alkaligrass
Elymus trachycaulus ssp. Trachycaulus		*Puccinellia pumila*	Dwarf Alkaligrass
Enneaopogon desvauxii	Nine-Awned Pappus Grass	*Scleropogon brevifolius*	Burro Grass
Erioneuron pulchellum	Fluffgrass	*Setaria gracilis*	Knotroot Bristlegrass

Species	**Common Name**		**Species**	**Common Name**
Festuca brachyphylla ssp. Breviculmis	Sheep Fescue		*Spartina foliosa*	Cordgrass
Festuca californica	California Fescue		*Spartina gracilis*	Alkali Cordgrass
Festuca elmeri	Elmer's Fescue		*Sphenopholis obtusata*	Prairie Wedgegrass
Festuca idahoensis	Idaho Fescue		*Sporobolus airoides*	Alkali Sacaton
Festuca kingii	King's Fescue		*Sporobolus contractus*	Spike Dropseed
Festuca minutiflora	Small-Flowered Sheep Fescue		*Sporobolus cryptandrus*	Sand Dropseed
Festuca occidentalis	Western Fescue		*Sporobolus flexuosis*	Mesa Dropseed
Festuca rubra	Red Fescue		*Swallenia alexandrae*	Eureka Valley Dune Grass
Festuca saximontana var. purpusiana	Sheep Fescue		*Torreyochloa erecta*	Tall Mannagrass
Festuca subulata	Bearded Fescue		*Torreyochloa pallida* var. pauciflora	Weak Mannagrass
Festuca subuliflora	Crinkle-Awn Fescue		*Tridens muticus*	Slim Tridens
Festuca viridula	Greenleaf Fescue		*Trisetum canescens*	Tall Trisetum
Glyceria borealis	Northern Mannagrass		*Trisetum cernuum*	Nodding Trisetum
Glyceria elata	Tall Mannagrass		*Trisetum spicatum*	Spike Trisetum
Glyceria grandis	American Mannagrass		*Trisetum wolfii*	Wolf Trisetum

California Grasslands

Butte, Colusa, Fresno, Glenn, Kings, Madera, Merced, Sacramento, San Joaquin, Solano, Stanislaus, Sutter, Tehama, Yolo, and Yuba Counties were queried for the California Grasslands ecoregion. Species found in less than eight of these fifteen counties were eliminated. The most promising species are listed in Table A.2. Some species, though promising in all other ways were eliminated because of lack of available seed (Table A.3). Others were eliminated because of narrow habitat descriptions, elevational ranges or soil moisture requirements (Table A.4). For this ecoregion, *Leymus triticoides* and *Festuca rubra* were selected as the two rhizomatous species. *L. triticoides* occurs in all fifteen counties queried while *F. rubra* occurs in only eight. A more commonly-occurring rhizomatous species could not be found, so *F. rubra* so was selected. As bunch grasses, *Bromus carinatus*, *Nassella pulchra*, *Nassella cernua*, *Elymus glaucus* and *Melica californica* were selected. *Bromus carinatus* was the only one occurring in all of the queried counties. *Nassella pulchra*, *N. cernua*, *E. glaucus* and *M. californica* occurred in fourteen, thirteen, fourteen and eight counties, respectively.

Table A.2. Most promising species for the California Grasslands ecoregion.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Bromus carinatus	15	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool	Bunch	8	ConservaSeed
Elymus multisetus	15	0/3200	Open sandy to rocky areas	Dry	Cool	Bunch		Hedgerow
Elymus glaucus	14	0/2500	Open areas, chaparrel, woodland, forest	Dry, Moist	Cool	Bunch	12	Hedgerow
Leymus triticoides	15	0/2300	Moist, often saline meadows	Moist	Cool	Rhizomatous	10	Hedgerow
Nassella pulchra	14	0/1300	Oak woodland, chaparral, grassland	Dry	Cool	Bunch	10	Hedgerow
Nassella cernua	13	0/1400	Grassland, chaparral, juniper woodland	Dry	Cool	Bunch	12	Hedgerow
Elymus elymoides	12	600/4200	Dry open areas	Dry, Moist	Cool	Bunch	12	Local Source Unavailable

[z] Total number of counties in which species is present out of fifteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.2. (cont'd) Most promising species for the California Grasslands ecoregion.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Koeleria macrantha	12	0/3500	Dry, open sites, clay to rocky soils, shrubland, woodland, coniferous forest, alpine	Dry, Moist	Cool	Bunch	20	Local Source Unavailable
Muhlenbergia rigens	10	0/2150	Sandy to gravelly places, canyons, stream bottoms	Dry, Moist	Warm	Bunch	14	Local Source Unavailable
Nassella lepida	10	0/1700	Dry slopes, chaparral, oak grassland	Dry	Cool	Bunch	12	Local Source Unavailable
Danthonia californica	9	0/2200	Gen moist, open sites, meadows, forests	Moist, Dry	Cool	Multiple Stem	16	Local Source Unavailable
Festuca rubra	8	0/2500	Sand dues, grassland, subalpine forest	Dry, Moist	Cool	Rhizomatous	12	S&S Seeds
Melica californica	8	0/2100	Open hillsides, oak woodland, coniferous forest	Dry	Cool	Bunch	10	Hedgerow

[z] Total number of counties in which species is present out of fifteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.3. Potential California Grasslands species eliminated due to seed availability.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Bromus carinatus var. *carinatus*	15	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool		8	Unavailable
Elymus glaucus ssp. *glaucus*	15	0/2500	Open areas, chaparrel, woodland, forest	Dry, Moist	Cool		12	Unavailable
Poa secunda	14	0/3800	Many habitats	Dry, Moist	Cool	Bunch	10	Unavailable
Elymus elymoides ssp. *californicus*	12	800/4200	Dry open areas	Dry, Moist	Cool		12	Unavailable
Deschampsia cespitosa ssp. *cespitosa*	8	0/3820	Meadows, streambanks, coastal marsh, forests, alpine	Dry, Moist	Cool		14	Unavailable
Melica imperfecta	8	0/1500	Dry rocky hillsides, chaparral, woodland	Dry	Cool	Stoloniferous	12	Unavailable

[z] Total number of counties in which species is present out of fifteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.4. California Grasslands ecoregion species eliminated due to habitat description, elevational range, or soil moisture requirements. Reasons for elimination are highlighted.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]
Andropogon glomeratus var. *scabriglumis*	15	0/600	Moist, open disturbed areas, seeps	Moist, wet, seeps, springs
Distichlis spicata	15	0/1000	Salt marshes, moist, alkaline areas	Wet, Moist, Dry
Elymus glaucus ssp. *jepsonii*	15	900/2200	Coniferous forest, woodland	Dry, Moist
Hordeum brachyantherum	15	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *brachtyantherum*	15	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *californicum*	15	0/500	Meadows, pastures, streambanks	Moist, Dry
Hordeum jubatum	15	0/3400		Moist, Dry
Leymus multiflorus x	15	0/300	Open areas, often saline soils	Dry, Moist
Phragmites australis	15	0/1600	Pond and lake margins, sloughs, marshes	Wet
Puccinellia nuttalliana	15	0/2300	Saline meadows, flats	Moist
Paspalum distichum	14	0/1650	Moist places, marshes	Moist
Setaria gracilis	14	0/400	Open areas, grassland, chaparral	Dry, Moist
Panicum acuminatum	13	0/2600	Moist places, marshes, streambanks	Moist, Wet
Aristida ternipes var. *hamulosa*	11	100/1350	Dry hills and slopes	Dry
Bromus laevipes	10	100/2500	Srubland, coniferous forest	Moist
Agrostis oregonensis	9	0/2100	Moist areas, meadows, streambanks	Wet, Moist
Bromus orcuttianus	9	900/2900	Dry places, meadows, shrubland, coniferous forest	Dry, Moist
Danthonia californica var. *americana*	9	150/2200	Gen moist, open sites, meadows, forests	Moist, Dry
Danthonia californica var. *californica*	9	100/1900	Gen moist, open sites, meadows, forests	Moist, Dry
Phalaris arundinacea	9	0/1600	Wet streambanks, moist areas, grassland, woodland	Moist
Deschampsia cespitosa	8	0/3900	Wet sites, meadows, streambanks, coastal marshes, forest, alpine	Wet, Moist, Dry

[z] Total number of counties in which species is present out of fifteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

Chaparral

The Chaparral ecoregion encompasses Alameda, Contra Costa, Monterey, San Benito, San Francisco, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, and Ventura Counties. These counties were queried for this ecoregion. Any species found in fewer than five of these eleven counties was eliminated. The most promising species are listed in Table A.5. Some species were eliminated because a seed source could not be secured, despite their being a suitable species in all other ways (Table A.6). Other species were eliminated because their elevational range, habitat description, or soil moisture descriptions rendered their successful use unlikely for this study (Table A.7). *Elymus trachycaulus* and *Festuca rubra* were chosen as the rhizomatous species for this ecoregion because of their adaptability. *Elymus trachycaulus* is found in all eleven counties queried for the ecoregion. *F. rubra* is only found in five of eleven counties, but was the only other rhizomatous species for this ecoregion with suitable habitat characteristics for which a seed source could be secured. *Bromus carinatus*, *Nassella lepida*, *Koeleria macrantha*, *Nassella pulchra*, and *Elymus glaucus* were chosen as bunch grasses for this ecoregion. All were found in every county except for *K. macrantha*, which was found in ten of eleven.

Table A.5. Most promising species for the Chaparral ecoregion.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Bromus carinatus	11	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool	Bunch	8	Hedgerow
Elymus elymoides	11	600/4200	Dry open areas	Dry, Moist	Cool	Bunch	12	Local Source Unavailable
Elymus glaucus	11	0/2500	Open areas, chaparral, woodland, forest	Dry, Moist	Cool	Bunch	12	S&S Seeds
Elymus multisetus	11	0/3200	Open sandy to rocky areas	Dry	Cool	Bunch		Local Source Unavailable
Elymus trachycaulus	11	0/3400	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Bunch	16	S&S Seeds
Nassella lepida	11	0/1700	Dry slopes, chaparral, oak grassland	Dry	Cool	Bunch	12	Hedgerow

[z] Total number of counties in which species is present out of eleven counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.5. (cont'd) Most promising species for the Chaparral ecoregion.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Nassella pulchra	11	0/1300	Oak woodland, chaparral, grassland	Dry	Cool	Bunch	10	Hedgerow
Koeleria macrantha	10	0/3500	Dry, open sites, clay to rocky soils, shrubland, woodland, coniferous forest, alpine	Dry, Moist	Cool	Bunch	20	S&S Seeds
Danthonia californica	8	0/2200	Gen moist, open sites, meadows, forests	Moist, Dry	Cool	Multiple Stem	16	Local Source Unavailable
Melica californica	8	0/2100	Open hillsides, oak woodland, coniferous forest	Dry	Cool	Bunch	10	Local Source Unavailable
Nassella cernua	8	0/1400	Grassland, chaparral, juniper woodland	Dry	Cool	Bunch	12	Local Source Unavailable
Festuca rubra	5	0/2500	Sand dunes, grassland, subalpine forest	Dry, Moist	Cool	Rhizomatous	12	S&S Seeds

[z] Total number of counties in which species is present out of eleven counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.6. Potential Chaparral ecoregion species eliminated due to seed availablitilty.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Bromus carinatus var. *carinatus*	11	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool			Unavailable
Elymus glaucus ssp. *glaucus*	11	0/2500	Open areas, chaparral, woodland, forest	Dry, Moist	Cool			Unavailable
Elymus trachycaulus ssp. *trachycaulus*	11	0/3300	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Rhizomatous	16	Unavailable
Melica imperfecta	11	0/1500	Dry rocky hillsides, chaparral, woodland	Dry	Cool	Stoloniferous	12	Unavailable
Poa secunda	11	0/3800	Many habitats	Dry, Moist	Cool			Unavailable

[z] Total number of counties in which species is present out of eleven counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.6. (cont'd) Potential Chaparral ecoregion species eliminated due to seed availablitilty.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Agrostis hallii	10	0/1500	Open oak woodland, coniferous forest	Dry	Cool			Unavailable
Elymus elymoides ssp. *californicus*	9	800/4200	Dry open areas	Dry, Moist	Cool			Unavailable
Melica torreyana	9	0/1200	Chaparral, coniferous forest	Dry	Cool			Unavailable
Danthonia californica var. *americana*	8	150/2200	Gen moist, open sites, meadows, forests	Moist, Dry	Cool			Unavailable
Danthonia californica var. *californica*	8	100/1900	Gen moist, open sites, meadows, forests	Moist, Dry	Cool			Unavailable
Festuca californica	8	0/1800	Open forest, chaparral	Dry	Cool	Bunch	8	Unavailable

[z] Total number of counties in which species is present out of eleven counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.6. (cont'd) Potential Chaparral ecoregion species eliminated due to seed availablitilty.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Bromus grandis	7	400/4000	Dry, open places, shrubland, oak woodland, coniferous forest	Dry	Cool			Unavailable
Melica geyeri	7	0/2000	Dry open sites, oak woodland, coniferous forest	Dry	Cool			Unavailable
Melica harfordii	7	0/2150	Dry slopes, coniferous forest	Dry	Cool			Unavailable

[z] Total number of counties in which species is present out of eleven counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.7. Chaparral ecoregion species eliminated due to elevational range, habitat description, or soil moisture requirements. Reasons for elimination are highlighted.

Species	**Score^z**	**Min/Max Elevation^y (m)**	**Habitat Description^x**	**Soil Moisture^y**
Bromus laevipes	11	100/2500	Shrubland, coniferous forest	Moist
Distichlis spicata	11	0/1000	Salt marshes, moist, alkaline areas	Wet, Moist, Dry
Elymus glaucus ssp. *jepsonii*	11	900/2200	Coniferous forest, woodland	Dry, Moist
Elymus glaucus ssp. *virescens*	11	0/300	Coniferous forest, chaparral	Dry, Moist
Elymus trachycaulus ssp. *subsecundus*	11	1000/3400	Dry to moist, open areas, forest, woodland	Dry, Moist
Hordeum brachyantherum	11	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *brachyantherum*	11	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *californicum*	11	0/500	Meadows, pastures, streambanks	Moist, Dry
Hordeum jubatum	11	0/3400		Moist, Dry
Leymus multiflorus x	11	0/300	Open areas, often saline soils	Dry, Moist
Leymus triticoides	11	0/2300	Moist, often saline meadows	Moist
Puccinellia nuttalliana	11	0/2300	Saline meadows, flats	Moist
Calamagrostis rubescens	10	0/900	Wooded slopes, montane forests	Moist, Dry
Paspalum distichum	10	0/1650	Moist places, marshes	Moist
Phragmites australis	10	0/1600	Pond and lake margins, sloughs, marshes	Wet
Panicum acuminatum	9	0/2600	Moist places, marshes, streambanks	Moist, Wet
Festuca elmeri	8	0/300	Moist, wooded slopes, under trees in rich soil	Moist
Phalaris californica	8	0/700	Moist areas, meadows, woodlands	Moist
Calamagrostis nutkaensis	7	0/1000	Wet areas, beaches, dunes, coastal woodland	Wet, Moist
Deschampsia cespitosa	7	0/3900	Wet sites, meadows, streambanks, coastal marshes, forest, alpine	Wet, Moist, Dry
Deschampsia cespitosa ssp. *cespitosa*	7	0/3820	Meadows, streambanks, coastal marsh, forests, alpine	Dry, Moist
Deschampsia cespitosa ssp. *holciformis*	7	0/850	Coastal marshes and meadows	Dry, Moist

Deschampsia elongata	7	100/3100	Wet sites, meadows, lakeshores, shaded slopes	Moist, Wet
Bromus carinatus var. *maritimus*	6	0/100	Dunes, meadows	Moist
Elymus californicus	5	0/300	Coniferous forest	Moist
Leymus vancouverensis x	5	0/100	Sandy beaches	Moist

[z] Total number of counties in which species is present out of eleven counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

Great American Desert

The Great American Desert ecoregion covered Inyo, Riverside and San Bernardino Counties in southern California. Species occurring in fewer than two of the queried counties for this ecoregion were eliminated. The species most likely suited to this application are listed in Table A.8. Some species, although suited to this application, were eliminated because of the lack of seed availability (Table A.9). Still other species were eliminated because of specific habitat descriptions, narrow elevational ranges or soil moisture requirements (Table A.10). In the Great American Desert ecoregion, two warm season species were selected. *Pleuraphis rigida* was selected as a warm-season, rhizomatous species, while *Aristida purpurea* was selected as a warm-season bunch grass. Both occurred in all three counties queried. The other rhizomatous species selected was *Leymus condensatus* which is a cool-season grass occurring in all queried counties. The other four bunch grasses were *Achnatherum hymenoides*, *Elymus elymoides*, *Koeleria macrantha* and *Nassella cernua*—all cool season species with the first three occurring in every county and *N. cernua* occurring in two of three.

