Technical Report Documentation Page

1. REPORT No.
FHWA/CA/TL-91/06

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Effectiveness of Legume Seeding for Erosion Control

5. REPORT DATE
November, 1991

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
John F. Haynes

8. PERFORMING ORGANIZATION REPORT No.
65328-637349

9. PERFORMING ORGANIZATION NAME AND ADDRESS
California Department of Transportation
Division of New Technology, Materials & Research
Sacramento, California 95819

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
E87TL23

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
Sacramento, California 95807

13. TYPE OF REPORT & PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This project was performed in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. ABSTRACT
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17. KEYWORDS
Legumes, Erosion Control, inoculation, hydroseeding, rose clover

18. No. OF PAGES:
78

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1989-1996/91-06.pdf

20. FILE NAME
91-06.pdf

State of California

Department of Transportation
Division of New Technology, Materials and Research
Office of Research, Corrosion, Enviro-Chemical & Graphics
Erosion Control, Graphics & Geosynthetics Branch

EFFECTIVENESS OF LEGUME SEEDING FOR SOIL EROSION

FINAL REPORT

#FHWA/CA/TL-91/06

CALTRANS STUDY NO. E87TL23

Study Made By Division of New Technology Materials and Research

General Direction. . . . . Mas Hatano, P.E.

Principal Investigator . . . . . . Thomas P. Hoover, P.E.

Co-Principal Investigator/. . . . . . . John Haynes, L.A.
Project Manager

EARL SHIRLEY, Chief
Division of New Technology, Materials and Research

TECHNICAL REPORT STANDARD TITLE PAGE

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This research project reviews the use of legumes for erosion control on Caltrans projects, problems of inoculation and nodulation, pellet inoculation, preinoculation, hydroseeding of legumes and fertilization practices.

17 KEY WORDS Legumes, Erosion Control, inoculation hydroseeding, rose clover	18. DISTRIBUTION STATEMENT No Restriction. This document is available to the public through the National Technical Information Springfield, VA 22161

19 SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified		

DS-TL-1242 (Rev.6/76)

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INTRODUCTION

The construction of most major highway projects requires the movement of large amounts of earth. The excavation and placement of this material represent a large portion of the investment in constructing a highway facility. To protect this investment and to prevent offsite pollution, it is common practice to establish vegetation as one of the erosion control measures. Traditionally, grasses have been the primary vegetation used to provide a protective cover on newly constructed highway slopes. They can provide excellent erosion control when used on fertile soils, or where they are the primary indigenous vegetation. Grasses are relatively inexpensive to apply, grow quickly, and are readily available. Because of these characteristics, they are generally recommended by the USDA Soil Conservation Service and the range management departments of many universities.

There can be problems, however, with the use of grass for erosion control. Many nonnative grasses used for erosion control need high rates of nitrogen and will grow on sterile soils only if they are supplied with fertilizer. Since most of the exposed soil of a new facility is lacking in available nutrients and microorganisms, a large amount of fertilizer is required to establish and maintain an effective stand of grass. Much of the nitrogen supplied in the initial fertilization is used in biomass production.

Much of the existing life zone of the earth is contained in the duff and top few inches of topsoil. On mature soils it is in this zone that decomposition and recycling of nutrients takes place. In the construction of a project, this material is often removed and buried under infertile parent material that is excavated later. As a result, new highway slopes are lacking the soil microfauna that are necessary to recycle organic matter into primary minerals available for plant growth. As the applied fertilizer is taken up by the plants and not recycled, the cover required for erosion protection wanes. When that cover is reduced and not replaced by other vegetation, the erosion processes will begin and eventually degrade the highway facility.

