California Department of Transportation
New Technology and Research Program

Inputs and Maintenance for Revegetation with Native Herbaceous Species

Final Report

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October 15, 1996– June 30, 1999
Report Number FHWA/CA/TL-2001/06
Submitted January 31, 2001

STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION
TECHNICAL REPORT STANDARD TITLE PAGE
MR-1242 (Rev. 11/90)

<table>
<tr><td>1. Report No.
FHWA/CA/TL-2001/06</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Inputs and Maintenance for Revegetation with Native Herbaceous Species</td><td colspan="2">5. Report Date
January 2001</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="2">7. Authors
Cynthia S. Brown and Kevin J. Rice</td><td colspan="2">8. Performing Organization Repot No.</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Department of Agronomy and Range Science
University of California
One Shields Avenue
Davis, CA 95616</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
59Y570</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
Division of New Technology, Materials and Research
Environmental and Engineering Services
California Department of Transportation
P.O. Box 19128
Sacramento, CA 95819</td><td colspan="2">13. Type of Report and Period Covered
Final</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code
California Department of Transportation</td></tr>
<tr><td colspan="4">15. Supplementary Notes
In cooperation with the U.S. Department of Transportation, Federal Highway Administration</td></tr>
<tr><td colspan="4">16. Abstract
We report the results of three experiments that were conducted in the median of Interstate 5 in the Sacramento Valley of California. In the first, we tested the effects of soil decompaction to 76 cm and three seeding methods (broadcast, drill and hydroseed with 25% more seed than other methods) on the establishment and growth of four perennial grasses native to California (Elymus glaucus, Hordeum brachyantherum ssp. brachyantherum, Hordeum brachyantherum ssp. californicum and Nassella pulchra). Soil decompaction generally benefited the perennial grasses. Perennial grass seedling densities were greater in decompacted soil in the second year after seeding. Perennial grass cover was also greater in decompacted treatments, while weed cover was unaffected. In soils that were not decompacted, drill and broadcast seeding generally resulted in better performance of perennial grasses than hydroseeding. The second experiment evaluated a number of cultural practices for maintaining populations of California native perennial grasses. The species were the same as the first experiment and planted by drill. This experiment was designed to test the use of (1) well-timed mowing, (2) mowing with broadleaf specific herbicides and (3) mowing with pre-emergence herbicides for promoting the establishment and long-term persistence of native perennial grasses, but not all treatments were applied. The use of pre-emergence herbicides in the fall of the second year of growth resulted in improved performance of native perennial grasses and reduction in the abundance of weeds. In the third expriment, we studied the effects of compost, slow-release nitrogen fertilizer and different types of straw mulch (rice, wheat and blue wildrye) on the establishment and growth of California native perennial grasses. Perennial grasses responded to interactions between nutrient availability, weeds and volunteers of the mulch species. They performed best in rice straw mulch, having better nutrient status and growth. Growth and nutrient status of perennial grasses were worst with blue wildrye straw mulch. Rice straw had the lowest amount of weeds and volunteers from mulch, blue wildrye straw had the highest amounts and wheat straw was intermediate. Differences in decomposition rates of the straws may have contributed to the effects we detected. Rice straw appeared to be the best type of straw mulch to use because it resulted in the poorest performance of species that compete with seeded species for resources and the best performance of seeded perennial grasses. Whatever straw is applied, it should be free of weeds. The addition of compost benefited weeds, but not perennial grasses unless no mulch was applied. Competition from weeds suppressed the growth of perennial grasses, but this negative effect was eliminated by the addition of nitrogen fertilizer.</td></tr>
<tr><td colspan="2">17. Key Words
erosion control, California native perennial grasses, plant establishment, native plants,
seeding methods, hydroseed, drill seeding, broadcast seeding, soil decompaction, subsoiling, soil amendments, slow-release fertilizer, compost, straw mulch, rice straw, wheat straw, native grass straw, blue wildrye straw, pre-emergence herbicide, mowing</td><td colspan="2">Distribution Statement
No restrictions. This document is available to

the public from the National Technical Information Service, Springfield, Virginia</td></tr>
<tr><td>19. Security Clasif. (of this report)
Unclassified</td><td>20. Security Clasif. (of this page)
Unclassified</td><td>21. No. Of Pages
164</td><td>22. Price</td></tr>
</table>

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Financial Disclosure Statement

This research was funded by the State of California, Department of Transportation (Contract No. 59Y570). The total ceiling amount was $159,000. The research is reported in the final report titled “Inputs and Maintenance for Revegetation with Native Herbaceous Species.”

Implementation Statement

Information from this project will be disseminated through distribution of copies of this report, publication in journal articles and presentations at conferences and in courses. Further details are included in the implementation section following the report conclusions and in the list of presentations in the appendix.

Executive Summary

Standard methods for the establishment and management of native perennial grasses in erosion control and revegetation projects are needed and continue to be developed. We conducted a series of experiments to test a number of seeding, soil preparation, fertilization, mulching and management methods in order to determine which led to the best performance of perennial grasses. The experiment reported in Chapter 1 was conducted in the Sacramento Valley of California and tested the effects of soil decompaction to 76 cm and three seeding methods (broadcast, drill and hydroseed with 25% more seed than other methods) on the establishment and growth of four perennial grasses native to California (*Elymus glaucus*, *Hordeum brachyantherum* ssp. *brachyantherum, Hordeum brachyantherum* ssp. *californicum* and *Nassella pulchra*). Soil decompaction generally benefited the perennial grasses. Perennial grass seedling densities were greater in decompacted soil in the second year after seeding. Perennial grass cover was also greater in decompacted treatments, while weed cover was unaffected. In soils that were not decompacted, drill and broadcast seeding generally resulted in better performance of perennial grasses than hydroseeding. Heavy rainfall within 24 hrs after hydroseeding probably washed much of the seed off of the site. Differences between seeding methods that were apparent in untreated soil disappeared with subsoil decompaction. Abundance of weeds was not greatly affected by seeding method.

We conclude that hydroseeding was the least efficient method to establish native perennial grasses. The results indicated that perennial grass performance in the hydroseed treatment was often inferior to other methods when soil was not decompacted, despite the fact

that 25% more seed was planted than the drill and broadcast treatments. The poor performance of grasses in the hydroseed treatment was probably due to its having been washed off by inopportune rain. These results indicate that evaluation of the potential for compaction is an important first step in developing soil preparation and seeding specifications for erosion control and revegetation projects. For sites that are likely to have a high-density layer that will impede plant growth, soil decompaction may be especially important if hydroseeding is the only feasible method of planting. If decompaction is not an option, then drill or broadcast seeding is likely to result in the best success of native perennial grasses.

As the use of native perennial grasses for erosion control, restoration and revegetaion has increased, the need for long-term management methods has grown. In Chapter 2 we report the results of an experiment in the median of Interstate 5 in Sacramento Valley to evaluate a number of cultural practices for maintaining populations of California native perennial grasses. The species, planted by drill, were *Elymus glaucus*, *Hordeum brachyantherum* ssp. *brachyantherum*, *Hordeum brachyantherum* ssp. *californicum*, *Melica californica* and *Nassella pulchra*. This experiment was designed to test the use of (1) well-timed mowing, (2) mowing with broadleaf specific herbicides and (3) mowing with pre-emergence herbicides for promoting the establishment and long-term persistence of native perennial grasses. The use of pre-emergence herbicides in the fall of the second year of growth resulted in improved performance of native perennial grasses and reduction in the abundance of weeds. We did not detect any effect of mowing on perennial grass or weed performance. Due to problems in executing the experiment, we were unable to evaluate many of the treatments that the experiment was initially intended to test.

In an experiment reported in Chapter 3, we studied the effects of compost, slow-release nitrogen fertilizer and different types of straw mulch on the establishment and growth of California native perennial grasses. Perennial grasses responded to interactions between nutrient availability, weeds and volunteers of the mulch species. They performed best in rice straw mulch, having better nutrient status and growth. Growth and nutrient status of perennial grasses were worst with blue wildrye straw mulch. Rice straw had the lowest amount of weeds and volunteers from mulch, while blue wildrye straw had the highest amounts. Wheat straw was intermediate. Differences in decomposition rates of the straws may have contributed to the effects we detected. Rice straw appeared to be the best type of straw mulch to use because it resulted in the poorest performance of species that compete with seeded species for resources and the best performance of seeded perennial grasses. Whatever straw is applied, it should be weed free. The addition of compost benefited weeds, but not perennial grasses. Competition from weeds suppressed the growth of perennial grasses, but this negative effect was eliminated by the addition of nitrogen fertilizer.

Acknowledgements

We would like to thank H. Kibunguchy and John Haynes for making this project possible. Barbara Pollack and Dan Pollack provided generous assistance, advice and support. Monica Finn and Carolyn Brown assisted with data collection in the first year and Marcia Haver, Craig Schreiffer and Catherine Wardner in the second year; the project could not have been completed without their help and we greatly appreciate their contributions. John Anderson, David Gilpin, and Scott Stewart, as well as his staff and family, provided very helpful advice and assistance throughout the project. We would like to thank Al Nitta and the staff of Nitta Construction for their enthusiastic participation and continued cooperation on this project and to recognize the very competent work of William Kuhl, who kept careful records of the seeding methods.

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General Introduction

New methods of vegetation management for California roadways are being developed in response to concerns about the past predominance of chemical control methods. Such concerns and a court injunction led to suspension of these practices in some districts and an environmental impact report on the chemical control practices of the Department of Transportation (Rich Knapp, memorandum, July 18, 1995). Since then, the Roadside Vegetation Management Committee has encouraged the development of methods that result in effective erosion control and slope stabilization, while reducing maintenance and weedy vegetation.

The use of California native perennial grasses for erosion control seedings is one alternative management method being explored. Perennial grasses have great potential for revegetation of newly constructed roadsides in order to control erosion. The use of perennial grasses has expanded in recent years due to their erosion control properties as well as potential to reduce weeds, maintenance costs, herbicide use and fire hazard and to improve environmental quality. In the long run, perennial grasses have the potential to more effectively control erosion than annual grasses. Extreme fluctuations in annual grass populations have been reported (Talbot et al. 1939). Long-lived perennial grasses are more consistent producers of biomass than annual grasses because of their life history and ability to tap deep soil water sources once established (Holmes and Rice 1993, Brown 1998).

Not only are perennial grasses excellent for reducing erosion, but also they can suppress weeds, which can in turn reduce maintenance costs and herbicide use. Some species of perennial grasses, e.g. meadow barley, are very competitive against annual grasses during their first year of growth (Bugg et al. 1997). Once established, long-lived perennials are good competitors, persisting in plant communities for decades (White 1967). Although perennial grasses are generally slower growing than annual grasses (Chapin 1980), they can be helpful in controlling weeds (Northam and Callihan 1988). Once a stable perennial community has been established and is being properly managed, the need for herbicides to control weeds can be reduced (Bugg et al. 1997), decreasing costs for materials and labor.

Growth characteristics of perennial grasses can also reduce the need for mowing and decrease fire hazard. Some short statured species provide little biomass to serve as fuel or visual obstruction, eliminating the need for mowing (Bugg et al. 1997). In order to address concerns of fire hazard and visibility, taller species can be managed with a single annual mowing once they have become dormant (Anderson, personal communication).

In addition to reduced biomass production of some species, perennial grass longevity and timing of growth can result in reduced flammability compared to annual grasses. Many perennial species stay green longer into the summer and begin growth earlier in the fall than annuals (Laude 1953), while others grow actively throughout the summer. Green tissue has considerably higher water content than dry tissue and is less likely to burn, all else being equal.

Finally, an important advantage of using native perennial grasses and other native plants in roadside seedings is improved environmental quality. There is growing awareness of and concern for the conservation of California's native flora. Highway right-of-ways represent thousands of miles of potential habitat for native plants, including grasses and forbs. The complex nature of native plant communities proves more aesthetically pleasing than monocultures of starthistle or wild oat, which often line our roadsides.

Native prairie restoration on roadsides has been successfully implemented in other states such as Iowa (Integrated Roadside Vegetation Management, no date). However, restoration of California's prairies has met with mixed success. There has been an increase in the use of native species in erosion control seedings, but the methods that best promote their establishment and growth are still being developed. Few studies investigate alternative methods for seeding native species (Montalvo et al. 2001). Direct seeding studies generally included fast-growing introduced annual grasses, shrubs or legumes and were non-replicated, trials of plant performance (Clary 1983, Stromberg and Kephart 1996). Until the study of Montalvo et al. (2000), common seeding practices had not been compared in a replicated experiment that allowed quantitative comparison of seeding and soil preparation methods in California. Cultural practices for the establishment of native species should be tested in a controlled manner to determine what methods are most effective under particular conditions and what may limit the success of such plantings.

Not only can seeding methods be determinants of the success of perennial grasses, but soil preparation may also have important impacts. Traffic of heavy equipment causes soil compaction, i.e. a decrease in soil volume and increase in its density (Håkansson et al.1988), which often subsequently results in decreased plant growth. Decreased pore volume and increased soil strength impedes root growth. Compaction due to construction vehicles and operations necessary for road building may have important effects on the success of revegetation and erosion control plantings in areas adjacent to roadways. Deep tillage has been reported to improve the growth and productivity of many crops in various soil types (Unger and Kaspar 1994, Vepraskas et al. 1986, Vepraskas et al. 1990, Oussible et al. 1992, Mathers et al. 1971). More information is needed about the impacts of soil compaction and decompaction on establishment, growth and persistence of native perennial grasses in California.

Many questions remain about the effects on native perennial grasses of applying fertilizer and straw mulch at the time of planting. Application of highly soluble fertilizers may provide a greater advantage to weedy species than seeded perennial grasses. Applying soil amendments that will immobilize nitrogen and release it slowly can be a valuable tool in successful revegetation and restoration of plant communities (Morgan 1994; Zink and Allen 1998). The practice may provide an advantage for slower growing native perennial species in competition with fast growing, weedy species that benefit from high nitrogen conditions (Chapin 1980; Jackson et al. 1988; Hart et al. 1993; Davidson et al. 1990; Claassen and Marler 1998; Zink and Allen 1998)(but also see Wilson and Gerry 1995 and Reever Morghan and Seastedt 1999).

The application of straw mulch is a common practice in revegetation. The benefits of surface mulch for establishing plants from seed have been well demonstrated (Clary 1983; Gupta et al. 1984; Phillips and Phillips 1984; Kwon et al. 1995; Abrecht et al. 1996; Bautista et al. 1996; Byard et al. 1996; Cavero 1996; Rahman et al. 1997). Surface mulch application also has well-known erosion control benefits (Osborn 1954; Kay 1978; Clary 1983; Bautista et al. 1996). Applying mulches to the soil surface can result in increased immobilization of nitrogen similar to incorporation of soil amendments with high C:N (carbon to nitrogen ratio). However, the impacts of different types and amounts of straw mulch on nitrogen availability and subsequent effects of plant growth have not been studied in the context of revegetation.

In addition to the need to develop reliable methods to establish native perennial grasses, there is a great deal of uncertainty about the methods of managing prairie communities on highway rights-of-way to ensure the long-term survival. Anderson (1993) suggested the use of pre-emergence herbicides in the second year after seeding of perennial grasses, post-emergence, broadleaf specific herbicides and well-timed chemical or mechanical mowing to selectively damage competing vegetation. These methods have not been evaluated and compared in a systematic way. There is clearly a need to test them in a controlled and replicated manner to evaluate their efficacy for management of native perennial grasses in California roadside and highway rights-of-way.

Here we report the results of three studies designed to investigate methods for optimal establishment, growth and management of native perennial grasses. Two studies were conducted in the median if Interstate 5, just south of Sacramento, which allowed evaluation of methods under realistic conditions. The first study evaluated the effects of decompacting soil to 76 cm and three seeding methods (broadcast, drill and hydroseed with 25% more seed than other methods) on the establishment and growth of four perennial grasses native to California (*Elymus glaucus*, *Hordeum brachyantherum* ssp. *brachyantherum, Hordeum brachyantherum* ssp. *californicum* and *Nassella pulchra*). The second study was designed to test the use of (1) well-timed mowing, (2) mowing with broadleaf specific herbicides and (3) mowing with pre-emergence herbicides for promoting the establishment and long-term persistence of native perennial grasses.

We also report the results of an experiment conducted on abandoned low fertility agricultural soils that investigated the effects on native perennial grasses of amending soils with compost and slow-release nitrogen fertilizer as well as application of different types and amounts of straw mulch. These experiments were designed to fill gaps in our knowledge about methods for establishment, growth and management of native perennial grass plantings so that we may learn their true potential for erosion control, slope stabilization and creation of low-maintenance, weed-free roadside communities.

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Chapter 1

Effects of seeding methods and soil decompaction on the establishment and growth of California native perennial grasses

Keywords: decompaction, subsoiling, hydroseeding, broadcast seeding, drill seeding

ABSTRACT

Standard methods for the establishment of native perennial grasses in erosion control and revegetation projects are needed and continue to be developed. This experiment was conducted in the Sacramento Valley of California and tested the effects of soil decompaction to 76 cm (30 inches) and three seeding methods (broadcast, drill and hydroseed with 25% more seed than other methods) on the establishment and growth of four perennial grasses native to California (*Elymus glaucus*, *Hordeum brachyantherum* ssp. *brachyantherum*, *Hordeum brachyantherum* ssp. *californicum* and *Nassella pulchra*). Soil decompaction generally benefited the perennial grasses. Perennial grass seedling densities were greater in decompacted soil in the second year after seeding. Perennial grass cover was also greater in decompacted treatments, while weed cover was unaffected. In soils that were not decompacted, drill and broadcast seeding generally resulted in better performance of perennial grasses than hydroseeding. Heavy rainfall within 24 hrs after hydroseeding caused flooding and washed much of the seed off of the site. Differences between seeding methods that were apparent in untreated soil disappeared with subsoil decompaction. Abundance of weeds was not greatly affected by seeding method. We conclude that hydroseeding was the least effective method to establish native perennial grasses. The results indicated that perennial grass performance in the hydroseed treatment was often inferior to other methods when soil was not decompacted, even though 25% more seed was planted than the drill and broadcast treatments. The poor performance of grasses in the hydroseed treatment was probably due to its having been washed off by inopportune rain and a hard crust of hydromulch

that formed when the soil surface dried. In some areas, the hydroseed fiber crust cracked and curled, lifting seedlings out of the soil. These results indicate that evaluating the potential for compaction is an important first step in developing soil preparation and seeding specifications for erosion control and revegetation projects. For sites that are likely to have a high-density layer that will impede plant growth, soil decompaction may be especially important if hydroseeding is the only feasible method of planting. Unfortunately, such sites are also unlikely to be accessible to soil decompaction equipment. If decompaction is not an option, then drill or broadcast seeding is likely to result in the best success of native perennial grasses. Finally, the effects of weather conditions at the time of seeding and during the establishment period may be as or more important than the methods used in determining perennial grass success. Seeding should be performed early enough in the wet season to avoid problems created by heavy rainfall, saturated soils and low temperatures.

INTRODUCTION

A great deal of money is spent each year on erosion control with construction of bridges, roadways and other structures. These costs increase when erosion control measures fail. One common problem with seeding for erosion control is poor establishment of vegetation. This may be especially true when slower growing native perennial grass species are used (Garnier 1992, Bugg et al. 1997, but see Bishop 1995). There has been an increase in the use of native species in erosion control seedings, but the methods that best promote their establishment and growth are still being developed. Few studies investigate alternative methods for seeding native species (Montalvo et al.

2001). Direct seeding studies generally included fast-growing introduced annual grasses, shrubs or legumes and were non-replicated, trials of plant performance (Clary 1983, Stromberg and Kephart 1996, Bishop 1995). Until the study of Montalvo et al. (2001), common seeding practices had not been compared in a replicated experiment that allowed quantitative comparison of seeding and soil preparation methods in California. Cultural practices for the establishment of native species should be tested in a controlled manner to determine what methods are most effective under particular conditions and what may limit the success of such plantings.

Traffic of heavy equipment causes soil compaction, i.e. a decrease in soil volume and increase in its density (Håkansson et al.1988), which often results in decreased plant growth. The soil strength, i.e. resistance to external forces (Håkansson et al.1988) and depth of compaction after a given force is applied is a function of the compacting forces exerted and the texture, structure and moisture content of the soil. Compaction can persist for years and, in some cases, be permanent (Håkansson et al.1988). Voorhees et al. (1989) found that loads of 9 and 18 Mg (1 Mg is approximately 1 long ton) per axle compacted soil up to 60 cm and decreased crop production in the first year on one soil type. On a second soil type, these high axle loads only resulted in compaction when the soil was wet. Voorhees et al. (1986) found that when wet soil was subjected to axle loads of 9 and 18 Mg, bulk density (soil mass/soil volume) increased at depths from 30 to 50 cm, below the normal depth of tillage. There was evidence of subsoil compaction 4 years after the initial treatments, even when the soil froze to 90 cm each winter. Even in areas with freeze-thaw cycles, compaction can persist for long periods (Unger and Kaspar 1994).

One of the primary effects of compaction is that pore volume is reduced and the relative number of large pores decreases (Håkansson et al.1988). Large pores are important for gas exchange in respiration of plant roots and aerobic microorganisms, i.e. for processes that require oxygen. Pores provide space for roots and soil fauna to live and grow (Håkansson et al.1988). Large pores are also important determinants of the drainage and water storage characteristics of a soil. Loss of these pores can result in poorer infiltration and drainage due to reduced hydraulic conductivity, which can in turn result in increased runoff and erosion (Håkansson 1988). However, as soils dry, water no longer fills the pores and the water available to plants is that held by matric forces (i.e. attractive forces of surfaces) of the soil particles. The movement of water and nutrients under these conditions (i.e. unsaturated flow) can be more rapid in dense soils because they have higher unsaturated hydraulic conductivity than loose soils. Increased unsaturated hydraulic conductivity can benefit plants (Håkansson et al.1988). Compaction can also benefit plants under some conditions because the amount of water and nutrients in a given volume of soil may be greater in more dense soils (Håkansson et al.1988).

Plant growth is generally negatively affected by soil compaction due to decreased pore volume and increased soil strength, which impedes root growth. Håkansson et al. (1988) and Abou-Arab et al. (1998) reported that the negative effects of compaction on plants generally increase with increased clay content of the soil and traffic intensity (but see Vepraskas et al. 1986). Shallow rooting depth, lower root length densities or decreased yields, or all three, have been reported in compacted soils (Unger and Kaspar 1994, Voorhees et al. 1989, Oussible et al. 1992, Abou-Arab et al. 1998). Reduced root growth can limit the ability of plants to acquire water and nutrients (Håkansson et al.1988). Oussible et al. (1992) found that subsoil compaction resulted in fewer shoots per unit area, denser, finer and shallower roots and reduced production of grain and straw. Whether soil compaction will negatively affect plant growth depends on the availability of resources, especially water. When irrigation is available, water can be applied to compensate for shallow root systems or the lack of water stored deep in the soil profile (Burnett and Hauser 1967 as cited by Mathers et al. 1971). However, in conditions such as erosion control plantings, irrigation is costly, logistically or economically unfeasible and, hence, rarely available.

Deep tillage has been reported to improve the growth and productivity of many crops in various soil types (Unger and Kaspar 1994, Vepraskas et al. 1986, Vepraskas and Wagger 1990, Oussible et al. 1992, Mathers et al. 1971). Vepraskas and Wagger (1990) reported that decompaction of subsoil was most likely to improve production in soils having a layer that restricted root growth and sand or loamy sand topsoil without aggregate structure that has low water holding capacity. Root development in subsoils with hard tillage pans that impeded root growth was usually improved by decompaction when the bulk densities of the subsoil were greater than 1.66 Mg m^{-3} and the subsoil had a sand content less than or equal to 50.8%. Subsoil decompaction generally had no effect on root penetration in soils that had bulk densities of less than 1.66 Mg m^{-3} and sand contents greater than or equal to 55.9%.

Many methods are available for planting seed in erosion control projects, including broadcasting, drilling and hydroseeding, but few tests of their relative efficacy have been conducted (Montalvo et al. 2001). Broadcast seeding can be performed by hand or using a mechanical seeder that distributes the seed by dispersing it onto the soil surface. Seed may then be incorporated by hand with a rake, or with a mechanical device pulled behind a seeder such as a harrow, chains or weighted chain-link fence. This method can be very effective but does not precisely control the depth of seeding. Seed may be left too shallow, which may result in desiccation or removal by water, wind or granivores, or buried too deep, preventing germination or emergence, or both. Drilling seed using a mechanical device that creates an opening for the seed in the soil, deposits the seed in the opening and then covers the seed with soil increases the chance of placing seed in ideal conditions for germination and growth. However, this method can only be applied on sites that are flat enough to allow the use of the necessary equipment. Hydroseeding, in which a slurry of water, seed, fertilizer and fiber is sprayed onto a site, is commonly used after road construction to stabilize soils. This method has a number of advantages. Hydroseeding can be used on steep slopes because the slurry can be projected from level ground at the base or top of the slope. The fiber in the slurry covers the soil and helps to prevent erosion before the seeded vegetation provides cover. However, this method is the least likely of those described to place seed in close contact with the soil and optimal conditions for growth. As a result, seeding rate specifications are sometimes increased by 25% or more when hydroseeding is used in order to compensate for this shortcoming (J. Haynes personal communication).

Compaction due to construction vehicles and operations necessary for road building may have important effects on the success of revegetation and erosion control plantings in areas adjacent to roadways. One purpose of this study was to determine the effects of post-construction subsoil decompaction on the establishment of selected

California native perennial grasses. We were also interested in testing the efficacy of different seeding methods and investigating the interactions between soil compaction and the method of seeding. We expected that soil decompaction would benefit native perennial grasses and that drilling seed would lead to the best perennial grass performance, followed by broadcast seeding with hydroseeding resulting in the poorest plant performance.

Plots of other native species were also planted in monocultures for demonstration purposes. These plots were not monitored (see Appendix 1, 3 and 5).

METHODS

The experiment was established in December of 1996 in the median strip between north and south bound lanes of traffic of Interstate 5, south of Sacramento and north of Elk Grove in California (post mile 11.5 to 15.9) (see Appendix 1). The southern extent of the experiment was located just south of the Laguna Boulevard freeway exit, the Morrison Creek over crossing was approximately in the middle, and the northern end was just south of the Meadowview Road/Pocket Road freeway exit. The native soils in the area are Dierssen clay loam, Egbert clay, Galt clay and Clear Lake clay (Tugel 1993). Soils at the experiment site appeared to be Dierssen clay loam in the area south of Morrison Creek over crossing with higher clay content on the far southern end, close to the Laguna Boulevard exit. The soils on the northern extent of the site had higher clay content than the Dierssen clay loam (Vic Claassen personal communication 21 June 2000).

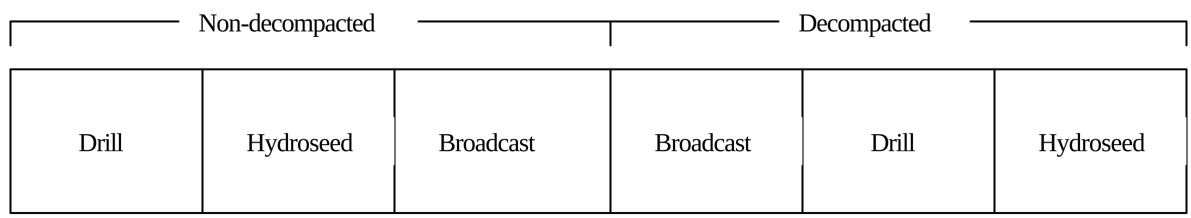
The experiment was planted in order to revegetate the site as part of a freeway widening project. The original erosion control specifications (Appendix 2) called for drill seeding a mixture of native species including two legume species, one forb species and three perennial grass species. An application of a mixture of fiber (500 lbs/acre), stabilizing emulsions (100 lb/acre) and fertilizer (200 lb/acre 16:20:0) after the seed had been applied was also specified. The species actually planted, their amounts and methods of soil preparation and seeding are described below.

The experiment reported here included all combinations of three different seeding methods (broadcast, drill and hydroseed) with two levels of soil decompaction (decompacted or non-decompacted), resulting in six experimental treatment combinations. Each of the six treatment combinations was applied to one plot (250 ft long and 40 ft wide) within each of four replications for a total of 24 plots (Fig. 1a). The three seeding methods were randomly assigned to plots within each soil decompaction level (split-plot design). Treatments were indicated by stakes labeled with the treatment names (Photo 1) and with paint labels on the pavement (Photo 2).

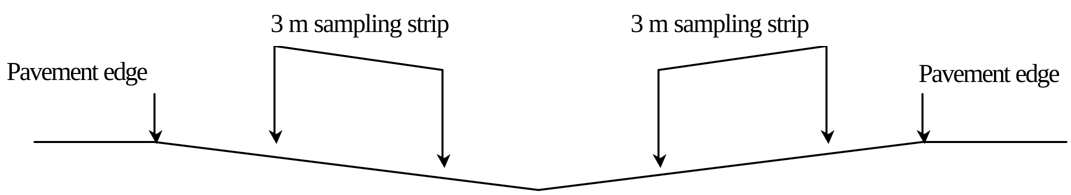
1996-7 and 1997-8 rainfall

The total precipitation in Davis (approximately 20 km north-west from the experiment site with rainfall patterns similar to the experiment site) for 1997 was 467.36 mm (18.4 in), near the thirty-year average of 460.05 mm (18.1 in) (Owenby and Ezell 1992). Despite this, the pattern of rainfall was unusual. In January 219.96 mm (8.7 in) of precipitation fell, 220% of the thirty-year average, causing considerable flooding at the experiment site (Photo 3). Precipitation in Februrary, March and April was a fraction of normal with 0.9%, 16% and 11% of the thirty-year average falling. In May and June rainfall was about 30% higher than the thirty-year average, which extended water availability for plant growth.

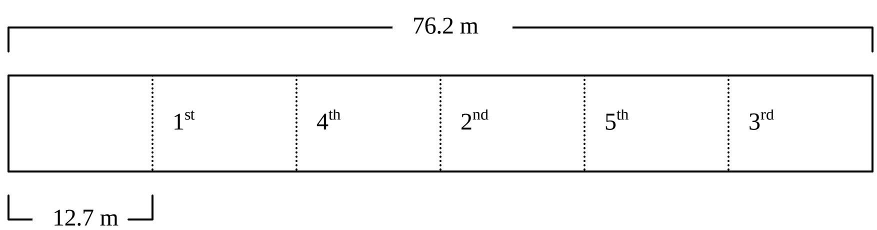
Figure 1. a) Diagram of a single replication of the experiment. The de-compaction treatment was randomly assigned to half of the block. The seeding methods were randomly assigned to plots within decompacted and non-decompacted treatments.



b) Cross section of the freeway median showing the areas sampled.



c) An aerial view of a single plot is depicted below with 5 sampling transects represented by dashed lines. The numbers next to each transect indicate the order in which they were sampled.



The second wet season began in the autumn of 1997 with 111.0 mm (4.4 in) of rain falling in November, about 150% of the thirty-year average. Rainfall for December 1997 and January 1998 were close to the average, but precipitation was well above average for February (297.94 mm or 11.7 in, 410% of the thirty year average) and May (59.44 mm or 2.3 in, 835% of the thirty year average). Precipitation was below average for March (47.24 mm or 1.9 in, 70% of the thirty year average). Overall during 1998, 565.15 mm (22.2 in) of rain fell, 123% of the thirty-year average. This year was an above normal rainfall year and water availability was extended due to considerable precipitation late in the season.

Temperatures were not optimal for seed germination at the time of seeding. According to data collected at the NOAA Reference Climatological Station operated by the Department of Land, Air and Water Resources, University of California, Davis, the average air temperature was 13.3 °C (56 °F) and 12.2 °C (54 °F) and the average soil temperatures were 10.6 °C (51 °F) and 10.0 °C (50 °F) during December 1996 and January 1997, respectively. These temperatures are at the lower boundary of the range suitable for germination of most species (Mayer and Poljakoff-Mayber 1963).

December rainfall caused some flooding, but the pattern of rainfall during the critical period for germination of the perennial grass seeds was otherwise favorable for establishment. In December, there were four to six days between rainfall events, except for one 13-day drought. However, rainfall events in December were poorly timed with respect to the hydroseed treatment application, as described below, and caused flooding of the site. In January and February, there was one nine-day drought, otherwise only one to three days between storms.

Cultural practices

The plots assigned to the subsoil decompaction treatment were ripped to 76 cm (30 in) using 91 cm (36 in) shanks in three passes over the area. Soil was decompacted one third of the total depth in the first pass, two thirds in the second pass and the full 76 cm (30 in) in the final pass. A water-filled flat roller (approximately 91 cm or 36 in in diameter, with rigid rings approximately 10 cm or 4 in in height and 12.5 cm or 5 in apart) was pulled behind the ripper to break up large clods of soil (Daniel Olford personal communication December 2000) in the final pass with the ripper (Photo 4). This operation was performed relatively late in the year when soils were too wet for optimal breaking of compacted soil and ripper shanks sliced through the soil more than would be ideal, "like slicing a pie," according to erosion control contractor Al Nitta (personal communication 5 January 2001).

The perennial grasses were seeded at the density listed in Table 1 for drill and broadcast treatments and the hydroseed treatment was seeded with 25% more seed by weight. The seeding rates were based on standard practices modified to in order to achieve equal cover of each species. To do this, the base-seeding rate of 16.7 seeds/ft^2 was multiplied by a factor for each species that reflected its seed size, vigor of seedlings and final plant size. Relatively more seed of species with small seeds, low seedling vigor and small plant size was included than species with large seeds, high seedling vigor and large plant size. Seeding rates were adjusted for the purity and germination percentage of the seed used to achieve the desired density of pure, live seed. Calculation of the species factors and seeding rates are detailed in Appendix 3.

Drill seeding was conducted using a 1.82 m (6 ft) wide Truax Flex II no-till grass drill (Model IXII-88, Truax Company, Inc., 3609 Vera Cruz Avenue North, Minneapolis, Minnesota 55422) on 19 December 1996 (Photo 5). A small disk in front of the seed distribution mechanism disturbs the soil and the seed is dropped into the prepared soil. The seeder is often followed by a spike tooth harrow to further incorporate the seed but was not in our experiment according to equipment usage records provided by Nitta Construction, Inc.

Seed was mixed with a bulking agent (grain product horse feed supplement) to achieve the desired seeding density (Photo 6). On 20 December 1996, seed was spread by hand (Photo 7) and incorporated with one pass of a 1.52 m (5 ft) wide iron spike tooth farm harrow for plots assigned the broadcast treatment. A hydromulch layer with fiber (898 kg/ha or 800 lbs/acre) and fertilizer (224 kg/ha or 200 lbs/acre) (described in Appendix 4) was applied to the broadcast and drill treatments on 20 December 1996 using the same method as the hydroseed treatment (Photo 8). The hydroseeding treatment included spraying a water-based slurry of fiber (898 kg/ha or 800 lbs/acre), fertilizer (224 kg/ha or 200 lbs/acre) and seed on the plots assigned this treatment using a 1992 Model T330 Finn Hydroseeder (Photo 8). An application of fiber and fertilizer was made on top of the first hydroseed layer in replicates 1 and 2. Thus a total of 1960 kg/ha (800 lbs/acre) of fiber and 448 kg/ha (200 lb/acre) of fertilizer were applied to the hydroseed treatment plots in replicates 1 and 2, while half as much fiber and fertilizer were applied to hydroseed treament plots in replicates 3 and 4.

Table 1. Perennial grass seeding rates for broadcast and drill treatments based on pure live seed. Hydroseed treatment was seeded with 25% more seed by weight. Species authors are according to Hickman (1993).

Species	**Seeding density**	
	seeds/m^2	kg/ha
Elymus glaucus Buckley var. Yolo Bypass blue wildrye	59	2.92
Hordeum brachyantherum ssp. *brachyantherum* Nevski var. Salt meadow barley	72	4.40
Hordeum brachyantherum ssp. *californicum* Nevski var. Prostrate California barley	96	3.18
Nassella pulchra (A. Hitchc.) Barkworth var. Jepson Prairie purple needlegrass	60	2.80
Poa secunda ssp. *secunda* J. S. Presl pine bluegrass	957	4.10
Melica californica Scribner California melic	159	1.39
Total	1,403	18.80

According to climate data from Davis (NOAA Reference Climatological Station operated by the Department of Land, Air and Water Resources, University of California, Davis), 1.32 cm (0.51 in) and 2.74 cm (1.08 inches) of precipitation fell on 21 and 22 December 1996, respectively. A visible portion of the hydromulch washed away because it did not have 24 hours to cure before significant precipitation fell (William Kuhl personal communication 27 December 2000).

All plots were mowed to a height of 6 inches in the spring of 1997 and again 10-11 July 1997.

Monitoring

In preliminary sampling in 1997, we estimated perennial grass and weed densities using a 0.1 m^2 circular sampling frame. Sampling was conducted in a linear strip (transect) that spanned the median. Each strip began about 1.5 m from the edge of the pavement in order to avoid anomalous effects that might be caused by traffic, compaction or disturbance associated with the roadway as shown in Fig. 1b. The central 3 m of the median was also avoided during sampling because this area might remain flooded longer than the remainder of the plot and could represent very different environmental conditions. The sampling frame was placed at two locations that appeared to be representative of the plot in each of two sampling strips, one on either side of the median.

