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16. ABSTRACT
The objective of this research was to develop and demonstrate native grass sod for sediment control from disturbed lands associated with California highways. The research evaluated native grass species for inclusion in sod and evaluated the sod at a California highway field site.

Seed mixes, including rhizomatous and bunchgrass species, were evaluated in a greenhouse setting for six California ecoregions. Growth and sod development potential of each seed mix for each ecoregion were evaluated. Seed mixes for three California ecoregions were further evaluated with a reinforcement material, and for establishment and weed suppression. Establishment and weed suppression of select ecoregion seed mixes and reinforcement materials were evaluated. Results indicated that multispecies sod has potential for use in revegetation of disturbed lands associated with highways.
Native grass seed mix designs developed for the California Grassland ecoregion were field tested on a highway steep slope and swale area near Sacramento. Following an eight month propagation period, a sod composed of four native grass species was transplanted using conventional harvest and transport procedures. The sod resisted weed invasion from the underlying soil seed bank, no bare ground was present, and sediment loss was exceptionally low (0.1-0.6 tons/hectare/year). Native grass sod was more expensive to implement compared with conventional hydroseeding, but their long-term maintenance and environmental costs associated with weed control, mowing, soil erosion, and fire control are expected to be much lower.

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Using Reinforced Native Grass Sod for Biostrips, Bioswales, and Sediment Control

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& Innovation

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USING REINFORCED NATIVE GRASS SOD FOR BIOSTRIPS, BIOSWALES, AND SEDIMENT CONTROL

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EXECUTIVE SUMMARY

The objective of this research was to develop and demonstrate native grass sod for use in sediment control and permanent stabilization of disturbed lands associated with California highways. The research was divided into two components—evaluation of native grass species for inclusion in sod and an evaluation of the sod at a California field site.

Various mixtures of native grass seeds, including rhizomatous and bunchgrass species, were evaluated in a greenhouse setting for six California ecoregions. Growth and sod development potential of each seed mix for each ecoregion were evaluated. Fewer grass species in a mix resulted in strong sod with reduced diversity. Increasing the diversity of rhizomatous species increased sod strength. The initial greenhouse research identified multispecies mixes for four California ecoregions–Pacific Forest, Sierran Forest, Chaparral, and California Grasslands—that grew native grass sod with adequate sod strength for harvesting and transportation.

Seed mixes for three California ecoregions were further evaluated for establishment and weed suppression, with and without a reinforcement material. A small-scale field experiment performed over two years indicated that multispecies sod established and survived without supplemental water. Multispecies sod reduced weed emergence sown as a seedbank and as seed rain, and survival of weeds was significantly reduced as the sod became more established. The reinforced multispecies native grass sod increased potential for desired species establishment and increased weed suppression, even under low precipitation conditions. These results indicated that multispecies sod has potential for use in revegetation of disturbed lands associated with highways.

Native grass seed mix designs for the California Grassland ecoregion for the field evaluation were selected based on plant growth characteristics, growth habits, and results from the research in the greenhouse component of this study. The seed mixes that were developed were composed of either four or five native grass species; ultimately, two different sods were transplanted to a field site located just south of Sacramento, California. In the field, plant growth parameters, weedy species invasion, and soil erosion parameters were monitored. The results of the field demonstration support the greenhouse and field data, indicating that a native grass sod species mix must be one that develops a strong-contiguous root mass, enables harvest of large sod rolls, and provides a dense sod that precludes weedy species propagation from the soil seed bank. The MSU Native Grass Sod–Delta (composed of red fescue, purple needlegrass, California meadow barley, and California brome), produced in California, had a near zero sediment loss rate (steep slope 0.6 and drainage swale 0.1 tons/hectare/year) beginning the day of sod installation, and three months after installation the site was almost entirely composed of desired native grass species. The cost to propagate, harvest and install native grass sod was estimated to be approximately five times greater than the cost of the hydroseed-mulch procedure; nonetheless, long-term maintenance and environmental costs associated with weed control, mowing and fire control are expected to be greater for hydroseeding when compared to native grass sod.

1. INTRODUCTION

1.1. Research Objective

The objective of this research was to develop and demonstrate native grass sod for control of sediment loss from land disturbances associated with the California highway system.

Efforts to establish native grass from seed require long establishment periods before a degree of stabilization is attained on slopes and water conveyance features. Native grass sod has the potential to provide immediate and permanent stabilization of highway land disturbances. Use of native grass sod raises concern pertaining to propagation and transplant methods, effectiveness in controlling sediment loss, weed control, and cost, which are addressed in this investigation.

1.2. Introduction

Disturbed lands associated with recently completed highway construction can be extremely erosive sources of sediment in water resources. To prevent sediment displacement during runoff events that can impair streams, wetlands, and water quality, surface stabilization is essential on land adjacent to highways, particularly land associated with steep slopes and water conveyance features.

Biological methods of erosion control that establish a protective vegetation cover not only reduce sediment yield and runoff but also enhance the aesthetic values of an area. Numerous methods have been tested for native grass species establishment on highway project sites including broadcast seeding, drill seeding, combinations of broadcast and drill seeding, hydroseeding with mulch, and erosion control blankets impregnated with seed. Common to these methods is that plant establishment and root development that helps to hold the soil together and prevent erosion is slow. Thus soil erosion control may not be effective for many years or never if early erosion reverses the control itself.

During the initial stages of native plant establishment from seed, there is an abundance of bare soil. The bare soil provides potential sites for not only the sown native species but also the non-native weedy species. Many weed species are annuals with high growth rates and seed production, thus are able to exploit the environment more rapidly than the generally slower growing perennials. If weed species become established they may further jeopardize establishment and growth of native grass species due to their above ground dominance and reduction in the number of safe sites for germination.

The presence of weeds means that considerable resources have to be spent to control them. In many counties, herbicides are the primary management control option, and large quantities of money are spent on an annual basis. Many Californians are concerned about the increasing use of herbicides to reduce noxious and other non-native plant species on highway sites. While selective herbicides can be used to target specific weeds, they often have an injury impact on some of the native species which reduces their productivity.

The use of native grass sod can reduce the risk of non-native weeds because it is placed on top of the soil or geological material and because weed seeds in the seed bank will be buried five centimeters or more. In addition, the native species are well established in the sod, therefore, have a competitive advantage over any weed seeds that do germinate and establish through the reinforced sod layer. Reinforced sod should consolidate the soil more immediately than broadcast seed application approaches, thus reducing soil erosion, and improving water quality. Furthermore, because the native species are adapted to the local environment, once established they should require minimal maintenance and should continue to grow and spread into adjacent areas which were not laid with sod. The growth habit and maximum height of most of the native species means that they should not obstruct the view of highway drivers and that neither mowing nor supplemental water would be required.

With the methods that are currently in place, large amounts of money are being spent trying to resolve the problems associated with highway construction. Using native grass sod is more expensive in the short term, but can reduce maintenance, herbicide and water treatment costs, thus may be more cost-effective in the long term. If sod composed of grass species native to the area of interest can be commercially produced and harvested, native multispecies sod could become another tool for rehabilitation efforts. Such sod could be particularly useful for sensitive areas found along roadsides, including those areas near streams, areas prone to high erosion rates (such as steep slopes), and areas where the rapid establishment of non-native species reduces the establishment success of native species planted by other methods.

1.3. Scope

This study began with an evaluation of several native grass species from six different ecoregions in California to determine their suitability to be used in multispecies sod for roadside rehabilitation. Seed mixtures developed specifically for the conditions in each ecoregion were sown in greenhouse growth chambers at Montana State University, and sod development was monitored relative to species biomass, relative ground cover, and total ground cover. Based on these results, the best species mixes for three ecoregions were further studied with respect to sod production. Greenhouse plots were used to investigate the effect of seeding density and reinforcement material on sod strength.

Field experiments were subsequently conducted at a research farm at Montana State University to further investigate weed suppression potential of multispecies sod. These experiments were conducted without and with various reinforcement materials, and under different water regimes. Over a two year period (and possibly continuing into the future), weed emergence, biomass, and survival were evaluated relative to the above variables in conditions. Additionally, limited work was done on the effect of watering treatment on basic establishment success of unreinforced sod.

Based on the knowledge gained from the research described above, a field experiment was conducted on a disturbed area along a highway south of Sacramento, California. Work began with an evaluation of the propagation of three native grass sods by three different commercial sod producers in California based on species presence, canopy cover and weed emergence. Two native grass sods were subsequently transplanted at the field test site, and part of the site was restored using Caltrans standard hydroseeding practice. Native grass establishment was then monitored for a 20 month period. Observations were made of plant density, canopy cover, weed development, root biomass, and sediment loss.

1.4. How This Report is Organized

Following this introduction, Chapter 2 of this report presents a review of salient literature on the use of native grass sod for re-vegetating disturbed soils. Chapters 3 and 4 discuss the greenhouse and field research experiments conducted at Montana State University (MSU) to investigate native grass sods for applications along California roadways. Chapter 5 presents the field research conducted at the field site just south of Sacramento, California. In general, each chapter is dedicated to individual sets of experiments. Each chapter includes a brief introduction, experimental methodology, results of experiments, and conclusions. Chapter 6 reports on how the results can be used, and some insights of future directions of this research. Finally, Chapter 7 summarizes the key findings across all the research that was conducted.

2. BACKGROUND: USE OF SOD AND NATIVE SPECIES IN ROADSIDE REVEGETATION

2.1. Introduction

Roadside corridors are particularly susceptible to invasion by non-native species (Spellerberg 1998; Tyser et al. 1998). Non-native species are typically well-suited to such highly disturbed sites and can establish rapidly there (Greenberg et al. 1997). In fact, because they are inexpensive and easy to establish, non-native species such as smooth brome (*Bromus inermis*) have been intentionally sown on disturbed roadside soil (Rentch et al. 2005). Non-native species are used because they are able to quickly stabilize disturbed soil (Wilson 1989), reducing erosion and sedimentation. The documented difficulty of obtaining quality native seed in large quantities may be another reason for the frequent sowing of non-native species (Lippett et al. 1994; Stevenson et al. 1995).

Aside from the fact that sowing non-native species alters the vegetation of a community, roadside areas can also be regarded as separate ecosystems due to the major changes in soil structure, fertility and hydrology incurred during construction (Forman & Alexander 1998). These changes result in soil instability and can increase erosion (Forman & Alexander 1998) which warrants the rapid reestablishment of vegetative cover. However, revegetating disturbed sites with non-native species has shown the potential to compromise adjacent ecosystems (Pysek et al. 1995). Non-native species can alter water and fire regimes, damage natural resources, increase soil nitrogen levels, release toxic chemicals, harbor diseases, and displace native species that are vital for herbivore consumption (Pysek et al. 1995; National Park Service 1996). In addition, non-native species may be more susceptible to stress and may interfere with the recruitment and establishment of native species (Wilson 1989; Jefferson et al. 1991; Tyser et al. 1998). Consequently, the use of native species for rehabilitation is preferable to that of non-native species for both ecological and aesthetic reasons (Tyser et al. 1998) because a mixture of native species more closely resembles the natural plant communities present before disturbance than does a mixture or monostand of non-native species.

Some of the non-native species that invade roadsides are listed as noxious weeds and, by law, must be controlled. The Federal Noxious Weed Act, enacted in 1975, mandates that both private landowners and government agencies apply control measures for species designated as "noxious." Applying chemical control is one potential method of controlling noxious weeds. However, herbicides are expensive and may not be labeled for use in sensitive areas (such as those near water). Therefore, pre-empting the establishment of noxious weeds as well as other unwanted non-natives has great potential economic and ecological benefits.

Revegetating roadside corridors after extensive disturbance with native species is a potential method of preventing the establishment of non-native species and noxious weeds. In fact, Rentch et al. (2005) found that the composition of species after rehabilitation was most likely to be influenced by the species initially planted during rehabilitation. Therefore, the rapid establishment of native species could preclude the establishment of non-native ones (Bugg et al. 1997; Rentch et al. 2005). Indeed, Booth et al. (2003) demonstrated that, once established, native perennial grasses have shown the ability to suppress non-native annual species. Accordingly, the rapid establishment of non-native species (particularly noxious weeds) has been cited as grounds for prompt rehabilitation efforts with native species (Tyser et al. 1998) because correctly chosen native species (i.e., those from the same ecoregion) do not pose a threat to the biodiversity of adjacent plant communities (Berger 1993; Wilson and Gerry 1995; Grant et al. 2003). Additionally, native species are more suited to local environments and require less maintenance (Humphrey & Schupp 2002). Accordingly, the within species genetic variance of native grass species and the importance of using a locally appropriate seed source has been well documented (Quinn & Ward 1969; Akeroyd 1994; Lippett et al. 1994; Millar & Libby 1994; Knapp & Rice 1996; Bugg et al. 1997; Montalvo et al. 2002; Landis et al. 2005).

It is difficult to rapidly mimic all of the environmental and biological conditions that have created a diverse stable community during the course of a rehabilitation project. Accordingly, post-rehabilitation communities often differ from their pre-disturbance conditions (Ehrenfeld 2000; Maina & Howe 2000). To minimize this post-restoration difference, optimal methods to plant and establish native species must be delineated to ensure establishment success. There are many potential methods of establishment. Broadcast seeding is inexpensive, but establishment is very slow and weeds tend to be prevalent (Beard & Green 1994). Imprinting and drill seeding are successful methods, but the required use of large machinery precludes the use of these methods in small areas or on steep slopes (Caltrans 2004). Hydroseeding may be a successful method of native species establishment depending on site-specific characteristics. Hydroseeding is more expensive than broadcast seeding, drill seeding or imprinting, but can be used on very steep slopes (Caltrans 2004). All of these methods result in increased erosion and weed proliferation before the seeded species become established (Caltrans 2004). The same is true for plugging, but it is very labor-intensive and even more expensive (Caltrans 2004). Each of these methods has advantages and disadvantages; however, a common disadvantage persists for all of these methods. Broadcast seeding, imprinting, hydroseeding, drill seeding and plugging all result in delayed vegetation establishment and, consequently, the potential for weed proliferation (Caltrans 2004).

2.2. Use of Sod in Revegetation Projects

One potential method for rapidly revegetating roadsides with native species is the use of sod. Sod installation has long been used to rapidly establish turfgrass in home and commercial landscape settings (Beard & Rieke 1969; Beard & Green 1994). Despite the fact that sod has been used to quickly establish grass cover in lawns and commercial landscapes, only limited research has been done on its use as a rehabilitation tool. Montana State University began research with native grass sod for highway stabilization in the 1970s. Jensen and Sindelar (1979) used a “dryland-sodding machine” to extricate rangeland sod four to eight centimeters thick composed of western wheatgrass (*Elymus smithii*), Kentucky bluegrass (*Poa pratensis*), or inland saltgrass (*Distichlis spicata*). These sods were applied to highway construction disturbances that required rapid stabilization due to high erosion potential. The Kentucky bluegrass sod was the most effective for site stabilization due to a thick fibrous root mat. The western wheatgrass sod provided an effective erosion control mat, but lack of a thick fibrous root mat necessitated careful handling so that it would not break apart during transplant efforts. The inland saltgrass sod was not effective primarily due to poor survival. These results prompted the U.S. Forest Service to engineer the Sod Mover Bucket at the Missoula Equipment Development Center in 1980. The bucket fit on a front-end loader and was used to extricate two meter by four meter slabs (10-20 cm thick) of native grass sod and shrubs. These slabs were then placed in strategic patterns on an adjacent highway construction project. Results pertaining to establishment and aesthetics were encouraging, but cost was notable and transplant-slabs raised concern that the borrowed areas served to increase the land disturbance.

A major step forward occurred in 2001 when Montana State University (MSU), in association with Bitterroot Turf Farms, Corvallis, Montana, propagated ten hectares of two native grass sod types for use in land reclamation projects. One sod was composed of a mix of western wheatgrass, thickspike wheatgrass (*Elymus lanceolatus*), Idaho fescue (*Festuca idahoenis*) and Canada bluegrass (*Poa compressa*). The other sod was developed for wetland landscapes and was composed of beaked sedge (*Carex rostrata*). In Spring 2003, MSU (Dollhopf, Dougher and Stone 2003) established test plots in a 33 centimeter precipitation zone on a south-facing highway construction fill with a 40% slope gradient. At the same site, the native grass sod mix was compared to broadcast seeding, using the Montana Department of Transportation native grass seed mix for that region, covered with a hydromulch, and broadcast seeding covered with an erosion control blanket. The highway fill site had no topsoil applied and was composed of unconsolidated geologic sediments. The native grass sod was irrigated on the day of plot construction, but no supplemental water was added after that date. At peak plant growth during Summer 2003 perennial grass production on native grass sod plots was 15-135 times greater than broadcast seeding methods. Weed invasion on native grass sod plots was zero, while both perennial and annual forb weed species established in broadcast seeded plots covered with either the erosion control blanket or hydromulch. Both perennial plant basal and canopy cover was 95.8% on the native grass sod plots compared to 2-8% for broadcast seeded plots.

The California Department of Transportation (Caltrans) (2004) conducted limited experimentation with monostands of native grass sod. This sod showed promise for reducing erosion and potentially reducing weed seed recruitment. Stone (2004) showed that native sod installed on steep slopes was capable of reducing soil runoff and erosion in comparison to broadcast seeding with either a hydromulch or straw blanket cover. The installation of native sod showed promise as a future rehabilitation tool, particularly for areas with steep slopes and those with a large non-native species seed bank, where rapid rehabilitation is essential.

Though sod installation is labor intensive and initially more expensive (Hottenstein 1969), sod has been shown to cover the ground more rapidly than broadcast seeding (Beard & Rieke 1969; Beard & Green 1994). Additionally, by covering the existing seed bank, weed germination and establishment are reduced compared to broadcast seeding (Beard & Green 1994; Caltrans 2004), which could potentially reduce the amount of chemical controls necessary to combat weed establishment. Research has shown that sod used for erosion control applications can remove up to 99% of the total suspended solids in runoff (USEPA 2002). In Maryland, Krenitsky et al. (1988) compared runoff and sediment loss on turf (bluegrass) grass slopes (8-21% gradient) to slopes treated with wood excelsior, jute fabric, coconut fiber blanket, coconut strand mat and straw. Using simulated rainfall, sod reduced runoff rates 54-59% more than all other treatments. McGinnies and Wilson (1982) evaluated blue gramma (*Bouteloua gracillis*) sod for rangeland revegetation in Colorado. Different sites were covered with sod from May through August and each was irrigated. They concluded that sod should be wetted prior to cutting, and sod placement should be done early in the growing season then irrigated as soon as possible following placement. In Australia, Jimbomba Turf Group (2004) developed Stayturf® which is a turfgrass designed to line channels where concentrated water flow is expected. This product consists of turfgrass growing in an organic geotextile mat supported with a polymer netting. It is intended to line water conveyance channels and replace some types of rock and concrete water drop structures on highway projects.

The advent of new technologies that allow sod to be harvested and installed mechanically may render the commercial production of native sod more feasible. 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 rehabilitation management tool.

Prior research suggests that a mixture of species more closely resembles native vegetation (Bugg et al. 1997) and is more appropriate than a monoculture for ecological and aesthetic reasons (Tyser et al. 1998). In addition, niche theory suggests that community assembly is based on competition and that multiple species are present to the extent that they occupy different niches (Tilman 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 because of pre-emptive niche occupation. Therefore, including a greater number of species in rehabilitation sod may lead to more rapid and complete ground cover and to greater potential weed suppression capabilities as different species occupy different niches.

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3. EVALUATION OF CALIFORNIA NATIVE GRASS SPECIES FOR SOD DEVELOPMENT

3.1. Introduction

The objective of this part of this study was to evaluate a number of native grass species and reinforcement materials for their suitability for contributing to a harvestable multispecies sod for roadside rehabilitation. The initial evaluation for determining native grass species was performed using species from six different ecoregions of California. The second evaluation, for determining suitable reinforcement materials, was conducted on native grass species for three of those ecoregions. Evaluations were performed using sample plantings in a greenhouse setting. Basic species evaluation was done using biomass, species abundance, and total ground cover. Reinforcement materials were evaluated with respect to effect on sod strength for different seeding densities.

3.2. Evaluation of Multispecies Sod for Each Ecoregion

3.2.1. Materials and Methods

3.2.1.1. Species Selection

Native grass species selections were performed for each of six selected Californian ecoregions: Pacific Forest, Chaparral, California Grasslands, Intermountain Sagebrush, Sierran Forest, and Great American Desert, as defined by Jepson (Hickman 1993). Selection of the most appropriate species for inclusion in our study included evaluations of habitat requirements, geographic distribution, and typical elevational range, which was achieved primarily by using the information in Hickman (1993), the Native Grass Database (Caltrans 2001) and United States Department of Agriculture, Natural Resource and Conservation Service (USDA, NRCS (2007)). The frequency of each species within each of the selected ecoregions was evaluated by determining the number of counties in which the species was present out of the total number of counties in the ecoregion. By combining frequency data with growth characteristics (rhizomatous, stoloniferous or bunchgrass), warm or cool season grass, and habitat preferences, the species most frequently found across counties and recorded in the widest range of habitats were selected. Some selected species could not be used because a commercial seed source could not be procured, which further reduced the number of species to those shown in Table 3.1.

All seed accessions were acquired from commercial enterprises that provided information on the locality of their seed collection. The seed source had to be within the intended ecoregion to meet our requirements. Two seed accessions used in the Great American Desert ecoregion—Indian ricegrass (*Achnatherum hymenoides*) and prairie junegrass (*Koeleria macrantha*)—were the exceptions and were from the Chaparral region because no seed could be commercially sourced from the Great American Desert. Nomenclature used in this document comes from the Native Grass Database (Caltrans 2001).

Table 3.1 Selected species for all ecoregions and their role in the chosen mixtures. For each ecoregion, RX, RY indicate species used for their rhizomatous growth habit. 3B indicates the three bunch-type species used in all mixtures. 5B indicates the two additional bunch-type species used when five bunch-type species were included.

	California Grasslands	Chaparral	Great American Desert	Intermountain Sagebrush	Pacific Forest	Sierran Forest
Achantherum hymenoides			3B			
Achnatherum occidentale				5B		
Aristida purpurea			5B			
Bromus carinatus	3B	3B			3B	5B
Elymus elymoides			3B	3B		3B
Elymus glaucus	3B	5B			3B	5B
Elymus multisetus				5B		
Elymus trachycaulus		RX		RY	RY	RY
Festuca idahoensis					3B	
Festuca rubra	RY	RY			RX	RX
Hordeum brachyantherum						3B
Koeleria macrantha		3B	3B	3B	5B	
Leymus cinereus				3B		
Leymus condensatus			RX			
Leymus triticoides	RX			RX		
Melica californica	5B				5B	
Muhlenbergia rigens						3B
Nassella cernua	3B		5B			
Nassella lepida		3B				
Nassella pulchra	5B	5B				
Pleuraphis rigida			RY			

3.2.1.2. Experimental Design

Six seed mixtures were chosen for each ecoregion, with the exception of the Great American Desert ecoregion, which had two mixtures. The six different mixtures for each ecoregion were as follows: rhizomatous species X (RX) and the three most frequent bunchgrass species (3B) (i.e., RX3B); rhizomatous species Y (RY) with the same three bunchgrass species (i.e., RY3B); rhizomatous species X (RX) with the same three bunchgrass species, plus a the next two most frequent bunchgrass species (5B) (i.e. RX5B); rhizomatous species Y (RY) with the same five bunchgrass species (i.e., RY5B); rhizomatous species X and Y (RXY) with the first three bunchgrass species (i.e., RXY3B); and, lastly, rhizomatous species X and Y (RXY) with all five bunchgrass species (i.e., RXY5B). The experiment was set up as a complete randomized block with three replications.

Only two mixtures, RX3B and RX5B, were planted for the Great American Desert ecoregion with nine replications in a completely randomized design. This reduction of mixtures evaluated was due to the fact that the RY species, big galleta (*Pleuraphis rigida*), was eliminated from the study after preliminary tests revealed poor germination.

3.2.1.3. Growth Chambers

Six polycarbonate growth chambers with wood framing and 1.5 m x 1.8 m x 0.9 m were constructed to mimic the climate of each of the six selected California ecoregions for the seven-month growing period when sod is most likely to be grown. These growth chambers were then placed in a greenhouse. Horizontal air flow (HAF) fans 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 to permit the spread of heated air throughout the chamber. Two cooling fans were placed in diagonally opposite corners of each chamber to pull air from the greenhouse into the chambers in order to cool them when necessary due to a "double greenhouse effect" caused by the growth chambers being inside a greenhouse. All fans used were axial fans (4WT46, Dayton Electronic Manufacturing Company, Niles, Illinois) rated at 115 CFM.

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. Algae removal was also performed when necessary.

Each chamber was 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) that were used to control the heating, cooling, and humidification of the chambers.

3.2.1.4. Climate Control

Monthly settings for each growth chamber were determined by calculating the mean minimum and maximum temperature and mean relative humidity data from historical data obtained from the Western Regional Climate Center for weather stations within each respective ecoregion. These metrics were calculated for each month from September through March for the California Grasslands, Chaparral, Great American Desert and Pacific Forest ecoregions, and from March through September for the Intermountain Sagebrush and Sierran Forest ecoregions. Growing degree days (GDD) for cool season species were calculated based on baseline temperatures for wheat (5°C), while GDDs for warm season species were calculated based on baseline temperatures for corn (10 °C). Day and night relative humidity and PAR ($mol \cdot m^{-2} \cdot day^{-1}$) were also recorded for each ecoregion.

3.2.1.5. Sowing and Establishment

Eighteen round black plastic pots (30.5 cm diameter and 35.5 cm deep) were arranged in a completely randomized design for each chamber. These pots were filled with a soil mixture of 1:1:1 ratio by volume containing Canadian sphagnum peat moss, washed concrete sand, and loam soil. AquaGro 2000 G wetting agent was blended in at a rate of 0.59 kg per cubic meter 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.

Germination tests were performed on all seed lots prior to sowing to determine accurate seeding rates. Pots were seeded at a rate of 5,382 pure live seed per meter squared (PLS/m^2) based on research by Burton et al. (2006), which suggests that higher sowing densities result in more rapid ground cover. Each species was equally represented by dividing the seeding rate by the number of species to determine the rate for each species. 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. The soil was kept evenly moist until the seeds germinated. Volunteer dicot species (mostly clover (*Melilotus* ssp.)) and grass species (mostly downy brome (*Bromus tectorum*)) were removed by hand.

Pots were checked daily and hand-watered as needed. Pots in each ecoregion were re-randomized at each mowing. Each mixture 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 N/m^2, one at 60 days after planting (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.

3.2.1.6. Measures of Growth

Each mixture was grown for a period of seven months and was clipped to 8 cm above the soil surface at two-week intervals. Clippings were bagged, dried for 48 hours at 50ºC then weighed to determine clipped dry biomass. Once the clippings were removed, the percent cover of each species and total ground cover within each pot were visually estimated for each mixture of species and harvest date. These assessments were not conducted at the first two harvests of the Pacific Forest and Chaparral ecoregions, nor at the first harvest of the California Grasslands ecoregion. Red fescue (*Festuca rubra*) and Idaho fescue (*Festuca idahoensis*) were extremely difficult to differentiate in the greenhouse and thus were pooled together for the purpose of percent species composition for the Pacific Forest ecoregion—the only region in which they were planted together. In the California Grasslands ecoregion, purple needlegrass (*Nassella pulchra*) and nodding needlegrass (*Nassella cernua*) were also pooled because of difficulty distinguishing between the two species in the greenhouse.

3.2.1.7. Data Analysis

Clipped dry biomass, species abundance (percent cover), and total ground cover (percent) were the response variables used for analysis. For species occurring in more than one ecoregion, analysis of variance (ANOVA) with repeated measures statements was used to compare differences in abundance between ecoregions. Where significant differences existed, data from the differing ecoregion(s) were separated. Data from all other ecoregions were combined.

Linear regression was performed using accumulated growing degree days as a predictor of percent species abundance.

All statistical analyses were performed using SAS (SAS Institute, Cary, North Carolina). In order to account for temporal autocorrelation, ANOVAs were conducted using repeated measures statements with the PROC MIXED procedure using an autoregressive correlation structure as described by Littell (1998).

3.2.2. Results

3.2.2.1. Climate Control

The growth chambers representing each ecoregion were all located in the same greenhouse; desired temperature settings could not be consistently achieved for every ecoregion simultaneously due to the vast range in temperatures between ecoregions. For this reason daytime temperatures were generally higher or lower than the intended set point. In addition, night temperatures were warmer than the temperature settings because temperatures could not fall below the minimum greenhouse setting due to greenhouse climate control system limitations. Monthly temperature settings and mean day and night temperatures for each ecoregion are reported in Table 3.2.

Mean accumulated daily PAR ($mol \bullet m^{-2} \bullet day^{-1}$), monthly accumulated GDD, and day and night relative humidity are reported in Table 3.3 for each month and each ecoregion. Despite some differences between desired temperature settings and achieved temperatures, the chambers accomplished their purpose of creating different environments for each ecoregion in terms of relative humidity and temperature as evidenced by significant differences between chambers in both relative humidity and temperature ($p < 0.0001$ for both—data not shown).

Table 3.2 Day and night temperature settings and achieved mean day and night temperatures (°C) and standard deviations by month for each ecoregion.

