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Restoring a native grass to reduce runoff in the Watsonville sloughs

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Restoring a Native Grass to

Reduce Farm Runoff in the

Watsonville Sloughs

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ABSTRACT

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by Michael Ashworth Powers

Reestablishing native biodiversity in agricultural ecosystems is increasingly viewed as an opportunity to restore some of the ecological functions of farmscapes. In California, resource managers recommend planting the native grass Creeping Wild Rye (*Leymus triticoides*) on farm margins as vegetated filter strips to stabilize soils and reduce polluted runoff.

This study assessed effects of three planting treatments on *L. triticoides* establishment and farm runoff volume, sediment and nutrient load. Results indicated that planting high-density plugs (9 /m^2) established greater *L. triticoides* cover than did direct seeding ($p < 0.001$; n=8), and both surpassed low-density plugs (4 /m^2).

Seeding, however, tended to prevent runoff ($p = 0.055$) and reduce sediment and nutrient concentrations in runoff better than plugs or unplanted controls. This study suggests that broadcast seeding is the most cost-effective and practical strategy for establishing *Leymus triticoides* filter strips, and such plantings may indeed reduce pollution while increasing farm biodiversity.

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Introduction

Non-point source pollution is the nation's largest water quality problem, with agriculture contributing to at least half of all non-point source pollution in our nation's surface water bodies (EPA 2004). Conservation practices, such as vegetated filter strips (VFS), are being used as a best management practice to assist with such pollution problems (Daniels and Gilliam 1996, Delgado et al. 1995). VFS are defined in the Environmental Protection Agency's (EPA) non-point source pollution website glossary using the definition of Dillaha et al. (1989a) who state that vegetated filter strips are:

> ". . .created areas of vegetation designed to remove sediment and other pollutants from surface water runoff by filtration, deposition, infiltration, adsorption, decomposition, and volatilization. A vegetated filter strip is an area that maintains soil aeration as opposed to a wetland, which at times exhibits anaerobic soil conditions" (EPA 2003).

This research focuses on the first six months of the establishment for the California native perennial grass, *Leymus triticoides* used in a VFS (see Figure 1). The study site is located on a farm at the edge of Harkins Slough, found in the Watsonville Sloughs complex, Santa Cruz County, California (see Figure 2). The Watsonville Sloughs complex is a sub-watershed located within the greater Pajaro River watershed, one of eleven major watersheds that drain into the Monterey Bay National Marine Sanctuary (see Figures 3, 4, and 5).

Vegetated buffers are being promoted to reduce the impacts of intensive agriculture on the Watsonville Sloughs, and *Leymus triticoides* has been recommended by the United States Department of Agriculture (USDA)-Natural Resources Conservation

Service (NRCS) and the Santa Cruz County Resource Conservation District for use in VFS that address agricultural non-point source pollution (AMBAG 1995, WQPP 1999, USDA-NRCS 2005). However, the effectiveness of particular grass species has not been well studied. The objectives of this research include studying the difference in effectiveness between three *Leymus triticoides* planting treatments at: 1) establishing among non-native, early seral vegetation in the first six months, and 2) reducing farm runoff, including sediment and nutrient concentrations in storm event grab samples.

Background

Non-point source pollution comes from many diffuse sources, unlike pollution from industrial and sewage treatment plants. The EPA defines non-point source pollution as rainfall or snowmelt moving over and through the ground, picking up and carrying away natural and human-made pollutants (EPA 2003). NPS pollution also includes irrigation water. Pollutants are carried to lakes, rivers, wetlands, coastal waters, and even underground sources of drinking water. These pollutants include, but are not limited to, fertilizers, herbicides, and insecticides from agricultural lands, and sediment from improperly managed crop lands (EPA 2003).

Although the Clean Water Act is responsible for advances made in regulating point sources of water pollution in the United States, non-point sources have proven difficult to regulate (EPA 2004). Non-point sources from agriculture, such as high sediment, nutrient, and pesticide concentrations, continue to pose serious threats to water quality both nationally and locally (EPA 2004, CSWRCB 2005, AMBAG 1995).

Section 303(d) of the Federal Clean Water Act requires each state to list all surface waters not attaining, or not expected to attain, water quality standards after the application of best management practices (EPA 2005). In July of 2003, the EPA approved the continued listing of the Watsonville Sloughs under Section 303(d) for contamination of approximately 6.2 miles of water body by pathogens, pesticides, and sedimentation / siltation (CSWRCB 2005). These pollutants have been targeted for Total Maximum Daily Load (TMDL) plans to restore impaired water bodies required by the Clean Water Act for all surface waters on the 303(d) list (EPA 2005, CSWRCB 2005).

The California State Water Resources Control Board (CSWRCB) conducts a Non-point Source Management Program as set forth in Section 319 of the Clean Water Act. In responding to the issues of non-point source pollution in the Watsonville Sloughs complex, the CSWRCB has recognized the importance of implementing vegetative conservation practices for water quality and habitat diversity. The CSWRCB has recently funded a three year program that is a collaborative effort between the *Community Alliance with Family Farmers* (CAFF) and the Central Coast Regional Water Quality Control Board to promote "farmscaping" and provide habitat for wildlife, while addressing natural resource conservation. The long term goal of the project is to demonstrate the agronomic and conservation benefits of native plant hedgerows, vegetative buffer strips, and grassed waterways. A major part of the program's focus is to increase farm biodiversity with native plant hedgerow projects while slowing runoff, reducing sediment transport, and reducing nutrient and pesticide loading into surface waters (CAFF 2005).

Sedimentation and agricultural runoff entering the sloughs can negatively impact threatened and endangered species habitat. The Watsonville Sloughs serve as a stop on the Pacific Flyway and are home to at least 18 species of fauna and 2 species of flora that are either listed federally or by the state as threatened or endangered, or as species of special concern (see Table 1). VFS are important in protecting critical aquatic habitat from the impacts of non-point source pollution, and native grass species are preferred in order to promote California's native plant biodiversity.

Creeping wild rye (*Leymus triticoides*) is an ideal native grass for controlling runoff impacts. The species is known for its rhizomatous character and subsequent ability to stabilize soil (Barkworth and Atkins 1984, USDA 2005). In addition, *Leymus* species have been observed occurring naturally in the Watsonville Sloughs (AMBAG 1995).

RELATED RESEARCH

VFS Characteristics

The EPA recommends vegetated filter strips as a best management practice to mitigate non-point source pollution (EPA 2003). Vegetated filter strips are principally applied in the treatment of non-point source pollution generated by agricultural and livestock farming activities (Delgado et al. 1995).

Reduced plant cover strongly affects soil erosion, with agricultural sites experiencing six to ten times greater erosion rates than natural vegetation or pasture sites (Castillo et al. 1997, Olshansky 1982). Previous research indicates that VFS are effective for controlling loss of soil, trapping sediments, and removing soluble contaminants before they enter surface bodies of water (Belt et al. 1992, Vought et al. 1994, Coyne et al. 1995, Daniels and Gilliam 1996, Munoz-Carpena et al. 1999). VFS can successfully improve water quality as water moves through them (Karr and Schlosser 1978, Muscutt et al. 1993, Lowrance et al. 1997).

The USDA-NRCS sets forth guidelines for the design and installation of VFS, including recommendation of various grass species such as *Leymus triticoides* (Daniels and Gilliam 1996). However, Daniels and Gilliam (1996) indicate that there is little quantitative data regarding the effectiveness of VFS on sediment and nutrient removal, nor is there much information on effects of vegetation type (grass, forest, or weeds) or specific grass species. In particular, data are insufficient regarding the ability of recommended grass species to effectively compete with weeds commonly found in the areas where filter strips are installed.

The most important consideration in the design of VFS is width in the direction of flow (Jin and Romkens 2001). Robinson et al. (1996) found that the first 3 to 4 meters of width were the most effective part of a brome grass filter strip in removing sediment from shallow uniform flow. Dillaha (1989) found that a 4.6 meter wide orchard grass filter strip on plots with uniform flow removed 53%-86% of the sediment, and that a 9.1 meter wide filter strip in the same conditions removed as much as 70%-98% of the incoming sediment. A 6.1 meter wide VFS with a mixture of ryegrass and fescue did not exhibit a significant difference in sediment trapping efficiency compared to a 3.0 meter wide VFS of the same mix (Line 1991). Rein (1999) recorded a vegetated buffer strip 40 meters long and 20-39 meters wide, on a 12% slope, reducing the suspended sediment concentration of runoff leaving the VFS by 93% compared to the runoff entering the VFS. Other factors that influence the effectiveness of vegetated filter strips in reducing sediment loss are the timing of vegetation establishment, rainfall intensity, soil texture and soil water content at the onset of rain, area of land producing runoff, and slope length and gradient.

Dillaha et al. (1989) concluded that slope steepness and filter width affect sediment yield and concentration based on results of plots with slopes of 5%, 11%, and 16%. Sediment yield from a 12% slope was found to be greater than that from a 7% slope (Robinson et al. 1996). The effect of filter strips generally diminishes as the ratio of vegetated area (filter strip area) to non-vegetated area (pollution originating area) decreased (Magette et al. 1989).

Leymus triticoides. Species in the genus *Leymus* are known for their rhizomatous natures, and the species *Leymus triticoides* is no exception, being a strongly rhizomatous perennial found in dry to moist, and often saline meadows (see Figures 6 and 7) (Barkworth and Atkins 1984). Widespread throughout North America, *L. triticoides* has been observed growing in many stands relatively high in clay and bare soil in the Carmel Valley (Stromberg and Griffin 1996). It is the most variable species of *Leymus*, hybridizing with several other species. One such example of a hybrid is *Leymus multiflorus*, a cross between *L. condensatus* and *L. triticoides* that is found on the coast region of central and southern California (Barkworth and Atkins 1984).

Competition. Establishment and persistence of a healthy grass population is determined by many factors, including competition between plants for light, water, and nutrients, and how the results affect community succession. What happens below ground is equally, if not, more important than what occurs above ground.

Casper and Jackson (1997) state that below ground competition occurs when plants reduce available soil resources, and decrease the growth, survival, or fecundity of each other. Even though below ground competition often decreases with increasing nutrient levels, it would not be accurate to generalize about above and below ground competition across resource gradients (Casper and Jackson 1997). According to Casper and Jackson's definition of competition, the ability to take up soil resources and competitive ability are not necessarily correlated. As is possibly the case with *Leymus triticoides*, a plant may improve water uptake by growing a deeper root system and tapping a source of water unavailable to neighbors with shallow roots.

Competition for water may decrease with habitat partitioning, but competition for nutrients or light may increase as a consequence of more vigorous plant growth or increased plant densities (Casper and Jackson 1997). Water-use efficiency or nutrient-use efficiency is a plants ability to convert soil resources to biomass, and plants differ in this ability. Even in the absence of below ground interactions, these differences can affect relative plant growth rates (Casper and Jackson 1997).

Casper and Jackson (1997) also state that occupation of soil space is of primary importance in below ground competition, with the ability to occupy space depending on several root characters such as relative growth rate, fine root density, and total surface area; they cite an experiment where two evergreen shrubs and a perennial grass were grown in the field with four competition treatments: no competition, aboveground only, belowground only, and above- and belowground together. The grass was the superior competitor in the experiment, allocating three times the proportion of biomass to its roots as did either of the shrubs. It was the only species to extend roots into the soil compartment of competitors.

In this case, Casper and Jackson (1997) concluded that the apparent success of the grass was due mostly to its high productivity and extensive root system; however, they also reported on an experiment measuring root density and nutrient uptake in competing root systems that showed root abundance alone was insufficient to explain relative nutrient uptake among three species in the sagebrush steppe. *Agropyron desertorum*, a non-native tussock grass, had eight to tenfold more roots in nutrient patches than did *Artemisia tridentata*, sagebrush, one week after the patches were established, and four to sixfold more roots at three weeks. Nonetheless, the two species acquired the same amount of phosphate from the patches while taking up six to eight times more phosphate than did *Pseudoroegneria spicata*, a native grass which also had greater root densities than the sagebrush (Casper and Jackson 1997).

Nutrient availability is a major limiting factor in plant competition and resulting succession patterns, with nitrogen or nutrient enriched plots often dominated by early seral (early succession), ruderal species adapted to high fertility habitats (Tilman 1984, 1986, Carson and Barrett 1988, Herron et al. 2001). In addition, Parrish and Bazzaz (1982) noted that general plant survival was significantly lower at high nutrient concentrations and that early succession species were less affected than mid and late succession species. The ability of early succession species to adapt may explain why Tilman (1986) noted that even in low nitrogen soils early succession species grew more rapidly than plants that dominate in late succession, acquiring more nitrogen per plant from nitrogen-poor soils than late succession species.

Timing of growth and patterns of nutrient availability are important considerations in plant competition and distribution (Fowler and Antonovics 1981, Mueller-Warrant 1998, Robertson et al. 1988). As nitrogen availability changes competitive relationships among species, composition of plant communities can shift (Herron et al. 2001). The later the successional niche, the more competitive the species is for nitrogen (Herron et al. 2001).

Herron et al. (2001) studied the interactions between a non-native invasive weed, spotted knapweed (*Centaurea maculosa*), and a perennial native grass, bluebunch wheatgrass (*Pseudoegneria spicatum*), in the rangelands of northwestern United States and Canada. Spotted knapweed displaces perennial grasses and increases bare ground, surface water runoff, and stream sedimentation (Tyser and Key 1988, Lacey et al. 1989).

The early seral species, spotted knapweed, was more competitive without nutrient manipulation. Nitrogen availability was reduced with the introduction of mid-seral species of annual rye (*Secale* cereale) and bottlebrush squirreltail (*Elymus elimoides*), shifting the competitive advantage from the early seral species (knapweed) to the late seral species (wheatgrass). It is possible the persistence of mid seral species is sufficient to lower nitrogen availability in the root zone of surrounding plants, creating an environment conducive to establishment of late seral species (Herron et al. 2001).

Research reflects that early succession species have a highly adaptive ability to colonize in soils that are either nutrient rich or poor, and although Tilman (1986) found that early successional species grew more rapidly in nitrogen-poor soils than late successional species, Herron et al. (2001) believe late seral grasses such as bluebunch wheatgrass require less nitrogen than early seral species such as spotted knapweed, retaining the ability to out-compete early seral species at lower nitrogen levels.

With respect to successfully establishing perennial grasses over time, former research indicates that late successional plant communities are often found on lower nutrient soils (Herron et al 2001). Perennial grasses may have a greater chance of establishment on low nutrient soils even though early succession species are capable of removing more nutrients from the soil in early stages of growth.

Climate. Climate differences are important to consider when researching plant competition (Fowler and Antonovics 1981). Most research on VFS has been conducted in temperate climates, where rainfall is distributed through the year (Lowrance et al. 1984; Peterjohn and Correll 1984; Jacobs and Gilliam 1985; Correll et al. 1997). The Mediterranean climate of California's central coast presents a challenge in applying the results of previous farm-related VFS research (Rein 1999).

Timing of growth cycles differs in a Mediterranean climate from that of a temperate climate, where plants are dormant in the winter (Haycock and Pinnay 1993). Research demonstrates that species composition can strongly influence nutrient cycling

(Hooper and Vitousek 1998). In the Mediterranean climate, early-season annuals and nitrogen fixers set seed and senesce in the spring; perennial grasses set seed about a month later, going dormant during the dry season (Hooper and Vitousek 1998). This affects the efficiency of a VFS seasonally, depending on the species composition. The differing growth cycles of annuals and perennials may affect their ability to take up nitrogen and phosphorous due to the differing carbon input into the soil profile and its effects on microbial transformation (Rein 1999).