Table A.8. Most promising species for the Great American Desert ecoregion.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Achnatherum hymenoides	3	0/3400	Dry, well-drained, often sandy soil	Dry	Cool	Bunch	18	Larner Seeds
Achnatherum occidentale	3	150/3400	Open, dry sites, sagebrush shrubland, coniferous forest, alpine	Dry	Cool			Local Source Unavailable
Elymus elymoides	3	600/4200	Dry open areas	Dry, Moist	Cool	Bunch	12	S&S Seeds
Elymus multisetus	3	0/3200	Open sandy to rocky areas	Dry	Cool	Bunch		Local Source Unavailable
Koeleria macrantha	3	0/3500	Dry, open sites, clay to rocky soils, shrubland, woodland, coniferous forest, alpine	Dry, Moist	Cool	Bunch	20	Larner Seeds
Leymus condensatus	3	0/1500	Dry slopes, open woodlands	Dry, Moist	Cool	Rhizomatous	18	S&S Seeds

[z] Total number of counties in which species is present out of three counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.8. (cont'd) Most promising species for the Great American Desert ecoregion.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Aristida purpurea	2	200/2000	Sandy to rocky soils, slopes, plains	Dry	Warm		12	Stover Seeds
Melica imperfecta	2	0/1500	Dry rocky hillsides, chaparral, woodland	Dry	Cool	Stoloniferous	12	S&S Seeds
Nassella cernua	2	0/1400	Grassland, chaparral, juniper woodland	Dry	Cool	Bunch	12	Hedgerow Farms
Nassella lepida	2	0/1700	Dry slopes, chaparral, oak grassland	Dry	Cool	Bunch	12	Local Source Unavailable
Pleuraphis rigida	2	0/1600	Dry, open, sandy to rocky slopes, flats, and washes, sand dunes, scrub, woodland	Dry	Warm	Rhizomatous	12	S&S Seeds

[z] Total number of counties in which species is present out of three counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.9. Potential Great American Desert ecoregion species eliminated due to seed availability.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Achnatherum occidentale ssp. *californicum*	3	150/3100	Sagebrush shrubland, coniferous forest	Dry	Cool			Unavailable
Achnatherum occidentale ssp. *pubescens*	3	150/3100	Sagebrush shrubland, coniferous forest	Dry	Cool			Unavailable
Achnatherum speciosum	3	0/2200	Rocky slopes, canyons, washes	Dry	Cool	Bunch	10	Unavailable
Bothriochloa barbinodis	3	0/1200	Dry slopes	Dry	Warm		10	Unavailable
Elymus elymoides ssp. *brevifolius*	3	600/3000	Dry open areas	Dry, Moist	Cool			Unavailable

[z] Total number of counties in which species is present out of three counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.10. Potential Great American Desert ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Elymus elymoides ssp. *californicus*	3	800/4200	Dry open areas	Dry, Moist	Cool			Unavailable
Elymus elymoides ssp. *elymoides*	3	800/4000	Dry open areas	Dry, Moist	Cool			Unavailable
Erioneuron pulchellum	3	300/1700	Sandy to rocky slopes, flats, desert shrubland, woodland	Dry	Warm			Unavailable
Melica frutescens	3	300/1500	Dry slopes, chaparral, woodland	Dry	Cool			Unavailable
Sporobolus cryptandrus	3	350/2800	Rocky to sandy washes, slopes, shrubland, woodland	Dry	Warm	Bunch	18	Unavailable
Sporobolus flexuosis	3	0/1200	Rocky to sandy washes, slopes, shrubland	Dry	Warm	Bunch	10	Unavailable

[z] Total number of counties in which species is present out of three counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.10. Potential Great American Desert ecoregion species eliminated due to seed availability.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Trisetum spicatum	3	150/4000	Open, dry to moist sites, meadows, streambanks	Dry, Moist	Cool	Bunch	12	Unavailable
Aristida californica var. *californica*	2	0/150	Dry sandy sites, shrubland	Dry	Warm			Unavailable
Aristida divaricata	2	0/1000	Dry slopes, shrubland, grassland	Dry	Warm	Bunch	12	Unavailable
Aristida purpurea var. *longiseta*	2	300/1600	Dry slopes plains, shrubland	Dry	Warm	Bunch	12	Unavailable
Aristida purpurea var. *nealleyi*	2	200/2000	Dry slopes, plains, shrubland	Dry	Warm			Unavailable
Aristida purpurea var. *parishii*	2	300/1300	Dry slopes, plains, chaparral, shrubland	Dry	Warm			Unavailable

[z] Total number of counties in which species is present out of three counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.10. Potential Great American Desert ecoregion species eliminated due to seed availability.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Aristida purpurea var. *purpurea*	2	250/800	Dry slopes, shrubland	Dry	Warm			Unavailable
Aristida purpurea var. *wrightii*	2	500/1800	Sandy to rocky slopes, plains, shrubland	Dry	Warm	Bunch		Unavailable
Aristida ternipes var. *hamulosa*	2	100/1350	Dry hills and slopes	Dry	Warm			Unavailable
Bouteloua curtipendula	2	0/1900	Dry rocky slopes, crevices, sandy to rocky drainages, scrub,	Dry	Warm	Rhizomatous	12	Unavailable
Bromus orcuttianus	2	900/2900	Dry places, meadows, shrubland, coniferous forest	Dry, Moist	Cool			Unavailable
Elymus stebbinsii	2	0/1600	Dry slopes, chaparral, coniferous forest	Dry	Cool			Unavailable

[z] Total number of counties in which species is present out of three counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.10. Potential Great American Desert ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Festuca kingii	2	0/2000	Dry sandy places, sagebrush plains to subalpine forest	Dry	Cool			Unavailable
Hesperostipa comata	2	200/3500	Well-drained soils	Dry	Cool	Bunch	16	Unavailable
Hesperostipa comata ssp. *comata*	2	200/3500	Grassland, sagebrush shrubland	Dry	Cool	Thicket Forming	16	Unavailable
Muhlenbergia porteri	2	610/1680	Among boulders or shrubs, rocky slopes, cliffs	Dry	Warm	Single Crown	12	Unavailable
Panicum hirticaule	2	0/1400	Sandy soils, open sites, creosote-bush scrub	Dry	Warm			Unavailable
Poa secunda	2	0/3800	Many habitats	Dry, Moist	Cool	Bunch	10	Unavailable

[z] Total number of counties in which species is present out of three counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.10. Great American Desert ecoregion species eliminated due to habitat description, elevational range, or soil moisture requirements. Reasons for elimination are highlighted.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]
Achnatherum coronatum	3	0/1550	Gravelly rocky slopes	Dry
Achnatherum occidentale ssp. *occidentale*	3	3000/3400		Dry
Achnatherum parishii	3	900/2700	Dry rocky slopes, shrubland, pinyon/juniper woodland	Dry
Agrostis idahoensis	3	0/3500	Open , wet meadows, coniferous forest	Moist, Wet
Alopecurus aequalis	3	100/3500	Wet meadows, shores	Saturated, Wet
Distichlis spicata	3	0/1000	Salt marshes, moist, alkaline areas	Wet, Moist, Dry
Elymus trachycaulus	3	0/3400	Dry to moist, open areas, forest, woodland	Dry, Moist
Elymus trachycaulus ssp. *subsecundus*	3	1000/3400	Dry to moist, open areas, forest, woodland	Dry, Moist
Elymus trachycaulus ssp. *trachycaulus*	3	0/3300	Dry to moist, open areas, forest, woodland	Dry, Moist
Hordeum brachyantherum	3	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *brachyantherum*	3	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *californicum*	3	0/500	Meadows, pastures, streambanks	Moist, Dry
Hordeum jubatum	3	0/3400		Moist, Dry
Leymus multiflorus x	3	0/300	Open areas, often saline soils	Dry, Moist
Leymus triticoides	3	0/2300	Moist, often saline meadows	Moist
Muhlenbergia richardsonis	3	1220/3670	Open sites, moist meadows, talus slopes, along streams	Dry, Moist
Panicum acuminatum	3	0/2600	Moist places, marshes, streambanks	Moist, Wet
Phleum alpinum	3	1500/3350	Wet meadows, steambanks, coniferous forest, alpine	Moist, Wet
Poa fendleriana ssp. *fendleriana*	3	2000/3200	Mtn slopes, sagebrush scrub to subalpine	Dry
Puccinellia nuttalliana	3	0/2300	Saline meadows, flats	Moist
Sphenopholis obtusata	3	300/2000	Wet meadows, streambanks, ponds	Moist, Wet

Achnatherum latiglume	2	1200/1800	Dry slopes, coniferous forest	Dry
Agrostis oregonensis	2	0/2100	Moist areas, meadows, streambanks	Wet, Moist
Andropogon glomeratus var. *scabriglumis*	2	0/600	Moist, open disturbed areas, seeps	Moist, wet, seeps, springs
Bouteloua trifida	2	700/2000	Dry rocky, often calcareous slopes, crevices, scrub	Dry
Bromus anomalus	2	3000/3500	Dry, open places, slopes, coniferous forest	Moist, Dry
Bromus carinatus	2	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist
Bromus carinatus var. *carinatus*	2	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist
Bromus ciliatis	2	1100/3200	Meadows, coniferous forest	Moist
Danthonia intermedia	2	1500/3400	Meadows, bogs, damp banks, moist forests	Moist
Deschampsia elongata	2	100/3100	Wet sites, meadows, lakeshores, shaded slopes	Moist, Wet
Elymus glaucus	2	0/2500	Open areas, chaparral, woodland, forest	Dry, Moist
Elymus glaucus ssp. *glaucus*	2	0/2500	Open areas, chaparral, woodland, forest	Dry, Moist
Elymus glaucus ssp. *jepsonii*	2	900/2200	Coniferous forest, woodland	Dry, Moist
Festuca brachyphylla ssp. *breviculmis*	2	2800/4300	Rocky places, subalpine or alpine	Dry, Moist
Festuca minutiflora	2	0/3000	Moist, shady banks	Moist
Festuca rubra	2	0/2500	Sand dues, grassland, subalpine forest	Dry, Moist
Festuca saximontana var. *purpusiana*	2	3000/4500	Alpine, subalpine summits, dry granitic gravel, talus fields, sagebrush, scrub	Dry, Moist
Glyceria elata	2	0/2600	Wet places, coniferous forest	Wet, Moist
Imperata brevifolia	2	0/500	Wet springs, meadows, streamsides, flood plains	Moist
Leersia oryzoides	2	0/700	Marshes, streams, ponds	Moist, Marshes
Leymus cinereus	2	0/3000	Streamsides, canyons, roadsides, sagebrush shrubland, open woodlands	Moist, Dry
Lycurus phleoides	2	400/600	Joshua tree woodland, pinyon/juniper woodland	Dry
Melica aristata	2	1000/3000	Dry open sites, coniferous forest	Dry
Melica stricta	2	1200/3350	Open sites, coniferous forest, rocky areas in alpine	Dry, Moist

Muhlenbergia andina	2	0/3100	Canyons, streambanks, wet meadows	Moist
Muhlenbergia asperifolia	2	120/2150	Moist, often alkaline meadows, seeps, hot springs	Moist
Muhlenbergia californica	2	100/2000	Streambanks, canyons, moist ditches	Moist
Muhlenbergia rigens	2	0/2150	Sandy to gravelly places, canyons, stream bottoms	Dry, Moist
Muhlenbergia utilis	2	250/1000	Wet sites along streams, ponds	Moist
Panicum oligosanthes var. *scribnerianum*	2	0/1400	Meadows, open sites in forest	Dry
Panicum urvilleanum	2	0/900	Sandy soils dunes	Dry
Piptatherum micranthum	2	700/2950	Gravel benches, rocky slopes, creek banks	Dry
Pleuraphis jamesii	2	1000/2500	Dry, sandy to rocky slopes, flats, scrub, woodland	Dry
Poa wheeleri	2	1300/3800	Mtns, open forest in rich soil	Dry, Moist
Sporobolus airoides	2	0/2100	Seasonally moist, alkaline areas	Moist
Trisetum cernuum	2	0/1000	Moist, shaded sites, redwood, coniferous forest	Moist

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *The Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

Intermountain Sagebrush

Only Mono and Inyo Counties were queried for the Intermountain Sagebrush ecoregion. Species occurring in only one of the two counties were eliminated. The most promising species are listed in Table A.11. Other species were eliminated due to the unavailability of seed (Table A.12). Still others were eliminated because of specific elevational ranges, habitat types or soil moisture requirements (Table A.13). Since, seed sources could not be found for some of the selected species from the original list of California-based vendors and species to select from were sparse, Comstock Seed in Gardnerville, Nevada was contacted for an additional source of seed for this habitat-type. *Leymus triticoides* and *Elymus trachycaulus* were selected as rhizomatous species. The habitat description for *Leymus triticoides* indicates that it may prefer moist soils; however, we elected to include it, as rhizomatous species were limited and this species occurred in both counties queried. *Elymus elymoides*, *Koeleria macrantha*, *Leymus cinereus*, *Achnatherum occidentale* and *Elymus multisetus* were selected for the bunch grass species. All species were cool season grasses adapted to dry sites that occurred in both Mono and Inyo counties.