California Grasslands

	Day Temp. (°C)		Night Temp. (°C)	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	32	24.5 ± 2.19	14	16.3 ± 3.04
Month 2	26	24.7 ± 2.40	10	18.2 ± 4.15
Month 3	18	21.4 ± 3.43	6	12.3 ± 2.86
Month 4	13	21.4 ± 3.59	3	11.1 ± 0.79
Month 5	13	21.4 ± 3.52	3	11.4 ± 0.64
Month 6	16	23.7 ± 3.91	5	11.6 ± 0.59
Month 7	19	24.2 ± 2.98	6	16.4 ± 3.38

Chaparral

	Day Temp. (°C)		Night Temp. (°C)	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	27	23.3 ± 3.07	12	12.8 ± 1.12
Month 2	25	22.0 ± 2.18	9	12.9 ± 1.50
Month 3	19	24.2 ± 3.62	6	19.0 ± 3.76
Month 4	16	22.9 ± 4.07	3	10.9 ± 0.80
Month 5	16	23.3 ± 4.37	4	11.0 ± 0.85
Month 6	17	24.2 ± 4.84	5	11.1 ± 0.64
Month 7	19	28.0 ± 4.99	6	13.3 ± 3.76

Great American Desert

	Day Temp. (°C)		Night Temp. (°C)	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	31	27.4 ± 3.04	15	17.1 ± 3.22
Month 2	25	24.6 ± 1.34	9	11.6 ± 0.72
Month 3	18	20.8 ± 2.99	4	11.6 ± 0.70
Month 4	14	22.5 ± 3.35	0	11.5 ± 0.59
Month 5	14	24.0 ± 2.77	1	15.9 ± 3.94
Month 6	16	25.4 ± 3.57	2	13.7 ± 1.91
Month 7	18	26.9 ± 2.69	4	15.3 ± 1.26

Intermountain Sagebrush

	Day Temp. (°C)		Night Temp. (°C)	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	14	23.4 ± 2.01	-4	13.9 ± 2.53
Month 2	18	23.4 ± 2.54	-1	18.5 ± 4.76
Month 3	23	19.1 ± 2.90	3	11.8 ± 0.73
Month 4	28	20.2 ± 3.56	6	12.2 ± 0.68
Month 5	32	20.2 ± 3.24	9	11.9 ± 0.51
Month 6	31	22.5 ± 3.09	8	15.3 ± 3.89
Month 7	27	23.4 ± 2.90	4	13.4 ± 1.74

Pacific Forest

	Day Temp. (°C)		Night Temp. (°C)	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	22	21.0 ± 2.78	10	12.5 ± 1.13
Month 2	19	19.8 ± 1.70	8	14.4 ± 3.07
Month 3	15	22.5 ± 3.79	6	18.5 ± 3.72
Month 4	13	20.9 ± 4.05	4	10.3 ± 0.81
Month 5	13	20.8 ± 4.42	4	10.4 ± 0.91
Month 6	14	21.2 ± 3.85	5	10.5 ± 0.75
Month 7	15	23.6 ± 3.72	6	11.9 ± 3.63

Sierran Forest

	Day Temp. (°C)		Night Temp. (°C)	
	Set	Actual ± SD	Set	Actual ± SD
Month 1	11	23.9 ± 1.88	-1	17.6 ± 2.79
Month 2	15	23.1 ± 3.08	1	18.2 ± 4.55
Month 3	20	19.2 ± 3.10	4	11.4 ± 0.73
Month 4	25	20.5 ± 3.78	8	11.8 ± 0.62
Month 5	29	20.3 ± 3.41	10	11.7 ± 0.56
Month 6	29	22.5 ± 3.11	10	15.0 ± 3.93
Month 7	25	23.3 ± 2.87	7	13.7 ± 1.89

Table 3.3 Mean daily accumulated photosynthetically active radiation (PAR) (mol•m^{-2}•day^{-1}), monthly accumulated growing degree days (GDD) (computed using baselines of 5°C for cool season and 10°C for warm season species), and average day and night relative humidity (RH) by month for each ecoregion.

	California Grasslands					Chaparral				
	PAR	GDD		RH (%)		PAR	GDD		RH (%)	
		5°C	10°C	Day	Night		5°C	10°C	Day	Night
Month 1	4.5	442	-	26	39	3.9	365	-	36	48
Month 2	4.4	476	-	29	44	5.5	367	-	27	34
Month 3	5.4	347	-	30	40	5.7	476	-	29	46
Month 4	7.3	290	-	29	42	7.8	349	-	24	38
Month 5	8.9	339	-	36	49	9.8	317	-	26	41
Month 6	13.5	340	-	37	46	9.3	352	-	33	49
Month 7	12.6	401	-	57	70	15.6	477	-	37	50
Total		**2636**					**2703**			

	Great American Desert					Intermountain Sagebrush				
	PAR	GDD		RH (%)		PAR	GDD		RH (%)	
		5°C	10°C	Day	Night		5°C	10°C	Day	Night
Month 1	6.1	518	358	22	36	6.1	411	-	23	34
Month 2	8.9	344	209	24	36	6.2	459	-	27	42
Month 3	9.1	339	184	32	43	6.6	327	-	27	34
Month 4	12.1	346	191	34	45	8.8	296	-	30	37
Month 5	13.9	397	257	50	59	8.0	323	-	37	45
Month 6	15.8	432	272	60	77	8.8	405	-	46	50
Month 7	12.2	418	278	57	72	10.1	390	-	59	72
Total		**2793**	**1748**				**2610**			

	Pacific Forest					Sierran Forest				
	PAR	GDD		RH (%)		PAR	GDD		RH (%)	
		5°C	10°C	Day	Night		5°C	10°C	Day	Night
Month 1	4.2	321	-	39	50	5.7	457	307	24	38
Month 2	5.6	344	-	30	39	4.0	447	297	30	45
Month 3	6.7	443	-	34	49	5.0	317	157	30	39
Month 4	8.7	309	-	29	43	6.7	289	149	33	43
Month 5	10.6	274	-	32	47	7.0	318	163	41	50
Month 6	10.5	311	-	38	53	8.6	399	244	48	54
Month 7	13.3	376	-	43	55	10.1	414	249	61	72
Total		**2378**					**2642**	**1567**		

3.2.2.2. Clipped Dry Biomass

Differences in the clipped dry biomass between mixtures over time (DAP) within an ecoregion could indicate that some mixtures established more rapidly than others. There were no significant sod composition (mixture) main effects for the California Grasslands, Chaparral, Great American Desert and Pacific Forest ecoregions, which indicated that there were no differences in clipped dry biomass between mixtures for these ecoregions. A significant DAP main effect merely indicated that biomass changed over the course of production, which was the case for all ecoregions.

For the Intermountain Sagebrush ecoregion, there was a significant sod composition by DAP interaction (p = 0.0308), which indicated that there were significant differences in dry biomass between mixtures at some harvests, but not at others. RX5B mixtures had significantly lower clipped dry biomass than all other mixtures from 100 through 128 DAP, but, from 156 DAP through the final harvest, there were no significant differences between mixtures (Fig. 3.1).

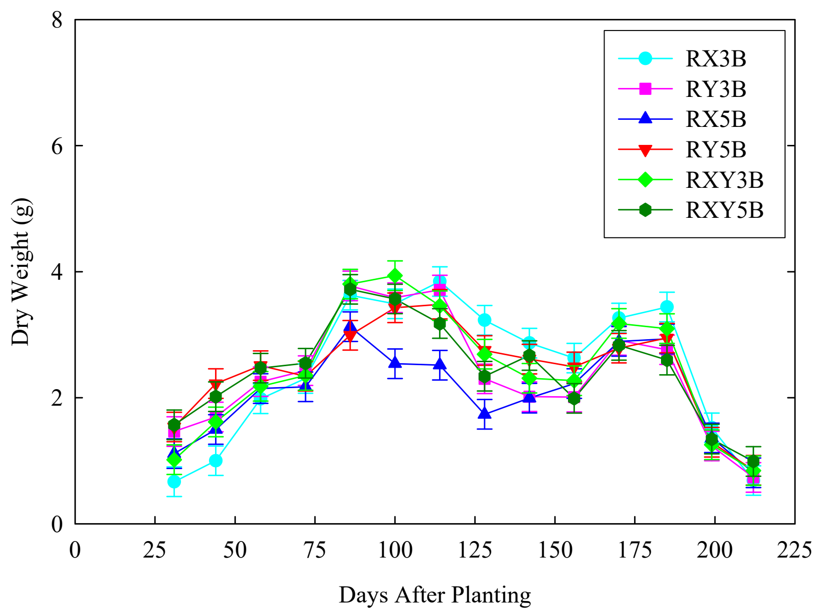

Figure 3.1 Effect of sod composition and days after planting on clipped dry weight for the Intermountain Sagebrush ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

There was also a significant sod composition by DAP interaction for the Sierran Forest ecoregion (p = 0.0199). RX3B mixtures were significantly lower from the first harvest through 74 DAP than all other mixtures. However, beyond 172 DAP, there were no significant differences between mixtures (Figure 3.2).

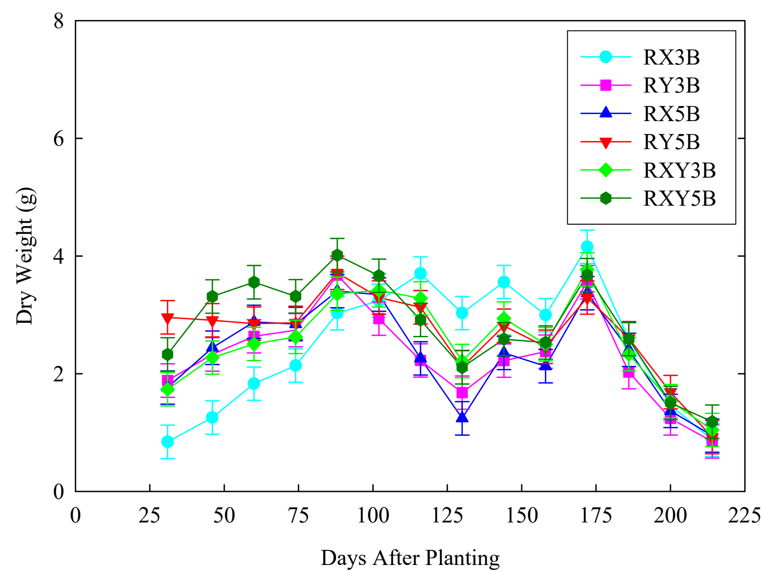

Figure 3.2 Effect of sod composition and days after planting on clipped dry weight for the Sierran Forest ecoregion mixtures. Points represent means and error bars represent standard errors from the SAS MIXED model.

3.2.2.3. Species Abundance

The contribution of individual species to a mixture's composition was evaluated by estimating the percent cover of each species within it. Species composition varied widely within and between mixtures as well as across ecoregions. Such variation was expected. Data for all ecoregions were initially analyzed together and where significant differences occurred, as determined by ANOVA, an ecoregion's data were regressed separately. Squirrel tail (*Elymus elymoides*), blue wildrye (*Elymus glaucus*), slender wheatgrass (*Elymus trachycaulus*), prairie junegrass (*Koeleria macrantha*) and California melic grass (*Melica californica*) were separated by ecoregion for this analysis and the response of these species for the different ecoregions is provided in Table 3.4. Cover of most species (16 of 20) increased significantly as growing degree days accumulated (Table 3.4, as indicated by an $r^2 > 0.20$ and $p < 0.0001$). Red fescue, prairie junegrass, California melic grass (California Grasslands ecoregion), deergrass (*Muhlenbergia rigens*), and nodding needlegrass (Great American Desert ecoregion) all had especially strong positive correlations ($r^2 > 0.50$). Cover for a few species, including blue wildrye (Chaparral ecoregion) did not change significantly as GDDs accumulated ($r^2 \leq 0.20$ and $p \geq 0.05$), while other species (particularly slender wheatgrass) changed significantly over GDDs, but very little of this variation was explained by a linear regression ($r^2 \leq 0.20$ and $p < 0.05$) (Table 3.4).

3.2.2.4. Total Ground Cover

Total ground cover changed significantly over the course of the experiment (DAP). A significant sod composition main effect indicated that some mixtures covered the ground more completely than others. For example, in the Great American Desert ecoregion, the sod composition main effect was significant (p = 0.0102), with RX5B mixtures having significantly greater total ground cover than RX3B mixtures (Figure 3.3b).

Neither the sod composition main effect nor the sod composition by DAP interaction were significant for the California Grasslands or Pacific Forest ecoregions. In terms of differences in total ground cover, there were no differences in sod establishment for these two ecoregions. At the final harvest, total ground cover averaged 72% for the California Grasslands ecoregion and 82% for the Pacific Forest.

Table 3.4 Summary of regression of individual species percent cover and accumulated growing degree days.

Species	Ecoregion(s)	r^2	f Value	p > f
Achnatherum hymenoides	Great American Desert	0.33	123.47	< 0.0001
Achnatherum occidentale	Intermountain Sagebrush	0.01	2.55	0.1132
Aristida purpurea	Great American Desert	0.36	71.14	< 0.0001
Bromus carinatus	California Grasslands, Chaparral, Pacific Forest, Sierran Forest	0.34	415.72	< 0.0001
Elymus elymoides	Intermountain Sagebrush, Sierran Forest	0.00	2.26	0.1337
Elymus elymoides	Great American Desert	0.06	17.29	< 0.0001
Elymus glaucus	California Grasslands	0.01	3.73	0.0547
Elymus glaucus	Chaparral	0.09	11.45	0.0010
Elymus glaucus	Pacific Forest, Sierran Forest	0.02	6.18	0.0134
Elymus multisetus	Intermountain Sagebrush	0.40	82.93	< 0.0001
Elymus trachycaulus	Pacific Forest, Chaparral	0.07	23.50	< 0.0001
Elymus trachycaulus	Intermountain Sagebrush, Sierran Forest	0.01	4.81	0.0291
Festuca rubra	California Grasslands, Chaparral, Sierran Forest	0.55	566.22	< 0.0001
Festuca rubra/idahoensis	Pacific Forest	0.38	418.87	< 0.0001
Hordeum brachyantherum	Sierran Forest	0.36	143.72	< 0.0001
Koeleria macrantha	Chaparral, Pacific Forest	0.60	480.37	< 0.0001
Koeleria macrantha	Great American Desert, Intermountain Sagebrush	0.66	978.83	< 0.0001
Leymus cinereus	Intermountain Sagebrush	0.44	195.90	< 0.0001
Leymus condensatus	Great American Desert	0.48	230.07	< 0.0001
Leymus triticoides	California Grasslands, Intermountain Sagebrush	0.27	122.45	< 0.0001
Melica californica	Pacific Forest	-0.01	0.01	0.9233
Melica californica	California Grasslands	0.74	329.47	< 0.0001
Muhlenbergia rigens	Sierran Forest	0.66	490.94	< 0.0001
Nassella cernua	Great American Desert	0.62	206.89	< 0.0001
Nassella lepida	Chaparral	0.36	123.40	< 0.0001
Nassella pulchra	Chaparral	0.22	30.82	< 0.0001
Nassella pulchra/cernua	California Grasslands	0.21	63.14	< 0.0001

Significant sod composition by DAP interactions occurred for the three remaining ecoregions (Chaparral, Intermountain Sagebrush and Sierran Forest), indicating either changes in rank order or differences between mixtures in total ground cover at some clipping dates, but not others. There was a significant sod composition by DAP interaction for the Chaparral ecoregion (p = 0.0035). RX3B mixtures had significantly greater total ground cover than all other mixtures at

159 DAP, while RX5B mixtures had significantly less total ground cover than all other mixtures at 117 and 159 DAP. Beyond 159 DAP, there were no significant differences in total ground cover between mixtures (Figure 3.3a).

There was a significant sod composition by DAP interaction for the Intermountain Sagebrush ecoregion ($p < 0.0001$). Minor variations in total ground cover occurred early on, but major differences were present beginning at 100 DAP (Figure 3.3c). 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.

There was also a significant sod composition by DAP interaction for the Sierran Forest ecoregion ($p < 0.0001$). Ground cover of all mixtures linearly increased until 100 DAP when ground cover percentages plateaued (Figure 3.3d). Ground cover for five bunchgrass mixtures was significantly greater than mixtures with only three bunchgrasses. Beyond 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 bunchgrasses were similar in ground cover throughout the experiment, while the ground cover rank of mixtures with three bunchgrasses fluctuated throughout the growing period.

3.2.3. Discussion

Natural plant communities are commonly species-diverse, and this diversity is regarded as essential to the stability of these communities (Tilman 1996) and often to their ability to resist disturbance and invasion (Elton 1958; Tilman 1997; Brown et al. 1998; Levine and D'Antonio 1999; but see Stohlgren et al. 1999; Stohlgren et al. 2003). When a major disturbance does occur, it opens a pathway to a drastic shift in community assemblage (Mouquet et al. 2003; but see Connell 1978; Huston 1979). Over time, the progression of re-colonization generally moves from annuals and biennials to perennial species (Grime 1979). During this period, plant communities are more susceptible to change and invasion (Hobbs & Huenneke 1992). This time period offers an opportunity for a diverse native community to be replaced by non-native species.

Thus, in accordance to native community ecology, native rehabilitation sod should be composed of as many species as possible to increase its versatility and adaptability to varied installation sites and to mimic the diversity found in many natural communities. However, limitations imposed by a species habit, seed availability, soil moisture and texture, etc. may greatly limit the number of species that may be included in a rehabilitation sod. This supports Ehrenfeld's (2000) stand that restoration goals must be realistic because it is impossible to mimic all of the events that have contributed to the pre-disturbance state of a plant community during the course of a restoration project.

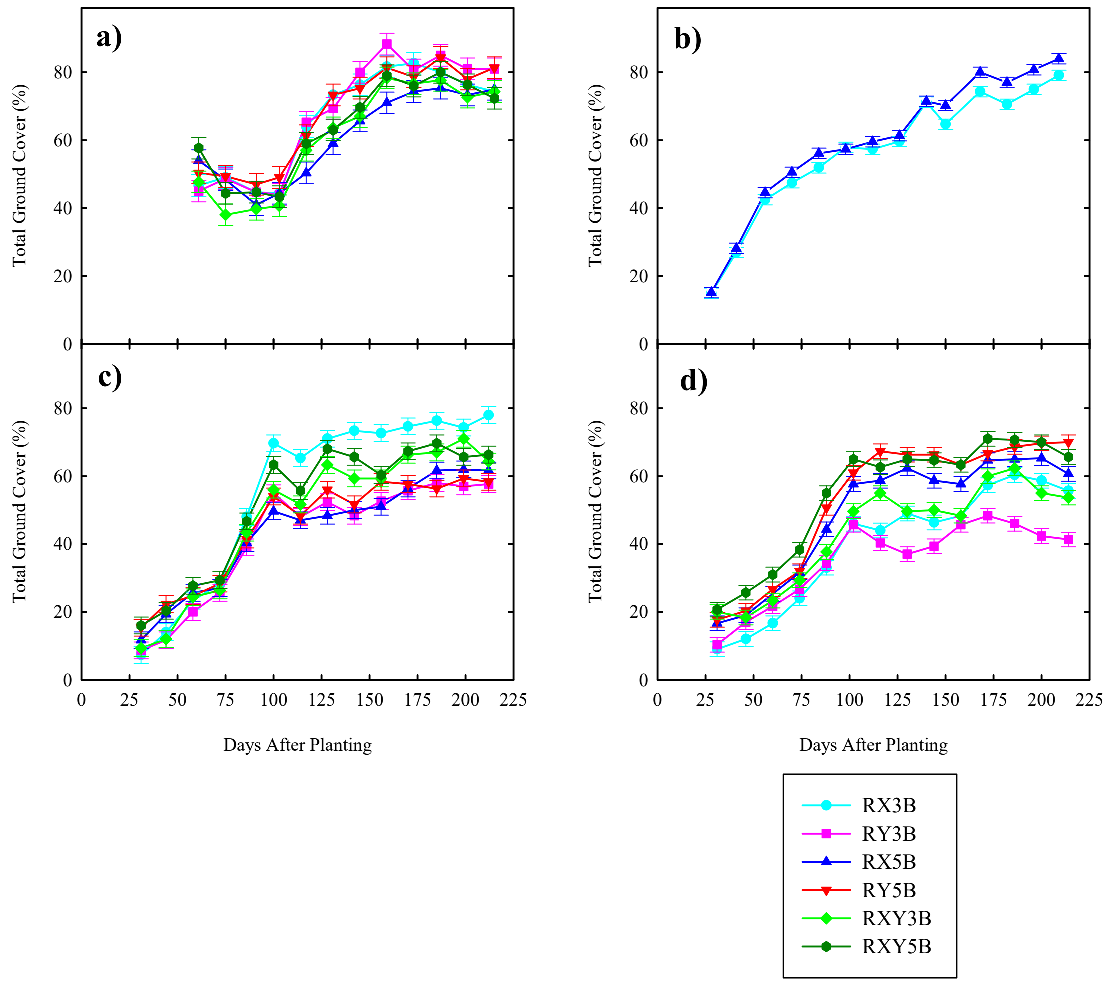

Figure 3.3 Effect of sod composition and days after planting on total ground cover for the a) Chaparral, b) Great American Desert, c) Intermountain Sagebrush, and d) Sierran Forest ecoregions. Points represent means and error bars represent standard errors from the SAS MIXED model.

The majority of species we studied increased significantly in abundance over time, as evidenced by the significant positive correlation between accumulated GDDs and percent abundance. A few species, such as blue wildrye, squirrel tail and slender wheatgrass, persisted at moderate percentages (5 to 10%) over the course of the experiment. However, we would not recommend that such species be excluded from native sod mixtures as we would envisage that the composition of a sod would change over time, depending on where it was laid. In addition, with regard to the vacant niche hypothesis having a diverse number of species in the sod would increase the number and type of niches and resources being exploited which could reduce the establishment of undesired species from seed.

Germination requirements of seeds is another consideration; for our experimental purposes we did stratify species that required it prior to sowing but this would be more difficult in commercial situations. For example, even though there was a significant positive correlation between accumulated GDDs and Indian ricegrass cover, the species made up less than 3% of the total ground cover at the final harvest of Great American Desert samples. This is likely because Indian ricegrass requires a 60-day cold stratification for germination. This stratification was performed prior to sowing but still resulted in minimal germination. In a commercial production setting it may be necessary to sow Indian ricegrass in the fall prior to spring sowing of the remaining species. The capacity to achieve this is unknown but should be investigated for this and other species requiring cold stratification for germination.

Some warm season species may also require special consideration. Deergrasss is a warm season species and did not begin to establish until nearly 1,000 GDDs had accumulated. However, purple three-awn grass (*Aristida purpurea*), another warm season species began to establish immediately. Either deergrass required more GDDs to establish (such information was not located) or this seed lot performed poorly in general.

Different performance of the same individual species sown in different mixtures and ecoregions was observed. California melic grass cover did not increase significantly over GDD in the Pacific Forest ecoregion, and cover at cover increased significantly as GDDs accumulated and final percentages ranged from the final harvest ranged from 2-5%. However, in the California Grasslands ecoregion, California melic grass 16-36%. In constrast, there was no significant difference in blue wildrye cover between the Pacific Forest and Sierran Forest ecoregions. In both cases, seed from the relevant ecoregion was used but our experimental design did not allow us to evaluate the relative role of seed source versus interspecific competition.

There was no obvious direct relationship between total ground cover and species diversity. The performance of individual species more readily explained differences between mixtures in total ground cover than did species diversity. For example, the decline of particular species in the Intermountain Sagebrush (western needlegrass (*Achnatherum occidentale*), slender wheatgrass, and squirrel tail), and Sierran Forest ecoregions (slender wheatgrass, squirrel tail, and blue wildrye) reduced total ground cover for the mixtures in which they were included as compared to mixtures in which they were not. When two or more of these species were present in the same mixture, the effect was compounded.

For the Great American Desert ecoregion, differences in total ground cover between mixtures seemed to be an artifact of the "sampling effect" (i.e., the occurrence of a particularly productive species that dominated the overall pattern) as originally suggested by Aarssen (1997) and Huston (1997) (see Wardle 2002). In the Great American Desert ecoregion, nodding needlegrass was very productive and made up a large percentage of total ground cover. This species was only included in the RX5B mixtures, which likely explains the significantly greater total ground cover of these mixtures. However, this same effect was not observed in the California Grasslands ecoregion, but this could be explained by differences in interspecific competition and/or seed source for the two ecoregions.

3.2.4. Conclusions

Although species do not perform equally in terms of percent cover and biomass production, seeding as many species as possible should aid in the diversity of sod. When grown for seven months (essentially the establishment phase for sod production in California), there appeared to be no difference in establishment success of mixtures that contained four to seven species as indicated by total ground cover. Accordingly, as long as a species does not fail to establish or disappear over the course of sod production, they should be included in the initial mix to ensure ecological versatility and overall diversity in the native rehabilitation sod. This study has demonstrated the capacity for producing native multispecies sod and its potential for use as a rehabilitation tool in these six ecoregions. The methods and results of this study could also be expanded in order to produce native multispecies sod for use in other geographical areas.

These results have several important implications for practice including:

- Native grass sod mixtures can mimic the diversity of native ecosystems while providing a method for rapid rehabilitation and restoration.
- Mixtures of native grass species can be grown together and harvested as sod.
- Native grass sod provides immediate soil surface stabilization and plant cover and can be used in areas where rapid rehabilitation is required.
- Theoretically, native grass sod for restoration should be composed of many species. However, native grass seed availability is limited. As demand for native grass seed increases, more consistent sources of quality native seed will be required.

3.3. Native Grass Species Mix and Plant Density Evaluation

In light of the results of the previous experiments evaluating multispecies sod, the research team selected the best species mixes for three ecoregions for further evaluation. At the same time these recommendations were sent to nursery collaborators so these sod mixes could be grown in sufficient quantity to establish test plots.

3.3.1. Materials and Methods

The three selected ecoregions were Sierran Forest, Pacific Forest, and Chaparral. The selection criteria used to determine these ecoregions focused on areas within California that showed the greatest need for native sod to treat storm water run-off. Caltrans officials and the MSU native grass sod project team collaborated on this determination. The best sod mixes from each region (Table 3.5) were grown on 1.2 m x 1.5 m (4 ft x 5 ft) plots under California environmental conditions and sod production standards. Each ecoregion mix was grown at two densities, 500 PLS/ft^2 (same as the multispecies evaluation conducted previously) and 1,000 PLS/ft^2. A reinforcement material, biodegradable coconut blanket comprised of 100% coir fiber coconut with biodegradable double jute netting (1.5 inch thread spacing), was added at harvest in accordance with sod harvesting general practices. At eight months, the sod was harvested and tested for sod strength (Figure 3.4).

Table 3.5 Species mixes used for each ecoregion in establishment success and weed suppression experiments.

Native Grass Species Selected for Three Ecoregions		
Pacific Forest	Sierran Forest	Chaparral
Festuca rubra	*Festuca rubra*	*Festuca rubra*
Elymus trachycaulus	*Muhlenbergia riggen*	*Elymus trachycaulus*
Bromus carinatus	*Elymus elymoides*	*Bromus carinatus*
Festuca idahoensis	*Horeum brachyantherum*	*Nassella lepida*
Elymus glaucus		*Koeleria macrantha*

Figure 3.4 Early growth of 1.2 m x 1.5 m plot of the high density Chaparral mix (left) and early growth of 1.2 m x 1.5 m plot of the low density Sierran Forest mix (right).

3.3.2. Results

Similar to the results from the multispecies experiment, sod from the Pacific Forest ecoregion produced the highest sod strength. In all three ecoregions, the higher seeding density increased sod strength (Figure 3.5). Native grass sod most likely benefited from a higher seeding rate when compared to traditional non-native sod because native grass growth habits are less aggressive rhizomatous and bunch types. These growth habits will not become denser with time as will traditional non-native species. Therefore, the initial seeding rate of native grass sod will need to be higher to construct a sod as strong and dense as non-native species. Reinforcement materials for sod were further tested for sod establishment and weed suppression.

3.3.3. Conclusion

Native grass seed at this juncture can be prohibitively expensive. In the initial experiment, multispecies sod growth efforts produced some sods with adequate sod strength. For the Pacific Forest region, the standard 500 PLS/ft^2 should be adequate. For all other ecoregions, a higher seeding rate should be considered.

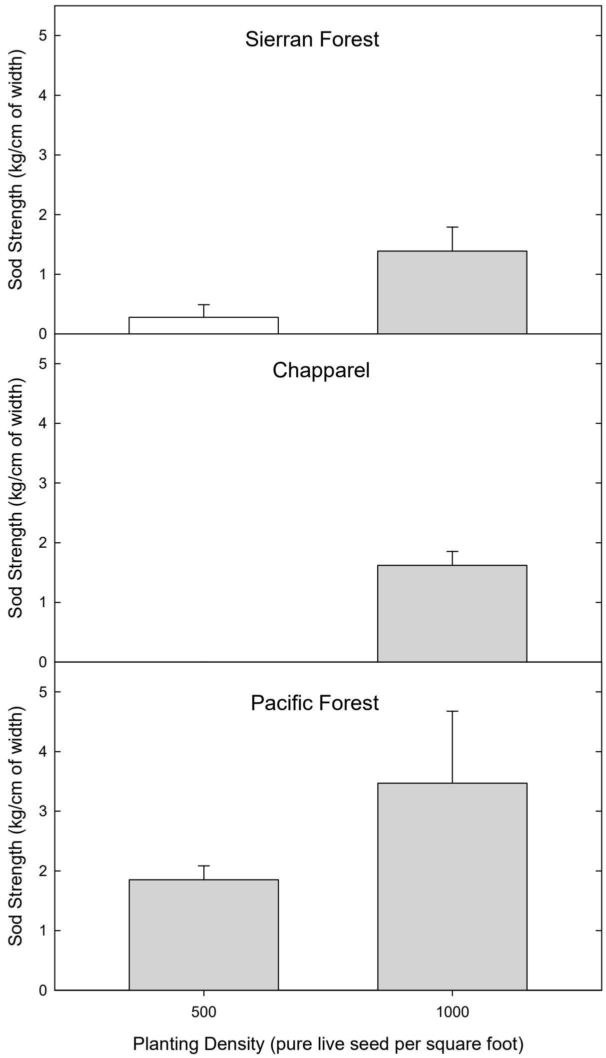

Figure 3.5 Effect of planting density on the sod strength of native grass mixes for the Sierran Forest, Chaparral, and Pacific Forest ecoregions.