Native perennial grasses that thrive during the "cool season" are appropriate for use in VFS installed in Mediterranean climates. They provide a strong, fibrous stand of vegetation which is required to handle the heavy winter rains. It is possible the longer growth cycle of the native perennial grasses enables a VFS to continue functioning into the later part of the season and grow back rapidly with the arrival of winter rains.

This type of research plays an important role in fulfilling our society's need for sound environmental practices, attempting to improve water quality and reduce soil loss, while enhancing habitat with vegetative practices that promote biodiversity. It comes at a time when there is a clear need to address issues such as non-point source pollution.

CURRENT POLICY AND MANAGEMENT NEEDS

There is still insufficient information regarding the ability of a perennial grass, such as *Leymus triticoides*, to compete with ruderal species that are typically fast growing, non-native plants (early seral species). The basic objective of this research was to determine the extent to which 3 different treatments of *Leymus triticoides* can establish among highly competitive, early seral vegetation, reduce runoff and nutrient and sediment concentrations.

Implementing land use conservation practices such as VFS require time, labor, seed and plugs, mulch, irrigation, and many other supplies. These practices cost money that conservation agencies, farmers, and land users may justify spending elsewhere if the practices are not proven effective. Therefore, it is necessary to monitor the effectiveness of *Leymus triticoides* to determine whether it is a wise investment for use inVFS.

The Resource Conservation Districts of Santa Cruz and Monterey Counties, as well as the Capitola and Salinas USDA-NRCS offices, make recommendations to local growers and rural land users regarding the use of vegetation in various conservation practices (SCCRCD 1997). They base their recommendations on current research and observations of what works successfully in the field.

While research has been conducted on the effectiveness of VFS and grassed waterways, there is insufficient literature to confirm the effectiveness of *Leymus triticoides* when used inVFS. This research will assist the agencies in their recommendations to local growers and rural land users with relevance to *Leymus triticoides*' effectiveness in competing with non-native ruderal plants and reducing erosion.

Water Quality Protection Program (WQPP). Agriculture thrives on the central coast of California, where the Monterey Bay National Marine Sanctuary receives runoff from approximately 7000 square miles of inland watershed (NOAA 1999). A number of actions have been taken due to mounting concerns regarding the effects of non-point source pollution on the region's water bodies and the Sanctuary's central feature, Monterey Bay.

The National Oceanic and Atmospheric Administration (NOAA) oversees policy-making and regulation of the National Marine Sanctuary (NOAA 1999). They have instituted a Water Quality Protection Program (WQPP) consistent with the objectives of the Clean Water Act, EPA best management practices, California's *Non-Point Source Pollution Control Program,* and many other agencies' objectives or existing programs (NOAA 1999). The participating agencies, growers, special interest groups, and other parties are numerous, and there are many jurisdictions overlapping various political and resource-related boundaries (NOAA 1999).

VFS and grassed waterways are two common practices accepted for purposes of addressing non-point source pollution (Daniels and Gilliam 1996, Delgado et al. 1995, Los Huertos 1999). Although critical in reducing sediment loss, little quantitative data exists regarding the efficiency of specific types of vegetative cover under field conditions (Daniels and Gilliam 1996, Correll et al. 1997).

The USDA-NRCS and the Santa Cruz County Resource Conservation District recommend the use of creeping wild rye (*Leymus triticoides*), among other species, in vegetated filter strips adjacent to the Watsonville Sloughs. There is a need to update vegetation-related information for appropriate development and implementation of best management practices, and the Santa Cruz offices of the USDA-NRCS and Resource Conservation District, as well as CAFF, are currently working on this project (Camara 2002).

Casper and Jackson (1997) have conducted study on root characteristics and their relationship to resource uptake as it pertains to water and nutrients, and there has also been research on the effects of living plant roots on soil strength, erodibility, and detachment rate (Mamo and Bubenzer 2001). In addition, research has also been conducted examining plant associations and succession patterns, including the effects of nutrient gradients and manipulation of early, mid, and late succession species (Carson and Barrett 1988, DiTomasso and Aarssen 1991, Herron et al. 2001, Mueller-Warrant 1998, Parrish and Bazzaz 1982, Robertson et al. 1988, Tilman 1984, 1986, Tilman and Wedin 1991).

Reliable information about plant competition is limited, and there is no guarantee current information on recommended grass species is sufficient for positive results in conservation practices. Best management practices are constantly evolving; therefore, the goal of this research is to assist agencies such as the USDA-NRCS, the Resource Conservation Districts of Santa Cruz and Monterey Counties, and CAFF in future recommendations they make, contributing to an evolving vegetation database. The results of the study will also be available to the public, enabling growers and landowners to use the information when considering conservation and land-use practices.

OBJECTIVES

This research investigated how successfully the California native perennial grass, creeping wild rye (*Leymus triticoides*), established in VFS during the first 6-7 months after planting (November – May). Furthermore, this research investigated how effective

3 different treatments of *Leymus triticoides* were at establishing among non-native, early seral vegetation, and reducing sediment, and nitrogen and phosphorous concentrations from farm runoff in the Watsonville Sloughs area of Santa Cruz County, California.

After a series of initial weedings to prepare the plots, the percentage cover of vegetation data, and the water quality and sediment data reflected the combined effect of the vegetation found in each plot. The research was guided by the following questions and hypotheses.

1. To what extent does broadcast *Leymus triticoides* seed establish among early seral, non-native, plants compared to plugs of *Leymus triticoides* planted at 4 or 9 plugs /m^2?

   H_1: During the first six months of vegetated filter strip (VFS) establishment, plugs of *Leymus triticoides* planted in the ground will provide greater percentage cover than will broadcast seed of *Leymus triticoides*.

   H_2: *Leymus triticoides* VFS planted with plugs at a density of 9 plugs /m^2 will provide greater percentage cover than will VFS planted at 4 plugs /m^2.

2. During the first six months of VFS establishment, do any of the three *Leymus triticoides* treatments (seed, Plugs-9/m^2 or 4/m^2) planted in a 3 meter wide VFS reduce total runoff significantly compared to the control treatment?

   H_3: Plots planted with plugs of *Leymus triticoides* will be significantly more effective at reducing runoff than plots broadcast with seed or the control treatment in the first six months of VFS establishment as measured by runoff versus no runoff.

H_4: *Leymus triticoides* VFS planted with a density of 9 plugs /m^2 will reduce total runoff significantly compared to VFS planted with a density of 4 plugs /m^2.

3. During the first six months of VFS establishment, do any of the three *Leymus triticoides* treatments (seed, Plugs- 9/m^2 or 4/m^2) planted in a 3 meter wide VFS reduce sediment concentrations in surface water runoff significantly compared to the control treatment?

   H_5: Plots planted with plugs of *Leymus triticoides* will be significantly more effective at reducing sediment concentrations in surface water runoff than plots broadcast with seed or the control treatment in the first six months of VFS establishment as measured by g/l of coarse, dissolved, and fine sediment in storm event grab samples.

   H_6: *Leymus triticoides* VFS planted at 9 plugs /m^2 will reduce sediment concentrations significantly compared to VFS planted with a density of 4 plugs /m^2.

4. During the first six months of VFS establishment, do any of the three *Leymus triticoides* treatments (seed, Plugs- 9/m^2 or 4/m^2) planted in a 3 meter wide VFS reduce nitrogen or phosphorous in surface water runoff compared to the control treatment?

   H_0: VFS planted with plugs of *Leymus triticoides* will not significantly reduce nitrogen or phosphorous concentrations in surface water runoff compared to broadcast seed of *Leymus triticoides* or the control treatment in the first 6 months of VFS establishment as measured by parts per million of ammonium (NH_4), nitrate

(NO_3), ortho-phosphate (PO_4), total nitrogen (TN), and total phosphorous (TP) caught in grab samples during storm events.

H_0: *Leymus triticoides* VFS planted at 9 plugs /m^2 will not significantly reduce nitrogen or phosphorous concentrations in surface water runoff compared to a VFS of *Leymus* triticoides planted at 4 plugs /m^2.

METHODS

Study Site

The study site is located at High Ground Organics, an organic farming operation located in the Watsonville Sloughs watershed. High Ground Organics is adjacent to Harkins Slough, a popular bird watching location in the wetland complex (see Figure 8) (Busch 2000). Most of the runoff from the farm flows in the direction of Harkins Slough.

Soil type. High Ground Organics is located on the Tierra-Watsonville soil complex. It can be found in the Watsonville West Quadrangle, frame number 174 of the USDA-NRCS soil maps. This complex is about 55 percent Tierra Sandy loam and 30 percent Watsonville loam.

According to soil maps, the study site is located on the Tierra soil which is very deep and moderately well drained; it formed from alluvium derived from sedimentary rock. Permeability of the Tierra soil is very slow, and water is perched above a clay layer at times. The effective rooting depth of this soil is as much as 60 inches, but roots are restricted to cracks in the clay below a depth of 12 to 20 inches (NRCS 2003). It is possible the limitations of water infiltration and rooting depth can have an effect on VFS efficiency.

A soil texture test was performed with soil collected from the vegetated filter strip location. *A Flow Diagram for Teaching Texture-by-Feel Analysis* was used to determine soil texture by the "feel method" (Thien 1979). The soil test yielded a texture close to the Tierra soil, a sandy loam-to-loam soil with grittiness slightly predominant.

Climate. High Ground Organics is located in a region of Watsonville that has a mean annual air temperature of 58° (F). The low temperature can reach into the high 30's (F°) in the winter months, but usually remains closer to 40° (F) and higher (CIMIS 2005). The mean annual precipitation for the Watsonville area is about 28 inches per year (NRCS 2003). High Ground Organics experiences mean annual precipitation of about 23 inches per year, with a recent "two-year, twenty-four hour storm event" recording a peak of 2.58 inches of precipitation (Camara 2003).

Flora. Several plant communities characterize the Watsonville Sloughs, including northern coastal salt marsh, freshwater emergent marsh, central coast Arroyo willow riparian forest, coastal oak woodland, and upland and lowland grasslands (AMBAG 1995).

Both upland and lowland grassland species composition have been altered over time by disturbance, especially the invasion of non-native weeds. While possibly serving as an ecotonal community between freshwater marsh and other adjacent grasslands, the lowland grasslands have historically been affected by grazing and other farming related activities (AMBAG 1995). However, a native creeping grass (*Leymus spp.*) has been identified as part of the lowland grassland community that characterizes the seasonal wetlands of the Watsonville Sloughs (AMBAG 1995). This is consistent with the indicator status provided by the US Fish and Wildlife Service and listed on the USDA-NRCS *The Plants Database* which indicates *Leymus triticoides* as, "FAC-Facultative, equally likely to occur in wetlands or non-wetlands" (USFWS 1988). There is a 34-66% chance that sample plots containing *Leymus triticoides*, randomly selected across the range of the species, would be wetland (USFWS 1988).

Some of the other species observed in the lowland grassland community are annual bluegrass (*Poa annua*), perennial ryegrass (*Lolium perenne*), rush (*Carex spp.*), and wiregrass (*Juncus spp.*) (AMBAG 1995).

There are many non-native plant species in the sloughs. Most have either become invasive or have naturalized themselves, and the vast majority of them are herbaceous (AMBAG 1995). A few commonly seen in the sloughs are wild mustard (*Brassica spp*), wild radish (*Raphanus raphanistrum*), poison hemlock (*Conium maculatum*), dock (*Rumex crispus*), Canada thistle (*Cirsium arvense*), and Italian thistle (*Carduus pycnocephalus*).

Experimental Design

The research used an experimental design that tested the effectiveness of creeping wild rye seed and plugs for use in a VFS at High Ground Organics farm (see Table 2). Four vegetation treatments were compared in the filter strip: *Leymus triticoides* seed (S), high density of plugs (P9=9plugs/m^2), low density of plugs (P4=4plugs/m^2), and a control

(C) (no treatment). Each treatment received 8 replicates assigned in two randomized blocks (4 replicates per treatment per block) (see Figures 9 and 10).

Planting site. The planting site for the experimental plots was a filter strip installed as a buffer at the downhill edge of a growing field. There were no sources, other than the agricultural field, contributing to the runoff through the filter strip. The field has been in organic production since at least 1997, with salad mix grown as the main crop originally. Currently a polyculture of vegetables, berries, and cut-flowers is grown. During this time, the field has been annually cover-cropped during winter months with a mix of cayuse oat (*Avena spp.*), vetch (*Vicia spp.*), 'biomaster' pea (*Pisum sativum*), and bell beans (*Vicia faba*) (Pedersen 2005).

The field measured approximately ¾ to 1 acre, with a slope ranging from 17-20%. The area of the filter strip covered 192 square meters (64m x 3m). The individual plots measured 3 x 2 meters (see Figure 11). The water flowed through the 3 meter length of each plot.

VFS preparation. In studies such as this one that use transplants, removal of pre-existing herbaceous vegetation provides a general positive effect on success of the transplants (Fowler 1990). Each treatment received the same preparation for all 8 plots. To begin, all of the plots were irrigated and disked at least twice in order to remove existing plants and reduce the weed seed "bank;" then the plots were each graded with a hand-rake before planting plugs or sowing seed.

Seeded plots. The seeded treatments were sown at a rate of 16.8 g / plot

($2.8 g/m^2$ or 25 lbs./acre). The seed was raked in and "finish-graded," and lightly mulched with crop residue from the field in order to prevent desiccation or transport by wind or irrigation water.

Plugged plots. One plug treatment had a planting density of 9 plugs $/m^2$ (P9), resulting in 54 plugs / plot. The other plug treatment had a planting density of 4 plugs $/m^2$ (P4), resulting in 24 plugs / plot. Each plot was also raked to accomplish a "finish" grade and contained a light mulch of crop residue.

See Table 3 for a general break down of the material and labor costs associated with the various planting methods.

No treatment. The control treatment remained unplanted but the plots were otherwise prepared the same (raked for "finish" grade and light mulch of crop residue). They were left open for the non-target species to return and were otherwise untouched, except when string-cut in March, 2004 along with all other treatment plots.

To maintain randomization, 32 separate pieces of paper, each representing one of four different treatments, were pulled from a hat to designate the order the particular treatments would come in each VFS block.

Data Collection

Table 4 provides a model of data collection for vegetation, sediment, and water quality.

Percentage cover. Two frame rectangle quadrats measuring $1m^2$ (80cm x 125cm) were used to sample percentage cover of the plants in the center square meter of each plot. One quadrat was divided into 100 even units with fishing line, each measuring 8cm x 12.5cm (see Figure 12). Each unit represented one percent of the total area covered by the frame quadrat. The second quadrat was divided into four even units, each representing 25% of the total area. The frame quadrat broken down into 100 units was used in the earliest stages of the VFS establishment. The second quadrat (see Figure 13) was used later in the season when plant height and density made it impractical to use the first.

Data were collected from each plot approximately every 30 days, beginning in December of 2003 and ending in May of 2004. Percentage cover of ramets rather than genets was estimated in the grassed plots; ramets are grasses that result from the spreading rhizomes of genets (genetically distinct individuals). However, the fact that research was conducted during early establishment phase meant that there were only genets available to record.

Percentage cover of vegetation was not recorded in March 2004 because of challenges with abundant weed growth. The VFS was subsequently string-cut at a height of approximately 3-6 inches (see Figure 14). This replicated the farmer's management strategies and those of local conservation agencies. High weed mowing is preferred because it produces better mulch, but the string and stakes framing the individual plots of the VFS prohibited this.