Table A.11. Most promising species for the Intermountain Sagebrush ecoregion.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Achnatherum hymenoides	2	0/3400	Dry, well-drained, often sandy soil	Dry	Cool	Bunch	18	Local Source Unavailable
Achnatherum occidentale	2	150/3400	Open, dry sites, sagebrush shrubland, coniferous forest, alpine	Dry	Cool	Densely Tufted		Comstock Seed
Elymus elymoides	2	600/4200	Dry open areas	Dry, Moist	Cool	Bunch	12	Comstock Seed
Elymus multisetus	2	0/3200	Open sandy to rocky areas	Dry	Cool	Bunch		S&S Seeds
Elymus trachycaulus	2	0/3400	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Bunch	16	S&S Seeds

[z] Total number of counties in which species is present out of two counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.11. (cont'd) Most promising species for the Intermountain Sagebrush ecoregion.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Koeleria macrantha	2	0/3500	Dry, open sites, clay to rocky soils, shrubland, woodland, coniferous forest, alpine	Dry, Moist	Cool	Bunch	20	Hedgerow Farms
Leymus cinereus	2	0/3000	Streamsides, canyons, roadsides, sagebrush shrubland, open woodlands	Moist, Dry	Cool	Bunch	16	Comstock Seed
Leymus triticoides	2	0/2300	Moist, often saline meadows	Moist	Cool	Rhizomatous	10	Comstock Seed

[z] Total number of counties in which species is present out of two counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.12. Table of potential Intermountain Sagebrush ecoregion species eliminated due to seed availability.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Achnatherum nevadense	2	0/3100	Sagebrush shrubland, open woodlands	Dry	Cool			Unavailable
Achnatherum occidentale ssp. *californicum*	2	150/3100	Sagebrush shrubland, coniferous forest	Dry	Cool			Unavailable
Achnatherum occidentale ssp. *pubescens*	2	150/3100	Sagebrush shrubland, coniferous forest	Dry	Cool			Unavailable
Achnatherum speciosum	2	0/2200	Rocky slopes, canyons, washes	Dry	Cool	Bunch	10	Unavailable
Calamagrostis strica ssp. *stricta*	2	1500/3350	Coniferous forest, meadows, slopes	Wet, Moist	Cool	Rhizomatous	7	Unavailable

[z] Total number of counties in which species is present out of two counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.12. (cont'd) Table of potential Intermountain Sagebrush ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Elymus elymoides ssp. *californicus*	2	800/4200	Dry open areas	Dry, Moist	Cool			Unavailable
Elymus elymoides ssp. *elymoides*	2	800/4000	Dry open areas	Dry, Moist	Cool			Unavailable
Elymus trachycaulus ssp. *subsecundus*	2	1000/3400	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool			Unavailable
Elymus trachycaulus ssp. *trachycaulus*	2	0/3300	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Rhizomatous	16	Unavailable
Festuca kingii	2	0/2000	Dry sandy places, sagebrush plains to subalpine forest	Dry	Cool			Unavailable

[z] Total number of counties in which species is present out of two counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.12. (cont'd) Table of potential Intermountain Sagebrush ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Hesperostipa comata ssp. *comata*	2	200/3500	Grassland, sagebrush shrubland	Dry	Cool	Thicket Forming	16	Unavailable
Melica aristata	2	1000/3000	Dry open sites, coniferous forest	Dry	Cool			Unavailable
Melica bulbosa	2	0/3400	Dry rocky slopes, coniferous forest	Moist, Dry	Cool	Bunch	12	Unavailable
Melica frutescens	2	300/1500	Dry slopes, chaparral, woodland	Dry	Cool			Unavailable
Melica stricta	2	1200/3350	Open sites, coniferous forest, rocky areas in alpine	Dry, Moist	Cool			Unavailable
Muhlenbergia richardsonis	2	1220/3670	Open sites, moist meadows, talus slopes, along streams	Dry, Moist	Warm	Rhizomatous	6	Unavailable

[z] Total number of counties in which species is present out of two counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.12. (cont'd) Table of potential Intermountain Sagebrush ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Panicum oligosanthes var. *scribnerianum*	2	0/1400	Meadows, open sites in forest	Dry	Warm			Unavailable
Poa cusickii	2	1500/3600	Moist or dry meadows, sagebrush scrub, montane forest	Moist, Dry	Cool			Unavailable
Poa secunda ssp. *secunda*	2	0/3800	Many habitats	Dry, Moist	Cool	Bunch	10	Unavailable
Sporobolus crytandrus	2	350/2800	Rocky to sandy washes, slopes, shrubland, woodland	Dry	Warm	Bunch	18	Unavailable

[z] Total number of counties in which species is present out of two counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.13. Intermountain Sagebrush ecoregion species eliminated due to habitat description, elevational range, or soil moisture requirements. Reasons for elimination are highlighted.

Species	Score^z	Min/Max Elevation^y (m)	Habitat Description^x	Soil Moisture^y
Achnatherum latiglume	2	1200/1800	Dry slopes, coniferous forest	Dry
Achnatherum nelsonii	2	500/3500	Clearings, sagebrush shrubland steppe, meadows 500-3500m	Dry
Achnatherum occidentale ssp. *occidentale*	2	3000/3400		Dry
Achnatherum pinetorum	2	1900/3810	Rocky soil, pinyon/juniper woodland, coniferous forest	Dry
Achnatherum therberianum	2	1500/2600	Canyons, foothills, sagebrush shtubland, juniper woodland	Dry
Achnatherum webberi	2	1500/3000	Dry, open flats, rocky slopes, gen with sagebrush	Dry
Agrostis variabilis	2	1600/4000	Meadows, subalpine forest, talus, alpine	Moist
Alopecurus aequalis	2	100/3500	Wet meadows, shores	Saturated, Wet
Alopecurus geniculatus	2	0/1550	Open wet meadows, pools, shores, streambanks	Saturated, Wet
Blepharidachne kingii	2	1350/1600	Pinyon/juniper woodland	Dry
Calamagrostis breweri	2	1300/3800	Moist, sub-alpine and alpine meadows, lake margins, streambanks	Moist, Wet
Calamagrostis canadensis	2	1500/3400	Moist meadows, bogs open woodlands	Saturated, Wet
Calamagrostis purpurascens	2	1300/4000	Subalpine, alpine rocky slopes, sandy soils	Dry, Moist
Calamagrostis strica	2	0/3400	Mtn slopes, meadows, coastal marshes	Wet, Moist
Calamagrostis strica ssp. *inexpansa*	2	0/3400	Mtn slopes, meadows, coastal marshes	Wet, Moist
Cinna bolanderi	2	1850/2400	Streambanks, wet meadows, moist sites in coniferous forest	Moist
Cinna latifolia	2	1350/2800	Streambanks, wet meadows, moist sites in coniferous forest	Moist
Deschampsia cespitosa	2	0/3900	Wet sites, meadows, streambanks, coastal marshes, forest, alpine	Wet, Moist, Dry
Deschampsia cespitosa ssp. *cespitosa*	2	0/3820	Meadows, streambanks, coastal marsh, forests, alpine	Dry, Moist
Distichlis spicata	2	0/1000	Salt marshes, moist, alkaline areas	Wet, Moist, Dry

Festuca brachyphylla ssp. *breviculmis*	2	2800/4300	Rocky places, subalpine or alpine	Dry, Moist
Festuca minutiflora	2	0/3000	Moist, shady banks	Moist
Festuca saximontana var. *purpusiana*	2	3000/4500	Alpine, subalpine summits, dry granitic gravel, talus fields, sagebrush, scrub	Dry, Moist
Hesperostipa comata	2	200/3500	Well-drained soils	Dry
Hordeum brachyantherum	2	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *brachyantherum*	2	0/3400	Meadows, pastures, streambanks	Moist
Hordeum brachyantherum ssp. *californicum*	2	0/500	Meadows, pastures, streambanks	Moist, Dry
Hordeum jubatum	2	0/3400		Moist, Dry
Leymus multiflorus x	2	0/300	Open areas, often saline soils	Dry, Moist
Muhlenbergia andina	2	0/3100	Canyons, streambanks, wet meadows	Moist
Muhlenbergia asperifolia	2	120/2150	Moist, often alkaline meadows, seeps, hot springs	Moist
Muhlenbergia montana	2	1640/3420	Open slopes, granitic rock outcrops, dry meadows	Dry
Panicum acuminatum	2	0/2600	Moist places, marshes, streambanks	Moist, Wet
Piptatherum micranthum	2	700/2950	Gravel benches, rocky slopes, creek banks	Dry
Poa fendleriana ssp. *fendleriana*	2	2000/3200	Mtn slopes, sagebrush scrub to subalpine	Dry
Poa glauca ssp. *rupicola*	2	3300/4000	Dry alpine slopes, ridges	Dry
Poa keckii	2	3000/4500	High alpine, often in open ground	Dry
Poa leptocoma ssp. *leptocoma*	2	1800/3200	Moist subalpine, lower alpine meadows	Moist, Wet
Poa stebbinsii	2	2700/3700	Subalpine to lower alpine meadows	Moist
Poa wheeleri	2	1300/3800	Mtns, open forest in rich soil	Dry, Moist
Puccinellia nuttalliana	2	0/2300	Saline meadows, flats	Moist
Spartina gracilis	2	1000/2100	Alkaline lake shores, stream banks, meadows, marshes	Wet
Sphenopholis obtusata	2	300/2000	Wet meadows, streambanks, ponds	Moist, Wet

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *The Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

Pacific Forest

The Pacific Forest ecoregion covers the western parts of Del Norte, Humboldt, Marin, Mendocino, and Sonoma Counties along the northern California coast. These five counties were queried to determine the species most likely to be successfully utilized for this ecoregion (Table A.14). Any species occurring in three or fewer of these five counties was eliminated. Other species were eliminated because the habitat description, soil moisture requirements or elevational range of the species deemed them inappropriate for this project (Table A.15). Some species, although suitable for use in all other ways, were eliminated because a seed source was not available for that particular species or subspecies (Table A.16). The rhizomatous species selected for the Pacific Forest ecoregion were *Festuca rubra* and *Elymus trachycaulus*. Both occurred in all five counties queried and had sufficient elevational range and habitat characteristics to be considered. The bunch grasses selected were *Festuca idahoensis*, *Bromus carinatus*, *Elymus glaucus*, *Koeleria macrantha* and *Melica californica*. The first four species occurred in every county while *M. californica* occurred in four of five counties queried. All species were cool season grasses and showed sufficient adaptability.

Table A.14. Most promising species for the Pacific Forest ecoregion.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Agrostis pallens	5	200/3500	Open meadows, woodland, forest, subalpine	Dry, Moist	Cool	Rhizomatous	8	Local Source Unavailable
Bromus carinatus	5	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool	Bunch	8	Hedgerow Farms
Danthonia californica	5	0/2200	Gen moist, open sites, meadows, forests	Moist, Dry	Cool	Bunch	16	S&S Seeds
Elymus elymoides	5	600/4200	Dry open areas	Dry, Moist	Cool	Bunch	12	S&S Seeds
Elymus glaucus	5	0/2500	Open areas, chaparral, woodland, forest	Dry, Moist	Cool	Bunch	12	Hedgerow Farms
Elymus multisetus	5	0/3200	Open sandy to rocky areas	Dry	Cool	Bunch		Local Source Unavailable

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.14. (cont'd) Most promising species for the Pacific Forest ecoregion.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Elymus trachycaulus	5	0/3400	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Bunch	16	S&S Seeds
Festuca idahoensis	5	0/1800	Dry, open, shady places	Dry, Moist	Cool	Bunch	14	S&S Seeds
Festuca rubra	5	0/2500	Sand dunes, grassland, subalpine forest	Dry, Moist	Cool	Rhizomatous	12	S&S Seeds
Hordeum brachyantherum	5	0/3400	Meadows, pastures, stream banks	Moist	Cool	Bunch	6	Local Source Unavailable
Koeleria macrantha	5	0/3500	Dry, open sites, clay to rocky soils, shrubland, woodland, coniferous forest, alpine	Dry, Moist	Cool	Bunch	20	Hedgerow Farms

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.14. (cont'd) Most promising species for the Pacific Forest ecoregion.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Melica californica	4	0/2100	Open hillsides, oak woodland, coniferous forest	Dry	Cool	Bunch	10	Hedgerow Farms
Nassella lepida	4	0/1700	Dry slopes, chaparral, oak grassland	Dry	Cool	Bunch	12	Local Source Unavailable
Nassella pulchra	4	0/1300	Oak woodland, chaparral, grassland	Dry	Cool	Bunch	10	Local Source Unavailable

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.15. Table of potential Pacific Forest ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Agrostis hallii	5	0/1500	Open oak woodland, coniferous forest	Dry	Cool			Unavailable
Bromus carinatus var. *carinatus*	5	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool			Unavailable
Danthonia californica var. *americana*	5	150/2200	Gen moist, open sites, meadows, forests	Moist, Dry	Cool			Unavailable
Danthonia californica var. *californica*	5	100/1900	Gen moist, open sites, meadows, forests	Moist, Dry	Cool			Unavailable
Elymus elymoides ssp. *californicus*	5	800/4200	Dry open areas	Dry, Moist	Cool			Unavailable
Elymus glaucus ssp. *glaucus*	5	0/2500	Open areas, chaparral, woodland, forest	Dry, Moist	Cool			Unavailable

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.15. (cont'd) Table of potential Pacific Forest ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Elymus trachycaulus ssp. *trachycaulus*	5	0/3300	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Rhizomatous	16	Unavailable
Festuca californica	5	0/1800	Open forest, chaparral	Dry	Cool	Bunch	8	Unavailable
Festuca occidentalis	5	0/1900	Open pine/oak woodland, redwood forest	Dry	Cool	Bunch	10	Unavailable
Hordeum brachyantherum ssp. *brachyantherum*	5	0/3400	Meadows, pastures, stream banks	Moist	Cool			Unavailable
Melica geyeri	5	0/2000	Dry open sites, oak woodland, coniferous forest	Dry	Cool			Unavailable
Melica harfordii	5	0/2150	Dry slopes, coniferous forest	Dry	Cool			Unavailable

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.15. (cont'd) Table of potential Pacific Forest ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Poa secunda	5	0/3800	Many habitats	Dry, Moist	Cool	Bunch	10	Unavailable
Trisetum canescens	5	0/2700	Open to shaded sites, meadows, coniferous forest	Moist	Cool	Stoloniferous	10	Unavailable
Bromus laevipes	4	100/2500	Shrubland, coniferous forest	Moist	Cool			Unavailable
Calamagrostis koelerioides	4	0/2300	Meadows, slopes, dry hills, ridges	Dry, Moist	Cool			Unavailable
Melica torreyana	4	0/1200	Chaparral, coniferous forest	Dry	Cool			Unavailable
Trisetum spicatum	4	150/4000	Open, dry to moist sites, meadows, stream banks	Dry, Moist	Cool	Bunch	12	Unavailable