3.4. Native Grass Species Mix and Reinforcement Evaluation

Additional experiments were conducted on the native grass sods grown in the experiment described above to further study their performance when transplanted onto deep soil beds (similar to the situation encountered in actual field deployment). These experiments were done both with and without reinforcement material.

3.4.1. Materials and Methods

Sod of the Chaparral, Sierran Forest, and Pacific Forest ecoregions were cut into six 0.37 m x 0.38m pieces (14.5" x 15" pieces). The sod was grown in the experiment discussed in Section 3.3 of this report at a high (1000 PLS/ft^2) and low (500 PLS/ft^2) initial seeding density. The sod pieces were transported onto deep soil beds mimicking the soil of a roadside. Three pieces of each ecoregion sod were placed over a reinforcement mat (Excelsior® recycled wood product with a biodegradable string added at harvest in accordance with the general practice of sod harvesting) or over bare ground. One hundred weed seeds (canola) were planted beneath each of the sod pieces with and without reinforcement material. Sod was watered in at the beginning. The sod was then only watered intermittently to coincide with natural rainfall for the ecoregion. The sod was grown for 6 months. Each month, information was collected on species diversity, percent green coverage, percent ground coverage, number of weeds, and percent cover of weeds. Six months after transport, weeds, weed pods, and above ground biomass were harvested, dried, and weighed.

Figure 3.6 Three deep soil boxes each with 12 transported sod pieces (both high and low initial planting density) on reinforcement mats or bare ground. Dried weeds can be seen breaking through the sod.

Figure 3.7 The transported sod and invasive weed biomass of the Pacific Forest ecoregion at termination of the experiment.

3.4.2. Results

3.4.2.1. Chaparral

The initial planting density greatly affected the sod composition. The majority species in the high density sod was red fescue (*Festuca rubra*) while the majority in the low density sod was California brome (*Bromus carinatus*) (Figure 3.8A). The reinforcement mat did not affect weed suppression, but rather a higher initial planting density reduced the number of weeds and the percent weed coverage (Figure 3.8B). Weed biomass production was higher under low density sod, but the overall grass biomass was not significantly different (Figure 3.8C). The presence or absence of reinforcement mat did not affect weed or grass biomass production.

3.4.2.2. Sierran Forest

The initial planting density affected many parameters of the Sierran Forest sod, while the reinforcement mat affected only red fescue percent sod composition and percent bare ground. There was a higher percentage of red fescue at low density and treatments without mats (Figure 3.9), while bare ground made up for the difference rather than filling in with other species (Figure 3.10). Contrary to our hypothesis, the low planting density suppressed more weeds and weed cover (Figure 3.11A). This was also reflected in the final harvest weed biomass (Figure 3.11B). It was evident that the higher percent bare ground at the high initial planting density allowed weed germination and growth.

3.4.2.3. Pacific Forest

From the previous experiments, it was evident that sod from the Pacific Forest ecoregion was the easiest to establish and was the strongest sod. Weed suppression characteristics were clearly significant while all other parameters were not. Both high initial planting density and the presence of reinforcement material aided in the suppression of weeds (Figure 3.12A, 3.12B). The final harvest biomass revealed that initial planting density affected weed biomass, but grass biomass was unaffected (Figure 3.12C).

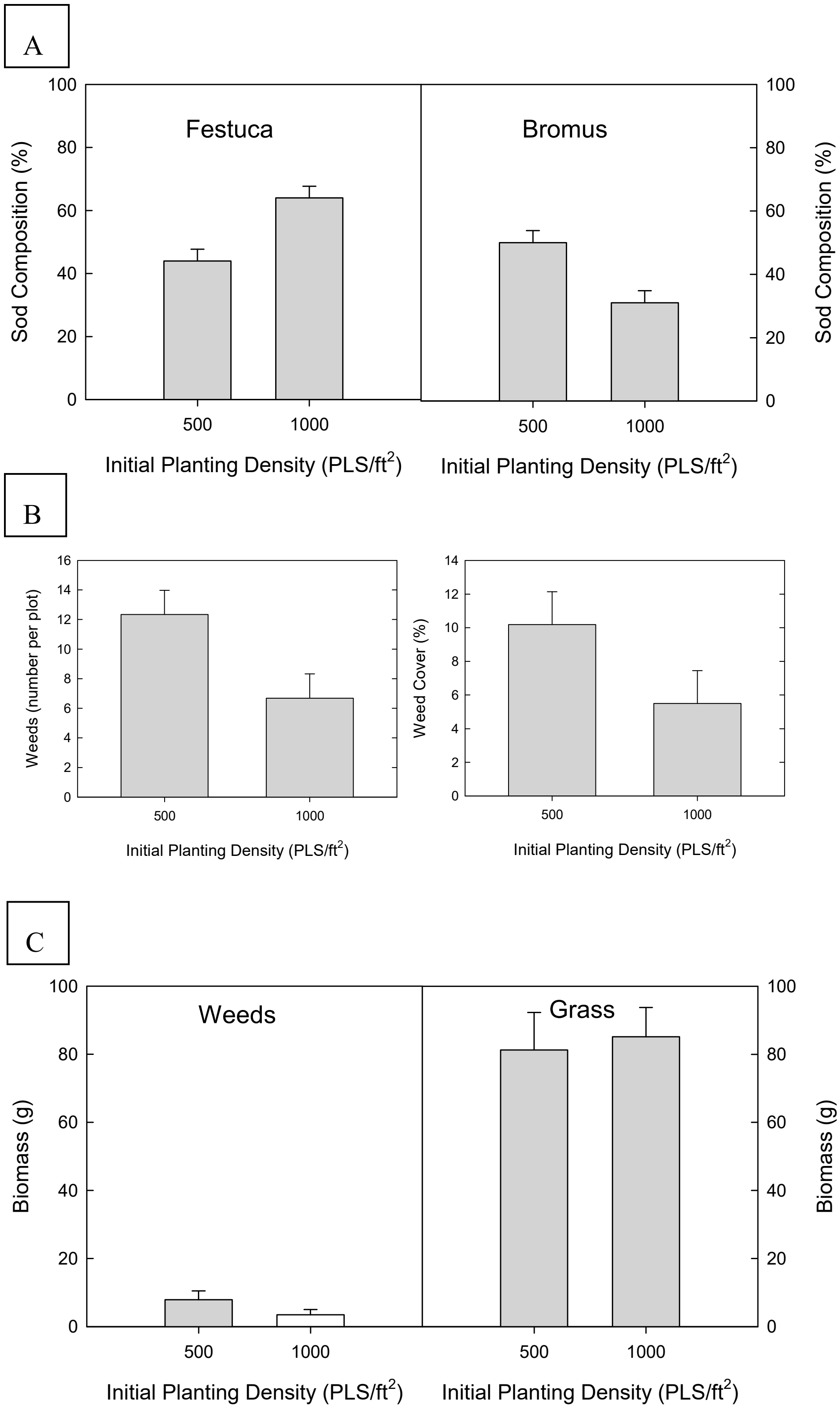

Figure 3.8 Effect of initial planting density on the composition of the sod for red fescue (*Festuca rubra*) and California brome (*Bromus carinatus*) (A), on the weed number and weed cover (B), and weed and grass biomass (C) in the Chaparral mix.

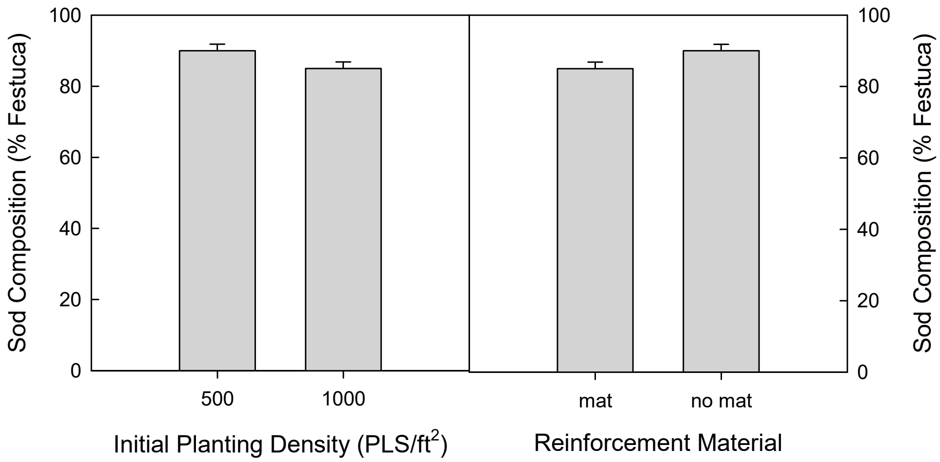

Figure 3.9. Effect of initial planting density and reinforcement mat on percent red fescue in the plots of the Sierran Forest mix.

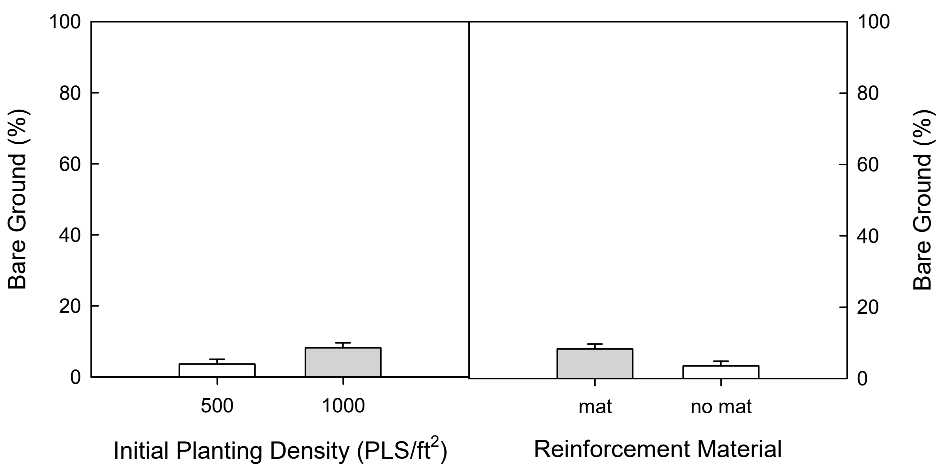

Figure 3.10 Effect of initial planting density and reinforcement mat on the percent bare ground in the Sierran Forest mix.

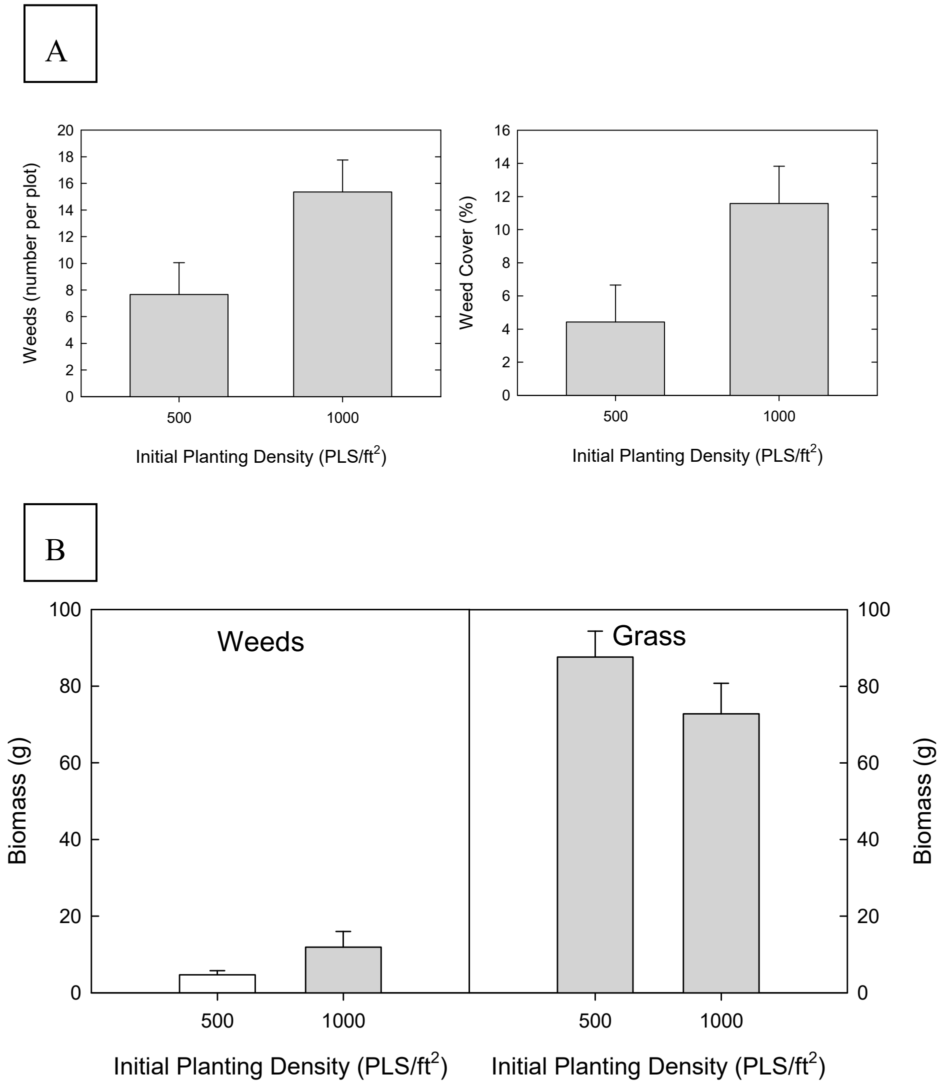

Figure 3.11 Effect of initial planting density on the weed number and weed cover (A) and weed and grass biomass (B) in the in the Sierran Forest mix.

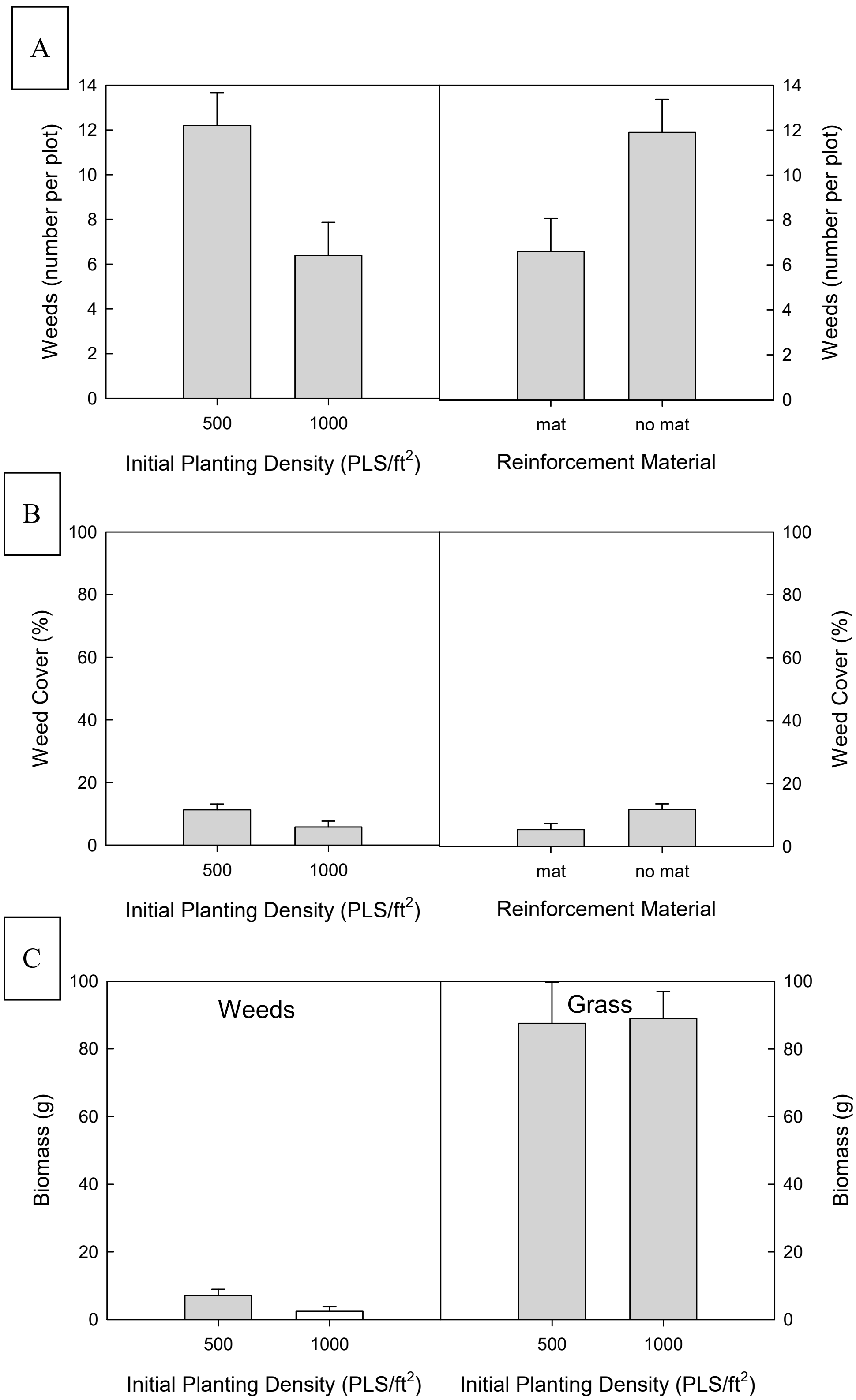

Figure 3.12 Effect of initial planting density and reinforcement material on the weed number (A), weed cover (B), on weed and grass biomass (C) in the Pacific Forest mix.

3.4.3. Conclusion

Overall, all transported sod, regardless of ecoregion, initial planting density, and reinforcement material successfully reestablished on the deep soil plots. Red fescue and/or California brome species dominated the resulting sod in all three ecoregions. Although planted at equal seed numbers, the other species in each mix comprised less than 5% of the ground cover by the end of the transport experiment. These species were present throughout the duration of the experiment and could fulfill a niche not addressed in these experiments, but that are likely to occur in sensitive and roadside conditions.

A general conclusion regarding initial planting density and the use of reinforcement mats cannot be drawn across ecoregions. It is believed that the sod composition at the time of transport determines the sensitivity to the reinforcement mat.

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4. ESTABLISHMENT SUCCESS AND WEED SUPPRESSION POTENTIAL OF MULTISPECIES SOD

4.1. Introduction

Field experiments were conducted to assess the potential of multispecies sod to suppress weeds of different density and with different reinforcement materials over a two year period. Two distinct series of trials were performed. Plots sodded without reinforcement materials were used to assess suppression of weeds sown at six densities (the "A" trials). Reinforcement materials are often required to transport harvested sod. The effect of this material on weed suppression was assessed (the "B" trials). Both experiments were conducted from 2006 to 2008 at Montana State University (MSU). In both experiments the surrogate weed, canola (*Brassica napus*), was sown either below the sod to represent the existing weed seed bank or into the sod from above to represent weed seed rain. In the second year seed was sown from above only. All experiments were subjected to five different water regimes including a no irrigation/natural precipitation only regime. The initial trials (A_1 and B_1) were conducted for two years, 2006-2007. Identical trials (A_2 and B_2) were then started in adjacent plots in 2007 and were also conducted for two years, 2007-2008. This design enables two years of first-year data and two years of second-year data to be collected and compared within and between years so that the experiments are replicated in both time and space.

Details Common to Both Experiments

The multispecies sod (Figure 4.1) consisted of three grasses native to Montana: Idaho fescue (*Festuca idahoensis*), thickspike wheatgrass (*Elymus lanceolatus*), western wheatgrass (*Agropyron smithii*) and one naturalized species, Canada bluegrass (*Poa compressa*). The sod was purchased from Bitterroot Turf Farm (Bitterroot, Montana).

Figure 4.1 The multispecies sod before it was laid in 2006.

The experiments were of split-plot block design. Plots were subjected to four levels of line-source irrigation and a no irrigation/natural precipitation-only regime (Figure 4.2). Plots were irrigated three times per week (Monday, Wednesday and Friday). The amount of water contacting the surface was recorded in rain gauges. If natural precipitation occurred between irrigation intervals the amount of precipitation was recorded and the irrigation routine modified appropriately to achieve the desired amount. The high water level received a mean of 28.2 mm of water/week. The three intermediate water levels ranged from 23.7 mm to 11.6 mm of water/week. The lowest water level, the control treatment, received only natural precipitation (mean of 8.9 mm water/week) with no supplemental irrigation.

Figure 4.2 The line-source used to establish the four levels of irrigation regime plus a no irrigation control (Experiment A_1).

Canola was used as a surrogate weed species to represent annual non-native invasive plant species in the Brassicaceae family. Seed was sown either as seed bank (i.e., below the multispecies sod (Figure 4.3) and/or reinforcement material, or as seed rain (i.e., on top of the sod). In the second year canola was sown only as seed rain.

Figure 4.3 Canola sown as seed bank beneath the multispecies sod in the first year Experiment A_2 (2007).

4.2. Annual Weed Suppression Potential of Multispecies Sod – the "A" Trials

This experiment was designed to test the hypothesis that multispecies sod has the potential to suppress annual weed invasion.

4.2.1. Materials and Methods

The initial experiment (A_1) was conducted for in 2006-2007. Experiment A_1 was then replicated in an adjacent plot to create Experiment A_2 which was conducted in 2007-2008. During the first year of A_1 and A_2 single plots contained six densities of canola (0, 25, 50, 100, 500, 1000 seeds) sown seperately in 0.21 m^2 subplots (equivilent to 0, 119, 238, 476, 2,381, 4,762 seeds/m^2 respectively) as shown in Figure 4.4. Initial seeding was either below the multispecies sod to represent seed bank, or above the multispecies sod to represent seed rain.

A_1 was replicated four times and A_2 six times within the water levels described above. During the second year of A_1 and A_2, canola was sown only as seed rain into the existing sod using the same six different densities described above.

Figure 4.4 Inside the frame are two of the six 0.21 m^2 subplots of multispecies sod shown during the first year of A_2 (2007). Flipping the frame down the plot reveals the other four subplots.

Canola seedling emergence and survival was assessed for the six densities and the five water levels (Figure 4.5) twice per week during the first month of the growing season and then once a week thereafter until harvest. The data were analyzed using general logistic regression. All surviving canola plants were harvested when the first fruit was produced. The dry weight of both the vegetative and seed biomass was recorded to determine, by general linear regression, plant productivity given the different seedling emergence and water regimes.

Figure 4.5 Canola seedlings in Eexperiment A_2 before harvest in August 2007, with the closest plot receiving only natural precipitation and those further away receiving supplemental water.

4.2.2. Results

As of this report, data from two years of first year (2006(A_1) & 2007(A_2)) and one year of the second year (2007(A_1)) trials were analyzed. The remaining data collection and analysis of A_2 will be completed by Spring 2009.

4.2.2.1. Weed Emergence

Samples of the canola seed had 100% germination when tested in the laboratory. During the first year of both experiments A_1 and A_2, the proportional emergence of canola sown was greatly reduced in all treatments when compared to the 100% germination rates observed in the laboratory. While there was a significant difference ($p < 0.001$) in proportional total emergence between years, both years demonstrated the same trend of a significant ($p < 0.001$) increase in canola emergence in plots sown as seed rain compared to plots sown as seed bank (Figure 4.6). There was no significant effect of sown seed density or water regime on the proportion of total emergence in A_1, however in A_2 seed density significantly affected ($p < 0.001$) canola emergence from the seed bank with an increase in emergence as sowing density increased. In A_2, water rate also significantly affected ($p < 0.001$) canola emergence from seed rain plots with an increase in emergence as the cumulative water level increased. The overall reduction in canola emergence suggests that the multispecies sod suppressed the emergence of the surrogate weed.

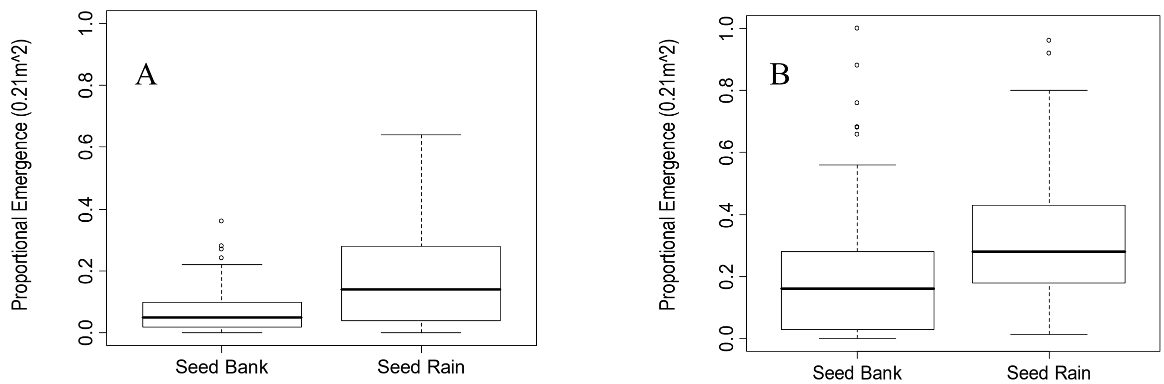

Figure 4.6 Seed bank and seed rain proportional emergence of sown canola during the first year the sod was laid: A) Experiment A_1 in 2006, B) Experiment A_2 in 2007. Density and water effects are removed from experiment A_2 to visually demonstrate results. Each box captures 50% of the data. The dark line represents the median with whiskers extending to the minimum and maximum values within 95% of the data. Circles represent outliers.

During the second year canola emergence in the plots re-sown as seed rain was significantly lower ($p < 0.001$) than the first year for all treatments (Figure 4.7, Figure 4.8). However, in the second year of A_1 there was a significant increase ($p < 0.01$) in canola proportional emergence with an increase in cumulative water.

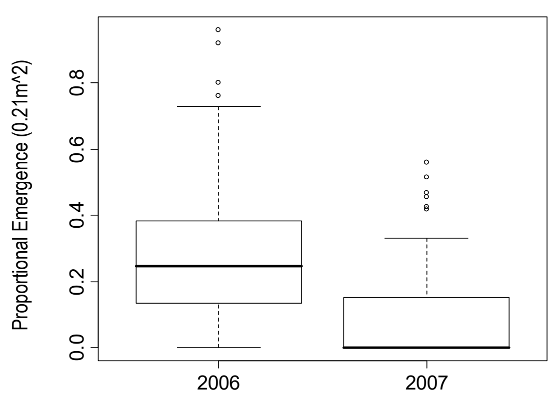

Figure 4.7 Canola proportional emergence of seed rain sown canola in Experiment A_1 in 2006, the first year the sod was laid, and in 2007 when the sod was more established.

Figure 4.8 Seed rain canola emergence the second year of Experiment A_2 (2007) when the sod was more established.

4.2.2.2. Weed Survival

The proportional survival of emerged canola seedlings was not significantly different for seed rain or seed bank plots in the first year of both experiments A_1 and A_2. However, survival was affected by the water gradient ($p < 0.05$), with decreased survival in reduced water (Figure 4.9).

Proportional survival of emerged seedlings in the seed rain plots between years was significant ($p < 0.001$), with more plants surviving over the summer of the first year than over the summer of the second year (Figure 4.10). This decrease in the survival of canola was especially apparent the second year of experiment A_1, where only one plant (Figure 4.11) of the 210 plants that emerged, survived the entire season until harvest. This plant was in the high water treatment, in a 1000 seeds/0.21 m^2 subplot.

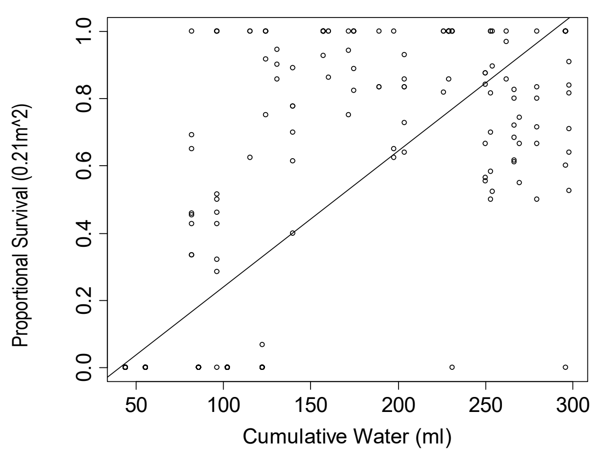

Figure 4.9 Proportional survival of emerged seed bank and seed rain canola seedlings the first year the sod was laid (2006) in Experiment A_1 ($r^2 = 0.0076$, $p < 0.05$).