Most Caltrans erosion control applications are not irrigated. In most of the state, there is little rainfall from early May to late September or October. Erosion treatments are applied during most of the year with the intent that there will be no growth until there is adequate rain to germinate the seed. If the rain is early in the season and persistent, a satisfactory cover can be established. But if it doesn't rain until late fall, the temperatures may be too low for vegetation to establish despite the amount of fertilizer applied. During cold weather many plants are dormant and the roots are not utilizing nutrients. Succeeding rains can leach the fertilizer from the soil and transport it in runoff. If fortunate weather allows a good grass crop to be established, erosion protection is provided.

There are also nonerosion-oriented problems associated with the use of grasses. Because Caltrans doesn't usually refertilize erosion control vegetation, initial fertilizer is applied to last for several seasons. This abundance of fertilizer encourages the grasses to grow tall and dense the first years. These grasses become dry early in the season and can provide an abundance of fuel for fires. Burning grasses create a tremendous amount of smoke which can seriously impair the vision of motorists and the fires may damage highway facilities.

To ensure their own survival, many plants have developed a property of dispensing a chemical substance that impairs the germination of other plants. Some grasses are so predominant with this allelopathic property that they can hinder the germination of their own seed. This is especially true of densely planted annual rye grass, which has been extensively used for erosion control on highway projects. The allelopathic properties of these grasses not only hinder the persistence of their own species, they virtually prohibit the invasion of other species whenever there is dense cover. There are numerous studies (20,28,69), that indicate grasses also compete for both moisture and sunlight to the detriment of the woody species.

The goals in erosion control should be for both immediate and long-term protection. Annual grasses do a suitable job in providing initial protection, but they are often inadequate for areas where they are not the dominant indigenous vegetation. For long-term protection, it is desirable to establish vegetation that will persist, or to allow local native woody vegetation to invade and provide a multistoried cover. Trees and shrubs have a variety of root depths that bind the soil together and enhance slope stability. However, they have great difficulty initially competing with the grasses often used for erosion control.

The problems associated with the primary use of grasses have led to the use of other plants, legumes in particular, for erosion control. Many highway departments in the eastern part of the United States have converted the swards along the roadsides to covers of crownvetch, flat pea or vetch (51,53,70,78,79,80). Legumes are in the pea family and include such plants as clover, vetch, alfalfa and lupine. In association with the bacterial genus Rhizobium, they have the ability to take the free nitrogen out of the atmosphere and convert it to nitrates which are usable by the legumes. Most of the nitrogen produced is contained in the foliage. As the leaves drop and decompose, the nitrogen becomes available to other plants as well. The use of legumes for erosion control also allows the invasion and establishment of native woody vegetation.

This research project investigated the use of legumes to provide erosion protection, build a fertile soil profile and allow the establishment or invasion of native woody vegetation.

LITERATURE REVIEW

A Transportation Research Information Service (TRIS) literature review was conducted in preparation of the proposal for this research project. Through the course of this project, additional information on the use and culture of legumes was reviewed and studied. A vast amount of information is available on the use of legumes, but much of it is related to agriculture production or sustainable agriculture. However, there has been considerable research in other states on the establishment of legumes on roadsides (9, 12, 21, 26, 51, 53, 70, 79, 80).

Many highway department seed mixes for erosion control originated from recommendations by the USDA Soil Conservation Service. These seed mixes were primarily grasses, generally a quick cover crop, with some perennial grasses for long-term cover. Much of the research for erosion control in other states was to find methods of establishing legumes such as crownvetch, flat pea, sericea and birds-foot trefoil in declining swards. Based upon the literature, these legumes now provide long-term, low-maintenance ground cover for highway roadsides in much of the eastern United States .

Other literature reviewed included information and research on legume species, importance of rhizobia, methods of inoculation, preinoculated seed, effects of hydroseeding, fertilization, nitrogen fixation and competition between legumes and grasses. All of the pertinent literature reviewed is listed in the bibliography of this report.