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.16. Pacific Forest ecoregion species eliminated due to habitat description, elevational range, or soil moisture requirements. Reasons for elimination are highlighted.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]
Agrostis densiflora	5	0/200	Coastal bluffs, sandy soil	Dry
Agrostis oregonensis	5	0/2100	Moist areas, meadows, streambanks	Wet, Moist
Bromus carinatus var. *maritimus*	5	0/100	Dunes, meadows	Moist
Bromus vulgaris	5	50/1900	Shaded streambanks, coniferous forest	Moist
Calamagrostis nutkaensis	5	0/1000	Wet areas, beaches, dunes, coastal woodland	Wet, Moist
Danthonia unispicata	5	900/3200	Dry meadows, rocky slopes, open sites in coniferous forest	Dry, Moist
Deschampsia cespitosa	5	0/3900	Wet sites, meadows, streambanks, coastal marshes, forest, alpine	Wet, Moist, Dry
Deschampsia cespitosa ssp. *cespitosa*	5	0/3820	Meadows, streambanks, coastal marsh, forests, alpine	Dry, Moist
Deschampsia cespitosa ssp. *holciformis*	5	0/850	Coastal marshes and meadows	Dry, Moist
Elymus glaucus ssp. *jepsonii*	5	900/2200	Coniferous forest, woodland	Dry, Moist
Elymus glaucus ssp. *virescens*	5	0/300	Coniferous forest, chaparral	Dry, Moist
Elymus trachycaulus ssp. *subsecundus*	5	1000/3400	Dry to moist, open areas, forest, woodland	Dry, Moist
Glyceria elata	5	0/2600	Wet places, coniferous forest	Wet, Moist
Hierochloe occidentalis	5	0/750	Moist to dry, coniferous forest	Moist, Dry
Hordeum brachyantherum ssp. *californicum*	5	0/500	Meadows, pastures, streambanks	Moist, Dry
Hordeum jubatum	5	0/3400		Moist, Dry
Leymus mollis	5	0/10	Sandy beaches	Dry
Leymus multiflorus x	5	0/300	Open areas, often saline soils	Dry, Moist
Leymus triticoides	5	0/2300	Moist, often saline meadows	Moist
Leymus vancouverensis x	5	0/100	Sandy beaches	Moist
Melica subulata	5	0/2300	Moist sites, streambanks, coniferous forest	Moist
Paspalum distichum	5	0/1650	Moist places, marshes	Moist
Phalaris californica	5	0/700	Moist areas, meadows, woodlands	Moist
Phleum alpinum	5	1500/3350	Wet meadows, streambanks, coniferous forest, alpine	Moist, Wet

Phragmites australis	5	0/1600	Pond and lake margins, sloughs, marshes	Wet
Poa confinis	5	0/100	Ocean beaches, stabilized dunes	Dry
Poa tenerrima	5	0/700	Thin, drying soils, often on serpentine	Dry
Puccinellia nuttalliana	5	0/2300	Saline meadows, flats	Moist
Torreyochloa pallida var. *pauciflora*	5	0/3500	Wet areas in forests, stream or lake margins	Wet, Moist
Trisetum cernuum	5	0/1000	Moist, shaded sites, redwood, coniferous forest	Moist
Deschampsia elongata	4	100/3100	Wet sites, meadows, lakeshores, shaded slopes	Moist, Wet
Distichlis spicata	4	0/1000	Salt marshes, moist, alkaline areas	Wet, Moist, Dry
Elymus californicus	4	0/300	Coniferous forest	Moist
Festuca elmeri	4	0/300	Moist, wooded slopes, under trees in rich soil	Moist
Festuca subuliflora	4	0/700	Near streams, redwood, oak/pine forest	Moist
Festuca viridula	4	2000/4500	Subalpine meadows, open forests, rocky slopes	Moist
Panicum acuminatum	4	0/2600	Moist places, marshes, streambanks	Moist, Wet
Pleuropogon refractus	4	0/1600	Wet meadows, shady banks	Moist
Poa douglasii	4	0/100	Shifting coastal dunes	Dry
Poa kelloggii	4	0/500	Shady openings or in mixed-conifer and redwood forests	Moist
Poa macrantha	4	0/100	Shifting coastal dunes	Dry
Poa unilateralis	4	0/200	Coastal bluffs in saline soils	Dry

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *The Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

Sierran Forest

Alpine, Amador, Calaveras, El Dorado, Fresno, Kern, Madera, Mariposa, Nevada, Placer, Plumas, Sierra, Tulare, and Tuolumne County were the counties included in the query for species in the Sierran Forest ecoregion. Any species occurring in fewer than ten of the fourteen counties queried was eliminated. Species with characteristics indicating their likely success in this project are listed in Table A.17. Other species with suitable characteristics were eliminated because seed was not available for that particular species or subspecies (Table A.18). Some species were eliminated due to narrow habitat descriptions, elevational ranges or soil moisture requirements (Table A.19). *Festuca rubra* and *Elymus trachycaulus* occurred in all fourteen counties queried for this ecoregion and were, thus, selected as the rhizomatous species. *Muhlenbergia rigens* was included as a warm season bunchgrass species in this ecoregion and occurred in ten counties. *Elymus elymoides*, *Hordeum brachyantherum*, *Bromus carinatus* and *Elymus glaucus* were the four cool season bunchgrass species selected. *Elymus elymoides* and *H. brachyantherum* occurred in all fourteen counties; *B. carinatus* and *E. glaucus* occurred in thirteen.

Table A.17. Most promising species for the Sierran Forest ecoregion.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Achnatherum occidentale	14	150/3400	Open, dry sites, sagebrush shrubland, coniferous forest, alpine	Dry	Cool	Densely Tufted		Local Source Unavailable
Elymus elymoides	14	600/4200	Dry open areas	Dry, Moist	Cool	Bunch	12	Comstock
Elymus trachycaulus	14	0/3400	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Bunch	16	Comstock
Festuca rubra	14	0/2500	Sand dues, grassland, subalpine forest	Dry, Moist	Cool	Rhizomatous	12	S&S Seeds
Hordeum brachyantherum	14	0/3400	Meadows, pastures, streambanks	Moist	Cool	Bunch	6	Comstock
Bromus carinatus	13	0/3500	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool	Bunch	8	Conserva

[z] Total number of counties in which species is present out of fourteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.17. (cont'd) Most promising species for the Sierran Forest ecoregion.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Elymus glaucus	13	0/2500	Open areas, chaparrel, woodland, forest	Dry, Moist	Cool	Bunch	12	Hedgerow
Elymus multisetus	13	0/3200	Open sandy to rocky areas	Dry	Cool	Bunch		Local Source Unavailable
Danthonia californica	12	0/2200	Gen moist, open sites, meadows, forests	Moist, Dry	Cool	Multiple Stem	16	Local Source Unavailable
Melica californica	11	0/2100	Open hillsides, oak woodland, coniferous forest	Dry	Cool	Bunch	10	Local Source Unavailable
Nassella cernua	11	0/1400	Grassland, chaparral, juniper woodland	Dry	Cool	Bunch	12	Local Source Unavailable
Muhlenbergia rigens	10	0/2150	Sandy to gravelly places, canyons, stream bottoms	Dry, Moist	Warm	Bunch	14	Hedgerow

[z] Total number of counties in which species is present out of fourteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.18. Potential Sierran Forest ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Achnatherum nelsonii	14	500/3500	Clearings, sagebrush shrubland steppe, meadows 500-3500m	Dry	Cool			Unavailable
Achnatherum occidentale ssp. *californicum*	14	150/3100	Open sites, moist meadows, talus slopes, along streams	Dry, Moist	Cool			Unavailable
Achnatherum occidentale ssp. *pubescens*	14	150/3100	Sagebrush shrubland, coniferous forest	Dry	Cool			Unavailable
Elymus elymoides ssp. *californicus*	14	800/4200	Sagebrush shrubland, coniferous forest	Dry	Cool			Unavailable
Elymus trachycaulus ssp. *subsecundus*	14	1000/3400	Dry open areas	Dry, Moist	Cool			Unavailable

[z] Total number of counties in which species is present out of fourteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.18. (cont'd) Potential Sierran Forest ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Elymus trachycaulus ssp. *trachycaulus*	14	0/3300	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool	Rhizomatous	16	Unavailable
Hordeum brachyantherum ssp. *brachyantherum*	14	0/3400	Dry to moist, open areas, forest, woodland	Dry, Moist	Cool			Unavailable
Muhlenbergia richardsonis	14	1220/3670	Meadows, pastures, streambanks	Moist	Warm	Rhizomatous	6	Unavailable
Agrostis scabra	14	1000/3100	Moist or dry meadows, sagebrush scrub, montane forest	Moist, Dry	Cool	Bunch	12	Unavailable
Bromus carinatus var. *carinatus*	13	0/3500	Mtn slopes, meadows, coastal marshes	Wet, Moist	Cool			Unavailable

[z] Total number of counties in which species is present out of fourteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.18. (cont'd) Potential Sierran Forest ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Calamagrostis strica	13	0/3400	Open shrubland, woodland, coniferous forest	Dry, Moist	Cool			Unavailable
Calamagrostis strica ssp. *inexpansa*	13	0/3400	Mtn slopes, meadows, coastal marshes	Wet, Moist	Cool	Rhizomatous	7	Unavailable
Danthonia unispicata	13	900/3200	Dry meadows, rocky flopes, open sites in coniferous forest	Dry, Moist	Cool	Single Crown	6	Unavailable
Elymus glaucus ssp. *glaucus*	13	0/2500	Dry open sites, coniferous forest	Dry	Cool			Unavailable
Melica aristata	13	1000/3000	Open areas, chaparrel, woodland, forest	Dry, Moist	Cool			Unavailable
Melica bulbosa	13	0/3400	Dry rocky slopes, coniferous forest	Moist, Dry	Cool	Bunch	12	Unavailable

[z] Total number of counties in which species is present out of fourteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.18. (cont'd) Potential Sierran Forest ecoregion species eliminated due to seed availability.

Species	Score[z]	Min/Max Elevation[y] (m)	Habitat Description[x]	Soil Moisture[y]	Season[w]	Rooting Habit[v] and Depth[v] (in.)		Seed Source[u]
Melica stricta	13	1200/3350	Open sites, coniferous forest, rocky areas in alpine	Dry, Moist	Cool			Unavailable
Poa cusickii	13	1500/3600	Open, dry to moist sites, meadows, streambanks	Dry, Moist	Cool			Unavailable
Poa secunda	13	0/3800	Many habitats	Dry, Moist	Cool	Bunch	10	Unavailable
Trisetum spicatum	13	150/4000	Open roadsides, meadows, confierous forest	Moist, Dry	Cool	Bunch	12	Unavailable
Bromus laevipes	12	100/2500	Srubland, coniferous forest	Moist	Cool			Unavailable

[z] Total number of counties in which species is present out of fourteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.18. (cont'd) Potential Sierran Forest ecoregion species eliminated due to seed availability.

Species	**Score**[z]	**Min/Max Elevation**[y] **(m)**	**Habitat Description**[x]	**Soil Moisture**[y]	**Season**[w]	**Rooting Habit**[v] **and Depth**[v] **(in.)**		**Seed Source**[u]
Bromus orcuttianus	12	900/2900	Dry places, meadows, shrubland, coniferous forest	Dry, Moist	Cool			Unavailable
Bromus suksdorfii	12	1200/3200	Slopes, meadows, coniferous forest	Dry, Moist	Cool			Unavailable
Trisetum canescens	12	0/2700	Open to shaded sites, meadows, coniferous forest	Moist	Cool	Stoloniferous	16	Unavailable

[z] Total number of counties in which species is present out of fourteen counties queried for this ecoregion.

[y] *Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

[w] As classified by Lavin and Seibert (2003).

[v] *PLANTS Database* (USDA, NRCS 2007).

[u] S&S Seeds, Carpenteria California; Hedgerow Farms, Winters, California; ConservaSeed, Rio Vista, California; Comstock Seed, Gardnerville, NV; Larner Seeds, Bolinas, California.

Table A.19. Sierran Forest ecoregion species eliminated due to habitat description, elevational range, or soil moisture requirements. Reasons for elimination are highlighted.

Species	**Score^z**	**Min/Max Elevation^y (m)**	**Habitat Description^x**	**Soil Moisture^y**
Achnatherum occidentale ssp. *occidentale*	14	3000/3400		Dry
Deschampsia cespitosa	14	0/3900	Wet sites, meadows, streambanks, coastal marshes, forest, alpine	Wet, Moist, Dry
Deschampsia cespitosa ssp. *cespitosa*	14	0/3820	Meadows, streambanks, coastal marsh, forests, alpine	Dry, Moist
Distichlis spicata	14	0/1000	Salt marshes, moist, alkaline areas	Wet, Moist, Dry
Glyceria striata	14	1500/2500	Wet meadows, stream margins, coniferous forest	Wet, Moist
Hesperostipa comata	14	200/3500	Well-drained soils	Dry
Hesperostipa comata ssp. *comata*	14	200/3500	Grasssland, sagebrush shrubland	Dry
Hordeum brachyantherum ssp. *californicum*	14	0/500	Meadows, pastures, streambanks	Moist, Dry
Hordeum jubatum	14	0/3400		Moist, Dry
Leymus multiflorus x	14	0/300	Open areas, often saline soils	Dry, Moist
Leymus triticoides	14	0/2300	Moist, often saline meadows	Moist
Torreyochloa pallida var. *pauciflora*	14	0/3500	Wet areas in forests, stream or lake margins	Wet, Moist
Agrostis idahoensis	13	0/3500	Open , wet meadows, coniferous forest	Moist, Wet
Agrostis oregonensis	13	0/2100	Moist areas, meadows, streambanks	Wet, Moist
Agrostis thurberiana	13	1300/3500	Moist, often heavy soils, coniferous forest	Moist
Agrostis variabilis	13	1600/4000	Meadows, subalpine forest, talus, alpine	Moist
Calamagrostis strica ssp. *stricta*	13	1500/3350	Coniferous forest, meadows, slopes	Wet, Moist
Cinna bolanderi	13	1850/2400	Streambanks, wet meadows, moist sites in coniferous forest	Moist
Cinna latifolia	13	1350/2800	Streambanks, wet meadows, moist sites in coniferous forest	Moist
Deschampsia elongata	13	100/3100	Wet sites, meadows, lakeshores, shaded slopes	Moist, Wet
Elymus glaucus ssp. *jepsonii*	13	900/2200	Coniferous forest, woodland	Dry, Moist

Elymus stebbinsii	13	0/1600	Dry slopes, chaparrel, coniferous forest	Dry
Glyceria elata	13	0/2600	Wet places, coniferous forest	Wet, Moist
Poa fendleriana ssp. *fendleriana*	13	2000/3200	Mtn slopes, sagebrush scrub to subalpine	Dry
Poa wheeleri	13	1300/3800	Mtns, open forest in rich soil	Dry, Moist
Puccinellia nuttalliana	13	0/2300	Saline meadows, flats	Moist
Torreyochloa erecta	13	2000/3500	Stream, lake margins, coniferous forest	Moist, Wet
Achnatherum pinetorum	12	1900/3810	Rocky soil, pinyon/juniper woodland, coniferous forest	Dry
Calamagrostis canadensis	12	1500/3400	Moist meadows, bogs open woodlands	Saturated, Wet
Danthonia californica var. *americana*	12	150/2200	Gen moist, open sites, meadows, forests	Moist, Dry
Danthonia californica var. *californica*	12	100/1900	Gen moist, open sites, meadows, forests	Moist, Dry
Festuca occidentalis	12	0/1900	Open pine/oak woodland, redwood forest	Dry
Muhlenbergia montana	12	1640/3420	Open slopes, granitic rock outcrops, dry meadows	Dry
Poa stebbinsii	12	2700/3700	Subalpine to lower alpine meadows	Moist
Poa tenerrima	12	0/700	Thin, drying woils, often on serpentine	Dry
Trisetum cernuum	12	0/1000	Moist, shaded sites, redwood, coniferous forest	Moist
Calamagrostis breweri	11	1300/3800	Moist, sub-alpine and alpine meadows, lake margins, streambanks	Moist, Wet
Elymus sierrus	11	2200/3400	Rocky slopes, coniferous forest	Dry
Glyceria striata	11	1500/2500	Wet meadows, stream margins, coniferous forest	Wet, Moist
Panicum acuminatum	11	0/2600	Moist places, marshes, streambanks	Moist, Wet
Phalaris arundinacea	11	0/1600	Wet streambanks, moist areas, grassland, woodland	Moist
Nassella pulchra	10	0/1300	Oak woodland, chaparral, grassland	Dry
Phleum alpinum	10	1500/3350	Wet meadows, steambanks, coniferous forest, alpine	Moist, Wet
Phragmites australis	10	0/1600	Pond and lake margins, sloughs, marshes	Wet
Poa leptocoma ssp. *leptocoma*	10	1800/3200	Moist subalpine, lower alpine meadows	Moist, Wet

[z] Total number of counties in which species is present out of five counties queried for this ecoregion.