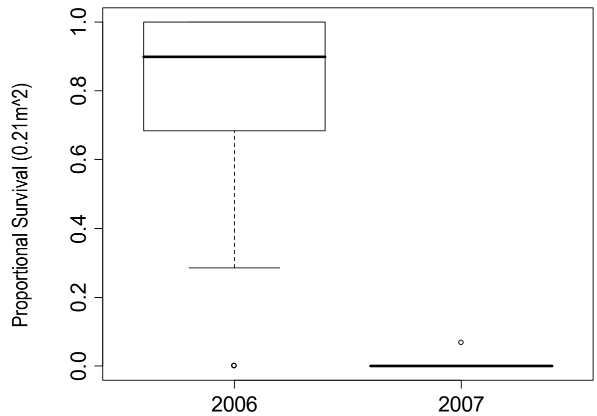

Figure 4.10 Canola proportional survival of emerged canola seedlings sown as seed rain in Experiment A_1 in 2006, the first year the sod was laid, and in 2007 when the sod was more established.

Figure 4.11 The one canola plant that survived of all the emerged seedlings. The plant was in a 1000 seeds/0.21 m^2 subplot in the high water treatment in the second year of Experiment A_1 (2007).

4.2.2.3. Weed biomass

Vegetative and seed biomass increased significantly ($p < 0.001$) with an increase in cumulative water (Figures 4.12 and 4.13) in both seed bank and seed rain plots. Again, this was especially apparent the second year of Experiment A_1 where only one plant of all the plants that emerged survived; it weighed 4.2 g and did not produce seed.

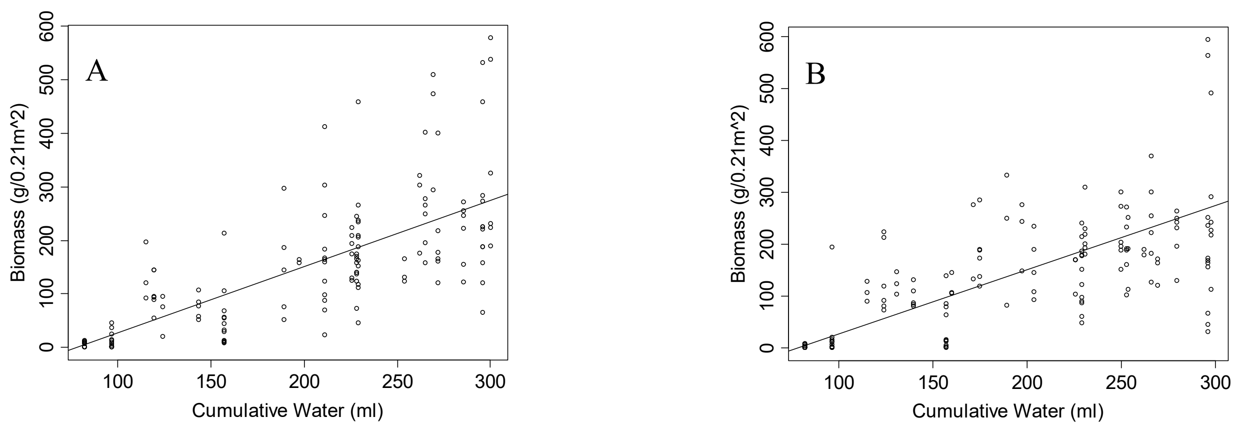

Figure 4.12 Vegetative biomass of the canola plants that survived the first year from both Experiments A_1 and A_2: A) seed bank ($r^2 = 0.5060$, $p < 0.001$), B) seed rain ($r^2 = 0.4178$, $p < 0.001$).

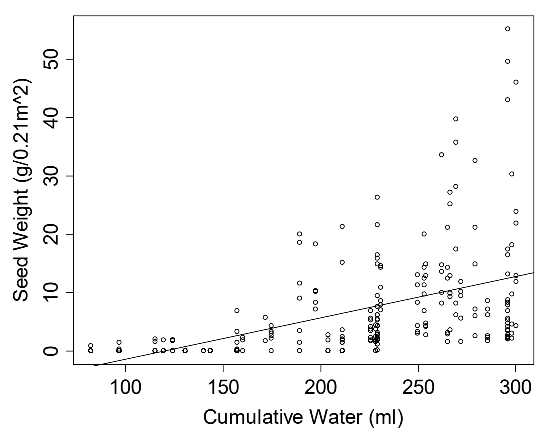

Figure 4.13 Seed weight of the canola plants that survived the first year from both Experiments A_1 and A_2. No significant difference was observed between seed bank and seed rain so the results are combined.

4.2.3. Conclusions

The data demonstrate that multispecies sod reduced the proportion of seed bank canola emergence by 0.62-0.99 and the proportion of seed rain canola emergence by 0.50-0.98 during the first year in both Experiments A_1 and A_2 relative to the 100% germination determined in the laboratory. In Experiment A_2 sowing density significantly and positively affected ($p < 0.001$) canola seed bank seedling emergence, and increased water significantly affected ($p < 0.001$) canola seed rain seedling emergence. Comparing the first year of both Experiments A_1 and A_2, however, there was not a continuous trend of either sowing density or water level affecting seedling emergence. The reason for these differences is not known but could be due to climatic variation between years.

Seedling survival was affected by water treatment with more seedlings surviving as the water treatment level increased. In addition, the seedlings that did survive produced significantly more vegetative biomass and seed biomass as the water level increased. During the second year the multispecies sod was established enough, even in the only natural precipitation treatment that only one plant survived from all the plots. Overall the results from the first year (A_1 and A_2) indicate that the multispecies sod is capable of reducing weed emergence at all water levels. Results from the second year (A_1) indicate that more established sod is even more resistant to weed invasion. Experiment A_2 will be monitored a second season to further verify these results.

4.3. Establishment Success of Multispecies Sod – The "A" Trials

The results of the A trials were also analyzed to assess the hypothesis that the ability of multispecies sod to establish will be affected by different watering treatments.

4.3.1. Materials and Methods

In addition to the activities associated with the A trials that were previously discussed, the ability of the multispecies sod to establish throughout the five level water regime in Experiments A_1 (2006 and 2007) and A_2 (2007 and 2008) was assessed by repeat measures of percent sod cover in each subplot from June through September over a three year period for experiment A_1 and a two year period for experiments A_2. Establishment success was determined by the relative abundance of the vegetative above-ground biomass, whether it was actively photosynthesizing, senescing/dormant, or producing new seedlings.

4.3.2. Results

Analysis was conducted on the control plots (0 density of canola sown) for Experiment A_1. Preliminary results suggest that towards the end of the first growing season (September 2006) the proportion of actively photosynthesizing sod was positively related to total water input over the season (Figure 4.14A). By the end of the second growing season (2007) there was no significant difference in the relative abundance of photosynthesizing and non-photosynthesizing grasses throughout all the water treatments (Figure 4.14B).

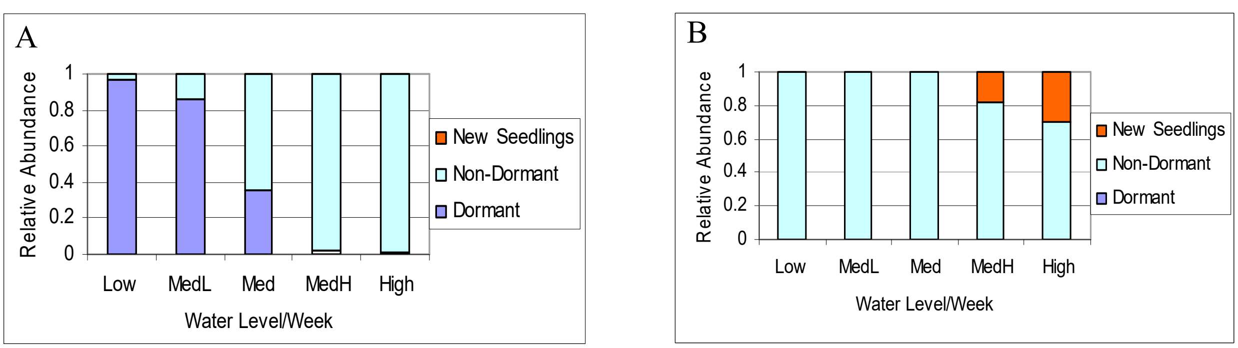

Figure 4.14 Relative abundance of photosynthesizing (non-dormant) and non-photosynthesizing (dormant) plants in Experiment A_1: A) September 2006, B) September 2007. X-axis indicates cumulative water treatment categories: "Low" is lowest water level with no supplemental irrigation, "MedL", "Med", "MedH" are the three intermediate water levels respectively: medium low, medium, medium high. "High" is the highest water level.

4.3.3. Conclusions

Overall, the results suggest that our multispecies sod was able to establish and persist at all water levels including the plots receiving no supplemental irrigation. This pattern was evident for all plots. The fact that the proportion of dormant multispecies sod decreased in the second season (2007), as well as produced new seedlings, demonstrates that the sod has become established in the soil and may make better use of available soil moisture and nutrients (though this was not tested).

A **B**

Figure 4.15 Lowest water level sod plots in Experiment A_1: A) September 2006, B) September 2007.

4.4. Weed Suppression under Different Reinforcement Materials and Sod – The "B" Trials

In this experiment, four different reinforcement materials were laid under the multispecies sod to assess their potential to suppress annual weed invasion.

4.4.1. Materials and Methods

After reviewing the literature, the three reinforcement materials (coconut straw, excelsior wood, and loosely woven jute with (1.5 turns per inch) were chosen because they appeared to span the typical range of products that are used for erosion control. These materials also showed the promise of contributing additional benefits beyond aiding in sod transportation, including soil moisture retention, erosion control, natural degradation which may also contribute organic matter, etc. The nylon netting was chosen as the control because Bitterroot Turf Farm, Bitterroot, Montana, currently uses it to aid in transportation of their sod. The nylon netting that the sod came with has 3.175 cm x 1.905 cm (1.25 inches x 0.75 inches) squares and is 101.6 cm (40 inches) across. The four reinforcement materials: coconut-straw, jute, excelsior (recycled wood product), and nylon netting (control), were randomized and laid separately in 0.42 m^2 subplots beneath the multispecies sod (Figure 4.16). During the first year, one canola seed density (100 seeds/0.42 m^2, equivalent to 238 seeds/m^2) mid-range of A experiments was sown as seed bank, below each reinforcement material. During the second year canola was sown only as seed rain, at the same density as the first year. The water regime was the same as the A experiments, as was the time sequence of the B_1 and B_2 experiments. The number of replicates per block was four for B_1 and six for B_2.

Figure 4.16 Installation of the four reinforcement materials: coconut-straw, jute, excelsior, and nylon netting (control) placed beneath the multispecies sod in Experiment B_2 (2007).

To evaluate the weed suppression capability of the multispecies sod in combination with the reinforcement materials, canola seedling emergence, survival, and productivity was assessed in each subplot at all water levels. Data were collected and analyzed in the same way as the A experiments. Seedlings were counted twice per week during the first month of the growing season and once per week thereafter until harvest. Surviving canola plants were harvested when the first fruit was produced. All data were analyzed with general linear regression.

4.4.2. Results

4.4.2.1. Weed Emergence

During the first year, when canola was sown as seed bank, in both Experiments B_1 and B_2 the proportional emergence of canola sown was greatly reduced in all treatments compared to the 100% germination rates observed in the laboratory. In Experiment B_1, the proportion of the sown canola seeds to emerge was 0.17-0.3. Reinforcement material and water level had no significant effect on canola emergence. In Experiment B_2, the proportion of the sown canola seeds to emerge was 0.11-0.28. In contrast to B_1, reinforcement material and water level both had a significant ($p < 0.05$) effect on canola emergence in Experiment B_2. More seedlings emerged in the control plots than in any of the reinforcement material plots (Figure 4.17) and more seedlings emerged in the high water regime (Figure 4.18).

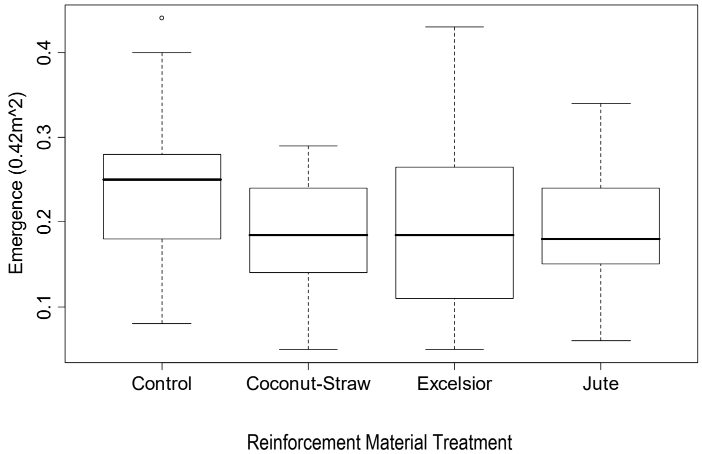

Figure 4.17 Proportional emergence of canola from the seed bank under different reinforcement materials and multispecies sod in Experiment B_2 (2007), the first year the sod was laid.

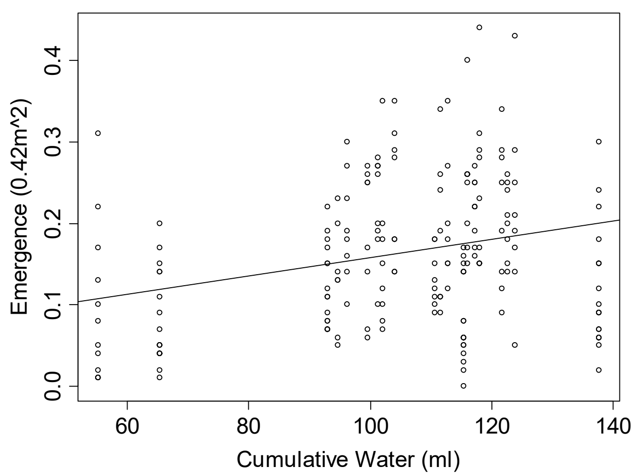

Figure 4.18 Proportional emergence of canola from the seed bank under different water levels. Experiment B_2 (2007), the first year the sod and reinforcement materials were laid ($r^2 = 0.0723$, $p < 0.05$).

4.4.2.2. Weed Survival

The proportional survival of the canola seedlings that did emerge was significantly ($p < 0.01$) less in the control plots compared to the plots containing reinforcement materials (Figure 4.19) in the first growing seasons of both Experiments B_1 and B_2. The water regime had no significant effect on proportional survival. These results suggest that the reinforcement materials may have contributed to the establishment of canola after the plants emerged.

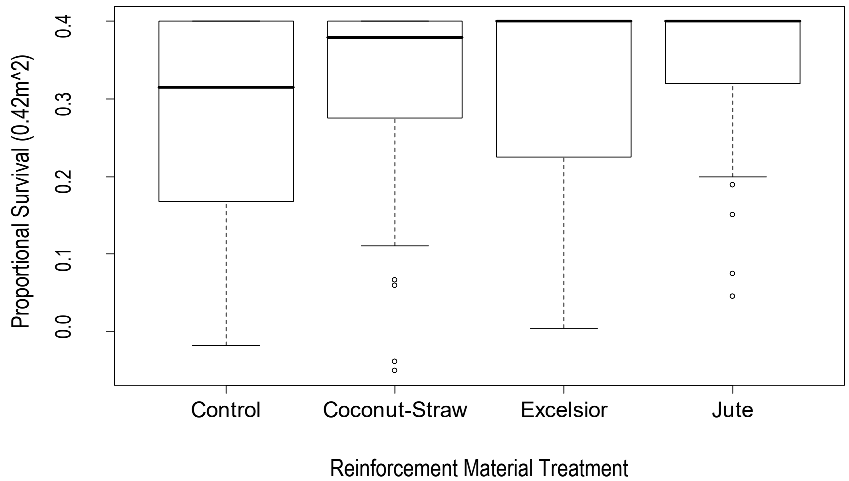

Figure 4.19 Canola proportional survival of emerged seedlings by reinforcement material for Experiments B_1 and B_2 the first year the sod was laid.

In the second growing season of Experiment B_1 (2007), when canola was sown as seed rain on top of the existing reinforcement materials, there was significantly less ($p < 0.001$) proportional emergence of sown canola compared to the first year (Figure 4.20). Water had a significant effect ($p < 0.001$) with an increase in emergence with increased water levels (Figure 4.21). None of the seedlings that emerged survived more than a couple of weeks resulting in a significantly ($p < 0.001$) reduced survival rate of emerged seedlings the second year compared to the first (Figure 4.22).

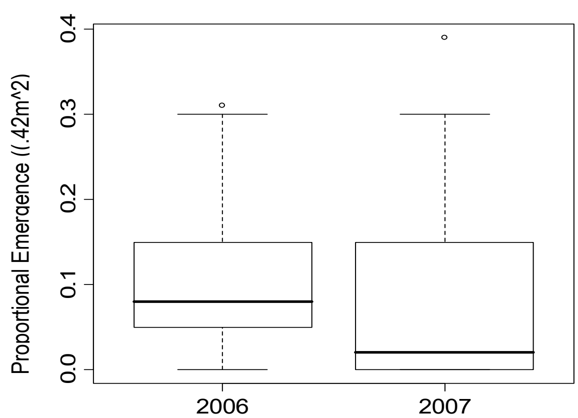

Figure 4.20 Canola proportional emergence by year for Experiment B_1.

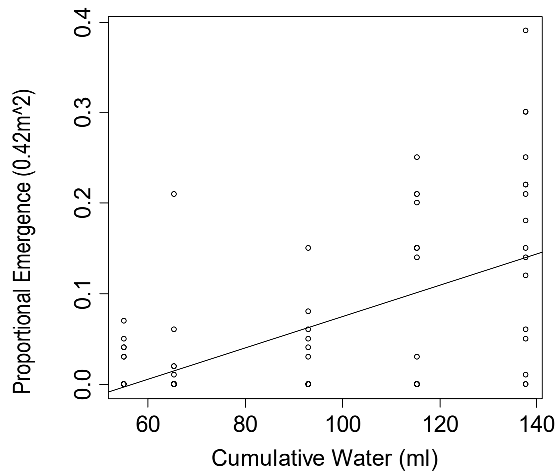

Figure 4.21 Canola proportional emergence from seed rain the second year of Experiment B_1 ($r^2 = 0.3029$, $p < 0.01$).

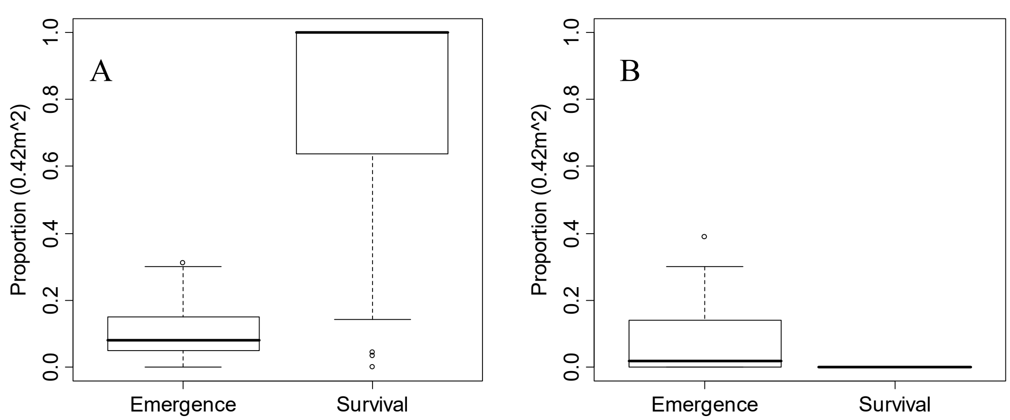

Figure 4.22 Canola proportional emergence and survival by year for Experiment B_1: A) first year (2006) the year the sod was laid ($p < 0.001$), B) second year (2007) when the sod was more established,($p < 0.001$).

4.4.2.3. Weed Biomass

Vegetative biomass and seed weight of canola was affected by cumulative water. Regardless of the reinforcement material, the productivity of the surrogate weed canola decreased significantly ($p < 0.001$) with water level (Figures 4.23 and 4.24) in the first growing seasons of both experiments B_1 and B_2. Because none of the canola seedlings that emerged the second year survived, the loss of productivity was apparent.

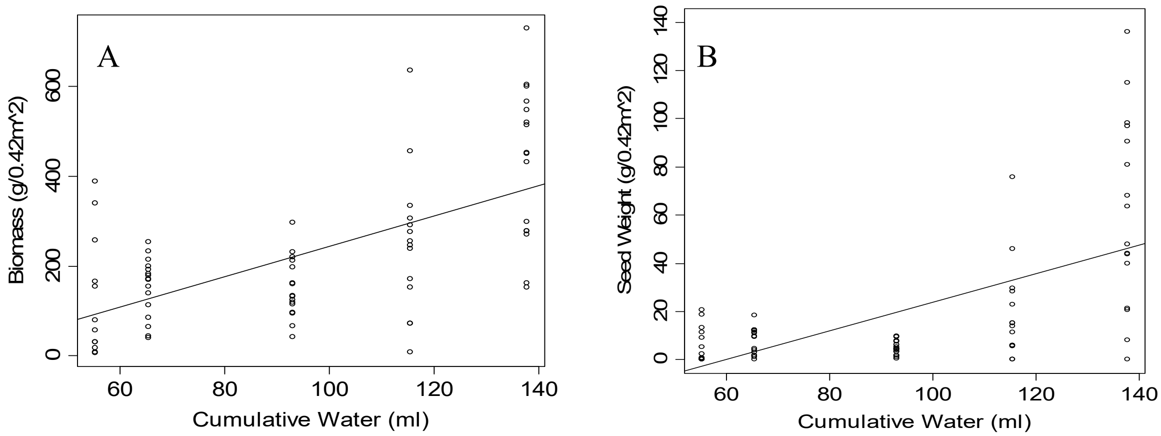

Figure 4.23 Canola productivity in the first year of Experiment B_1: A) vegetative biomass, ($r^2 = 0.3257$, $p < 0.001$), B) seed weight ($r^2 = 0.3452$, $p < 0.001$). Note different y-axis scale.

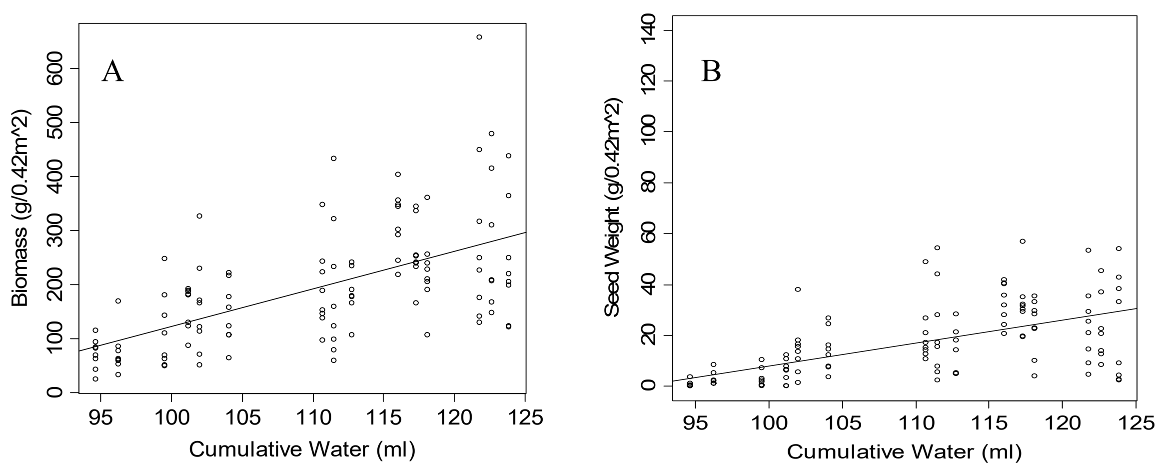

Figure 4.24 Canola productivity in the first year of Experiment B_2: A) vegetative biomass ($r^2 = 0.3137$, $p < 0.001$), B) seed weight ($r^2 = 0.3128$, $p < 0.001$). Note different y-axis scale.

4.4.3. Conclusions

The weed suppression potential of the multispecies sod found in Experiments B_1 and B_2 are consistent with the findings in Experiments A_1 and A_2. The purpose of reinforcement material is to aid in transportation of sod by providing tensile strength and allowing for installation of intact sod. However, these results suggest that reinforcement materials in combination with multispecies sod also suppressed annual weeds, as indicated by an overall reduction in the proportional emergence of sown canola by 0.72-0.97. In Experiment B_2 the control plots contained significantly more emerged seedlings, suggesting that the reinforcement materials may additionally contribute to weed suppression; however, this effect was only significant in Experiment B_2 and not seen in Experiment B_1.

During the second year when the multispecies sod was more established, independent of the reinforcement materials and throughout all water levels, no seedlings that emerged survived to maturation. The results from the second year of experiment B_1 indicate that more established sod provides fewer microsites for seedling emergence and survival.

4.5. Overall Conclusions

In general, these experiments provide evidence that emergence of canola was low when sown as seed rain or seed bank with multispecies sod and was significantly ($p < 0.001$) lower the second year after sod was laid. Experiment B results indicated the reinforcement materials did significantly ($p < 0.05$) further decrease canola emergence in Experiment B_2 (2007). Of the emerged seedlings survival to maturation the vegetative biomass and the seed biomass of these plants was significantly affected by water regime for both the A and B experiments. In contrast, in the reinforcement (B) experiments water regime did not affect survival but the presence of the material increased the proportion of surviving plants. These experiments indicated that multispecies sod could be used as an alternative roadside revegetation technique. It established and survived without supplemental water (Figure 4.15) and reduced weed emergence and survival.

5. HIGHWAY RECLAMATION USING NATIVE GRASS SOD FOR SEDIMENT CONTROL AND AESTHETIC ENHANCEMENT

5.1. Introduction

As previously established, native grass sod has the potential to provide immediate sediment control and permanent stabilization on disturbed land along highways. Based on the knowledge gained from the research described in the previous chapters, a field experiment was conducted using native grass sod to revegetate a disturbed area along a California highway at a location just south of Sacramento. This experiment began with an investigation of the basic characteristics of three native grass sods produced by three different commercial farms. While successfully grown in relative small, controlled experimental settings, it was critical to establish the characteristics of these sods when produced at the larger scale necessary for their practical use on highway projects. The commercially grown sods were evaluated with respect to species abundance, canopy coverage, and weed emergence. Based on the results of this investigation, two of these native grass sods were subsequently transplanted to the field test site, where their performance was evaluated over a 20 month period relative to a control section that used Caltrans standard hydroseeding practice.

5.2. Propagation of Native Grass Sod for the California Grassland Ecoregion

Native grass sod was propagated at three different farms in the California Grassland Ecoregion during February 2005 to May 2008. Native grass sods were named as follows:

- MSU Native Grass Sod – Sierra
- MSU Native Grass Sod – Hedgerow
- MSU Native Grass Sod – Delta

5.2.1. Propagation of MSU Native Grass Sod – Sierra

Grass species selection criteria included root length, root distribution traits, phenology of growth at all life stages, and growth habit (Table 5.1). This approach built on the success of a previous Caltrans native grass project that suggested a combination of five native grasses better utilized water resources and produced more stable biomass during establishment (Brown et al. 1998).

Sierra Sod and Supply, Davis, California, was contracted to propagate the sod. Seed for the native species mix listed in Table 5.1 was delivered in mid-February 2005. Because of heavy precipitation and work schedule conflicts at the farm, the planting date was April 1, 2005. No reinforcement material (such as a plastic mesh) was used in the seedbed to facilitate future sod harvesting. It was hoped the native grass species mix selected would form a sufficiently dense shallow root mat to enable routine sod cutting and rolling procedures during transplanting.

On April 29, 2005, the seeded area was evaluated by randomly dropping a 0.1 m^2 Daubenmire frame 16 times on the sod plot. Within each frame, density of the seeded grass species was determined by counting individual tillers, and percent canopy cover was estimated by ocular observation (BLM 1995). An attempt was made to differentiate between species of native grasses, but due to the early growth stage it was not possible. Density ranged from 190 to 3590 tillers/m^2 with an average of 1528 tillers/m^2. Percent cover averaged 10.2% and ranged from 1 to 25%. There were areas of an annual grass weed and dense broadleaf weeds that were beginning to compete with seeded native grass.

Table 5.1 Grass species included in the MSU Native Grass Sod – Sierra.

Scientific Name	Common Name
Poa secunda	One-sided Blue Grass
Elymus multisetus	Squirrel Tail
Leymus triticoides	Creeping Wildrye
Nassella pulchra	Purple Needlegrass
Nassella cernua	Nodding Needlegrass

The seeded area was evaluated a second time on September 2, 2005. All native grasses were dormant, and weeds dominated the plot. A 0.1 m^2 Daubenmire frame was randomly dropped ten times over the seeded area. Within each frame, percent canopy cover was estimated for the seeded native species. Weedy species were included in this estimate because they dominated all but one frame. Density of native species was not determined. Percent canopy cover of the seeded natives averaged of 17.2% and ranged from zero to 65%. There was no evidence of native grasses in four of the ten frames. Weedy species canopy cover ranged from 25 to 100% with an average of 85.5%. The percent cover of weedy species was 100% in half of the observed frames.

It was determined that a standard level of care pertaining to weed control associated with native grass sod propagation was absent. Therefore, work was terminated at the farm.

5.2.2. Propagation of MSU Native Grass Sod – Hedgerow

A new native grass sod was designed. In addition to a review of information provided in the report titled *Caltrans Native Grass Evaluation Pilot Program* (P & D Environmental 2004), discussions with both the Montana State University (MSU) native grass sod project team and the plant ecologist with the Caltrans program in Sacramento resulted in selection of five native grass species (Table 5.2). Hedgerow Farms, Winters, California, was contracted to propagate the new native grass sod mix.