Much of the information that was anticipated to be found in the field reviews of Caltrans construction projects was not there. The construction records were not readily available to verify seeding times or variances from specifications. Some of the projects that were expected to be successful were not, and some that were expected to be failures were eminently successful. Sometimes reasons could be determined for success or failure, other times not. However, there is considerable information on legumes and their use in erosion control. Much of the content of this report was derived from the available literature rather than information gained from field research.

RESULTS

Legumes are a viable alternative to the exclusive use of grasses for erosion control. They can provide benefits that grasses can't. The most important feature of legumes is their ability to enrich the soil by adding nitrogen. This eliminates the need for reapplication of fertilizer to maintain vegetation and begins the process of nutrient cycling that maintains fertility. Based on the experience in the San Diego area, legumes can also be compatible with the establishment of native woody plants.

Grasses have been recommended for erosion control because they are familiar to many specifiers, are readily available and usually inexpensive, and many give quick cover. A quick cover has been considered important for construction projects, agrarian use and other areas, such as forest burns, to protect the soil from raindrop impact and overland flow. In those nonconstruction situations, there is often no other cost-effective material to protect the soil surface. But in most construction projects, materials such as straw, hydroseeding mulch or commercial blankets can be used to protect the soil until vegetation is established. This reduces the need for the quick vegetative cover which annual grasses provide, and can reduce many of the problems that accompany the exclusive use of grasses for erosion control.

Low seeding rates of legumes along with grasses were successful in a number of the projects reviewed. There were many other projects where, for various reasons, the legumes apparently did not survive. There are numerous references that indicate legumes are highly susceptible to competition from other species for light and moisture (35,36,47,60,63,69,74,). If legumes are planted with slower growing species such as perennial grasses, they are able to establish sufficiently to persist. However, when planted with aggressive annual grasses, the competition can be lethal to legumes.

The number of legumes species available for use in erosion control is quite limited. Rose clover is the dominant species used in Caltrans projects. Its range of usage is limited by precipitation and elevation. Hykon rose clover requires about ten inches of rain; the Wilton variety matures later and needs about 16 inches. The minimum elevation has been limited to about 3000 feet in the past. Now, strains are being discovered at much higher elevations. Crimson clover is often used, primarily for the color of its blossoms. It is a good short-term species for warm climates, and will persist in cool coastal conditions. Lotus corniculatus has had limited use in coastal areas with at least 20 inches of rain. It appears to do well along mowed roadsides or where there is little competition from taller grasses. Alfalfa has been used sparingly. On rural roadsides it is often present from seed spread by passing hay trucks. Alfalfa is very palatable to deer and its use can create a traffic hazard. Cicer milkvetch is the predominant legume used by Caltrans in high

altitude areas. Several species of lupines have been used but primarily for color rather than as a primary erosion control species.

It is critical that legumes be properly inoculated if they are to be successful in erosion control applications. Caltrans specification for inoculation currently refers to a methodology described in a University of California bulletin that is no longer available. The newer Bulletin 1842 referred to in the contract special provisions includes the Pelinoc-Pelgel method which is not always appropriate for highway erosion control. This method of inoculation can be used by the contractors to inoculate seed in the field immediately before it is applied. However, the seed suppliers were using the Pelinoc-Pelgel method because the specifications were not explicit. By the time the seed arrived on the project, most of the inoculant was at the bottom of the seed bag. Caltrans inspectors have not been properly trained to determine whether legume seed is properly inoculated.

Current specifications require reinoculation of seed if the seed is not applied in a given time period. There is no evidence that reinoculation is beneficial. It adds considerable weight and bulk to the seed and may retard germination. Preinoculated seed is commonly used and successful in many installations. However, it generally does not meet the specifications for amount of rhizobia, and often exceeds the time limitations. Pellet inoculation with lime coating appears to be the most effective inoculation method unless the legume seed is inoculated and planted without delay, and at a time of year that the seed will germinate soon.