We counted the number of live perennial grass seedlings within the sampling frame. *Poa secunda* ssp. *secunda* was not included in these density estimates because it was already dormant by the time that we monitored. We conducted preliminary sampling of all six treatment combinations in blocks 2, 3 and 4 on 16 May 1997. These data were used to estimate the number of samples needed to detect an effect if it were present, given the amount of variation there was in the experiment. The fifth replicate of the experiment, located at the north end of the site, was eliminated due to flooding that may have resulted in removal or death of seeds. The first replicate, on the south end of the experiment, was eliminated due to lack of time.

The primary sampling took place 27 and 28 May and 10 and 26 June 1997. The data were combined with those from the preliminary sampling. Samples were taken along transects that stretched across the median (Fig. 1b). Transects were evenly space within each 76.2 m long plot (Fig. 1c). Transects were located 12.7 m from the end of the plot and 12.7 m apart and were sampled in the order indicated in Fig. 1a. Sampling was restricted to 3 m strips on either side of the median as illustrated in Fig. 1c. Four samples were taken in each transect, two randomly located within each 3 m strip. The number of samples taken in each treatment plot was no less than 12 (3 transects) and no more than 20 (5 transects). After each transect was sampled (4 samples), we calculated the coefficient of variation (CV = mean/standard deviation * 100). We stopped sampling when the CV of all samples collected changed less than 10 % from the previously calculated CV or we had sampled all 5 transects, whichever occurred first.

In 1998, percent cover of individual perennial grass species and the three most abundant weed species in each sampling frame were estimated. We sampled 2 or 3 transects that were regularly spaced in each plot. We sampled 4 locations along each transect, as described above. We evaluated percent cover of the vegetation at each location using the Daubenmire (1959) method with the following cover classes: 0 = 0 %, 1 = 0-5 %, 2 = 6-25 %, 3 = 26-50%, 4 = 51-75%, 5 = 76-95%, 6 = 96-100%.

Statistical analyses

The data were analyzed using the appropriate split-plot analyses of variance (ANOVA) models. This design results in greater statistical power to detect differences between sub-plot or split-plot factors (i.e. seeding method) than to detect differences between main-plot factors (i.e. seedbed preparation) compared to experimental designs in which the location of all treatment combinations are completely randomized (e.g. randomized complete block design). Differences between means were determined using Tukey's studentized range test. Probabilities for statistical significance were set at 0.05, but probabilities greater than 0.05 and less than 0.1 are also presented because this level of significance indicates an interesting trend than may warrant further investigation.

In 1997, only blocks 2, 3 and 4 were monitored resulting in the corresponding reduction in degrees of freedom in the analysis. Perennial grass and weed densities were monitored in that year.

In 1998, percent cover and height of perennial grasses, density of perennial grass seedlings and percent cover of weeds were evaluated. For established perennial grasses, the sum of the percent cover values of all perennial grass species (total cover) and the average height across species (mean height) were evaluated as composite measures of perennial grass mixture performance. The performance indices (percent cover and height) of individual species were also evaluated using the same ANOVA model in order to compare species responses to the experimental treatments. The sums of the cover estimates for the three most abundant weeds in each sample were evaluated in1998. This weed cover measure was also partitioned into cover of annual grasses and forbs and these two variables were analyzed. Mean height of established perennial grasses and weed forb cover data in 1998 met the assumptions of ANOVA and untransformed data were analyzed. Densities of perennial grass seedlings in 1998 were log transformed before analysis. For all other response variables, the basic ANOVA assumption of equal variances was violated by the raw data and the log transformed data, so ranks of the data were analyzed. In these analyses, the performance measures were ranked and the value of the ranks were used in the analysis instead of the measurements themselves. Analysis of ranks is equivalent to a non-parametric test and avoids the necessity of having equal variances (Conover and Iman 1981, Hora and Conover 1984). Tukey's Studentized Range Test was applied to perform mean separations, i.e. to determine which means differed when ANOVA indicated that at least two of the means were significantly different from one another.

Melica californica and *Poa secunda* ssp. *secunda* performed too poorly to be analyzed statistically as individual species. Percent cover and height of both species were usually 0 in all treatments. However, their performance measures were included in the composite measures of perennial grass mixture performance (i.e. mean height and total percent cover).

RESULTS

Density of the perennial grass mixture and weeds in 1997

The only experimental factor that affected perennial grass and weed density in the first year was seeding method (Table 2). Perennial grass densities were highest in the drill treatment and lowest in the broadcast treatment with hydroseed intermediate (Table 3). In contrast, weeds had highest densities in the hydroseed treatment and lowest densities in the drill treatment with the broadcast treatment intermediate (Table 3). Examples of each seeding treatment are shown in Photos 9, 10 and 11. Although percent cover was not estimated in 1997, plant growth appeared greater in decompacted subsoils than in subsoils that were not decompacted (Photo 9).

Table 2. Analysis of variance table for density of the mixture of perennial grasses and weeds in 1997. Ranks of data were analyzed.

Source of Variation	**df**	***Perennial grass mixture***		*Weeds*	
		SS	F	SS	F
Block	2	174.33	3.09	2.33	0.01
Soil preparation	1	180.50	6.41	29.39	0.23
Seeding method	2	41.33	7.29*	118.75	6.29*
Block X soil preparation	2	56.33	9.94**	251.44	13.31**
Soil preparation X seeding method	2	9.33	1.65	4.53	0.24

Notes: df = degrees of freedom; SS = sum of squares; MS = mean square; F = F-value; + = $0.05 < p < 0.1$, * $p < 0.05$, ** $p < 0.01$

Table 3. Perennial grass mixture and weed densities in different seeding method treatments (1997). Means followed by different letters are significantly different according to Tukey's studentized range test ($p < 0.05$).

Seeding method	**Perennial grass mixture** (plants/m^2)		**Weeds** (plants/m^2)	
	mean	s.e.m.	mean	s.e.m.
Broadcast	30.3 B	7.8	9.8 ab	2.2
Drill	40.6 A	8.7	7.1 b	0.8
Hydroseed	36.7 AB	8.5	12.8 a	1.9

Notes: s.e.m. = standard error of the mean

Performance of perennial grasses in 1998

Seeding method

The effect of seeding method on total percent cover (the sum of the absolute cover of each of the six seeded species) was marginally non-significant (Table 4). The trend was for percent cover to be greater in the drill treatment than the hydroseed treatment (25% more seed included in hydroseed), with broadcast seeding intermediate (Table 4). When individual species were evaluated separately, seeding method had a marginally non-significant effect on the percent cover of *Elymus glaucus* (Table 4). Percent cover of *Elymus glaucus* tended to be greatest in the drill treatment, lowest in the hydroseed treatment and intermediate in the broadcast treatment. Although not significant, patterns for most other species were similar (Table 5).

There was a significant interaction between seeding method and soil decompaction for cover of *Hordeum brachyantherum* spp. *brachyantherum* (Table 4). This species had similar percent cover in both soil preparation treatments for broadcast and drill treatments. However, it produced much less cover in the non-decompacted control compared to the decompacted treatment in the hydroseed treatment (Figure 2).

Seeding method had a significant effect on the average height of the seeded perennial grasses, but this response depended upon soil preparation (Table 6). The heights of grasses in the broadcast treatment were greater than those in the hydroseed treatment and the heights of grasses in the drill treatment were intermediate without soil decompaction. Differences between seeding methods were not apparent when soil was decompacted (Fig. 3a).

When individual species were evaluated, heights of *Hordeum brachyantherum* ssp. *brachyantherum*, *Hordeum brachyantherum* spp. *californicum* and *Nassella pulchra* were affected by seeding method, although the response of *Nassella pulchra* depended on soil preparation (Table 6). The first two species were taller in the broadcast and drill treatments, respectively, than the hydroseed treatment (Table 7). Seeding treatments did not affect *Nassella pulchra* height when soil was decompacted. Without decompaction, this species performed best in the broadcast and least well in the hydroseed treatments (Fig. 3b). *Hordeum brachyantherum* ssp. *brachyantherum* also performed most poorly in the hydroseed treatment when soils were not decompacted, but this response was marginally non-significant (Fig. 3c).

Table 4. Analysis of variance table for percent cover of perennial grasses (1998). Ranks of data were analyzed.

Source of Variation	**df**	**Elymus glaucus**			***Hordeum brachantherum* ssp. *brachyantherum***			***Hordeum brachantherum* ssp. *californicum***			**Nassella pulchra**			**Total cover**		
		SS	MS	F	SS	MS	F	SS	MS	F	SS	MS	F	SS	MS	F
Block	3	145.1	48.4	1.72	627.1	209.0	11.26*	95.6	31.9	6.2+	70.7	23.6	1.2	180.0	60.0	6.6+
Soil preparation	1	704.2	704.2	25.0*	126.0	126.0	6.79+	253.5	253.5	49.3**	73.5	73.5	3.75	345	345	37.7**
Seeding method	2	62.4	31.2	2.93+	71.3	35.6	3.3+	111.0	55.5	1.06	247	123	2.52	172.7	86.4	3.16+
Block X soil preparation	3	84.6	28.2	2.65+	55.7	18.6	1.72	15.4	5.1	0.1	58.8	19.6	0.40	27.4	9.1	0.33
Soil preparation X seeding method	2	14.4	7.2	0.68	138.8	69.4	6.43*	31	15.5	0.29	24.2	12.1	0.25	96.1	48.0	1.76

Notes: df = degrees of freedom; SS = sum of squares; MS = mean square; F = F-value; + = $0.05 < p < 0.1$, * $p < 0.05$, ** $p < 0.01$

Table 5. Percent cover of perennial grasses (1998). Means followed by different letters are significantly different according to Tukey's studentized range test ($p < 0.05$).

Seeding method	**Elymus glaucus** (percent cover)		***Hordeum brachantherum* ssp. *brachyantherum*** (percent cover)		***Hordeum brachantherum* ssp. *californicum*** (percent cover)		**Nassella pulchra** (percent cover)		**Total** (percent cover)	
	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.
Broadcast	5.8 AB	1.7	9.2	1.9	3.9	3.0	3.3	4.1	22.3 ab	3.4
Drill	10.1 A	3.8	13.9	3.4	5.5	4.8	7.3	7.8	36.8 a	8.4
Hydroseed	5.2 B	2.6	10.1	2.9	2.5	2.7	0.3	0.2	18.2 b	5.4

Notes: s.e.m. = standard error of the mean

Hordeum brachyantherum* ssp. *brachyantherum
Percent cover

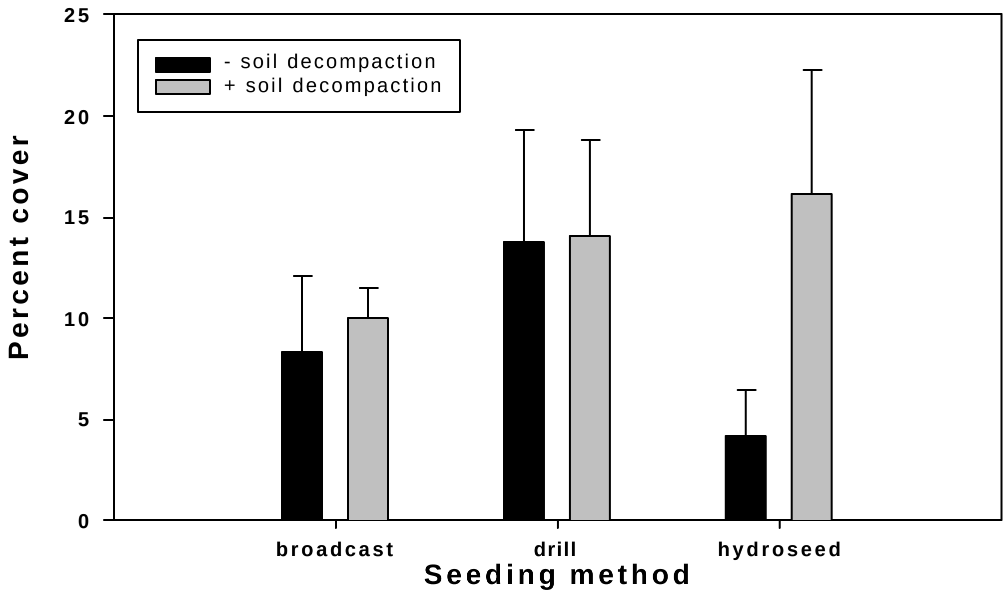


Figure 2. Percent cover of *Hordeum brachyantherum* ssp. *brachyantherum* was similar whether or not soils were decompacted broadcast or drill treatments. However, cover was much lower in treatments without decompaction when this species was hydroseeded.

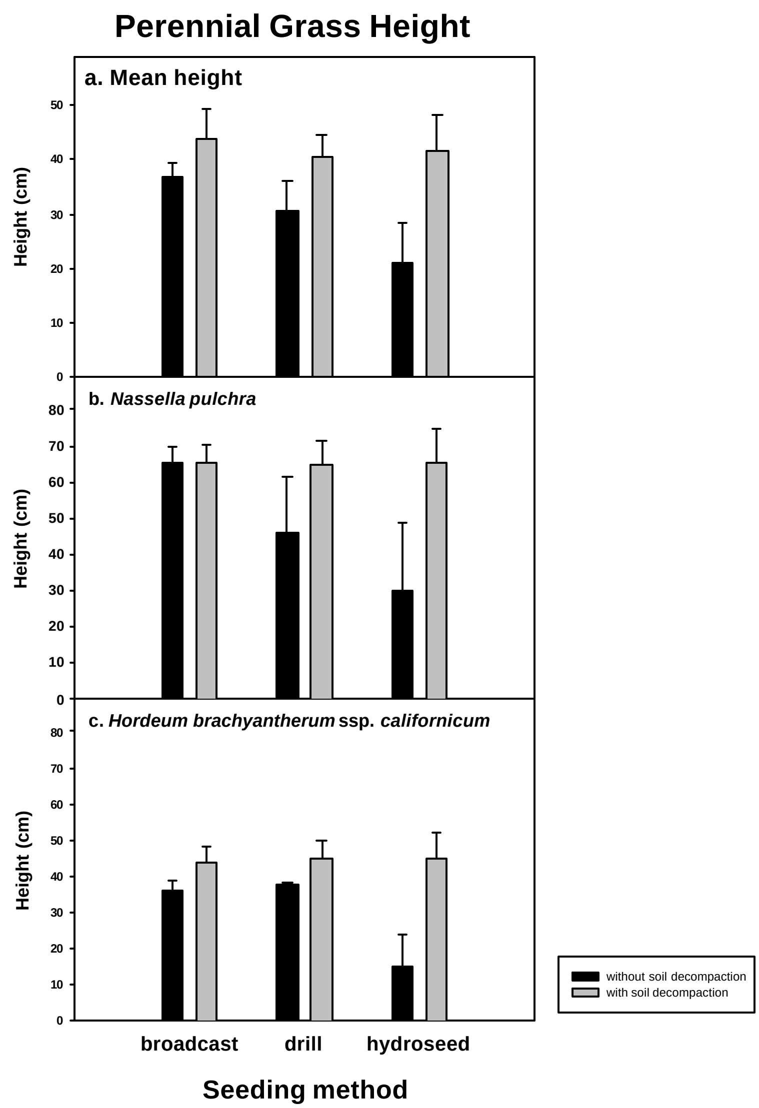


Figure 3. Heights of native perennial grasses were similar in all seeding method treatments when soil was decompacted. However, when soil was not decompacted, the mean heights across all species and heights of *Hordeum brachyantherum* spp. *californicum* and *Nassella pulchra* were greater in the broadcast and drill treatments than the hydroseed treatment.

Table 6. Analysis of variance table for established perennial grass height. Ranks of data for individual species were analyzed; mean height data were not transformed.

Source of Variation	df	Elymus glaucus			*Hordeum brachantherum* ssp. *brachyantherum*			*Hordeum brachantherum* ssp. *californicum*			Nassella pulchra			Mean height		
		SS	MS	F	SS	MS	F	SS	MS	F	SS	MS	F	SS	MS	F
Block	3	53.1	26.5	3.8	343.0	114.3	0.79	138.7	46.2	0.3	594.3	198.1	3.2	1317.2	439.1	2.17
Soil preparation	1	221.6	73.9	10.7	181.5	181.5	1.25	280.2	280.2	2.1	121.5	121.5	1.95	944.3	944.3	4.7
Seeding method	2	5.4	2.7	0.4+	85.7	42.9	6.98**	103.0	51.5	4.1*	100.7	50.4	8.2**	311.4	155.7	7.48**
Block X soil preparation	3	557.7	185.9	2.5**	436.8	145.6	23.72***	395.6	131.9	10.6**	186.8	62.3	10.1**	605.7	201.9	9.7**
Soil preparation X Seeding method	2	228.2	228.2	3.1	29.2	14.6	2.38	82.3	41.2	3.3+	70.7	35.4	5.7*	207.4	103.7	5.0*

Notes: df = degrees of freedom; SS = sum of squares; MS = mean square; F = F-value; + = $0.05 < p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 7. Heights of perennial grasses in different seeding method treatments for species without significant interaction between seeding method and soil preparation treatments.

Seeding method	Elymus glaucus (cm)		*Hordeum brachyantherum* ssp. *brachyantherum* (cm)		*Hordeum bracyhantherum* ssp. *californicum* (cm)	
	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.
Broadcast	61.9	4.8	65.2 A	4.0	39.6 ab	3.1
Drill	53.1	8.5	63.2 AB	4.6	41.2 a	2.6
Hydroseed	52.7	9.5	52.1 B	8.3	30.0 b	7.7

Notes: s.e.m. = standard error of the mean; means followed by different letters are different from each other according to Tukey's studentized range test (" = 0.05).

Subsoil decompaction had a large effect on percent cover of perennial grasses (Table 4) (Photo 12). Percent cover was higher in the decompacted treatment than the non-compacted control for total cover (i.e. sum of all species) and for percent cover of *Elymus glaucus* and *Hordeum brachyantherum* spp. *californicum* (Table 8). Percent cover of *Hordeum brachyantherum* spp. *brachyantherum* was marginally non-significantly higher in the decompacted treatment compared to the control (Table 8).

We were unable to detect an effect of decompaction on perennial grass height (Table 6), although heights tended to be greater in decompacted soils compared to the control (Table 9).

Density of perennial grass seedlings from seedbank in 1998

The density of perennial grass seedlings in the second year after planting was affected by soil decompaction and there was an interaction between soil decompaction and seeding method (Table 10). Overall, seedling density was much greater in decompacted plots than plots that were not decompacted. When soil was decompacted, seedling density was greater in the hydroseed treatment than drill and broadcast treatments. This was the only case in which the hydroseed treatment outperformed both of the other seeding methods. When soil was not decompacted, seedling densities were greater in the drill treatment than the broadcast and hydroseed treatments (Fig. 4).

Table 8. Percent cover of perennial grasses in decompacted soil treatment and control in which soil was not decompacted.

Soil preparation	**Elymus glaucus** (percent cover)		***Hordeum brachantherum* ssp. *brachyantherum*** (percent cover)		***Hordeum brachantherum* ssp. *californicum*** (percent cover)		**Nassella pulchra** (percent cover)		**Total** (percent cover)	
	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.
Control	2.02*	0.96	8.76+	2.46	2.42**	0.92	3.01	1.75	16.21**	4.28
Decompacted	12.05	2.38	13.38	1.92	5.56	1.04	4.28	1.58	35.30	4.92

Notes: s.e.m. = standard error of the mean; + = $0.05 < p < 0.1$, * $p < 0.05$, ** $p < 0.01$

Table 9. Heights of perennial grasses in decompacted soil treatment and control in which soil was not decompacted.

Soil preparation	**Elymus glaucus** (percent cover)		***Hordeum brachantherum* ssp. *brachyantherum*** (percent cover)		***Hordeum brachantherum* ssp. *californicum*** (percent cover)		**Nassella pulchra** (percent cover)		**Total** (percent cover)	
	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.	mean	s.e.m.
Control	45.92	6.54	53.94	5.36	29.46	4.19	47.13	8.35	29.41	3.47
Decompacted	65.87	4.60	66.46	3.85	44.46	2.98	65.06	3.89	41.95	2.89

Table 10. Analysis of variance table for perennial grass seedling densities in 1998. Data were log transformed for analysis.

Source of Variation	**df**	**Mean density**		
		SS	MS	F
Block	3	243.38	81.13	3.78*
Soil preparation	1	482.85	482.85	22.48***
Seeding method	2	74.62	37.31	1.74
Block X soil preparation	3	41.02	13.67	0.64
Soil preparation X Seeding method	2	205.45	102.73	4.78*

Notes: df = degrees of freedom; SS = sum of squares; MS = mean square; F = F-value; + = $0.05 < p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

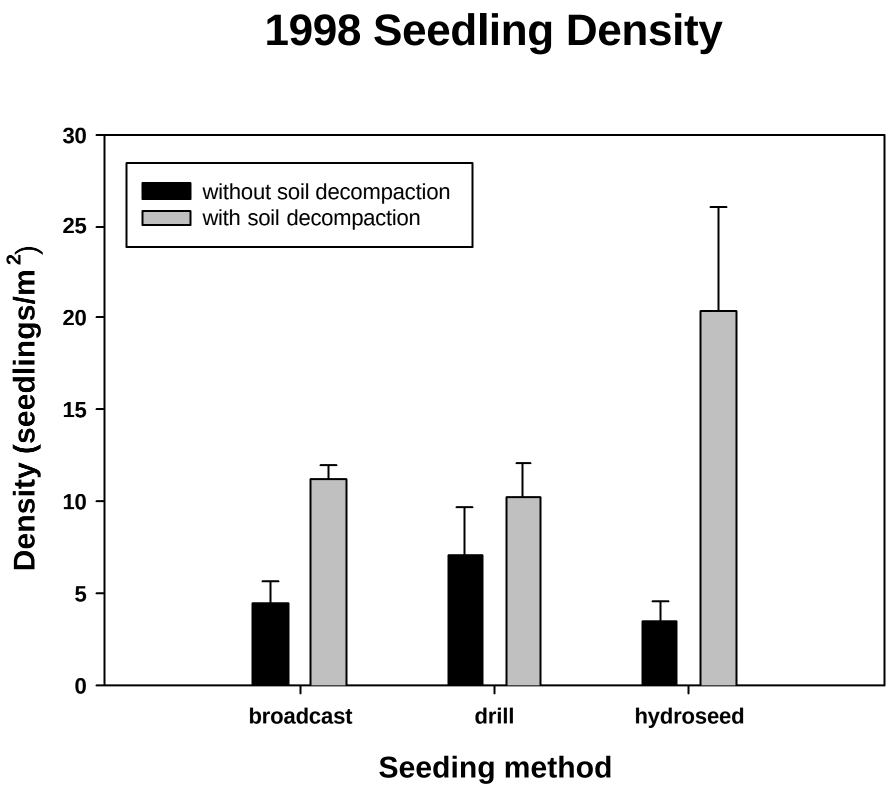


Figure 4. Densities of perennial grass seedlings in 1998 were greatest in the hydroseed treatment, which included 25% more seed than the other seeding methods, when soil was decompacted. However, without decompaction, seedling densities were highest in the drill treatment and lowest in the hydro-seed treatment. Seedling densities were generally greatest in treatments with soil decompaction.

Weed cover in 1998

Weed cover was comprised of 71 % annual grasses and 29 % forbs, which were mainly annuals. The most common annual grass weeds were *Lolium multiflorum* L. (Italian ryegrass), *Bromus* spp., *Phalaris minor* Retz. and *Hordeum* spp. The most common forbs were *Medicago polymorpha* L. (California burclover), *Pichris echioides* L. (bristly ox-tongue), *Centaurea solstitialis* L. (yellow star-thistle), *Anthemis cotula* L. (mayweed), *Sonchus asper* (L.) Hill (prickly sow thistle) and *Melilotus indica* (L.) All. (sourclover). We detected no effect of soil decompaction and seeding methods on the percent cover of the three most abundant weeds in each plot combined and the cover of annual grass weeds (Table 11). Forb weeds were marginally affected by seeding method and tended to have higher cover in the hydroseeding treatment (52.47 ± 11.76 a) than the drill treatment (32.64 ± 7.58 b), with cover in the broadcast treatment intermediate (47.66 ± 9.87 ab) (means followed by different letters are different from each other according to Tukey's Studentized Range Test with " = 0.05).

DISCUSSION

Decompaction of the soil generally enhanced perennial grass growth. Native perennial grasses performed best (and weeds performed most poorly) in the drill treatment than in the broadcast and hydroseed treatments, despite the fact that 25% more seed was planted in hydroseed plots. However, these differences between seeding methods were only apparent when soil was not decompacted before seeding. Across all species and for the individual species *Hordeum brachyantherum* ssp. *brachyantherum*, *Hordeum brachyantherum* spp. *californicum* and *Nassella pulchra*, different seeding methods did not affect performance when soil was decompacted. However, in the control in which soil was not decompacted, these species did not perform as well in the hydroseeding treatment as in drill and broadcast treatments. Even though perennial grass seedling densities were higher in decompacted hydroseed plots in 1998, variability in that treatment was extremely high and densities do not reflect plant growth. Therefore, percent cover is a better indicator of success.

Once the rainy season ended, the hydroseed treatment resulted in a thick layer of fiber, which may have impeded emergence of seedlings (Photo 13). The layer cracked and curled, sometimes lifting seedlings out of the soil by their roots (Photo 14). Hydromulch (fiber and fertilizer in water) was applied to all seeding treatments, but twice as much fiber and fertilizer were applied to half of the hydroseed treatment plots (once when the seed was applied and again when fiber and fertilizer in water were applied alone). In addition, seed mixed with the hydromulch slurry in the hydroseed treatment may have been less likely to have optimal seed-soil contact. These factors may have contributed to the seeding method treatment effects we detected.

It appears that subsoil decompaction at least partially compensated for the shortcomings of hydroseeding. We cannot assess the extent to which the effects of hydroseeding were mitigated because the seeding and hydromulch rates differed among methods. What we can say is that differences between perennial grass growth in hydroseeding, drill and broadcast seeding treatments could not be detected when subsoils were decompacted and the seeding rate for seeds planted by the hydroseed method were increased by 25%. However, differences between the seeding methods were apparent when subsoils were not decompacted. We can only speculate about the mechanisms that led to these results. Reducing impedence to root growth and improving water infiltration through the decompaction were probably at least in part responsible for the improved growth of the seeded species (Håkansson et al.1988). Roughening of the soil surface may have provided better adhesion of the hydroseed slurry to the soil surface and resulted in improved performance. Other side-effects of the soil preparation may also have led to the effects we detected.

Our decompaction results are consistent with those of Montalvo et al. (2001) in that the effects of decompaction did not become apparent until the second growing season. However, we found strong effects of subsoil decompaction on perennial grass growth the second year, whereas, soil decompaction in the Montalvo et al. study (2001) led to variable results and the authors concluded that it had minimal effects on plant establishment. There were several differences between the two studies that may have resulted in contrasting results. The depths of decompaction in the Montalvo et al. study were 0, 20 and 40 cm, whereas, subsoil decompaction depths in the current study were 0 and 76 cm. The two studies share only a single species, *Nassella pulchra,* in common. This was one of the species that showed a positive response to soil decompaction in the Montalvo et al. study. Whereas, only perennial grasses were included in the experiment being reported here, Montalvo et al. included annual grasses and forbs and perennial shrubs.

Soil and climate of the two study sites were also very different. The Montalvo et al. experiment was conducted on a sandy loam soil in southern California where annual precipitation is 340 mm (Montalvo et al. 2001). The experiment reported here was conducted on clay, clay-loam soils in northern California where the annual rainfall is 460 mm. The granular structure of the southern California soil may have resulted in lower tendency to become compacted, therefore, reducing the effects of ripping. Differences in soil type and moisture content have been reported to result in differential effects of compaction on plant growth (Vepraskas et al. 1986) and compaction can even be beneficial to plant growth in sandy soils (Abou-Arab et al. 1998).

Montalvo et al. (2001) also found that weed density decreased with soil ripping, whereas, we detected no effects of soil decompaction on weed abundance. In our experiment, only the abundance of forb weeds was affected by seeding method and was greatest in the hydroseed treatment. There is no reason to believe that weed seed abundance would be greater in the hydroseed treatment than in broadcast and drill treatments. Water, fiber and fertilizer were applied to all seeding method treatments, eliminating these as factors causes of the results we detected. This effect must be due to factors that we did not measure.

RECOMMENDATIONS

Based on our experimental results and the findings of others, it is clearly very important to consider the compactibility of the soils of a revegetation site before selecting soil preparation and seeding methods. First, it should be determined whether a compacted layer exists and whether the soil texture, structure and moisture content are conducive to compaction. Second, the feasibility of alternative seeding methods should be evaluated. When conditions allow the use of a seed drill, our results suggest that this method may be most efficient. Broadcast seeding may be nearly as effective but will require more labor than drill seeding or hydroseeding if performed by hand and seed should be incorporated with hand tools or a tractor drawn harrow, if possible. If hydoseeding is the most practical option (e.g. due to steep slopes or wet soil), our results suggest that at least 25% greater seeding rates should be used and soil should be decompacted (if warranted and practicable) for plant growth levels to equal those of drill or broadcast seeding.

ACKNOWEDGEMENTS

This project was possible only with the assistance of many people. Thanks are due to all who participated in the process of planning and executing this experiment including Scott Stewart, John Anderson, Jennfier Malcolm, H. Kibunguchy and others. We would like to thank Al Nitta, for his cooperation and assistance in applying the seeding treatments and William Kuhl for his detailed record keeping and efforts to precisely adhere to the experimental design. We appreciate the help of Carolyn Brown, Monica Finn, Craig Schreiffer, Catherine Wardner, Marcia Haver and several others who participated in collecting data. We also thank Barbara Pollock, Dan Pollock and the Caltrans District 3 maintenance crew for their support and assistance with management of the site.

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Photo 1 Photo 2

Photo 1 and 2 illustrate the stakes and pavement markings that indicated the soil preparation and seeding methods to be applied in each area of the freeway median.

Photo 3 - Flooding caused by winter rains

Photo 4 - Subsoiling equipment with 76 cm shanks and followed by flat roller to break up large soil clods.

Photo 5 - 1995 Truax Flex II Grass Drill being pulled by 40 hp1978 Ford 515 tractor-loader.

Photo 6 - Bill Kuhl mixes seed with horse feed supplement before loading it into seed hoppers of the grass drill.

Photo 7 - Hand broadcasting seed

Photo 8 - Hydroseeding with 1992 Model T330 3,300 gallon Finn hydroseeder mounted on a 1980 Freightliner truck.

Photo 9 - Drill seeded section with non-decompacted treatment in foreground and decompacted treatment in background. Note greater plant growth in decompacted soils.

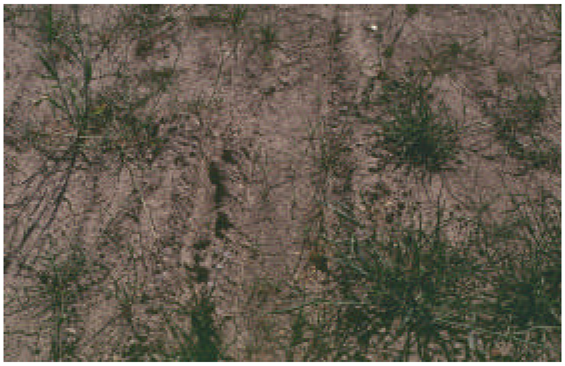

Photo 10 – Native grass seedlings were growing in the depressions of these tire tracks in a broadcast treatment plot.

Photo 11 – Hydroseeded plot

Photo 12 – Soils to the left of this picture were decompacted while those to the right were not. Note that plants were taller in the decompacted soils.

Photo 13

Photo 14

Photos 13 and 14 show the thick hydromulch layer. It created a tough layer when it dried that may have inhibited seedling emergence and sometimes lifted seedlings from the soil as it curled, as demonstrated in Photo 14.

Chapter 2

Long-term vegetation management methods for California native perennial grasses in highway and roadside rights-of-way

Keywords: California native perennial grasses, erosion control, restoration, management, mowing, pre-emergence herbicides, post-emergence herbicides

ABSTRACT

As the use of native perennial grasses for erosion control, restoration and revegetaion has increased, the need for long-term management methods has grown. We conducted an experiment in the median of Interstate 5 in Sacramento Valley to evaluate a number of cultural practices for maintaining populations of California native perennial grasses. The species, planted by drill seeding, were *Elymus glaucus*, *Hordeum brachyantherum* ssp. *brachyantherum*, *Hordeum brachyantherum* ssp. *californicum*, *Melica californica* and *Nassella pulchra*. This experiment was designed to test the use of (1) well-timed mowing, (2) mowing with broadleaf specific herbicides and (3) mowing with pre-emergence herbicides for promoting the establishment and long-term persistence of native perennial grasses. The use of pre-emergence herbicides in the fall of the second year of growth resulted in improved performance of native perennial grasses and reduction in the abundance of weeds. We did not detect any effect of mowing on perennial grass or weed performance. Due to problems in executing the experiment, we were unable to evaluate many of the treatments that the experiment was initially intended to test.

INTRODUCTION

Because of their many potential benefits, native perennial grasses are being included in erosion control, restoration and revegetation projects with increasing frequency. Although most native perennial grasses grow slowly compared to annual species (e. g. Garnier 1992), they can be good competitors once established and persist for extended periods (Bugg et al. 1997, White 1967). They can help reduce the abundance of weedy species and provide a more stable plant community that serves as habitat for desirable flora and fauna (Bugg et al. 1997).

Some experiments and informal studies of native perennial grass seeding methods and management during establishment have been conducted (Montalvo et al. 2001, Stromberg and Kephart 1996, Anderson 1993, Dyer et al. 1996). However, there have been very few studies of the long-term management of these species. Most of the existing studies have examined the effects on perennial grasses of grazing or burning, or both (Langstroth 1991, Menke 1992, Dyer et al. 1996). Grazing and burning may be problematic for use on roadside rights-of-ways for safety reasons. However, many of the management methods suggested for promoting the growth and establishment of newly seeded native perennial grass species might be appropriate for their long-term maintenance as well. The biggest obstacle to establishment of native perennial grasses is competition from resident vegetation, mostly exotic annual grasses. Anderson (1993) suggested the use of pre-emergence herbicides in the second year after seeding of perennial grasses, post-emergence, broadleaf specific herbicides and well-timed chemical or mechanical mowing to selectively damage competing vegetation. There is clearly a need to test these methods in a controlled and replicated manner to evaluate their efficacy for management of native perennial grasses in California roadside and highway rights-of-way.

Here we present the results of an experiment that was designed to investigate the effectiveness of (1) well-timed mowing, (2) mowing with broadleaf specific herbicides and (3) mowing with pre-emergence herbicides for promoting the establishment and long-term persistence of native perennial grasses. Several groups conducted the project, each agreeing to execute a part of the experiment, as described in the introduction of the report. Briefly, the University of California researchers were responsible for designing the experiment, instructing California Department of Transportation Biological Unit employees in monitoring methods, analyzing the data and producing the reports. California Department of Transportation Biological Unit personnel were to monitor the growth and establishment of the perennial grasses. California Department of Transportation District 3 Maintenance crews were responsible for applying the management treatments.

METHODS

The experiment described in this chapter, was conducted in the same area as the experiment described in the previous chapter. The replications or blocks of experiment I and II were interspersed. The soil was decompacted before seeding by ripping to 76 cm (30 inches) using 91 cm (36 inches) shanks in three passes over the area. Soil was decompacted one third of the total depth in the first pass, two thirds in the second pass and the full 76 cm (30 inches) in the final pass. A water-filled flat roller (approximately 91 cm or 36 inches in diameter, with rigid rings approximately 10 cm or 4 inches tall and

12.5 cm or 5 inches apart) was pulled behind the ripper to break up large clods of soil (Daniel Olford personal communication December 2000) in the final pass with the ripper. This operation was performed relatively late in the year when soils were too wet for optimal breaking of compacted soil and ripper shanks sliced through the soil more than would be ideal, "like slicing a pie," according to Al Nitta (personal communication 5 January 2001).

This experiment was drill seeded with the mixture of species that were selected to be compatible with the conditions at the site (Table 1) at 4.4 lbs/acre. Drill seeding was conducted using a 1.82 m (6 feet) wide Truax Flex II no-till grass drill (Model IXII-88, Truax Company, Inc., 3609 Vera Cruz Avenue North, Minneapolis, Minnesota 55422) on 19 December 1996 (previous chapter, Photo 5). Seed was mixed with a bulking agent (wheat product horse feed supplement) in order to achieve the appropriate seeding density. A hydromulch layer with fiber (898 kg/ha or 800 lbs/acre) and fertilizer (224 kg/ha or 200 lbs/acre) (described in Appendix 1) was applied to the experiment on 20 and 23 December 1996 using a 1992 Model T330 Finn Hydroseeder (previous chapter, Photo 8).

Each treatment plot was 39.6 m long and 12.2 m wide (the width of the median). One of five management treatments was assigned to each plot. The treatments were:

(1) No treatment control

(2) Mowing only

(3) Mowing with pre-emergence herbicides

(4) Mowing with broadleaf herbicides

(5) Mowing with pre-emergence and broadleaf herbicides

Table 1. Perennial grass seeding rates for broadcast and drill treatments based on pure live seed. Hydroseed treatment was seeded with 25% more pure live seed seed by weight. Species authors are according to Hickman (1993).