Starting in October 2005, each species was grown in monoculture to evaluate individual sod-forming characteristics. These five species were also grown together, i.e. MSU Native Grass Sod–Hedgerow, to assess the overall quality and success of a mixed native grass sod. No reinforcement material was used in the seedbed to facilitate future sod harvesting. It was hoped the native grass species mix selected would form a sufficiently dense shallow root mat to enable routine sod cutting and rolling procedures during transplanting. In addition, two cover crop species were over-seeded into all monocultures except the California meadow barley. Cover crop species included annual hairgrass (*Deschampsia elongatum*), and Quickguard® which was a sterile annual cross between wheat and cereal rye.

Table 5.2 Grass species included in the MSU Native Grass Sod – Hedgerow.

Scientific Name	Common Name
Leymus triticoides	Creeping Wildrye
Nassella pulchra	Purple Needlegrass
Poa secunda	Sandberg's Bluegrass
Hordeum brachyantherum californicum	California Meadow Barley
Elymus multisetus	Squirrel Tail

5.2.2.1. Hedgerow Farms Soil Traits

The Brentwood silty clay loam soil type dominated most of the landscape at Hedgerow Farms. Two composite soil samples from the 0-15 cm depth increment were collected and analyzed for physical and chemical properties at Energy Laboratories, Helena, Montana. Soil textural classes were clay and silty clay; the rock content, i.e. particles greater than 2 mm diameter, was less than 1%. (Table 5.3). The soil had adequate plant-available levels of phosphorus and potassium, but nitrogen levels were low.

Table 5.3 Soil physical traits and plant nutrient availability for two soil samples from Hedgerow Farms, Winters, California.

Soil Sample	Soil Physical and Chemical Traits[1]							
	Rock Content (%)	Sand (%)	Silt (%)	Clay (%)	Textural Class	Phosphorous (mg/kg)	Nitrate-N (mg/kg)	Potassium (mg/kg)
A	<1	27	45	28	Clay	27	1	330
B	<1	5	52	43	Silty Clay	37	6	430

[1]Analytical methods are presented in Appendix A.

5.2.2.2. Assessment of Sod Development at Hedgerow Farms

During January 2006, plant development in the seeded area was evaluated by collecting density and canopy cover data on native grass, cover crop, and weed species. Ten Daubenmire frames were randomly dropped on the native grass monoculture, on the monoculture/cover crop mix, and on the MSU Native Grass Sod–Hedgerow species mix. Plant density and canopy cover data were collected within each frame (BLM 1995).

Soil cover was measured using line-intercept sampling (BLM 1995). Soil cover is the percentage of the soil surface covered by an object (e.g., plant basal cover or litter) regardless of what is above the object. One randomly located 15 m long point-intercept transect was located within each native grass monoculture, monoculture/cover crop mix, and in the native grass species mix. A mark was placed every 30 cm, and the type of soil cover was recorded, resulting in 50 data collection points.

Observational data were collected on root density for each grass species. A shovel was used to cut into the soil to observe root density and root binding ability of each species monoculture and monoculture/cover crop. Root density in the top 6 cm verses the top 30 cm of soil was also observed.

Native grass monocultures and monoculture/cover crops were tested for their ability to cut, roll, and transplant as a sod product. This was accomplished by cutting each species with a self-propelled sod cutter 46 cm wide by 6 cm deep. Cut sod was moved to a nearby location on Hedgerow Farms for propagation and observation.

Table 5.4 Mean vegetative density for MSU Native Grass Sod–Hedgerow, native grass monocultures, and monocultures/cover crops at Hedgerow Farms in January 2006.

Seeded Species	Mean Density (stems+tillers/m^2)			
	Seeded Native Grass	Cover Crop	Other Grass (volunteers)	Weedy Forbs
MSU Native Grass Sod–Hedgerow (5 species, see Table 5.2)	2418	n/a	0	29
Native Grass Monocultures and Monocultures/Cover Crops				
Creeping Wildrye	767	n/a	0	10
Creeping Wildrye + Hairgrass	1039	1459	0	18
Creeping Wildrye + Quickguard®	1238	48	0	9
Purple Needlegrass	1555	n/a	0	0
Purple Needlegrass + Hairgrass	1435	1010	0	1
Purple Needlegrass + Quickguard®	1181	245	0	0
Sandberg's Bluegrass	1930	n/a	0	2
Sandberg's Bluegrass + Hairgrass	1729	1958	0	15
Sandberg's Bluegrass + Quickguard®	751	508	0	42
California Meadow Barley	2219	n/a	131	42
Squirrel Tail	1208	n/a	0	0
Squirrel Tail + Hairgrass	749	1024	0	18
Squirrel Tail + Quickguard®	338	357	0	3

Table 5.5 Mean canopy cover for MSU Native Grass Sod–Hedgerow, native grass monocultures, and monocultures/cover crops at Hedgerow Farms in January 2006.

Seeded Species	Mean Canopy Cover (%)					
	Seeded Native Grass	Cover Crop	Other Grass (volunteers)	Weedy Forbs	Litter	Bare Ground
MSU Native Grass Sod–Hedgerow (5 species, see Table 5.2)	10	n/a	0	1	4	85
Native Grass Monocultures and Monocultures/Cover Crops						
Creeping Wildrye	40	n/a	0	1	24	35
Creeping Wildrye + Hairgrass	44	29	0	7	1	19
Creeping Wildrye + Quickguard®	54	8	0	1	1	36
Purple Needlegrass	60	n/a	0	0	0	40
Purple Needlegrass + Hairgrass	56	30	0	0	0	14
Purple Needlegrass + Quickguard®	56	40	0	0	0	4
Sandberg's Bluegrass	34	n/a	0	1	0	65
Sandberg's Bluegrass + Hairgrass	30	34	0	5	0	31
Sandberg's Bluegrass + Quickguard®	27	57	0	12	0	4
California Meadow Barley	69	n/a	1	3	0	27
Squirrel Tail	44	n/a	0	0	0	56
Squirrel Tail + Hairgrass	28	23	0	7	3	39
Squirrel Tail + Quickguard®	21	60	0	2	0	17

Table 5.6 Percent soil cover for MSU Native Grass Sod–Hedgerow, native grass monocultures, and monocultures/cover crops, and at Hedgerow Farms in January 2006.

Seeded Species	Soil Cover (%)		
	Basal Cover	Litter	Bare Ground
MSU Native Grass Sod–Hedgerow (5 species, see Table 5.2)	10	4	86
Native Grass Monocultures and Monocultures/Cover Crops			
Creeping Wildrye	48	2	50
Creeping Wildrye + Hairgrass	74	0	26
Creeping Wildrye + Quickguard®	72	2	26
Purple Needlegrass	50	0	50
Purple Needlegrass + Hairgrass	68	0	32
Purple Needlegrass + Quickguard®	78	6	16
Sandberg's Bluegrass	34	2	64
Sandberg's Bluegrass + Hairgrass	54	2	44
Sandberg's Bluegrass + Quickguard®	70	4	26
California Meadow Barley	32	6	62
Squirrel Tail	52	4	44
Squirrel Tail + Hairgrass	46	0	54
Squirrel Tail + Quickguard®	72	0	28

Mean vegetative density (Table 5.4), canopy cover (Table 5.5), and soil cover (Table 5.6) were collected for each native grass monoculture, monoculture/cover crop, and the MSU Native Grass Sod–Hedgerow species mix.

Weedy Forbs

Weedy forb density was highly variable across sod production areas and ranged from 0 to 42 stems/m^2, and percent canopy cover ranged from 0 to 12% (Tables 5.4 and 5.5). Grass plots were sprayed with Telar® to decrease weed species. However, not all fields were treated at the same time, likely contributing to the observed variability. Dominant weedy forbs included shepherd's-purse (*Capsella bursa-pastoris*), common mallow (*Malva neglecta*), filaree (*Erodium cicutarium*), and other unidentifiable species.

Creeping Wildrye

Creeping wildrye was seeded in a 30-cm row spacing in November 2004. This rhizomatous species filled in the row spaces so rows were not apparent in January 2006. Roots were concentrated within the top 15 cm of soil.

Creeping wildrye had a lower stem density when grown alone than when grown with a cover crop (Table 5.4). When creeping wildrye monoculture was test cut, it held together as a sod and rolled but tended to fall apart as it was unrolled (Figure 5.1).

Creeping wildrye over-seeded with Quickguard® and hairgrass cover crops produced greater soil cover when compared to creeping wildrye seeded alone (Table 5.6). However, the cover crops did not establish well. Quickguard® had a low density and canopy cover. Hairgrass had a relatively high density and canopy cover, but the majority of hairgrass was in the seedling stage and did not have a developed root system. As a result, the creeping wildrye with cover crops did not cut or roll well and did not hold together when moved.

Figure 5.1 Test cut of creeping wildrye sod at Hedgerow Farm in January 2006.

Purple Needlegrass

Purple needlegrass is a deep-rooted species that was seeded November 2004 using 30 cm row spacing. The high percent of bare soil, particularly in the monoculture, was due to the row spacing (Table 5.6). Purple needlegrass had a greater mean density and canopy cover when seeded alone than when seeded with a cover crop (Tables 5.4 and 5.5). When the monoculture of purple needlegrass was test cut, it held together fairly well as a sod, but fell apart when it was unrolled.

When over-seeded with Quickguard®, the row spaces filled in, resulting in less bare ground (Table 5.6). When purple needlegrass/Quickguard® was test cut and rolled, the rows of native grass held together well, but separated from Quickguard®. When hairgrass was over-seeded into the purple needlegrass rows, the hairgrass was dense, mature, and had a relatively high canopy cover (Table 5.5). However, the growth of hairgrass was not adequate to fill in the row spaces between purple needlegrass. When the purple needlegrass/hairgrass sod was cut and rolled, it did not hold together well. Small sod rolls were formed but fell apart when unrolled (Figure 5.2).

Figure 5.2 A test cut of purple needlegrass sod indicated it rolled but the root system was not able to hold the sod together for the transplant and unrolling at Hedgerow Farm in January 2006.

<u>Sandburg's Bluegrass</u>

Sandberg's bluegrass was seeded in November 2003 in rows spaced 30 cm apart. Although this grass was mature and well established in 2006, prominent row spaces were visible and a large percent of bare ground was recorded (Table 5.6).

Sandberg's bluegrass was the second most dense of the native grass monocultures (Table 5.4). Species density and canopy cover decreased when over-seeded with a cover crop (Table 5.5). When the monoculture of Sandberg's bluegrass was test–cut for sod transplanting, the space between rows fell apart when rolled, but the row of Sandberg's bluegrass held together well because of the thick root mat. The majority of the roots were within the top 15 cm of soil (Figure 5.3). Of all the native grass species tested, Sandberg's bluegrass provided the greatest visual evidence for holding the soil together when it was cut and rolled.

When Sandberg's bluegrass was over-seeded with hairgrass, percent bare ground between rows decreased but was still notable. The Sandberg's bluegrass/hairgrass cut and rolled well. It had the strongest sod mat of the native grass/cover crops tested. This grass species and cover crop mix had good binding of the root–soil matrix in the top 7 cm of soil.

When Quickguard® was over-seeded into Sandberg's bluegrass, the Quickguard® filled in the row spaces and decreased the percent of bare ground (Table 5.6). When test cut, rows where Sandberg's bluegrass was seeded rolled well, but the row inter-spaces where Quickguard® dominated fell apart.

Figure 5.3 Cut sod of Sandberg's bluegrass showing root–soil matrix (left photo) and sod roll (right photo) at Hedgerow Farm in January 2006.

<u>California meadow barley</u>

California meadow barley was seeded in October 2004 with a 30-cm row spacing. California meadow barley had the highest density and cover of any seeded native grass species (Tables 5.4 and 5.5). It was able to spread and readily filled in the rows spaces. The sod cutter was able to cut the sod well, but the meadow barley would not roll and thus could only be harvested as platter-size soil clumps (Figure 5.4). Observation of the rooting profile suggested the species was deep-rooted with the majority of roots extending greater than 15 cm deep.

No cover crop was over-seeded with this native grass species.

<u>Squirrel Tail</u>

This species was seeded in November 2004 using a 30-cm row spacing. Squirrel tail established in clumps with a large amount of bare ground between rows. Even though this species had good root establishment, the test–cut of the monoculture did not hold together well. This result may be attributable to large spaces between clumps of plants and/or this deep-rooted species did not develop enough shallow root mass to bind the soil in the 0 to 7 cm depth increment.

Squirrel tail density and canopy cover decreased when cover crops were inter-seeded (Tables 5.4 and 5.5). Where hairgrass and Quickguard® were interseeded, the row spaces filled in well, particularly where the hairgrass received early supplemental moisture. The shovel test indicated that hairgrass is a good soil binder when seeded and watered early enough for the cover crop to establish and develop a dense root system. When the squirrel tail sod was test-cut where hairgrass was thick, it rolled well but in areas where hairgrass was thinner, the sod fell apart.

Figure 5.4 California meadow barley formed sod and cut well, but because the plant formed soil-root clumps, the sod fell apart into plate size pieces at Hedgerow Farms in January 2006.

The shovel test found Quickguard® does not have dense roots for binding soil. When the squirrel tail/Quickguard® sod was cut, the Quickguard separated from the native grass causing the sod to fall apart as it was unrolled.

Native Species Monoculture And Monoculture/Cover Crop Findings

Measurements of native grass monocultures and monoculture/cover crop provided the following findings pertaining to sod development and harvesting:

- Quickguard® is not a good cover crop for holding sod together because root development is too deep.
- Hairgrass provided good binding of the soil and improved the ability to cut, roll and move native sod. If used, hairgrass should be given ample irrigation prior to sod cutting to ensure it is well established.
- For most native grass species, density and/or cover decreased when seeded in conjunction with a cover crop.
- Sandberg's bluegrass was the native species with the most roots in the upper soil profile and had the best sod forming traits regarding cutting, rolling and moving.

MSU Native Grass Sod–Hedgerow

The MSU Native Grass Sod–Hedgerow, composed of five native grass species, was seeded November 27, 2005 (Table 5.7). The seed was mixed with Allegiance® (a fungicide) at a rate of 59 cm^3 fungicide per 45 kg seed (2 ounces/100 pounds seed) and broadcast seeded using a Truax broadcast seeder pulled behind a four-wheeler. A chain harrow was used to incorporate the seed into the soil.

Table 5.7 MSU Native Grass Sod–Hedgerow species mix and seeding rate.

Grass Species	%	Pounds	PLS/m^2
Creeping Wildrye	25.4	9.33	2140
Purple Needlegrass	20.8	7.66	2140
Sandberg's Bluegrass	10.6	3.90	4280
California Meadow Barley	14.1	5.19	1070
Squirrel Tail	29.1	10.70	1070
Total	100	36.78	10,700

Figure 5.5 MSU Native Grass Sod–Hedgerow propagation area at Hedgerow Farms in January 2006.

The native species mix had the second highest density of all sod plots surveyed, but also had very low canopy cover (Tables 5.4 and 5.5). This is most likely due to the young age of plants (Figure 5.5).

No observation of root density was made in January 2006 since the species mix was in the establishment phase.

5.2.2.3. Preliminary Sod Transplant and Survival Test – Hedgerow Farm

Small squares of native grass sod monocultures and monoculture/cover crop sod were cut in January 2006 and transplanted to a nearby location at Hedgerow Farm. Transplanted sod tests were observed periodically for survival. In May 2006, all sod transplants had rooted into topsoil, though not all native grasses survived the cutting and transplanting process.

Purple Needlegrass

In February 2006, one month after transplanting, purple needlegrass had low survival, perhaps because it is a deep-rooted grass. By May 2006, purple needlegrass still had low survival and did not appear to be tolerant of cutting and transplanting. Four live plants were present in the test sod plot, representing only 5% cover. Quickguard® dominated the transplant plot.

Creeping Wildrye

Creeping wildrye had fair survival in February 2006, one month after cutting, and continued to improve with time. When transplanted alone, creeping wildrye plants were robust and had about 60% cover. When interseeded with Quickguard®, wildrye cover was reduced to 35%, and with Quickguard® the cover was reduced to 45%.

Sandberg's Bluegrass

Compared to other native grasses tested, Sandberg's bluegrass had the highest survival in March 2006, two months after transplanting. By May 2006, Sandberg's bluegrass had 85% canopy cover when interseeded with hairgrass. Bluegrass represented 45% of the cover, while hairgrass made up the remaining 55% (Figure 5.6). Both plant species flowered and set seed. However, when interseeded with Quickguard®, bluegrass plants were out-competed, and there were no survivors within the sod transplant.

Figure 5.6 Sandberg's bluegrass sod transplant plot at Hedgerow Farm in May 2006. The right side of the photo shows the bluegrass-hairgrass sod, and the left side is bluegrass-Quickguard® sod transplant.

California Meadow Barley

In February 2006, one month after transplanting, California meadow barley had high survival. By May 2006, it had grown into a dense mat with 100% cover (Figure 5.7). It had just begun to flower and showed signs of setting seed. While this species survived well after being transplanted, transplanting this species was a difficult task because it did not hold together well during the sod–cutting process.

Figure 5.7 California meadow barley sod transplant plot at Hedgerow Farms in May 2006.

Squirrel Tail

Squirrel tail did not appear to survive cutting and transplanting in either the short or long term. In the plots seeded with hairgrass and Quickguard®, one squirrel tail plant survived in each test plot, representing less than 5% canopy cover. Both hairgrass and Quickguard had 65% canopy cover.

Merit of Cover Crops To Aid In Sod Development, Harvest, And Transplanting

The cover-crop Quickguard® did not survive well for the first month in transplanted grass sod, and negatively impacted survival of the native grass species (Figure 5.8). Overall, Quickquard® appeared to out-compete native grasses, and the one meter tall plant did not provide good cover. Hairgrass did not appear to compete with natives, provided good cover between bunches of native grass, and provided good root binding traits that held sod together while transplanting.

5.2.2.4. MSU Native Grass Sod-Hedgerow Evaluation

The MSU Native Grass Sod–Hedgerow propagation area was evaluated in May 2006. Each of the five species seeded were present and were healthy (Figure 5.9). Seeded native grass species had a mean canopy cover of 80% and ranged from 60% in the thinnest areas to 100% in the densest areas (Table 5.5). There were a few unwanted grasses and broadleaf weeds which contributed to less than 5% of the canopy cover.

Figure 5.8 Example of poor native grass survival when the tall cover crop Quickguard® was present in transplanted sod at Hedgerow Farms in May 2006.

Figure 5.9 MSU Native Grass Sod–Hedgerow propagation area before herbicide treatment and mowing at Hedgerow Farms in May 2006.

In May 2006, squirrel tail and Sandberg's bluegrass were the dominant species in the MSU Native Grass Sod–Hedgerow. Purple needlegrass and squirrel tail were flowering and setting seed. Several Sandberg's bluegrass plants were in flower, but most had already gone dormant. In late May 2006, the native grass mix plot was sprayed with herbicide (Telar®) to decrease weed species cover and density. The native sod plot was mowed in late May to encourage root growth. All species were dormant in July and August.

In September 2006, the MSU Native Grass Sod–Hedgerow propagation area was doing well. Each of the five species seeded was present. Squirrel tail and Sandberg's bluegrass remained the dominant species. Irrigation was initiated and weeds were manually removed.

The sod was tested for root-binding ability. To test the root binding ability, a 10 cm x 15 cm portion of the sod was cut, and the root mass was manually shaken and pulled to test strength. The sod appeared to be holding together well.

In October 2006, slender hairgrass (*Deschampsia elongata*) was interseeded into the MSU Native Grass Sod–Hedgerow to increase root binding strength. It was anticipated that slender hairgrass would establish in less-dense areas of the sod propagation area where the binding ability of this annual cover crop would aid in holding the root mat together during transplanting. However, when MSU Native Grass Sod–Hedgerow was harvested and transplanted to the highway study site in November 2006, the root binding ability was poor and the sod could not be rolled.

In January 2007, the MSU Native Grass Sod–Hedgerow canopy cover increased to 95% and weeds composed 5% of the canopy cover. The basal ground cover was still low (approximately 60%), resulting in gaps of bare soil between grass bunches.

In April 2007, the MSU Native Grass Sod–Hedgerow canopy cover was approximately 70% (Figure 5.10). Plant species composition was observed to be approximately half native and half non-native species. Broadleaf weeds composed less than 1% of the canopy cover. Basal ground cover remained low at approximately 60%.

Figure 5.10 MSU Native Grass Sod-Hedgerow propagation area illustrating live canopy cover (left photo) and soil cover (right photo) at Hedgerow Farms in April 2007.

A plan was established to increase live basal cover and root mass of the MSU Native Grass Sod-Hedgerow propagation area. Hedgerow Farms staff were asked to increase irrigation frequency, mow grass every other week to promote root growth, apply nitrogen and phosphorus fertilizer to enhance root growth, inter-seed with red fescue (*Festuca rubra*) to increase sod strength, and control broadleaf weeds.

The red fescue failed to establish in the MSU Native Grass Sod–Hedgerow propagation area. Weed control was not successful and weedy annuals were producing seed. Since the MSU Native Grass Sod–Hedgerow was transplanted to the highway test area in November 2006, continued efforts to improve the sod quality in the propagation area were terminated in Spring 2007.

5.2.3. Propagation of MSU Native Grass Sod – Delta

Greenhouse research at MSU indicated that a sod mixture with four native grass species tended to have higher sod strength. It was determined the rhizomatous growth trait of red fescue increased sod strength when combined with other native grass species. In addition, the combination of red fescue and three native bunchgrasses had very high sod strength, comparable to Kentucky bluegrass (*Poa pratensis*) (Stott 2007). Three bunchgrass species were included in the MSU Native Grass Sod–Delta: Purple needlegrass, California brome, and California meadow barley (Table 5.8). These bunchgrass species were selected based on excellent sod development in MSU greenhouse research and on information gained during propagation and transplanting the MSU Native Grass Sod–Hedgerow. In September 2007, Delta Bluegrass Company in Stockton, California, was contracted to propagate the MSU Native Grass Sod–Delta.

Table 5.8 Grass species seeded in September 2007 and seeding rate for the MSU Native Grass Sod – Delta.

Scientific and Common Name	PLS/m^2	Percent of Mix
Festuca rubra (Red fescue)	11235	70
Nassella pulchra (Purple needlegrass)	1605	10
Hordeum brachyantherum californicum (California meadow barley)	1605	10
Bromus carinatus (California brome)	1605	10
Total	16,050	100

To minimize weed and fungus problems, the sod production field was fumigated prior to seeding the native grasses. A fumigation application of methyl bromide 448 kg/ha (400 pounds/acre) occurred on August 25, 2007. The methyl bromide was applied through an air-fan dilution system (tractor mounted), injected in the soil with a Modified Noble Plow, and covered with plastic for five days. Prior to seeding, a 17-17-17 (N-P-K) fertilizer was applied at 0.25 kg/m^2 (6 pounds/1000 ft^2). The native grass mix was seeded at a rate of 16,050 pure live seed per square meter (PLS/m^2) (1500 PLS/ft^2) on September 21, 2007. Prior to seeding, a Brillion seeder was used to flatten the soil. A seeder was used to superficially plant the grass seed, and a Brillion Seeder was used to pack and cover the seed (Figure 5.11). Plastic netting with approximately one inch separation distance between threads was laid down after seeding.

While the grass was germinating, the MSU Native Grass Sod–Delta propagation area was watered approximately 90 minutes per day. Following germination, the area was irrigated as needed to keep the soil moist. Mowing was instituted to keep the above ground plant growth approximately seven centimeters tall. A light-weight tractor was used to mow the sod which minimized plant damage and soil compaction.

Figure 5.11 Grass seeder (left photo) and Brillion seeder used to pack and cover the seed (right photo) at the Delta Bluegrass Company farm in September 2007.

5.2.3.1. Delta Bluegrass Company Farm Soil Traits

A composite soil sample from the 0-15 cm depth increment was collected and analyzed at Energy Laboratories, Helena, Montana. Soil textural class was clay loam and the rock content, i.e. particles greater than 2 mm diameter, was less than 2%. (Table 5.9). The soil had adequate plant-available levels of nitrogen, phosphorus and potassium.

Table 5.9 Soil physical traits and plant available nutrients at the Delta Bluegrass Company farm.

Soil Test[1]	Laboratory Analysis
Sand Content	27.5 %
Silt Content	38.3 %
Clay Content	31.3 %
Rock Content	<2.0 %
Textural Class	Clay Loam
Nitrogen (NO_3-N)	61 ppm
Potassium (K)	131 ppm
Phosphorus (P)	44 ppm

[1]Analytical methods are presented in Appendix A.

5.2.3.2. Assessment of Sod Development at Delta Bluegrass

In December 2007, ten weeks after seeding, the MSU Native Grass Sod–Delta propagation area was evaluated at the Delta Bluegrass Company farm. All seeded species were present in the native grass sod which had a total canopy cover of approximately 90%. Red fescue and California meadow barley were the dominant species in the mix, each having a canopy cover of approximately 40%. Sod density was measured by randomly placing three 20 by 50 cm Daubenmire frames within the sod propagation area. The 70 day old sod had an average density of 7,200 tillers per square meter.

In late January 2008 observations indicated the MSU Native Grass Sod–Delta had strong root development (Figure 5.12). In February 2008, a test cut of the sod indicated the sod root mass was well developed, and it could be rolled into a cylinder without falling apart (Figure 5.13).

Figure 5.12 MSU Native Grass Sod–Delta in the propagation area at the Delta Bluegrass Company farm in January 2008.

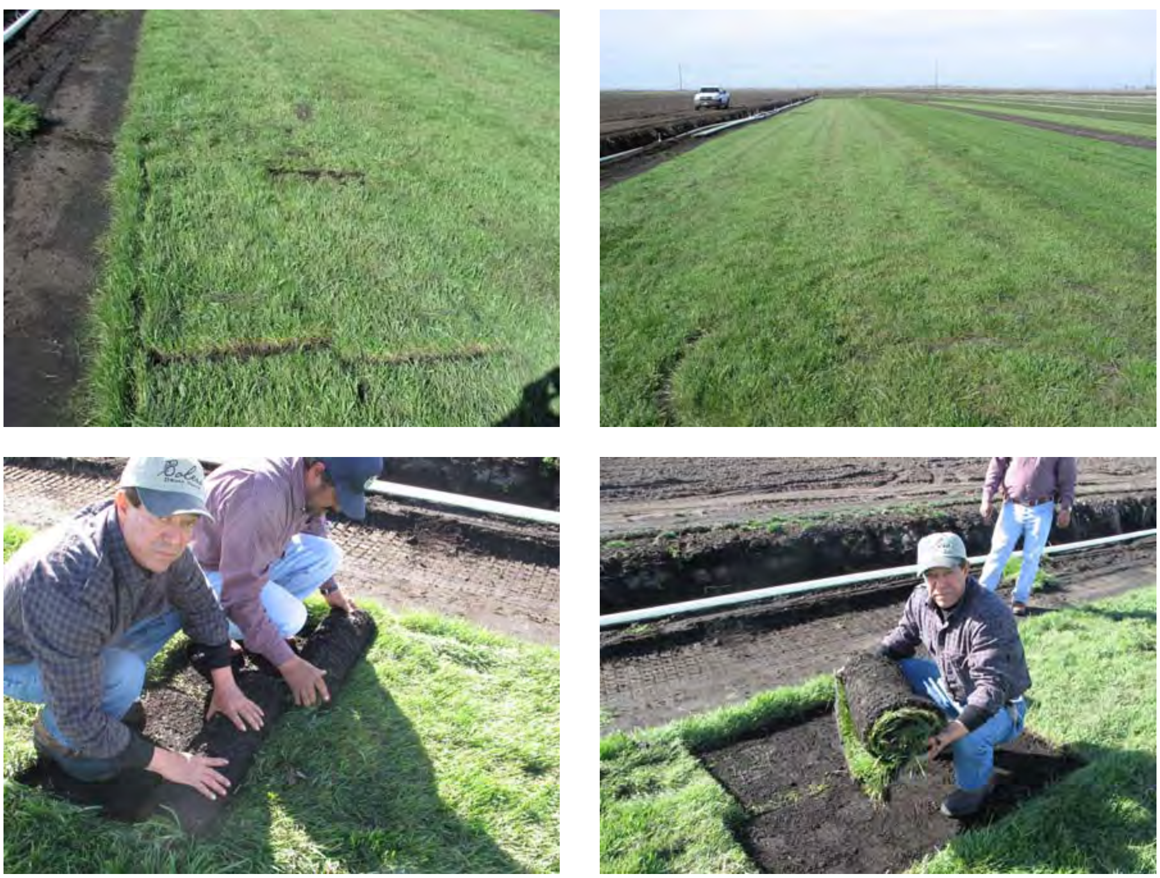

Figure 5.13 Test harvest of the MSU Native Grass Sod–Delta in the propagation area at the Delta Bluegrass Company farm in February 2008.

5.3. California Grassland Highway Demonstration Area

5.3.1. Native Grass Sod Highway Demonstration Location

Within the California Grassland Ecoregion, a test plot area was selected approximately 10 km south of Sacramento, California, at the intersection of Mack Road and Highway 99 (Figure 5.14). A highway fill-steep slope and a drainage swale test area were delineated at this location (Figure 5.15).