Non-target species were lumped into one category for the purpose of measuring percentage cover. However, in March, 2004 a non-target species diversity index was created to characterize the weed composition of the VFS based on the DAFOR (dominant, abundant, frequent, occasional, rare) method (Sutherland 1996). The non-target species were identified and assigned a qualitative measurement of cover relative to each other. The method was used only for the last three months (March, April, and May) of the trial.

Runoff – sediment and nutrients. The VFS was to be monitored for as many as five storm events by conducting grab samples at the bottom of the individual plots that had runoff. However, there was sufficient runoff to capture grab samples during only two different storm events for the entire season, on December 29^{th}, 2003 and February 25^{th}, 2004. Table 5 provides a log of dates and the amount of precipitation received at the VFS during the extent of the research. There is also the possibility that the peak flow was missed in sampling attempts during storms with sudden, short lasting downpours, when runoff through the VFS potentially could have occurred.

Presence or absence of runoff was recorded, and runoff was captured with a hand-held device shaped similar to a dust pan, but it had a hollow handle that served as a funnel. The grab sample device measured 29 cm wide by 10 cm high, and 23cm from the front edge to the exit of the spout. The spout was 5 cm in diameter (see Figure 15).

Concentrations (g/l) of coarse, dissolved, and fine sediment were measured from the grab samples taken during the storm events. Samples were caught in 1 liter Nalgene bottles and allowed to settle for at least 24 hours. Each sample required a meticulous process of filtering to analyze the fractional sedimentation, requiring the use of 1.2 μm retention glass fiber filters, a Fisher Scientific sieve #230, a Buchner funnel, an Erlenmeyer flask and other lab accessories. Samples were initially weighed, then filtered into coarse, dissolved, and fine fractions, dried in an oven and weighed again. See Appendix 1 for a detailed explanation of the laboratory methods required to process the sediment samples.

Nutrient grab samples were caught in 100 ml bottles. They were put into a cooler with ice and taken to UCSC Environmental Studies lab where the LACHAT 8000 was used to conduct flow injection analysis for parts per million (ppm) of the following nutrients: ammonium (NH_4), nitrate (NO_3), ortho-phosphate (PO_4), total nitrogen, and total phosphorous.

Data Analysis

A one-way analysis of variance (ANOVA) for percentage cover of *Leymus triticoides* was performed between and within treatments (P9, P4, S, C) by month using a single degree-of-freedom polynomial contrast (see Table 6). The values for monthly mean percentage cover of non-target species, including standard errors, were also calculated. There was no analysis of the DAFOR data collected for non-target species because of insufficient literature related to conversions of qualitative DAFOR assessments to quantitative data sets.

The number of plots in each treatment that had runoff was recorded. Each of the four treatments was then compared for the number of plots with runoff using a series of chi-square tests, with each of the two storm events assessed separately. A chi-square test was also done on the largest individual difference between treatments for each storm event.

The low number of plots with runoff presented a challenge in producing a normalized distribution of data and prevented in-depth analysis. As a result, sediment and nutrient concentrations were combined by treatment and averaged between the two different storm events, and the means were graphically compared.

RESULTS

Competition

Vegetation - percentage cover. The higher density planting of *Leymus triticoides* plugs ($9/m^2$ or P9) maintained a greater average percentage cover of vegetation than both the lower density of plugs ($4/m^2$ or P4) and the seeded treatment throughout the entire trial (see Figure 16) (see Table 7) (repeated measures ANOVA, $p < 0.001$) (see also Table 8). In the first month of the six month period (December), the high density plug plots had an average cover of 1.20%; the low density plug and seeded plots had an average of 0.40% and 0.30% cover of vegetation, respectively. By the second month, the average percentage cover of *L. triticoides* seeded plots was already diverging from that of the low density plug plots, and this remained the case through the duration of the six month trial. By the third month, the P9 plug plots had an average of 2.60% cover of vegetation, the P4 plug plots had an average of 0.70% cover of vegetation, and the seeded plots had an average of 1.70% cover. The seeded plots had roughly 1.00% greater cover than the low density plug plots.

At month five, the high density plug plots reached an average of 4.00 % cover of vegetation, the low density plug plots had an average of 1.30 % cover of vegetation, and the seeded plots had an average of 2.90 % cover. By the sixth month, at the end of the trial, the high density plug plots had an average of 6.60% vegetation cover, the low density plug plots had an average of 2.80%, and the seeded plots had an average of 3.90% vegetation cover.

The non-target weed species grew rapidly in January and February, and the average percentage cover of non-target species observed during the study is portrayed by the graph in Figure 17 (see also Table 9). The percentage cover of non-target species remained roughly the same for all four treatments throughout the trial. Wild mustard (*Brassica* spp.) and wild radish (*Raphanus raphanistrum*) appeared to be the dominant non-target vegetation, with dock (*Rumex crispus*), and annual blue grass (*Poa annua*) appearing to be abundant in the vegetated filter strip. Italian thistle (*Carduus pycnocephalus*), Canadian thistle (*Cirsium arvense*), common barley grass (*Hordeum vulgare*), Italian ryegrass (*Lolium multiflorum*), and perennial ryegrass (*Lolium perenne*) appeared frequently in the vegetated filter strip. See Table 10 for a list of the non-target species in the VFS, and see Appendix 2 for the raw DAFOR data sheets. Grasses and thistles were each lumped into separate categories for the DAFOR data collection.

Runoff

Few plots had any runoff in either storm event. Storm Event 1 generated runoff in only 6 out of 32 plots, and Chi-square tests yielded no difference between the *Leymus triticoides* treatments and the control. Storm Event 2 generated runoff in 7 plots, and a Chi-square test yielded no significant difference when comparing all 4 treatments.

However, in the second event, a comparison of the largest difference between individual treatments showed more control plots tended to have runoff than seeded plots ($p= .055$) (see Table 11) (see Figure 18).

A comparison of the control treatment with both of the two plug treatments in the Storm Event 2 revealed no difference in runoff probability among control and high ($9/m^2$) or low ($4/m^2$) density plug plots ($p= 0.82$).

Sediment

The mean coarse, dissolved, and fine sediment concentrations (g/L) were all lower, though not significant, in seeded plots than either high or low density plugs, or control plots (see Figure 19) (see Table 12). Plug plots were indistinguishable from each other and from the controls for these parameters.

Coarse. Coarse sediment concentrations were lowest in the seeded plots, at 0.014 g/l, followed by the high density ($9/m^2$) plug plots at 0.020 g/l. The low density ($4/m^2$) plug plots had a mean concentration of 0.050 g/L, and the control plots had a mean concentration of 0.323 g/L coarse sediment.

Dissolved. The mean concentrations of dissolved sediment were 0.039 g/L, 0.127 g/L, 0.182 g/L, and 0.225 g/L for seeded, high and low density plugs, and control plots respectively.

Fine. The mean concentrations of fine sediment were 0.037 g/L, 0.270 g/L, 0.278 g/L, and 0.637 g/L for seeded, high and low density plugs, and control plots respectively.

Nutrients

Nutrient concentrations are given in Table 13. The mean levels (ppm) of ammonium (NH_4), nitrate (NO_3), ortho-phosphate (PO_4), total nitrogen, and total phosphorous were all significantly lower in seeded plots compared to the control treatment. Nutrient concentrations were also lower in seeded plots compared to high ($9/m^2$) or low ($4/m^2$) density plugs, and often the difference was significant (see Figures 20 and 21). On the other hand, the low and high density plug plots were not significantly different from each other or the control treatment for any of the nutrient parameters.

DISCUSSION

Success in establishing plug and seeded treatments of *L. triticoides* is based on variables such as successional niches of plant and grass competitors, percentage cover of non-target vegetation, and above and below ground competition for resources (Tilman and Wedin 1991, Herron et al. 2001, Rein 1999, Casper and Jackson 1997). The first research question was based on the premise that plants with established roots have a greater chance of surviving and establishing in competition with other plants than does broadcast seed because native perennial grass seedlings establish relatively poorly among annual grass seedlings (Robinson 1971, Bartolome and Gemmill 1981, Fossum 1990). In addition, it was assumed the low density plug treatment would not have adequate time to catch up to the high density plug treatment with respect to percentage cover.

While the $9/m^2$ plug treatment maintained a significantly higher percentage cover of *L. triticoides* than the $4/m^2$ plug or seeded treatments, the seeded treatment revealed potential to compete as effectively with other species as the $4/m^2$ plug treatment while establishing. In a similar study on a vegetated buffer strip, Rein (1999) found that a mix of seeded native perennial grasses (*Nasella pulchra, Bromus carinatus, Deschampsia cespitosa*) were well established by the second year and still the dominant species in the third year relative to weeds. It is suggested that, given more time, it is possible the seeded treatment could catch up with the high density plug treatment in percentage cover.

The relatively high percentage cover of non-target species compared to seeded or plugged plots of *L. triticoides* is explained by fact that the timing of data collection only lasted through the first 6-7 months of establishment for a long-lived perennial grass, and by the rapid growth rate and high seed production (i.e. there was an abundance of seed in the ground from previous years of flowering cycles) of early seral species (Herron et al. 2001). Regardless, all 3 treatments of *L. triticoides* appeared to be increasing in their establishment, and it did not appear that the *L. triticoides* treatments had an effect on, nor experienced a significant difference in, the percentage cover of non-target vegetation. However, the data revealed that the composition, and therefore the DAFOR classifications, of non-target species changed after the VFS was string-cut in March, 2004.

Casper and Jackson (1997) suggest that the relative success of the *L. triticoides* seeded treatment in establishing is based on differences in competition for above and below ground resources. While *L. triticoides* plugs have established roots, they may also compete with the fast growing non-target species for similar resources such as nutrients, water, and sunlight. The *L. triticoides* plugs are substantially bigger than the seedlings, and they occupy more soil space, contributing to elevated competition between the *L. triticoides* plugs and non-target species for nutrients and water. The *L. triticoides* plugs also require more canopy space above ground to compete for sunlight. Thus, plugs may be at a relative competitive disadvantage compared to seedlings.

The early stages of *L. triticoides* seedling growth may have benefited from the filtered sunlight created by the presence of non-target species. The broadleaf non-target species such as wild mustard (*Brassica* spp.) and wild radish (*Raphanus* raphanistrum) grew rapidly after the onset of winter rains, giving the appearance that their understory retained moisture and helped prevent dessication of the *L. triticoides* seedlings during exceptionally warm and windy winter days. Transplanted plugs of *L. triticoides* are also susceptible to shock that the germinating seedlings don't experience. It may be that the resiliency of a seed-grown, rather than a transplanted, grass would contribute to its ability to establish a healthy stand and catch up to the high density plug treatment with respect to percentage cover.

Variability in frequency and intensity of single storm events drives soil saturation levels and strongly influences sediment yield (Hobbs and Mooney 1995, Munoz-Carpena 1999). Munoz-Carpena (1999) also found that soil water content at the onset of rain was the most sensitive parameter in predicting sediment transport and trapping efficiency in a sediment loss model.

These findings may explain why Storm Event 1 had more precipitation and less overall percentage cover of vegetation to prevent runoff through the filter strip but had less runoff than Storm Event 2, which had less precipitation, more overall percentage cover of vegetation and more recorded runoff. The apparent lack of soil water content at the onset of Storm Event 1 may explain the result of there being less recorded runoff than Storm Event 2. Although Storm Event 2 was only the second time runoff was recorded, precipitation was recorded between the two storm events, possibly contributing sufficiently to soil water content at the onset of Storm Event 2 and the result of more recorded runoff.

The *L. triticoides* seeded treatment showed promise with respect to reducing runoff and sediment concentrations compared to the plug or control treatments. In non-submerged overland flow, flow resistance is made up of resistance due to surface roughness and drag force resulting from vegetative elements (Thompson and Roberson 1976). It may be that the *L. triticoides* seeded treatment possibly reduced runoff and sediment concentrations more for this reason.

Architecture of the vegetation, especially the effect of canopy layers of target and non-target vegetation, is important to consider when accounting for reduction in runoff and sediment concentrations (Sutherland 1996). Although the percentage cover of non-target vegetation was higher than *L. triticoides*, and the high density plug treatment had greater *L. triticoides* percentage cover than the seeded treatment, the non-target vegetation in the control treatment was composed of a diversity of species dominated by broadleaf weeds with solitary stalks, and the plugs were still patchy in the early stages of establishment. *Leymus triticoides* seeded treatment had its vegetation well distributed at ground level, possibly increasing the residence time of runoff and amount of sediment deposition.

The results of nutrient concentrations in storm event grab samples may be influenced by the total composition of vegetation in the plots with runoff. Although the *L. triticoides* seeded treatment had lower nutrient concentrations than the *L. triticoides* plug or the control treatments, the nutrient uptake is a function of many variables.

For example, the early seral species representing the non-target vegetation typically thrive in high nutrient soils compared to late seral species (*L. triticoides*), which perform better at lower nutrient levels (Carson and Barrett 1988, Tilman and Wedin 1991, Herron et al. 2001). It is possible the non-target species played a greater role in reducing nutrient concentrations in storm event grab samples. However, researchers have been found that well established late seral species (e.g. *L. triticoides*) create soils with high carbon-to-nitrogen ratios and low nitrogen mineralization rates, yielding less nitrogen available for leaching while early seral and ruderal treatments allow higher inorganic nitrogen accumulations for leaching (Tilman and Wedin 1991, Los Huertos 1999, Rein 1999).

Furthermore, Rein (1999) found no effect by the vegetative treatments on uptake of surface nutrient concentrations in a vegetated buffer strip. In addition, the data collection for this study of *L. triticoides* was conducted in winter when soil temperatures can slow biological and chemical transformations in the soil profile. Such transformations are intimately related to root activity, as illustrated by reduced uptake of phosphorous in cool soil (CFA 1998). Nonetheless, the raw data illustrates in the first 6-7 months of VFS establishment, the *L. triticoides* seeded treatment reduced nutrient concentrations in runoff more effectively compared to the *L. triticoides* plug or control treatments. This result indicates that, even in the first year of establishment, the *L. triticoides* seeded treatment may be more effective at reducing nutrient concentrations in farm surface water runoff. It is hypothesized that *L. triticoides* seedlings experienced more vigorous root growth than the plugs due to the plugs experiencing shock from being transplanted.

CONCLUSION

Future Research

The complexity of nutrient dynamics in both plant uptake and farm water runoff requires further research to assess the effects of establishing vegetative treatments for reducing sediment and nutrient concentrations in farm surface runoff. Plugs have established roots that can compete with non-target species for nutrients and space at different depths of the soil profile compared to seedlings. The ability to take up soil resources (nutrients and water) and competitive ability are not necessarily correlated. As is possibly the case with this study, plugs may improve water uptake by growing a deeper root system and tapping a source of water unavailable to germinating non-target species with shallow roots. Competition may decrease with habitat partitioning if perennial grass seedlings can establish their roots, but competition for nutrients or light may increase as a consequence of more vigorous non-target species plant growth or increased plant densities (Casper and Jackson 1997).

Research on late seral species such as *L. triticoides* would benefit from a longer trial period, perhaps 2-4 years, which would allow for more complete establishment of the *L. triticoides* treatments. Herron (2001) states that a mid-seral nurse crop can be used to lower nitrogen availability, reducing the ability of early seral species to compete and assisting in the establishment of late seral vegetation (e.g. *L. triticoides*). Common barley (*Hordeum vulgare*) has been advocated as a non-invasive annual grass suitable as a nurse crop (Rein 1999). Tilman and Wedin (1991) found that late seral species displaced early and mid-seral species when grown in pairwise competition. Further research is needed to determine if *L. triticoides* treatments would be more successful at establishing if sown or planted with a mid-seral nurse crop.