Species	**Seeding density**	
	seeds/m^2	kg/ha
Elymus glaucus Buckley var. Yolo Bypass blue wildrye	59	2.92
Hordeum brachyantherum ssp. *brachyantherum* Nevski var. Salt meadow barley	72	4.40
Hordeum brachyantherum ssp. *californicum* Nevski var. Prostrate California barley	96	3.18
Nassella pulchra (A. Hitchc.) Barkworth var. Jepson Prairie purple needlegrass	60	2.80
Poa secunda ssp. *secunda* J. S. Presl pine bluegrass	957	4.10
Melica californica Scribner California melic	159	1.39
Total	1,403	18.80

There were initially 4 replications of each treatment. Due to weather, miscommunication and difficulties in managing the logistics of experimental treatment needs in addition to normal maintenance workloads, most of these treatments were not applied and none of them were applied to all 4 replications.

All plots but the no treatment controls were mowed in the spring of 1997. The northern blocks were mowed approximately one month prior to the southern blocks. The same plots were mowed again 10-11 July 1997.

The pre-emergence herbicide Pendimethalin (Pendulum ®) was applied at a rate of 1 gal/acre on 23 October 1997. It was only applied to the plots that were assigned to the pre-emergence herbicide and pre-emergence with broadleaf herbicides treatments in replicate 4 due to a misunderstanding about the area that should be treated.

Sections to receive broadleaf herbicides were marked out 20 March 1998. We planned to apply the broadleaf specific herbicide triclopyr (Garlon 4 ®), but were unable to due to rain that would have eliminated its effectiveness. The weather then became too warm for safe use of the chemical, which is prone to volatilize, drift and can cause damage to plants in non-application areas in warm weather.

10-12 March 1998 all plots but the no treatment controls were mowed, but only in replications 1 and 2 due to misunderstanding about the extent of the experiment.

1996-7 and 1997-8 Climate

The total precipitation in Davis (approximately 20 km north-west from the experiment site with rainfall patterns similar to the experiment site) for 1997 was 467.36 mm (18.4 in), near the thirty-year average of 460.05 mm (18.1 in) (Owenby and Ezell 1992). Despite this, the pattern of rainfall was unusual. In January 219.96 mm (8.7 in) of precipitation fell, 220% of the thirty-year average, causing considerable flooding at the experiment site (previous chapter, Photo 3). Precipitation in Februrary, March and April was a fraction of normal with 0.9%, 16% and 11% of the thirty-year average falling. In May and June rainfall was about 30% higher than the thirty-year average, which extended water availability for plant growth.

The second wet season began in the autumn of 1997 with 111.0 mm (4.4 in) of rain falling in November, about 150% of the thirty-year average. Rainfall for December 1997 and January 1998 were close to the average, but precipitation was well above average for February (297.94 mm or 11.7 in, 410% of the thirty year average) and May

(59.44 mm or 2.3 in, 835% of the thirty year average). Precipitation was below average for March (47.24 mm or 1.9 in, 70% of the thirty year average). Overall during 1998, 565.15 mm (22.2 in) of rain fell, 123% of the thirty-year average. This year was an above normal rainfall year and water availability was extended due to considerable precipitation late in the season.

The pattern of rainfall during the critical period for germination of the perennial grass seeds was favorable for establishment. In December, there were four to six days between rainfall events, except for one 13-day drought. However, rainfall events in December were poorly timed with respect to the hydroseed treatment application, as described below, and caused flooding of the site. In January and February, there was one nine-day drought, otherwise only one to three days between storms.

Although rainfall was conducive to establishment, temperatures were too low for seed germination at the time of seeding. According to data collected at the NOAA Reference Climatological Station operated by the Department of Land, Air and Water Resources, University of California, Davis, the average air temperature was 13.3 °C (56 °F) and 12.2 °C (54 °F) and the average soil temperatures were 10.6 °C (51 °F) and 10.0 °C (50 °F) during December 1996 and January 1997, respectively. These temperatures are at the lower boundary of the range suitable for germination of most species (Mayer and Poljakoff-Mayber 1963).

Monitoring

Monitoring was conducted in a manner similar to the seeding method and soil preparation method experiment. The first evaluation of this experiment took place in 1998 because 1997 was the establishment year and management methods were not applied until 1998. We measured percent cover and height of individual perennial grass species as well as cover, height and identity of weeds. All data were collected on 29 April 1998. We monitored two transects (eight samples) in each of the areas that received a management treatment and the area in the same replicate that did not receive that treatment. Sampling for the effect of pre-emergence herbicide was conducted in replicate 4, the only area that received the treatment. A two-sample t-test was used to determine if the means of the two treatments were different. We monitored the effect of mowing in replicates 1 and 2. Analysis of variance (ANOVA) was used to test for treatment effects. Each sample or quadrat was treated as if it were an independent observation.

RESULTS

Pre-emergence herbicide application reduced the cover of weeds to about 30% of the level found in plots that did not receive the herbicide (Table 2, $P = 0.0007$) (Photos 1, 2, 3 and 4). Percent cover of perennial grasses was about three times higher in plots that received pre-emergence herbicide (Table 2, $P = 0.003$). Percent cover of *Hordeum brachyantherum* was higher in pre-emergence herbicide plots ($P = 0.002$), and the same statistical trend was present for *Elymus glaucus* ($P = 0.05$) (Table 2). Although effects on cover could not be detected for other species of perennial grass due to low statistical power (power = 0.06 and 0.05 for *Hordeum californicum* and *Nassella pulchra*, respectively, i.e. there was a 6% and 5% chance of detecting a real effect if it were present), the means exhibited a similar pattern. Height of the perennial grasses was not affected by the application of pre-emergence herbicides (Table 2, $P = 0.97$). We were unable to detect an effect of fall application of pre-emergence herbicide on spring perennial grass seedling densities. However, the probability that we would be able to detect an effect if it was present given the amount of variation and number of observations was very low (power = 0.06).

Table 2. Percent cover of weeds and perennial grasses, perennial grass height and perennial grass seedling densities (mean ± standard error of the mean). Means of pre-emergence herbicide treatments that are significantly different are indicated (+, *, **, *** $P < 0.1, 0.05, 0.01, 0.001$, respectively).

Response variable	Plant type or species	With pre-emergence herbicide	Without pre-emergence herbicide
Percent cover	Weed	44.69 ± 17.21 ***	150.94 ± 17.44
	Perennial grasses	111.25 ± 17.60 **	31.56 ± 14.12
	Elymus glaucus	42.50 ± 10.65 +	16.25 ± 6.46
	Hordeum brachyantherum ssp. *brachyantherum*	51.25 ± 13.14 **	2.19 ± 1.86
	Hordeum brachyantherum ssp. *californicum*	11.25 ± 6.01	7.81 ± 7.81
	Nassella pulchra	6.25 ± 2.59	5.31 ± 4.61
Height (cm)	Perennial grasses	68.60 ± 5.11	68.33 ± 5.11
Seedling density (seedlings/m^2)	Perennial grasses	18.75 ± 9.15	25.00 ± 9.45

Table 3. Percent cover of weeds and perennial grasses, perennial grass height and perennial grass seedling densities (mean ± standard error of the mean). Means of mowed and not mowed treatments are not significantly different at significance level 0.05.

Response variable	Plant type	Mowed	Not mowed
Percent cover	Weed	160.31 ± 9.83	163.39 ± 10.51
	Perennial grasses	35.56 ± 8.83	43.12 ± 8.83
Height (cm)	Perennial grasses	36.02 ± 2.84	43.16 ± 2.84
Seedling density (seedlings/m^2)	Perennial grasses	63.33 ± 28.31	96.87 ± 27.41

We detected no effects of mowing on percent cover of weeds or perennial grasses, height of perennial grasses (i.e. they had recovered their height be the time we sampled), or density of perennial grass seedlings (Table 3) (Photos 5, 6 and 7).

DISCUSSION

As expected, the use of pre-emergence herbicides improved the performance of native perennial grasses and reduced the success of species that were not planted (Photos 1, 2, 3 and 4). The use of these herbicides has been widely recommended because of these benefits. However, negative effects of the pre-emergence herbicide oryzalin (Surflan ®) on established *Poa secunda* ssp. *secunda* have been observed (Bugg and Brown unpublished data).

Although we cannot broadly apply our conclusions due to lack of replication and low statistical power, the mowing treatment neither benefited the seeded grasses nor reduced the cover of weeds (Photos 5, 6 and 7). It has been suggested that this method may perform both of these functions (Anderson 1993), although controlled experiments have not been performed. More work needs to be done in order to understand how well-timed mowing can be used as a tool for management of perennial grasses as seedlings.

This experiment represented the opportunity for many branches of the California Department of Transportation to be involved in developing new vegetation management methods that will help achieve the goals of lower herbicide use. However, the experiment was added to the normal responsibilities of maintenance forces and it could not be made a high priority. Therefore, we did not get the response from maintenance that was necessary for success of the project.

RECOMMENDATIONS

There is still a tremendous need to develop cultural practices for long-term management of perennial grasses on roadsides. The results of this experiment would have provided excellent basic information to help fill the gaps in our knowledge about management of perennial grass stands after initial establishment had the experiment been executed as designed. The problems were largely due to this project being added to the normal workloads of biological and maintenance personnel and the absence of on-site supervision by someone with detailed information about the experiment, its design and intent at the time of the maintenance activities. Department of Transportation personnel were cooperated with this project and did their best to do what was needed as requested.

We believe that a similar long-term experiment should be conducted in the future. To avoid the problems encountered in the experiment reported here, independent contractors should be hired to perform all soil preparation, seeding, treatment and maintenance activities. This will ensure that treatments are applied properly. Another improvement that can be incorporated into future studies will be to require the presence of a supervisor who is knowledgeable about the experimental design and objectives when each of the activities is carried out.

The involvement of Department of Transportation personnel, at the minimum as advisors, is essential. The relevance of experimental treatments (e.g. specifications for herbicide use) will suffer without their input and advice. However, they should not be expected to apply the treatments or collect the data, unless these activities are recognized as part of their normal workload and responsibilities and are treated that way by their supervisors. We believe that the relevance of the questions addressed and the information learned through any experiment will be transferred into practice most efficiently when Department of Transportation personnel who will utilize the methods tested are intellectually and physically involved in development and execution of the experiment. However, due to our previous experience, we recommend a larger role for independent contractors in the future. This will eliminate the benefit of direct participation of Department of Transportation maintenance personnel in these activities. We suggest that education and training of Department of Transportation personnel also be included as a research activity in order to integrate the knowledge gained from experiments into standard maintenance protocols.

ACKNOWEDGEMENTS

This project was possible only with the assistance of many people. Thanks are due to all who participated in the process of planning and executing this experiment including Scott Stewart, John Anderson, Jennfier Malcolm, H. Kibunguchy and others. We would like to thank Al Nitta, for his cooperation and assistance in applying the seeding treatments and William Kuhl for his detailed record keeping and efforts to precisely adhere to the experimental design. We appreciate the help of Carolyn Brown, Monica Finn, Craig Schreiffer, Catherine Wardner, Marcia Haver and several others who participated in collecting data. We also thank Barbara Pollock, Dan Pollock and the Caltrans District 3 maintenance crew for their support and assistance with management of the site.

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Photo 1 and 2 – With pre-emergence herbicide (4/13/98)

Photo 3 and 4 – No pre-emergence herbicide (4/13/98)

Photo 5 – Border between mowed (right) and unmowed (left) treatments on 13 April 1998.

There was no visible difference between the mowed and not mowed treatments on 29 April 1998.

Photo 6 – Mow treatment

Photo 7 – No mow treatment

Chapter 3

The effects of soil amendments and mulches on establishment of seeded California native perennial grasses

ABSTRACT

We studied the effects of compost, slow-release nitrogen fertilizer and different types of straw mulch [rice (*Oryza* sativa), wheat (*Triticum aestivum*) and blue wildrye (*Elymus glaucus*)] on the establishment and growth of California native perennial grasses in a factorial experiment. Perennial grasses responded to interactions between nutrient availability, weeds and volunteers of the mulch species. They performed best in rice straw mulch, having better nutrient status and growth. Growth and nutrient status of perennial grasses were most poor with blue wildrye straw mulch. Rice straw had the lowest amounts of weeds and volunteers from mulch, blue wildrye straw had the highest amounts, and wheat straw was intermediate. Nitrogen status of seeded perennial grasses was highest in rice straw treatments, lowest in blue wildrye straw mulch and intermediate in wheat straw mulch. Differences in decomposition rates of the straws and resulting differences in nitrogen immobilization may have been responsible for the patterns in perennial grass performance that we detected. The addition of compost benefited weeds, but not perennial grasses unless weeds were removed. Competition from weeds suppressed the growth of perennial grasses, but this negative effect was ameliorated by the addition of slow-release nitrogen fertilizer. We suggest that rice straw is a superior mulch because had less potential of containing weeds and mulch volunteers that compete with seeded species and because it resulted in the best performance of seeded perennial grasses in our study. Whatever straw is applied, it should be weed free.

INTRODUCTION

The appropriate cultural practices to apply in revegetation projects using native perennial grasses have yet to be established. Many currently used methods provide a great deal of promise, but their efficacy individually and in combination need to be tested. Applying soil amendments that will immobilize nitrogen and release it slowly can be a valuable tool in successful revegetation and restoration of plant communities (Morgan 1994; Zink and Allen 1998). The practice may provide an advantage for slower growing native perennial species in competition with fast growing, weedy species that benefit from high nitrogen conditions (Chapin 1980; Jackson et al. 1988; Hart et al. 1993; Davidson et al. 1990; Claassen and Marler 1998; Zink and Allen 1998) (but also see Wilson and Gerry 1995 and Reever Morghan and Seastedt 1999).

The use of soil amendments that provide small amounts of nitrogen over long periods of time can also encourage the establishment and persistence of vegetation on severely degraded sites (Claassen and Hogan 1998, Brown et al. 1998). On revegetation sites in the Lake Tahoe Basin, Claassen and Hogan (1998) found that total nitrogen and mineralizable nitrogen, forms of nitrogen that are not immediately available to plants but become available over a period of months, were better correlated with vegetation cover than readily available ammonium and nitrate. Claassen and Hogan (1998) recommended "the use of amendments with slow N release rates so that the N applied to the site will be retained in the soil until it is incorporated into plant tissue (page i, Abstract)." Similar results were detected in a study comparing relict stands of native perennial grasses and revegetation sites throughout California. In this study, the same less readily available forms of nitrogen were more abundant in relict stands of perennial grasses than revegetation sites (Brown et al. 1998). Soils of relict sites also tended to have higher organic matter content than revegetation sites.

Slow-growing perennial grasses can benefit from limited nutrient availability when competing with fast-growing species. Claassen and Marler (1998) found that growth of the introduced annul grass *Bromus hordeaceus* exceeded that of the native perennial *Elymus glaucus*, at levels of 50-100 uM (0.7 – 1.4 ppm) N or higher, but that there was no difference between performance of the two species or the pattern was reversed at lower levels. The soil solution nitrogen levels tested by Claassen and Marler were low compared to those provided by typical erosion control nitrogen applications. Standard erosion control fertilizer applications of 250 kg 16:20:0 dissolved in a soil with bulk density of 1.3 and 25% water content would result in 82 ppm N (Victor Claassen personal communication 13 December 2000) and values of 100-150 ppm are common in soils (Reisnenaur 1964). These findings indicate that high-levels of soluble nitrogen can favor weedy exotic species over native perennials.

The application of straw mulch is a common practice in erosion control and revegetation. The benefits of surface mulch for establishing plants from seed have been well demonstrated (Dudeck et al. 1970; Clary 1983; Gupta et al. 1984; Phillips and Phillips 1984; Kwon et al. 1995; Abrecht et al. 1996; Bautista et al. 1996; Byard et al. 1996; Cavero 1996; Rahman et al. 1997). Surface mulch application also has well-known erosion control benefits (Osborn 1954; Meyer et al. 1970; Kay 1978; Clary 1983; Bautista et al. 1996). Applying mulches to the soil surface can result in increased immobilization of nitrogen similar to incorporation of soil amendments with high C:N (carbon to nitrogen ratio). Zink and Allen (1998) applied pine bark, which has high C:N and decomposes very slowly, and oat straw, which has lower C:N and decomposes less slowly, to plots with planted seedlings of *Artemisia californica* (California sagebrush) and *Nassella pulchra* (purple needlegrass). Amended plots had lower ammonium and nitrate in the soil under the mulch compared to the unamended control for all but one of the sampling events, while total nitrogen levels remained similar in all three treatments. Frey et al. (2000) found convincing evidence that fungi play an important role in translocation of nitrogen from the soil into organic matter on the soil surface, thereby, reducing nitrogen availability in soils. Holland and Coleman (1987) also showed that placement of straw on the soil surface led to immobilization of nitrogen, and slowed the loss of organic matter and nutrients. Plots with straw on the surface had more fungi than plots with incorporated straw and the authors suggest that fungi may be important decomposers of surface straw. Fungi are able to utilize both carbon in the straw on the soil surface and nitrogen within the soil through their network of hyphae and are better able to tolerate dry conditions than bacteria. Holland and Coleman (1987) also found that straw was drier, soils were moister and soil temperature was moderated in the surface straw treatments compared to the incorporated straw treatments.

Straw mulch is typically applied to erosion control plantings after road-construction at a rate of 4,500 kg/ha (4,000 lbs/acre) (Haynes personal communication, Kay 1978, Barnett et al. 1967). Wheat and barley straws have been the most easily obtainable and most widely used straw mulch in the past. However, there are now several alternatives to wheat and barley straw available. Rice straw is abundant since burning of rice fields post-harvest has been reduced in the Central Valley of California (Pal and Broadbent 1975). Use of rice straw for erosion control would provide a valuable market for this agricultural by-product and, indirectly help improve air quality through reduced burning. Rice straw may also be preferable to wheat or barley straw for revegetation because it and its associated weed flora are adapted to flooded conditions. As recognized by Clary (1983), these wetland plants may compete significantly less with species seeded for erosion control than wheat, barley and their associated dryland weeds because they are less likely to survive under typical upland revegetation conditions.

However, at least one revegetation specialist has reported poor performance of native perennial grasses when rice straw mulch is applied after seeding (Scott Stewart personal communication). Because of its high silica content (Nassar 1999) rice may decompose less quickly than other types of straw. This may, in turn, result in reduced nitrogen immobilization compared to more labile materials (Singer and Munns 1987). Relatively more nitrogen may be available under rice straw mulch in the first year after application than other types of straw mulch that decompose more readily. In addition, slower decomposition of rice straw may protect the soil surface for a longer period of time than other types of straw mulch.

Rice straw may have negative effects on the growth of other plants because it contains phytotoxic compounds. The allelopathic (i.e. effects on the growth of plants mediated by plant-produced chemicals) potential of different accessions of rice varies and is reduced in cultivars that have been subjected to selection for yield or other factors (Olofsdotter et al. 1995). Most allelochemicals are released during rice germination and early growth, they are also present in straw (Olofsdotter et al. 1995). These compounds can be extracted by water and their phytotoxicity is greater in extracts from a mixture of soil, straw and fertilizer than soil and straw mixtures, soil and fertilizer mixtures or soil alone (Chou 1981). Other straws, including oat, wheat and barley, have also been shown to have allelopathic effects on *Rubus idaeus* (red raspberry) (Jobidon et al. 1989a), but no effect on black spruce seedlings (Jobidon 1989b).

Rice straw also has greater loft than other types of straws, resulting in a thicker, less dense layer for a given weight of rice straw. Because of this, it is typically specified at the lower rate of 3,375 - 3,940 kg/ha (3,000 - 3,500 lbs/acre) than other types of straw (John Haynes personal communication).

Now that native perennial grass seed is being produced commercially, straws of these species have become available for erosion control projects. One of the benefits of using these straws is that volunteers of the straw species can contribute to the stand of desirable vegetation. It is also possible that native grasses have evolved to grow best under the vegetation of their own species or other native species. They may benefit from the particular light, nutrient and chemical environment created by native grass straws, but this hypothesis has not been investigated. Native grasses, when used as straw mulch, have the disadvantage of being upland species like wheat and barley. The weed flora contained in their straws is more likely to be adapted to erosion control planting sites and may compete significantly with the seeded species, although Clary (1983) noted that native grass straw may minimize weed problems.

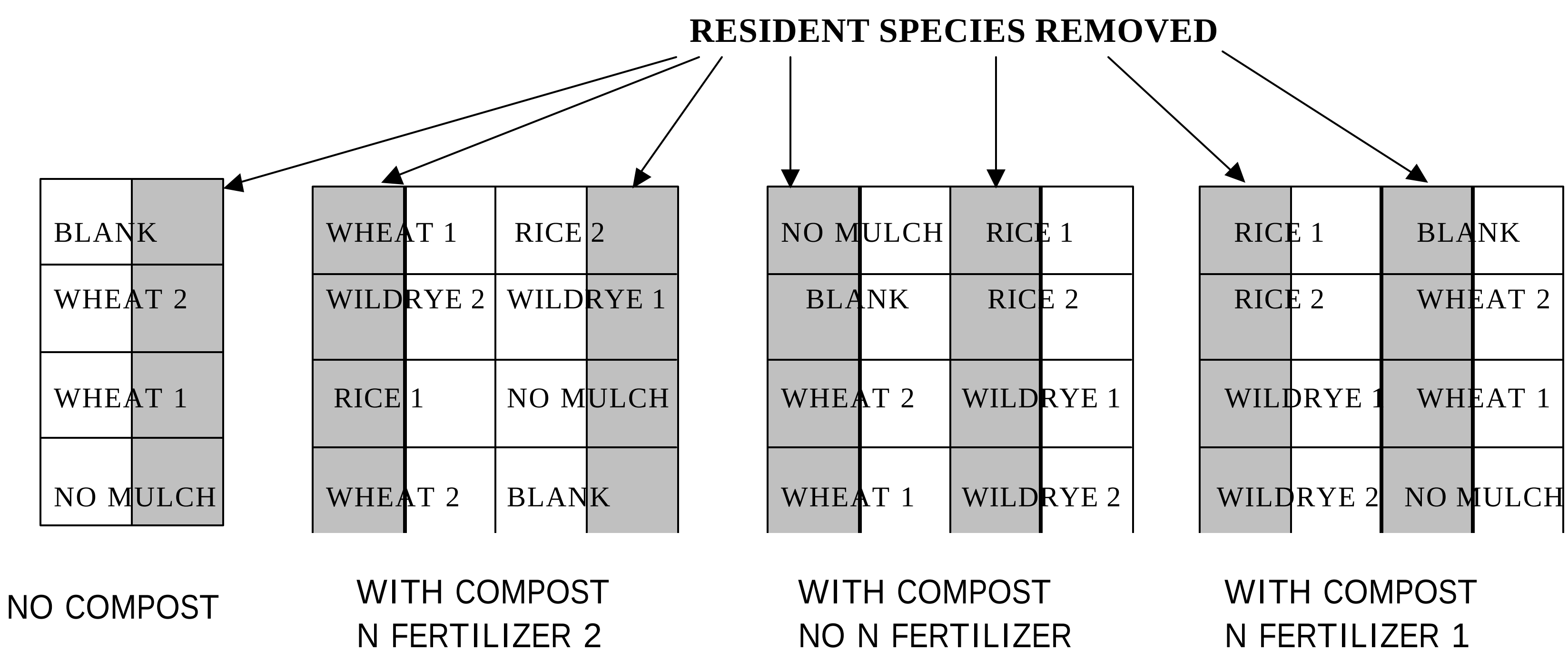
In this experiment, we investigated the effects of (1) soil amendments including low nitrogen availability compost and slow release synthetic nitrogen fertilizer and (2) straw mulch application, including different applications rate and straw types, on the establishment and growth of a seeded mixture of California native perennial grasses and resident vegetation. We designed the experiment to gain insight into the relative advantages these cultural practices gave weeds and seeded species in order to develop recommendations that will maximize benefits to the seeded species and minimize those to weeds.

METHODS

Site description

The experiment was conducted in Yolo County, California on Corning gravelly loam soil from fall 1997 through spring 1998 (Photo 1). Concentrations of nitrate in soil samples from the experimental site were 2 ppm at 0-10 cm and 9 ppm at 20-30 cm (Brown et al. 1998). The experiment was an incomplete split-split block design with five blocks. The main plot factor was soil amendment level. Straw mulch treatments (low and high-levels of wheat, rice and California native perennial grass straw [*Elymus glaucus* Buckley]) were completely randomized within each of the compost treatments as the split-plot factor. Each strip of plots was then divided in half and weed control was either applied or not as the split-block treatment (Figure 1). There was also a control without compost, which did not include nitrogen fertilizer amendment but included the other fertilizers added to the compost treatments. In this control the only split plot factors

Figure 1. Layout of experimental treatments.



included were no-mulch and low and high wheat straw, making the experiment an incomplete factorial design. Randomization of the no-compost control was restricted to the northern half of the experiment area because of the locations of beds in the southern half that had not been prepared for seeding.

Precipitation

The wet season for 1998 began in the fall of 1997 with 111.0 mm of rain falling in November, about 150% of the thirty-year average. The experiment is shown in Photo 4 on 20 November 1997, after initial germination and in Photo 5 on 11 November 1998, at the beginning of the second growing season. Rainfall for December 1997 and January 1998 were close to the average, but precipitation was well above average for February (297.94 mm, 410% of the thirty year average) and May (59.44 mm, 835% of the thirty year average). Precipitation was below average for March (47.24 mm, 70% of the thirty year average). Overall during 1998, 565.15 mm of rain fell, 123% of the thirty-year average. This year was an above normal rainfall year and water availability was extended due to considerable rainfall late in the season. The pattern of rainfall during the critical period for germination of the perennial grass seeds was favorable for establishment. The first precipitation after seeding fell in November and was very consistent; there were no more than two days without rain after the first rainfall was measured that month. In December, there were four to six days between rainfall events, except for one 13-day drought. In January and February, there was one nine-day drought, otherwise only one to three days between storms.

Soil preparation

The experimental area was sprinkler irrigated September 9-16, 1997. The area was watered for 12 hours (7/64 " nozzles, approximately 35 psi, 2.05 gpm) for a total of 6.42 gal/ft^2 (liter/m^2). On September 25, 1997 the existing beds (152 cm or 60 inches wide) were harrowed and reformed using a spring-tooth harrow with shovels mounted on a tractor. Due to the configuration of the tractor implement which harrowed three beds at a time, and in order to leave beds between treatments unharrowed to preserve established native grasses growing there, the two beds in the middle of each compost treatment were harrowed twice as many times as the two beds on the outer edge. Beds were harrowed to as equally fine soil structure as possible and to a depth of 10 cm. This required 5 passes with the tractor (the two inner beds on each set of four beds for each compost treatment received 10 passes). The four northern beds were not moist enough to harrow to 10 cm so they were further irrigated September 25-27, 1997 (7/64 " nozzles, approximately 35 psi, 45 hours, 2.05 gpm). 12.04 gal/ft^2 was applied. On October 10, 1997 these beds were harrowed several times until of comparable consistency to other beds. Remaining beds to the south were harrowed once more on the same date.

Compost

Before soil amendments were applied, soils contained on average 9.65 ± 1.11 kg extractable (i.e. immediately available) nitrogen per hectare and 45.77 ± 1.73 kg mineralizable (i.e. available over a period of weeks to months) nitrogen. The compost was a municipal biosolids and greenwaste product (Hydropost, Organics International, Irvine, CA, U.S.A.). Compost was amended with available phosphate (1.90 %) from triple superphosphate, soluble potassium phosphate (3.34 %), sulfur (3.34 %), and magnesium (1.67 %) from potassium magnesium sulphate ($KMgSO_4$ 0:0:22). These nutrients were also added at the same rate to the no compost control treatment. 0.97 % and 1.92 % nitrogen from equal weights of the slow release nitrogen fertilizers isobutylidene diurea (IBDU) and urea-formaldehyde were added to compost to create low and high nitrogen level treatments, respectively. This corresponds to 15.48 kg N/ha (13.73 lb N/acre) and 31.43 kg N/ha (27.89 lb N/acre) for the low and high nitrogen levels, respectively. Amended compost was applied by hand at a rate of 91.4 m^3/ha (48.4 yrd^3 per acre) and rototilled into soil to the depth of 2.54-10 cm (1-4 inches). The compost itself contained approximately 1.65 % N (Claassen and Hogan 1998), so contributed no more than 878 kg N/ha (782 lb N/acre), although no more than about 128 kg N/ha (114 lb N/acre) would probably become available to plants (see below). A third compost treatment included no nitrogen fertilizer, containing only phosphate, potassium, sulfur and magnesium at the same final rates.In incubations described in Claassen and Hogan (1998), the total nitrogen content, the amount of nitrogen released and its rate of release were determined for different soil amendments mixed with soil substrate over an 18 week period. In this study, a wide variety of soil amendments including highly soluble forms of nitrogen, slow release chemical formulations and organic matter based blends were compared. Hydropost had relatively low cumulative nitrogen release of 14.56 % over a four-month incubation and slow nitrogen release rates of 0.15 % between the 12^{th} and 18^{th} weeks of the incubation. In similar tests, IBDU had cumulative nitrogen release of 60.97 % and a monthly release rate of 2.73 %, while urea formaldehyde had cumulative nitrogen release of 34.80 % and monthly release rate of 1.36 %.

Seeding

A mixture of three species of California native perennial grasses was seeded on October 16, 1997 using a wildflower broadcast seeder (Truax Company, Inc., 3609 Vera Cruz Avenue North, Minneapolis, Minnesota 55422), followed with chains to cover the seed and a ring roller to compact the soil. The species included were *Melica californica* Scribner (151pure live seeds/m^2,14 seeds/ft^2)(from Fisk Creek in the Cache Creek watershed), *Nassella pulchra* (A. Hitchc.) Barkworth (54 seeds/m^2, 5 seeds/ft^2)(from the Stone Ranch, Yolo County, CA), and *Poa secunda* ssp. *secunda* (J.S. Presl.) (872 seeds/m^2, 81 seeds/ft^2)(from Fisk Creek) (Table 1).

Mulch

Straw of *Triticum aestivum* L. (wheat), *Oryza sativa* L. (rice), and the California native perennial grass *Elymus glaucus* Buckley (blue wildrye) was applied at two different levels, 3,375 kg/ha (3,000 lbs/acre) and 5,625 kg/ha (5,000 lbs/acre). The standard prescription for straw is 4,000 lb/acre. Mulch was first applied on October 21-22, 1997 (Photo 2 on 3). Straw was weighed in plastic garbage bags using an Ohaus spring scale (accurate to the nearest 100g) and spread evenly by hand over each 4.67 m^2 plot. Also on that day, an irrigation ditch overflowed, flooding the furrow between the 2nd and 3rd beds from the south edge of the experiment and making irrigation of the entire experiment necessary. In order to keep moisture levels comparable throughout the experiment, sprinkler irrigation was initiated on October 23, 1997.

Table 1. Native perennial grass mixtures seeding densities.

Species	**Live seeds/ft^2**	**Live seeds/m^2**	**Live seeds/lb**	**Live seeds/kg**	**lb/ft^2**	**kg/m^2**	**lb/acre**	**kg/ha**
Melica californica	14	150.64	255,787	562,731	$5.47 * 10^{-5}$	$2.68 * 10^{-4}$	2.38	2.68
Nassella pulchra	5	53.8	45,253	99,557	$1.10 * 10^{-4}$	$5.42 * 10^{-4}$	4.79	5.42
Poa secunda ssp. *secunda*	81	871.56	531,149	1,168,528	$1.52 * 10^{-4}$	$7.46 * 10^{-4}$	6.62	7.46
Total	100	1076			$3.17 * 10^{-4}$	$1.6 * 10^{-3}$	13.79	15.54

The irrigation ditch overflowed again on October 25, 1997 flooding the furrows between the 2nd and 3rd beds, and 3rd and 4th furrows. On October 24, 1997 a 25 mph north wind with 40 mph gusts blew some or all of the straw off of the treatment plots. Not knowing the extent to which different treatments had been affected, all straw was raked from the plots by hand on October 27, 1997. Ability to clear mulch was variable due to the muddy conditions in the three southern-most beds caused by the irrigation ditch overflow. Fresh straw mulch was applied on October 28, 1997 and secured by covering it with plastic bird netting (1.9 cm, 0.75 inch squares) tacked down with six inch pieces of wire bent in half. A good deal of seed from mulch species, especially wheat, was visible after straw removal. As a result of applying straw twice and being unable to remove the seed that fell out of the straw first applied, the seed load of mulch and weed species will be greater than if straw had been applied only once.

Weed control

Half of each compost, nitrogen, and mulch treatment combination was assigned to a weeding treatment. The treatment was applied in a strip across the different mulch treatments within each compost and fertilizer level (the split-plot treatment combinations). Because the weeding treatment was not randomized for each mulch level this is a split block factor. Plots assigned the no weed treatment were sprayed with Banvel February 28, 1998 at 1.0 a.i. kg/ha (0.91 a.i. lb/acre). Banvel is a broadleaf specific herbicide that also killed the monocot *Juncus bufonius*, a common weed in the experiment. Species that were not seeded or were not volunteers from the mulch species in each plot were removed by hand April 7-8 and May 15, 1998.

Monitoring

Monitoring of the experiment began May 5, 1998. A 0.1 m^2 circular quadrat was place in the center of each 2.3 m^2 plot (1.5 m X 1.5 m, 5 ft X 5 ft). The non-seeded, non-mulch species (weeds) providing cover and representing at least 80% of the biomass in the quadrat were recorded. The aboveground biomass of weeds and mulch species were clipped and separated into annual grasses, dicots, other moncots and mulch species. The number of seedlings of each of the seeded species rooted within the quadrat were counted. Three individuals of each of the seeded species were measured in order to make non-destructive estimates of biomass. Biomass estimates were based in regressions that related non-destructive measures such as height and basal length and width to biomass using BMDP New System version 1.0 (BMDP Statistical Software, Inc., Los Angeles, California). Regressions were developed for each species and each phenological stage (i.e. vegetative or flowering) and included the range of plant sizes sampled during monitoring.

Weed and mulch biomass samples were kept cool in the field by placing them in an ice chest with frozen ice packs. At the end of each day, the biomass samples were dried at 105 °C for 1 hr. then 60-65 for 24 hrs. Dried samples were cooled then weighed.

Individual *M. californica* and *N. pulchra* plants were harvested on 22 or 26 May 1998 for tissue nutrient content analyses. Within high mulch level treatments, four individuals from blocks I and II and two individuals from blocks III, IV and V were collected from each treatment combination plot and pooled in a single sample. Harvested plants were kept cool until the end of the day when they were placed in a 40 °C oven and dried to constant weight (48 or 96 hours). Leaf tissue (no crowns) was ground and total carbon and nitrogen determined using Carlo Erba NA 1500 (dry combustion, gas chromatography, thermal conductivity detection; Dumas 1831).

Data analysis

The experiment was analyzed in two parts using analysis of variance (ANOVA). All treatments that included compost were included in a single analysis to evaluate the effects of nitrogen fertilizer and mulch level and type. In a second analysis, the mulch treatments without compost were compared to the corresponding mulch treatments that included compost in order to evaluate the effect of compost. The effects of no-mulch and two levels of wheat mulch were also evaluated in this analysis. The effects of weeds and the interactions between weeds and other factors were evaluated in both analyses.

The raw data did not meet assumptions of ANOVA, in particular, the variances were not equal. Log transformation of the data corrected this problem for a few of the response variables, but not for most of them. As a result, the raw data were ranked and the ranks were analyzed, a method that does not require variances to be equal and is generally considered to be more conservative (i.e. less likely to detect a true difference) (Conover and Iman 1981, Hora and Conover 1984, Iman et al. 1984). The rank transformed analysis is somewhat controversial because there may be problems detecting significant statistical interactions (Seaman et al. 1994). However, a simulation study by Pirie and Rauch (1984) indicated that the rank method is more powerful than the standard approach when data are not distributed ideally, even for detecting interactions. Results based on ranked data are reported except for percent carbon and nitrogen for *Nassella pulchra* for which the untransformed data were analyzed. Reported probability levels (*P* values) are for ANOVA unless specified otherwise (e.g. linear contrast or Tukey's Studentized Range Test).

Differences between mulch treatment means were determined using planned linear contrasts that compared (1) the no-mulch control to the mean of all other mulch treatments, (2) the no-mulch control to the mean of the low-level of the three mulch types, (3) the no-mulch control to the mean of the high-level of the three mulch types, (4) the mean of both levels of rice straw to the mean of both levels of wheat and blue wildrye straw, (5) the low-level of rice straw to the mean of the low-levels of wheat and blue wildrye straws, (6) the high-level of rice straw to the mean of the high-levels of wheat and blue wildrye straws and contrasts analogous to (4), (5) and (6) with blue wildrye straw in place of rice straw. In some cases, Tukey's Studentized Range Test was used for post-hoc mean separation. Analyses were performed with SAS for Windows version 6.10 and 6.12 (SAS Institute, Cary, North Carolina, U.S.A.).

RESULTS

Compost effects

In this section we present the results of the comparison of the two compost treatments (with and without compost) without nitrogen fertilizer and selected mulch levels (low wheat straw, high wheat straw and no-mulch).

Mixture of perennial grasses and individual species

The density and biomass of the perennial grass mixture (averaged across all species) were not affected by addition of compost (without nitrogen fertilizer) (P = 0.54 and 0.22, respectively). There was no effect of compost, mulch or weeds on *Poa* and

Nassella densities ($P > 0.05$). *Melica*, on the other hand, had higher densities with mulch than without it ($P = 0.01$) for this group of treatments. Growth in the plots without compost are shown in Photo 8 and can be compared to Photo 9 to which wheat straw was applied and Photo 10 to which compost but no mulch was added.