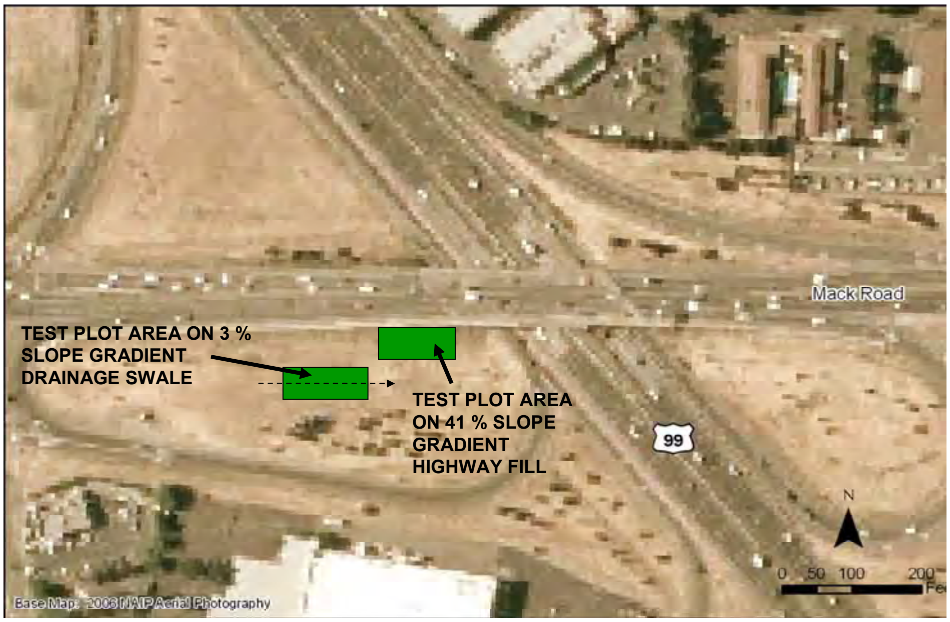

Figure 5.14 Location of native grass sod demonstration areas at the intersection of Mack Road and Highway 99 south of Sacramento, California (Section 4, Township 7N, Range 5E) (38°28.43'N by 121°25.49'W).

Figure 5.15 Highway fill-steep slope (left photo) and drainage swale (right photo) located at the Mack Road and Highway 99 intersection.

The highway fill-steep slope had a southern exposure (172°) and a slope gradient of 41%. The slope was largely devoid of vegetation and weeds were present on the perimeter of the planned test plot area. A variable thickness (0-10 cm) of woodchips was present across the surface.

Side slopes forming the drainage swale had a 5% gradient and the channel bottom had a 3% gradient that conveyed water off the site. The swale area had a western exposure (258°).

5.3.2. Precipitation Record during the Investigation Period

During the period of this study, September 2006 to August 2008, precipitation was 27% below the historical average of 92.4 cm (Figure 5.16). During the last four months of 2006, precipitation was 32% below the historical average of 16.2 cm. During 2007, precipitation was 29% below the historical average of 46.2 cm. During the first eight months of 2008, precipitation was 20% below the historical average of 29.9 cm.

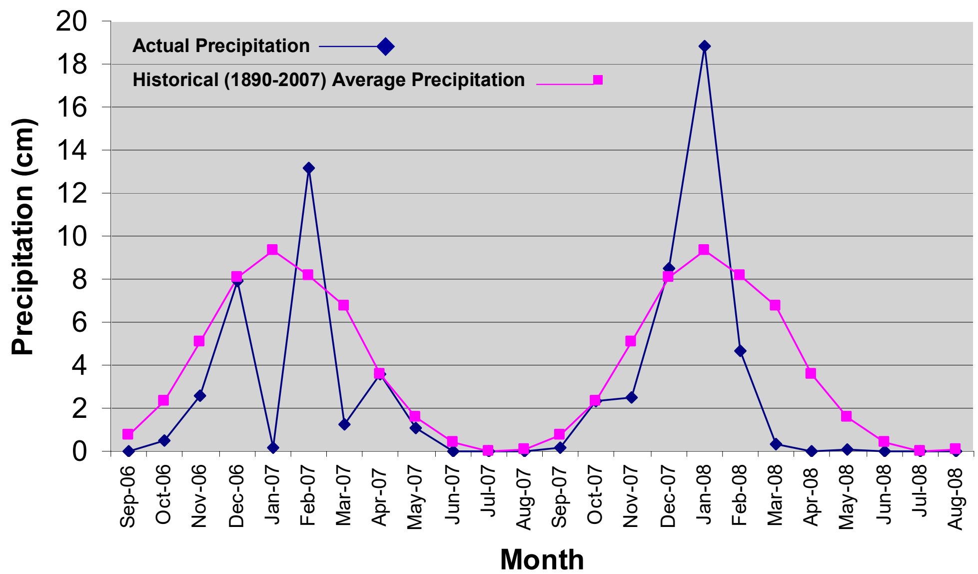

Figure 5.16 Actual precipitation received during the period of this native grass sod investigation compared to historical average precipitation.

5.3.3. Experimental Design – Treatment Implementation

The experimental design at the Mack Road location was implemented during an 18 month period from November 2006 to May 2008 (Figure 5.17). Each test plot treatment was three meters wide and ten meters long. With one exception, each treatment was replicated three times on the steep slope and three times on the drainage swale. The Delta Fescue Sod treatment was instituted on the drainage swale and steep slope areas, but was not replicated.

5.3.3.1. Highway Test Area Preparation and Maintenance

In April 2005, Restoration Resources sprayed the entire steep slope and drainage swale test areas with Roundup® at a rate of 4673 cm^3/ha (2 quarts/acre) in order to kill all actively growing plant material. During the period May 2005 through December 2007, weed growth was managed using a garden hoe and localized applications of Roundup®. Exposed soil areas adjacent to hydroseed and sod test plots were maintained in this manner. Weeds were not removed if they were growing within the hydroseed- and sod-treated areas.

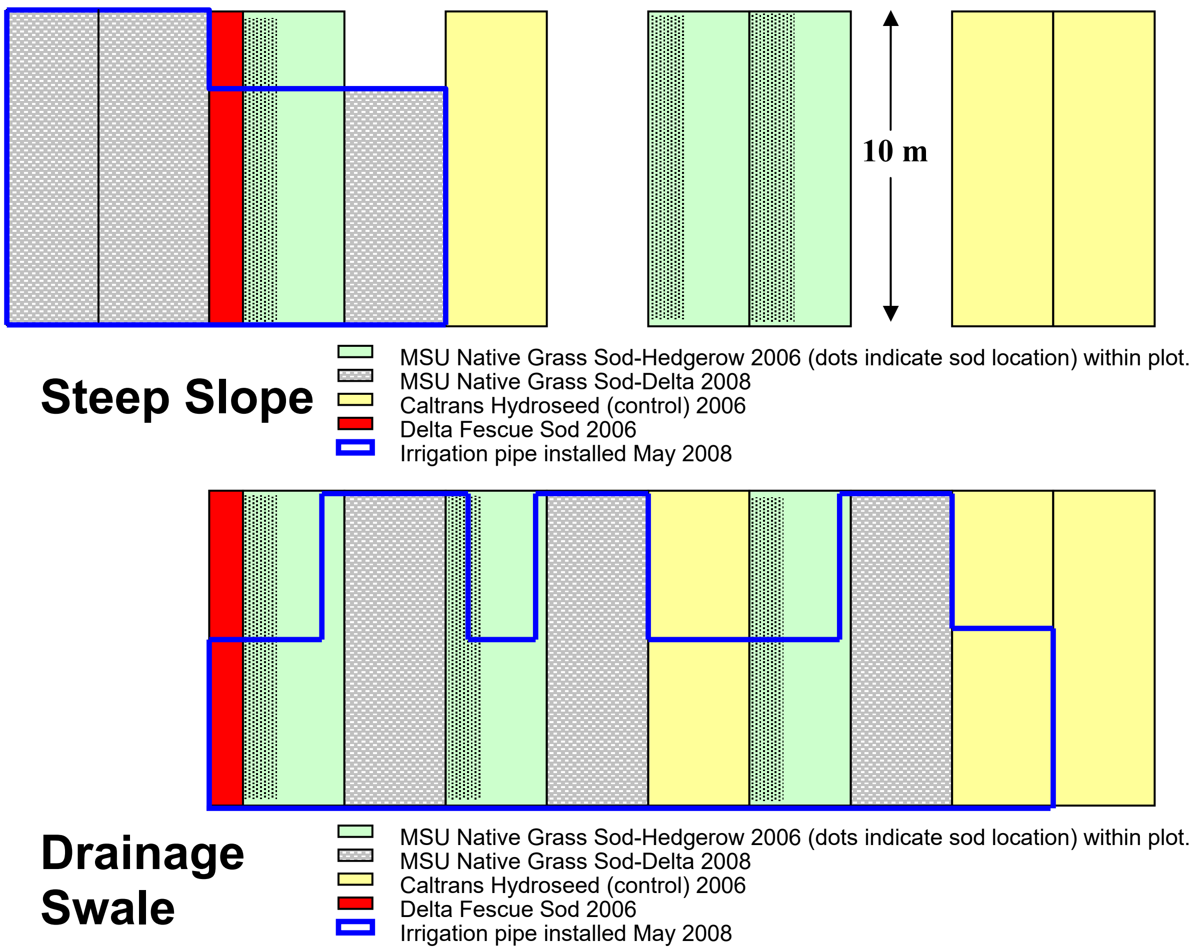

Figure 5.17 Experimental design for the highway fill-steep slope and the drainage swale area located at the Highway 99 and Mack Road intersection south of Sacramento, California.

In October 2006, Restoration Resources was contracted to scrape approximately 12 cm of woodchip mulch off the steep slope area until mineral soil was exposed. Both the drainage swale and the steep slope were tilled to a depth of 15 cm. Test plots in the drainage swale and steep slope area, where sod was going to be placed, were fertilized with 70 kg/ha of 15-30-0 grade fertilizer. Fertilizer was raked into the soil. Fertilizer consisted of 11.7% ammonia nitrogen, 3.3% urea nitrogen, and 30% P_2O_5. Control test plots received fertilizer in concert with the standard Caltrans Hydroseed-mulch procedure.

Caltrans staff specified that the demonstration area should not be mowed since this procedure could influence plant species presence. However, in December 2006 a highway maintenance crew inadvertently mowed the test plot area. This meant that the MSU Native Grass-Hedgerow, Caltrans Hydroseed-Mulch treatment, and Delta Fescue Sod were mowed once. Since the MSU Native Grass Sod-Delta was not transplanted until May 2008, it was never mowed.

A fence surrounding the test plot area was not approved since it could pose a safety problem. Alternately, four survey posts were installed at the corners of the drainage swale and steep slope plot areas. Caltrans maintenance crew members were advised to not disturb these two staked areas during routine highway maintenance.

5.3.3.2. Caltrans Hydroseed Treatment Implementation

In November 2006, the standard Caltrans Hydroseed-mulch procedure was instituted which was the control treatment (Figure 5.18). Caltrans Special Provisions for hydroseeding (erosion control type D) were followed for control plots. This treatment conformed to the provisions in Section 20-3, "Erosion Control," of the Standard Specifications. According to the provisions, the seed mix consisted of the following species: Spanish clover (*Lotus pershianus*), blue wildrye (*Elymus glaucus*), meadow barley (*Hordeum brachyantherum*), tidy tips (*Layia platyglossa*), creeping wildrye (*Leymus triticoides*), and purple needlegrass (*Nassella pulchra*).

Figure 5.18 View of the Caltrans Hydroseed treatment on the highway fill-steep slope in November 2006.

Fertilizer was incorporated into the hydroseed mixture and consisted of 6-7% nitrogen, 2-3% phosphoric acid and 3-4% water soluble potash. Erosion control material was applied in a separate application using the following sequence:

1) the seed mix was applied with hydroseeding equipment within 60 minutes after the seed has been added to the slurry,

2) straw was applied at the rate of four tons per hectare (0.07 lbs/ft^2), and

3) fiber, fertilizer and stabilizing emulsion were applied with the hydro-seeding equipment.

Samples of straw per square foot were taken on November 13, 2006, dried at MSU and weighed to measure the actual rate of straw applied. The rate was 11.6 tons/ha (0.20 lbs/ft^2).

5.3.3.3. MSU Native Grass Sod–Hedgerow Treatment Implementation

In November 2006, the MSU Native Grass Sod–Hedgerow was harvested at Hedgerow Farms and transplanted to the highway test area. Sod in the propagation area developed a weak root matrix that impaired harvest at the farm. Therefore, the quantity of MSU Native Grass Sod–Hedgerow harvested was sufficient to cover half of each test plot on the steep slope and drainage swale (Figure 5.17).

Prior to cutting the sod, the grass was rolled with an industrial roller. This technique leveled the cutting surface and firmed the soil to help hold the sod together while transplanting. The sod, composed of five native grass species, was cut to the 6 cm depth using a 45 cm wide self-propelled sod cutter (Figure 5.19). Because the cut sod did not hold together when rolling, it was further cut into 45 cm x 50 cm pieces then lifted and placed onto wood boards using metal scoop shovels. Stacking sod loaded boards in the trailer minimized vibration during transport (Figure 5.20).

Figure 5.19 Cutting MSU Native Grass Sod–Hedgerow at Hedgerow Farms in November 2006 and placement of sod slabs on transport boards.

Figure 5.20 Lifting the cut sod onto boards using a shovel (left photo) and stacking the boards for transport on a trailer bed (right photo).

At the Mack Road highway test area, the MSU Native Grass Sod–Hedgerow was slid off boards and placed in a 1 m x 10 m long strip on each plot (Figure 5.21). While handling the sod, some sod broke into smaller pieces. When transplanted, the sod was pieced together so no gaps were present across the surface. Because the sod did not form a binding root-mass, it could not be stapled into place. Within 24 hours of transplanting, the MSU Native Grass Sod–Hedgerow was irrigated with 3 cm of water using a Caltrans water truck.

Figure 5.21 Placing MSU Native Grass Sod–Hedgerow on the highway fill-steep slope area in November 2006.

5.3.3.4. Delta Fescue Sod Treatment Implementation

In November 2006, a 0.6 m wide by 10 m long strip of the Delta Fescue Sod was placed on the highway steep slope and drainage swale test areas (Figure 5.17). This fescue mix was composed of 30% hard fescue (*Festuca longifolia,* non-native), 30% sheep fescue (*Festuca ovina*, non-native), 20% creeping red fescue (*Festuca rubra*, native), and 20% chewings fescue (*Festuca rubra commutate*, non-native). This sod product was designed, propagated, and installed at the highway test area by the Delta Bluegrass Company.

5.3.3.5. MSU Native Grass Sod–Delta Treatment Implementation

In May 2008, the MSU Native Grass Sod–Delta was harvested at the Delta Bluegrass Company farm and transplanted to the highway test area (Figure 5.17). In order to enhance sod root-soil contact, a 4 cm thickness of a compost material termed "Topsoil Blend" was applied between the sod and underlying natural soil. This material had a pH suitable for plant growth, very high content of organic matter, and high plant available nitrogen, phosphorus, and potassium (Table 5.10). The Topsoil Blend had a very high soluble salt content (5.9 dS/m), which may have impaired root development.

Table 5.10 Physical and chemical traits of the "Topsoil Blend" provided by Redi-Gro Corporation, Sacramento, California, that was applied between sod and underlying natural soil.

Analytical Parameter[1]	Levels In Topsoil Blend
pH	7.5
Electrical Conductivity	5.9 dS/m
Organic Matter Content	10.0 %
Cation Exchange Capacity	21.0 meq/100g
Sodium Adsorption Ratio	4.4
Exchangeable Sodium Percentage	4.9
Nitrate-Nitrogen	43 ppm
Phosphorus	111 ppm
Potassium	1818 ppm
USDA Soil Textural Class	Loam

[1]Analytical methods are presented in Appendix A.

Each harvested roll of MSU Native Grass Sod–Delta was three meters long with a thickness of 10 cm (i.e., 3 cm of soil, 7 cm of sod). The diameter of each roll was 25 cm (Figure 5.22). A total of 210 rolls were transported to the highway test site and installed on the steep slope and drainage swale areas (Figures 5.23 and 5.24). Once transplanted, a roller was used to press the sod to the prepared bed to ensure root/soil contact. The sod on the slope was stapled in place using 15 cm long iron pins (Figure 5.25). The task of cutting, rolling, transport, installation and pinning native grass sod at the demonstration site was similar to harvesting and installing traditional turf sod.

Figure 5.22 Harvested rolls of MSU Native Grass Sod–Delta prepared for transport to the highway test area in May 2008.

Figure 5.23 Installation of MSU Native Grass Sod–Delta on the highway fill-steep slope test area in May 2008.

Figure 5.24 Installation of MSU Native Grass Sod–Delta on the highway drainage swale test area in May 2008.

Figure 5.25 Installed sod was rolled to enhance contact with underlying soil (left photo), then staples were inserted by hand to hold sod in place (middle and right photos).

5.3.3.6. Irrigation Water Application

Based on the study design, the plan was to transplant sod to the highway demonstration area in late fall to take advantage of the October through March rainy season. Consequently supplemental irrigation was not planned. However, due to contractor limitations, the MSU Native Grass Sod–Delta was transplanted on May 7, 2008. To ensure that the MSU Native Grass Sod–Delta survived transplanting during unusually high temperatures in May 2008, and through the hot and dry summer months of 2008, a temporary sprinkler irrigation system was installed immediately after sod installation at the Mack Road demonstration area (Figure 5.26). UV-resistant PVC pipe was installed on grade and multiple sprinkler heads were elevated 30 cm from grade to enhance water coverage. A Caltrans water well located in a pump house approximately 100 m from the test plots provided irrigation water. It was estimated that the water application rate was 5.1 cm/hr.

Analysis of the irrigation water indicated it was good quality with a low salt content, low sodic hazard, low nitrogen level, and suitable pH (Table 5.11).


Figure 5.26 Irrigation line installation following transplanting the MSU Native Grass Sod–Delta on the drainage swale (left phote) and steep slope (right photo) areas on May 7, 2008.

Table 5.11 Analysis of water used to irrigate test plots at the Mack Road site.

Analyte	Lab Analysis
Specific Conductance	0.15 dS/m
Nitrate-Nitrogen	Not Detected
pH	8.1
Sodium Adsorption Ratio	0.4

Following installation of the MSU Native Grass Sod–Delta, it was sprinkler irrigated four times per day for 14 days, then reduced to three times per day for 14 days, and finally to once a day. Irrigation cycles began at 1:00 am (long cycle), 7:00 am, 1:00 pm, and 7:00 pm. The long irrigation cycle was set for 30 minutes on the swale and 45 minutes on the slope. Other irrigation cycles were set for 10 minutes on the swale and 30 minutes on the slope. When the water schedule was reduced to three times per day, the 1:00 pm cycle was eliminated. After four weeks, the sod was watered once per day at 1:00 am and all irrigation cycles were 10 minutes long.

5.4. Native Grass Establishment with Sod and Hydroseed

Native grass establishment was monitored during a 20 month period following implementation of sod and hydroseed-mulch treatments at the Mack Road steep slope and drainage swale test area. The sequence of vegetation monitoring events was as follows:

- November 2006 – Immediately following installation of the Caltrans Hydroseed-mulch treatment and transplanting the MSU Native Grass Sod–Hedgerow and the Delta Fescue Sod, selected plant measurement were completed. During November 2006 to March 2007 a test was completed to determine the origin of weeds in test plot areas.
- May 2007 – Six months after implementing the Caltrans Hydroseed-mulch treatment and transplanting the MSU Native Grass Sod–Hedgerow and the Delta Fescue Sod; plant measurements were completed at the Mack Road test area.
- May 2008 – Eighteen months after implementing the Caltrans Hydroseed-mulch treatment and transplanting the MSU Native Grass Sod–Hedgerow and the Delta Fescue Sod; plant measurements were completed at the Mack Road test area.
- August 2008 – Three months after implementing the MSU Native Grass Sod–Delta treatment; plant measurements on this treatment were made at the Mack Road test area.

5.4.1. Monitoring Procedures

5.4.1.1. Vegetation Monitoring Procedure

Above-ground plant development was evaluated by collecting density and canopy cover data for native grass and weed species using methods presented by the U.S. Bureau of Land Management (BLM 1995). Seven randomly located Daubenmire frames (20 cm x 50 cm) were sampled in each treatment plot. Density was recorded as the number of stems (forbs) or tillers (grass) per frame. Canopy cover is the percentage of the soil surface covered by the vertical projection of a species regardless of what is below. Above-ground plant biomass was collected by species by clipping the plant at the soil surface within each frame. Plant biomass was dried at 40°C for a 160 hour period, and the dry plant mass was determined on an analytical balance.

Soil cover was measured using the line-intercept sampling method (BLM 1995). Soil cover is the percentage of the soil surface covered by an object (e.g. plant basal cover or litter) regardless of what is above the object. One randomly located 10 m long point-intercept transect was placed within each test plot area. At each 30 cm interval, a mark was placed and the type of soil cover was recorded, resulting in 30 data collection points along the transect.

5.4.1.2. Weed Source Assessment Procedure

It was necessary to determine whether weed development in treatment plots originated from the site's preexisting soil seed bank, or established from the sod and hydroseed treatments. To evaluate potential weed sources, composite soil samples were collected before grass establishment treatments were instituted, sod samples were collected for each treatment, and soil that received the hydroseed-mulch treatment was collected in November 2006 at the Mack Road highway test area. Samples were placed on sterilized soil in flats at the MSU Plant Growth Center and watered three times weekly. Plant growth continued until March 2007, at which time germinated species were mature enough to identify. All germinated species were counted and recorded. Unidentifiable species were pressed and sent to the University of California (Davis) Herbarium for identification.

5.4.2. Sod and Hydroseed Traits Immediately Following Treatment Implementation

At the time of seeding in November 2006, plant density and canopy cover on the Caltrans Hydroseed-mulch treatment were neglible, while the straw mulch provided 100% soil cover on both the steep slope and drainage swale (Tables 5.12, 5.13, and 5.14).

The MSU Native Grass Sod–Hedgerow plant density was composed of five native grass species in the sod mix, and only a trace of weedy forbs was present (Table 5.12). Since the MSU Native Grass Sod–Hedgerow was transplanted as broken plate size pieces, as opposed to a contiguous roll of sod, canopy cover of native grass was 58.9% and 70.0%, while bare ground and litter largely composed the remainder of the canopy cover (Table 5.13). At the soil surface, plant basal cover was 28.9% and 40%, and the remainder of the area was composed of bare ground and litter (Table 5.14).

Table 5.12 Mean plant density at the highway steep slope and drainage swale area as a function of grass establishment treatments in November 2006.

Grass Establishment Procedure	Location	Plant Density (stems+tillers/m^2)		
		Desired Grass[1]	Weedy Grass	Weedy Forbs
MSU Native Grass Sod – Hedgerow	Slope	2193.0	0.0	0.1
Caltrans Hydroseed	Slope	0.0	0.0	0.0
Delta Fescue sod	Slope	11900.00	0.0	0.0
MSU Native Grass Sod – Hedgerow	Swale	2523.0	0.1	1.2
Caltrans Hydroseed	Swale	0.0	0.0	0.0
Delta Fescue sod	Swale	11000.0	0.0	0.0

[1]Desired grass includes those seeded species in the MSU Native Grass Sod–Hedgerow and Caltrans Hydroseed-mulch treatments. Not all of the Delta Fescue Sod species are native but are considered desired because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

Table 5.13 Mean percent canopy cover at the highway steep slope and drainage swale area as a function of grass establishment treatments in November 2006.

Grass Establishment Treatment	Location	Canopy Cover (%)					
		Desired Grass[1]	Annual Grass	Weedy Forbs	Litter	Rock	Bare Ground
MSU Native Grass Sod – Hedgerow	Slope	58.9	0.0	0.1	13.7	0.0	27.3
Caltrans Hydroseed	Slope	0.0	0.0	0.0	100.0	0.0	0.0
Delta Fescue Sod	Slope	100.0	0.0	0.0	0.0	0.0	0.0
MSU Native Grass Sod – Hedgerow	Swale	70.0	0.1	2.3	5.7	0.0	22.0
Caltrans Hydroseed	Swale	0.0	0.0	0.0	100.0	0.0	0.0
Delta Fescue Sod	Swale	100.0	0.0	0.0	0.0	0.0	0.0

[1]Desired grass includes those seeded species of the MSU Native Grass Sod─Hedgerow and Caltrans Hydroseed-mulch treatment. Not all of the Delta Fescue Sod species are native but are considered desired here because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

Table 5.14 Mean percent soil cover at the highway steep slope and drainage swale area as a function of grass establishment treatments in November 2006.

Grass Establishment Treatment	Location	Soil Cover (%)			
		Plant Basal Cover	Litter	Rock	Bare Ground
MSU Native Grass Sod – Hedgerow	Slope	28.9	10.0	0.0	61.1
Caltrans Hydroseed	Slope	0.0	100.0	0.0	0.0
Delta Fescue Sod	Slope	93.3	6.7	0.0	0.0
MSU Native Grass Sod – Hedgerow	Swale	40.0	12.2	0.0	47.7
Caltrans Hydroseed	Swale	0.0	100	0.0	0.0
Delta Fescue Sod	Swale	90.0	10.0	0.0	0.0

Plant density and canopy cover for the Delta Fescue Sod was composed entirely of the four fescue plant species that were seeded to form this sod product (Tables 5.12 and 5.13). At the soil surface, this sod covered 90% or more of the area (Table 5.14).

5.4.3. Origin of Weedy Plant Species in Test Plots

When a Delta Fescue Sod sample was grown in the MSU greenhouse, only those fescue species seeded were present in the sod. This indicates weedy plant species were not introduced to the Mack Road test plot area by the Delta Fescue Sod.

When the Caltrans Hydroseed-mulch treatment was grown in the greenhouse, no plant species were present except those seeded. This indicates weedy plant species were not introduced to the Mack Road test plot area by the Caltrans Hydroseed-mulch treatment.

The in-place soil seed bank at the Mack Road test plot area contained at least nine undesirable grass and forb species (Table 5.15). These non-native grass and forb species had potential to propagate within sod and hydroseed treatments at the Mack Road test area.

The MSU Native Grass Sod–Hedgerow contained one undesirable non-native grass, soft brome, and one undesirable non-native forb, common knotweed (Table 5.15). Presumably, the origin of these undesirable species was the native grass sod propagation area located at Hedgerow Farms. These two undesirable species could propagate within the native grass sod at the Mack Road test area and deteriorate the effort to produce a plant cover of only native plant species.

When the MSU Native Grass Sod–Hedgerow was grown on soil from the Mack Road test area, only two non-native species, groundsel and Italian ryegrass, were present. The overlying sod precluded growth of seven other non-native grass and forb species present in the Mack Road soil seed bank. In principle, this indicated native grass sod had potential to prevent propagation of many weed species present in the soil seed bank at highway projects.

5.4.4. Sod and Hydroseed Plant Traits Six Months after Treatment Implementation

Plant measurements were completed at peak standing crop during April 30 to May 3, 2007. In tables presented in this section, desired grasses and forbs are those species that were seeded in the treatments and weedy grasses and forbs are non-native or volunteer species on the site.

Canopy cover, plant density, and plant biomass data indicated the Delta Fescue Sod was dominated by desired grass species, and the sod effectively resisted weed invasion (Tables 5.16, 5.17, and 5.18). This sod was harvested in rolls, transported to the test plot area, where sod was rolled out as a contiguous mat that was pinned to the underlying soil. The contiguous sod mat prevented emergence of weedy species contained in the underlying soil seed bank.

The MSU Native Grass Sod–Hedgerow was dominated by weedy grasses (Tables 5.16, 5.17, and 5.18). While desired grass is present in the MSU Native Grass Sod–Hedgerow, its density, canopy cover and biomass was much lower than that of weedy grasses. Weedy grasses originated from both the Mack Road soil seed bank underlying the sod and inadvertently transplanted as contaminants from the sod propagation area located at Hedgerow Farms. Since the MSU Native Grass Sod–Hedgerow was transplanted as broken plate size pieces, as opposed to a contiguous roll of sod, the sod soil cover was 40%, or less, at the time of transplanting which provided openings for weedy species to propagate into the sod from the underlying soil seed bank.

Table 5.15 Undesired grass and forb species present in the preexisting soil seed bank and the MSU Native Grass Sod–Hedgerow at the Mack road test area.

Common Name	Scientific Name	Sod and/or Seed Bank Treatment	Density (plants/m^2)	Lifeform	Lifecycle	Origin
Soft Brome	*Bromus hordeaceus*	MSU Native Grass Sod─Hedgerow	24	grass	annual	non-native
Common Knotweed	*Polygonum arenastrum*	MSU Native Grass Sod─Hedgerow	8	forb	annual or perennial	non-native
Groundsel	*Senecio vulgaris*	MSU Native Grass Sod─Hedgerow and Existing Seed Bank	4 and 4	forb	annual or biennial	non-native
Italian Ryegrass	*Lolium multiflorum*	MSU Native Grass Sod─Hedgerow and Existing Seed Bank	4 and 6	grass	annual, biennial or perennial	non-native
Annual Bluegrass	*Poa annua*	Existing Seed Bank	232	grass	annual	non-native
Common Dandelion	*Taraxacum officinale*	Existing Seed Bank	8	forb	perennial	native and non-native
Narrowleaf Plantain	*Plantago lanceolata*	Existing Seed Bank	4	forb	annual or perennial	non-native
Burclover	*Medicago polymorpha*	Existing Seed Bank	12	grass	annual or perennial	non-native
Toad Rush	*Juncus bufonius*	Existing Seed Bank	32	grass	annual	native
Purslane Speedwell	*Veronica peregrina*	Existing Seed Bank	8	forb	annual	native
Yellow Starthistle	*Centaurea solstitialis*	Existing Seed Bank	4	forb	annual	non-native

For MSU Native Grass Sod–Hedgerow species composition, the most common native grasses were California meadow barley and Sandberg's bluegrass on the drainage swale and California meadow barley and purple needlegrass on the steep slope. The three weedy grasses most common in the MSU Native Grass Sod–Hedgerow were soft brome, Italian ryegrass, and zorro fescue. No desired forbs were present in the MSU Native Grass Sod–Hedgerow. The most common weedy forbs in MSU Native Grass Sod–Hedgerow were field bindweed (*Convolvulus arvensis*) and groundsel.