[y] *The Native Grass Database* (2001).

[x] Habitat description from *The Jepson Manual: Higher Plants of California* (Hickman 2003).

APPENDIX B

SEED GERMINATION

Introduction

Despite the fact that the use of native species is on the rise, information about how to germinate and establish these species is limited. A few companies provide native seed either by collecting and selling it or by collecting and then producing seed commercially from the native seed source (Lippitt et al. 1994). Some species are quiescent and germinate readily as soon as the proper environment is provided. Others have either physiological or chemical dormancy and, thus, require a scarification and/or stratification treatment in order to germinate (Hartmann et al. 2002). Lastly, other species may have some type of chemical dormancy and may not germinate well on blotter paper (Hartmann et al. 2002). These species may need to be germinated in soil rather than in germination boxes. The literature regarding the selected species indicates that seed germination protocols are potentially as varied as are the selected species (Table B.1).

Table B.1. Specific germination requirements for the selected species for all ecoregions.

Species	**Pre-Treatment**	**Reference**
Achnatherum hymenoides	light may be required 60-day cold, moist stratification	Baskin and Baskin (2002b) Majerus (2005)
Achnatherum occidentale	20-week cold, moist stratification; 2-day pre-chill is beneficial	Trindle and Flessner (2003a)
Aristida purpurea	none necessary	Decker (2003)
Bromus carinatus	7-day pre-chill sometimes used 10-day pre-chill	Trindle and Flessner (2003b) Winslow (2002a)
Elymus elymoides	10-day pre-chill none necessary	Winslow (2002b) Baskin and Baskin (2002a)
Elymus glaucus	none necessary	Dyer (2001)
Elymus multisetus	NA[z]	
Elymus trachycaulus	10-day pre-chill germinates well without pre-treatment may or may not need a pre-chill depending on elevation of collection	Winslow (2002c) Skinner (2002) Evans et al. (2001)
Festuca rubra	none necessary	Baskin and Baskin (2002d)
Festuca idahoensis	none necessary	Skinner (2002a)

Species	**Pre-Treatment**	**Reference**
Hordeum brachyantherum	may take 21 days to germinate	Young (2001a)
Koeleria macrantha	none necessary 10-day pre-chill may take 21 days to germinate	Skinner (2002b) Winslow (2002d) Young (2001b)
Leymus cinereus	none necessary none necessary cold pre-chill may reduce time and increase percentage	Winslow (2002e) Skinner (2005)
Leymus condensatus	NA[z]	
Leymus triticoides	none required	Baskin and Baskin (2002c)
Melica californica	NA[z]	
Muhlenbergia rigens	NA[z]	
Nassella cernua	NA[z]	
Nassella lepida	NA[z]	
Nassella pulchra	3-week pre-chill for optimum germination	Young (2001c)
Pleuraphis rigida	soak to remove inhibitors and imbibe seeds	Graham (2003)

[z] Specific germination information was not available.

Even though a commercial seed test had been performed on all seed lots prior to shipping, some of the results were nearly 12 months old, therefore, germination tests were conducted on each seed lot to determine its germination rate. Four methods were employed. Every seed lot was tested first using blotter paper moistened with potassium nitrate (2 g/L) as specified in the *Rules for Seed Testing* (Association of Official Seed Analysts 1988, rev. 1990). More specific research was conducted as to the germination requirements of the species that did not germinate well on blotter paper. In doing so, we discovered three other likely methods of germination. The first method was a 10-day pre-chill, followed by incubation. Another method required a 60-day cold moist stratification of the seeds prior to germination. Lastly, seeds were germinated in the soil to be used for the experiment rather than on blotter paper.

Blotter Paper Test

After the seed lots arrived, a germination test was conducted for all seed lots on blotter paper with a solution of potassium nitrate (2 g/L) to determine the germination rate of each seed lot. One hundred seeds of each lot were counted and placed onto the moistened blotter paper and then placed in individual plastic germination boxes. These samples were incubated in darkness at 25 °C and germinated seeds were counted and removed daily. Additional potassium nitrate solution was added as necessary to prevent drying of the blotter paper and seeds.

10-Day Pre-Chill Test

For seed lots that did not germinate well with the above protocol, we attempted other methods to improve seed germination. This time, one hundred seeds were counted and placed on blotter paper moistened with potassium nitrate (2 g/L) in germination boxes. However, instead of placing the seeds in an incubator, they were stratified at 4 °C in darkness for ten days. At the end of this ten-day cold wet stratification treatment the seed lots were transferred to a dark incubator at 25 °C and germinated seeds were counted and removed daily.

60-Day Stratification Test

For those that still had little or no germination more species-specific protocols were performed. *Achnatherum hymenoides*, for example, had no germination after a 10-

day pre-chill, but requires a cold moist stratification for 60 days prior to germination (Majerus 2005). In order to stratify sufficient amounts of seeds to plant upon completion of the stratification period, rag dolls (Hartmann and Kester 2002) were assembled from rolled paper towels moistened with potassium nitrate solution (2 g/L) and placed in sealed plastic bags and stratified at 4 °C for 60 days. A separate sample of 100 seeds was also placed in a germination box on moistened blotter paper and stratified for 60 days. This sample was placed in the incubator at 25 °C at the end of the cold treatment to determine germination rates.

Direct Seeding Test

For other seed lots with little or no germination, we placed 100 seeds of each species on the soil to be used for the experiment (1:1:1 ratio by volume of loam soil, washed concrete sand and Canadian sphagnum peat moss) in 4-inch square containers in the greenhouse. Germination levels were observed by emergence of the coleoptiles, but germinated seedlings were not removed in this test.

Germination Rates

Using one of these methods, all seed lots achieved an acceptable level of germination except for *Pleuraphis rigida* which was very difficult to germinate and was therefore eliminated from the study altogether. Acceptable levels of germination varied by species and were based on seed size and seed availability.

California Grasslands

Excepting *Leymus triticoides*, all species in the California Grasslands ecoregion also germinated well on blotter paper moistened with potassium nitrate (Figure B.1). A ten-day pre-chill of *Leymus triticoides* improved germination from 1.0% to 5.0%, but this was still a very low percentage. Seeds of this species sown in the soil to be used for the experiment germinated at 59.0%.

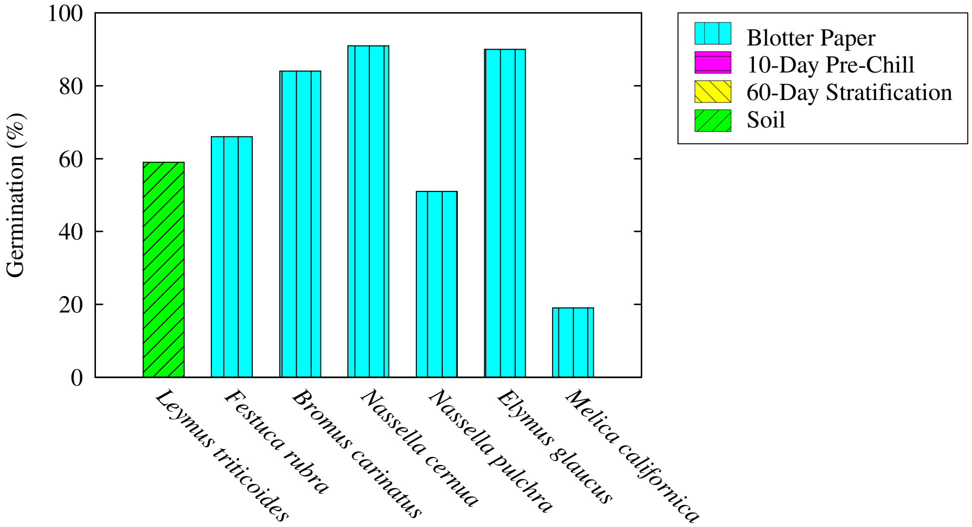

Figure B.1. Final germination percentages for the California Grasslands ecoregion selected species.

Chaparral

The species selected for the Chaparral also germinated well with the blotter paper protocol (Figure B.2). The same accession of *Elymus trachycaulus* was used for this ecoregion as was for the Pacific Forest. Again, there was not a great difference in germination percentages between the blotter paper and the 10-day pre-chill protocols.

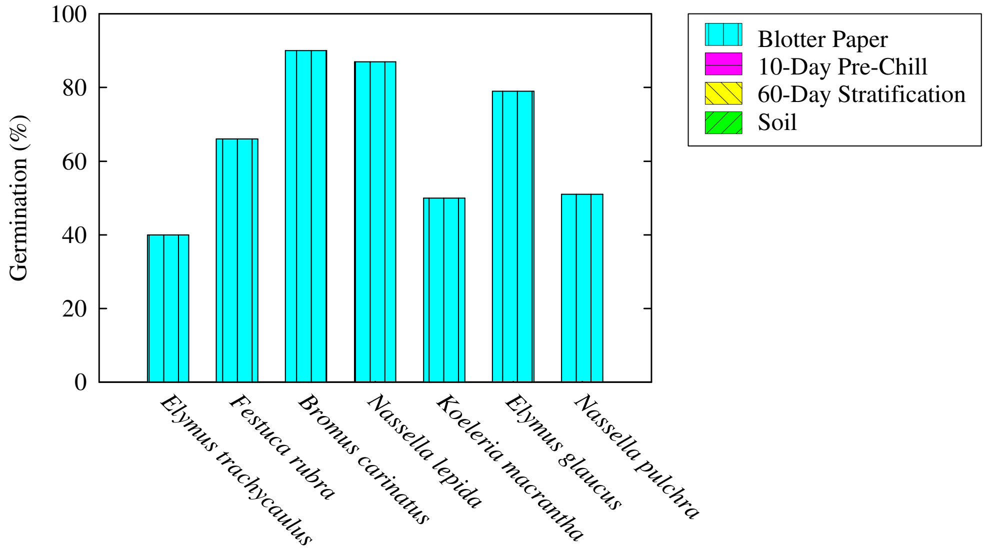

Figure B.2. Final germination percentages for the Chaparral ecoregion selected species.

Great American Desert

Seeds of *Achnatherum hymenoides* germinated at 51.0% using the 60-day stratification test. *Pleuraphis rigida* was extremely difficult to germinate. The seed vendor acknowledged that the seed lot had only 20.0% germination in commercial tests (Miller 2005). Graham (2003) suggested soaking *Pleuraphis* seeds in water to remove inhibitors and allow for complete imbibition before sowing. This method resulted in a 1.0% germination rate. The seeds of this species are small and are surrounded by a lot of chaff. Hypothesizing that this chaff might interfere with germination, the chaff was removed with a rub board. The naked seeds did not germinate with this method, whether planted in soil or germinated on blotter paper. No matter the method, the maximum germination for *Pleuraphis* was 1.0%. Because the seeds were so difficult to germinate and over-seeding was not feasible in this case, the species was removed from the experiment. The remaining species selected for this ecoregion germinated well under the blotter paper protocol (Figure B.3).

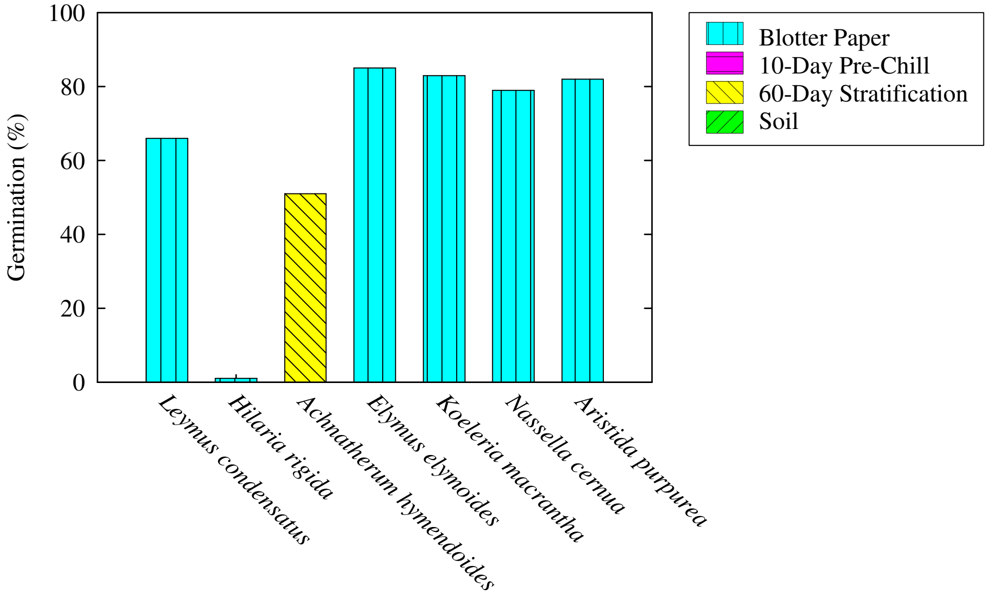

Figure B.3. Final germination percentages for the Great American Desert ecoregion selected species.

Intermountain Sagebrush

In the Intermountain Sagebrush ecoregion, *Elymus trachycaulus*, *Elymus elymoides*, *Koeleria macrantha*, *Leymus cinereus* and *Elymus multisetus* germination was sufficient to preclude the testing of other protocols (Figure B.4). *Achnatherum occidentale* had 8.0% germination with the standard protocol, but increased to 15.0% with a 10-day pre-chill. The collection of *Leymus triticoides* selected for this ecoregion had poor germination no matter the protocol used. The 60-day cold wet stratification was not conducted as seed size was such that over-seeding did not pose a physical barrier to germination of the other species in the mixture. Germination was 1.0% for both the blotter paper protocol and the 10-day pre-chill, while planting the seeds on the soil to be used for the experiment increased germination to 4.0%.