Compost and mulch treatments had no effect on *Poa* biomass, but this species tended to produce more biomass when weeds were removed (9.4 $\pm$ 1.1 g/m^2) than in the presence of weeds (6.6 $\pm$ 0.8 g/m^2) ($P = 0.06$). This response to weeds was not observed when the treatments that included compost and nitrogen fertilizer were considered. Like *Poa*, the biomass of *Melica* was unaffected by compost. However, *Melica* differed from both *Poa* and *Nassella* in that it responded to mulch treatments ($P = 0.02$) and produced more biomass at the high-level of wheat mulch (2.4 $\pm$ 0.3 g/m^2) than without mulch (1.3 $\pm$ 0.2 g/m^2) (Tukey's Studentized Range $P < 0.05$). Like *Poa*, *Melica* produced more biomass when weeds were removed ($P = 0.04$) in these treatment combinations. However, *Nassella* biomass was not affected by the presence of weeds ($P = 0.39$) and was greater with compost than without it ($P = 0.02$). The response of *Nassella* to compost depended on mulch level ($P = 0.02$) (Figure 2). *Nassella* biomass was higher with compost than without compost when neither mulch nor nitrogen fertilizer was applied, but there was little difference between the two compost treatments with either wheat straw levels. Mulch appeared to eliminate the benefit of compost for *Nassella*. This result suggests that straw mulch immobilized nitrogen, making it less available to *Nassella* plants, or that wheat straw had a negative effect on *Nassella* through allelopathy (Jobidon et al. 1989a, 1989b), or both.

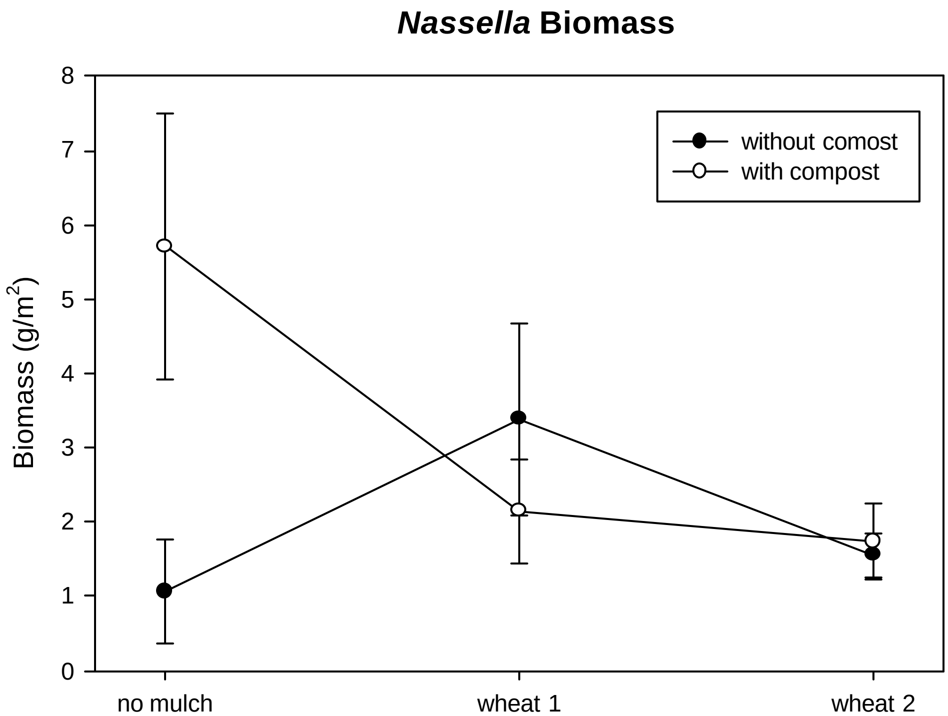


Figure 2. Biomass produced by *Nassella* with different mulch treatments depended upon whether or not compost had been applied. Wheat 1 treatment was 3,375 kg/ha; wheat 2 treatment was 5,625 kg/ha. The mean ± the standard error of the mean is plotted.

Weeds

There was over twice as much weed biomass in the treatment with compost (333.6 ± 66.3 g/m^2) than the treatment without compost (143.0 ± 29.5 g/m^2) ($P = 0.008$).

Nitrogen and mulch effects

In this section, we compare treatments that received compost, the three slow-release nitrogen fertilizer treatments (none, low and high) and seven mulch treatments (two levels each of three types of straw plus the no-mulch control). Samples of each of the treatments can be compared in Photos 11 through 19.

Mixture of perennial grasses and individual species

In an analysis of the plots that received compost and varying levels of nitrogen fertilizer, we found no effects of fertilizer, mulch or weeds on the density of the mixture of perennial grasses (P = 0.64, 0.69 and 0.17, respectively). Photos 6 and 7 illustrate that there was little difference in initial germination between plots with and without mulch. However, there was a significant interaction between mulch and weeds ($P = 0.02$) (Figure 3). The density of perennial grasses depended upon which straw mulch was applied, at which level and whether or not weeds were removed. These varied responses cancelled each other out so that there was no overall effect of either mulch or weeds alone.

When the treatments that included compost and varying levels of nitrogen fertilizer were considered, *Melica* response to mulch was marginally insignificant (P =

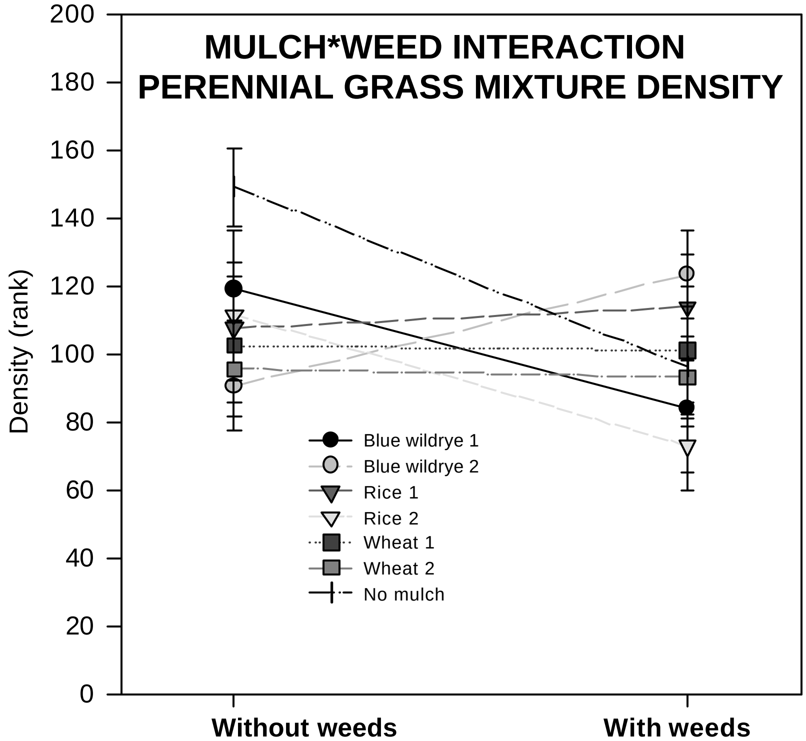


Figure 3. Changes in the density of the perennial grass mixture in response to weeds depended upon mulch treatment. Straw mulch was applie at 3,375 kg/ha in level 1 and 5,625 kg/ha in level 2. Means ± standard error of the mean are plotted.

Nassella

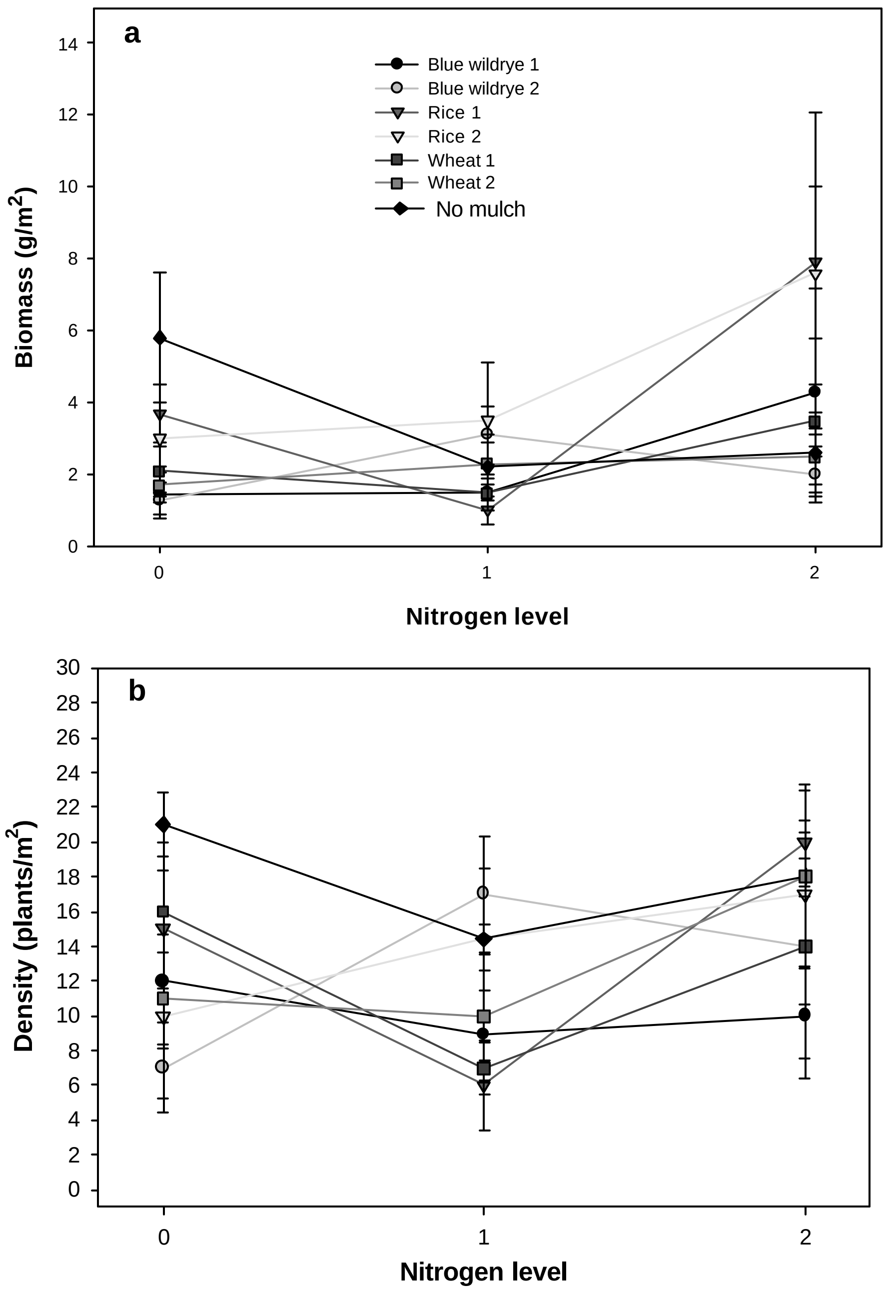


Figure 4. Response of *Poa* biomass and density to weeds depended upon mulch treatment. Mulch 1 = 3,375 kg/ha, mulch 2 = 5,625 kg/ha (mean ± standard error of the mean)

between mulch and nitrogen level for *Nassella* density (P = 0.01) (Figure 4b), meaning that the response of *Nassella* density to nitrogen depended upon which straw mulch had been applied. Without nitrogen added, the highest densities were in the no-mulch treatment and lowest in the high-level mulch treatments, with the low-level mulch treatments intermediate. At the low nitrogen level, *Nassella* densities were greater in the no-mulch and high-level mulch treatments than the low-level mulch treatments. At the high nitrogen level, the high-level mulch treatments were interspersed with the other mulch treatments. This patterns hints that addition of nitrogen fertilizer reduced a negative effect that high mulch levels may have had on seeded perennial grass densities.

We also found that *Poa* and *Melica* densities were increased by the removal of weeds (P = 0.02 and 0.0009, respectively) (Table 3).

There was a strong effect of mulch treatments on the biomass of the perennial grass mixture (P = 0.0004) (Table 4) when all mulch types and amounts, including the control without mulch, were compared (all plots in the comparison received compost). Surprisingly, the differences were not between plots with and without mulch, but between the types and amounts of mulch applied. There was no difference between plots with mulch and plots without mulch (linear contrast P = 0.17), plots with the low-level of mulch and plots without mulch (linear contrast P = 0.24), or plots with the high-level of mulch and plots without mulch (linear contrast P = 0.17). Perennial grasses produced the most biomass in rice straw treatments compared to the average of the other straw mulch treatments (i.e. the average in the rice treatments was greater than the average across the other mulch treatments, excluding the control without mulch) (linear contrast P =

Table 2. Densities of individual perennial grass species in different mulch treatments. Values are means ± standard error of the mean. N is the number of samples.

Mulch Type	*Melica*		*Nassella*		*Poa*	
	N	**Density (plants/m^2)**	**N**	**Density (plants/m^2)**	**N**	**Density (plants/m^2)**
0	29	35.5 ± 6.1	29	17.9 ± 3.9	29	287.6 ± 23.8
Blue wildrye 1	29	46.5 ± 5.7	29	10.3 ± 1.9	29	234.5 ± 26.3
Blue wildrye 2	30	54.3 ± 5.8	30	12.7 ± 2.6	30	231.3 ± 16.1
Rice 1	30	55.0 ± 5.5	30	13.7 ± 2.0	30	252.7 ± 21.8
Rice 2	29	62.8 ± 6.9	29	13.8 ± 02.5	29	200.0 ± 16.1
Wheat 1	30	58.3 ± 7.6	30	12.3 ± 1.9	30	231.0 ± 22.4
Wheat 2	30	62.0 ± 6.0	30	13.0 ± 2.2	30	203.3 ± 14.1

Table 3. Densities of individual perennial grass species in different weed treatments. Values are means ± standard error of the mean. Weed treatment means within species followed by an asterisk are significantly different based on planned linear contrasts ($P < 0.05$). N is the number of samples.

Treatment	*Melica*		*Nassella*		*Poa*	
	N	**Density (plants/m^2)**	**N**	**Density (plants/m^2)**	**N**	**Density (plants/m^2)**
With Weeds	102	47.7 ± 3.3 *	102	12.2 ± 1.2	102	25.18 ± 1.02 *
Without Weeds	105	59.2 ± 3.2	105	14.5 ± 1.5	105	21.72 ± 1.17

Table 4. Biomass of perennial grasses for mulch treatments. Straw was applied at 3,000 lbs/acre for level 1 is and 5,000 lbs/acre for level 2. N is the number of samples.

Mulch Type	N	Biomass (g/m^2)
0	28	22.4 $\pm$ 3.8
Blue wildrye 1	28	20.9 $\pm$ 5.0
Blue wildrye 2	30	14.6 $\pm$ 1.7
Rice 1	29	35.7 $\pm$ 7.6
Rice 2	29	27.1 $\pm$ 3.6
Wheat 1	30	15.7 $\pm$ 1.7
Wheat 2	30	14.8 $\pm$ 1.1

0.0001). Perennial grass biomass was also greater with rice straw when the low-level of rice straw was compared to the average of the low-levels of wheat and blue wildrye straw (linear contrast *P* = 0.0001) and when the high-level of rice straw was compared to the average of the high-levels of wheat and blue wildrye straw (linear contrast *P* = 0.0005). Perennial grasses produced significantly less biomass in the blue wildrye mulch treatment compared to the average of the other mulch treatments (linear contrast *P* = 0.0007). This was also true when the low-level blue wildrye mulch was compared to the average of the low-level rice and wheat straw (*P* = 0.009) and when the high-level blue wildrye mulch was compared to the average of the high-level rice and wheat straw (*P* = 0.02). Mean biomass of the seeded perennial grass mixture across all treatments was 28.5 $\pm$ 7.0 g/m^2.

Perennial grass biomass increased with increasing nitrogen fertilizer levels (*P* = 0.036). However, the response of perennial grasses to nitrogen fertilizer levels depended upon whether weeds were present or absent. A significant nitrogen fertilizer level by weed interaction indicated this (*P* = 0.02). In treatments receiving compost without nitrogen fertilizer, perennial grasses produced more biomass in the absence of weeds. When nitrogen fertilizer was added, biomass of perennial grasses was similar with and without weeds (Figure 5) suggesting that fertilizer compensated for the competitive effects of weeds.

When the compost treatments with nitrogen fertilizer were considered, there were weak tendencies for *Poa* to produce more biomass with increasing nitrogen fertilizer (P = 0.06) and for its biomass production to vary with mulch treatment (P = 0.09). This species produced more biomass in rice straw treatments compared to the average of the other mulches, and in low and high-level rice straw treatments compared to the means across other mulch treatments at the same levels (linear contrasts P = 0.0001 all levels, 0.002 low-level and 0.01 high-level). This result must be viewed in light of the significant interaction between mulch treatment and weeding for *Poa* biomass (P = 0.02) (Figure 6). Weeding resulted in little difference in *Poa* biomass for most mulch treatments and the no-mulch control. However, *Poa* biomass decreased slightly with weeding for the rice straw treatments. This result is difficult to explain and may have been the result of weeding errors.

Melica biomass was affected by mulch (P = 0.004), but there was no effect of nitrogen level (P = 0.42) or weeds (P = 0.73). *Melica* produced more biomass when mulch was applied, whether comparing the no-mulch treatment to the mean of all other mulch treatments (P = 0.0004), the mean of the low-level mulch treatments (P = 0.01) or the mean of the high-level mulch treatments (P = 0.002). *Melica* produced more biomass in rice straw treatments than other mulches (P = 0.005) and in low-level rice straw treatments compared to the mean of other low-level mulch treatments P = 0.01). *Melica* produced less biomass in blue wildrye straw treatments compared to other mulch treatments (P = 0.006) and in low-level blue wildrye straw treatments compared to other low-level mulch treatments (P = 0.026). According to Tukey's Studentized Range test, *Melica* only produced more biomass than treatments without mulch in the rice straw treatment (P < 0.05).

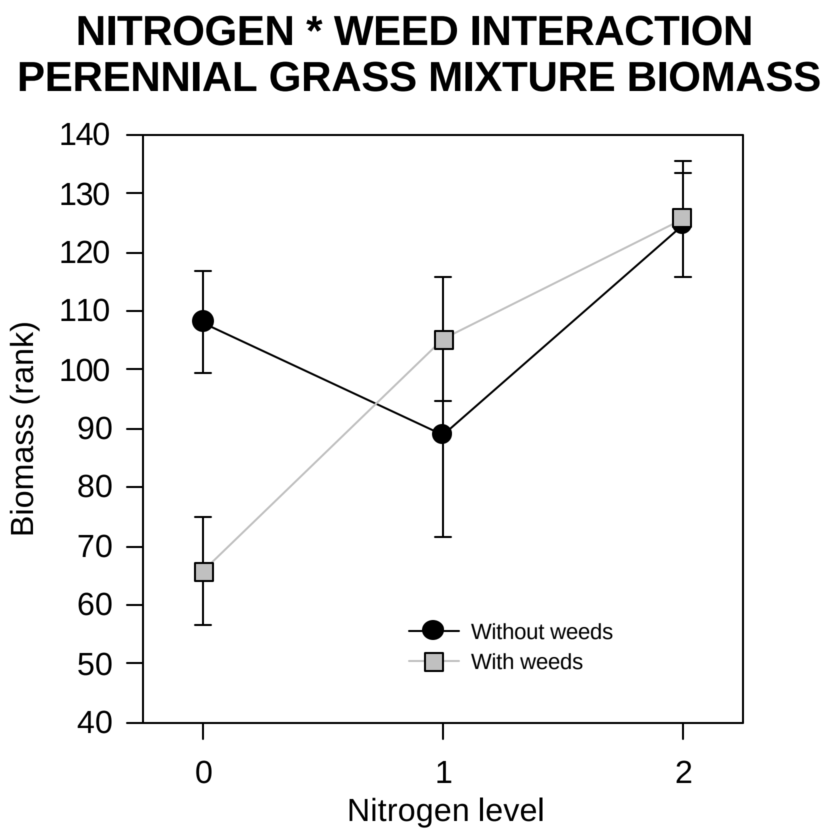


Figure 5. Response of perennial grass biomass to nitrogen fertilizer depended upon the presence or absence of weeds. Ferilizer appears to compensate for the competitive effect of weeds (mean ± standard error of the mean).

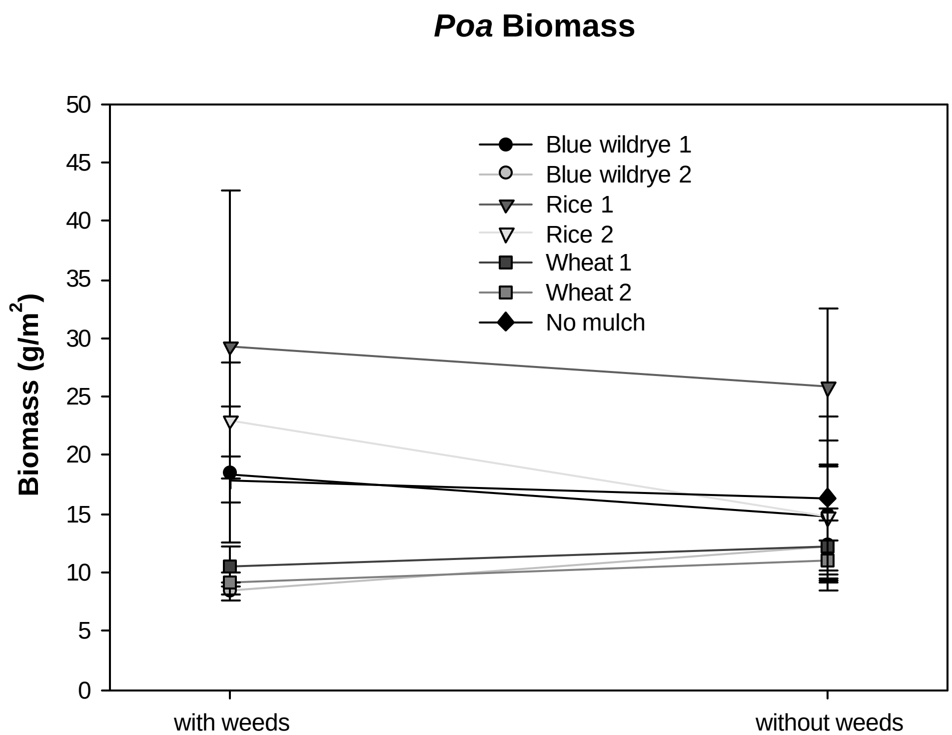


Figure 6. The response of *Poa* biomass to weeds depended upon the mulch treatment. Means ± standard error of the mean are plotted.

Nassella was similar to *Poa* in that it did not respond strongly to mulch treatments (P = 0.08). Like *Melica*, *Nassella* biomass did not respond to nitrogen level alone (P = 0.15). However, *Nassella* response to nitrogen depended upon mulch treatment, indicated by a significant mulch by nitrogen level interaction (P = 0.02) (Figure 4 a). *Nassella* biomass was greatest in the no mulch control when no fertilizer was added. Nassella biomass decreased or remained about the same with increasing nitrogen level in the no-mulch control and with wheat and blue wildrye straws. The most pronounced effect was that *Nassella* biomass increased with increasing nitrogen level with rice straw mulch, suggesting greater nitrogen availability than other mulches.

The relative nitrogen content (% N) is an indication of the nutrient status of a plant and will be higher in plants growing in soils with greater available nitrogen. *Melica* leaf tissue %N responded to type of mulch (P = 0.0497) and was greater in the rice straw treatment (1.64 $\pm$ 0.14 %) (linear contrast P = 0.02) compared to the average of the other mulch types (1.44 $\pm$ 0.07 %). This result should be considered in light of an interaction between mulch type and the presence of weeds. Tissue % N for *Melica* was similar for all mulch types in the presence of weeds. However, in the absence of weeds, tissue % N was highest in rice straw, second highest in wheat straw and lowest in blue wildrye straw, i.e. the strength of the response of *Melica* tissue % N to weeds depended on the type of straw (interaction between mulch and weeds P = 0.02) (Figure 7).

The response of *Nassella* tissue % N to mulch type was marginally insignificant (P = 0.08). However, there was a tendency for *Nassella* tissue % N to be greater in rice straw than the average of wheat and blue wildrye (linear contrast P = 0.045) and lower in blue wildrye than the average of rice and wheat (linear contrast P = 0.036). Carbon to nitrogen ratios (C:N) for *Melica* were affected by mulch type (P = 0.02), but marginally insignificantly for *Nassella* (P = 0.08). *Melica* and *Nassella* C:N were greater with blue wildrye straw compared to the average of rice and wheat straws (linear contrast P = 0.026 and 0.03, respectively) and lower in rice straw than the average of blue wildrye and wheat straws (linear contrast P = 0.0004 and 0.015, respectively).

Melica tissue % N was greater in weeded than unweeded treatments (P = 0.0001 and 0.006, respectively). Similar to *Melica*, *Nassella* tissue % N was greater without weeds than with weeds (*P* = 0.0001). C:N for both species were greater in the presence of weeds than in their absence (*P* = 0.0001 for both).

Nitrogen fertilizer had no significant effect on *Melica* and *Nassella* %N (*P* = 0.35 and 0.42, respectively). There was no effect of nitrogen fertilizer on C:N for either *Melica* or *Nassella* (*P* = 0.56 and 0.12, respectively).

Weeds

The amount of weed biomass produced depended upon the mulch treatment (*P* = 0.04) (Table 5). The biomass of weeds was higher in the no-mulch treatment than the average across the high-level mulch treatments (linear contrast *P* = 0.02). The same but insignificant trend was detected for the no-mulch treatment and the average across all mulch treatments (linear contrast *P* = 0.07). Weed biomass was significantly lower in rice mulch treatments than the average of the other types of mulch (linear contrast *P* = 0.04).

There were no differences in weed biomass between the low-level of rice straw compared to the average of the low-level of wheat and blue wildrye straw treatments (linear contrast *P* = 0.42), but there was significantly less weed biomass produced in the high-level rice straw plots compared to the average of the high-levels of other straw mulches (linear contrast *P* = 0.04). Weed biomass was marginally greater in blue wildrye straw plots compared to the average of the wheat and rice straw plots (linear contrast *P* = 0.05). The biomass of weeds was lower in the no weed treatment

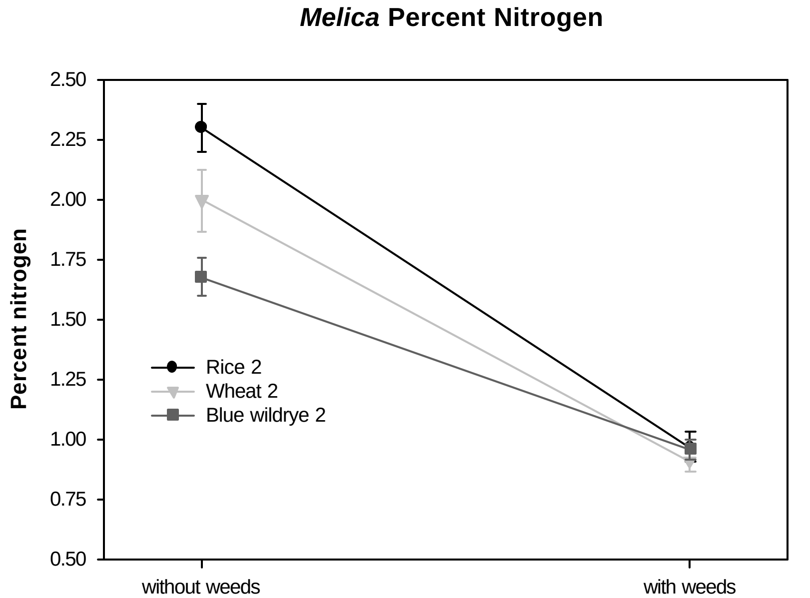


Figure 7. The response of *Melica* percent nitrogen to weeds depended upon the mulch treatment. (mean ± standarde error of the mean)

Table 5. Biomass of weeds for mulch treatments. Straw was applied at 3,000 lbs/acre for level 1 is and 5,000 lbs/acre for level 2. N is the number of samples.

Mulch Type	N	Weed Biomass (g/m^2)
0	29	381.8 ± 74.1
Blue wildrye 1	29	368.8 ± 74.9
Blue wildrye 2	30	296.7 ± 63.6
Rice 1	30	324.5 ± 62.1
Rice 2	29	287.5 ± 70.0
Wheat 1	30	307.9 ± 61.4
Wheat 2	30	316.2 ± 65.6

(16.3 ± 02.1 g/m^2) compared to the plus weed treatment (626.7 ± 26.7 g/m^2) due to weed removal (P = 0.0001), indicating effective treatment application.

Mulch species

We evaluated the biomass production by mulch species in their respective treatment plots (i.e. wheat, rice and blue wildrye plants that volunteered from seed in the straw). Different amounts of biomass were produced by the three mulch species (P = 0.0001) (Table 6). No rice plants grew in the rice mulch plots whereas a moderate amount of wheat and blue wildrye grew in those respective mulch treatments. Planned linear contrasts revealed the following: (1) the high-level mulch plots had greater biomass of mulch species than the no-mulch treatment (P = 0.0001), (2) the high-level of rice mulch had significantly less mulch biomass (i.e. rice) than the average of the other high- level mulch species had of their respective species (linear contrast P = 0.0001), and (3) the high-level of blue wildrye straw produced more biomass than the average of high-level treatments of other mulch types (P = 0.0001). No other planned linear contrasts could be calculated.

Table 6. Biomass of volunteer plants from the respective mulch types for mulch treatments. Straw was applied at 3,000 lbs/acre for level 1 is and 5,000 lbs/acre for level 2. N is the number of samples.

Mulch Type	N	Mulch Biomass (g/m^2)
0	29	0
Blue wildrye 1	29	41.1 ± 6.7
Blue wildrye 2	30	88.9 ± 15.3
Rice 1	28	0
Rice 2	29	0
Wheat 1	28	95.2 ± 15.4
Wheat 2	30	82.9 ± 22.9

The response of mulch species to weeds depended on the mulch type. For the no-mulch treatment and both levels of rice straw, biomass of mulch species was zero for both weeded and unweeded treatments. For both levels of wheat and blue wildrye straw, mulch species biomass was greatest when weeds were not present. These responses resulted in a significant mulch by weed interaction ($P = 0.047$) (Figure 8). This interaction did not cancel out the main effect of weeds on mulch biomass. The amount of biomass produced by mulch species was greater when weeds were removed (56.8 $\pm$ 9.6) than when weeds were present (32.3 $\pm$ 5.1) ($P = 0.01$). Mean biomass of blue wildrye from mulch was 75.0 $\pm$ 9.4 g/m^2, more than two and a half times as large as the seeded perennial grass mixture biomass.

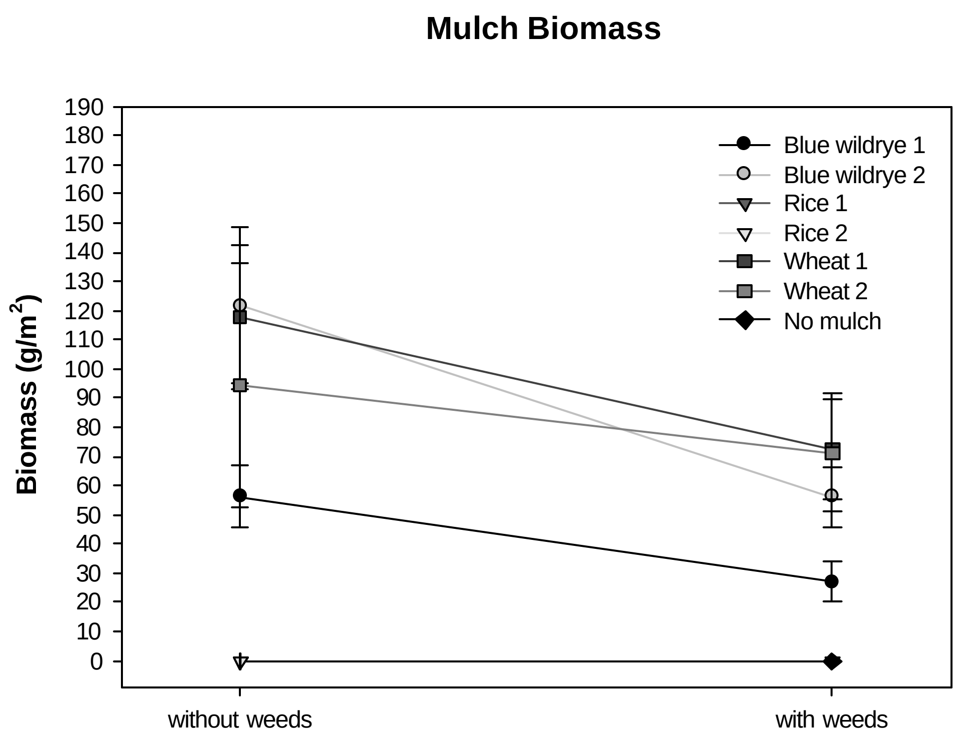


Figure 8. The response of mulch biomass to weeds depended upon the mulch treatment. No mulch and both rice mulch lines are atop one another at 0. Means $\pm$ standard error of the mean are plotted.

DISCUSSION

Effects of compost

Weeds were the only plants that grew larger with compost than without it regardless of whether or not mulch was applied. The response of *Nassella* biomass to compost depended upon mulch treatment, and was greater with compost than without compost if mulch was not applied, but similar in both compost treatments when straw mulch was applied. Adding mulch apparently eliminated the benefit of compost, which may have been due to competition from weeds that were in the straw mulch, immobilization of nitrogen by microbes decomposing the straw, or phytotoxic compounds in the straw, or a combination of the three. Since weed biomass was greatest in the no-mulch control, it is unlikely that weeds introduced with the straw competed with perennial grass seedlings more vigorously than those in the no-mulch treatment. It is more probable that wheat straw resulted in lower nitrogen availability to plants due to immobilization by microbes decomposing the straw or that it had allelopathic effects on the seeded perennial grass seedlings.

Effects of mulch

Even though applying mulch only benefited the growth and establishment of *Melica*, the use of mulch in such plantings should not be abandoned. One reason that we may not have detected a benefit for most species was the climatic conditions of the year. The distribution of rainfall events was very regular and so problems of soil crusting that may have been ameliorated by mulch were not evident. Also, the benefits of mulches to seedling establishment, especially under dry and hot conditions has been shown in many cases (Rahman et al. 1997, Ewing 1997, Abrecht and Bristow 1996, Townend et al. 1996, Byard et al. 1996, Cavero et al. 1996, Kwon et al. 1995).

Mulch suppressed weed growth. Plots with mulch tended to have lower weed biomass, on average, than those without mulch. The means in Table 5 show that weed biomass decreased with increasing mulch. This suggests that mulch suppressed weeds and few weeds were introduced to the site in the straw. Successful native grass restoration and revegetation depends on the use of weed free straw to minimize competition with weedy species.

Application of mulch may also have led to decreased nutrient availability. Nitrogen is immobilized by micro-organisms decomposing the straw, in particular fungi since the straw was not incorporated (Holland and Coleman 1987, Zink and Allen 1998). Our data indicate that the nutrient status (i.e. % N) of the seeded perennial grasses was highest in rice mulch, lowest in blue wildrye mulch and intermediate in wheat mulch. This suggests that rice straw decomposed the most slowly, resulting in less nitrogen immobilization than the other straw species. This nitrogen became available to the perennial grass seedlings as long as there were not weeds present to use it first (Figure 7).

Another possible effect of mulches is suppression of perennial grass growth by phytotoxic compounds contained in the straw, or allelopathy (e.g. Jobidon et al. 1998a). If this mechanism of suppression were at work, we would expect perennial grass biomass or densities, or both, to be lower in mulch treatments than the no-mulch control. Without nitrogen fertilizer, *Nassella* biomass and densities were slightly higher in the no-mulch control than the mulch treatments, but the effect disappeared when nitrogen was added (Figure 4). In addition, some research has shown phytotoxic compounds from rice to be more active in the presence of fertilizer (Chou 1981), which could result in decreased plant growth with added fertilizer. Instead, fertilizer tended to compensate for the negative effects of straw, suggesting alleviation of some of the nitrogen deficit caused by mulch. Furthermore, rice straw appeared to stimulate perennial grass biomass at the high-level of nitrogen (Figure 4a). Densities of the perennial grass mixtures tended to be higher in the no-mulch control than mulch treatments when weeds were removed, but this effect disappeared in the presence of weeds (Figure 3), suggesting competition for resources as a more important determinant of perennial grass success. *Melica* performed better and no perennial grass performed worse in mulch treatments than the no-mulch control. Thus, our results do not suggest that the mulches had allelopathic effects on the perennial grasses.

Effects of mulch type

Perennial grasses performed best under rice straw. Perennial grasses produced more biomass and had better nutrient status (i.e. higher %N and lower C:N) in the rice straw treatment than other mulch treatments. Weed biomass was lower in rice straw than other types of straw and no rice plants volunteered, minimizing competition. These findings appear to be the result of interactions between the effects of mulches on weed growth and volunteers of the mulch species themselves, but may also be affected by the decomposition rates of the different types of straw. Nitrogen from fertilizer may have been immobilized by micro-organisms breaking down more labile wheat and blue wildrye straw (Sarmah and Bordoloi 1994, Zink and Allen 1998). Rice may be a more recalcitrant substrate (Nassar 1999) and less nitrogen may have been tied up in microorganisms making more available to the plants in rice mulch treatments. However, tests of C:N rations in a range of organic materials in Uganda showed that rice had C:N of 20.7 (standard deviation 4.1) and wheat 22.4 (standard deviation 3.1) (Ilukor and Oluka 1995). These values are not greatly different from one another and would probably not lead to differences in decomposition rates and nitrogen immobilization. On the other hand, elevated silica content, which rice has compared to at least some grasses (Nassar 1999) or tough plant cell components such as lignin, could result in decreased decomposition rates and greater nutrient availability to plants with rice straw. Lower nitrogen immobilization by rice straw would explain the apparently stimulatory effect of rice straw on perennial grasses.