The Caltrans Hydroseed-mulch treatment was dominated by the seeded desired forb tidy tips. Desired grasses were present in the Caltrans Hydroseed-mulch treatment, but canopy cover, density, and biomass were less than weedy grass species (Tables 5.16, 5.17, and 5.18). The source of weedy grass and forb species was the preexisting seed bank present in graded soil that was hydroseeded.

The most prevalent desired grass in the Caltrans Hydroseed-mulch treatment was wildrye on the drainage swale and purple needlegrass on the steep slope. The two weedy grasses most common in the Caltrans yydroseed-mulch treatment were soft brome and zorro fescue. Tidy tips, a seeded forb, was the dominant species on both the steep slope and drainage swale. The most common weedy forbs were bindweed, annual mustard species, and groundsel.

Photos of grass and forb establishment on the steep slope and drainage swale area are presented in Figure 5.27.

Table 5.16 Mean percent canopy cover at the Mack Road slope and swale test areas and at the Delta Bluegrass Company sod farm in May 2007.

Location	Grass Establishment Treatment	Desired Grass[1]	Weedy Grass	Desired Forb	Weedy Forb	Litter	Bare Ground
		% Canopy Cover					
Swale	Delta Fescue Sod	95.3	0.0	0.0	1.4	3.3	0.0
Swale	MSU Native Grass Sod─Hedgerow	16.4	64.5	0.0	4.7	10.6	3.8
Swale	Caltrans Hydroseed	1.5	5.1	56.8	19.3	17.3	0.0
Slope	Delta Fescue Sod	40.0	0.0	0.0	0.0	60.0	0.0
Slope	MSU Native Grass Sod─Hedgerow	3.8	66.6	0.0	10.1	12.1	7.4
Slope	Caltrans Hydroseed	8.1	21.0	26.5	22.4	22.0	0.0

[1]Desired grass includes those seeded species in the MSU Native Grass Sod─Hedgerow and Caltrans Hydroseed-mulch treatments. Not all of the Delta Fescue Sod species are native but are considered desired here because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

Table 5.17 Mean plant density at the highway fill-steep slope and the drainage swale locations as a function of native grass establishment procedures in May 2007.

Grass Establishment Treatment	Location	Plant Density (stems+tillers/m^2)			
		Desired Grass[1]	Weedy Grass	Desired Forbs	Weedy Forbs
MSU Native Grass Sod – Hedgerow	Swale	360	940	0	16
Caltrans Hydroseed	Swale	27	47	163	20
Delta Fescue Sod	Swale	10,840	0	0	0
MSU Native Grass Sod – Hedgerow	Slope	68	76	72	12
CALTANS Hydroseed	Slope	140	188	0	8
Delta Fescue Sod	Slope	400	0	0	1

[1]Desired grass includes those seeded species in the MSU Native Grass Sod–Hedgerow and Caltrans Hydroseed-mulch treatment. Not all of the Delta Fescue Sod species are native but are considered desired here because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

Table 5.18 Above-ground biomass (live vegetation) at the highway fill-steep slope and the drainage swale locations as a function of native grass establishment procedures in May 2007.

Grass Establishment Treatment	Location	Above Ground Biomass (grams/m^2)			
		Desired Grass[1]	Weedy Grass	Desired Forbs	Weedy Forbs
MSU Native Grass Sod – Hedgerow	Swale	34	474	0	10
Caltrans Hydroseed (control)	Swale	7	4	339	90
Delta Fescue Sod	Swale	220	0	0	3
MSU Native Grass Sod – Hedgerow	Slope	10	403	0	43
Caltrans Hydroseed (control)	Slope	31	136	124	169
Delta Fescue Sod	Slope	79	0	0	4

[1]Desired grass includes those seeded species in the MSU Native Grass Sod–Hedgerow and Caltrans Hydroseed-mulch treatment. Not all of the Delta Fescue Sod species are native but are considered desired here because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

A. Delta Fescue Sod (left) and MSU Native Grass Sod-Hedgerow (right) in the drainage swale. The tall grass in the MSU Native Grass Sod─Hedgerow is a non-native weedy grass (Soft brome) and the short grass in the lower right is native grass (California meadow barley).

B. The Caltrans Hydroseed-mulch plot in the drainage swale was dominated by a seeded native forb (tidy tips).

C. Canopy cover of the MSU Native Grass Sod─Hedgerow plot on the steep slope was dominated by annual weedy grasses.

D. Daubenmire frame in the MSU Native Grass Sod─Hedgerow plot.

Figure 5.27 Photos of grass and forb establishment in the drainage swale (A, B) and steep slope (B,C) test plot area in May 2007.

Species richness values indicated greater plant diversity was present as weedy grass and forb species compared to seeded species on sod and hydroseed treatment areas (Table 5.19). Richness data were not collected for the Delta Fescue Sod treatment because fescue species were not flowering at time of data collection and could not be identified by species.

Table 5.19 Plant species richness at the highway fill-steep slope and the drainage swale locations in May 2007 as a function of native grass establishment procedures.

Grass Establishment Procedure	Location	Mean Species Richness/m²			
		Desired Grass[1]	Weedy Grass	Desired Forbs	Weedy Forbs
MSU Native Grass Sod – Hedgerow	Swale	1.5	2.7	0.0	0.3
Caltrans Hydroseed	Swale	0.5	1.3	0.9	1.4
MSU Native Grass Sod – Hedgerow	Slope	0.4	2.4	0.0	0.8
Caltrans Hydroseed	Slope	0.5	1.2	0.8	0.8

[1]Desired grass includes the species seeded for the MSU Native Grass Sod–Hedgerow and Caltrans Hydroseed-mulch treatment. Weedy grass and forbs are non-native and volunteer species.

At the soil surface, both Delta Fescue Sod and the Caltrans Hydroseed-mulch treatment had more than 96% soil cover consisting of live plant stems, plant litter, and straw mulch (Table 5.20). The MSU Native Grass Sod–Hedgerow had 28.0% to 54.8% bare ground, which indicated six months since transplanting was not sufficient time for native grasses to encroach into- and fill-voids between sod pieces.

Table 5.20 Percent soil cover for the highway fill-steep slope and the drainage swale in May 2007 as a function of native grass establishment procedures.

Grass Establishment Treatment	Location	Soil Cover (%)			
		Plant Basal Cover	Litter	Rock	Bare Ground
MSU Native Grass Sod – Hedgerow	Slope	23.2	22.0	0.0	54.8
Caltrans (Hydroseed)	Slope	46.6	50.1	0.0	3.3
Delta Fescue Sod	Slope	32.3	68.0	0.0	0.0
MSU Native Grass Sod - Hedgerow	Swale	54.9	16.1	0.0	28.0
Caltrans Hydroseed	Swale	48.8	49.8	0.0	1.4
Delta Fescue Sod	Swale	86.4	10.1	0.0	3.5

5.4.5. Sod and Hydroseed Plant Traits 18 Months After Implementation

Eighteen months after implementing sod and hydroseed treatments at the Mack Road test plot area, plant traits were measured at peak standing crop during May 3-4, 2008.

The MSU Native Grass Sod–Delta had been under propagation for eight months at the Delta Bluegrass Company farm and was scheduled to be transplanted to the Mack Road test plot area on May 7, 2008. On May 5, 2008, sod growth traits were measured prior to transplanting at the Delta Bluegrass Company farm, and these results are presented below.

5.4.5.1. Plant Canopy Cover, Density, and Above Ground Biomass

MSU Native Grass Sod–Delta canopy cover, density, and biomass indicated only the desired four native grass species seeded were present (Tables 5.21, 5.22, and 5.23). The sod was well maintained and free of weedy species at the Delta Bluegrass Company farm (Figure 5.28).

Figure 5.28 Photo of MSU Native Grass Sod–Delta at the Delta Bluegrass Company farm in May 2008 shortly before being transplanted to the Mack Road test plot area.

Canopy cover, density and biomass measurements indicated the four species of fescue composing Delta Fescue Sod were not present, and weedy grass species dominated (Tables 5.21, 5.22, and 5.23). Desired fescue grass species were dormant, dead, or inadvertently mowed (Figure 5.29). The deterioration of this sod treatment may be, in part, attributable to the narrowness of the strip installed on the drainage swale and steep slope, which may have invited rapid invasion by weedy species.

MSU Native Grass Sod–Hedgerow had desired grass and forb species present on both the drainage swale and steep slope, but weedy grass and forb species had greater canopy cover, density and biomass (Tables 5.21, 5.22, and 5.23; Figure 5.30). Observation indicated there were patches of desired grasses thriving on portions of the drainage swale and steep slope, which may be attributable to the manner in which the MSU Native Grass Sod–Hedgerow was transplanted. This sod was transplanted as broken plate size pieces, as opposed to a contiguous roll of sod, and bare ground was present between patches of sod.

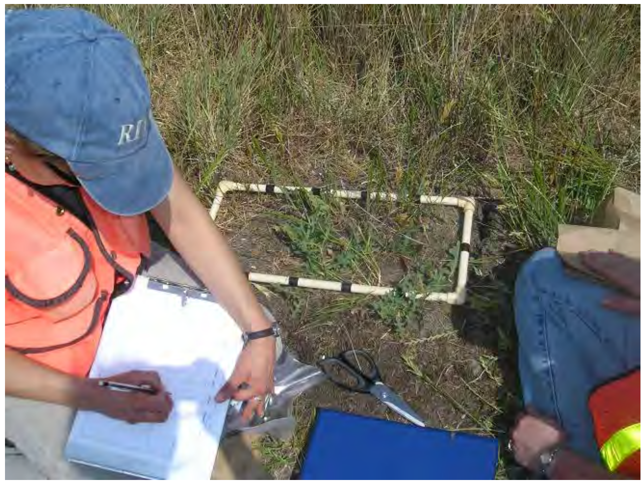

Figure 5.29 Biomass and canopy cover data collection in the Delta Fescue Sod treatment located on the drainage swale test plot in May 2008.

The Caltrans Hydroseed-mulch treatment contained zones where the seeded and desired forb tidy tips was thriving in the drainage swale and to a lesser degree on the steep slope. However, canopy cover, density and biomass in the Caltrans Hydroseed-mulch treatment were dominated by weedy grasses (Tables 5.21, 5.22, 5.23).

Table 5.21 Canopy cover at the Mack Road steep slope and drainage swale area and at the Delta Bluegrass Company sod farm in May 2008.

Location	Grass Establishment Treatment	Desired Grass[1]	Weedy Grass	Desired Forb	Weedy Forb	Litter	Bare Ground
		Canopy Cover (%)					
Swale	Delta Fescue Sod	0.0	27.8	0.0	26.0	45.0	1.2
Swale	MSU Native Grass Sod–Hedgerow	32.1	33.2	0.0	0.9	29.2	4.0
Swale	Caltrans Hydroseed	6.5	36.9	11.1	8.5	39.8	1.2
Slope	Delta Fescue Sod	0.0	26.5	0.0	0.0	70.0	3.8
Slope	MSU Native Grass Sod–Hedgerow	2.7	63.2	1.2	11.8	19.6	2.5
Slope	Caltrans Hydroseed	10.8	48.8	4.1	6.5	29.9	0.0
Sod Farm	MSU Native Grass Sod-Delta	100.0	0.0	0.0	0.0	0.0	0.0

[1]Desired grass includes those species seeded for the MSU Native Grass Sod–Hedgerow, MSU Native Grass Sod–Delta, and Caltrans Hydroseed-mulch treatment. Not all of the Delta Fescue Sod species are native but are considered desired here because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

Table 5.22 Mean plant density at the Mack Road steep slope and drainage swale area and at the Delta Bluegrass Company sod farm in May 2008.

Grass Establishment Treatment	Location	Plant Density (stems+tillers/m^2)			
		Desired Grass[1]	Weedy Grass	Desired Forbs	Weedy Forbs
MSU Native Grass Sod – Delta	Sod Farm	12,432	0	0	0
MSU Native Grass Sod – Hedgerow	Swale	545	663	0	11
Caltrans Hydroseed (control)	Swale	95	423	178	21
Delta Fescue Sod	Swale	0	635	0	93
MSU Native Grass Sod – Hedgerow	Slope	32	883	5	21
Caltrans Hydroseed (control)	Slope	100	424	20	13
Delta Fescue Sod	Slope	0	273	0	0

[1]Desired grasses are those species seeded in the MSU Native Grass Sod–Hedgerow, MSU Native Grass Sod–Delta, and Caltrans Hydroseed-mulch treatment. Not all of the Delta Fescue Sod species are native but are considered desired because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

Table 5.23 Mean above ground plant biomass at the Mack Road steep slope and drainage swale area and at the Delta Bluegrass Company sod farm in May 2008.

Grass Establishment Treatment	Location	Above Ground Biomass (grams/m^2)			
		Desired Grass[1]	Weedy Grass	Desired Forbs	Weedy Forbs
MSU Native Grass Sod – Delta	Sod Farm	1326	0	0	0
MSU Native Grass Sod – Hedgerow	Swale	97	91	0	5
Caltrans Hydroseed (control)	Swale	18	136	29	19
Delta Fescue Sod	Swale	0	98	0	64
MSU Native Grass Sod – Hedgerow	Slope	17	296	2	39
Caltrans Hydroseed (control)	Slope	67	336	13	21
Delta Fescue Sod	Slope	0	0	0	0

[1]Desired grasses are those species seeded in the MSU Native Grass Sod–Hedgerow, MSU Native Grass Sod–Delta, and Caltrans Hydroseed-mulch treatment. Not all of the Delta Fescue Sod species are native but are considered desired because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

A. MSU Native Grass Sod─Hedgerow in the swale. Plots are marked with Caltrans markers. The majority of the grass is the native grass California meadow barley.

B. The MSU Native Grass Sod─Hedgerow dominated by California meadow barley in the swale.

C. MSU Native Grass Sod─Hedgerow in the swale.

D. MSU Native Grass Sod─Hedgerow plot on the slope. Irrigation was on-going during this photo event.

Figure 5.30 Photos of MSU Native Grass Sod-Hedgerow on the drainage swale (A, B, C) and on the steep slope plot area in May 2008.

5.4.5.2. Plant Species Composition and Richness

Soft brome, foxtail (*Hordeum* spp.), and Italian ryegrass were the dominant weedy grasses in Delta Fescue Sod on both the drainage swale and steep slope. Yellow starthistle was the most common weedy forb on the Delta Fescue Sod drainage swale plot area.

California meadow barley was the most common desired grass species in the MSU Native Grass Sod-Hedgerow on the drainage swale. The most common desired grass species was purple needlegrass in the MSU Native Grass Sod–Hedgerow treatment on the steep slope. Soft brome and Italian ryegrass were the most common weedy grass species in the MSU Native Grass Sod–Hedgerow on the drainage swale and steep slope. The most common weedy forb was field bindweed (*Convolvulus arvensis*) on the steep slope.

In the Caltrans Hydroseed-mulch treatment, the most prevalent desired grass on the drainage swale and steep slope was purple needlegrass. Tidy tips was the most common desired forb on the drainage swale and steep slope. Soft brome and foxtail were common weedy grass species on the drainage swale, while soft brome and wild oat (*Avena fatua*) was most common on the steep slope. There were few weedy forbs in the Caltrans Hydroseed-mulch treatment on the drainage swale, but field bindweed was the most common. Annual mustard *(Brassica* L. spp.) species were the most common weedy forb on the steep slope.

Species richness values for MSU Native Grass Sod–Delta indicate only the four native grass species that were seeded were present in the sod (Table 5.24). Conversely, the four fescue species composing Delta Fescue Sod were not present, and weedy grass and forb species were present. Both MSU Native Grass Sod–Hedgerow and Caltrans Hydroseed-mulch treatment had desired grass species present that were seeded, but invasion of weedy grass species resulted in species richness values equal or greater than seeded-desirable grass species.

5.4.5.3. Soil Cover

At the soil surface, the MSU Native Grass Sod–Delta had 100% live plant basal cover, which would effectively preclude sediment loss (Table 5.25). Plant basal cover for MSU Native Grass Sod–Hedgerow and Caltrans Hydroseed-mulch treatment ranged between 45% and 70%, but as discussed above, most of these plants were weedy grasses. Bare ground surface for MSU Native Grass Sod–Hedgerow and Caltrans Hydroseed-mulch treatment ranged between 10% and 20% eighteen months after treatment installation. Bare ground surface increases the potential for sediment loss. Plant litter for the Caltrans Hydroseed-mulch treatment ranged between 10% and 45% which indicted a portion of the straw mulch was no longer present as a result of redistribution due to wind and water erosion.

Table 5.24 Species richness at the Mack Road steep slope and drainage swale area and at the Delta Bluegrass Company sod farm in May 2008.

Location	Grass Establishment Treatment	Desired Grass[1]	Weedy Grass	Desired Forb	Weedy Forb
		Species Richness/m²			
Swale	Delta Fescue Sod	0.0	2.5	0.0	1.5
Swale	MSU Native Grass Sod–Hedgerow	1.5	1.5	0.0	0.2
Swale	Caltrans Hydroseed	0.9	2.4	0.9	1.0
Slope	Delta Fescue Sod	0.0	2.0	0.0	0.0
Slope	MSU Native Grass Sod–Hedgerow	0.2	2.1	0.2	0.6
Slope	Caltrans Hydroseed	0.8	1.8	0.2	0.6
Sod Farm	MSU Native Grass Sod–Delta	1.0	0.0	0.0	0.0

[1]Desired grasses are those species seeded in the MSU Native Grass Sod–Hedgerow, MSU Native Grass Sod–Delta, and Caltrans Hydroseed-mulch treatment. Not all of the Delta Fescue Sod species are native but are considered desired because they were included in the sod seed mix. Weedy grass and forbs are non-native and volunteer species.

Table 5.25 Soil cover at the Mack Road steep slope and drainage swale area and at the Delta Bluegrass Company sod farm in May 2008.

Location	Grass Establishment Treatment	Live Plant Basal Cover	Plant Litter	Rock	Trash	Bare Ground
		Soil Cover (%)				
Swale	Delta Fescue Sod	16.7	76.6	0.0	0.0	6.7
Swale	MSU Native Grass Sod–Hedgerow	53.3	25.5	0.0	1.1	18.9
Swale	Caltrans Hydroseed	46.7	43.3	0.0	0.0	10.0
Slope	Delta Fescue Sod	3.3	73.3	0.0	0.0	23.3
Slope	MSU Native Grass Sod–Hedgerow	60.0	28.9	0.0	1.1	10.0
Slope	Caltrans Hydroseed	70.0	13.3	0.0	0.0	16.7
Sod Farm	MSU Native Grass Sod–Delta	100.0	0.0	0.0	0.0	0.0

5.4.6. MSU Native Grass Sod – Delta Plant Traits Three Months After Transplanting

The MSU Native Grass Sod–Delta was transplanted from the nursery to the Mack Road test plot area on May 7, 2008. The transplanted sod was sprinkler irrigated to enhance survival for a several week period. On August 1, 2008, the sod was evaluated for vegetative traits at peak standing crop (Figure 5.31).

Canopy cover, density and biomass measurements indicated the MSU Native Grass Sod–Delta on the drainage swale and steep slope was dominated by desired grass (Tables 5.26, 5.27, and 5.28). The sod very effectively resisted weed invasion. On both the drainage swale and steep slope, the dominant native grass in the sod was California meadow barley. The second most dominate native grass species was California brome. California brome had a higher density, cover, and biomass on the steep slope compared to the drainage swale. A small amount of the native grass red fescue was measured, and the fourth native grass species propagated in the sod purple needlegrass was not observed. Red fescue was the dominate species in the sod seed mix (70% of the seed, see Table 5.8). However, on the Mack Road test area, only a trace of this species was measured. Supplemental sprinkler irrigation likely contributed to the dominance of California meadow barley which can prevail over other grass species in moist soils. On California highway projects, in the absence of irrigation, purple needlegrass is often the dominate grass species on steep slopes (Hanson 2008). It is possible that after sprinkler irrigation is terminated, California meadow barley may die back and purple needlegrass may develop as the dominant grass species on the steep slope area.

No weedy forb species invaded the native grass sod during the three month period the sod was growing at the Mack Road test area. Two weedy grasses, soft brome and Italian ryegrass, were present in the MSU Native Grass Sod–Delta but had very low density and canopy cover. It was not apparent whether the minimal presence of weedy species was enhanced by irrigation or that they will persist given the short observation period of three months.

Figure 5.31 MSU Native Grass Sod–Delta on the drainage swale test plot on July 21, 2008.

On both the drainage swale and steep slope, the MSU Native Grass Sod–Delta rooted effectively into the subsoil. The sod was well anchored into the subsoil as evidenced by failure to dislodge the sod with hand pulling.

Table 5.26 Mean canopy cover in August 2008 for the MSU Native Grass Sod–Delta located on the highway steep slope and drainage swale test area.

Grass Establishment Treatment	Location	Canopy Cover (%)[1]				
		Desired Grass	Weedy Grass	Desired Forbs	Weedy Forbs	Litter/Bare Ground
MSU Native Grass Sod – Delta	Swale	94	3	0	0	3
MSU Native Grass Sod – Delta	Slope	93	3	0	0	4

[1]Desired grasses and forbs are those species seeded for the MSU Native Grass Sod–Delta. Weedy grass and forbs are non-native and volunteer species.

Table 5.27 Mean plant density in August 2008 for the MSU Native Grass Sod–Delta located on the highway steep slope and drainage swale test area.

Grass Establishment Treatment	Location	Plant Density (stems+tillers/m²)[1]			
		Desired Grass	Weedy Grass	Desired Forbs	Weedy Forbs
MSU Native Grass Sod –Delta	Swale	4454	163	0	0
MSU Native Grass Sod –Delta	Slope	4425	113	0	0

[1]Desired grasses and forbs are those species seeded for the MSU Native Grass Sod–Delta. Weedy grass and forbs are non-native and volunteer species.

Table 5.28 Mean above ground plant biomass in August 2008 for the MSU Native Grass Sod–Delta located on the highway steep slope and drainage swale test area.

Grass Establishment Treatment	Location	Plant Biomass (grams/m²)[1]			
		Desired Grass	Weedy Grass	Desired Forbs	Weedy Forbs
MSU Native Grass Sod – Delta	Swale	702	27	0	0
MSU Native Grass Sod – Delta	Slope	1092	24	0	0

[1]Desired grasses and forbs are those species seeded for the MSU Native Grass Sod–Delta. Weedy grass and forbs are non-native and volunteer species.

At the soil surface, there was no bare ground exposed in the MSU Native Grass Sod–Delta test plot area (Table 5.29). Absence of bare ground will resist invasion of weedy grass and forb species and decrease sediment loss during storm water runoff.

Table 5.29 Percent soil cover in August 2008 for the MSU Native Grass Sod–Delta located on the highway steep slope and drainage swale test area.

Grass Establishment Treatment	Location	Soil Cover (%)				
		Plant Basal Cover	Litter	Rock	Bare Ground	Trash
MSU Native Grass Sod – Delta	Swale	41	56	0	0	3
MSU Native Grass Sod – Delta	Slope	44	56	0	0	0

5.5. Loss of Sediment from Highway Disturbances Using Native Grass Sod and Hydroseeding

Native grass sod has potential to provide immediate and permanent stabilization of highway land disturbances. In comparison, grass established from seed may require years before the soil is stabilized by the plant root system. Supplementing native grass seeding with hydromulch can provide immediate effective soil stabilization, but this is a temporary fix as the mulch will deteriorate with time.

Sediment loss from native grass sod and hydroseed-mulch treatments on a highway steep slope and a drainage swale was estimated using the Revised Universal Soil Loss Equation 2 model, referred to by acronym as RUSLE2 (USDA Agricultural Research Service 2008).

5.5.1. Environmental Factors Used to Estimate Sediment Loss Rate

Environmental factors included in the RUSLE2 soil loss model are outlined in Table 5.30.

Table 5.30 Key environmental factors used in the RUSLE2 model to estimate sediment loss from highway landscape features.

Precipitation Record • Sacramento long term (1890-2007) monthly average for precipitation.
Soil Traits • Soil percent sand, silt, clay and textural class. • Soil organic matter content, coarse fragment content, permeability class. • Soil very fine sand content, coarse sand content, and silt plus fine sand content. • Soil erodibility factor. • Rock cover. • Surface roughness.
Slope Characteristics • Slope length, gradient, and shape. • Physical measurements of rill and gully erosion features.
Soil Surface Operations • Disking, surface grading. • Hydro-mulch.
Plant Establishment and Growth Traits • Below ground root biomass. • Above ground plant biomass. • Plant canopy cover. • Plant basal cover. • Surface litter. • Average raindrop fall height from plant canopy to soil surface.

5.5.1.1. Precipitation Record

The long term (1890-2007) average monthly precipitation record for Sacramento was used as opposed to the actual precipitation received during the 2006-2008 investigation period. Using the long term precipitation record increased representativeness of the estimated annual sediment loss rate, compared to that attained with actual precipitation records for the relatively short time period of this investigation.

5.5.1.2. Soil Traits and Surface Operations

One composite soil sample was collected for analysis in the drainage swale area and another in the steep slope area (Table 5.31). Particle size distribution traits and organic matter content were used in the sediment loss model. Soil salinity (0.9-1.0 dS/m) and plant-available nutrients were at suitable levels to support plant growth. Soil sodicity (SAR 0.48-0.68) was low indicating soil infiltration and permeability traits were not impaired by excess sodium in the soil system. On-site observation indicated surface rock content was neglible. The soil erodibility factor was calculated by the RUSLE2 model and the soil permeability class was estimated.

Table 5.31 Soil physical and nutrient availability traits[1] at the Mack Road test plot area in November 2006.

										mg/kg		
Drainage Swale	23	39	38	53.8	1.5	Clay Loam	6.9	0.90	0.48	13	29	231
Steep Slope	35	38	27	43.7	2.4	Clay Loam	6.9	1.04	0.68	40	59	448

[1]Analytical methods are presented in Appendix A.

For the standard Caltrans Hydroseed-mulch treatment, it was assumed application of 4 tons/hectare (3200 pounds/acre) straw mulch covered an average of 70% of the soil surface during the 18 month period following treatment implementation.

5.5.1.3. Slope Characteristics

For the highway fill-steep slope test area, a 13.7 m (45 ft) slope length with 41% slope gradient was used in the sediment loss model. For the swale test area, two analyses were completed; a 15.2 m (50 ft) swale side slope length with 5% slope gradient and a 91.4 m (300 ft) swale channel with a 3% slope gradient were used to estimate sediment loss. A uniform slope shape was assumed for both the steep slope and the drainage swale.

The presence, or absence, of rill and gully erosion features was examined in all plots in 2006, 2007, and 2008. Neither rills nor gullies were present in these plots during the term of this investigation.

5.5.1.4. Below Ground Root Biomass

Root biomass was determined by collecting a composite soil sample from each test plot from the 0-30 cm depth increment in May 2007 and May 2008 using a 3.8 cm diameter bucket auger (Tables 5.32 and 5.33). A 600 mm sieve was used to separate roots from soil. Roots were oven dried and weighed.

Table 5.32 Mean below ground dry root biomass in steep slope and drainage swale test plots in May 2007.

Grass Establishment Treatment	Location	Below Ground Biomass (grams root / cm^3 soil)
MSU Native Grass Sod–Hedgerow	Drainage Swale	0.0028
Caltrans Hydroseed (control)	Drainage Swale	0.0003
Delta Fescue Sod	Drainage Swale	0.0086
MSU Native Grass Sod–Hedgerow	Steep Slope	0.0020
Caltrans Hydroseed (control)	Steep Slope	0.0003
Delta Fescue Sod	Steep Slope	0.0027

Table 5.33 Mean below ground dry root biomass at the Mack Road steep slope and drainage swale test areas and at the Delta Bluegrass Company sod farm in May 2008.

Grass Establishment Treatment	Location	Below Ground Root Biomass (grams root / cm^3 soil)
MSU Native Grass Sod – Delta	Delta Sod Farm	0.0040
MSU Native Grass Sod – Hedgerow	Drainage Swale	0.0003
Caltrans Hydroseed (control)	Drainage Swale	0.0005
Delta Fescue Sod	Drainage Swale	0.0003
MSU Native Grass Sod – Hedgerow	Steep Slope	0.0007
Caltrans Hydroseed (control)	Steep Slope	0.0002
Delta Fescue sod	Steep Slope	0.0027

5.5.1.5. Surface Roughness

In May 2007, surface roughness was measured as the change in relief at the soil surface at 30 randomly located points in each plot (Table 5.34). In August 2008, surface roughness in the MSU Native Grass Sod–Delta plots, both drainage swale and steep slope, averaged ± 0.25 cm.