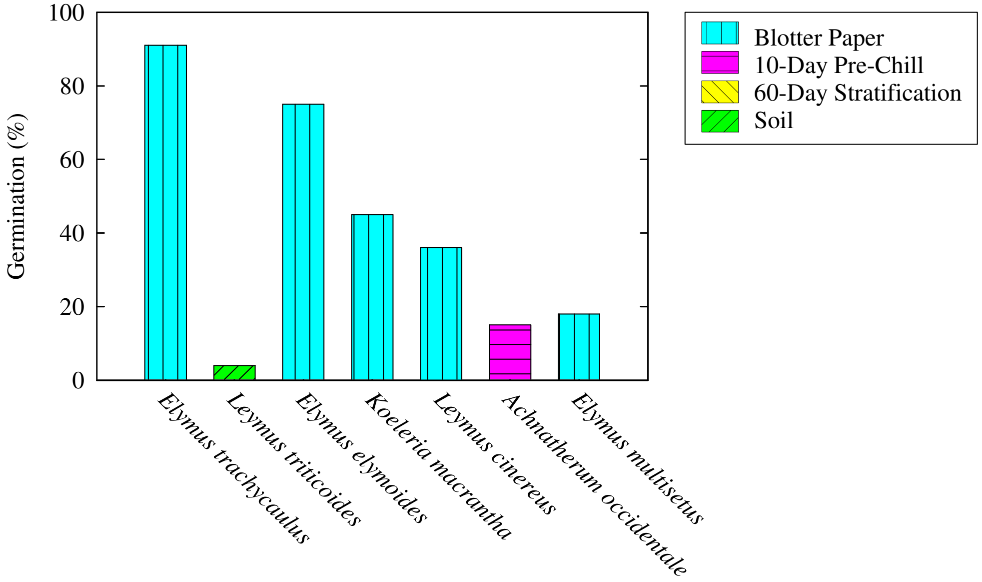

Figure B.4. Final germination percentages for the Intermountain Sagebrush ecoregion selected species.

Pacific Forest

In the Pacific Forest ecoregion, all species germinated sufficiently using the blotter paper protocol (Figure B.5). No other germination procedures were tested on these species, except for *Elymus trachycaulus*. Since the literature suggested a 10-day cold treatment could increase germination, this test was conducted, but showed little increase in germination (43% with and 40% without).

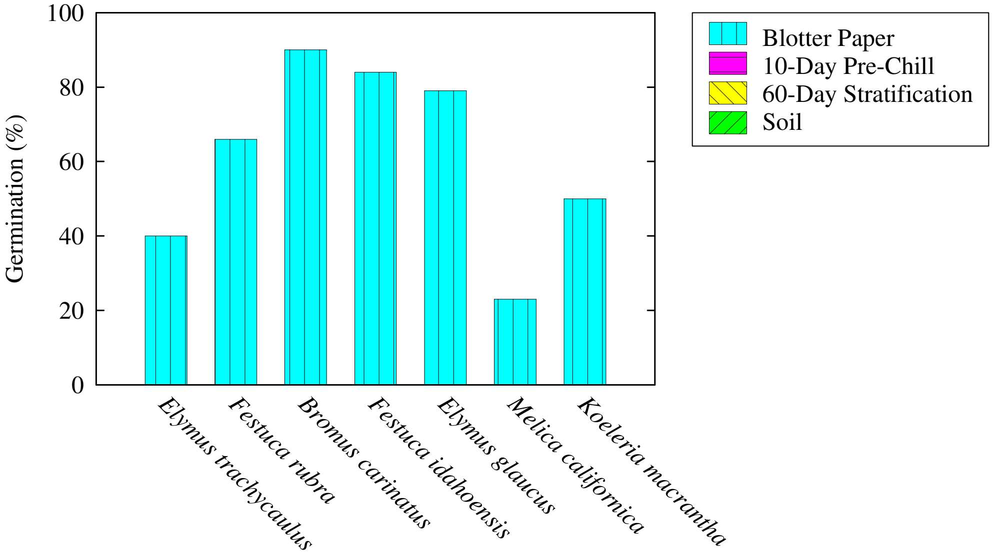

Figure B.5. Final germination percentages for the Pacific Forest ecoregion selected species.

Sierran Forest

The collection of *Elymus trachycaulus* selected for this ecoregion germinated at 9.0% on blotter paper, while a 10-day pre-chill increased germination to 38.0% (Figure B.6). *Hordeum brachyantherum* had 3.0% germination, which did not improve with a 10-day pre-chill. When placed on soil, 8.0% germination was achieved. *Muhlenbergia rigens* was another species with poor germination. Germination percentages for blotter paper, 10-day pre-chill and soil were 4.0%, 4.0%, and 3.0%, respectively. Seeds of this species are tiny and readily available so that this percentage was acceptable. The remaining species germinated sufficiently in the blotter paper test.

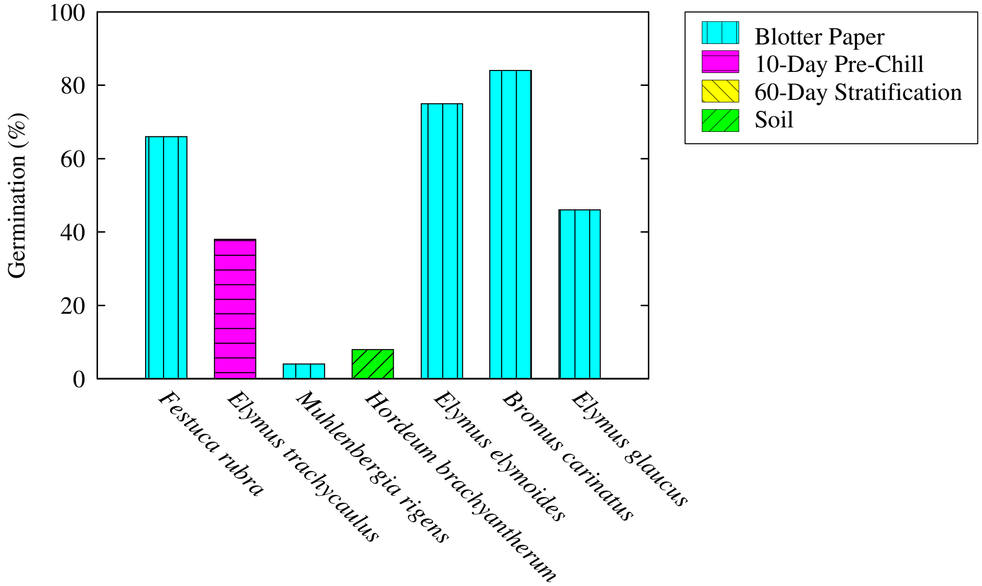

Figure B.6. Final germination percentages for the Sierran Forest ecoregion selected species.

APPENDIX C

STATISTICAL ANALYSES

California Grasslands

Clipping Fresh Weight

Clipping Fresh Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	30.79	< 0.0001
SOD COMPOSITION	5	12	1.11	0.4046
DAP * SOD COMPOSITION	65	156	0.5	0.9990

Clipping Fresh Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	182	22.33	< 0.0001
SPECIES	6	14	2.92	0.0460
DAP * SPECIES	78	182	3.25	< 0.0001

Clipping Percent Dry Weight

Clipping Percent Dry Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	54.18	< 0.0001
SOD COMPOSITION	5	12	0.97	0.4747
DAP * SOD COMPOSITION	65	156	0.98	0.5328

Clipping Percent Dry Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	179	23.28	< 0.0001
SPECIES	6	14	14.32	< 0.0001
DAP * SPECIES	78	179	0.79	0.8823

Total Ground Cover

Total Ground Cover	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	144	78.33	< 0.0001
SOD COMPOSITION	5	12	1.09	0.4132
DAP * SOD COMPOSITION	60	144	1.28	0.1162

Final Total Ground Cover	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	511.61	102.32	2.55	0.0850
RHIZ	2	256.78	128.39	3.21	0.0767
BUNCH	1	40.50	40.50	1.01	0.3345
RHIZ * BUNCH	2	214.33	107.17	2.68	0.1094
ERROR	12	480.67	40.06		
TOTAL	17	992.28			

Percent Species Composition

***Bromus carinatus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	144	46.24	< 0.0001
SOD COMPOSITION	5	12	6.16	0.0047
DAP * SOD COMPOSITION	60	144	1.61	0.0115

Final *Bromus carinatus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	2413.78	482.76	5.43	0.0077
RHIZ	2	831.44	415.72	4.68	0.0315
BUNCH	1	1352.00	1352.00	15.21	0.0021
RHIZ * BUNCH	2	230.33	115.67	1.30	0.3094
ERROR	12	1066.67	88.89		
TOTAL	17	3480.44			

***Elymus glaucus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	144	24.34	< 0.0001
SOD COMPOSITION	5	12	5.84	0.0058
DAP * SOD COMPOSITION	60	144	1.69	0.0058

Final *Elymus glaucus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	102.28	20.46	3.80	0.0271
RHIZ	2	12.44	6.22	1.15	0.3478
BUNCH	1	2.72	2.72	0.51	0.4908
RHIZ * BUNCH	2	87.11	43.56	8.08	0.0060
ERROR	12	64.67	5.39		
TOTAL	17	166.94			

***Festuca rubra* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	96	34.03	< 0.0001
SOD COMPOSITION	3	8	6.58	0.0149
DAP * SOD COMPOSITION	36	96	1.28	0.1685

Final *Festuca rubra* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	31.33	10.44	0.51	0.6856
RHIZ	1	1.33	1.33	0.07	0.8047
BUNCH	1	27.00	27.00	1.32	0.2834
RHIZ * BUNCH	1	3.00	3.00	0.15	0.7115
ERROR	8	163.33	20.42		
TOTAL	11	194.67			

***Leymus triticoides* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	96	64.57	< 0.0001
SOD COMPOSITION	3	8	6.93	0.0129
DAP * SOD COMPOSITION	36	96	1.14	0.3053

Final *Leymus triticoides* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	14.00	4.67	2.95	0.0985
RHIZ	1	5.33	5.33	3.37	0.1038
BUNCH	1	8.33	8.33	5.26	0.0509
RHIZ * BUNCH	1	0.33	0.33	0.21	0.6586
ERROR	8	12.67	1.58		
TOTAL	11	26.67			

***Melica californica* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	72	44.61	< 0.0001
SOD COMPOSITION	2	6	0.96	0.4333
DAP * SOD COMPOSITION	24	72	1.28	0.2065

Final *Melica californica* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	150.89	75.44	2.99	0.1256
RHIZ	2	150.89	75.44	2.99	0.1256
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	151.33	25.22		
TOTAL	8	302.22			

***Nassella pulchra/cernua* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	144	35.25	< 0.0001
SOD COMPOSITION	5	12	20.32	< 0.0001
DAP * SOD COMPOSITION	60	144	3.16	< 0.0001

Final *Nassella pulchra/cernua* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	7.17	1.43	2.35	0.1051
RHIZ	2	2.33	1.17	1.91	0.1906
BUNCH	1	4.50	4.50	7.36	0.0188
RHIZ * BUNCH	2	0.33	0.17	0.27	0.7659
ERROR	12	7.33	0.61		
TOTAL	17	14.50			

Total Root Mass

Total Root Mass	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	17.13	3.43	2.63	0.0787
RHIZ	2	14.73	7.37	5.66	0.0186
BUNCH	1	0.22	0.22	0.17	0.6893
RHIZ * BUNCH	2	2.18	1.09	0.84	0.4564
ERROR	12	15.61	1.3		
TOTAL	17	32.74			

Root Mass by Depth

Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	1.03	0.4449
DEPTH	6	72	86.26	< 0.0001
SOD COMPOSITION * DEPTH	30	72	1.55	0.0658

Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	17.43	< 0.0001
DEPTH	6	84	61.16	< 0.0001
SPECIES * DEPTH	36	84	11.28	< 0.0001

Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	3.65	0.73	1.71	0.2064
RHIZ	2	2.73	1.37	3.21	0.0766
BUNCH	1	0.59	0.59	1.38	0.2622
RHIZ * BUNCH	2	0.32	0.16	0.38	0.6910
ERROR	12	5.11	0.43		
TOTAL	17	8.76			

Percent Root Mass by Depth

Percent Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	0.00	1.0000
DEPTH	6	72	162.57	< 0.0001
SOD COMPOSITION * DEPTH	30	72	1.54	0.0702

Percent Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	0.00	1.0000
DEPTH	6	84	533.96	< 0.0001
SPECIES * DEPTH	36	84	18.2	< 0.0001

Percent Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.11	0.02	1.43	0.2813
RHIZ	2	0.05	0.03	0.69	0.2262
BUNCH	1	0.04	0.04	2.84	0.1175
RHIZ * BUNCH	2	0.01	0.007	0.48	0.6324
ERROR	12	0.19	0.02		
TOTAL	17	0.30			

Sod Strength

Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.50	0.10	5.78	0.0061
RHIZ	2	0.36	0.18	10.53	0.0023
BUNCH	1	0.05	0.05	2.67	0.1282
RHIZ * BUNCH	2	0.09	0.04	2.59	0.1161
ERROR	12	0.21	0.02		
TOTAL	17	0.70			

Correlation of Percent Rhizomatous Composition with Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**	**Adj. R^2**
MODEL	1	0.33	0.33	13.95	0.0018	0.4324
ERROR	16	0.38	0.02			
TOTAL	17	0.70				

Chaparral

Clipping Fresh Weight

Clipping Fresh Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	137.07	< 0.0001
SOD COMPOSITION	5	12	2.59	0.0825
DAP * SOD COMPOSITION	65	156	0.85	0.7638

Clipping Fresh Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	182	23.51	< 0.0001
SPECIES	6	14	3.82	0.0182
DAP * SPECIES	78	182	2.69	< 0.0001

Clipping Percent Dry Weight

Clipping Percent Dry Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	58.87	< 0.0001
SOD COMPOSITION	5	12	0.32	0.8939
DAP * SOD COMPOSITION	65	156	0.73	0.9226

Clipping Percent Dry Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	170	21.98	< 0.0001
SPECIES	6	14	13.23	< 0.0001
DAP * SPECIES	78	170	1.13	0.2540

Total Ground Cover

Total Ground Cover	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	129.04	< 0.0001
SOD COMPOSITION	5	12	1.98	0.1548
DAP * SOD COMPOSITION	55	132	1.80	0.0035

Final Total Ground Cover	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	217.61	43.52	1.00	0.4605
RHIZ	2	210.78	105.39	2.41	0.1318
BUNCH	1	0.50	0.50	0.01	0.9166
RHIZ * BUNCH	2	6.33	3.17	0.07	0.9305
ERROR	12	524.67	43.72		
TOTAL	17	742.28			

Percent Species Composition

***Bromus carinatus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	31.51	< 0.0001
SOD COMPOSITION	5	12	4.84	0.0118
DAP * SOD COMPOSITION	55	132	1.46	0.0426

Final *Bromus carinatus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	372.94	74.59	1.85	0.1766
RHIZ	2	345.44	172.72	4.29	0.0392
BUNCH	1	24.50	24.50	0.61	0.4502
RHIZ * BUNCH	2	3.00	1.50	0.04	0.9635
ERROR	12	482.67	40.22		
TOTAL	17	855.61			

***Elymus glaucus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	66	11.47	< 0.0001
SOD COMPOSITION	2	6	5.41	0.0453
DAP * SOD COMPOSITION	22	66	0.94	0.5455

Final *Elymus glaucus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	6.00	3.00	3.00	0.1250
RHIZ	2	6.00	3.00	3.00	0.1250
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	6.00	1.00		
TOTAL	8	12.00			

***Elymus trachycaulus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	88	24.58	< 0.0001
SOD COMPOSITION	3	8	15.70	0.0010
DAP * SOD COMPOSITION	33	88	1.17	0.2808