In contrast to rice straw, perennial grasses performed worst with blue wildrye straw mulch. This straw treatment had the greatest weed and mulch species amounts, creating the least favorable conditions for survival and growth of the seeded native perennial grasses. This was reflected in lower biomass and poorer nutrient status (i.e. lower %N and higher C:N) for perennial grasses growing in this straw mulch treatment.

Since blue wildrye is a native perennial grass, its success may be desirable. Blue wildrye biomass was over two and a half times as great as the seeded perennial grass mixture. This shows that successful stands of perennial grasses can be established simply by spreading perennial grass straw from which seed has been previously harvested.

Effects of weeds

Weeds generally had a negative effect on perennial grasses, although these responses often involved interactions with other factors we tested. Generally, perennial grass biomass production was lower and nutrient status was worse (lower %N and higher C:N) in the presence of weeds. Weed biomass was over ten-fold the biomass of seeded perennial grasses and revegetation efforts should attempt to minimize weed success.

Response of mulch species to weed removal depended upon mulch type due to the differences between the amounts of each mulch species in its respective straw. Mulch species biomass was greater in treatments without weeds for the straws that had significant volunteers of the mulch species (i.e. blue wildrye and wheat). There was no difference in mulch biomass between unweeded and weeded plots of rice straw and the no-mulch control because there were no volunteer rice plants from rice straw and no mulch species to measure in the control.

Effects of fertilizer

Fertilizer had remarkably little effect on the survival and growth of perennial grasses. It is particularly interesting that fertilizer level did not affect nutrient status of perennial grasses while nutrient status was affected by mulch type. Nitrogen fertilizer level was generally only significant in interactions with other factors (i.e. weeds and mulch). We attribute the responses to fertilizer in part to differences between mulches in growth of weeds and volunteers of the straw species that competed with the seeded species for resources.

Interaction between fertilizer and weeds

Nitrogen fertilizer appeared to compensate for the competitive effects of weeds because perennial grass biomass was greater without weeds when only compost was added and about the same with and without weeds when both nitrogen fertilizer and compost were added. The amount of fertilizer applied at this site, with the particular weed flora and inherent soil fertility, appeared to benefit the perennial grasses without affecting weed biomass significantly. It should be noted that weeds produced more biomass with the addition of compost (128 kg N/ha) than without it, but further fertilization (15.5 and 31 kg N/ha) did not increase their growth. Weeds were apparently able to reach their biomass production potential with the amount of nutrients from only the compost.

Interactions between mulch and weeds

The use of nutrients by weeds and mulch species was the driving force behind the differences we found between mulches. This is evident in the response of *Poa* biomass and *Melica* tissue %N to different mulches in the presence and absence of weeds. *Poa* biomass tended to be greater with rice straw than other straw types. Weeding made little difference in some mulch treatments, but *Poa* biomass increased when weeds were removed from the mulch treatments with the greatest amounts of weeds, i.e. blue wildrye and wheat straws. When weeds were not present, nutrient status of *Melica* was best in rice straw (with no mulch species volunteers and least weed biomass), next best in wheat mulch (intermediate biomass from mulch species volunteers and weeds), and poorest in blue wildrye mulch (greatest biomass from mulch species volunteers and weeds) (Figure 7, Table 5 and Table 6).

CONCLUSIONS

The performance of seeded native perennial grasses was determined by complex interactions between nutrient availability and competition from weeds and volunteer plants from the straw mulch. Performance of perennial grasses in rice straw treatments exceeded that in other types of straw mulch by a large margin. Weeds had important negative effects on the perennial grass mixtures and were most successful in plots with no or low levels of mulch. The positive response of perennial grasses to rice straw mulch and poor performance in blue wildrye straw mulch was primarily due to differences in competition from weeds and volunteer mulch species. In the presence of weeds, perennial grasses benefited from the addition of a slow release nitrogen source with compost while weeds benefited from the addition of compost alone.

RECOMMENDATIONS

1. Use rice straw because it is likely to have fewer weeds adapted to revegetation sites and rice plants are unlikely to volunteer in upland sites. It may result in lower nitrogen immobilization than other types of straw. All of these factors result in higher nutrient availability for the seeded species.
2. Use native straw when establishment of the straw species is desired and if the straw is free of weeds.
3. The performance of native perennial grasses with rice and other straw mulches on very low nutrient soils with varying nitrogen levels should be studied. In these studies, plant nutrient status and available nutrients in the soil should be measured.
4. Apply high carbon content, slow nitrogen release fertilizers to benefit grasses without giving weeds an even bigger advantage.
5. Always use weed free straw

ACKNOWLEDGEMENTS

We would like to thank the many people who made this experiment possible and participated in its success including John Haynes, Victor Claassen, John Anderson, Scott Stewart, Craig Schreiffer, Catherine Wardner, Marcia Haver and many others who maintained the weeding treatments.

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Photo1 – Aerial photograph of experiment site with experimental area outlined in black.

Photo 2 – Spreading straw mulch on treatment plots by hand

Photo 3 – The experiment after being all treatments were applied 22 October 1997

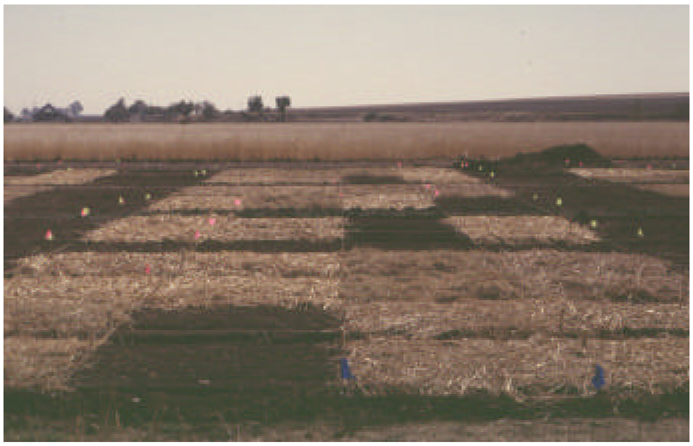


Photo 4 - 20 November 1997 after germination from southeast corner

Photo 5 - 11 November 1998 from northern side

Photo 6 - No mulch control (11/20/97)

Photo 7 - High-level wheat straw (11/20/97)

Photo 8 - No compost, no nitrogen, no mulch, with weeds on right, without weeds on left

Photo 9 - No compost, no nitrogen, low-level wheat, with weeds right, without weeds left

Photo 10 - With compost, no nitrogen, no mulch, with weeds right, without weeds left

Photo 11 - With compost, no nitrogen, low-level wheat mulch, with weeds right, without weeds left

Photo 12 - With compost, no nitrogen, low-level blue wildrye mulch, with weeds on right, without weeds on left

Photo 13 - With compost, no nitrogen, low-level rice mulch, with weeds right, without weeds left

Photo 14 – With compost, low-level nitrogen, low-level wheat mulch, with weeds right, without weeds left

Photo 15 – With compost, low-level nitrogen, low level blue wildrye mulch, with weeds right, without weeds left

Photo 16 – With compost, low-level nitrogen, low-level rice mulch, with weeds right, without weeds left

Photo - 17 With compost, high-level nitrogen, high-level wheat mulch, with weeds left, without weeds right

Photo18 – With compost, high-level nitrogen, high-level blue wildrye mulch, with weeds left, without weeds right

Photo 19 - With compost, high-level nitrogen, high-level rice mulch, with weeds left, without weeds right

IMPLEMENTATION

Implementation of the results of this project within the California Department of Transportation will be accomplished by sending a copy of the final report to the District Deputy Directors of Project Development, District Landscape Architects and Environmental Offices. Additional copies of the final report will be made available from the Caltrans Publication Unit. The availability of the report will be advertised in professional and trade journals.

Findings from this research have already changed Caltrans erosion control specifications by eliminating weed-contaminated straw and encouraging the use of rice straw. The specifications have also been changed to ensure native grass straw is available when it is specified.

CONCLUSIONS AND RECOMMENDATIONS

Based on our experimental results and the findings of others, it is clearly very important to consider the compactibility of the soils on a revegetation site before selecting soil preparation and seeding methods. First, it should be determined whether a compacted layer exists and whether the soil texture, structure and moisture content are conducive to compaction. Second, the feasibility of available seeding methods should be evaluated. When conditions allow the use of a seed drill, our results suggest that this method may be most efficient. Broadcast seeding may be nearly as effective but will require more labor if performed by hand than drill seeding or hydroseeding. If hydoseeding is the most practical option (e.g. due to steep slopes or wet soil), our results suggest that at least 25% greater seeding rates should be used and soil should be decompacted (if warranted) for plant growth levels to equal those of drill or broadcast seeding.

The performance of seeded native perennial grasses was determined by complex interactions between nutrient availability and competition from weeds and volunteer plants from the straw mulch. Performance of perennial grasses in rice straw treatments exceeded that in other types of straw mulch by a large margin. Weeds that were introduced in the straw had important negative effects on the perennial grass mixtures. The positive response of perennial grasses to rice straw mulch and poor performance in blue wildrye straw mulch was primarily due to differences in competition from weeds and volunteer mulch species. Slower decomposition rates of rice straw may also have been a factor in this response. In the presence of weeds, perennial grasses benefited from the addition of slow release nitrogen source with compost while weeds benefited from the addition of compost alone.

1. Use rice straw because it is likely to have fewer weeds adapted to revegetation sites, rice plants are unlikely to volunteer and it has a slow decomposition rate. All of these factors result in higher nutrient availability for the seeded species.

2. Use native straw when the straw species is desirable and if the straw is free of weeds.

3. The performance of native perennial grasses with rice and other straw mulches on very low nutrient soils with varying nitrogen levels should be studied. In these studies, plant nutrient status and available nutrients in the soil should be measured.

4. Apply high carbon content and slow nitrogen release fertilizers.

5. Use weed free straw

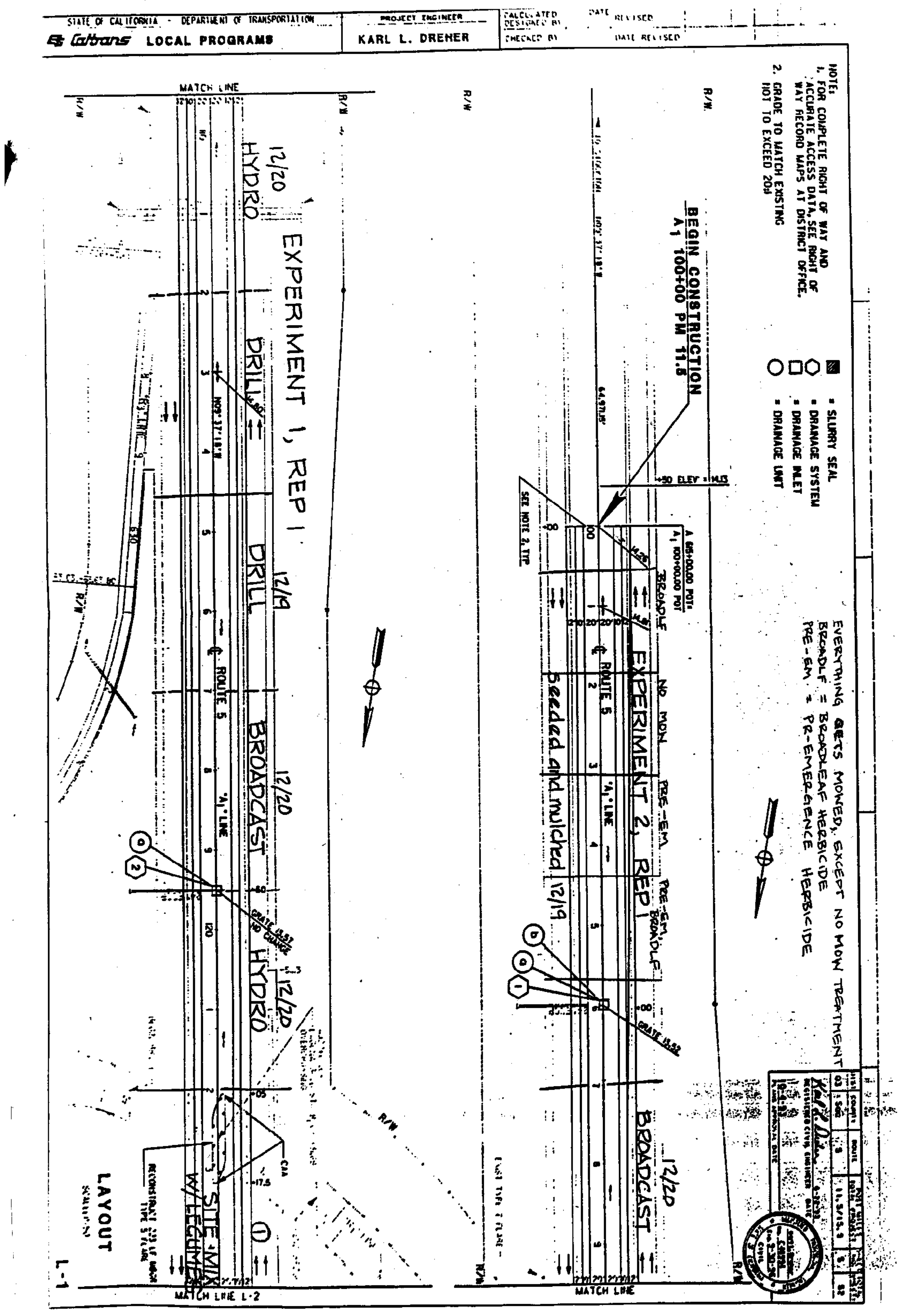
The use of pre-emergence herbicides improved the performance of native perennial grasses and reduced the success of species that were not planted in an unreplicated comparison. The mowing treatment neither benefited the seeded grasses nor reduced the cover of weeds, although we cannot broadly apply our conclusions due to lack of replication and low statistical power. More work needs to be done in order to understand how pre-emergence and post-emergence herbicides and well-timed mowing can be used as tools for management of perennial grasses as seedlings.

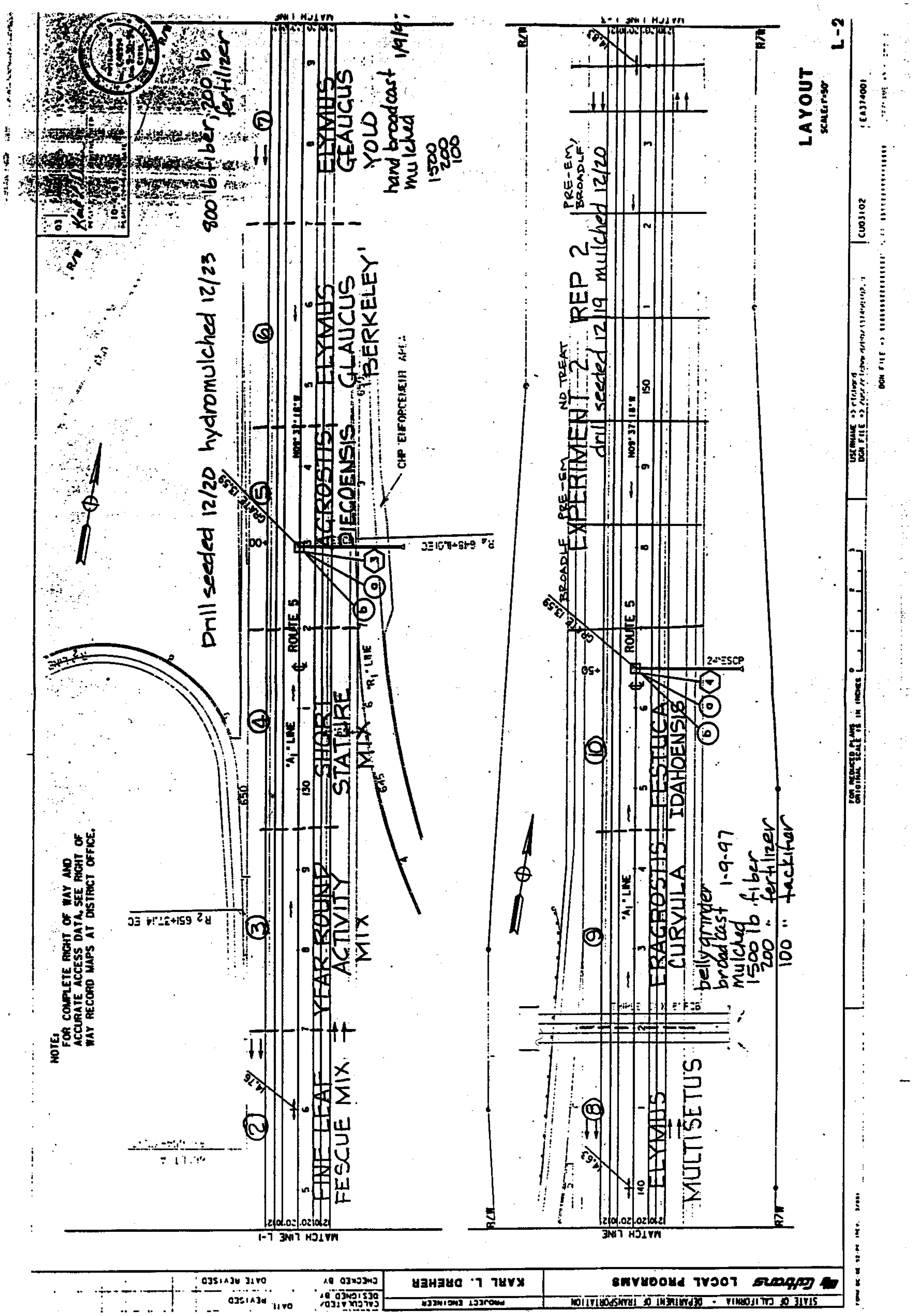
There is still a tremendous need to develop cultural practices for long-term management of perennial grasses on roadsides. The results of this experiment would have provided some good basic information to help fill the gaps in our knowledge about management of perennial grass stands after initial establishment had the experiment been executed as designed. A similar experiment should be conducted in the future. In order to avoid the difficulties experienced in the current experiment, someone with detailed knowledge of the experimental design and rationale should be present at the time of treatment application to confirm treatment locations and levels. Independent contractors might be hired to perform all soil preparation, seeding and maintenance activities. However, this would eliminate the benefits afforded Caltrans maintenance personnel through direct participation in these activities. The involvement of Department of Transportation personnel, at the minimum as advisors, is essential. The relevance of experimental treatments (e.g. specifications for herbicide use) will suffer without their input and advice. However, they should not be expected to apply the treatments or collect the data, unless these activities are recognized as part of their normal workload and responsibilities and are treated that way by their supervisors. We strongly believe that the relevance of the questions addressed and the information learned through any experiment will be transferred into practice most efficiently when Department of Transportation personnel who would utilize the methods tested are intellectually and physically involved in development and execution of the experiment.

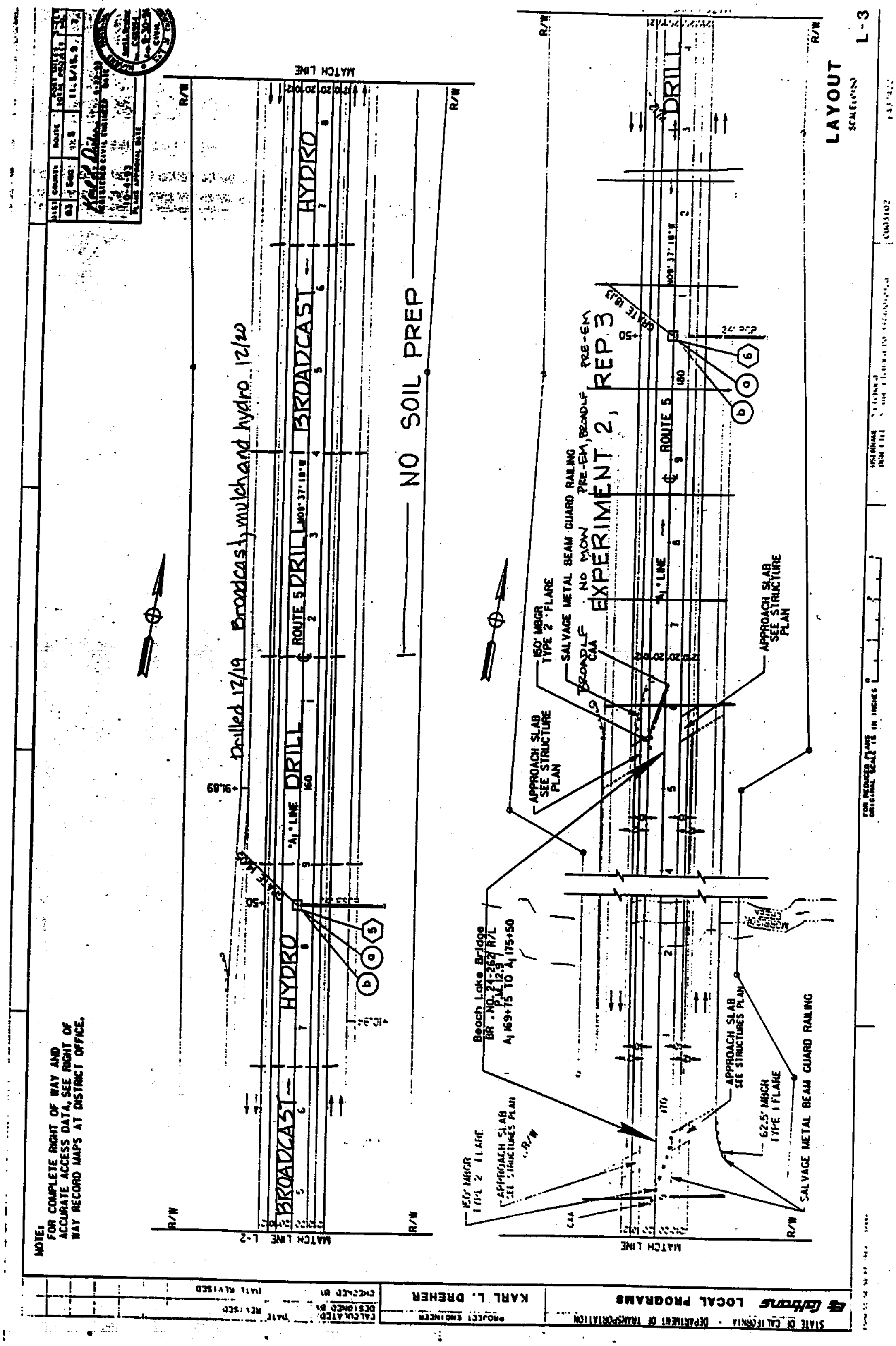
Overall, these experiments have provided a great deal of information that will improve the methods of establishment and growth of native perennial grasses for erosion control plantings. More work remains to be done on soils of different textures and fertility and long-term management methods still need to be tested.

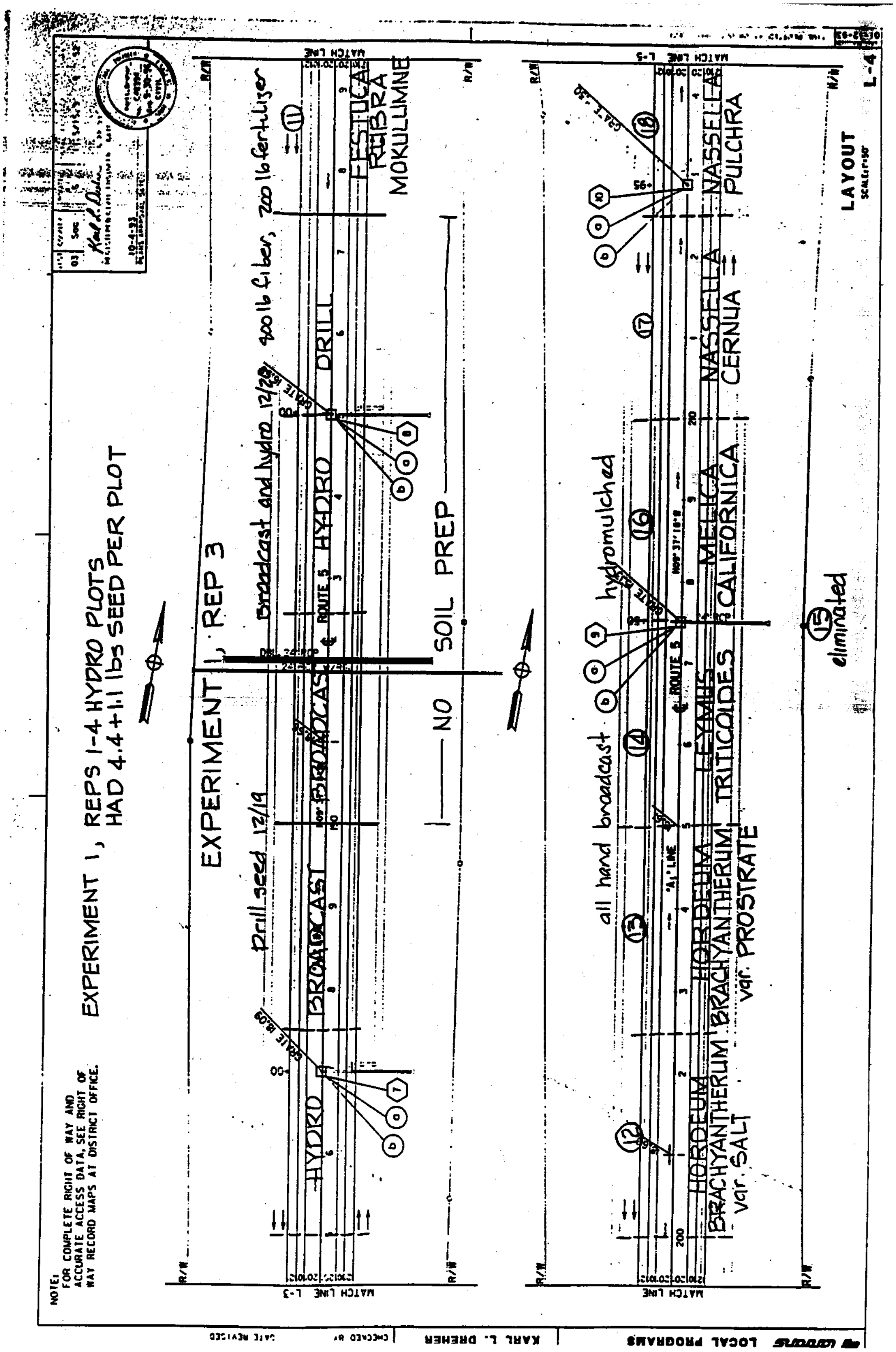
Appendix 1
Project Site Map

Assigned treatments and seed application dates and methods are indicated.

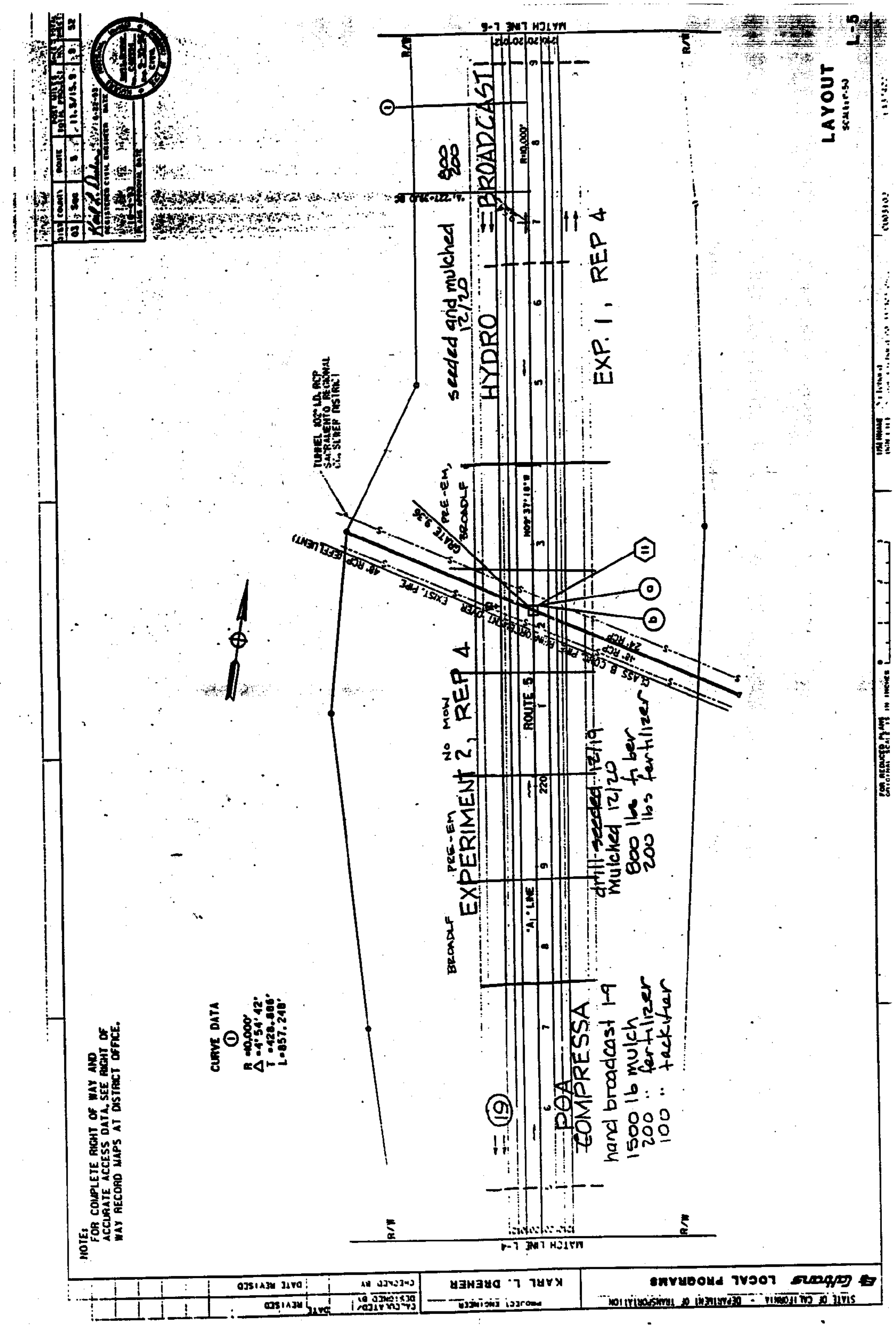

STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION
Caltrans LOCAL PROGRAMS
PROJECT ENGINEER
KARL L. DREHER
NOTE:
1. FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
2. GRADE TO MATCH EXISTING NOT TO EXCEED 20:1
= SLURRY SEAL
= DRAINAGE SYSTEM
= DRAINAGE INLET
= DRAINAGE UNIT
EVERYTHING GETS MOWED, EXCEPT NO MOW TREATMENT
BROADLF = BROADLEAF HERBICIDE
PRE-EM. = PRE-EMERGENCE HERBICIDE
BEGIN CONSTRUCTION
A1 100+00 PM 11.6
EXPERIMENT 2, REP I
NO MOW
PRE-EM.
BROADLF
seeded and mulched 12/19
BROADCAST 12/22
EXPERIMENT 1, REP I
12/20 HYDRO
DRILL
DRILL 12/19
BROADCAST 12/20
HYDRO 12/22
STE-MIX W/LEGUMES
ROUTE 5
"A1" LINE
MATCH LINE
MATCH LINE L-2
LAYOUT
L-1


Drill seeded 12/20 hydromulched 12/23 800 lb fiber, 200 lb fertilizer
FINE LEAF FESCUE MIX
YEAR ROUND ACTIVITY MIX
SHORT STATURE MIX
AGROSTIS DIEGOENSIS
ELYMUS GLAUCUS 'BERKELEY'
ELYMUS GLAUCUS YOLO
hand broadcast mulched
1500
200
100
EXPERIMENT 2 REP 2
drill seeded 12/19 mulched 12/20
PRE-EM BROADLF
NO TREAT
BROADLF PRE-EM
ELYMUS MULTISETUS
ERAGROSTIS CURVULA
FESTUCA IDAHOENSIS
belly grinder broadcast mulched 1-9-97
1500 lb fiber
200 " fertilizer
100 " tackifier
ROUTE 5
MATCH LINE L-1
CHP ENFORCEMENT AREA
NOTE: FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
KARL L. DREHER
LOCAL PROGRAMS
STATE OF CALIFORNIA · DEPARTMENT OF TRANSPORTATION
LAYOUT
L-2

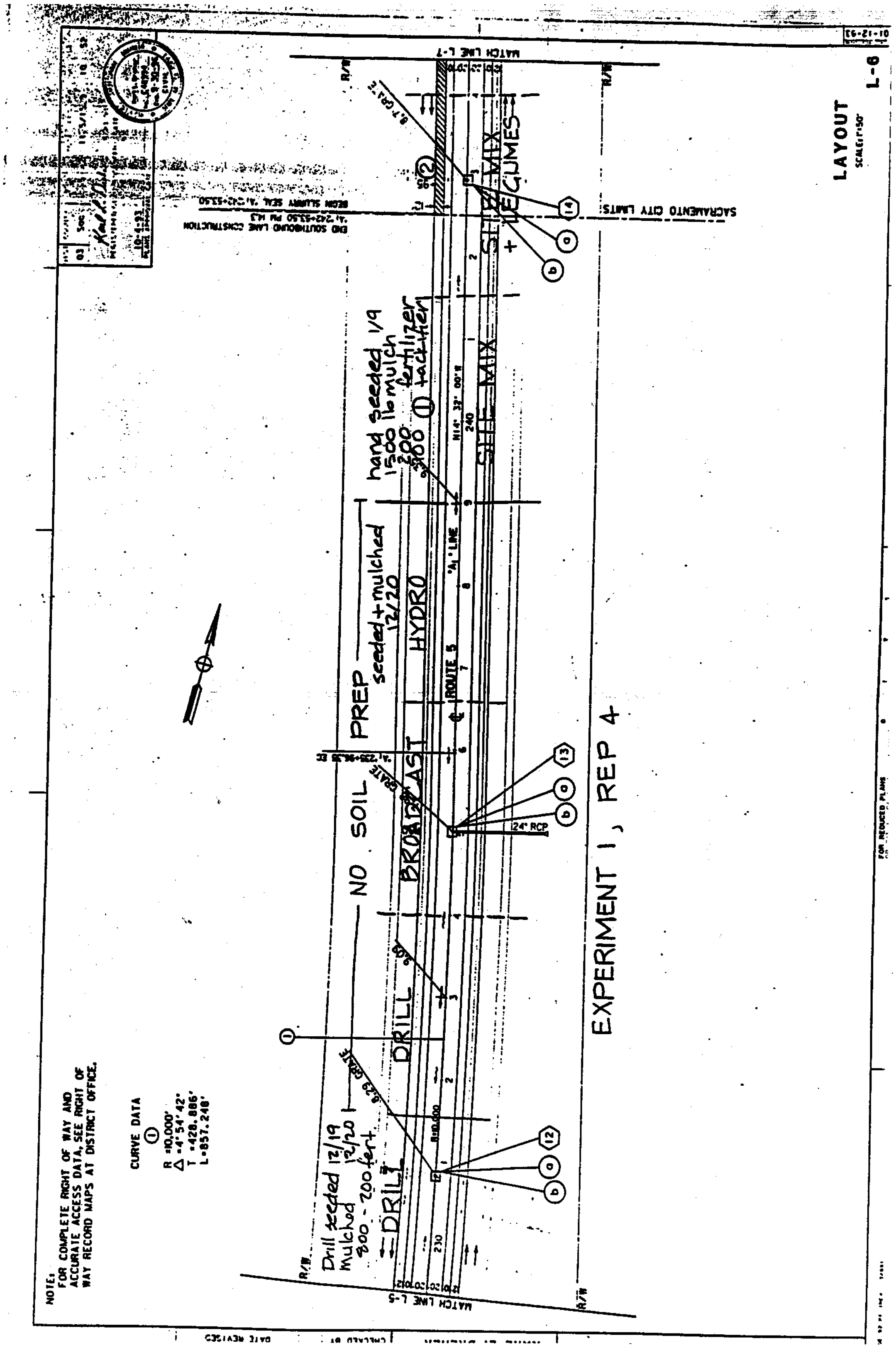

NOTES:
FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
Drilled 12/19 Broadcast, mulch and hydro 12/20
BROADCAST
HYDRO
DRILL
BROADCAST
HYDRO
NO SOIL PREP
MATCH LINE
R/W
ROUTE 5
EXPERIMENT 2, REP 3
DRILL
Beach Lake Bridge
APPROACH SLAB SEE STRUCTURE PLAN
SALVAGE METAL BEAM GUARD RAILING
LAYOUT
L-3
KARL L. DREHER
LOCAL PROGRAMS
STATE OF CALIFORNIA · DEPARTMENT OF TRANSPORTATION