Non-target species composition and architecture, and their respective successional niches, are important to consider with respect to competition for above and below ground resources, and potential to reduce sediment and tie-up or leach excess nutrients. Further research is necessary to determine the effects of non-target species composition on VFS effectiveness. Studying strategic timing of grass and non-target species cutting is also suggested, with respect to managing weed competition and seed production, and observing sediment and nutrient dynamics in the VFS.

In addition, testing the effectiveness of the *L. triticoides* treatments in different soil conditions would be helpful to ascertain its potential for application in various field conditions. *L. triticoides* is listed by the US Fish and Wildlife Service as equally likely to occur in wetlands or non-wetlands. Researching the effectiveness of *L. triticoides* for use in more saturated conditions such as grassed waterways is recommended.

It is also important to consider the unique effects of the Tierra-Watsonville soil complex on runoff. The perched water table created from a relatively impermeable, shallow, subsurface layer is ideal for researching subsurface, as opposed to surface, nutrient uptake and runoff dynamics through the VFS treatments (Los Huertos 1999). Research could be carried out to determine how effective *Leymus triticoides* is compared to the non-target species at reducing excess nutrients at the depth of the perched water table. Results may indicate that compared to the non-target species, *Leymus triticoides* performs exceptionally well with respect to reducing excess nutrients at the depth of the perched water table based on its rhizomatous nature and ability to grow deep roots (Barkworth and Atkins 1984).

Management Implications

Efforts at the federal, state, and local levels to address agricultural non-point source pollution are increasing, and sound research is necessary to contribute to the field of literature addressing such issues. The California State Water Resources Control Board has recognized the value in promoting farmscaping to provide wildlife habitat, while addressing natural resource conservation. They have funded a three year program as part of a collaborative effort with the *Community Alliance with Family Farmers* which aims to demonstrate the agronomic and conservation benefits of native plant hedgerows, vegetative buffer strips, and grassed waterways. As part of this effort, it is necessary that agencies are confident in the materials they promote for use in VFS.

The results of this study suggest that the seeded treatment of *Leymus triticoides* is, at the very least, worthy of further investigation as a standard method for establishing vegetated filter strips. The species, when seeded, demonstrates potential to have less runoff than a vegetated filter strip composed of ruderal vegetation (control treatment), which did not exhibit a significant difference from that of the high or low density plug treatments. In a 6-7 month trial, the seeded treatment of *Leymus triticoides* was cheaper to establish and performed better than grass plugs in reducing sediment and nutrient concentrations in farm water runoff, even though the high density plug treatment performed significantly better in terms of percentage cover.

When considering the adoption of measures to address erosion and water quality problems, the success of the *L. triticoides* seeded treatment suggests that it is a viable planting method to research further for use in farmscaping conservation practices. Monitoring of VFS and other conservation practices that use *L. triticoides* is of importance to determine relative success of the grass.

Because cost is usually an issue, the importance of promoting sound materials for use in VFS and other conservation practices is critical. This study, showed that the *L. triticoides* seeded treatment is the cheapest to install and appears most effective in a six month trial. *Leymus tritcoides* deserves further research for use in conservation practices addressing agricultural non-point source pollution, and the seeded treatment should be considered as a viable option for successful practices.

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Table 1: Special Status Species Potentially Occurring in the Watsonville Sloughs

SPECIES	STATUS	PREFERRED HABITAT
Plants: Santa Cruz Tarplant (*Holocarpha macradenia*)	FC 1,SE	Grassland
Wildlife: Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*)	FE, SE	Wetland, riparian, oak woodland
California tiger salamander (*Ambystoma tigrinum californiense*)	FC 2, SSC	Wetland, grassland
Western pond turtle (*Clemmys marmorata pallida*)	FC 2, SSC	Wetland, riparian, oak woodland
Black-crowned night heron (*Nycticorax nycticorax*)	SA	Wetland, riparian
California red-legged frog (*Rana aurora draytonii*)	FC 2, SSC	Wetland
Black-shouldered kite (*Elanus leucurus*)	CP	Wetland, grassland
Northern harrier (*Circus cyaneus*)	SSC	Wetland, grassland
Burrowing owl (*Speotyto cunicularia*)	SSC	Grassland
Short-eared owl (*Asio flammeus*)	SSC	Wetland, grassland
Tri-colored blackbird (*Agelaius tricolor*)	FC 2, SSC	Wetland, grassland, riparian
Golden eagle (*Aquila chrysaetos*)	SSC	Grassland
Ferruginous hawk (*Buteo regalis*)	FC 2, SSC	Grassland
Merlin (*Falco columbarius*)	SSC	Grassland, wetland
Peregrine falcon (*Falco peregrinus*)	FE, SE	Wetland, grassland
Loggerhead shrike (*Lanius ludovicianus*)	FC 2	Grassland
Horned lark (*Eremophila alpestris*)	FC 2	Grassland
Yellow warbler (*Dandroica petechia*)	SSC	Riparian
Steelhead fish (*Oncorhynchus spp.*)	SA	Streams

Status Explanations:

FE: Federally listed endangered
FC: Federal candidate
1 Category
2 Category
SE: State listed endangered
SSC: State species of special concern

CP: California fully protected
SA: Special Animal
(AMBAG 1995)

Table 2: Experimental Design

VFS = vegetated filter strip
1 plot = 3 x 2 meters

Treatment		Number of plots
Leymus triticoides seed 17g/plot (25#/acre)		8 plots
Leymus triticoides plugs	9/m^2 (P9)	8
	4/m^2 (P4)	8
Control (C) – no treatment		8

Table 3: Establishment Cost

Treatment	**Plugs**: \$25.60/tray, 128 plugs/tray, 20¢ / plug		**Seed**: \$45 / lb.
Method	**9/m^2**	**4/m^2**	2.83 grams/m^2 (25# /acre)
Cost (\$) / m^2 **(plugs and seed)**	\$86.40 / 48m^2	\$38.40 / 48m^2	\$13.44 / 48m^2
+ labor @ \$10/hr for 48m^2 (8 plots)	12 hrs = \$120 / 48m^2	10 hrs = \$100 / 48m^2	5 hrs = \$50 / 48m^2
Total cost / 48m^2	\$206.40 / 48m^2	\$138.40 / 48m^2	\$63.44 / 48m^2
Cost (\$) / Acre	\$7,285 / Acre	\$3,238 / Acre	\$1,125 / Acre 25# /Acre
+ labor @ \$10/hr/Acre	1,012 hrs = \$10,120/Acre	843 hrs = \$8,430/Acre	422 hrs = \$4,220
Total cost / Acre	\$17,405.00 / Acre	\$11,668.00 / Acre	\$5,345.00 / Acre
Cost (\$)/Hectare	\$18,000 / Hectare	\$8,000 / Hectare	\$ 2,780 / Hectare 62# / Hectare
+ labor @ \$10/hr/Hectare	2,500 hrs = \$25,000 / Hectare	2,083 hrs = \$20,830 / Hectare	1,042 hrs = \$10,420 / Hectare
Total cost / Hectare	\$43,000.00 / Hectare	\$28,830.00 / Hectare	\$13,200.00 / Hectare

Note: Labor figures are based on rough estimates that consider variables such as the time and labor required to prepare plots and to complete finish grading.

Table 4: Data Collection

Objectives	Data Collection
Plant competition (establishment)	• % cover - visual estimates once every 30 days
Runoff / Erosion control	• Presence /absence of runoff • Sediment yield (g/L): coarse, dissolved, and fine (taken from storm event grab samples)
Water Quality	• Ammonium (NH_4), nitrate (NO_3), phosphate (PO_4), total nitrogen, and total phosphorous levels in storm event grab samples

Table 5: Precipitation

Month / Year	Date(s)	Precipitation Recorded	
December 2003	12/5 -12/7/03	0.61"	
	12/9 – 12/11/03	0.61"	
	12/29/03	1.91"	Grab samples collected
January 2004	1/01/04	1.31"	
	1/26 – 1/27/04	0.65"	
February 2004	2/2/04	0.48"	
	2/15/04	0.55"	
	2/17/04	1.30"	
	2/19/04	0.10"	
	2/20/04	0.17"	
	2/23/04	0.23"	
	2/25	1.55"	Grab samples collected
	2/26	0.37"	
April 2004	4/19	0.20"	

Table 6: Data Analysis Equations

Vegetation – One way analysis of variance (ANOVA)	
Treatment + Time + Treatment x Time + E =	- % cover L.T. plugs - % cover L.T. seed
Runoff – Chi Square tests	
Treatment + E =	- Runoff versus no runoff
Sediment – Average concentrations	
Treatment + E =	- Concentration of coarse sediment (g/L) - Concentration of dissolved sediment (g/L) - Concentration of fine sediment (g/L)
Nutrients – Average concentrations	
Treatment + E =	- Parts per million (ppm) NH_4 (ammonium) - ppm NO_3 (nitrate) - ppm PO_4 (ortho phosphate) - ppm total nitrogen - ppm total phosphorous

Table 7: Monthly Percentage Cover Averages of *Leymus triticoides* Seed and Plug ($9/m^2$ and $4/m^2$) Treatments.

	Treatment		
Month / Year	Seed	Plugs- $4/m^2$	Plugs- $9/m^2$
December 2003	0.30 %	0.40 %	1.20 %
January 2004	0.90 %	0.50 %	1.70 %
February 2004	1.70 %	0.70 %	2.60%
April 2004	2.90 %	1.30 %	4.00 %
May 2004	3.90 %	2.80 %	6.60 %

Table 8: ANOVA; Univariate and Multivariate Repeated Measures Analysis

Between Subject Effects- test for effect called: Treatment					
Test of hypothesis					
Source	SS	df	MS	F	P
Hypothesis	0.022	3	0.007	32.618	0.000
Error	0.006	28	0.000		

Single Degree-of-Freedom Polynomial Contrasts

Within subject effects- test for effect called: Constant					
Degree	SS	df	MS	F	P
1	0.016	1	0.016	146.047	0.000
Error	0.003	28	0.000		
2	0.001	1	0.001	20.764	0.000
Error	0.001	28	0.000		
3	0.000	1	0.000	15.776	0.000
Error	0.001	28	0.000		
4	0.000	1	0.000	19.353	0.000
Error	0.000	28	0.000		
Within subject effects- test for effect called: Treatment					
Degree	SS	df	MS	F	P
1	0.008	3	0.003	23.221	0.000
Error	0.003	28	0.000		
2	0.001	3	0.000	4.807	0.008
Error	0.001	28	0.000		
3	0.000	3	0.000	3.958	0.018
Error	0.001	28	0.000		
4	0.000	3	0.000	3.987	0.018
Error	0.000	28	0.000		

Table 9: Monthly Percentage Cover Averages of Non-target Vegetation in the Seeded, Plug ($9/m^2$ and $4/m^2$), and Control Treatments.

	Treatment			
Month / Year	Seed	Plugs- $4/m^2$	Plugs- $9/m^2$	Control
December 2003	11.88 %	14.31 %	13.69 %	7.75 %
January 2004	39.63 %	54.00 %	49.88 %	33.75 %
February 2004	60.00 %	70.50 %	59.69 %	46.25 %
April 2004	79.38 %	71.00 %	73.50 %	77.25 %
May 2004	67.75 %	59.88 %	57.13 %	59.38 %

Table 10: Non-target Vegetation Species Occurring in the VFS.

Family	Genus/Species	Common Name
Asteraceae	*Carduus pycnocephalus*	Italian thistle
Asteraceae	*Cirsium arvense*	Canada thistle
Brassicaceae	*Brassica* spp.	wild mustard
Brassicaceae	*Raphanus raphanistrum*	wild radish
Fabaceae	*Medicago polymorpha*	bur clover
Fabaceae	*Vicia faba*	bell beans
Fabaceae	*Vicia sativa*	common vetch
Geraniaceae	*Geranium dissectum*	cutleaf geranium
Gramineae	*Hordeum vulgare*	common barley grass
Gramineae	*Lolium multiflorum*	Italian ryegrass
Gramineae	*Lolium perenne*	perennial ryegrass
Gramineae	*Poa annua*	blue grass
Polygonaceae	*Rumex crispus*	Dock
Umbelliferae	*Conium maculatum*	Poison hemlock

Table 11: Chi-square Test Between all Four Treatments in Storm Event 2, and Between the Two Individual Treatments with the Largest Difference.

Treatment	Flow	No flow	Total
Control	3	5	8
Plugs- 4/m^2	2	6	8
Plugs- 9/m^2	2	6	8
Seed	0	8	8
Total	7	25	
Expected value	1.75	6.25	

Chi Sq Test			
	0.892857	0.25	
	0.035714	0.01	
	0.035714	0.01	
	1.75	0.49	
Total	2.714286	0.76	
Total (flow + no flow)			3.47429
Degrees of freedom			3
P-value			0.32411

Treatment	Flow	No flow	Total
Control	3	5	8
Seed	0	8	8
Total	3	13	
Expected value	1.5	6.5	

Chi Sq Test			
	1.5	0.346154	
	1.5	0.346154	
Total	3	0.692308	
Total (flow + no flow)			3.692308
Degrees of freedom			1
P-value			0.054664

Table 12: Mean Coarse, Dissolved and Fine Sediment Concentrations (g/l) Resulting from the Combined Data of Storm Events 1 and 2.

	Treatment			
Sediment (g/l)	Seed	Plugs- 4/m^2	Plugs- 9/m^2	Control
Coarse	0.014 g/l	0.050 g/l	0.020 g/l	0.323 g/l
Dissolved	0.039 g/l	0.182 g/l	0.127 g/l	0.225 g/l
Fine	0.037 g/l	0.278 g/l	0.270 g/l	0.637 g/l

Table 13: Mean Nutrient Concentrations (ppm) Resulting from the Combined Data of Storm Events 1 and 2.

	Treatment			
Nutrients (ppm)	Seed	Plugs-4/m^2	Plugs-9/m^2	Control
Ammonium (NH_4)	0.005 ppm	0.035 ppm	0.051 ppm	0.061 ppm
Nitrate (NO_3)	0.033 ppm	0.261 ppm	0.350 ppm	0.392 ppm
Orthophosphate (PO_4)	0.054 ppm	0.150 ppm	0.177 ppm	0.251 ppm
Total Nitrogen	0.201 ppm	1.120 ppm	1.101 ppm	1.60 ppm
Total Phosphorous	0.106 ppm	0.373 ppm	0.397 ppm	0.624 ppm

Figure 1: Vegetated Filter Strip (VFS).

Figure 2: Research Site with Harkins Slough in the Background.