Table 5.34 Mean surface roughness in each treatment for the steep slope and drainage swale area in May 2007.

Grass Establishment Treatment	Location	Surface Roughness	Notes
MSU Native Grass Sod – Hedgerow	Swale	± 2.0 cm	Primarily due to breaks in sod.
Caltrans Hydroseed (control)	Swale	± 1.0 cm	Roughness due to changes in mulch depth.
Delta Fescue Sod	Swale	± 0.25 cm	Surface is relatively smooth from sod cover.
MSU Native Grass Sod – Hedgerow	Slope	± 2.0 cm	Primarily due to breaks in sod.
Caltrans Hydroseed (control)	Slope	± 2.0 cm	Roughness due to changes in mulch depth.
Delta Fescue sod	Slope	± 0.5 cm	Roughness due to litter from dead sod.

5.5.1.6. Above Ground Plant Growth Traits

Above ground plant biomass, canopy cover, plant density, and soil cover were measured in all test plots. These data are presented in Section 4.4.

Average raindrop fall height from the plant canopy to soil surface was estimated based on average plant canopy height.

5.5.2. Sediment Loss Rate

Using the RUSLE2 model, sediment loss rates ranged from 155.70 to 0.07 tons/hectare/year as a function of slope traits and vegetation establishment (Table 5.35). Following tillage and seedbed preparation, sediment loss rates were very high on the highway fill-steep slope (155.70 tons/hectare/year) and highway swale area (15.81-17.30 ton/hectare/year). This result indicated freshly tilled slopes are highly erosive and should receive mulch or sod as soon as possible following highway construction.

Implementation of the standard Caltrans Hydroseed-mulch treatment, i.e., no plant cover present, reduced the sediment loss rate to 16.80 tons/hectare/year on the steep slope and to 1.21-1.56 tons/hectare/year on the drainage swale. This was a reduction of 76% to 93%, compared to slopes with no mulch (Table 5.35). Six months after the Caltrans Hydroseed-mulch treatment was implemented (April 2007) sediment loss was still notable (21.50 tons/hectare/year) on the steep 41% gradient highway fill slope. By comparison, the Caltrans Hydroseed-mulch treatment in the swale area had low sediment loss rates (1.14-1.36 tons/hectare/year), which was attributable to gentle 3-5% slope gradient. Eighteen months after hydroseeding, in May 2008, the plant canopy cover was composed of only 14.9% to 17.6% desired native grass and forb species, while weedy grass and forb species dominated live plant material on hydroseeded areas. Therefore, the low sediment loss rate measured in May 2008 (0.77-4.45 tons/hectare/year) was largely a function of non-native plant materials that were not seeded on this site. Weedy grass and forb species propagated from the in-place soil seed bank that existed prior to hydroseeding.

Table 5.35 Sediment loss rate on a highway fill-steep slope and a drainage swale area that received sod and hydroseed treatments near Sacramento, California.

Treatment	Steep Slope	Swale-Side Slope	Swale-Channel
	Sediment Loss Rate (tons/hectare/year)*		
November 2006			
Freshly Tilled Soil - No Plant Or Mulch Cover	155.70	15.81	17.30
Caltrans Hydroseed - Mulch (No Plant Cover)	16.80	1.56	1.21
May 2007			
Caltrans Hydroseed-Mulch (Plant Cover Present)■	21.50	1.36	1.14
MSU Native Grass Sod–Hedgerow ■	1.93	0.40	0.32
May 2008			
Caltrans Hydroseed-Mulch (Plant Cover Present)□	4.45	0.89	0.77
MSU Native Grass Sod–Hedgerow □	3.95	0.69	0.62
August 2008			
MSU Native Grass Sod–Delta ♦	0.64	0.10	0.07

*tons/acre (2.471) = tons/hectare.

■Hydroseeding and sod installation were completed in November 2006 and plant growth measurements in April 2007 were applied to the RUSLE2 erosion model.

□Hydroseeding and sod installation were completed in November 2006 and plant growth measurements in May 2008 were applied to the RUSLE2 erosion model.

♦Sod was installed May 7, 2008, and plant growth measurements in August 2008 were applied to the RUSLE2 erosion model.

Six months after installing the MSU Native Grass Sod–Hedgerow, sediment loss rates were very small (0.32-1.93 tons/hectare/year) on both the highway steep slope and drainage swale test area (Table 5.35). Eighteen months after sod installation (May 2008), the sediment loss rate remained low (0.62-3.95 tons/hectare/year). At this point in time, the canopy cover associated with this sod was composed of only 4.0% to 32.1% desired native grass and forb species, while weedy grass and forb species dominated the canopy cover. Weedy plant species were introduced from the existing seed bank in soil underlying the sod and from the sod nursery propagation area. Therefore, the sediment loss rate was a function of both desired and weedy plant materials.

In August 2008, approximately three months after installing MSU Native Grass Sod–Delta, sediment loss rates were exceptionally low (0.07-0.64 tons/hectare/year) on both the highway steep slope and drainage swale test area (Table 5.35). Desired native grass species dominated the canopy cover (93-94%) and plant density (4454 stems/m^2), which resulted in a near zero sediment loss rate.

These results indicate freshly tilled steep slopes will undergo sediment loss at accelerated rates until plant materials are present to abate this problem. Application of straw hydromulch resulted in a low sediment loss rate on gentle slopes associated with a highway drainage swale feature, but the sediment loss rate was high on the steep 41% slope gradient. Eighteen months after hydroseeding, sediment loss rates were low. However, the hydroseed-mulch treatment resulted in plant materials composed largely of weedy grass and forb species. In comparison, the MSU Native Grass Sod-Delta had a near zero sediment loss rate beginning the day of sod installation, and three months after installation the site was almost entirely composed of desired native grass species.

5.6. Cost-Benefit of Native Grass Sod

Cost of native grass sod will always be a "moving target" since it is a function of supply and demand economic principles. Often as demand for a product increases the price increases proportionately, but this may not be the case for native grass sod. At present, the number of native grass sod producers is very low, and if consumer demand increases it is anticipated significantly more sod producers will offer this product for sale. This scenario would likely decrease the price of native grass sod in the future.

5.6.1. Estimated Cost of Native Grass Sod in 2008

For a California highway native grass sod project, the product should be purchased directly from a sod producer under a wholesale contract agreement, not from a distributor at an enhanced retail price. Propagation of native grass sod, including field preparation, seeding a mix of four species, irrigation, and maintenance will cost \$10.76 m^2 (\$1.00/ft^2). Harvest, delivery, and installation will average \$5.38/m^2 (\$0.50/ft^2). This equates to a cost of \$161,455/ha (\$65,340/acre).

5.6.2. Native Grass Sod Versus Hydroseeding

The cost of implementing the standard Caltrans Hydroseed-mulch treatment on highways may range from \$21,528/ha to \$32,292/ha (\$8,712-13,068/acre). Subsequent maintenance including mowing and weed control will costs an average of \$741/hectare/year (\$300/acre/year) (Brown 2008).

In comparison, weed control and mowing costs associated with native grass sod may be negligible since weed invasion is slight to none and canopy height and biomass production may not represent either a traffic or fire hazard. However, more than a century of time would be required before the Caltrans Hydroseed-mulch treatment plus maintenance cost of \$741/hectare/year would equate to the initial cost of native grass sod.

Therefore, native grass sod is approximately five times more expensive compared to the hydroseed-mulch treatment. Unfortunately, rapid invasion of non-native grass and forb species in the hydroseed-mulch treatment has historically prevented attaining the goal of native grass establishment. Prolific growth of non-native weedy grass and forb species triggers long term maintenance cost pertaining to weed control, mowing, and fire control. In comparison, native grass sod has significantly less invasion by weedy species and smaller plant canopy to maintain with mowing.

The cost-benefit of native grass sod may vary notably across the United States. Stone (2004) reported cost of native grass sod propagation and transplanting for a Montana highway demonstration area. The sod was composed of four native grass species, propagated at a commercial sod farm, delivered and installed on a steep highway fill slope at a cost of \$34,216/ha (\$13,847/acre), which equates to \$3.42/m^2 (\$0.32/ft^2). These costs are nearly five times less than those estimated above for California. Consequently, in Montana the cost-benefit of native grass sod compared to standard seeding practices may be more favorable.

5.7. Summary and Key Findings

The purpose of this research was to develop and demonstrate native grass sod for control of sediment loss from land disturbances associated with the California highway system.

Two types of native grass sod were developed at two different nurseries in the California Grassland Ecoregion near Sacramento. The first, MSU Native Grass Sod–Hedgerow, was composed of five species: creeping wildrye, purple needlegrass, Sandberg's bluegrass, California meadow barley, and squirrel tail. The second, MSU Native Grass Sod–Delta, was developed 18 months after the Hedgerow sod and was composed of two species common to the Hedgerow mix, purple needlegrass and California meadow barley and two new species California brome and red fescue.

5.7.1. Native Grass Sod Propagation and Harvest

Six months after seeding, the MSU Native Grass Sod–Hedgerow had seeded native grass species with 80% canopy cover while bare ground (15% canopy cover) and weedy species (5% canopy cover) composed the remainder. Presence of weedy species indicated site preparation procedures failed to kill all undesired species in the soil seed bank beneath the developing sod. When harvested one year after seeding, the root binding ability was poor and the sod could not be rolled for transport. Broken half meter square slabs of sod were placed on boards for transport and the sod was reassembled at the highway test plot area.

Ten weeks after seeding, the MSU Native Grass Sod–Delta had very high grass seedling density (7,200 tillers/m^2), a 90% canopy cover, and no weed species were present. Prior to seeding, soil in the propagation area was fumigated with methyl bromide and covered with plastic for five days to kill weedy species in the soil seed bank. Fumigation was a key step to insure weedy species do not grow into seeded native grass sod. Five months after seeding, a test cut of the sod indicated excellent root binding ability and the sod rolled easily. When harvested eight months after seeding, use of conventional sod cutting, rolling and transport equipment was successful. At the highway test plot area, sod was unrolled with no breakage and no bare ground was exposed between sod seams on the steep slope and drainage swale.

5.7.2. Highway Demonstration Area

Native grass sod was transplanted to a highway steep slope, 41% gradient, and drainage swale area located south of Sacramento, California.

As a control treatment, the standard Caltrans Hydroseed-mulch treatment was implemented with Spanish clover, blue wildrye, meadow barley, tidy tips, creeping wildrye, and purple needlegrass.

Sod and hydroseed-mulch treatments were replicated on the steep slope and drainage swale area.

5.7.3. Vegetation Growth Traits at the Highway Demonstration Area

Eighteen months after implementing the Caltrans Hydroseed-mulch treatment, invasive weedy grasses had greater canopy cover, density and biomass compared to seeded species. Tidy tip, the seeded forb, dominated the canopy cover. Tests indicated weedy grass species were present in the highway soil seed bank, and slow development of seeded native grass species provided ample time for invasive species to propagate from the seed bank.

For the MSU Native Grass Sod–Hedgerow, canopy cover, density and biomass for invasive non-native grasses was greater than for sod grass species on the steep slope. In the drainage swale, the abundance of native grass species and non-native species was similar. Since this sod had to be harvested in broken slab-like pieces as opposed to conventional rolls, the sod could not be tightly butted across the soil surface. Bare soil surface between sod pieces provided opportunity for weedy grasses to develop from the soil seed bank. Tests also indicated the transplanted sod contained one or more weedy grass and forb species from the original nursery propagation area. This result indicates a native grass sod species mix must be one that develops a strong-contiguous root mat, enabling harvest of large-as-possible sod rolls, and provides a dense root-grass mat at the transplant location that will preclude weedy species propagation from the soil seed bank.

Three months after transplanting the MSU Native Grass Sod–Delta, approximately 93% of the canopy cover and 96% of the plant density was native grass. The sod very effectively resisted weed invasion from the underlying soil seed bank. On both the drainage swale and steep slope, the dominant native grass in the sod was California meadow barley. Supplemental sprinkler irrigation likely contributed to the dominance of California meadow barley which can prevail over other grass species in moist soils. On California highway projects, in the absence of irrigation, purple needlegrass is often the dominate grass species on steep slopes. It is possible that after sprinkler irrigation is terminated, California meadow barley may die back and purple needlegrass may develop as the dominant grass species on the steep slope area. No bare ground was present. Absence of bare ground serves to resist invasion of weedy grass and forb species and decrease sediment loss during storm water runoff. No weedy forb species invaded the native grass sod. Propagation, transplanting, and plant growth traits of the MSU Native Grass Sod-Delta was a complete success as of August 2008.

5.7.4. Sediment Loss from Sod and Hydroseeded Areas

Using the RUSLE2 sediment loss model, it was determined the freshly tilled steep slope (41% gradient) sediment loss rate was 155 tons/hectare/year, while the drainage swale loss rate was 15-18 tons/hectare/year. This result indicated freshly tilled slopes are highly erosive and should receive mulch or sod as soon as possible following highway construction.

When no plant cover was present, application of straw hydromulch decreased the sediment loss rate to 1-2 tons/hectare/year in the drainage swale, and to 17 tons/hectare/year on the steep slope.

Eighteen months after hydroseeding, the plant cover composed of native and non-native species had a 0.9 tons/hectare/year sediment loss rate in the drainage swale and 4.4 tons/hectare/year on the steep slope.

In comparison, the MSU Native Grass Sod–Delta had a near zero sediment loss rate (steep slope 0.6 and drainage swale 0.1 tons/hectare/year) beginning the day of sod installation, and three months after installation the site was almost entirely composed of desired native grass species.

5.7.5. Sod Cost

The cost to propagate, harvest and install native grass sod was estimated to be $161,455/ha ($65,340/acre), which was approximately five times more expensive than the hydroseed-mulch procedure.

5.8. Literature Cited

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6. DEPLOYMENT

This research represents an exciting first step towards the use of native grass sod as a tool in the toolbox of best management practices (BMPs) for erosion control and for treating stormwater runoff from highway surfaces. The main "product" from the research is this final project report that documents the background, methodology, and research findings. The intended customers for this product include Caltrans planners, landscape architects, as well as other stakeholders such as highway resource managers. Caltrans decision-makers responsible for roadside vegetation management can benefit from the better knowledge gained from this research on the potential and feasibility of using native grass sod on disturbed land along highways. Information regarding the best native grass species mixes and reinforcement materials can also benefit researchers, sod producers and maintenance engineers for the production, transplantation, maintenance and establishment of native grass sod in California and potentially other states.

The initial greenhouse research identified multi-species mixes for four California ecoregions (Pacific Forest, Sierran Forest, Chaparral, and California Grasslands) that grew native grass sod with adequate sod strength for harvesting and transportation. Recommendations for further improvements in planting density, reinforcement materials, etc. were produced. Field based experiments performed over two years indicated that multispecies sod could be used as an alternative roadside revegetation technique, and it established and survived without supplemental water. Multispecies sod reduced weed emergence sown as a seedbank and as seed rain, and survival of weeds was significantly reduced as the sod became more established. The controlled field demonstration of native grass sod in California Grasslands supported the greenhouse and field data by indicating that a native grass sod species mix must be one that develops a strong-contiguous root mat, enabling harvest of large-as-possible sod rolls, and provides a dense root-grass mass at the transplant location that will preclude weedy species propagation from the soil seed bank. The MSU Native Grass Sod-Delta, produced in California, had a near zero sediment loss rate (steep slope 0.6 and drainage swale 0.1 tons/hectare/year) beginning the day of sod installation, and three months after installation the site was almost entirely composed of desired native grass species. The cost to propagate, harvest and install native grass sod was estimated to be approximately five times greater than the cost of the hydroseed-mulch procedure; nonetheless, long-term maintenance and environmental costs associated with weed control, mowing and fire control are expected to be greater with hydroseeding when compared with native grass sod.

These key research findings can find immediate practical application, as they can assist in the development and use of new materials for roadside vegetation management in California. Additional research is needed to further evaluate the ability of native grass sod to provide immediate sediment control and permanent stabilization and to move this innovative concept from its current stages of laboratory prototype and controlled field demonstration to field pilot and full corporate deployment stages.

This research also successfully demonstrated how to formulate grass mixes by matching desired species and cultivars to species ecological attributes, which may help Caltrans and other DOTs develop guidelines and successful standard procedures and methods to develop ecologically appropriate grass sods for specific state and local environmental requirements.

Reclamation of disturbed highway areas using native grasses can be considered the best method of reducing erosion without harming native ecosystems. It is anticipated that the use of native grass sod will facilitate quick vegetation establishment and soil reinforcement, reduce the risk of non-native weeds and fire hazards, and thus reduce the use of herbicides, pesticides and fertilizers. In addition, the native grass sod is expected to minimize the amount of mowing and supplemental irrigation needed for the vegetation management. The use of native grass sod can also help Caltrans meet requirements of the Clean Water Act.

At this stage, there are three major impediments identified for the successful deployment of the research findings. First, there may be a difference between research findings obtained from the controlled greenhouse environment and what actually occurs in the real highway environment. Thus, the research findings may need further validation through controlled field demonstration before full corporate deployment. Second, the suitability and performance of native grass sod in the field is affected by many other factors beyond the scope of this research. Those factors, such as climatic and soil conditions, are often site-specific and thus merit additional research for their role in the survival and performance of native grass sod. Finally, there are expected institutional issues to be addressed and resistance to change in practices and specifications before the research findings can be successfully implemented.

The research findings will be transferred to all Caltrans stakeholders through the circulation of the final report. The institutions and individuals who might take leadership in applying the research product will be the Caltrans landscape architecture office that hopefully will benefit from its implementation. The research findings are expected to help Caltrans planners and landscape architects make more informed decisions regarding roadside vegetation management and to allow them to include native grass sod as an option in their design practices. An implementation plan will be needed if Caltrans decides to move forward with more field pilot projects of native grass sod.

7. SUMMARY OF KEY FINDINGS

7.1. Evaluation of California Native Grass Species for Sod Development

The objective of this part of this study was to evaluate a number of native species and reinforcement materials for their suitability for contributing to a harvestable multispecies sod for roadside rehabilitation. The initial evaluation for determining native grass species was performed using species from six different ecoregions of California, and the second evaluation for determining suitable reinforcement materials was conducted on native grass species for three of those ecoregions. Evaluations were performed using sample plantings in a greenhouse setting. Basic species evaluation was done using biomass, species abundance, and total ground cover. Reinforcement materials were evaluated with respect to effect on sod strength for different seeding densities.

Although species do not perform equally in terms of percent cover and biomass production, seeding as many species as possible should aid in the diversity of sod. When grown for seven months (essentially the establishment phase for sod production in California), there appeared to be no difference in establishment success of mixtures that contained four to seven species as indicated by total ground cover. Accordingly, as long as a species does not fail to establish or disappear over the course of sod production, they should be included in the initial mix to ensure ecological versatility and overall diversity in the native rehabilitation sod. This study has demonstrated the capacity for producing native multispecies sod and its potential for use as a rehabilitation tool in these six ecoregions. The methods and results of this study could also be expanded in order to produce native multispecies sod for use in other geographical areas.

These results have several important implications for practice including:

- Native grass sod mixtures can mimic the diversity of native ecosystems while providing a method for rapid rehabilitation and restoration.
- Mixtures of native grass species can be grown together and harvested as sod.
- Native grass sod provides immediate soil surface stabilization and plant cover and can be used in areas where rapid rehabilitation is required.
- Theoretically, native grass sod for restoration should be composed of many species. However, native grass seed availability is limited. As demand for native grass seed increases, more consistent sources of quality native seed will be required.

Native grass seed at this juncture can be prohibitively expensive. In the initial experiment, multispecies sod growth efforts produced some sods with adequate sod strength. For the Pacific Forest region, the standard 500 PLS/ft^2 should be adequate. For all other ecoregions, a higher seeding rate should be considered. Due to sod production issues, the sod was not grown for the three ecoregions per request of Caltrans. Research emphasis shifted from this set of experiments to the next phase, Establishment Success and Weed Suppression Potential of Multispecies Sod.

7.2. Establishment Success and Weed Suppression Potential of Multispecies Sod

Field experiments were conducted to assess the potential of multispecies sod to suppress weeds of different density and with different reinforcement materials over a two year period. Two distinct series of trials were performed. Plots sodded without reinforcement materials were used to assess suppression of weeds sown at six densities (the "A" trials). Reinforcement materials are often required to transport harvest sod. The effect of this material on weed suppression was assessed (the "B" trials). Both experiments were conducted from 2006 to 2008 at Montana State University. In both experiments the surrogate weed, canola (*Brassica napus*), was sown either below the sod to represent the existing weed seed bank or into the sod from above to represent weed seed rain. In the second year seed was sown from above only. All experiments were subjected to five different water regimes including a no irrigation/natural precipitation only regime. The initial trials (A_1 and B_1) were conducted for two years, 2006-2007. Identical trials (A_2 and B_2) were then started in adjacent plots in 2007 and were also conducted for two years, 2007-2008. This design enables two years of first-year data and two years of second-year data to be collected and compared within and between years so that the experiments are replicated in both time and space.

In general these experiments provide evidence that emergence of canola is low when sown as seed rain or seed bank with multispecies sod and is significantly ($p < 0.001$) lower the second year after sod is laid. Experiment B results indicate the reinforcement materials did significantly ($p < 0.05$) further decreased canola emergence in experiment B_2 (2007). Of the emerged seedlings survival to maturation, and the vegetative and seed biomass of these plants was significantly affected by water regime for both the A and B experiments. In contrast in the reinforcement (B) experiments water regime did not affect survival but the presence of the material increased the proportion of surviving plants.

These experiments indicated that multispecies sod could be used as an alternative roadside revegetation technique. It established and survived without supplemental water (Figure 3.15) and reduces weed emergence and survival.

7.3. Highway Reclamation using Native Grass Sod for Sediment Control and Aesthetic Enhancement

Based on the knowledge gained from the research described in the previous chapters, a field experiment was conducted using native grass sod to revegetate a disturbed area along a California highway at a location just south of Sacramento. This experiment began with an investigation of the basic characteristics of three native grass sods produced by three different commercial farms. While successfully grown in relative small, controlled experimental settings, it was critical to establish the characteristics of these sods when produced at the larger scale necessary for their practical use on highway projects. The commercially grown sods were evaluated with respect to species abundance, canopy coverage, and weed emergence. Based on the results of this investigation, two of these native grass sods were subsequently transplanted to the field test site, where their performance was evaluated over a 20 month period relative to a control section that used Caltrans standard hydroseeding practice.

The purpose of this research was to develop and demonstrate native grass sod potentially suitable for control of sediment loss from land disturbances associated with the California highway system.

Two types of native grass sod were developed at two different nurseries in the California Grassland Ecoregion near Sacramento. The first, MSU Native Grass Sod–Hedgerow, was composed of five species: creeping wildrye, purple needlegrass, Sandberg's bluegrass, California meadow barley, and squirrel tail. The second, MSU Native Grass Sod–Delta, was developed 18 months after the Hedgerow sod and was composed of two species common to the Hedgerow mix, purple needlegrass and California meadow barley and two new species California brome and red fescue.

7.3.1. Native Grass Sod Propagation and Harvest

Two months after seeding, the MSU Native Grass Sod–Hedgerow had fair seedling density (2418 tillers/m^2), low canopy cover, and some weedy forbs were present indicating site preparation procedures failed to kill all undesired species in the soil seed bank beneath the sod. After six months of growth, seeded native grass species composed 80% of the canopy cover while bare ground and weedy species (5%) composed the remainder. When harvested one year after seeding, the root binding ability was poor and the sod could not be rolled for transport. Broken half meter square slabs of sod were placed on boards for transport and the sod was reassembled at the highway test plot area.

Ten weeks after seeding, the MSU Native Grass Sod–Delta had very high grass seedling density (7,200 tillers/m^2), a 90% canopy cover, and no weed species were present. Prior to seeding, soil in the propagation area was fumigated with methyl bromide and covered with plastic for five days to kill weedy species in the soil seed bank. Fumigation was a key step to insure weedy species do not grow into seeded native grass sod. Five months after seeding, a test cut of the sod indicated excellent root binding ability and the sod rolled easily. When harvested eight months after seeding, use of conventional sod cutting, rolling and transport equipment was successful. At the highway test plot area, sod was unrolled with no breakage and no bare ground was exposed between sod seams on the steep slope and drainage swale.

7.3.2. Highway Demonstration Area

Native grass sod was transplanted to a highway steep slope, 41% gradient, and drainage swale area located south of Sacramento, California.

As a control treatment, the standard Caltrans Hydroseed-mulch treatment was implemented with Spanish clover, blue wildrye, meadow barley, tidy tips, creeping wildrye, and purple needlegrass.

Sod and hydroseed-mulch treatments were replicated on the steep slope and drainage swale area.

7.3.3. Vegetation Growth Traits at the Highway Demonstration Area

Eighteen months after implementing the Caltrans Hydroseed-mulch treatment, invasive weedy grasses had greater canopy cover, density and biomass compared to seeded species. Tidy tips, the seeded forb, dominated the canopy cover. Tests indicated weedy grass species were present in the highway soil seed bank, and slow development of seeded native grass species provided ample time for invasive species to propagate from the seed bank.

For the MSU Native Grass Sod–Hedgerow, canopy cover, density and biomass for invasive non-native grasses was greater than for sod grass species on the steep slope. In the drainage swale, the abundance of native grass species and non-native species was similar. Since this sod had to be harvested in broken slab-like pieces as opposed to conventional rolls, the sod could not be tightly butted across the soil surface. Bare soil surface between sod pieces provided opportunity for weedy grasses to develop from the soil seed bank. Tests also indicated the transplanted sod contained one or more weedy grass and forb species from the original nursery propagation area. This result indicates a native grass sod species mix must be one that develops a strong-contiguous root mat, enabling harvest of large-as-possible sod rolls, and provides a dense root-grass mat at the transplant location that will preclude weedy species propagation from the soil seed bank.

Three months after transplanting the MSU Native Grass Sod–Delta, approximately 93% of the canopy cover and 96% of the plant density was native grass. The sod very effectively resisted weed invasion from the underlying soil seed bank. On both the drainage swale and steep slope, the dominant native grass in the sod was California meadow barley. Supplemental sprinkler irrigation likely contributed to the dominance of California meadow barley which can prevail over other grass species in moist soils. On California highway projects, in the absence of irrigation, purple needlegrass is often the dominate grass species on steep slopes. It is possible that after sprinkler irrigation is terminated, California meadow barley may die back and purple needlegrass may develop as the dominant grass species on the steep slope area. No bare ground was present. Absence of bare ground serves to resist invasion of weedy grass and forb species and decrease sediment loss during storm water runoff. No weedy forb species invaded the native grass sod. Propagation, transplanting, and plant growth traits of the MSU Native Grass Sod-Delta was a complete success as of August 2008.

7.3.4. Sediment Loss from Sod and Hydroseeded Areas

Using the RUSLE2 sediment loss model, it was determined the freshly tilled steep slope (41% gradient) sediment loss rate was 155 tons/hectare/year, while the drainage swale loss rate was 15-18 tons/hectare/year. This result indicated freshly tilled slopes are highly erosive and should receive mulch or sod as soon as possible following highway construction.

When no plant cover was present, application of straw hydromulch decreased the sediment loss rate to 1-2 tons/hectare/year in the drainage swale, and to 17 tons/hectare/year on the steep slope.

Eighteen months after hydroseeding, the plant cover composed of native and non-native species had a 0.9 tons/hectare/year sediment loss rate in the drainage swale and 4.4 tons/hectare/year on the steep slope.

In comparison, the MSU Native Grass Sod–Delta had a near zero sediment loss rate (steep slope 0.6 and drainage swale 0.1 tons/hectare/year) beginning the day of sod installation, and three months after installation the site was almost entirely composed of desired native grass species.

7.3.5. Sod Cost

The cost to propagate, harvest and install native grass sod was estimated to be $161,455/ha ($65,340/acre), which was approximately five times more expensive than the hydroseed-mulch procedure.

8. APPENDIX

A. SOIL ANALYTICAL METHODS FROM CHAPTER 5

NO_3-N	Method 33-8.3. Copperized cadmium reduction method. Methods of Soil Analysis, Agronomy Society of America, 1982.
PO_4-P	Method 24-5.4. Phosphorus soluble in sodium bicarbonate. Methods of Soil Analysis, Agronomy Society of America, 1982.
K	Method 13-3.3.1. Neutral 1N ammonium acetate extraction. Methods of Soil Analysis, Agronomy Society of America, 1982.
EC	Method 10-3.3 determined in a water extract from a saturated soil paste (method 10-2.3.1). Methods of Soil Analysis, Agronomy Society of America, 1982.
pH	Method 10-3.2 determined in a water extract from a saturated soil paste (method 10-2.3.1). Methods of Soil Analysis, Agronomy Society of America, 1982.
SAR	Method 10-3.4. Soluble cations (Ca, Mg, Na) determined in a water extract from a saturated soil paste (method 10-2.3.1). Methods of Soil Analysis, Agronomy Society of America, 1982.
OM	Method 29-3.4.2. Walkley-Black procedure. Methods of Soil Analysis, Agronomy Society of America, 1982. (Note that this procedure results in a determination of the percent soil organic-C. The percent soil organic matter content is derived by the following relationship. % Organic-C (**1.3**) = % Organic Matter
Texture	Modified from ASTM (1992) Method D422-63 or (pages 383-393, 404-408) in Methods of Soil Analysis, Agronomy Society of America, 1982. The hydrometer method with particle size separations at 40 seconds and 8 hours.
% Rock	Dry sieving is used after the sample has been passed through a mechanical “flailer” to disaggregate soil peds.