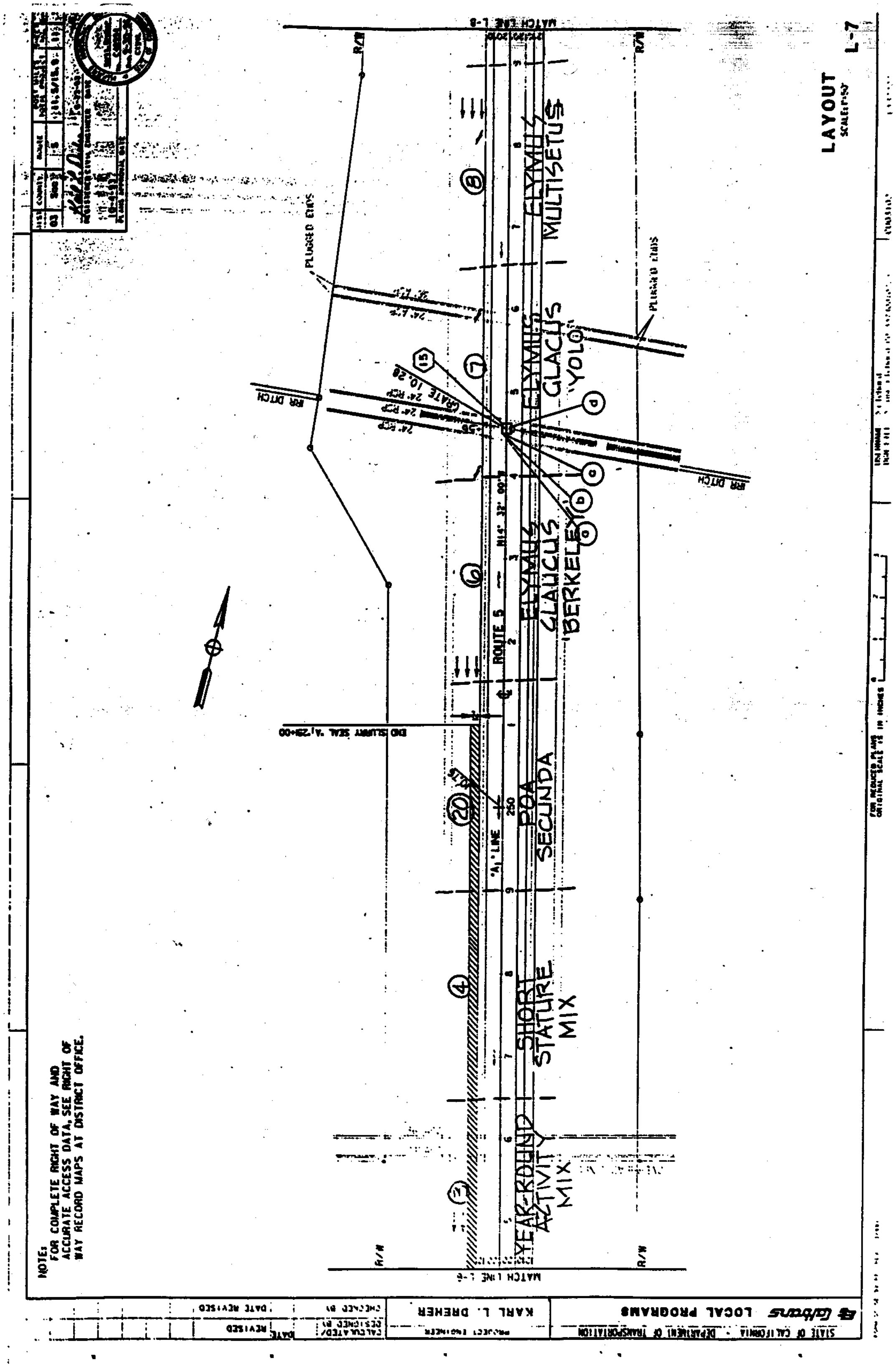
NOTE: FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
EXPERIMENT 1, REPS 1-4 HYDRO PLOTS
HAD 4.4+4.4+1.1 lbs SEED PER PLOT
EXPERIMENT 1, REP 3
Drill seed 12/19
Broadcast and hydro 12/20 900 lb fiber, 200 lb fertilizer
HYDRO
BROADCAST
HYDRO
DRILL
FESTUCA RUBRA MOKULUMNE
NO SOIL PREP
all hand broadcast
hydromulched
HORDEUM BRACHYANTHERIUM var. SALT
HORDEUM BRACHYANTHERIUM var. PROSTRATE
ELYMUS TRITICOIDES
MELICA CALIFORNICA
NASSELLA CERNUA
NASSELLA PULCHRA
eliminated
ROUTE 5
MATCH LINE L-3
MATCH LINE L-5
LAYOUT
L-4
KARL L. DREHER
LOCAL PROGRAMS

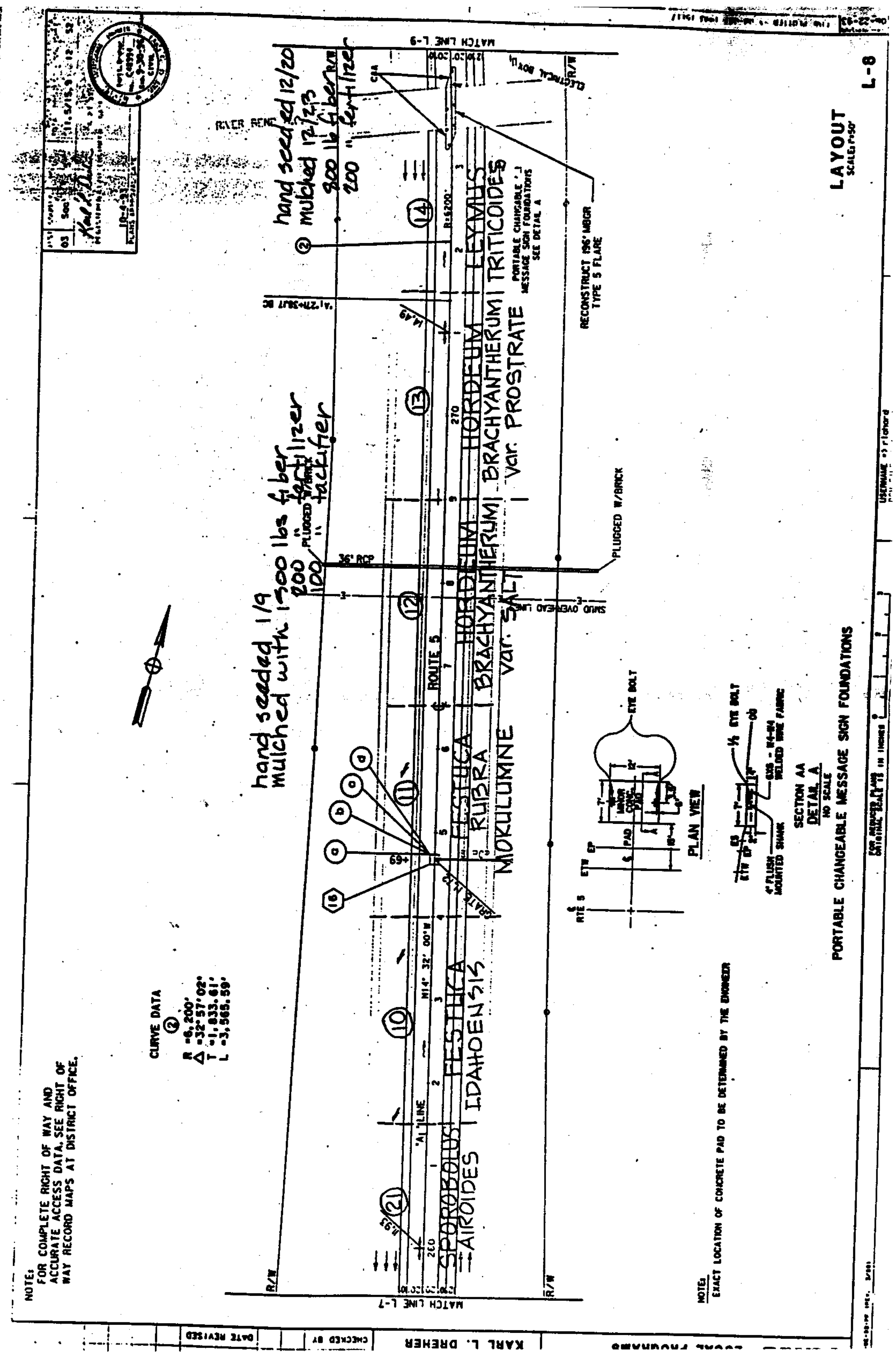


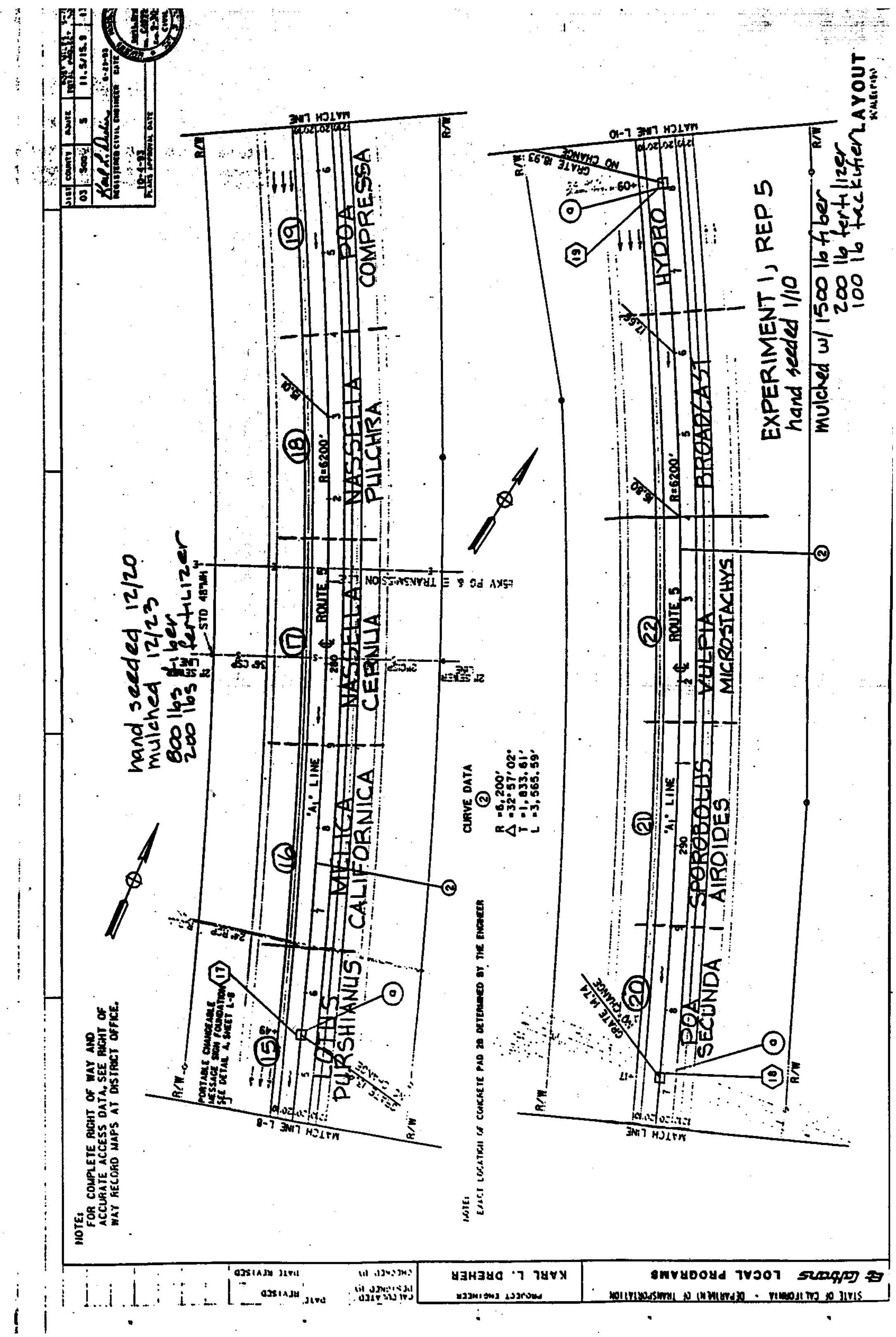
LAYOUT
MATCH LINE L-6
MATCH LINE L-4
NOTE: FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
CURVE DATA
ROUTE 5
TUNNEL 102" I.D. RCP SACRAMENTO REGIONAL C.S. SEWER DISTRICT
EXPERIMENT 2, REP 4
No MOW
PRE-EM
BROADLF
drill seeded 12/19
Mulched 12/20
800 lbs fiber
200 lbs fertilizer
HYDRO
BROADCAST
seeded and mulched 12/20
800
200
EXP. 1, REP 4
POA COMPRESSA
hand broadcast 1-9
1500 lb mulch
200 :: fertilizer
100 :: tackifier
KARL L. DREHER
LOCAL PROGRAMS
STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION

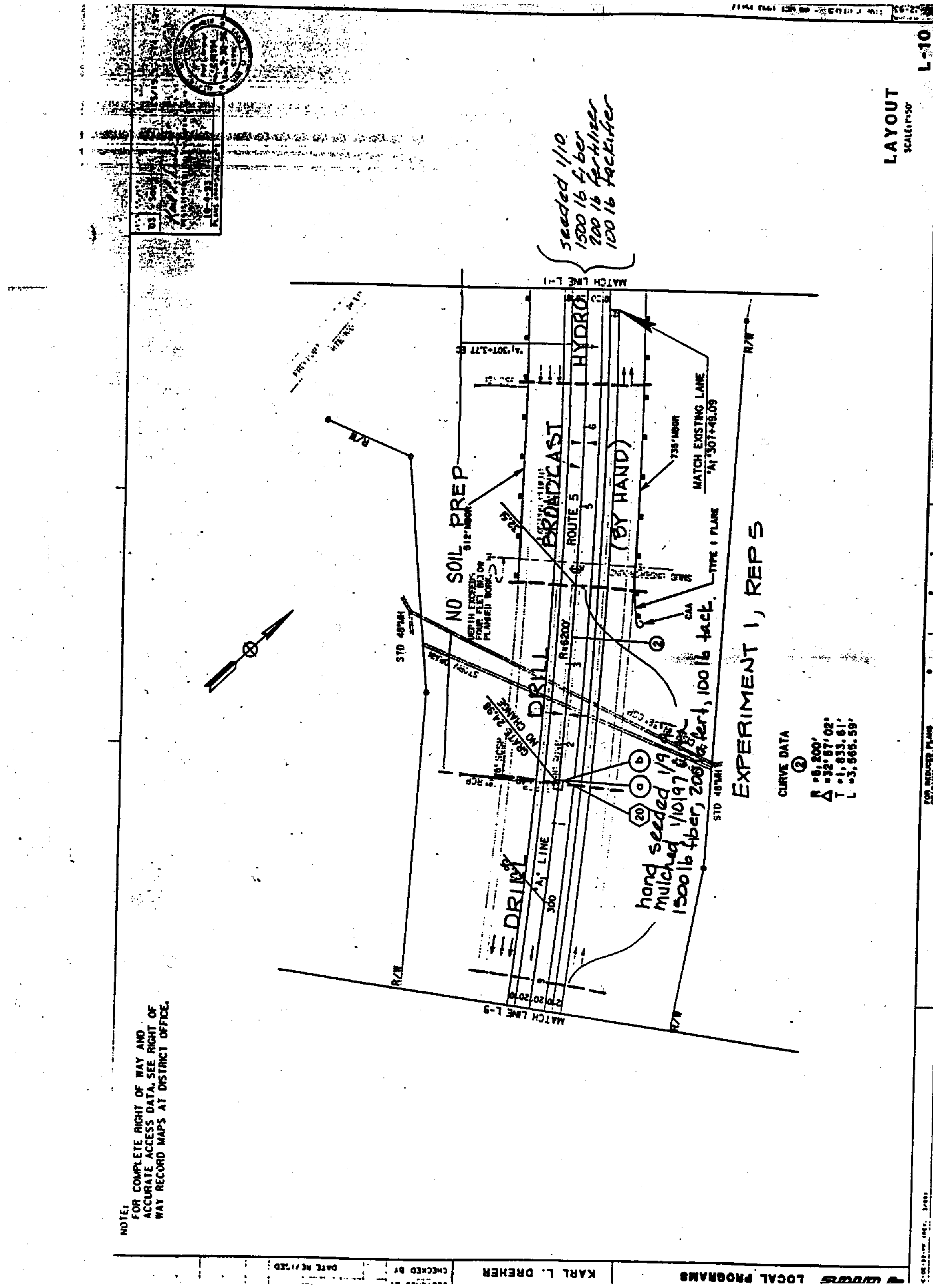


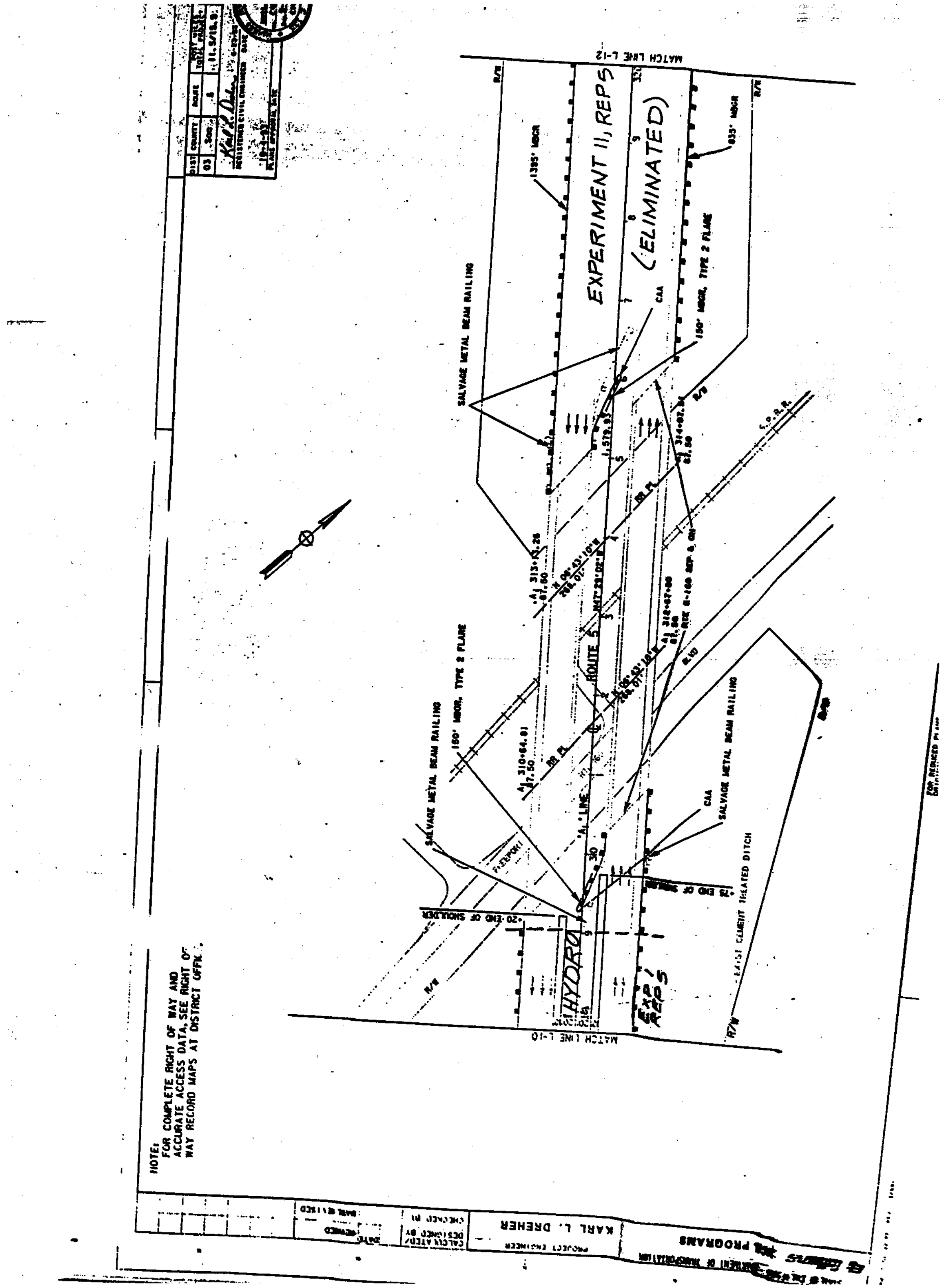
NOTE:
FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
CURVE DATA
R =10,000'
Δ =4°54'42"
T =428.886'
L =857.248'
MATCH LINE L-5
MATCH LINE L-7
SACRAMENTO CITY LIMITS
END SOUTHBOUND LANE CONSTRUCTION
BEGIN SLURRY SEAL
24" RCP
ROUTE 5
"A1" LINE
Drill seeded 12/19
mulched 12/20
800 - 200 fert.
DRILL
NO SOIL PREP
BROADCAST
seeded + mulched 12/20
HYDRO
hand seeded 1/9
1500 lb mulch
200 fertilizer
300 tackifier
SITE MIX
SITE MIX + LEGUMES
EXPERIMENT 1, REP 4
LAYOUT
L-6

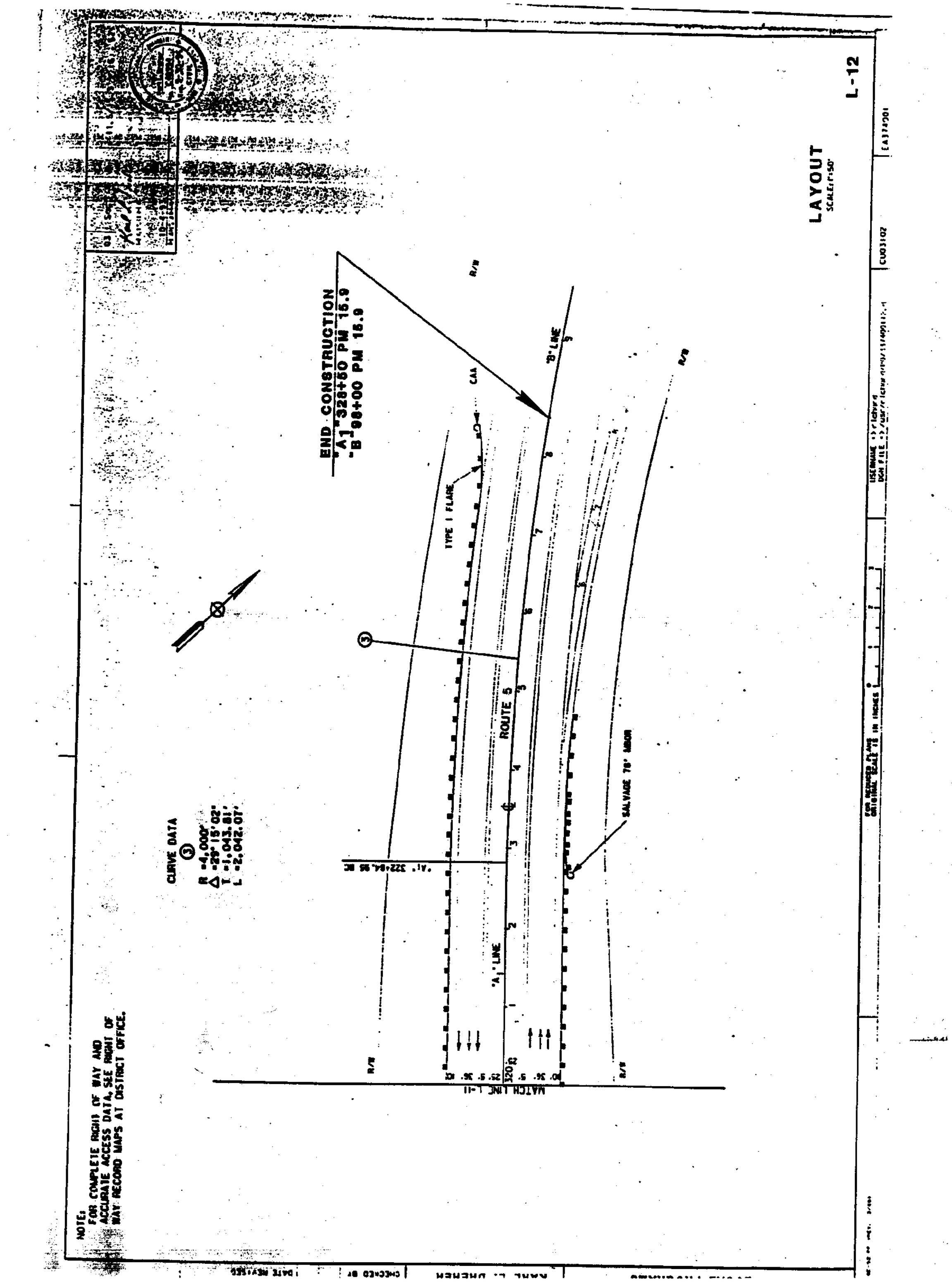

LAYOUT
L-7
MATCH LINE L-8
MATCH LINE L-6
ROUTE 5
"A1" LINE
ELYMUS GLAUCUS 'YOLO'
ELYMUS MULTISETUS
ELYMUS GLAUCUS 'BERKELEY'
POA SECUNDA
SHORT STATURE MIX
YEAR-ROUND ACTIVITY MIX
PLUGGED ENDS
RR DITCH
END SLURRY SEAL
NOTE: FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
KARL L. DREHER
LOCAL PROGRAMS
STATE OF CALIFORNIA · DEPARTMENT OF TRANSPORTATION


LAYOUT
L-8
PORTABLE CHANGEABLE MESSAGE SIGN FOUNDATIONS
PLAN VIEW
SECTION AA
DETAIL A
NO SCALE
EYE BOLT
MATCH LINE L-7
MATCH LINE L-9
ROUTE 5
KARL L. DREHER
CURVE DATA
NOTE:
FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
NOTE:
EXACT LOCATION OF CONCRETE PAD TO BE DETERMINED BY THE ENGINEER
RECONSTRUCT 156' MBGR TYPE 5 FLARE
PLUGGED W/BRICK
36" RCP
RIVER BEND
SPOROBOLUS AIROIDES
HORDEUM BRACHYANTHERUM
LEYMUS TRITICOIDES


EXPERIMENT 1, REP 5
hand seeded 1/10
mulched w/ 1500 lb fiber
200 lb fertilizer
100 lb tackifier
hand seeded 12/20
mulched 12/23
800 lbs fiber
200 lbs fertilizer
LOTUS PURSHIANUS
MELICA CALIFORNICA
NASSELLA CERNUA
NASSELLA PULCHRA
POA COMPRESSA
POA SECUNDA
SPOROBOLUS AIROIDES
VULPIA MICROSTACHYS
BROADCAST
HYDRO
CURVE DATA
R =6,200'
Δ =32°57'02"
T =1,833.61'
L =3,565.59'
'A1' LINE
ROUTE 5
MATCH LINE
LAYOUT
KARL L. DREHER
LOCAL PROGRAMS
STATE OF CALIFORNIA · DEPARTMENT OF TRANSPORTATION


LAYOUT
L-10
NOTE:
FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.
KARL L. DREHER
LOCAL PROGRAMS
seeded 1/10
1500 lb fiber
200 lb fertilizer
100 lb tackifier
MATCH LINE L-11
MATCH LINE L-9
NO SOIL PREP
BROADCAST
HYDRO
(BY HAND)
DRILL
ROUTE 5
'A' LINE
MATCH EXISTING LANE
EXPERIMENT 1, REP 5
hand seeded 1/9
mulched 1/10/97
1500 lb fiber, 200 lb fert, 100 lb tack.
STD 48"MH
CURVE DATA
②
R =6,200'
Δ =32°57'02"
T =1,833.61'
L =3,565.59'


EXPERIMENT II, REPS
(ELIMINATED)
HYDRO
EXP I REPS
MATCH LINE L-12
MATCH LINE L-10
SALVAGE METAL BEAM RAILING
SALVAGE METAL BEAM RAILING
SALVAGE METAL BEAM RAILING
ROUTE 5
KARL L. DREHER
NOTE:
FOR COMPLETE RIGHT OF WAY AND
ACCURATE ACCESS DATA, SEE RIGHT OF
WAY RECORD MAPS AT DISTRICT OFFICE.


LAYOUT
SCALE: 1"=50'
L-12
END CONSTRUCTION
"A1" 328+50 PM 15.9
"B" 98+00 PM 15.9
"B" LINE
CAA
TYPE I FLARE
ROUTE 5
SALVAGE 78" MBGR
"A1" LINE
"A1" 322+94.95 BC
MATCH LINE L-11
R/W
CURVE DATA
3
R =4,000'
Δ =29°15'02"
T =1,043.81'
L =2,042.07'
NOTE:
FOR COMPLETE RIGHT OF WAY AND ACCURATE ACCESS DATA, SEE RIGHT OF WAY RECORD MAPS AT DISTRICT OFFICE.

Appendix 2
Original Erosion Control Specifications

Original specifications before regional was proposed

Caltrans

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

NOTICE TO CONTRACTORS
AND
SPECIAL PROVISIONS

FOR CONSTRUCTION ON

STATE HIGHWAY

IN

SACRAMENTO COUNTY IN AND NEAR SACRAMENTO FROM 0.5 MILE SOUTH OF LAGUNA BOULEVARD TO 0.3 MILE NORTH OF ROUTE 5/160 SEPARATION

DISTRICT 03, ROUTE 5

For use in Connection with Standard Specifications **DATED JULY, 1992**, Standard Plans **DATED JULY, 1992**, and Labor Surcharge And Equipment Rental Rates.

CONTRACT NO. 03-374004

03-Sac-5-11.5/15.9

Federal Aid Project
***ACNHI-005-6(282)505N**

Bids Open: May 23, 1995
Dated: April 17, 1995

OSD

yard for roadway excavation and no additional compensation will be allowed therefor.

10-1.18 DRILL SEED (EROSION CONTROL).--Drill seed (Erosion control) shall conform to the provisions in Section 20-3, "Erosion Control," of the Standard Specifications and these special provisions.

Drill seed (Erosion control) work shall consist of drilling seed into embankment or excavation slopes with a slope ratio of 4:1 or flatter, the median, and other areas designated by the Engineer. A strip 5 feet wide adjacent to the edges of pavement shall not be seeded.

MATERIALS.--Materials shall conform to Section 20-2, "Materials," of the Standard Specifications and the following:

SEED.--Seed shall conform to the provisions in Section 20-2.10, "Seed," of the Standard Specifications. Individual seed species shall be measured and mixed in the presence of the Engineer.

Seed not required to be labeled under the California Food and Agricultural Code shall be tested for purity and germination by a seed laboratory certified by the Association of Official Seed Analysts, or a seed technologist certified by the Society of Commercial Seed Technologists.

Seed shall have been tested for purity and germination not more than one year prior to application of seed.

Results from testing seed for purity and germination shall be furnished to the Engineer prior to applying seed.

LEGUME SEED.--Legume seed shall be pellet-inoculated in accordance with the provisions in said Section 20-2.10, except that the inoculation shall be in accordance with the provisions in Bulletin 1842, "Range-Legume Inoculation and Nitrogen Fixation by Root-Nodule Bacteria," of the University of California, Division of Agriculture and Natural Resources, and shall be added at the rate of 5 times the amount recommended on the inoculant package.

Legume seed shall be sown within 60 days after inoculation or shall be reinoculated prior to application.

Legume seed may be pellet-inoculated by methods other than the provisions in said Bulletin 1842 provided the following conditions are fulfilled:

1. The method of inoculation shall be approved by the Engineer prior to inoculating the seed.
2. Inoculant shall be added at the minimum rate of 2 pounds of inoculant bacteria per 100 pounds of legume seed (exclusive of adhesive material to secure the inoculant to the seed).
3. Inoculated seed shall have a calcium carbonate coating.

Legume seed shall consist of the following:

LEGUME SEED			
Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	Pounds per acre (Slope measurement)
Lupinus bicolor (Pigmy Leafed Lupine)	98	80	5
Lotus corniculatas 'Kalo' (Kalo Swarf Trefoil)	95	85	5

NON-LEGUME SEED.--Non-legume seed shall consist of the following:

NON-LEGUME SEED			
Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	Pounds per acre (Slope measurement)
Eschscholzia californica (California Poppy)	90	70	1
Festuca Idahoensis (Bluebunch Fescue)	90	75	7
Festuca ovina 'Covar' (Covar Sheep Fescue)	95	80	14
Stipa pulchra (Purple Needle Grass)	70	60	3

A sample of approximately one ounce of seed will be taken from each seed container by the Engineer.

COMMERCIAL FERTILIZER.--Commercial fertilizer shall conform to the provisions in Section 20-2.02, "Commercial Fertilizer," of the Standard Specifications and shall have a guaranteed chemical analysis of 16 percent nitrogen, 20 percent phosphoric acid and 0 percent water soluble potash.

STABILIZING EMULSION (SOLIDS).--Stabilizing emulsion (solids) shall conform to the provisions in Section 20-2.11, "Stabilizing Emulsion," of the Standard Specifications and these special provisions, except that the requirement for an effective life of at least one year shall not apply.

Stabilizing emulsion shall be in a dry powder form, may be reemulsifiable, and shall be a processed organic adhesive used as a soil binder.

EQUIPMENT.--Seeding equipment shall be a range land drill seeder type. The seeder shall be equipped with a fluffy seed box and a small seed box with agitators to prevent bridging and clogging. The seed box shall have metal row dividers and individual box adjustment to meter seed flow.

APPLICATION.--Erosion control materials shall be applied in 2 separate applications as follows:

Seed shall be applied in rows 8 inches apart. Seed shall be drilled to a depth of 1/4 to 1/2 inch deep. A minimum of 3 passes with seeding equipment shall be required to distribute the seed uniformly and reduce the uniform row effect.

After the seed has been applied by drilling the following mixture in the proportions indicated shall be applied with hydro-seeding equipment:

Material	Pounds Per Acre (Slope measurement)
Fiber	500
Stabilizing emulsion (solids)	100
Commercial fertilizer	200

The ratio of total water to total stabilizing emulsion in the mixture shall be as recommended by the manufacturer of the emulsion, but shall not exceed 12 gallons of water per pound of stabilizing emulsion solids specified.

The mixture of fiber, stabilizing emulsion and commercial fertilizer shall be applied from the edge of the paved shoulder to the outside edge of drill seeded area.

10-1.19 WILLOW CUTTINGS (PLANT GROUP W).--Willow cutting work shall consist of obtaining, transporting and planting willow cuttings. Such work shall conform to the provisions in Section 20-4, "Highway Planting," of the Standard Specifications and these special provisions.

Plant Group W, willow cuttings, shall be planted where directed by the Engineer.

Willow cuttings shall not be planted before October 1 nor after January 15 and not until the soil is moist to a minimum depth of 8 inches, unless otherwise permitted, in writing, by the Engineer.

Prior to planting, an area 2 feet in diameter at each proposed plant (willow cutting) location shall be cleared of all weed growth. Pesticides shall not be used for weed control within said 2-foot diameter area.

The Contractor shall notify the Engineer, in writing, 10 working days prior to gathering willow cuttings. Such cuttings shall be taken only from the areas shown on the plans or other adjacent areas designated by the Engineer.

Willow cuttings shall be taken at random from healthy, vigorous plants and when such plants are in a dormant condition. Not more than 50 percent of the plants in any designated area shall be cut, nor shall more than 25 percent of each individual plant be cut. Cuts shall be made with sharp, clean tools.

Willow cuttings shall be reasonably straight, 24 inches to 30 inches in length, and 3/4 inch to 1 1/2 inches in diameter at the base of the cutting. The top of each willow cutting shall be cut square above a leaf bud, and the base of each willow cutting shall be cut below a leaf bud at an angle of approximately 45 degrees. Willow cuttings shall have all leaves and branches trimmed off flush with the stem. Pruned branches and trimmings shall be spread in the designated willow cutting areas so as not to leave the areas unsightly.

Willow cuttings shall be planted within 48 hours after cutting and shall be kept wet until planted. Willow cuttings not planted within 48 hours after cutting, or allowed to dry out, shall not be used. Willow cuttings not used shall be disposed of outside the highway right of way in accordance with the provisions in Section 7-1.13 of the Standard Specifications.

A root stimulant shall be applied to the willow cuttings immediately prior to planting. The stimulant shall be applied in accordance with the printed instructions of the root stimulant manufacturer. A copy of such instructions shall be furnished to the Engineer prior to applying the stimulant.

Planting holes shall be made perpendicular to the ground line and shall be formed with a steel bar or excavated by use of an auger, post hole digger or similar tools. Plant holes shall be large enough to receive the willow cuttings in order that the willow cuttings may be planted to the proper depths without damage to the bark. Where rock or other hard material prohibits holes from being excavated as specified, new holes shall be excavated and the abandoned holes backfilled.

If the soil in and around the plant hole is not wet prior to planting, the soil shall be watered and maintained in a wet state until the willow cuttings are planted.

Commercial fertilizer (tablet) shall be a slow release type, shall be 21-gram size tablets weighing 21 ± 1 grams each, and shall have the following guaranteed chemical analysis:

Ingredient	Percentage
Nitrogen	20
Phosphoric Acid	10
Water Soluble Potash	5

One 21-gram size commercial fertilizer tablet shall be placed at the bottom of each planting hole and covered with a minimum of 2 inches of soil before planting the willow cutting.