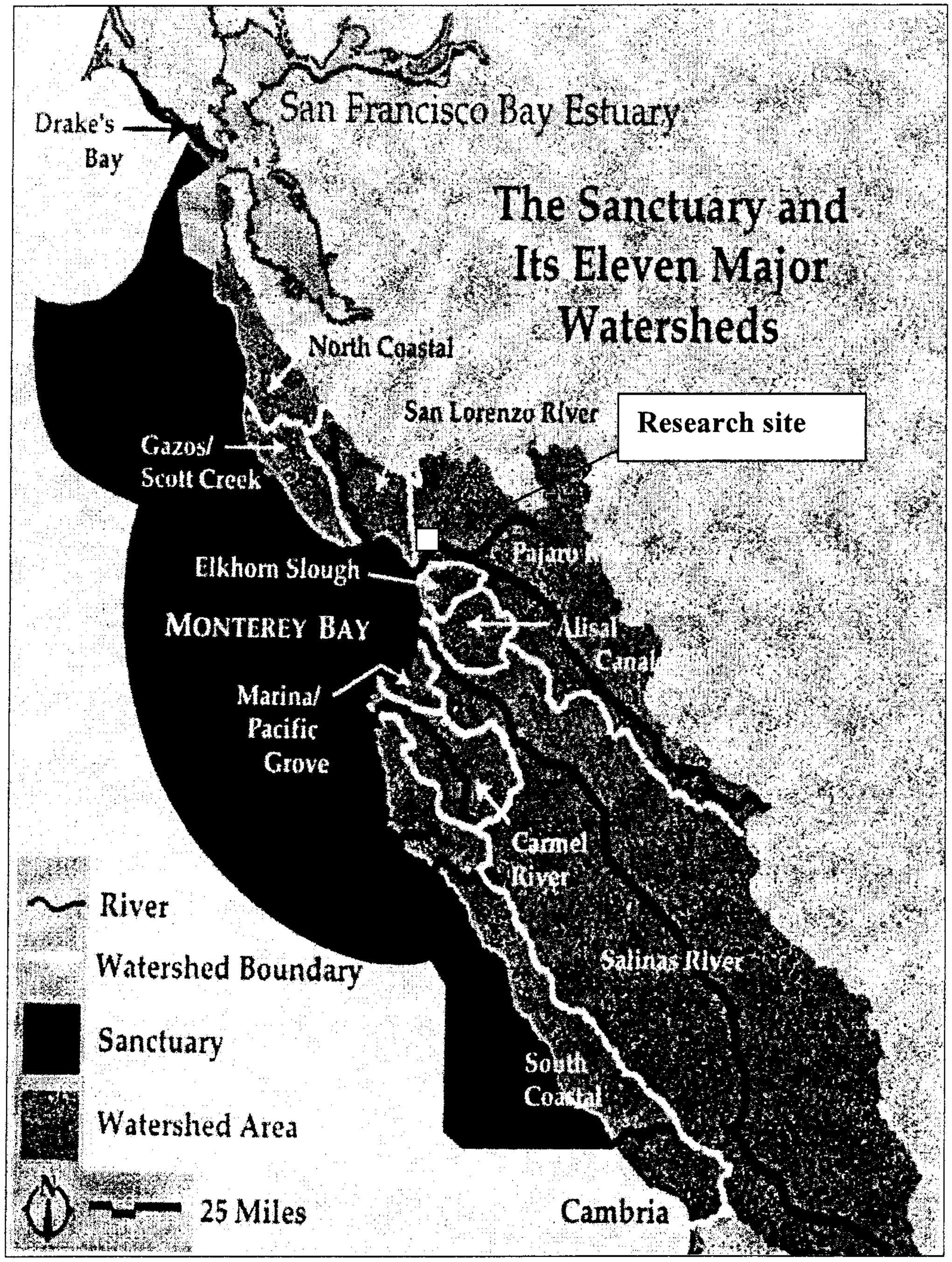

Figure 3: Map of the Eleven Major Watersheds Draining into the Monterey Bay National Marine Sanctuary (NOAA 1999).

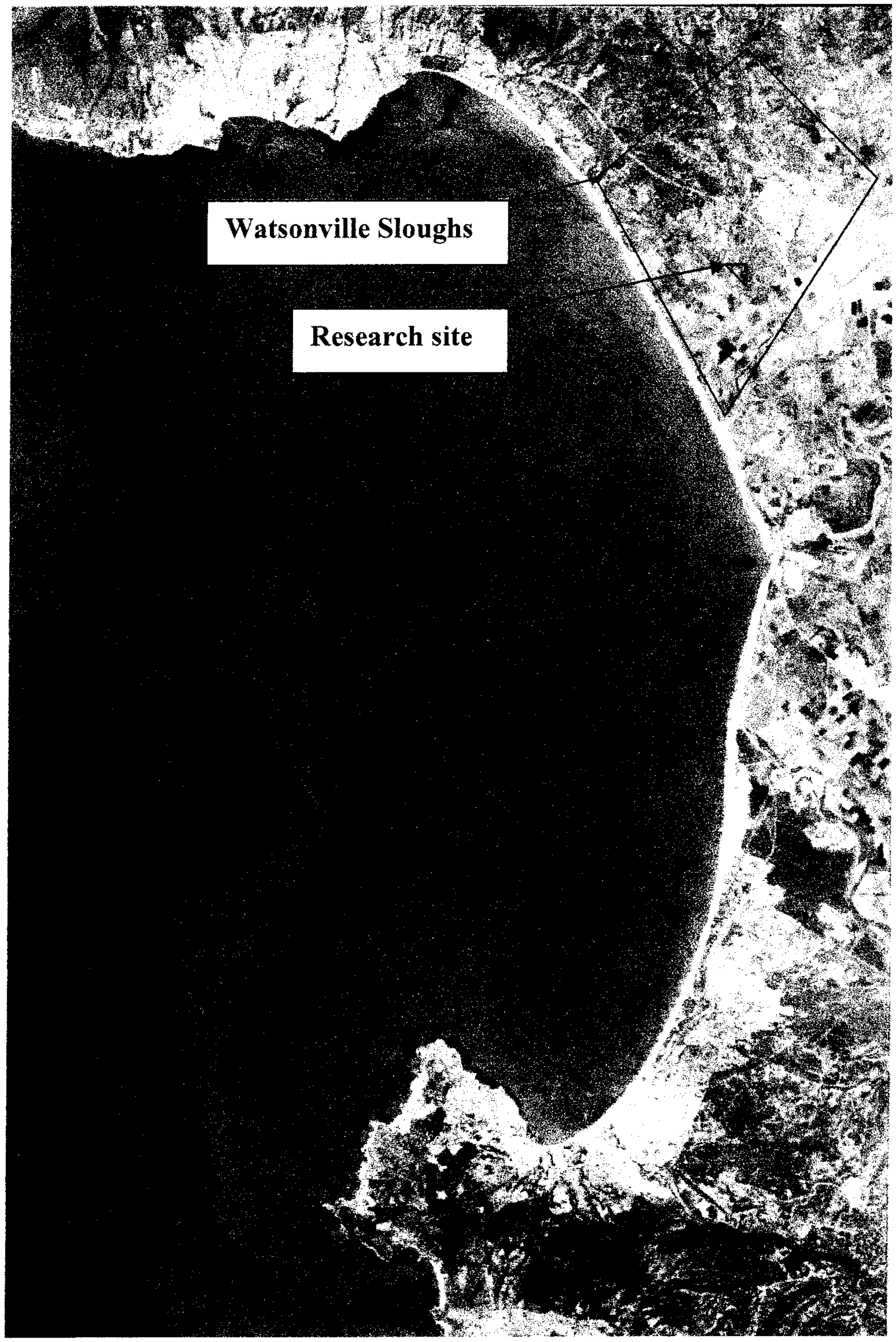

Figure 4: Satellite Image of Monterey Bay (Poster Imagery 1993)

Figure 5: Aerial Photo of Watsonville Sloughs Watershed and Research Site (SCCRCD 2002).

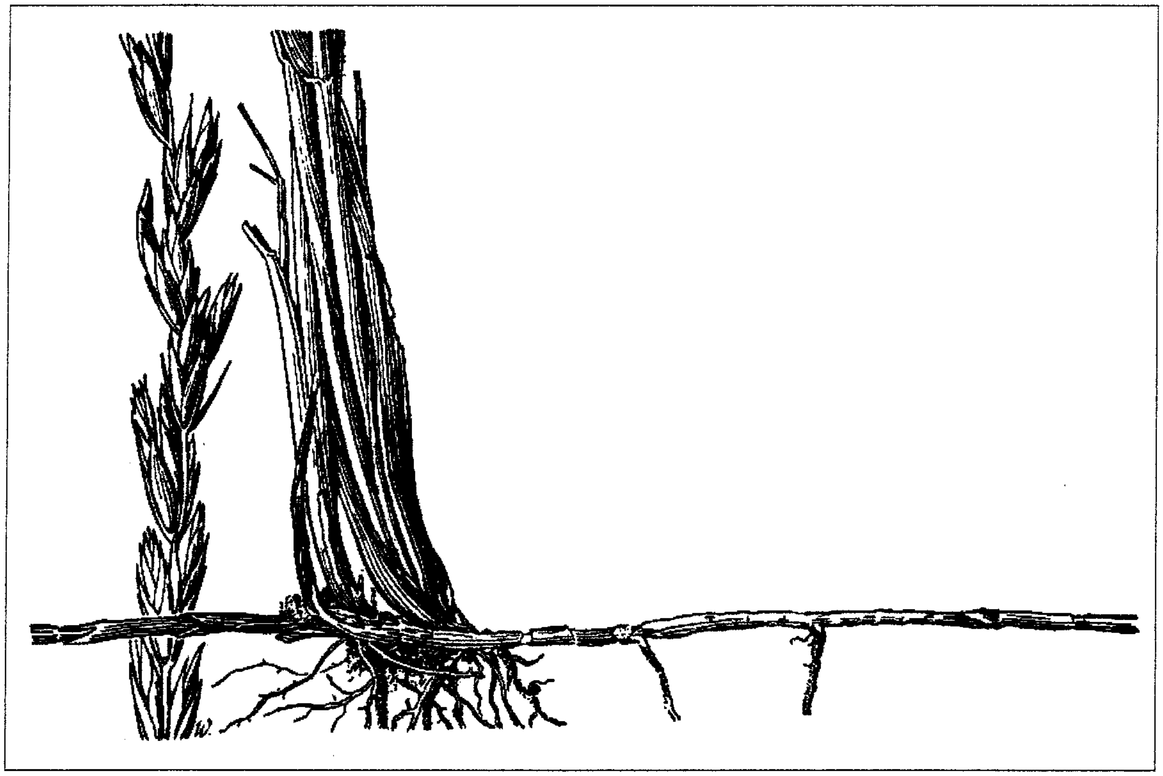

Figure 6: ***Leymus triticoides*****, Including Rhizome and Seed (Hitchcock 1950).**

Figure 7: *Leymus triticoides* Seed (USDA 2005).

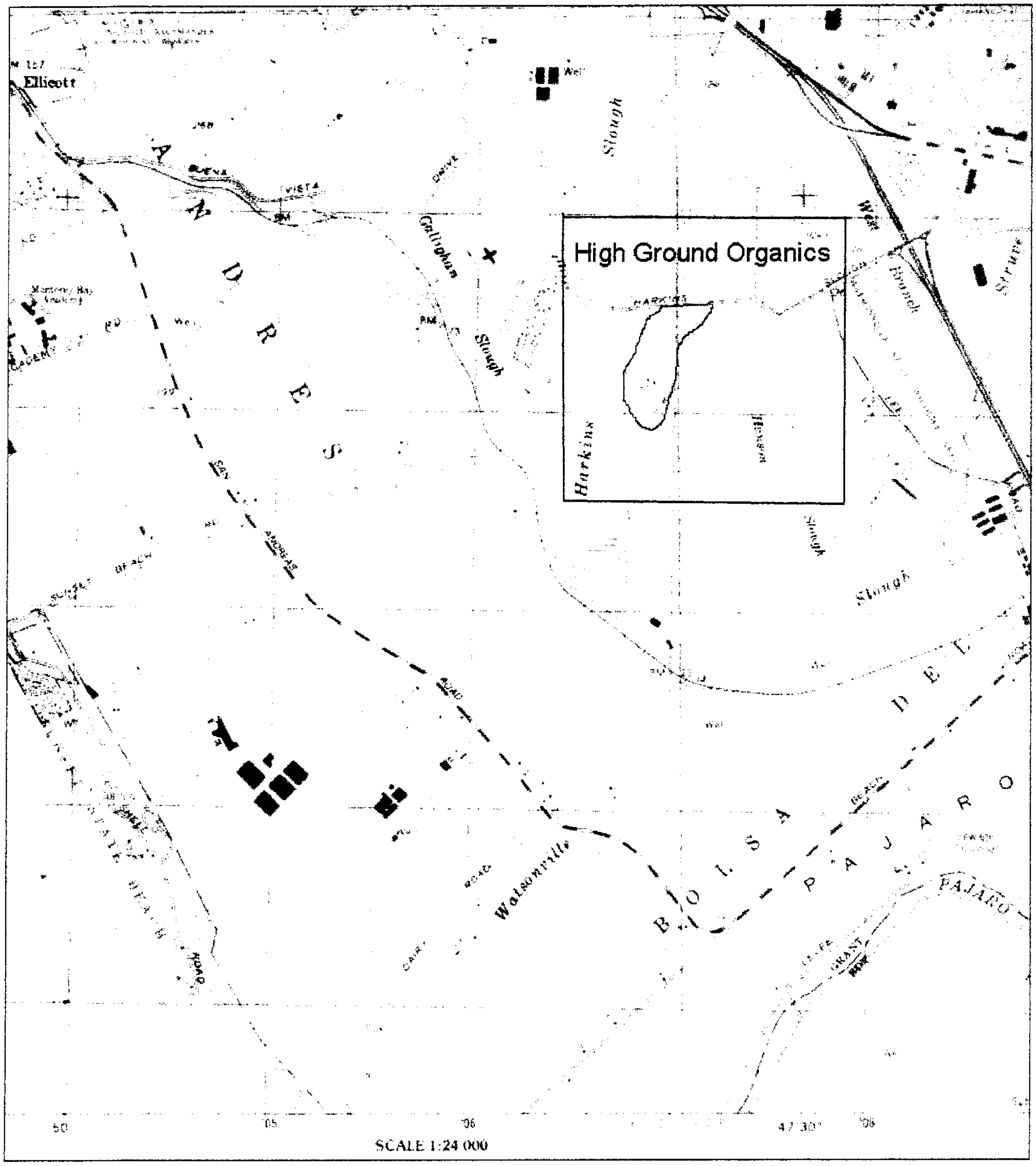

Figure 8: Topographic Map of Harkins Slough and High Ground Organics Research Site (USGS 1995).