Hydroseeding can have an adverse effect on inoculated legumes. There is evidence that the rhizobia is washed off the seed in the hydroseeding tank and can be killed in acid solutions. When the inoculant is removed from the seed, it is spread over the surface of the ground rather than being in intimate contact with the seed. Effective nodulation can be reduced, especially if there are native rhizobia in the soil. Hydroseeding legumes has been effective when the inoculated seed doesn't remain in the hydroseeding slurry for more than thirty minutes. Dry applied legumes are usually more effective than those hydroseeded when the slopes are flat enough that the seed doesn't roll off.

The availability of fertilizer formulations used for legumes is changing. The elements most commonly deficient and necessary for legumes in California soils are phosphorus and sulfur. Single superphosphate has been used to provide these nutrients, but its availability is scarce and becoming unreliable. A suitable substitute is a combination of triple superphosphate, 0-45-0, and "Popcorn" sulfur, which provides a 0-36-0-19s blend. This blend is available from at least two suppliers. Nitrogen fertilizer retards the formation of nodules and increases competition by favoring grass growth over the legumes.

CONCLUSIONS

The construction records were not a convenient or reliable source of information for conducting this research. The records are difficult to access and did not support their proposed use for this project. Field reviews were more informative, but because of great variance in performance of the seed mixes and vegetative cover several years after application, generalizations are easier to make than conclusions. However, the sites that used rose clover as the primary erosion control species show it to be very effective in preventing erosion. The field reviews also indicated annual grasses to be very competitive to the invasion of native vegetation. This is well verified by the literature reviewed.

Legumes have been successful in California and other states in providing roadside cover and preventing erosion. By producing their own nitrogen, legumes don't need refertilization to maintain a ground cover. Some species also allow invasion by native woody plants. Legumes will provide long-term fertility for erosion control applications if they are included as a major part of the erosion control seed mix. When legumes are planted as the primary erosion control species by themselves or with woody vegetation, the use of straw or manufactured products will provide temporary erosion protection until the legumes become established. The temporary mulch will reduce the historical problems encountered with the use of grasses. Grasses should be limited to where they would be the climax vegetation, or where they are used for a temporary cover.

The specifications for legume inoculation are not adequate. The instructions for applying inoculant to the seed are based on the University of California bulletin for the inoculation of seed by farmers for pasture or range use. These methods of application are not always appropriate for use on construction projects. New specifications are necessary for inoculation of seed for use on Caltrans projects. Manufacturers differ in the bacteria counts of their inoculant. It may be necessary to specify the number of bacteria to be applied to each seed rather than a weight of inoculant. The specifications must be self- explanatory so other references are not necessary.

The seed tags that accompany the seed for erosion control are not reliable. Often the purity and germination stated on the tags are inaccurate. On several occasions, seed that was labeled as inoculated was not. The seed suppliers must be informed of our requirements, and our inspectors taught what to look for when inspecting seed. Seed not in compliance should be rejected. The hydroseeding of legumes has been successful in Caltrans work when they are in the hydroseeding slurry for a limited time. If legumes are to be hydroseeded, they should be applied separately from the fertilizer application and be limited to thirty minutes in the hydroseeding slurry. Dry applying legume seed has also

been widely used and could be more successful than subjecting the inoculated seed to the agitation in the slurry and fertilizer.