Final *Elymus trachcaulus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	28.67	9.56	1.25	0.03555
RHIZ	1	27.00	27.00	3.52	0.0974
BUNCH	1	1.33	1.33	0.17	0.6876
RHIZ * BUNCH	1	0.33	0.33	0.04	0.8400
ERROR	8	61.33	7.67		
TOTAL	11	90.00			

***Festuca rubra* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	88	62.20	< 0.0001
SOD COMPOSITION	3	8	36.89	< 0.0001
DAP * SOD COMPOSITION	33	88	2.31	0.0010

Final *Festuca rubra* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	443.00	147.67	16.63	0.0016
RHIZ	1	280.33	280.33	25.88	0.0009
BUNCH	1	161.33	161.33	14.89	0.0048
RHIZ * BUNCH	1	1.33	1.33	0.12	0.7348
ERROR	8	86.67	10.83		
TOTAL	11	529.67			

***Koeleria macrantha* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	83.91	< 0.0001
SOD COMPOSITION	5	12	1.92	0.1639
DAP * SOD COMPOSITION	55	132	1.32	0.1014

Final *Koeleria macrantha* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	13.17	2.63	1.63	0.2248
RHIZ	2	10.33	5.17	3.21	0.0766
BUNCH	1	0.50	0.50	0.31	0.5877
RHIZ * BUNCH	2	2.33	1.67	0.72	0.5048
ERROR	12	19.33	1.61		
TOTAL	17	32.50			

***Nassella lepida* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	37.34	< 0.0001
SOD COMPOSITION	5	12	16.60	< 0.0001
DAP * SOD COMPOSITION	55	132	1.13	0.2838

Final *Nassella lepida* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	44.50	8.90	2.32	0.1077
RHIZ	2	19	9.5	2.48	0.1255
BUNCH	1	12.50	12.50	3.25	0.0961
RHIZ * BUNCH	2	13.00	6.50	1.70	0.2246
ERROR	12	46.00	3.83		
TOTAL	17	90.50			

***Nassella pulchra* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	66	15.62	< 0.0001
SOD COMPOSITION	2	6	4.41	0.0663
DAP * SOD COMPOSITION	22	66	1.95	0.0200

Final *Nassella pulchra* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	1.56	0.78	1.75	0.2519
RHIZ	2	1.56	0.78	1.75	0.2519
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	2.67	0.44		
TOTAL	8	4.22			

Total Root Mass

Total Root Mass	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	21.87	4.37	1.48	0.2668
RHIZ	2	2.94	1.47	0.50	0.6201
BUNCH	1	0.01	0.01	0.00	0.9500
RHIZ * BUNCH	2	18.92	9.46	3.2	0.0768
ERROR	12	35.45	2.95		
TOTAL	17	57.32			

Root Mass by Depth

Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	0.74	0.6050
DEPTH	6	72	158.18	< 0.0001
SOD COMPOSITION * DEPTH	30	72	2.58	0.0006

Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	2.04	0.1274
DEPTH	6	84	21.72	< 0.0001
SPECIES * DEPTH	36	84	2.61	0.0002

Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	4.59	0.92	2.23	0.1182
RHIZ	2	2.16	1.08	2.63	0.1129
BUNCH	1	0.65	0.65	1.57	0.2337
RHIZ * BUNCH	2	1.79	0.89	2.16	0.1577
ERROR	12	4.94	0.41		
TOTAL	17	9.53			

Percent Root Mass by Depth

Percent Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	0.00	1.0000
DEPTH	6	72	463.46	< 0.0001
SOD COMPOSITION * DEPTH	30	72	3.79	< 0.0001

Percent Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	0.00	1.0000
DEPTH	6	84	129.33	< 0.0001
SPECIES * DEPTH	36	84	5.61	< 0.0001

Percent Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.08	0.02	3.89	0.0251
RHIZ	2	0.06	0.03	7.60	0.0074
BUNCH	1	0.01	0.01	3.64	0.0805
RHIZ * BUNCH	2	0.002	0.001	0.30	0.7498
ERROR	12	0.05	0.004		
TOTAL	17	0.12			

Sod Strength

Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.50	0.10	5.78	0.0061
RHIZ	2	0.36	0.18	10.53	0.0023
BUNCH	1	0.05	0.05	2.67	0.1282
RHIZ * BUNCH	2	0.09	0.04	2.59	0.1161
ERROR	12	0.21	0.02		
TOTAL	17	0.70			

Correlation of Percent Rhizomatous Composition with Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**	**Adj. R^2**
MODEL	1	0.58	0.58	20.62	0.0003	0.5357
ERROR	16	0.45	0.03			
TOTAL	17	1.02				

Great American Desert

Clipping Fresh Weight

Clipping Fresh Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	160.76	< 0.0001
SOD COMPOSITION	1	16	1.01	0.3290
DAP * SOD COMPOSITION	13	208	0.75	0.7150

Clipping Fresh Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	182	73.84	< 0.0001
SPECIES	6	14	47.31	< 0.0001
DAP * SPECIES	78	182	12.86	< 0.0001

Clipping Percent Dry Weight

Clipping Percent Dry Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	154.27	< 0.0001
SOD COMPOSITION	1	16	2.22	0.1561
DAP * SOD COMPOSITION	13	208	0.36	0.9800

Clipping Percent Dry Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	146	23.60	< 0.0001
SPECIES	5	12	3.90	0.0247
DAP * SPECIES	63	146	2.65	< 0.0001

Total Ground Cover

Total Ground Cover	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	347.08	< 0.0001
SOD COMPOSITION	1	16	8.49	0.0102
DAP * SOD COMPOSITION	13	208	1.33	0.1990

Final Total Ground Cover	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	107.56	107.56	6.80	0.0190
ERROR	16	252.89	18.81		
TOTAL	17	360.44			

Percent Species Composition

***Achnatherum hymenoides* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	28.36	< 0.0001
SOD COMPOSITION	1	16	5.39	0.0338
DAP * SOD COMPOSITION	13	208	1.62	0.0804

Final *Achnatherum hymenoides* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	0.060	0.060	1.00	0.3322
ERROR	16	0.89	0.060		
TOTAL	17	0.94			

***Aristida purpurea* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	10.97	< 0.0001
SOD COMPOSITION	1	16	1482.37	< 0.0001
DAP * SOD COMPOSITION	13	208	10.97	< 0.0001

Final *Aristida purpurea* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	107.56	107.56	352.00	< 0.0001
ERROR	16	4.89	0.31		
TOTAL	17	112.44			

***Elymus elymoides* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	43.16	< 0.0001
SOD COMPOSITION	1	16	181.69	< 0.0001
DAP * SOD COMPOSITION	13	208	5.17	< 0.0001

Final *Elymus elymoides* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	60.50	60.50	9.68	0.0067
ERROR	16	100.00	6.25		
TOTAL	17	160.50			

***Koeleria macrantha* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	156.60	< 0.0001
SOD COMPOSITION	1	16	389.14	< 0.0001
DAP * SOD COMPOSITION	13	208	26.27	0.0010

Final *Koeleria macrantha* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	1901.39	1901.39	225.16	< 0.0001
ERROR	16	135.11	8.44		
TOTAL	17	2036.50			

***Leymus condensatus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	67.06	< 0.0001
SOD COMPOSITION	1	16	77.96	< 0.0001
DAP * SOD COMPOSITION	13	208	4.67	< 0.0001

Final *Leymus condensatus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	220.50	220.50	13.67	0.0020
ERROR	16	258.00	16.13		
TOTAL	17	478.50			

***Nassella cernua* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	208	67.14	< 0.0001
SOD COMPOSITION	1	16	2080.36	< 0.0001
DAP * SOD COMPOSITION	13	208	67.14	< 0.0001

Final *Nassella cernua* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	4355.56	4355.56	330.45	< 0.0001
ERROR	16	210.89	13.18		
TOTAL	17	4566.44			

Total Root Mass

Total Root Mass	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	4.26	4.26	1.41	0.2525
ERROR	16	48.37	3.02		
TOTAL	17	52.63			

Root Mass by Depth

Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	1	16	0.88	0.3625
DEPTH	6	96	73.96	< 0.0001
SOD COMPOSITION * DEPTH	6	96	1.52	0.1787

Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	5	12	62.08	< 0.0001
DEPTH	6	72	343.04	< 0.0001
SPECIES * DEPTH	30	72	159.75	< 0.0001

Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	0.97	0.097	1.60	0.2234
ERROR	16	9.66	0.60		
TOTAL	17	10.63			

Percent Root Mass by Depth

Percent Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	1	16	0.00	1.0000
DEPTH	6	96	255.13	< 0.0001
SOD COMPOSITION * DEPTH	6	96	2.46	0.0294

Percent Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	5	12	0.00	1.0000
DEPTH	6	72	95.18	< 0.0001
SPECIES * DEPTH	30	72	6.08	< 0.0001

Percent Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	0.03	0.03	2.63	0.1244
ERROR	16	0.16	0.01		
TOTAL	17	0.18			

Sod Strength

Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	1	0.09	0.09	7.13	0.0168
ERROR	16	0.2	0.01		
TOTAL	17	0.29			

Correlation of Percent Rhizomatous Composition with Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**	**Adj. R^2**
MODEL	1	0.03	0.03	2.10	0.1662	0.0610
ERROR	16	0.26	0.02			
TOTAL	17	0.29				

Intermountain Sagebrush

Clipping Fresh Weight

Clipping Fresh Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	58.15	< 0.0001
SOD COMPOSITION	5	12	2.38	0.1011
DAP * SOD COMPOSITION	65	156	1.49	0.0234

Clipping Fresh Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	182	15.77	< 0.0001
SPECIES	6	14	11.89	< 0.0001
DAP * SPECIES	78	182	3.48	< 0.0001

Clipping Percent Dry Weight

Clipping Percent Dry Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	105.33	< 0.0001
SOD COMPOSITION	5	12	2.99	0.0555
DAP * SOD COMPOSITION	65	156	1.77	0.0021

Clipping Percent Dry Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	164	5.07	< 0.0001
SPECIES	6	14	2.14	0.1129
DAP * SPECIES	72	164	1.12	0.2784

Total Ground Cover

Total Ground Cover	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	367.66	< 0.0001
SOD COMPOSITION	5	12	20.44	0.1548
DAP * SOD COMPOSITION	65	156	3.26	0.0035

Final Total Ground Cover	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	834.94	166.99	4.82	0.0119
RHIZ	2	428.11	214.06	6.18	0.0143
BUNCH	1	93.39	93.39	2.70	0.1264
RHIZ * BUNCH	2	313.44	156.72	4.53	0.0343
ERROR	12	415.33	34.61		
TOTAL	17	1250.28			

Percent Species Composition

***Achnatherum occidentale* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	78	11.51	< 0.0001
SOD COMPOSITION	2	6	0.09	0.9144
DAP * SOD COMPOSITION	26	78	0.57	0.9467

Final *Achnatherum occidentale* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	0.00	0.00	0.00	1.0000
RHIZ	2	0.00	0.00	0.00	1.0000
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	4	0.67		
TOTAL	8	4			

***Elymus elymoides* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	33.38	< 0.0001
SOD COMPOSITION	5	12	5.82	0.0059
DAP * SOD COMPOSITION	65	156	1.56	0.0136

Final *Elymus elymoides* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	13.11	2.62	0.52	0.7577
RHIZ	2	7.44	3.72	0.74	0.4993
BUNCH	1	0.22	0.22	0.04	0.8375
RHIZ * BUNCH	2	5.44	2.72	0.54	0.5971
ERROR	12	60.67	5.06		
TOTAL	17	73.78			

***Elymus multisetus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	78	7.06	< 0.0001
SOD COMPOSITION	2	6	3.23	0.1119
DAP * SOD COMPOSITION	26	78	1.08	0.3811

Final *Elymus multisetus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	64.89	32.44	2.81	0.1378
RHIZ	2	64.89	32.44	2.81	0.1378
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	69.33	11.56		
TOTAL	8	134.22			

***Elymus trachycaulus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	104	52.01	< 0.0001
SOD COMPOSITION	3	8	3.05	0.0922
DAP * SOD COMPOSITION	39	104	2.09	0.0017

Final *Elymus tracycaulus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	1.33	0.44	0.41	0.7501
RHIZ	1	0.00	0.00	0.00	1.0000
BUNCH	1	1.33	1.33	1.23	0.2995
RHIZ * BUNCH	1	0.00	0.00	0.00	1.0000
ERROR	8	8.67	1.08		
TOTAL	11	10.00			

***Koeleria macrantha* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	76.77	< 0.0001
SOD COMPOSITION	5	12	12.32	0.0002
DAP * SOD COMPOSITION	65	156	1.75	0.0026

Final *Koeleria macrantha* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	719.61	143.92	4.36	0.0170
RHIZ	2	64.11	32.06	0.97	0.4064
BUNCH	1	544.50	544.50	16.50	0.0016
RHIZ * BUNCH	2	111.00	55.50	1.68	0.2271
ERROR	12	396.00	33.00		
TOTAL	17	1115.61			

***Leymus cinereus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	49.65	< 0.0001
SOD COMPOSITION	5	12	27.08	< 0.0001
DAP * SOD COMPOSITION	65	156	2.53	< 0.0001

Final *Leymus cinereus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	504.50	100.90	6.88	0.0030
RHIZ	2	389.33	194.67	13.27	0.0009
BUNCH	1	102.72	102.72	7.00	0.0213
RHIZ * BUNCH	2	12.44	6.22	0.42	0.6637
ERROR	12	176.00	14.67		
TOTAL	17	680.50			

***Leymus triticoides* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	104	61.03	< 0.0001
SOD COMPOSITION	3	8	40.45	< 0.0001
DAP * SOD COMPOSITION	39	104	2.19	0.0009

Final *Leymus triticoides* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	32.25	10.75	5.16	0.0283
RHIZ	1	30.08	30.08	14.44	0.0052
BUNCH	1	2.08	2.08	1.00	0.3465
RHIZ * BUNCH	1	0.08	0.08	0.04	0.8465
ERROR	8	16.67	2.08		
TOTAL	11	48.92			

Total Root Mass

Total Root Mass	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	6.39	1.28	1.71	0.2058
RHIZ	2	2.80	1.40	1.88	0.1951
BUNCH	1	0.93	0.93	1.25	0.2855
RHIZ * BUNCH	2	2.66	1.33	1.78	0.2101
ERROR	12	8.95	0.75		
TOTAL	17	15.34			

Root Mass by Depth

Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	1.53	0.2534
DEPTH	6	72	55.46	< 0.0001
SOD COMPOSITION * DEPTH	30	72	0.38	0.9979

Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	17.43	< 0.0001
DEPTH	6	84	61.16	< 0.0001
SPECIES * DEPTH	36	84	11.28	< 0.0001

Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.42	0.08	0.42	0.8261
RHIZ	2	0.04	0.02	0.09	0.9103
BUNCH	1	0.05	0.05	0.24	0.6357
RHIZ * BUNCH	2	0.34	0.17	0.84	0.4567
ERROR	12	2.40	0.20		
TOTAL	17	2.82			

Percent Root Mass by Depth

Percent Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	0.00	1.0000
DEPTH	6	72	160.57	< 0.0001
SOD COMPOSITION * DEPTH	30	72	0.90	0.6164

Percent Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	0.00	1.0000
DEPTH	6	84	86.82	< 0.0001
SPECIES * DEPTH	36	84	4.97	< 0.0001