At the option of the Contractor, two 10 1/2-gram size tablets may be used in lieu of each 21-gram size tablet specified herein. Regardless of the tablet size used, each tablet shall be the slow release type and shall have the same guaranteed chemical analysis as specified for the 21-gram size tablets. Each 10 1/2-gram size tablet shall weigh 10 1/2 ± 0.5 grams.

The base of willow cuttings shall be planted from 12 to 15 inches deep (approximately one-half the willow

Appendix 3
Final Seeding Rates and Materials Specifications

Nature's Own Fiber

800 lbs/acre 19-23 December 1996, 1500 lb/acre 9 and 10 January 1997

6-20-0 fertilizer

200 lbs/acre all dates

Fisch-Stik Stabilizing Emulsion

100 lb/acre applied only on plots seeded 9 and 10 January 1997

CALTRANS PERENNIAL GRASS PROJECT SPECIES MIXTURES					
	species	base		PLS	
	factor	seeds/ft2	seeds/ft2	seeds/lb	lbs/acre
SITE MIX (for experimental plots...most of site)					
Elymus glaucus var. Yolo Bypass	0.33	16.67	5.50	92,000	2.60
Hordeum brachyantherum ssp. brachyantherum var. Salt	0.40	16.67	6.67	74,000	3.92
Hordeum brachyantherum ssp. californicum var. Prostrate	0.53	16.67	8.89	137,000	2.83
Nassella pulchra var. Jepson Prairie	0.33	16.67	5.56	97,000	2.49
Poa secunda ssp. secunda	5.33	16.67	88.89	1,061,054	3.65
Melica californica	0.89	16.67	14.81	520,000	1.24
		100.00	**130.31**		**16.74**
1. SITE MIX PLUS LEGUMES (for demonstration plots)					
Elymus glaucus var. Yolo Bypass	0.33	11.11	3.67	92,000	1.74
Hordeum brachyantherum ssp. brachyantherum var. Salt	0.40	11.11	4.44	74,000	2.62
Hordeum brachyantherum ssp. californicum var. Prostrate	0.53	11.11	5.93	137,000	1.88
Lotus purshianus	0.22	11.11	2.47	119,000	0.90
Melica californica	0.89	11.11	9.88	520,000	0.83
Nassella pulchra var. Jepson Prairie	0.33	11.11	3.70	97,000	1.66
Poa secunda ssp. secunda	5.33	11.11	59.26	1,061,054	2.43
Trifolium obtusiflora (Clammy clover)	0.89	11.11	9.89	325,000	1.33
Trifolium willdenovii (Tomcat clover)	0.89	11.11	9.89	325,000	1.33
		100.00	**109.12**		**14.71**
2. FINE LEAF FESCUE MIX (for demonstration plots)					
Festuca idahoensis	0.83	20.00	16.67	340,000	2.14
Festuca rubra var. Mokulumne	1.00	20.00	20.00	527,000	1.65
Festuca rubra var. Molate	1.00	20.00	20.00	527,000	1.65
Poa compressa	0.13	20.00	2.66	2,450,000	0.05
Poa secunda ssp. secunda	5.33	20.00	106.67	1,061,054	4.38
		100.00	**165.99**		**9.87**
3. YEAR-ROUND ACTIVITY MIX (for demonstration plots)					
Aristida ternipes var. hamulosa	2.67	14.29	38.14	500,000	3.32
Eragrostis curvula	2.67	14.29	38.14	1,500,000	1.11
Hordeum brachyantherum ssp. brachyantherum var. Salt	0.40	14.29	5.71	74,000	3.36
Hordeum brachyantherum ssp. californicum var. Prostrate	0.53	14.29	7.62	137,000	2.42
Melica californica	0.89	14.29	12.70	520,000	1.06
Nassella pulchra var. Jepson Prairie	0.33	14.29	4.76	97,000	2.14
Poa secunda ssp. secunda	5.33	14.29	76.19	1,061,054	3.13
		100.00	**183.27**		**16.55**
4. SHORT STATURE MIX (for demonstration plots)					
Festuca idahoensis	0.83	16.67	13.89	340,000	1.78
Hordeum brachyantherum ssp. californicum var. Prostrate	0.53	16.67	8.89	137,000	2.83
Melica californica	0.89	16.67	14.81	520,000	1.24
Nassella pulchra var. Jepson Prairie	0.33	16.67	5.56	97,000	2.49
Poa secunda ssp. secunda	5.33	16.67	88.89	1,061,054	3.65
Vulpia microstachys	0.44	16.67	7.41	358,000	0.90
		100.00	**139.44**		**12.89**
			seeds/ft2=		
	species	**base**	**sp factor***	**PLS**	
INDIVIDUAL SPECIES	**factor**	**seeds/ft2**	**sds/ft2**	**seeds/lb**	**lbs/acre**
5. Agrostis diegoensis	2.00	100.00	200	3,600,000	2.42
6. Elymus glaucus var. Berkeley	0.33	100.00	33	92,000	15.62
7. Elymus glaucus var. Yolo Bypass	0.33	100.00	33	92,000	15.62
8. Elymus multisetus	0.74	100.00	74.07407407	120,000	26.89
9. Eragrostis curvula	2.67	100.00	267	1,500,000	7.75
10. Festuca idahoensis	0.83	100.00	83.33333333	340,000	10.68
11. Festuca rubra var. Mokulumne	1.00	100.00	100	527,000	8.27
12. Hordeum brachyantherum ssp. brachyantherum var. Salt	0.40	100.00	40	74,000	23.55
13. Hordeum brachyantherum ssp. californicum var. Prostrate	0.53	100.00	53.33333333	137,000	16.96
14. Leymus triticoides	0.44	100.00	44.44444444	282,000	6.87
15. Lotus purshianus	0.22	100.00	22.22222222	119,000	8.13
16. Melica californica	0.89	100.00	88.88888889	520,000	7.45
17. Nassella cernua	0.67	100.00	66.66666667	187,000	15.53
18. Nassella pulchra var. Jepson Prairie	0.33	100.00	33.33333333	97,000	14.97
19. Poa compressa	4.00	100.00	400	2,450,000	7.11
20. Poa secunda ssp. secunda	5.33	100.00	533.3333333	1,061,054	21.90
21. Sporobolus airoides var. Los Banos	2.67	100.00	267	1,700,000	6.84
22. Vulpia microstachys	0.44	100.00	44.44444444	358,000	5.41

Species Factor Calculation

SPECIES	approximate seeds/lb	% pure seed	% germ-ination	P.L.S.	seed size factor	plant size factor	growth rate/ plasticity/ vigor factor	species factor		
Agrostis diegoensis	*3600000				0.25	1+1=2	1.00	2.00		
Aristida ternipes ssp. hamulosa	****500000				0.50	0.5+1=1.5	0.50	2.67		
Distichlis spicata	It is unlikely that this species will ever be commercially available due to difficulties with growth and seed production.									
Elymus glaucus var. Berkeley	*92000				1.00	2+1=3	1.00	0.33		
Elymus glaucus var. Yolo Bypass	*92000				1.00	2+1=3	1.00	0.33		
Elymus multisetus	*120000				0.75	0.5+1=1.5	0.90	0.74		
Eragrostis curvula	*1500000				0.25	2+1=3	0.50	2.67		
Festuca idahoensis	*340000				0.75	1+1=2	0.80	0.83		
Festuca rubra var. Mokulumne/Molate	*527000				0.50	1+1=2	1.00	1.00		
Hordeum brachyantherum ssp. brachyantherum var. Salt	*74000				1.00	1+1=2	1.25	0.40		
Hordeum brachyantherum ssp. californicum var. Prostrate	*137000				0.75	1+1=2	1.25	0.53		
Leymus triticoides	*282000				0.75	2+3=5	0.60	0.44		
Lotus purshianus	*119000				0.75	1+3=4	1.50	0.22		
Melica californica	**520,000				0.75	2+1=3	0.50	0.89		
Nassella cernua	*187000				0.50	2+1=3	1.00	0.67		
Nassella pulchra var. Jepson Prairie	*97000				1.00	2+1=3	1.00	0.33		
Nassella pulchra var. Parrot Ranch	*97000				1.00	2+1=3	1.00	0.33		
Poa compressa	*2450000				0.25	1+1=2	0.50	4.00		
Poa secunda ssp. secunda	*1061054				0.25	0.5+1=1.5	0.50	5.33		
Sporobolus airoides var. Los Banos	*1700000				0.25	2+1=3	0.50	2.67		
Trifolium obtusiflora	*325000				0.75	0.5+1=1.5	1.00	0.89		
Trifolium willdenovii	*325000				0.75	0.5+1=1.5	1.00	0.89		
Vulpia microstachys	***358000				0.75	0.5+1=1.5	2.00	0.44		
* From Conservaseed										
** From S&S Seeds										
*** From my own data										
****From John Haynes										

Elements of Species Factors

SEED SIZE FACTOR*	SEEDS/LB	PLANT SIZE FACTOR**	CLASSIFICATION	DIMENSIONS
		Height***		
0.25	> 1,000,000	0.5	short	<30 cm
0.5	500,000-1,000.000	1	intermediate	30-70 cm
0.75	100,000-500,000	2	tall	>70 cm
1	50,000-100,000			
2	<50,000	Area****		
		1		0-30 cm
		2		30-60 cm
		3	very large creeping	>60 cm

** Plant size factor =rating for height+rating for area covered by canopy of average mature plant including vegetative propagules (i.e. tillers, rhizomes, etc.)

***Height=average maximum height of the plant biomass.

****Area=average canopy diameter of the plant

PLASTICITY/GROWTH RATE/VIGOR RATING	PLANT CHARACTERISTICS	SPECIES
0.5	slower growing perennials	Melicas, Poa, Danthonia
0.6	slower growing perennials	Leymus (?), Festuca ovina
0.7	slower growing perennials	
0.8	slower growing perennials	
0.9	slower growing perennials	
1	slower growing perennials	Nassella
1.25	faster growing perennials	perennial Bromus, Hordeum
1.5	faster growing perennials	perennial Bromus, Hordeum
1.75	faster growing perennials	perennial Bromus, Hordeum
2	less aggressive annuals	
3	less aggressive annuals	
4	less aggressive annuals	Zorro fescue
5	more aggressive annuals	
6	more aggressive annuals	
7	more aggressive annuals	
8	more aggressive annuals	Avena spp

SEED SIZE FACTOR*PLANT SIZE FACTOR*GROWTH RATE/PLASTICITY/VIGOR FACTOR=INVERSE SPECIES FACTOR
1/INVERSE SPECIES FACTOR=SPECIES FACTOR

SPECIES FACTOR FOR INDIVIDUAL SPECIES /SUM OF SPECIES FACTORS FOR ALL OF THE SPECIES IN THE MIXTURE= PROPORTION OF INDIVIDUAL SPECIES = P

P * TOTAL # MIXTURE SEEDS/sq. ft. = # SEEDS OF INDIVIDUAL SPECIES/ sq. ft.

State of California
Department of Transportation

NOTICE OF MATERIALS TO BE USED

DC-CEM-3101 (OLD HC-30 REV. 10/92) 7541-3511-1

To: H. Kibunguchy
Resident Engineer

Date: November 27, 1996

You are hereby notified that material required for use under Contract No. 03-374004 *for construction of* Interstate 5 Median Native Grass and Forb Project in and near Sacramento from 0.5 mile south of Laguna Boulevard to 0.3 mile north of Route 5/160 Separation - Drill Seed, Broadcast and Harrow and Hydroseed (only) *Dist.* 03 *Co.* Sacramento *Rte.* 5 *P.M.* 11.5/15.9 *will be obtained from the following sources:*

CONTRACT ITEM NO.	KIND OF MATERIAL	NAME AND ADDRESS WHERE MATERIAL CAN BE INSPECTED
	Seed	Pacific Coast Seed, Inc. 6144A Industrial Way Livermore, CA 94550
	Fiber / Nature's Own recycled paper fiber mulch	Hamilton Manufacturing, Inc. 118 Market Street Twin Falls, ID 83301
	Commercial Fertilizer / 16-20-0	Sierra Pacific Turf Supply 4320 Anthony Ct. #6 Rocklin, CA 95677
	Stabilizing Emulsion / Fisch-Stik	Automatic Rain 3221 Swetzer Road Loomis, CA 95650

It is requested that you arrange for sampling, testing and inspection materials prior to delivery in accordance with Section 6 of the Standard Specifications where the same is practicable and in accord with your policy. It is understood that source inspection does not relieve me of the full responsibility for incorporating in the work materials that comply in all respects with the contract plans and specifications, nor does it preclude the subsequent rejection of materials found to unsuitable.

Yours Truly, Ellen M. Nitta

Nitta Construction, Inc.
Subcontractor
3778 Del Mar Avenue, Loomis CA 95650
(916) 652-7459

WHITE - DIV OF NEW TECHNOLOGY
MATERIALS AND RESEARCH
5900 FOLSOM BLVD.
SACRAMENTO, CA 95819

I.

EXPERIMENT II REP 1 (STA. 100+50 TO STA. 107+00)

650' long x 40' wide = 26,000 Sf

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	PLS Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie (Parrot Ranch type)			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

II.

EXPERIMENT I REP 1 (STA. 107+00 TO STA. 122+00)

6 -250' long x 40' wide sections = each 10,000 Sf with soil preparation and without soil preparation (combination of drill seeding - 2 sites, broadcast seeding - 2 sites, and hydroseeding - 2 sites) -> (6) separate 10,000 Sf mixtures

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	PLS Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

III.

INDIVIDUAL SPECIES PLOTS (SPPMIX) - individually bagged as to species and for each plot

STA. 122+00 to STA. 147+00 = 10 -250' long x 40' wide sections = each 10,000 Sf
STA. 197+50 to STA. 217+50 = 8 - 250' long x 40' wide sections = each 10,000 Sf
STA. 239+00 to STA. 294+00 = 22 - 250' long x 40' wide sections = each 10,000 Sf

Botanical Name (Common Name)	# of plots	**PLS Lbs** per plot	**PLS Lbs** total req.	Legume Seed
Poa secunda ssp. secunda	2	5.03	10.07	-
Elymus glaucus var. Berkeley	2	3.59	7.19	-
Elymus glaucus var. Anderson	2	3.59	7.19	-
Elymus multisetus	2	6.18	12.37	-
Sporobolus airoides	2	1.57	3.15	-
Festuca idahoensis	2	2.45	4.91	-
Festuca rubra var. Mokulumne	2	1.90	3.80	-
Hordeum brachyantherum ssp. brachyantherum var. Salt	2	5.41	10.83	-
Hordeum brachyantherum ssp. californicum var. Prostrate	2	3.89	7.80	-
Leymus triticoides	2	1.58	3.16	-
Lotus purshianus	2	1.87	3.74	x
Melica californica	2	1.71	3.43	-
Nassella cernua	2	3.57	7.14	-
Nassella pulchra var. Jepson Prairie	2	3.44	6.89	-
Vulpia microstachys	2	1.24	2.49	-
Totals			94.16	

TEST SAMPLE ONLY

Poa compressa (2 bags at 1.63 lbs. each) (contains 3% Rabbitsfoot's Grass)	2	1.63	3.27	

IV.

EXPERIMENT II REP 2 (STA. 147+00 TO STA. 154+00)

700' long x 40' wide = 28,000 Sf

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	**PLS** Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

V.

EXPERIMENT I REP 2 (STA. 154+00 TO STA. 169+00)

6 -250' long x 40' wide sections = each 10,000 Sf with soil preparation and without soil preparation (combination of drill seeding - 2 sites, broadcast seeding - 2 sites, and hydroseeding - 2 sites) -> (6) separate 10,000 Sf mixtures

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	**PLS** Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

VI.

MORRISON CREEK BEACH LAKE BRIDGE (STA. 169+00 to STA. 176+00)

700' long x 40' wide = 28,000 Sf

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	**PLS** Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

VII.

EXPERIMENT II REP 3 (STA. 176+00 TO STA. 182+50)

650' long x 40' wide = 26,000 Sf

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	**PLS** Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

VIII.

EXPERIMENT I REP 3 (STA. 182+50 TO STA. 197+50)

6 -250' long x 40' wide sections = each 10,000 Sf with soil preparation and without soil preparation (combination of drill seeding - 2 sites, broadcast seeding - 2 sites, and hydroseeding - 2 sites) -> (6) separate 10,000 Sf mixtures

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	PLS Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

IX.

EXPERIMENT II REP 4 (STA. 217+50 TO STA. 224+00)

650' long x 40' wide = 26,000 Sf

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	PLS Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

X.

EXPERIMENT I REP 4 (STA. 224+00 TO STA. 239+00)

6 -250' long x 40' wide sections = each 10,000 Sf with soil preparation and without soil preparation (combination of drill seeding - 2 sites, broadcast seeding - 2 sites, and hydroseeding - 2 sites) -> (6) separate 10,000 Sf mixtures

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	**PLS** Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

XI.

EXPERIMENT I REP 5 (STA. 294+00 TO STA. 309+00)

6 -250' long x 40' wide sections = each 10,000 Sf with soil preparation and without soil preparation (combination of drill seeding - 2 sites, broadcast seeding - 2 sites, and hydroseeding - 2 sites) -> (6) separate 10,000 Sf mixtures

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	**PLS** Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

XII.

700' long x 40' wide = 28,000 Sf

Botanical Name (Common Name)	Percent (Minimum) Purity	Percent (Minimum) Germination	**PLS** Pounds per Acre	Legume Seed
Elymus glaucus var. Anderson			2.60	-
Hordeum brachyantherum ssp. brachyantherum var. Salt			3.92	-
Hordeum brachyantherum ssp. californicum var. Prostrate			2.83	-
Nassella pulchra var. Jepson Prairie			2.49	-
Poa secunda ssp secunda			3.65	-
Melica californica			1.24	-
Totals			16.74	

XIII.

SITE MIX PLUS LEGUMES (SML)

2 - 10,000 Sf plots

Botanical Name (Common Name)	**PLS Lbs** per acre	**PLS Lbs** total req.	Legume Seed
Elymus glaucus var. Anderson	1.74	0.80	-
Hordeum brachyantherum ssp. brachyantherum var. Salt	2.62	1.21	-
Hordeum brachyantherum ssp. californicum var. Prostrate	1.88	0.86	-
Lotus purshianus	0.90	0.41	x
Melica californica	0.83	0.38	-
Nassella pulchra var. Jepson Prairie	1.66	0.76	-
Poa secunda ssp. secunda	2.43	1.12	-
Trifolium obtusiflora (Clammy Clover)	1.33	0.61	x
Trifolium willdenovii (Tomcat Clover)	1.33	0.61	x
Totals	14.71		

IXV.

FINE LEAF FESCUE MIX (FLF)

2 - 10,000 Sf plots

Botanical Name (Common Name)	**PLS Lbs** per acre	**PLS Lbs** total req.	Legume Seed
Festuca idahoensis	2.14	0.98	-
Festuca rubra var. Mokulumne	1.65	0.76	-
Festuca rubra var. Molate	1.65	0.76	-
Poa secunda ssp. secunda	4.38	2.01	-
Totals	9.87		

TEST SAMPLE ONLY

Poa compressa (2 bags at .05 lbs. each) (contains 3% Rabbitsfoot's Grass)	0.05	0.023	-

XV.

YEAR-ROUND ACTIVITY MIX (YRA)

2 - 10,000 Sf plots

Botanical Name (Common Name)	**PLS Lbs** per acre	**PLS Lbs** total req.	Legume Seed
Aristida ternipes var. hamulosa	3.32	1.53	-
Eragrostis curvula	1.11	0.51	-
Hordeum brachyantherum ssp. brachyantherum var. Salt	3.36	1.55	-
Hordeum brachyantherum ssp. californicum var. Prostrate	2.42	1.11	-
Melica californica	1.06	0.49	-
Nassella pulchra var. Jepson Prairie	2.14	0.98	-
Poa secunda ssp secunda	3.13	1.44	-
Totals	16.55		

XVI.

SHORT STATURE MIX (SSM)

2 - 10,000 Sf plots

Botanical Name (Common Name)	**PLS Lbs** per acre	**PLS Lbs** total req.	Legume Seed
Festuca idahoensis	1.78	0.82	-
Hordeum brachyantherum ssp. californicum var. Prostrate	2.83	1.30	-
Melica californica	1.24	0.57	-
Nassella pulchra var. Jepson Prairie	2.49	1.15	-
Poa secunda ssp secunda	3.65	1.68	-
Vulpia microstachys	0.90	0.41	-
Totals	16.55		

Seed shall conform to the provisions in Section 20-2.10, "Seed," of the Standard Specifications. Individual seed species shall be measured and mixed in the presence of the Engineer. Seed not required to be labeled under the California Food and Agricultural Code shall be tested for purity and germination by a seed laboratory certified by the Association of Official Seed Analysts, or a seed technologist certified by the Society of Commercial Seed Technologists. Seed shall have been tested for purity and germination not more than one year prior to application of seed or seed shall be retested at the Contractor's expense. Results from testing or retesting seed for purity and germination shall be furnished to the Engineer prior to applying seed.

Legume seed shall be pellet-inoculated in accordance with the provisions in said Section 20-2.10, except that the inoculation shall be in accordance with the provisions in Bulletin 1842, "Range-Legume Inoculation and Nitrogen Fixation by Root-Nodule Bacteria," of the University of California, Division of Agriculture and Natural Resources, and shall be added at the rate of 5 times the amount recommended on the inoculant package. Legume seed shall be sown within 90 days after inoculation. Legume seed may be pellet-inoculated by methods other than the provisions in said Bulletin 1842 provided the following conditions are fulfilled:

1. The method of inoculation shall be approved by the Engineer prior to inoculating the seed.

2. Inoculant shall be added at the minimum rate of 2 pounds of inoculant bacteria per 100 pounds of legume seed (exclusive of adhesive material to secure the inoculant to the seed).

Commercially inoculated legume seed shall be delivered to the job site in unopened separate containers.

NATURE'S OWN

High Quality Paper Fiber Hydroseeding Mulch

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SPECIFICATIONS OF HYDROMULCH

Cal-trans Specifications
CA-DOT-TL-2167-1-76-36

STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES & ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

Study made by Geotechnical Branch

Preprared in cooperation with the U. S. Department of Transportation, Federal Program No. F-5-17.

20-2.07 FIBER. Fiber shall be produced from natural or recycled (pulp) fiber, such as wood chips or similar wood materials or from newsprint, chipboard, corrugated cardboard or a combination of these processed materials, and shall be free of synthetic or plastic materials. Fiber shall not contain more than 7 percent ash as determined by the Technical Association of the Pulp and Paper Industry (TAPPI) Standard T-413, shall contain less than 250 parts per million boron, and shall be otherwise nontoxic to plant or animal life.

Fiber shall have a water holding capacity by weight of not less than 1,200 percent as determined by the procedure used in the Department's Final Report, CA-DOT-TL-2176-1-76-36, "Water-holding Capacity for Hydromulch," available at the Transportation Laborator, 5900 Folsom Boulevard, Sacramento, CA 95819.

Fiber shall be of such character that the fiber will disperse into a uniform slurry when mixed with water. Water content of the fiber before mixing into slurry shall not exceed 15 percent of the dry weight of the fiber. The percentage of water in the fiber shall be determined by California Test 226. Commercially packaged fiber shall have the moisture content of the fiber marked on the package. Fiber shall be colored to contrast with the area on which the fiber is to be applied and shall not stain concrete or painted surfaces.

A Certificate of Compliance for fiber shall be furnished to the Engineer in accordance with the provisions in Section 6-1.07, "Certificates of Compliance."

	Cal-Trans	Nature's Own
Moisture Content	15% max.	8.3%
Organic Matter	(not applicable)	95.4%
Ash Content	7% max.	4.6%
PH Range	(not applicable)	6.9
Water-Holding Capacity	1200% by weight min.	1438%
Boron	250 PPM max.	95.1 PPM

PRODUCT: # AMMONIUM PHOSPHATE 16-20-0

DESCRIPTION: **A HOMOGENEOUS HIGH PHOSPHATE FERTILIZER FOR MAINTENANCE AND PRE-PLANT APPLICATIONS**

BENEFITS: **BEST® Ammonium Phosphate 16-20-0:**

- is a homogeneous fertilizer (homogeneous means that each pellet contains the same ratio of nutrients) to prevent nutrient segregation and insure even and uniform distribution of the fertilizer, (no streaking).
- contains 13% sulfur to enhance plant color and density. Sulfur aids in drought tolerance and winter hardiness.
- is an economical and effective pre-plant fertilizer when used in conjunction with potassium, or where soils are sufficient in their potassium levels.

APPLICATION RATES:

TURFGRASS:

	Lbs. of Actual Nitrogen desired per 1,000 sq. ft.	Lbs. of 16-20-0 To Apply per 1,000 sq. ft.	Lbs. of 16-20-0 To Apply per Acre	Lbs. of Actual Phosphate Applied per 1,000 sq. ft.
	.50	3.1	136	.62
*Recommended Rate	.75	4.7	205	.94
	1.00*	6.2*	275*	1.2*

PREPLANT: Broadcast 12 lbs. per 1,000 sq. ft. (525 lbs. per acre) and incorporate into the top 2-3 inches of soil.

GROUNDCOVER: Broadcast at 5 lbs. per 1,000 sq. ft. (½ lb. per 100 sq. ft.)

SHRUBS & EVERGREENS: Sprinkle ¼ cup of Ammonium Phosphate evenly around drip line of plant and work into top 1 inch of soil.

TREES: Apply ½ lb. per 1 inch of trunk diameter. Distribute evenly under branches out to dripline.

NOTE: Liquid measuring cups are very close in estimating the weight of dry granular fertilizers.
Example: an 8 oz. (1 cup) measuring cup holds approximately 8 oz. of dry granular fertilizer.

PRODUCT COVERAGE:

MAINTENANCE	PRE-PLANT
ONE 50-LB. BAG COVERS 8,000 SQ. FT.	ONE 50-LB. BAG COVERS 4,000 SQ. FT.
5½ - 50-LB. BAGS COVERS 1 ACRE	10½ - 50-LB. BAGS COVERS 1 ACRE

SPREADER SETTINGS:

Listed Settings Will Approximately Apply the Recommended Rate.

	TURFGRASS	PRE-PLANT
BEST® Pro	5¾B	7B
BEST® Models 34, 44, 64	5.1	6.5
Cyclone Model B	5	6.5
Scotts	L	S+
Lely Type W Wheel-driven	6	5

NOTE: Spreader settings are guidelines only. Spreaders should be checked for accuracy.

APPLICATION PRECAUTIONS:

- Apply to dry turf or foliage and irrigate thoroughly immediately after application.
- Plant nutrients can cause staining of some sidewalks. Sweep walkways prior to irrigation. Walkways should be dry at time of application.
- Keep away from pools, ponds, etc. Do not contaminate potable water.

GUARANTEED MINIMUM ANALYSIS:

TOTAL NITROGEN (N)	16.0%
16.0% Ammoniacal Nitrogen	
AVAILABLE PHOSPHORIC ACID (P_2O_5)	20.0%
Calcium (Ca)	1.4%
Sulfur (S)	13.0%

Plant nutrients derived from Ammonium Phosphate Sulfate.

PACKAGE SIZE:

80-LB. & 50-LB. BAGS

16-20-0 (PRO 12/94)

HANDLING PRECAUTIONS:
MSDS - See Reverse

CAUTION: KEEP OUT OF REACH OF CHILDREN
HARMFUL IF SWALLOWED - DO NOT INHALE

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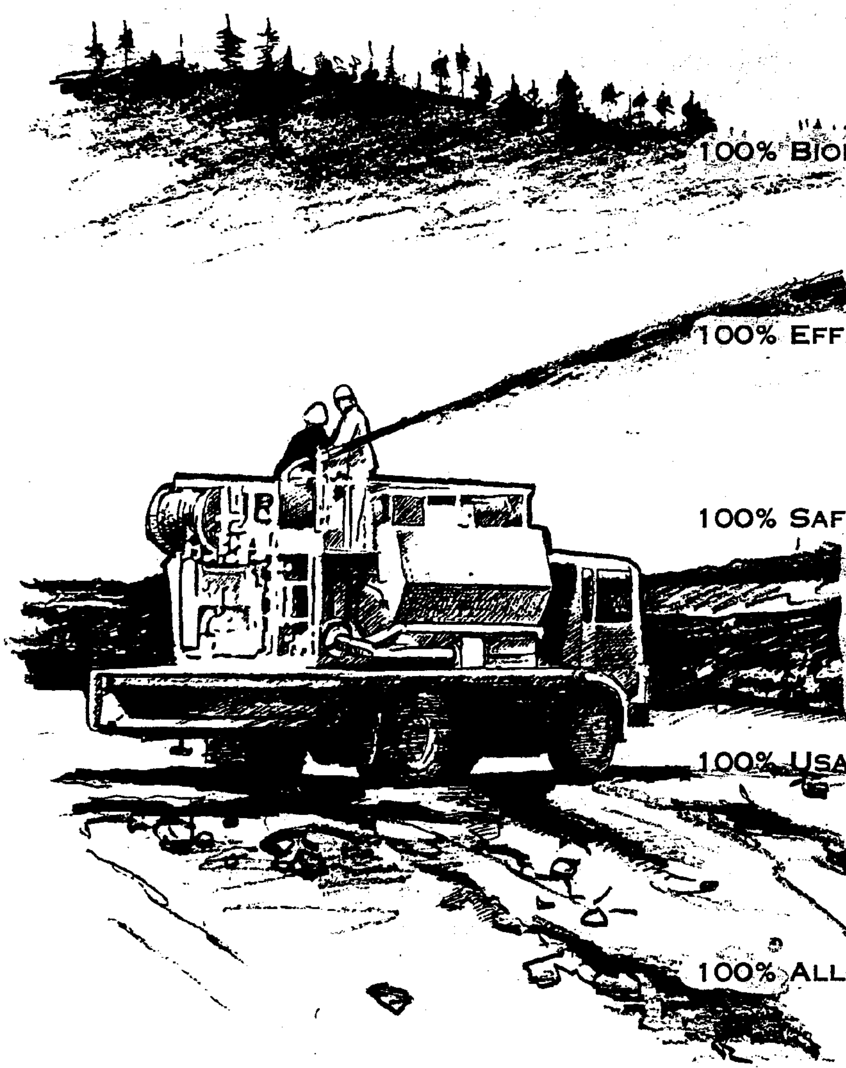
FISCH-**STIK**

The "100%" Mulch and Straw Tackifier



100% BIODEGRADABLE

Organic formula contains no harmful ingredients – 100% unmodified wheat starch – safe for the environment, plants, animals, and man – not harmful to equipment either.

100% EFFECTIVE

Keeps costs down – proven in our industry as a sister product – Also used in paper, wall board, and pottery products as a bonding agent! – Equipment runs smoother too.

100% SAFE AND CONSISTENT

One of few products that has its own MSDS – Easy to clean up – Our consistent formula guarantees that the product is free of foreign contaminants, toxins, weed seed residue, with less than 1% variance in quality of consistency. No imported product such as guar or plantago can claim this.

100% USABLE

Disperses rapidly in cold water – No gel-balling – Re-wets easily with every moisture cycle – No fillers or additives for weight – Product quality enhances slurry pumping – Fewer clogs – Not effected by fertilizers.

100% ALL-AMERICAN

We're keeping your money at home – No imported parts helps our American farmer. Not many can say this.

FISCH-**STIK** is used for the adhesive binding of wood cellulose fibers and seed through hydraulic planting machines directly onto prepared soil. It is also used as a straw tackifier, along with 500 lbs.per acre of wood cellulose fiber, over blown or crimped straw. FISCH-**STIK** is used as a surface treatment for temporary stabilization of erodible soils to protect against water and wind erosion – an excellent dust control product. FISCH-**STIK** helps hold fiber, seed, and soil particles in place and aids in germination of seed for revegetation and stabilization of critically disturbed sites.

FISCH-**STIK** meets or exceeds California Department of Transportation specifications for organic stabilizing emulsions and is registered and licensed as an auxiliary soil amendment with the California Department of Agriculture.

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Appendix 4
Dissemination of Results

List of Presentations and Publications

C. S. Brown and K. J. Rice. Effects of compost, slow-release nitrogen fertilizer and straw mulch on establishment of California native perennial grasses. California Society for Ecological Restoration Seventh Annual Conference, University of California, Santa Barbara, California, October 26-29, 2000.

C. S. Brown. Effects of straw mulch, nitrogen fertilizer and compost on establishment of California native perennial grasses. Ecological Society of America, Snowbird, Utah, August 6-10, 2000.

C. S. Brown, K. J. Rice and V. Claassen. The effects of soil amendments and mulches on establishment of California native perennial grasses: a summary of selected results. Grasslands 10:1-17 (2000).

C. S. Brown. Using basic research to improve applied results in California grassland restoration. Society for Ecological Restoration Annual International Conference, San Francisco, California, September 23-25, 1999.

Chair: David B. Kelley, Kelley & Associates Environmental Sciences, Inc., Davis, CA

EFFECTS OF COMPOST, SLOW-RELEASE NITROGEN FERTILIZER AND STRAW MULCH ON ESTABLISHMENT OF CALIFORNIA NATIVE PERENNIAL GRASSES

Cynthia S. Brown[1] and Kevin J. Rice[2]. [1]Department of Ecology, Evolution & Behavior, University of Minnesota, 1987 Upper Buford Circle, St. Paul, MN 55108-6097. [2]Department of Agronomy & Range Science, University of California, One Shields Avenue, Davis, CA 95616*

Improving our understanding of the efficacy of cultural practices such as fertilization and mulch application will improve our ability to establish native perennial grasses in restoration and erosion control projects. There are potential trade-offs for many of these practices. For example, fertilizer application may improve growth of seeded perennial grasses, but relatively greater growth of weeds could result in increased competition for resources and poorer perennial grass performance. We studied the effects of municipal green-waste compost, slow-release nitrogen fertilizer and different types of straw mulch on the establishment and growth of California native perennial grasses. The mixture of perennial grasses, *Melica californica* (California melic), *Nassella pulchra* (purple needlegrass) and *Poa secunda* ssp. *secunda* (pine bluegrass), responded to interactions between nutrient availability, weeds and volunteers of the mulch species. The mixture of grasses exhibited the best nutrient status (%N) and growth with rice (*Oriza sativa*) straw mulch. Application of blue wildrye (*Elymus glaucus*) straw mulch did not improve performance of the seeded species compared to wheat (*Triticum aestivum*). Differences in decomposition rates or allelopathic effects of the straws, or both, may have contributed to the effects we detected. Competition from weeds suppressed the growth of perennial grasses, but the addition of nitrogen fertilizer eliminated this effect. Compost benefited weeds more than the seeded perennial grasses. In summary, performance of perennial grasses was best with rice straw, was improved by the addition of nitrogen fertilizer in the presence of weeds and was not greatly affected by the addition of compost.

GRASSLAND RESTORATION ON A WILDLIFE REFUGE: PARAMETERS FOR SUCCESSFUL ESTABLISHMENT

Felicia Orah Rein[1] and Scott Frazer[2]. [1]116 John Street, University of California, Santa Cruz, CA 95060. [2]US Fish & Wildlife Service, San Luis National Wildlife Refuge, Los Banos, CA.*

This study examined the success of re-introducing native flora in the San Joaquin Valley of California. The US Fish & Wildlife Service (FWS) is conducting habitat restoration on newly acquired lands on the San Luis National Wildlife Refuge. This project measured the survival success of planting 35,000 individual plugs of the native perennial bunchgrass *Sporobolus airoides*, (alkali sacaton). Specifically, this project investigated individual survivorship and the importance of the following variables in terms of establishment success: planting strategy, soil texture, soil nutrient concentrations, pH, TDS, and weed management. A pilot study was implemented on a small scale in June, 1997. The pilot plantings suffered high mortality in 1999, having significantly lower survival than when surveyed in 1998. The main planting occurred in April, 1998. Planting sites were divided into two types: linear transects and clusters of ten individuals in small basins. Results indicated that both types of plantings initially had high survival success, with survival decreasing slightly in the second year. Transect survival decreased from 85% in June, 1998, to 73% in June, 1999. Cluster survival was initially slightly higher, being 98% in June, 1998, but decreased to 80% in June, 1999. Initial soil nitrate concentrations explained a significant amount of the variance using a stepwise regression, with pH and TDS also explaining some of the variance. Overall, *Sporobolus airoides* appears adapted to the conditions at the site, suggesting that it is an appropriate species to target for restoration over the long term.

Santa Barbara Airport Wetlands Restoration Project. *Shallow depressions, recently filled by rainwater, with plants and temporary irrigation system.* © 2000 Joe Donaldson, Jones & Stokes decline throughout the night. The model predicts three phases of activity. In the first, all prey and all predators forage actively. During the second, a constant fraction of prey remain active while the activity of owls declines steadily. During this phase the capture rate of predators remains constant and the prey experience a constant ratio of risk to net energy return. During the third phase, resources become so depleted that all prey and predators remain inactive. The behavioral game stabilizes the predator-prey interaction for two reasons: 1) The prey have a behavioral refuge, and 2) the predators, via the fear responses of the prey, negatively effect their ability to capture prey.