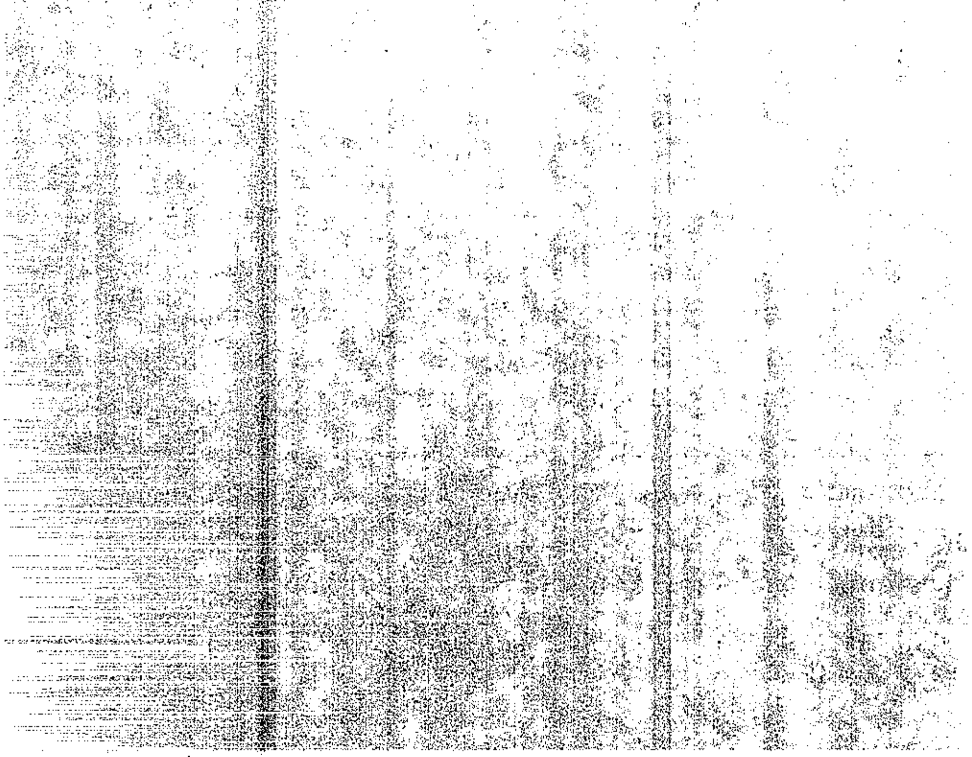
Legumes planted with a straw mulch generally don't need to be accompanied by grasses to provide a quick vegetative cover. The straw provides the immediate erosion protection. Wheat and barley straw contain up to five percent grain seed which will grow with the onset of fall rains. This provides good annual vegetative cover without adverse competition to the legumes.

RECOMMENDATIONS

To increase the use of legumes, the selection of available species should be expanded. More experience is needed with sub and bur clovers. These species are very low growing and often more drought tolerant than rose clover. Birds-foot trefoil has been used occasionally, but the limits of its use are not known. It appears to be an excellent ground cover in coastal areas. It is also found in central valley areas with rainfall in excess of sixteen inches. The greatest need is in low rainfall and high altitude locations. Additional experience needs to be gained by specifying little-used legumes and monitoring their performance. Additional research is needed to determine appropriate species.

A specification needs to be developed for legume inoculation that is complete and does not defer to other references. The specifications should also be made more explicit regarding the Pelgel-Pelinoc inoculation. This inoculation method is meant to be done immediately before sowing. The construction inspectors must be informed that this method shall be done only by the contractor on the project site, and applied within 48 hours. Seed supplier-applied inoculant by the Pelgel-Pelinoc method will not be in compliance. All legume seed not inoculated by the contractor should have a calcium carbonate coating.

The construction inspectors should receive additional information and training on how to examine inoculated seed for specification compliance. The seed suppliers must be informed about what information is required on the seed tags. The seed tags must show the species and amount of inoculant, the expiration date, and the date of inoculation. The current requirement for reinoculation should be deleted and not permitted.



PROCEDURES

Review of Contract Records

The specifications for erosion control treatments on Caltrans projects are maintained for ten years. These specifications were reviewed to determine where legumes had been used in erosion treatments, which legumes were used, and how they were applied. Great variance was found between Districts. Some had used legumes consistently and others had used none. The number of specifications available was too numerous to catalog and review all of them, so a random typical list was established for different parts of the state. A majority of the projects reviewed had varying amounts of legumes in the seed mixes. A representative sample of projects with grasses only were also included to evaluate their long-term performance.