Percent Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.06	0.01	0.69	0.6398
RHIZ	2	0.05	0.03	1.54	0.253
BUNCH	1	0.0001	0.0001	0.09	0.7747
RHIZ * BUNCH	2	0.005	0.002	0.14	0.8701
ERROR	12	0.20	0.02		
TOTAL	17	0.26			

Sod Strength

Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.004	0.0008	0.36	0.8678
RHIZ	2	0.002	0.001	0.45	0.6499
BUNCH	1	0.002	0.002	0.77	0.3986
RHIZ * BUNCH	2	0.0003	0.0002	0.06	0.9385
ERROR	12	0.03	0.002		
TOTAL	17	0.03			

Correlation of Percent Rhizomatous Composition with Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**	**Adj. R^2**
MODEL	1	0.00	0.00	0.02	0.8985	-0.0614
ERROR	16	0.03	0.002			
TOTAL	17	0.03				

Pacific Forest

Clippings Fresh Weight

Clipping Fresh Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	147.53	< 0.0001
SOD COMPOSITION	5	12	1.14	0.3929
DAP * SOD COMPOSITION	65	156	1.00	0.4883

Clipping Fresh Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	182	33.71	< 0.0001
SPECIES	6	14	6.66	0.0017
DAP * SPECIES	78	182	2.27	< 0.0001

Clipping Percent Dry Weight

Clipping Percent Dry Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	134.12	< 0.0001
SOD COMPOSITION	5	12	0.38	0.8535
DAP * SOD COMPOSITION	65	156	0.94	0.6071

Clipping Percent Dry Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	12	161	13.21	< 0.0001
SPECIES	6	14	6.18	0.0024
DAP * SPECIES	72	161	0.72	0.9408

Total Ground Cover

Total Ground Cover	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	72.45	< 0.0001
SOD COMPOSITION	5	12	1.46	0.2738
DAP * SOD COMPOSITION	55	132	0.78	0.8557

Final Total Ground Cover	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	180.27	36.06	1.20	0.3671
RHIZ	2	28.79	14.39	0.48	0.6314
BUNCH	1	122.72	122.72	4.08	0.0664
RHIZ * BUNCH	2	28.79	14.39	0.48	0.6314
ERROR	12	361.33	30.11		
TOTAL	17	541.61			

Percent Species Composition

***Bromus carinatus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	31.83	< 0.0001
SOD COMPOSITION	5	12	3.51	0.0346
DAP * SOD COMPOSITION	55	132	1.00	0.4896

Final *Bromus carinatus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	27.78	5.56	0.09	0.9926
RHIZ	2	8.11	4.05	0.06	0.9377
BUNCH	1	14.22	14.22	0.23	0.6425
RHIZ * BUNCH	2	5.44	2.72	0.04	0.9577
ERROR	12	752.67	62.72		
TOTAL	17	780.44			

***Elymus glaucus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	18.01	< 0.0001
SOD COMPOSITION	5	12	4.33	0.0175
DAP * SOD COMPOSITION	55	132	2.44	< 0.0001

Final *Elymus glaucus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	5.61	1.12	1.19	0.3709
RHIZ	2	0.78	0.39	0.41	0.6715
BUNCH	1	4.50	4.50	4.76	0.0496
RHIZ * BUNCH	2	0.33	0.17	0.18	0.8404
ERROR	12	11.33	0.94		
TOTAL	17	16.94			

***Elymus trachycaulus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	88	20.66	< 0.0001
SOD COMPOSITION	3	8	0.68	0.5886
DAP * SOD COMPOSITION	33	88	1.07	0.3866

Final *Elymus trachycaulus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	5.58	1.86	1.60	0.2653
RHIZ	1	0.75	0.75	0.64	0.4458
BUNCH	1	4.08	4.08	3.54	0.0983
RHIZ * BUNCH	1	0.75	0.75	0.64	0.4458
ERROR	8	9.33	1.17		
TOTAL	11	14.92			

***Festuca rubra/idahoensis* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	132	58.49	< 0.0001
SOD COMPOSITION	5	12	2.31	0.1093
DAP * SOD COMPOSITION	55	132	1.06	0.3912

Final *Festuca rubra/idahoensis* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	344.94	68.99	1.90	0.1672
RHIZ	2	317.44	158.72	4.38	0.0373
BUNCH	1	2.72	2.72	0.08	0.7886
RHIZ * BUNCH	2	24.78	12.39	0.34	0.7170
ERROR	12	434.67	36.22		
TOTAL	17	779.61			

***Koeleria macrantha* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	66	23.52	< 0.0001
SOD COMPOSITION	2	6	1.19	0.3676
DAP * SOD COMPOSITION	22	66	0.91	0.5860

Final *Koeleria macrantha* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	4.22	2.11	1.27	0.3476
RHIZ	2	4.22	2.11	1.27	0.3476
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	10.00	1.67		
TOTAL	8	14.22			

***Melica californica* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	11	66	7.60	< 0.0001
SOD COMPOSITION	2	6	1.16	0.3760
DAP * SOD COMPOSITION	22	66	0.49	0.9686

Final *Melica californica* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	0.22	0.11	0.11	0.8966
RHIZ	2	0.22	0.11	0.11	0.8966
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	6.00	1.00		
TOTAL	8	6.22			

Total Root Mass

Total Root Mass	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	222.76	44.55	1.57	0.2412
RHIZ	2	215.48	107.74	380%	0.0527
BUNCH	1	5.13	5.12	0.18	0.6782
RHIZ * BUNCH	2	2.16	1.08	0.04	0.9627
ERROR	12	340.26	28.36		
TOTAL	17	563.03			

Root Mass by Depth

Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	0.73	0.6124
DEPTH	6	72	78.82	< 0.0001
SOD COMPOSITION * DEPTH	30	72	1.37	0.1393

Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	8.16	0.0006
DEPTH	6	84	119.14	< 0.0001
SPECIES * DEPTH	36	84	13.90	< 0.0001

Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	43.20	8.64	1.38	0.2971
RHIZ	2	41.40	20.70	3.32	0.0713
BUNCH	1	1.32	1.32	0.21	0.6543
RHIZ * BUNCH	2	0.49	0.24	0.04	0.9619
ERROR	12	74.87	6.24		
TOTAL	17	118.07			

Percent Root Mass by Depth

Percent Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	0.00	1.0000
DEPTH	6	72	254.63	< 0.0001
SOD COMPOSITION * DEPTH	30	72	0.49	0.9838

Percent Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	0.00	1.0000
DEPTH	6	84	141.39	< 0.0001
SPECIES * DEPTH	36	84	3.39	< 0.0001

Percent Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.03	0.007	0.40	0.8381
RHIZ	2	0.03	0.01	0.82	0.4621
BUNCH	1	0.0003	0.0003	0.02	0.9043
RHIZ * BUNCH	2	0.006	0.003	0.17	0.8419
ERROR	12	0.21	0.02		
TOTAL	17	0.24			

Sod Strength

Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.22	0.04	0.77	0.5916
RHIZ	2	0.005	0.002	0.04	0.9583
BUNCH	1	0.14	0.14	2.50	0.1399
RHIZ * BUNCH	2	0.07	0.04	0.62	0.5529
ERROR	12	0.69	0.06		
TOTAL	17	0.91			

Correlation of Percent Rhizomatous Composition with Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**	**Adj. R^2**
MODEL	1	0.10	0.10	1.88	0.1893	0.0492
ERROR	16	0.81	0.05			
TOTAL	17	0.91				

Sierran Forest

Clipping Fresh Weight

Clipping Fresh Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	50.08	< 0.0001
SOD COMPOSITION	5	12	2.18	0.1245
DAP * SOD COMPOSITION	65	156	2.10	0.0001

Clipping Fresh Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	182	29.45	< 0.0001
SPECIES	6	14	11.69	< 0.0001
DAP * SPECIES	78	182	5.81	< 0.0001

Clipping Percent Dry Weight

Clipping Percent Dry Weight_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	99.51	< 0.0001
SOD COMPOSITION	5	12	1.38	0.2990
DAP * SOD COMPOSITION	65	156	2.67	< 0.0001

Clipping Percent Dry Weight_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	172	12.99	< 0.0001
SPECIES	6	14	2.05	0.1255
DAP * SPECIES	74	172	0.55	0.9978

Total Ground Cover

Total Ground Cover	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	288.97	< 0.0001
SOD COMPOSITION	5	12	56.77	< 0.0001
DAP * SOD COMPOSITION	65	156	2.98	< 0.0001

Final Total Ground Cover	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	1535.17	307.03	17.43	< 0.0001
RHIZ	2	49.00	24.50	1.39	0.2862
BUNCH	1	1042.72	1042.72	59.21	< 0.0001
RHIZ * BUNCH	2	443.44	221.72	12.59	0.0011
ERROR	12	211.33	17.61		
TOTAL	17	1746.50			

Percent Species Composition

***Bromus carinatus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	78	74.25	< 0.0001
SOD COMPOSITION	2	6	11.93	0.0081
DAP * SOD COMPOSITION	26	78	5.20	< 0.0001

Final *Bromus carinatus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	1292.67	646.33	24.97	0.0012
RHIZ	2	1292.67	646.33	24.97	0.0012
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	155.33	25.89		
TOTAL	8	1448.00			

***Elymus elymoides* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	37.85	< 0.0001
SOD COMPOSITION	5	12	14.95	< 0.0001
DAP * SOD COMPOSITION	65	156	3.20	< 0.0001

Final *Elymus elymoides* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	9.11	1.82	1.21	0.3600
RHIZ	2	3.11	1.56	1.04	0.3842
BUNCH	1	5.56	5.56	3.70	0.0783
RHIZ * BUNCH	2	0.44	0.22	0.15	0.8639
ERROR	12	18.00	1.50		
TOTAL	17	27.11			

***Elymus glaucus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	78	8.73	< 0.0001
SOD COMPOSITION	2	6	0.85	0.4742
DAP * SOD COMPOSITION	26	78	1.41	0.1249

Final *Elymus glaucus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	2	0.22	0.11	0.04	0.9596
RHIZ	2	0.22	0.11	0.04	0.9596
BUNCH	0	N/A	N/A	N/A	N/A
RHIZ * BUNCH	0	N/A	N/A	N/A	N/A
ERROR	6	16.00	2.67		
TOTAL	8	16.22			

***Elymus trachycaulus* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	104	36.03	< 0.0001
SOD COMPOSITION	3	8	14.93	0.0012
DAP * SOD COMPOSITION	39	104	2.18	0.0009

Final *Elymus tracycaulus* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	4.67	1.56	2.33	0.1504
RHIZ	1	1.33	1.33	2.00	0.1950
BUNCH	1	0.33	0.33	0.50	0.4996
RHIZ * BUNCH	1	3.00	3.00	4.50	0.0667
ERROR	8	5.33	0.67		
TOTAL	11	10.0			

***Festuca rubra* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	104	28.12	< 0.0001
SOD COMPOSITION	3	8	13.95	0.0015
DAP * SOD COMPOSITION	39	104	1.63	0.0264

Final *Festuca rubra* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	3	320.92	106.97	7.29	0.0112
RHIZ	1	24.08	24.08	1.64	0.2359
BUNCH	1	290.08	290.08	19.78	0.0021
RHIZ * BUNCH	1	6.75	6.75	0.46	0.5167
ERROR	8	117.33	14.67		
TOTAL	11	438.25			

***Hordeum brachyantherum* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	52.09	< 0.0001
SOD COMPOSITION	5	12	64.21	< 0.0001
DAP * SOD COMPOSITION	65	156	6.04	< 0.0001

Final *Hordeum brachyantherum* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	1326.28	265.26	20.58	< 0.0001
RHIZ	2	153.44	76.72	5.95	0.0160
BUNCH	1	1012.50	1012.50	78.56	< 0.0001
RHIZ * BUNCH	2	160.33	80.17	6.22	0.0140
ERROR	12	154.67	12.89		
TOTAL	17	1480.94			

***Muhlenbergia rigens* Composition**	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
DAP	13	156	60.07	< 0.0001
SOD COMPOSITION	5	12	2.49	0.0912
DAP * SOD COMPOSITION	65	156	1.20	0.1848

Final *Muhlenbergia rigens* Composition	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	2.28	0.46	1.37	0.3033
RHIZ	2	1.44	0.72	2.17	0.1573
BUNCH	1	0.06	0.06	0.17	0.6903
RHIZ * BUNCH	2	0.78	0.39	1.17	0.3444
ERROR	12	4.00	0.33		
TOTAL	17	6.28			

Total Root Mass

Total Root Mass	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	26.46	5.29	5.22	0.0089
RHIZ	2	24.28	12.14	11.99	0.0014
BUNCH	1	1.30	1.30	1.28	0.2800
RHIZ * BUNCH	2	0.88	0.44	0.44	0.6569
ERROR	12	12.15	1.01		
TOTAL	17	38.61			

Root Mass by Depth

Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	4.58	0.0144
DEPTH	6	72	133.39	< 0.0001
SOD COMPOSITION * DEPTH	30	72	4.21	< 0.0001

Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	11.61	< 0.0001
DEPTH	6	84	110.05	< 0.0001
SPECIES * DEPTH	36	84	28.84	< 0.0001

Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	5.04	1.01	4.36	0.0171
RHIZ	2	4.66	2.33	10.06	0.0027
BUNCH	1	0.0001	0.0001	0.00	0.9526
RHIZ * BUNCH	2	0.38	0.19	0.83	0.4596
ERROR	12	2.78	0.23		
TOTAL	17	7.82			

Percent Root Mass by Depth

Percent Root Mass by Depth_Mixtures	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SOD COMPOSITION	5	12	0.00	1.0000
DEPTH	6	72	599.12	< 0.0001
SOD COMPOSITION * DEPTH	30	72	3.67	< 0.0001

Percent Root Mass by Depth_Monostands	**NUM DF**	**DEN DF**	**F Value**	**Pr > F**
SPECIES	6	14	0.00	1.0000
DEPTH	6	84	414.86	< 0.0001
SPECIES * DEPTH	36	84	28.4	< 0.0001

Percent Root Mass 0.0 - 2.5 cm	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	0.13	0.03	3.16	0.0474
RHIZ	2	0.07	0.04	4.19	0.0417
BUNCH	1	0.03	0.03	4.00	0.0686
RHIZ * BUNCH	2	0.03	0.01	0.01	0.2207
ERROR	12	0.10	0.01		
TOTAL	17	0.23			

Sod Strength

Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**
MODEL	5	1.15	0.23	12.23	0.0002
RHIZ	2	0.85	0.43	22.62	< 0.0001
BUNCH	1	0.20	0.20	10.39	0.0073
RHIZ * BUNCH	2	0.10	0.05	2.77	0.1027
ERROR	12	0.23	0.02		
TOTAL	17	1.38			

Correlation of Percent Rhizomatous Composition with Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**	**Adj. R^2**
MODEL	1	0.86	0.86	26.44	< 0.0001	0.5994
ERROR	16	0.52	0.03			
TOTAL	17	1.38				

Ecoregions Combined: Correlation of Percent Rhizomatous Composition with Sod Strength

Correlation of Percent Rhizomatous Composition with Sod Strength	**DF**	**SS**	**MS**	**F Value**	**Pr > F**	**Adj. R^2**
MODEL	1	5.41	5.41	158.69	< 0.0001	0.5957
ERROR	106	3.62	0.03			
TOTAL	107	9.03				

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