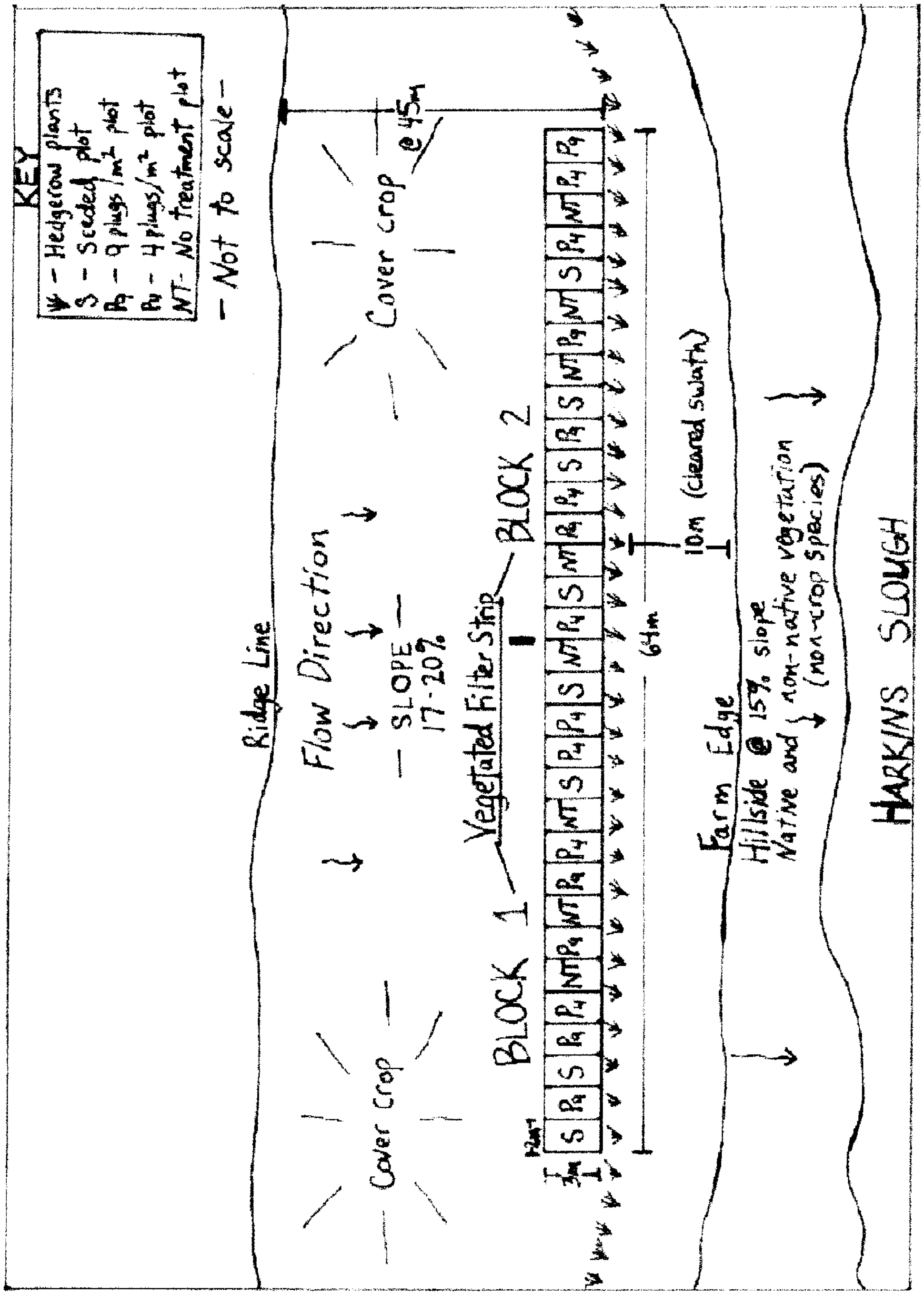

Figure 9: Research Site Including Experimental Design.

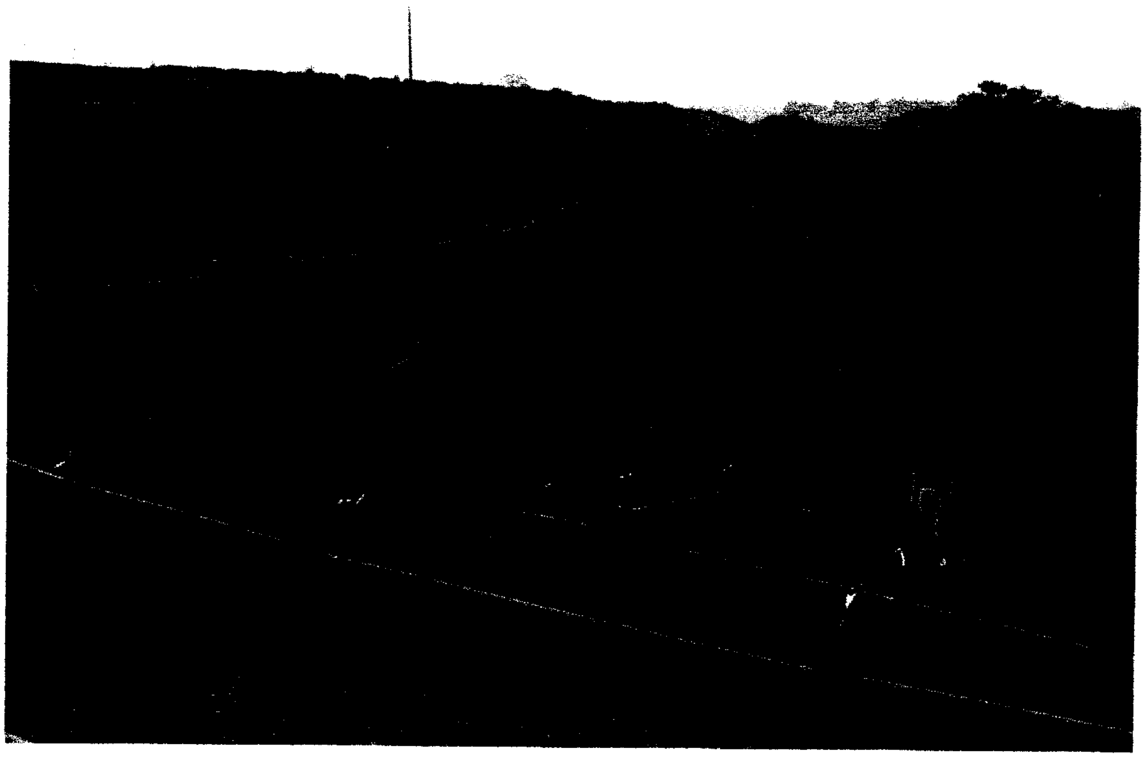

Figure 10: VFS Preparation (Photo taken by Jen Walton).

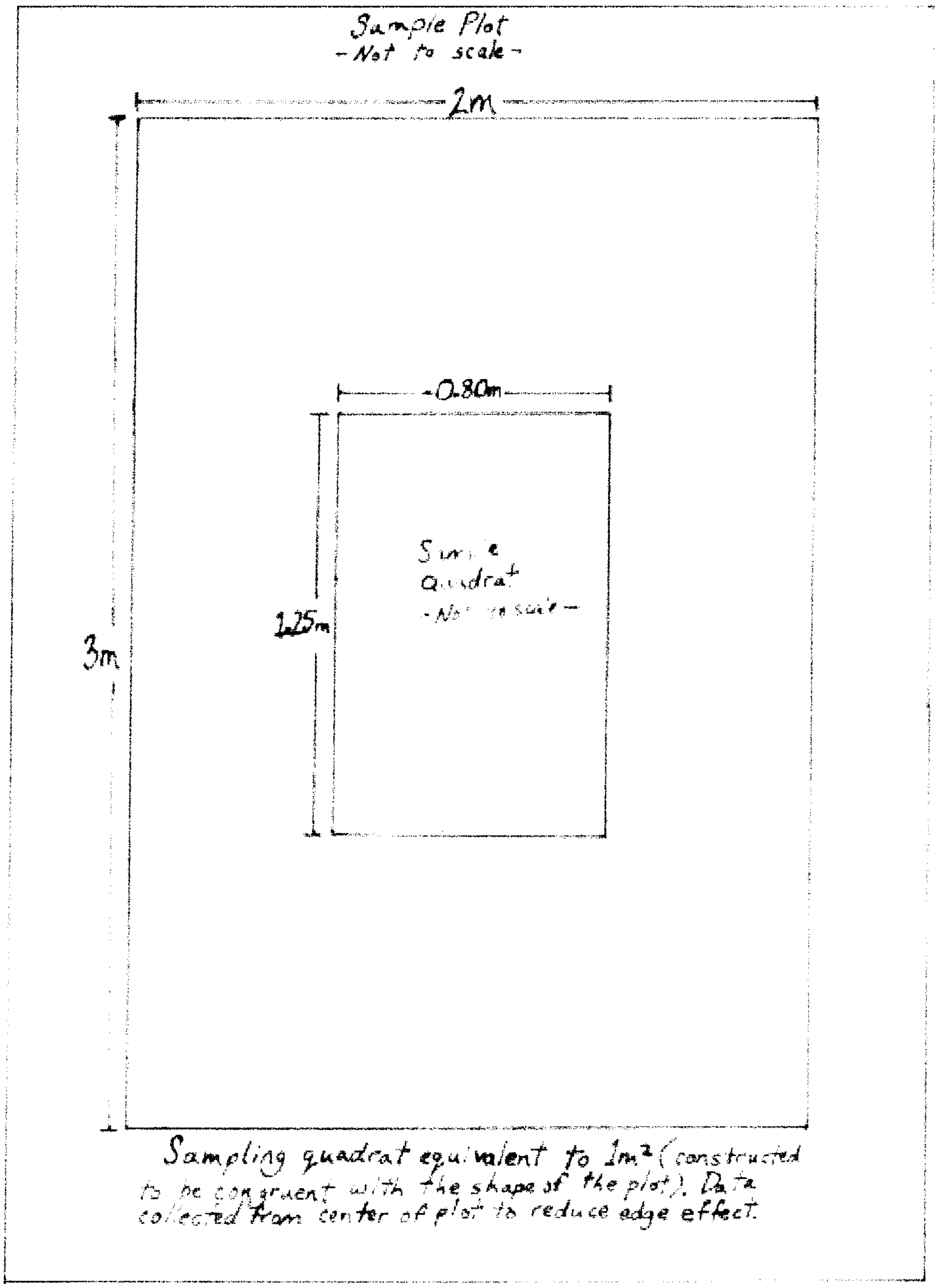

Figure 11: Sample Plot and Frame Quadrat.

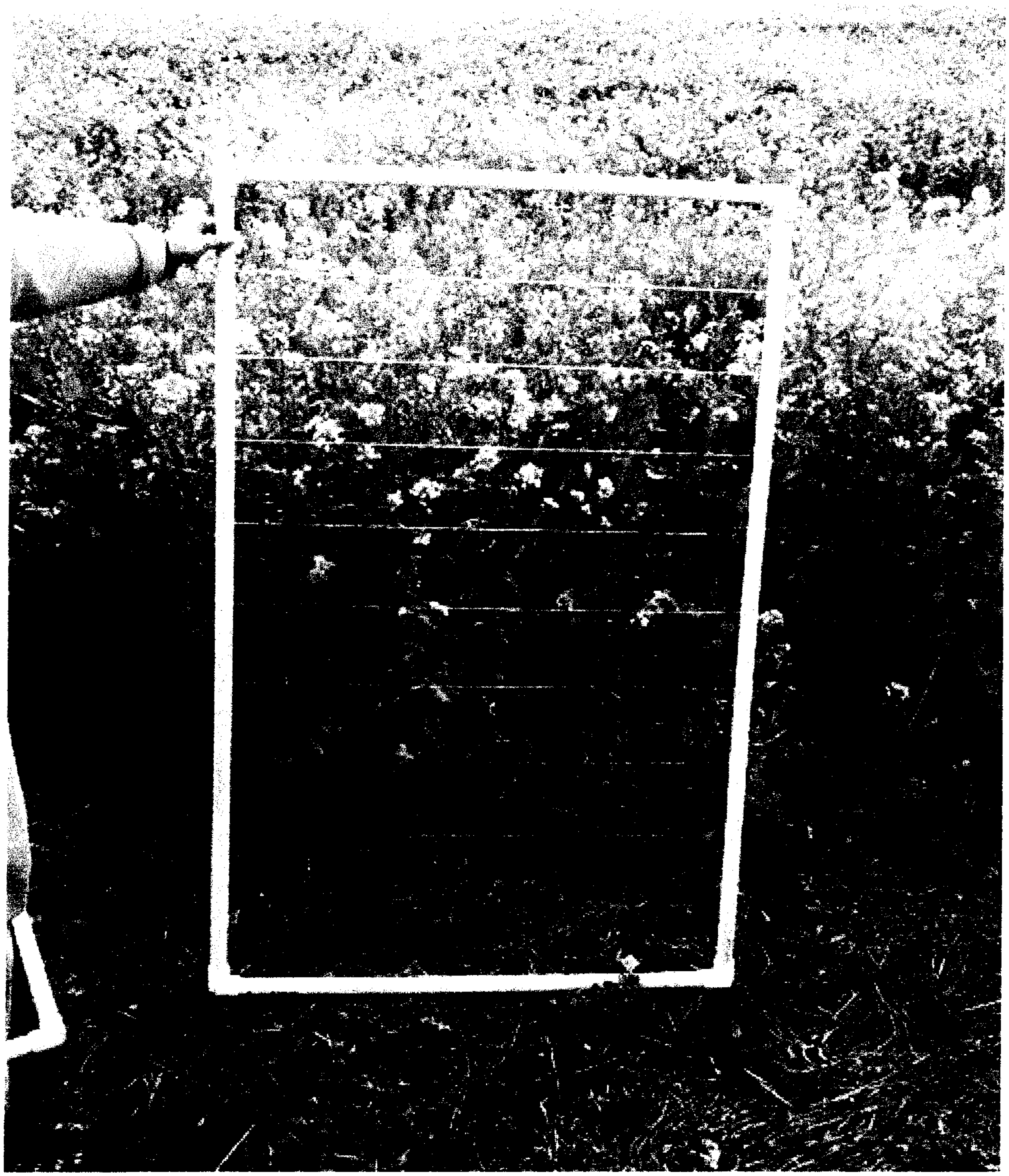

Figure 12: Frame quadrat.

Figure 13: Percentage Cover Data Collection.

Figure 14: String-cutting VFS in March, 2004 (Photo taken by Jen Walton).

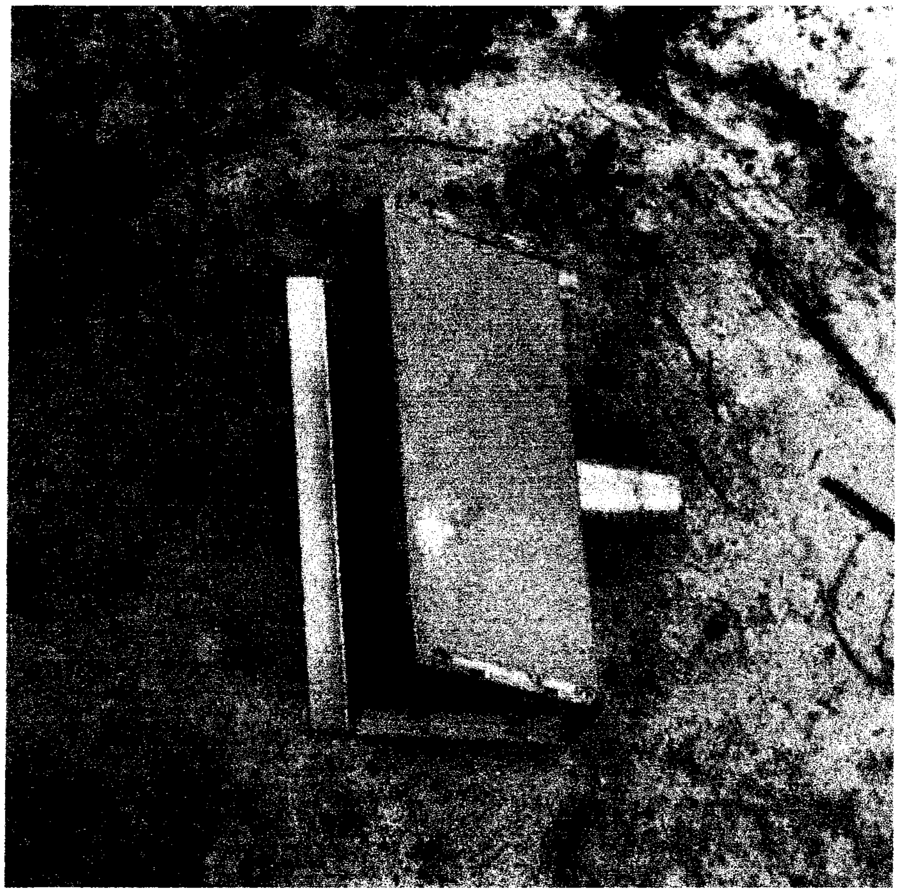

Figure 15: Grab Sample Collection Device.