An attempt was made to review construction records to determine the time of year that the erosion control applications were made and if they were applied as specified. It was expected that the time of application of seed would greatly influence the effectiveness of the legumes. Records older than three years are warehoused and it is difficult and extremely time-consuming to recover significant data. Many of the records are incomplete or do not contain the information to support their proposed uses for this project. In reviewing some project sites, it was obvious that more recent projects had occurred at the same locations and the original erosion treatment was superseded. The files for more recent projects were available and it was possible to determine the dates for some of the erosion control applications. These projects are discussed further under Field Reviews.

Agencies Contacted

Many other agencies were contacted to determine if they had knowledge or experience in using legumes for erosion control. State agencies included Parks and Recreation, Water Resources, Food and Agriculture, Conservation and Forestry. The federal agencies were the Army Corps of Engineers, U.S. Forest Service, Bureau of Reclamation, Bureau of Land Management, Fish and Wildlife Service, and Soil Conservation Service. Universities were also contacted, particularly the University of California at Davis, as were farm advisors and soil conservation districts.

Most agencies had little or no experience with legumes in erosion control. They often rely on the Soil Conservation Service for recommendations on plant species. Recently, many also rely on recommendations from Caltrans for erosion control. The majority of all erosion control treatments still rely primarily on grasses. In research on plant materials for erosion control(12, 17), the SCS recognizes the value of legumes in erosion control mixes for providing long-term fertility, but primarily for the enhancement of the grasses. They do not recommend the exclusive or primary use of legumes as an erosion control cover.

Field Reviews

Field reviews were made of selected projects throughout the state and treatments were evaluated for performance. The initial site selection was based on use of legumes in the seed mixes. Additional nearby sites that did not use legumes were also visited and evaluated. Qualitative evaluations of the erosion treatments were based on the amount of existing cover on the slopes, continued existence of legumes, evidence of past or current erosion and invasion of native species.

Erosion control seeding is done during most months of the year on Caltrans projects. In most of California, there is normally very little or no rain from about mid-April to October. Erosion control is generally the last order of work on a project, and is applied when the major construction is completed, regardless of the time of year. After the erosion treatment is applied, it lays in place until there is sufficient rainfall to germinate the seed. It is risky to apply seed in the late spring because there may not be adequate moisture to get the crop to maturity where it sets seed for the following year. Conversely, an early rain in the fall can germinate the seed, and if there is not sufficient moisture following, the seed may perish from drought.

The results of the erosion treatments on sites that were reviewed were extremely varied. On many of the sites, erosion had been so extensive that the face of the slopes had been removed and there was no evidence of the originally seeded vegetation. On other sites where the legumes were a small percentage of the seed mix, there was little evidence of them persisting. Annual grasses appear to have severely outcompeted the legumes. However, in other projects the legumes were eminently successful.

In the course of this study, it was sometimes perplexing that very good stands of legumes were found when the seeding practices seemed to preclude successful establishment. On several sites, low rates of five to six pounds of rose clover had been hydroseeded with twenty to thirty pounds of grasses and three to four hundred pounds of ammonium phosphate fertilizer (16-20-0). Both the hydroseeding and contact with the fertilizer are reported to be detrimental to the inoculated seed (5,6,9,43,54,). Seeding legumes with high rates of grasses and nitrogen fertilizer can result in tall grasses shading out the lower growing legumes. However, in many of the sites reviewed, the rose clover was either a dominant species or was in nearly pure stands.

A review of climatic data for the time of seeding gives some indications for these results. One of the sites was seeded in the fall of 1978. September 10th provided .36 inch of precipitation; the next rain was .29 inch on November 12th, followed by about two inches the following week. By then the minimum low temperatures were in the low thirties to low forties and too cold for the grasses to grow. The earlier rains were not sufficient

to germinate and establish the vegetation. Evidently, the slow start of the grasses allowed the clover to become established to successfully compete with the grasses in the spring.