BROWN, B. L.,[1,2] W. E. DOBSON[2] and R. P. CREED.[2] [1]Dartmouth College, Hanover, NH 03755 USA; [2]Appalachian State Univ., Boone, NC 28608 USA. **Mutualistic associations of branchiobdellids and their crayfish hosts: Evidence of a freshwater cleaning symbiosis.**

Branchiobdellid annelids are symbiotes on freshwater crustaceans. This relationship has traditionally been considered commensal, though an appropriate analysis of the costs and benefits of association has never been performed. We explored the hypothesis that the relationship between branchiobdellids and host crayfish in the New River is mutualistic rather than commensal using growth/mortality experiments, laboratory feeding experiments and field distributional surveys. Branchiobdellids significantly reduced mortality of the host crayfish *Cambarus chasmodactylus* during growth/mortality experiments, though no significant effects of branchiobdellids on host growth rates were observed. We hypothesized that potential host gill cleaning behavior exhibited by branchiobdellids could be the source of the observed reduction in mortality. To explore the mechanism behind this mutualism, we used fluorescent paint pigments to trace food items consumed by branchiobdellids and found that branchiobdellids will remove POM trapped in the gill chambers of host crayfish. Branchiobdellids also preferentially inhabit sites on host crayfish which are proximate to the host gill chamber, facilitating potential gill cleaning behavior. This evidence suggests that the interaction between branchiobdellids and their crayfish hosts in the New River may represent a rare freshwater case of a cleaning symbiosis akin to those found commonly among coral reef organisms.

BROWN, R. L. University of North Carolina, Chapel Hill, NC 27599-3275 USA. **Trends in community structure along the immigration-extinction gradient.**

Ecologists often invoke one of two contrasting groups of processes to explain the composition and structure of communities. One group includes density-dependent, extinction-driven processes, such as resource competition and assembly rules, which limit community membership to a particular subset of the available species pool that contains well-adapted, compatible, competitive species. The second group includes processes such as immigration (especially propagule pressure) and disturbance (which reduces competitive intensity) that allow a broader subset of species to establish. I propose ordering communities along a gradient from those organized largely by extinction processes to those organized largely by immigration as a means of understanding previously confusing patterns in the species diversity, compositional predictability, and invasibility of communities. Plant communities of southern Appalachian riparian zones span a broad range of disturbance and propagule pressure and, therefore, provide an ideal system to illustrate the utility of ordering plant communities along an immigration-extinction gradient. I determined species composition, richness and predictability across upland, scour bar, floodplain, and terrace positions. Species richness and exotic invasion is extremely high in floodplain and scour bar communities (immigration-driven communities). In terrace and upland communities (extinction-driven communities) there were 50% fewer species and substantially fewer plots with exotic plants. In addition, the vegetation of scour bars and floodplains is more unpredictable in species composition compared to terraces and uplands. The juxtaposition of high species richness, high frequency of exotic species, and lack of compositional predictability found in floodplain and scour bar communities can be explained by the high rates propagule pressure provided by flood water, combined with periodic disturbances from flood events. We suggest that similar patterns in other plant communities can be understood when viewed in the context of the dominance of immigration and establishment processes.

BROWN, C. S.[1] and K. J. RICE.[2] [1]University of Minnesota, Saint Paul MN 55105 USA; [2]University of California, Davis CA 95616 USA. **Effects of straw mulch, nitrogen fertilizer and compost on establishment of California native perennial grasses.**

Increased understanding of the relative efficacy of cultural practices such as fertilization and mulch application will improve our ability to establish native perennial grasses in restoration and erosion control projects. There are potential trade-offs for many of these practices. For example, fertilizing may improve growth of seeded perennial grasses but increase growth of weeds more, which could result in increased competition for resources and poorer perennial grass growth. Applying straw mulch may improve perennial grass seedling emergence, but weeds introduced in straw can negatively affect perennial grasses. We studied the effects of different types of straw mulch, municipal green-waste compost and slow-release nitrogen fertilizer on the establishment and growth of California native perennial grasses. The mixture of perennial grasses, California melic (*Melica californica*), purple needlegrass (*Nassella pulchra*) and pine bluegrass (*Poa secunda* ssp. secunda), responded to interactions between nutrient availability, weeds and volunteers of the mulch species. The mixture of grasses exhibited the best performance, i.e. nutrient status (%N and C:N) and growth, with rice (*Oriza sativa*) mulch and the poorest performance with blue wildrye (*Elymus glaucus*) mulch. Performance with wheat (*Triticum aestivum*) mulch was intermediate. Perennial grass success decreased with increasing abundance of weeds and volunteers of the mulch species, which competed with the perennial grasses for resources. Rice mulch had the lowest and blue wildrye mulch had the highest abundance of weeds and volunteers from straw, corresponding to the best and worst perennial grass performance, respectively. The effect of weed competition was eliminated by the addition of nitrogen fertilizer. Decreased nutrient availability due to differences in decomposition rates or allelopathic effects of the straws, or both, may have contributed to the effects we detected. The addition of compost benefited weeds, but not the perennial grasses overall, although the responses of individual species varied. In summary, perennial grass performance was best with rice straw, was improved by the addition of nitrogen fertilizer in the presence of weeds and was not greatly affected by the addition of compost.

BROWN, T. N., M. BOURDAGHS, B. W. DEWEY, C. A. JOHNSTON and J. PASTOR. University of Minnesota, Duluth. **Vertical N distribution and light interception as a mechanism for direct competition between sedges and grasses.**

A spatial and temporal transition from sedge dominated to grass dominated communities is characteristic of many wet graminoid meadows in the north-central US and south-central Canada. While the spatial distribution of the two plant groups is closely related to soil moisture, competition free trials show that moisture is not solely responsible for the transition. Field measurements of vertical biomass distribution in the dominant grass and sedge species are combined with an extensive light interception study to elucidate possible mechanisms for competition and exclusion between the two groups. At any one time the sedges *Scirpus cyperinus, Carex lacustris* and *C. rostrata* dominate the lower, wetter regions of the studied wetlands, while the grass *Calamagrostis canadensis* dominates the higher, drier regions. A shift towards *Calamagrostis* may also occur if there is a tendency for the wetland as a whole to become drier over time, as is the case for meadows forming in place of abandoned, drained, beaver ponds. By producing leaves at various heights on the stem, grasses like *Calamagrostis* are able to position more biomass in the mid-canopy than sedges, which produce leaves only at ground level. A *Calamagrostis* plant with 0.2 g of biomass between 0 and 10 cm above ground may have 0.4–0.5 g of biomass between 50 and 60 cm above ground. Sedges invariably displayed decreasing biomass with height, a function of their structure. However the tendency to increased mid-canopy biomass in *Calamagrostis* was reduced in saturated conditions. Light penetration was minimal below mid-canopy in dense, typically wet stands. The ability of *Calamagrostis* to produce more light capturing biomass at mid-canopy level in drier conditions may be the mechanism driving the sedge to grass transition along moisture gradients in wet graminoid meadows.

GRASSLANDS

A Publication of the California Native Grass Association Volume X, No. 1 Winter 2000

The effects of soil amendments and mulches on establishment of California native perennial grasses: a summary of selected results

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Editors note: Complete details of the results of this experiment will be available by July 2000 in a final report to the California Department of Transportation and can be obtained through their publications office at that time.

Abstract

Increased understanding of the relative efficacy of cultural practices such as fertilization and mulch application may improve our ability to establish native perennial grasses in restoration and erosion control projects. There are potential trade-offs for many of these practices. For example, fertilizing may improve growth of weeds to a greater extent than seeded perennial grasses, which could result in increased competition for resources and poorer perennial grass performance. Applying mulch may improve perennial grass seedling emergence, but weeds introduced in the straw may reduce perennial grass growth. We studied the effects of different types of straw mulch, compost and slow-release nitrogen fertilizer on the establishment and growth of California native perennial grasses. The mixture of perennial grasses, California melic (*Melica californica*), purple needlegrass (*Nassella pulchra*) and pine bluegrass (*Poa secunda* ssp. *secunda*), responded to interactions between nutrient availability, weeds and volunteers of the mulch species. The mixture of grasses exhibited the best nutrient status (%N and C:N) and growth with rice (*Oriza sativa*) straw mulch. These indices showed that the mixture performed most poorly with blue wildrye (*Elymus glaucus*) straw mulch; performance with wheat (*Triticum aestivum*) mulch was intermediate. The responses of individual species to mulch treatments varied. Success of the perennial grasses may have been primarily influenced by weeds and volunteers of the mulch species that grew from the straw. Rice straw mulch had the lowest and blue wildrye mulch had the highest abundance of weeds and volunteers from mulch. Differences in decomposition rates or allelopathic effects of the straws, or both may have also contributed to the effects we detected. The addition of compost benefitted weeds, but not the perennial grasses overall, although the responses of individual species varied. Competition from weeds suppressed the growth of perennial grasses, but this negative effect was eliminated by the addition of nitrogen fertilizer. In summary, perennial grass performance was best with rice straw, was improved by the addition of nitrogen fertilizer in the presence of weeds and was not greatly affected by the addition of compost.

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Introduction

The appropriate cultural practices to apply in revegetation projects using native perennial grasses are still being developed. Many

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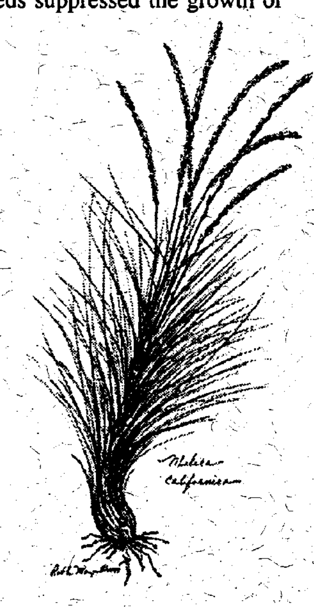

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currently used methods provide a great deal of promise, but their efficacy individually and in combination need to be tested. Applying soil amendments that will immobilize nitrogen and release it slowly can be a valuable tool in successful revegetation and restoration of plant communities (Morgan 1994; Zink and Allen 1998). The practice may provide an advantage for slower growing native perennial species in competition with fast growing, weedy species that benefit from high nitrogen conditions (Chapin 1980; Jackson et al. 1988; Hart et al. 1993; Davidson et al. 1990; Claassen and Marler 1998; Zink and Allen 1998)(but also see Wilson and Gerry 1995 and Reever Morghan and Seastedt 1999).

The use of soil amendments that provide small amounts of nitrogen over long periods of time can also encourage the establishment and persistence of vegetation on severely degraded sites (Claassen and Hogan 1998, Brown et al. 1998). Claassen and Marler 1998 showed that slow-growing perennial grasses can benefit from limited nutrient availability when competing with fast-growing species.

The application of straw mulch is a common practice in revegetation. The benefits of surface mulch for establishing plants from seed have been well demonstrated (Clary 1983; Gupta et al. 1984; Phillips and Phillips 1984; Kwon et al. 1995; Abrecht et al. 1996; Bautista et al. 1996; Byard et al. 1996; Cavero 1996; Rahman et al. 1997). Surface mulch application also has well-known erosion control benefits (Osborn 1954; Kay 1978; Clary 1983; Bautista et al. 1996). Applying mulches to the soil surface can result in increased immobilization of nitrogen similar to incorporation of soil amendments with high C:N (carbon to nitrogen ratio) (Zink and Allen 1998, Holland and Coleman 1987).

Straw mulch is typically applied to erosion control plantings after road construction at a rate of 4,500 kg/ha (4,000 lbs/acre) (Haynes personal communication, Kay 1978). Wheat and barley straws have been the most easily obtained and most widely used straw mulch in the past. However, there are now several alternatives to wheat and barley straw available. Rice straw is abundant since burning of rice fields post-harvest has been reduced in the Central Valley of California. Use of rice straw for erosion control would provide a valuable market for this agricultural by-product and, indirectly help improve air quality through reduced burning. Rice straw may also be preferable to wheat or barley straw for revegetation because it and its associated weed flora are adapted to flooded conditions. As recognized by Clary (1983), these wetland plants may compete significantly less with species seeded for erosion control than wheat, barley and their associated dryland weeds because they are less likely to survive under typical revegetation conditions.

However, at least one revegetation specialist has reported poor performance of native perennial grasses when rice straw mulch is applied after seeding (Scott Stewart personal communication). Because of its high silica content, rice decomposes less quickly than other types of straw. This may result in reduced nitrogen immobilization, resulting in relatively greater nitrogen availability under rice straw mulch than other types of straw mulch that decompose more readily. The slower decomposition of rice straw may protect the soil surface for a longer period of time than other types of straw mulch. Rice straw also has greater loft than other types of straws, resulting in a thicker layer for a given amount of rice. Because of this, it is typically specified at the lower rate of 3,375 - 3,940 kg/ha (3,000 - 3,500 lbs/acre) than other types of straw (John Haynes personal communication).

Now that native perennial grass seed is being produced commercially, straws of these species have become available for erosion control projects. One of the benefits of using native grass straw is that volunteers of the straw species can contribute to the stand of desirable vegetation. It is also possible that native grasses have evolved to grow best under the vegetation of their own species or other native species. They may benefit from the particular light, nutrient and chemical environment created by native grass straws, but this hypothesis has not been investigated. Native grasses, when used as straw mulch, have the disadvantage of being upland species like wheat and barley. The weed flora contained in their straws is more likely to be adapted to erosion control planting sites and may compete significantly with the seeded species, although Clary (1983) noted that native grass straw may help minimize weed problems.

In this experiment, we investigated the effects of (1) soil amendments including low nitrogen availability compost and slow release synthetic nitrogen fertilizer and (2) straw mulch application including application rate and straw type on the establishment and growth of a seeded mixture of California native perennial grasses and resident vegetation. We designed the experiment to gain insight into the degree to which weeds and seeded species benefitted from these cultural practices in order to develop recommendations that will maximize benefits to the seeded species and minimize those to weeds.

Methods

Site description and precipitation

The experiment was conducted in Yolo County, California on Corning gravelly loam soil from fall 1997 through spring 1998. The experiment was planted on beds (150 cm wide) that had been harrowed to as equally fine soil structure as possible and to a depth of 10 cm. The wet-season of 1998 was very long and the total amount of precipitation was 123% of the 30 year average (Owenby and Ezell 1992). The longest periods without rain between November and June were 13 days in December and 9 days in January-February. Otherwise, only 1 to 3 days passed between storms. Conditions were very favorable for perennial grass establishment.

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Soil amendments

All plots were amended with available phosphate (1.90 %), soluble potassium phosphate (3.34 %), sulfur (3.34 %), and magnesium (1.67 %) in order to ensure that these nutrients would not be limiting. The compost treatments were as follows:

(1) No compost or nitrogen added (hereafter control without amendments).

(2) Compost (hereafter compost alone).

(3) Low nitrogen treatment with 0.97 % slow release nitrogen fertilizer, from equal weights of isobutylidene diurea (IBDU) and urea-formaldehyde (15.48 kg N/ha 13.73 lb N/acre) added with compost (hereafter low nitrogen).

(4) 1.92 % slow release nitrogen fertilizer from equal amounts of IBDU and urea-formaldehyde (31.43 kg N/ha, 27.89 lb N/acre) added with compost (hereafter high nitrogen).

Compost (municipal greenwaste product from Hydropost, Organics International, Irvine, CA, U.S.A.) was applied by hand at a rate of 91.4 m^3/ha (48.4 yrd^3 per acre) and rototilled into soil to the depth of 2.54-10 cm (1-4 inches). The compost itself contained approximately 1.65 % N (Claassen and Hogan 1998), so contributed no more than 878 kg N/ha (782 lbN/acre), although no more than about 128 kg N/ha (114 lb N/acre) would probably become available to plants.

Seeding

A mixture of three species of California native perennial grasses was seeded on October 16, 1997 using a wildflower broadcast seeder (Truax Company, Inc., 3609 Vera Cruz Avenue North, Minneapolis, Minnesota 55422), followed with chains to cover the seed and a ring roller to compact the soil. The species included were California melic (*Melica californica* Scribner) (151 pure live seeds/m^2, 14 seeds/ft^2) (from Fisk Creek in the Cache Creek watershed), purple needlegrass (*Nassella pulchra* [A. Hitchc.] Barkworth) (54 pure live seeds/m^2, 5 seeds/ft^2) (from the Stone Ranch, Yolo County, CA), and pine bluegrass (*Poa secunda* ssp. *secunda* J.S. Presl.) (872 pure live seeds/m^2, 81 seeds/ft^2) (from Fisk Creek).

Mulch

Straw of wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), and the California native perennial grass blue wildrye (*Elymus glaucus* Buckley) was applied at two different levels, 3,375 kg/ha (3,000 lbs/acre) and 5,625 kg/ha (5,000 lbs/acre) to each of the nitrogen fertilizer treatment plots. Only wheat straw at two levels was applied to the control without amendments. The standard prescription for straw is 4,500 kg/ha (4,000 lb/acre). We first applied mulch on October 21-22, 1997 and sprinkler irrigated beginning October 23, 1997. Irrigation was discontinued when the wet-season began in November. Because of high winds that partially removed straw, all straw was raked from the plots and reapplied October 28, 1997.

Weed control

Weeds were removed from half of each compost, nitrogen, and mulch treatment combination. The weeded areas were sprayed with the broadleaf specific herbicide Banvel February 28, 1998 at 1.0 a.i. kg/ha (0.91 a.i. lb/acre). Species that were not seeded or were not volunteers from the mulch species in each plot were removed from the weeded areas by hand April 7-8 and May 15, 1998.

Monitoring

Monitoring of the experiment began May 5, 1998. A 0.1 m^2 circular ring was place in the center of each 2.3 m^2 plot (1.5 m X 1.5 m, 5 ft X 5 ft). We recorded the dominant weeds and clipped the aboveground biomass of weeds and mulch species. The number of seedlings of each of the seeded species rooted within the ring were counted. Three individuals of each of the seeded species were measured to make non-destructive estimates of biomass.

Data analysis

The effects of nitrogen fertilizer were evaluated in analyses that included the plots to which compost and mulches were applied (excluding the control without amendments). Plots that received compost with and without wheat mulch (without nitrogen fertilizer) were compared to plots without compost with and without wheat mulch (without nitrogen fertilizer) to evaluate the effects of compost.

RESULTS

Compost effects and interactions with wheat straw mulch

To evaluate these effects, we compared plots that received wheat straw mulch or no mulch with compost (no nitrogen fertilizer) to plots that received wheat straw mulch or no mulch without compost (no nitrogen fertilizer). We found that the density and biomass of the perennial grass mixture were not affected by addition of compost ($p = 0.54$ and 0.22, respectively). When the densities of the three species of perennial grass were analyzed individually, none were affected by the addition of compost ($p > 0.05$). Compost had no effect on pine bluegrass and California melic biomass, however, the response of purple needlegrass to compost depended on whether or not mulch was present ($p = 0.02$). Purple needlegrass biomass was greater with compost than without it when no mulch was applied, but there was little difference between the two compost treatments with either wheat straw level; mulch appeared to eliminate the benefit of compost for purple needlegrass (Figure 1). We did not detect an effect of weeds on purple needlegrass biomass ($p = 0.39$), but California melic produced more biomass when weeds were removed (*p*

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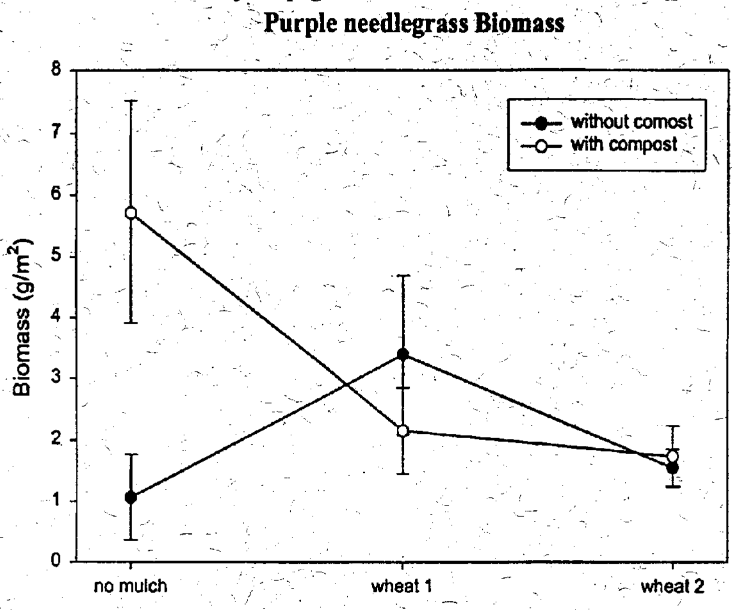

Figure 1. Biomass produced by purple needlegrass with different mulch treatments depended upon compost application (mean + 1 standard error of the mean). Wheat 1 = 3,375 kg/ha (3,000 lb/acre), wheat 2 = 5.625 kg/ha (5,000 lb/acre).

= 0.04) and pine bluegrass demonstrated a similar, but non-significant, tendency (p = 0.06). Weed biomass was greater in the treatment with compost (333.6 ± 66.3 g/m^2) than the treatment without compost (143.0 ± 29.5 g/m^2) (p = 0.008).

Nitrogen, mulch and weed effects

Mixture of perennial grasses and individual species

To evaluate these effects, we analyzed the plots that received compost, varying levels of nitrogen fertilizer and the different mulch treatments. We found no effects of fertilizer, mulch or weeds on the density of perennial grasses (p = 0.64, 0.69 and 0.17, respectively). However, there was a significant interaction between mulch and weeds (p = 0.02) because the perennial grasses responded differently to the presence of weeds in different mulch treatments. These varied responses canceled each other out so that there was no overall effect of either mulch or weeds when averages were calculated.

When individual species for the same group of treatments were evaluated, California melic was the only species that responded to mulch, although the response was marginally insignificant (p = 0.05). Densities of California melic tended to be higher in the presence of mulch at any level compared to the no mulch control (p = 0.0004). The densities of the individual species did not respond to nitrogen level (p = 0.75, 0.67 and 0.68 for pine bluegrass, California melic and purple needlegrass, respectively). However, there was a significant interaction between mulch and nitrogen level for purple needlegrass (p = 0.01), indicating that the response of purple needlegrass density to nitrogen depended upon which straw mulch had been applied. Pine bluegrass and California melic densities were affected by weeds (p = 0.02 and 0.0009, respectively); pine bluegrass densities were higher without weeds and California melic densities were higher with weeds (Table 1). We detected no effect of weeds on purple needlegrass densities ($p < 0.05$).

When all mulch types and amounts were compared, including the control without mulch, there was a strong effect of mulch treatment on the biomass of the perennial grass mixture (p = 0.0004) (Table 2). Surprisingly, when perennial grass biomass in the control without mulch was compared to the average biomass of plots with mulch, biomass of plots with the low level of mulch, and biomass of plots with the high level of mulch, there were no significant differences (p = 0.17, 0.24 and 0.17, respectively). Rather, the differences existed between the types of mulch and the amounts applied because, on average, mulch did not change the biomass of perennial grasses compared to the control without mulch. Perennial grasses produced the most biomass in rice straw treatments compared to the average of the other mulch treatments (i.e. the average perennial grass biomass of the rice treatments was greater than the average of the other mulch treatments,

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Table 1. Densities of individual perennial grass species in different weed treaments. Values are means ± standard error of the mean. Weed treatment means within species followed by an asterisk are significant different based on planned linear contrasts (P<0.05); N = number of plots included in the analysis

Treatment	California melic		Purple needlegrass		Pine bluegrass	
	N	Density (plants/m²)	N	Density (plants/m²)	N	Density (plants/m²)
With weeds	102	47.7 ±3.3*	102	12.2 ±1.2	102	25.18 ±1.02*
Without weeds	105	59.2 ± 3.2	105	14.5 ±1.5	105	21.72 ± 1.17

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Table 2. Biomass of perennial grasses for each mulch treatment. Straw was applied at 3,375 kg/ha (3000 lbs/acre) for level 1 and 5625 kg/ha (5000 lbs/acre) for level 2

Mulch type	N	Biomass (g/m²)
0	28	22.4 ± 3.8
Blue wildrye 1	28	20.9 ± 5.0
Blue wildrye 2	30	14.6 ± 1.7
Rice 1	29	35.7 ± 7.6
Rice 2	29	27.1 ± 3.6
Wheat 1	30	15.7 ± 1.7
Wheat 2	30	14.8 ± 1.1

excluding the control without mulch) ($p = 0.0001$). This was also true when the perennial grass biomass of the low level of rice straw was compared to the average of the low levels of wheat and blue wildrye straw ($p = 0.0001$) and when the perennial grass biomass of high level of rice straw was compared to the average of the high levels of wheat and blue wildrye straw ($p = 0.0005$). Perennial grasses produced significantly less biomass in the blue wildrye mulch treatment compared to the average of the other mulch treatments ($p = 0.0007$). This was also true when perennial grass biomass of the low level of blue wildrye mulch was compared to the average of the low levels of rice and wheat mulch ($p = 0.009$) and when the perennial grass biomass of the high level of blue wildrye mulch was compared to the average of the high levels of rice and wheat mulch ($p = 0.02$). Mean biomass of the seeded perennial grass mixture across all treatments was 28.5 ± 7.0 g/m².

Perennial grass biomass increased with increasing nitrogen fertilizer levels ($p = 0.04$). However, the response of perennial grasses to nitrogen fertilizer levels depended upon the presence of weeds, indicated by a significant nitrogen fertilizer by weed interaction ($p = 0.02$). In treatments receiving compost without nitrogen fertilizer, perennial grasses produced more biomass in the absence of weeds. When nitrogen fertilizer was added, biomass of perennial grasses was similar with and without weeds (Figure 2).

Weeds

The amount of weed biomass produced depended upon the mulch treatment ($p = 0.04$) (Table 3). The biomass of weeds was lower in the no mulch treatment than the high level mulch treatments ($p = 0.02$). The same but insignificant trend was detected for the no mulch treatment and the average across all mulch treatments ($p = 0.07$). Weed biomass was significantly lower in the rice mulch treatments than the average of the other types of mulch ($p = 0.04$). There was no difference in weed biomass between the low level of rice straw compared to the average of the low levels of wheat and blue wildrye straw treatments ($p = 0.42$), but there was significantly less weed biomass produced in the high level rice straw plots compared to the average of the high levels of other straw mulches ($p = 0.04$). Weed biomass was marginally non-significantly greater for the average of all blue wildrye straw treatments compared to the average of all wheat and rice straw treatments ($p = 0.05$).

Mulch species

We evaluated the biomass production by mulch species in their respective treatment plots (i.e. wheat, rice and blue wildrye plants that volunteered from seed in the straw). Different amounts of biomass were produced by the three mulch species ($p = 0.0001$) (Table 4). No rice plants grew in the rice mulch plots, whereas a moderate amount of wheat and blue wildrye grew in their respective mulch treatments. The high level of rice mulch had significantly less mulch biomass (i.e. rice) than the average of the other high level mulch treatments had of their respective mulch species (the average

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Table 3. Biomass of weeds for mulch treatments. Straw was applied at 3,375 kg/ha (3,000 lbs/acre) for level 1 and 5,625 kg/ha (5,000 lbs/acre) for level 2.

Mulch type	N	Weed Biomass (g/m²)
0	29	381.8 ± 74.1
Blue wildrye 1	29	368.8 ± 74.9
Blue wildrye 2	30	296.7 ± 63.6
Rice 1	30	324.5 ± 62.1
Rice 2	29	287.5 ± 70.0
Wheat 1	30	307.9 ± 61.4
Wheat 2	30	316.2 ± 65.6

Table 4. Biomass of volunteer plants from the respective mulch types for mulch treatments. Straw was applied at 3.375 kg/ha (3,000 lbs/acre) for level 1 and 5,625 kg/ha (5,000 lbs/acre for level 2.

Mulch type	N	Mulch Biomass (g/m²)
0	29	0
Blue wildrye 1	29	41.1 ± 6.7
Blue wildrye 2	30	88.9 ± 15.3
Rice 1	28	0
Rice 2	29	0
Wheat 1	28	95.2 ± 15.4
Wheat 2	30	82.9 ± 22.9

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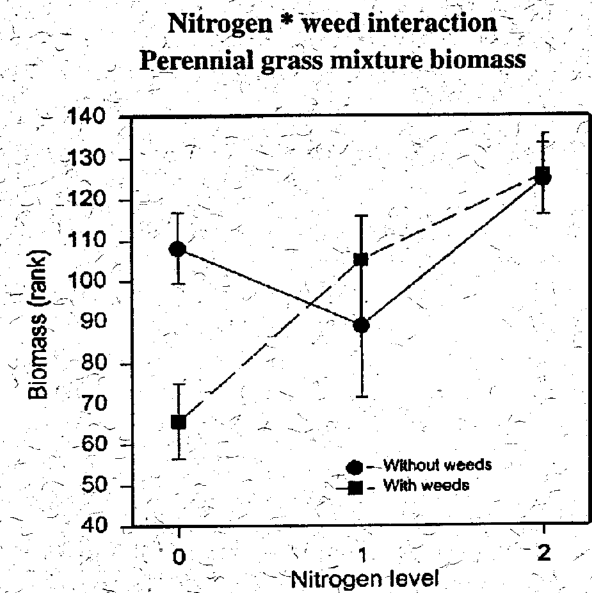

Figure 2. Response of perennial grass biomass to nitrogen fertilizer depended upon the presence or absence of weeds. Fertilizer appears to compensate for the competitive effect of weeds (mean + 1 standard error of the mean).

mulch volunteer biomass of high level wheat and blue wildrye) ($p = 0.0001$). The high level of blue wildrye straw produced more biomass of blue wildrye than the average of the high level treatments of other mulch types produced of their respective mulch species (i.e. the average mulch volunteer biomass in high level rice and wheat) ($p = 0.0001$). Mean biomass of blue wildrye from mulch was 75.0 ± 9.4 g/m^2, more than two and a half times as large as the perennial grass mixture biomass.

Discussion

Effect of compost

Weeds were the only plants that grew larger with compost than without it; purple needlegrass without mulch was the only case of improved growth with compost. Even though the nitrogen in the compost should have been released very slowly, the weeds appeared best able to utilize the available nutrients. The response of purple needlegrass biomass to compost depended upon mulch treatment. It was greater with compost than without compost if mulch was not applied, but similar in both compost treatments when straw mulch was applied. Adding mulch apparently eliminated the benefit of compost. It is unlikely that this result can be attributed to competition from weeds introduced in the mulch because we detected no effect of weeding on purple needlegrass biomass. Purple needlegrass growth was not reduced by the addition of mulch to plots without compost, making allelopathic effects of wheat straw an unlikely explanation for the observed effect. Several alternative explanations are possible, including that (1) volunteer wheat plants from the mulch were removing resources provided by compost, or (2) nutrients from compost were immobilized by microorganisms breaking down the straw mulch, or both.

Effect of mulch presence

Even though applying mulch only benefitted the growth and establishment of California melic, the use of mulch in such plantings should not be abandoned. One reason that we may not have detected a benefit for most species was the climatic conditions of the year. The distribution of rainfall events was very regular and so problems of soil crusting that may have been ameliorated by mulch were not evident. Also, the benefits of mulches to seedling establishment, especially under dry and hot conditions has been shown in many cases (Rahman et al. 1997, Abrecht and Bristow 1996, Townend et al. 1996, Byard et al. 1996, Cavero et al. 1996, Kwon et al. 1995).

It is important to note that plots without mulch had lower weed biomass than those with mulch. This suggests that significant weeds were introduced to the site in the straw. Optimal performance of native grass restoration and revegetation depends on the use of weed-free straw to minimize competition with weedy species.

Application of mulch may also have lead to decreased nutrient availability. Nitrogen may be immobilized by microorganisms decomposing the straw, even though it was not incorporated into the soil (Holland and Coleman 1987, Zink and Allen 1998).

Effects of mulch type

Perennial grasses performed best with rice straw mulch. These findings appear to be the result of interactions between the weeds present in mulches (there was lower weed biomass in rice straw treatments) and volunteers of the mulch species themselves (no rice plants volunteered), which led to reduced competition for resources. Resource availability may also have been affected by the decomposition rates of the different types of straw. Nitrogen from fertilizer may have been immobilized by micro-organisms breaking down the more easily decomposed wheat and blue wildrye straw (Zink and Allen 1998). Because rice is less readily broken down, less nitrogen may have been tied up in microorganisms and more available to the plants in the rice straw treatments.

Perennial grasses performed most poorly with blue wildrye straw mulch treatments. This straw treatment had the greatest weed and mulch species amounts, creating the least favorable conditions for survival and growth of the native perennial grasses, which was reflected in reduced growth.

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Chemicals released by straw mulch that negatively affect perennial grass growth (allelopathic compounds) may also have contributed to the effects we detected. If so, we would have expected poorer biomass production in the straw mulch treatments that contained allelopathic compounds compared to the control without mulch. Only wheat and blue wildrye straws resulted in reduced biomass compared to the control without mulch, indicating the potential for allelopathy. The notion that perennial grass species may be best adapted to conditions created by the litter of other native perennial species was not supported by our results. However, since blue wildrye volunteers from its straw performed so well, it is possible that this species is adapted to the conditions created by its own mulch. Whether this is generally the case should be systematically tested with seed and straw mulch of different native perennial grasses.

The success of blue wildrye volunteers from its straw may not be bad news for revegetation and erosion control with native perennial grasses. Since blue wildrye is a native perennial grass, its success may be desirable. The biomass of blue wildrye was over two and a half times as great as the seeded perennial grass mixture. This shows that it is possible for successful stands of perennial grasses to be established simply by spreading perennial grass straw.

Effects of weeds

Weeds generally had a negative effect on perennial grasses, although these responses often involved interactions with other factors we tested. Generally, perennial grass biomass production was lower in the presence of weeds and revegetation efforts should attempt to minimize weed introduction and success.

Effects of fertilizer

Fertilizer had remarkably little effect on the survival and growth of perennial grasses. Nitrogen fertilizer level was generally only significant in interactions with other factors (i.e. weeds and mulch). We attribute the responses to fertilizer to differences between mulches in the amount of weeds and volunteers of the straw species. The nitrogen added by fertilizer was probably removed by these plants and became unavailable to the perennial grasses. It is also possible that nitrogen was immobilized differentially by straws due to variability in their ease of decomposition, as described above.

Interaction between fertilizer and weeds

Nitrogen fertilizer appeared to compensate for the competitive effects of weeds because perennial grass biomass was greater without weeds when only compost was added and about the same with and without weeds when both nitrogen fertilizer and compost were added. The amount of fertilizer applied at this site, with the particular weed flora and inherent soil fertility, appeared to benefit the perennial grasses without affecting weed biomass significantly. It should be noted that weeds produced more biomass with the addition of compost, but further addition of nitrogen did not increase their growth significantly. Weeds were able to reach their biomass production potential with the amount of nutrients provided by the compost alone.

Interactions between mulch and weeds

The use of nutrients by weeds was the driving force behind the differences we found between mulch treatments. This is evident in the response of pine bluegrass biomass, which tended to be greater with rice straw than other straw types. Weeding made little difference in most mulch treatments, but pine bluegrass biomass increased when weeds were removed from the mulch treatments with the greatest amounts of weeds, i.e. blue wildrye and wheat straws.

CONCLUSIONS

The performance of seeded native perennial grasses was determined by complex interactions between nutrient availability and competition from weeds and volunteer plants from the straw mulch. Performance of perennial grasses in rice straw treatments exceeded that in other types of straw mulch by a large margin. Weeds that were introduced in the straw had important negative effects on the perennial grass mixtures. The positive response of perennial grasses to rice straw mulch and poor performance in blue wildrye straw mulch was primarily due to differences in competition from weeds and volunteer mulch species. Slower decomposition rates of rice straw may also have been a factor in this response. In the presence of weeds, perennial grasses benefitted from the addition of slow release nitrogen source with compost while weeds benefitted from the addition of compost alone.

Finally, we make the following recommendations:

1. Rice straw is a good mulch choice because it is likely to have fewer weeds adapted to revegetation sites, rice plants are unlikely to volunteer and it has a slow decomposition rate. All of these factors result in higher nutrient availability for the seeded species.

2. Use native straw when you want to establish the straw species and if the straw is free of weeds.

3. Apply high carbon content and slow nitrogen release fertilizers.

4. Use weed free straw.

5. Study the performance of native perennial grasses with rice and other straw mulches on very low nutrient soils with varying nitrogen levels. In these studies, plant nutrient status and available nutrients in the soil should be measured.

6. Investigate the performance of native perennial grass species with different types of native grass straw mulch to identify patterns of success and more species specific mulch recommendations.

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ACKNOWLEDGEMENTS

This research was funded by California Department of Transportation contract number 59Y570. We appreciate the assistance and advice provided by John H. Anderson, John Haynes and Scott Stewart. Many contributed time to maintaining and monitoring this experiment and we sincerely thank them all, with special recognition to the contributions of Catherine Wardner, Marcia Haver and Craig Schreifer.

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Appendix 5
Demonstration Description

One of the aims of this project was to provide examples of California native species and mixtures that may prove to be useful erosion control materials. In order to do this, we planted 22 individual species and four mixtures in separate plots. These species and mixtures are listed in the Seeding Rate Specifications Appendix 3. Locations of the plots can be found in the Site Map in Appendix 1.

There was one change to the Seeding Rate Specifications. *Poa compressa* was not included in the fine leaf fescue mix but was one of the individual species planted. Plots were seeded either with the Truax Flex II Grass Drill or by hand broadcasting without incorporation. Plots were covered with a mixture of fiber, fertilizer and (800 lbs/acre fiber, 200 lbs/acre 16:20:0 fertilizer).

Caltrans personnel qualitatively evaluated these demonstration plots, but not in a systematic manner. Establishment of most species was apparently poor due to flooding at the time of seeding, so fair comparisons or evaluations cannot be made. The legume *Lotus purshianus* performed satisfactorily in at least one plot.