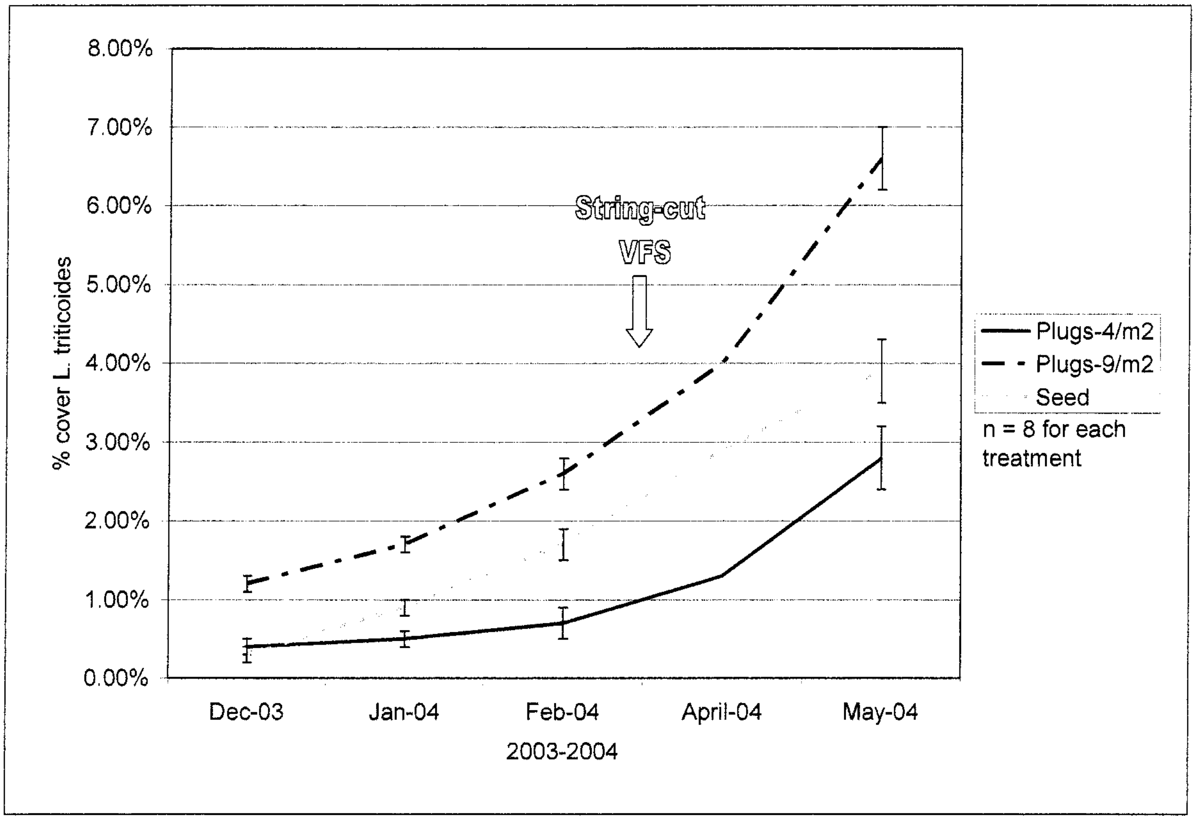

Figure 16: Monthly Percentage Cover Averages of *Leymus triticoides* Seed and Plug ($9/m^2$ and $4/m^2$) Treatments.

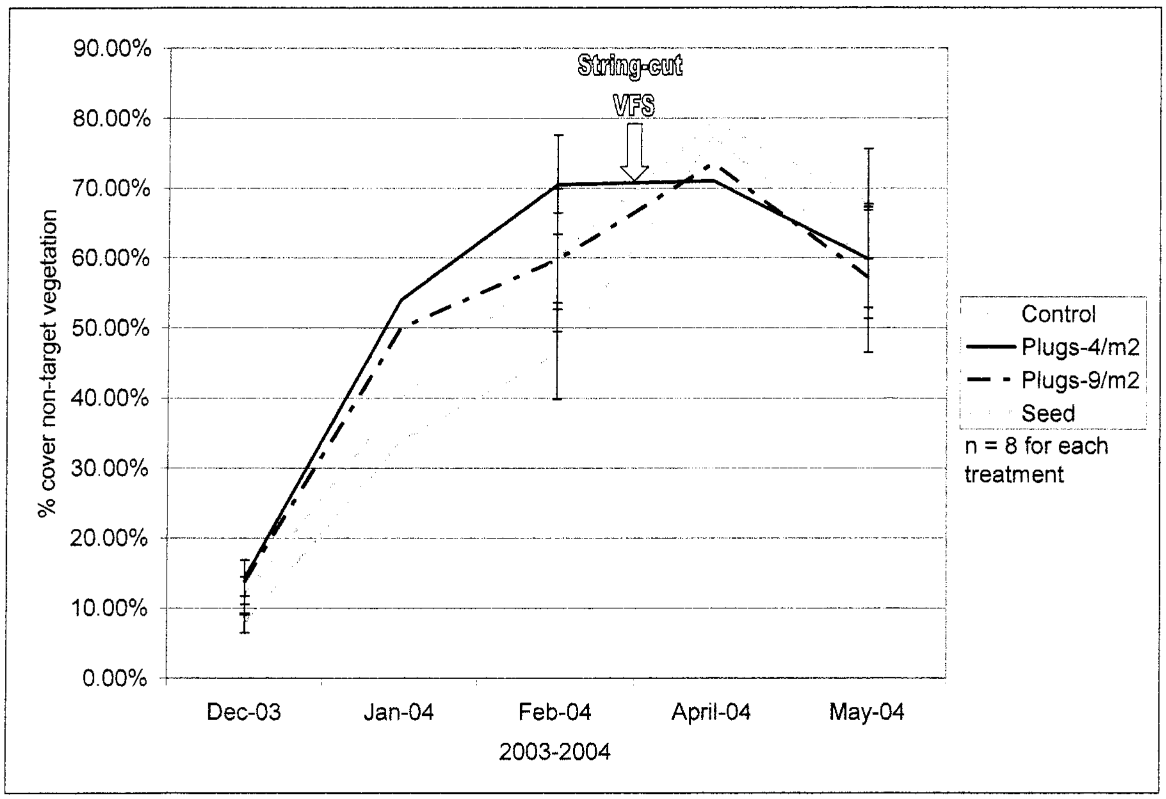

Figure 17: Monthly Percentage Cover of Non-target Vegetation in the VFS.

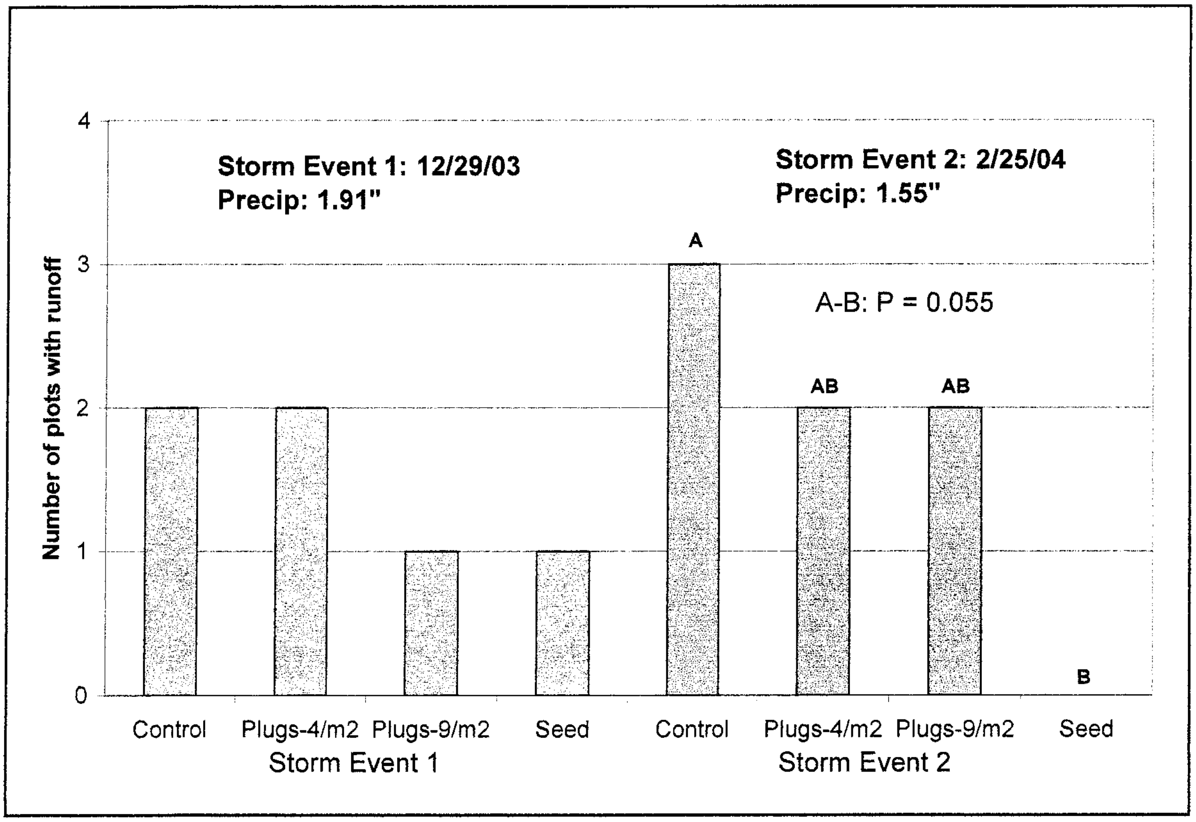

Figure 18: Number of Plots with Runoff in Each Treatment for Storm Events 1 and 2. Chi-square Test Between Control and Seeded Treatments for Storm Event 2(p= 0.055). "AB" label over plug treatments means there is a relationship between the plug treatments and the control, and a relationship between the plug treatments and the seeded treatment. The separate "A" and "B" labels over the control and seeded treatments indicate the trend in difference between them.

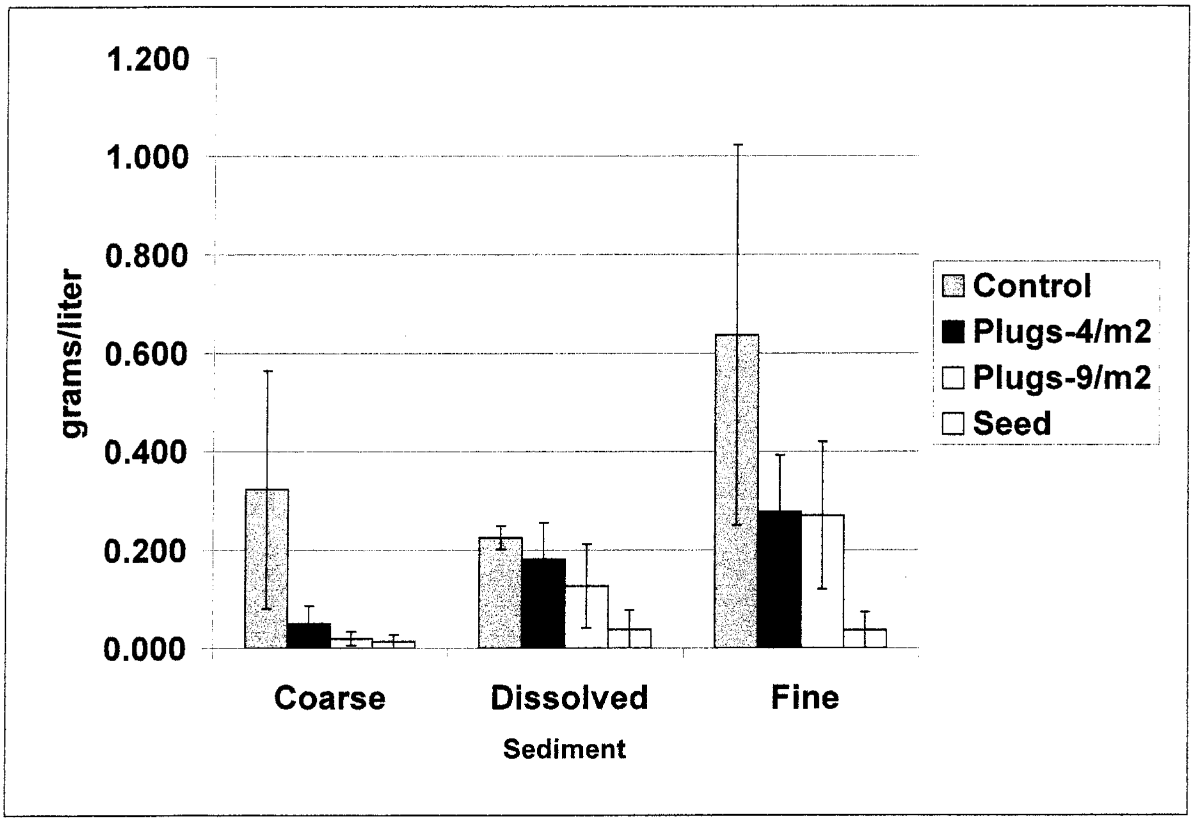

Figure 19: Mean Coarse, Dissolved and Fine Sediment Concentrations Resulting from the Combined Data of Storm Events 1 and 2.

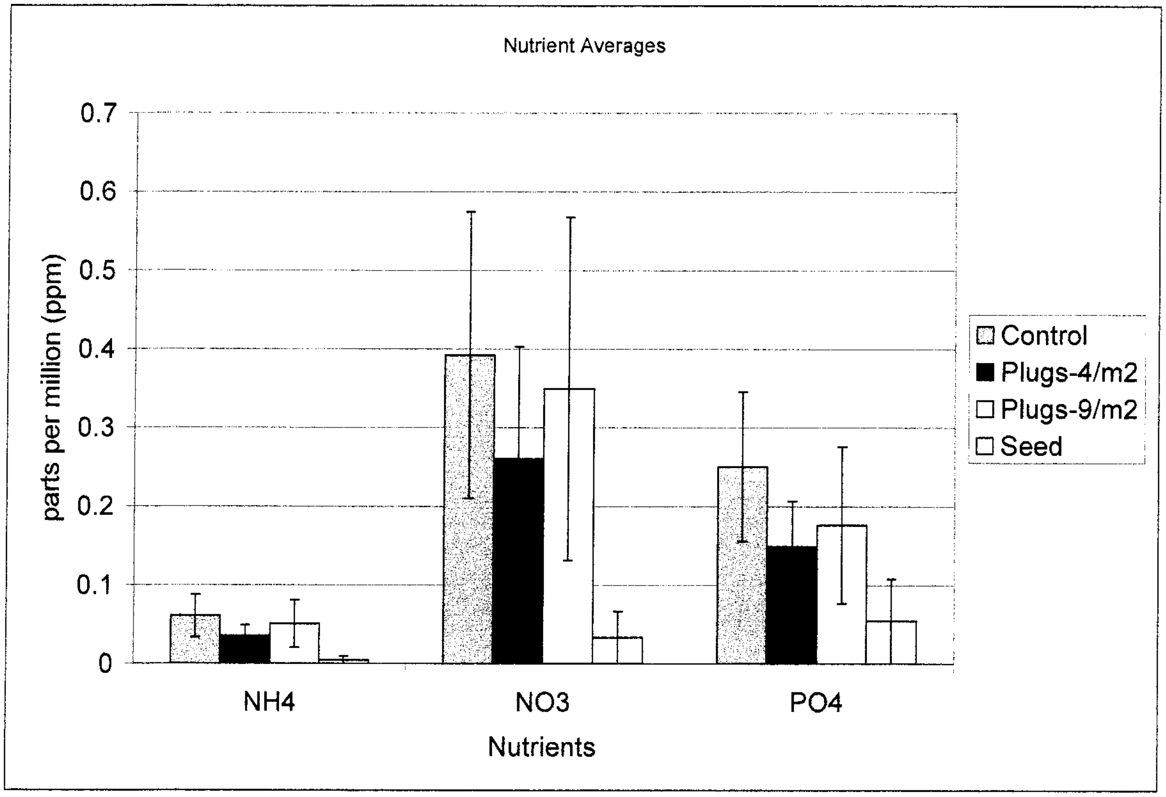

Figure 20: Mean Nutrient Concentrations Resulting from the Combined Data of Storm Events 1 and 2.

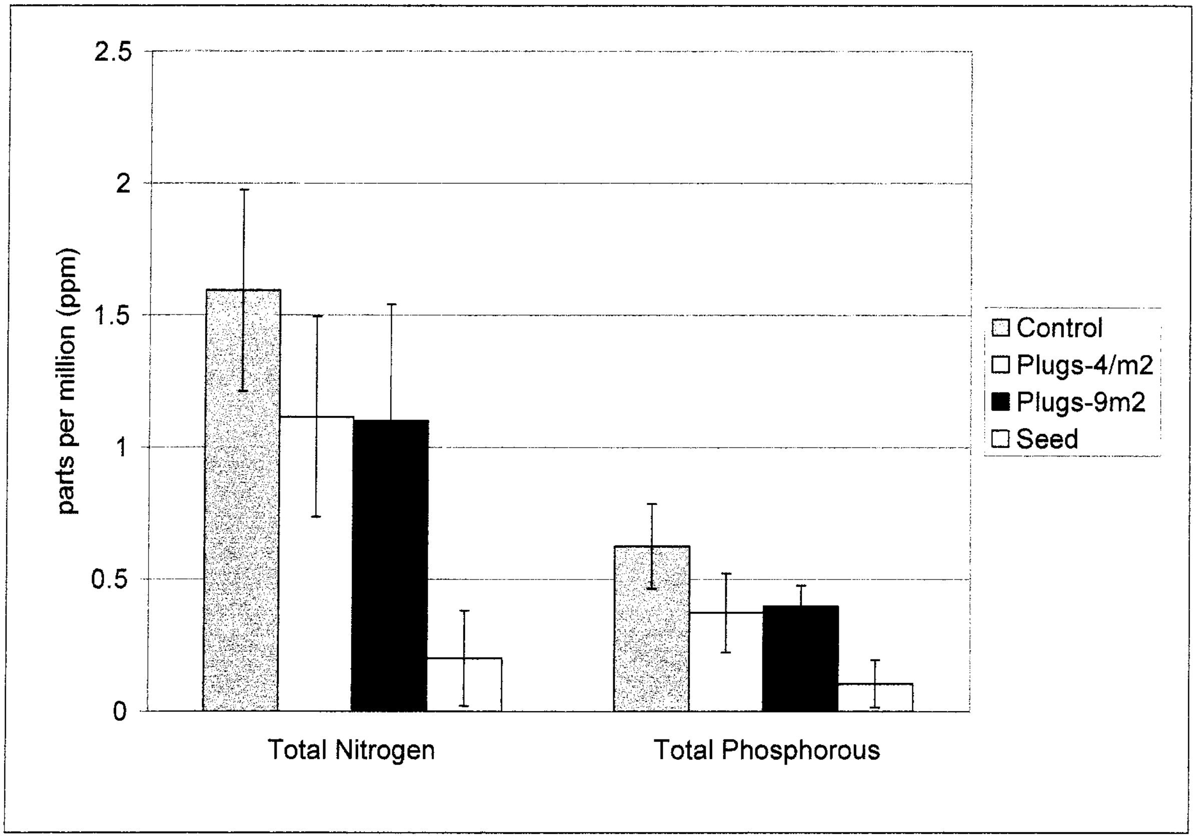

Figure 21: Mean Nutrient Concentrations Resulting from the Combined Data of Storm Events 1 and 2.

APPENDIX 1

Fractional Sedimentation Analysis Methods
Peter Tittmann, 2/9/01, last updated by Claire Phillips 12/22/02
Modified from USGS methods (taught by Brian Largay)
See also *Laboratory Theory and Methods for Sedimentation Analysis, Guy, Harold P., USGS, 1969*

This protocol separates fluvial sediment samples into dissolved, fine, and coarse sediment fractions, using both evaporation and filtration methods.

Pre-Separation Procedures:

Remember: handle both filters and tins with gloves and/or tweezers. The sediment weights are so small that added weight from oils on the skin can significantly affect the final measurements.

Filter Preparation: Use 90mm Glass Fiber Filters with 1.2μm retention (such as Whatman 934-AH). We have found that the Whatman filters lose mass when water is passed through them. This problem can be addressed by at least two methods we have thought of:

1) Weigh 10 dried filters, pass +/- 400mL DI water through each in the Buchner funnel, then dry them for at least one hour at 100°C and weigh them again to determine the average lost mass. This value should be subtracted from the final mass of the sediment fraction. It is important that there not be anything else in the oven while drying.
2) Pass +/- 500mL of DI water through all the filters that are to be used in the method before drying them as described above. Assuming that they only lose mass the first time water is passed through them, you can proceed with the method without further accounting for loss of filter mass. You can prepare a lot of filters in advance and store them in the drying box or the oven until you are ready to use them.

Aluminum Tin Preparation: Obtain 3 clean, dry tins for each sediment sample you are processing and label them with an ID number, plus "C" for coarse, "D" for dissolved, and "F" for fine sediment fractions. Record the initial mass of the "C" and "D" trays, and the "F" trays with a treated filter in it.

Separation of Sediment Fractions:

1. Allow the sample bottle to settle for a minimum of 24 hours.
2. Record the mass of the full sample bottle before extracting sediments.
3. Extract all but about 100mL of the sample into a clean filter flask without a side arm. Use a 2-hole stopper with a vacuum hose attached to one hole, and a suction line

attached to the other. Be careful not to extract the coarse sediment that will have settled to the bottom of the sample bottle.

4. Using a dried, treated filter, filter the extract sample through a Buchner funnel into a Clean Erlenmeyer flask.
5. Pipette 25mL of the filtered sample into the "D" tray. This sub-sample will be used to determine the dissolved sediment fraction. Set aside the tray and leave the filter apparatus to use again in step 8.
6. Pour the remaining 100mL of sample from the original sample bottle through a Fisher Scientific sieve #230 (or equivalent) and into a 400mL collecting beaker. Use a DI water squirt bottle to make sure all of the coarse grains have been washed out of the bottle and onto the sieve. Squirt DI water on the sieve to force dirty water through.
7. Invert the sieve over the "C" tin and squirt DI water through to wash all of the coarse grain sediment into the tin.
8. Pour the dirty water in the collecting beaker through the Buchner funnel apparatus with the same filter paper used earlier. If there is a lot of fine sediment in the beaker, it may be necessary to use 2 or more filters to collect it all. You will have to label and record the initial mass of additional trays + filters if this is the case.
9. Transfer the filter paper to the "F" tin. If necessary, squirt off sediments that are stuck to the funnel into the tray.
10. Record the mass of the empty sample bottle. The difference in mass between the empty and full bottle will be used to estimate the volume of water in the bottle.
11. Transfer all the trays to the oven. Leave trays at least 8 hours or overnight to dry.
12. Remove trays from oven with gloves and record final mass.

APPENDIX 2

DAFOR (dominant, abundant, frequent, occasional, rare) Data Set for Non-target Species Composition by Treatment: March, April, and May, 2004. Listed by initials of genus and species, except grasses and thistles which were lumped together (see Table 10)

Plot	Treatment	*V.f.*	*M.p.*	*R.c.*	Grasses	*C.m.*	Thistles	*V.s.*	*G.d.*	*B.spp.*	*R.r.*
Date:3/04											
6	Control	N	N	F	F	N	N	N	N	D	F
8	Control	N	N	A	F	N	N	N	N	D	F
11	Control	N	N	R	F	N	F	N	N	D	F
16	Control	N	N	A	F	N	R	N	N	D	F
19	Control	N	N	R	R	N	N	N	N	D	F
25	Control	R	N	R	F	R	N	N	N	R	A
27	Control	R	N	R	A	N	N	N	N	R	A
30	Control	N	N	F	R	N	N	N	N	F	A
4/04											
6	Control	N	O	A	D	N	N	N	N	N	N
8	Control	N	N	D	A	N	O	N	N	O	O
11	Control	N	N	D	A	N	O	N	N	R	O
16	Control	N	R	A	A	N	O	N	N	O	D
19	Control	N	N	A	F	N	N	N	N	O	D
25	Control	N	O	O	A	N	F	O	N	R	D
27	Control	R	A	R	D	N	F	R	O	N	F
30	Control	N	N	F	F	N	N	N	R	R	D
5/04											
6	Control	N	O	A	D	N	O	N	N	N	R
8	Control	N	N	A	A	N	O	N	N	N	R
11	Control	N	R	A	A	N	O	N	R	N	F
16	Control	N	O	A	F	N	F	N	N	N	D
19	Control	N	N	D	F	N	O	N	N	N	A
25	Control	N	F	O	A	N	F	N	R	N	D
27	Control	R	F	O	D	N	O	N	O	N	F
30	Control	N	N	F	F	N	N	N	N	N	D

3/04		*V.f.*	*M.p.*	*R.c.*	Grasses	*C.m.*	Thistles	*V.s.*	*G.d.*	*B.spp.*	*R.r.*
5	P-4/m^2	N	N	A	A	N	R	N	N	D	F
10	P-4/m^2	N	N	R	F	N	R	N	N	D	F
13	P-4/m^2	N	N	N	F	N	N	N	N	D	F
14	P-4/m^2	N	N	R	F	N	R	N	N	D	F
17	P-4/m^2	N	N	F	F	N	N	N	N	D	R
21	P-4/m^2	N	N	R	R	N	N	N	N	D	A
29	P-4/m^2	N	N	R	A	N	R	N	N	A	A
31	P-4/m^2	N	N	F	F	N	R	N	N	A	A
4/04											
5	P-4/m^2	N	N	A	D	N	F	N	N	N	O
10	P-4/m^2	N	N	F	D	N	N	N	N	O	R
13	P-4/m^2	N	N	N	F	N	R	N	N	O	D
14	P-4/m^2	N	N	N	A	R	O	N	N	R	D
17	P-4/m^2	N	N	D	F	N	O	N	N	O	F
21	P-4/m^2	N	N	F	O	N	N	N	R	O	D
29	P-4/m^2	N	O	O	D	N	R	N	N	R	A
31	P-4/m^2	N	O	A	F	N	R	N	R	O	D
5/04											
5	P-4/m^2	N	O	A	D	N	F	N	N	N	O
10	P-4/m^2	N	N	O	D	N	R	N	N	N	O
13	P-4/m^2	N	N	O	F	N	O	N	N	N	D
14	P-4/m^2	N	O	N	F	R	F	N	N	N	D
17	P-4/m^2	N	R	D	F	N	F	N	R	N	F
21	P-4/m^2	N	N	F	O	N	O	N	R	N	D
29	P-4/m^2	N	F	O	D	N	N	N	F	N	A
31	P-4/m^2	N	O	F	F	N	O	N	F	N	D

3/04		*V.f.*	*M.p.*	*R.c.*	Grasses	*C.m.*	Thistles	*V.s.*	*G.d.*	*B.spp.*	*R.r.*
2	P-9/m^2	N	N	N	O	N	N	N	N	D	O
4	P-9/m^2	N	N	A	A	N	N	N	N	D	F
7	P-9/m^2	N	N	F	F	N	R	N	N	D	F
9	P-9/m^2	N	N	F	F	N	R	N	N	D	R
20	P-9/m^2	N	N	F	F	N	R	N	N	D	A
23	P-9/m^2	N	N	R	F	R	N	N	N	F	A
26	P-9/m^2	R	N	R	A	N	R	N	N	R	A
32	P-9/m^2	N	N	F	R	N	N	N	N	F	F
4/04											
2	P-9/m^2	N	N	N	D	N	F	N	N	N	F
4	P-9/m^2	N	N	A	D	N	N	N	R	N	N
7	P-9/m^2	N	R	A	D	N	O	N	N	N	O
9	P-9/m^2	N	N	A	D	N	R	N	N	N	N
20	P-9/m^2	N	N	A	F	N	O	N	N	N	D
23	P-9/m^2	N	N	O	F	R	F	N	N	R	D
26	P-9/m^2	N	F	R	D	N	F	N	R	N	A
32	P-9/m^2	N	R	F	F	N	N	N	R	O	D
5/04											
2	P-9/m^2	N	N	O	A	N	A	N	N	N	A
4	P-9/m^2	N	O	A	D	N	O	N	N	N	O
7	P-9/m^2	N	O	A	D	N	O	N	N	N	R
9	P-9/m^2	N	R	A	A	N	O	N	N	N	N
20	P-9/m^2	N	N	A	F	N	F	N	N	N	D
23	P-9/m^2	N	N	R	A	R	O	N	N	N	D
26	P-9/m^2	N	F	R	D	N	O	N	R	N	O
32	P-9/m^2	N	N	O	A	N	N	N	R	N	D

3/04		*V.f.*	*M.p.*	*R.c.*	Grasses	*C.m.*	Thistles	*V.s.*	*G.d.*	*B.spp.*	*R.r.*
1	Seed	N	N	N	O	N	R	N	N	D	R
3	Seed	N	N	A	A	N	N	N	N	D	O
12	Seed	N	N	R	R	N	F	N	N	D	F
15	Seed	N	N	A	F	N	R	N	N	D	F
18	Seed	N	N	A	F	N	N	N	N	D	F
22	Seed	N	N	F	A	N	N	N	N	F	A
24	Seed	N	N	R	F	N	N	N	N	A	A
28	Seed	N	N	R	A	N	N	N	N	R	A

4/04											
1	Seed	N	N	N	D	N	F	N	N	O	O
3	Seed	N	N	A	D	N	R	N	R	N	R
12	Seed	N	N	N	A	N	F	N	N	R	D
15	Seed	N	N	A	D	N	F	R	R	O	A
18	Seed	N	R	D	F	N	O	N	R	O	F
22	Seed	N	N	A	A	N	R	N	R	N	D
24	Seed	N	N	D	A	N	O	N	R	R	A
28	Seed	N	O	O	D	N	N	N	O	N	A

5/04											
1	Seed	N	N	N	D	N	O	N	N	N	F
3	Seed	N	N	A	D	N	N	N	R	N	O
12	Seed	N	R	N	A	N	A	N	N	N	A
15	Seed	N	O	A	F	N	F	N	R	N	D
18	Seed	N	R	D	F	N	F	N	R	N	F
22	Seed	N	N	A	A	N	R	N	R	N	D
24	Seed	N	N	A	A	N	F	N	O	N	D
28	Seed	N	O	O	D	N	N	N	R	N	A