On another project where there was successful establishment of legumes, the erosion control was applied in the fall of 1979. The seed mix was 20 pounds of perennial grasses, five pounds rose clover, ten pounds Vicia dasycarpa (lana vetch) and a few pounds of wildflowers. This seed was applied hydraulically along with 500 pounds fiber and 300 pounds 16-20-0 fertilizer between two applications of two tons of incorporated straw. There was 1 3/4 inches of rain in late October followed by a little over two inches in November. The weather stayed warm with minimum temperatures in the fifties in October and mostly forties and fifties in November. With the rain and warm temperatures, there should have been good vegetation growth in the fall. The perennial grasses are slow to germinate and establish, whereas the clover started with the early rains.

A review of the project ten years later revealed there was still some perennial grass, mostly on the cooler north facing slopes of the overpasses. Some annual grasses had invaded, particularly wild oats (Avena spp.) and Zorro fescue (Volpia myuros). Yellow star thistle (Centaurea solstitialis) dominated much of the roadside. In most areas small amounts of rose clover could be found, particularly at the edge of the barren strip that is sprayed by maintenance forces. The denser the grasses, the lower the density of the clovers. There were areas however, that had pure stands of the rose clover. These were always on southwest facing slopes which were the hottest and driest. It became a typical finding in reviewing projects that the clover did best where it was too dry for other species.

We assume that the legumes did establish along with the grasses and they survived symbiotically. The legumes provided a source of nitrogen; as the nitrogen supply increased, the grasses could dominate at the expense of the legumes until the nitrogen supply was consumed. As the grasses declined and reduced competition, the clovers would flourish again. It is also possible that durinf the first year, the seeded grasses, along with the seed in the straw, provided such competition for the legumes that there was not much clover initially. But with the hard seed in the clover, it could germinate several years later after the grasses had begun to decline from lack of fertility. This would probably require that the rhizobium be blown in from surrounding areas, or that it was able to survive with little symbiotic assistance .

There is generally one-half to five percent by weight of grain seed available in straw, or 10 to 100 pounds of seed per ton of straw. This amount of seed is often sufficient to provide an early vegetative cover, even without fertilizer. Unless there is excessive seed in the straw, its growth doesn't appear to provide excessive competition to the legumes.

On another project, the climate influenced the success of the legumes. Installed during the fall of 1986, the erosion control seed mix consisted of 35 lb blando brome (Bromus mollis), 75 lb barley (Hordeum vulgare), 9 lb coyote brush (Baccharis pilularis), 20 lb crimson clover (Trifolium incarnatum), 9 lb golden lupine (Lupinus densiflorus aureus), and 2 lb California poppy (California Eschscholzia). This was hydroseeded along with 400 lb 16-20-0 fertilizer. Normally this amount of grass should provide severe competition to legumes. However, during early September there was sufficient rainfall to promote germination. When the site was reviewed later that month, the grasses and lupine had sprouted and were growing vigorously. But it didn't rain again until late December, and by that time all the sprouted plants had died. By the following spring, there was a excellent ground cover of crimson clover and lupine with almost no grass. There was also very little visible erosion. The legumes evidently regerminated from the hard seed and were able to dominate without competition from the grasses.

Alfalfa (Medicago sativa) is occasionally used as an erosion control material in arid areas of the west. It is often found growing along highway shoulders where the seed has blown from passing hay trucks. The roots tap the moisture available under the pavement and allow the alfalfa to survive in areas normally too arid for it. The San Bernardino Caltrans district often used alfalfa in their seed mixes.

At one site in southern California near Riverside, the area is undergoing rapid urbanization. The erosion control seed mix used consisted of 10 lb Blando brome, 5 lb barley, 5 lb California buckwheat (Eriogonum fasciculatum), 10 lb 'Moapa' alfalfa, 5 lb Gedling golden lupine and one pound California poppy. The seed was applied between two applications of straw at a total rate of four tons per acre. The legumes were dry applied. The remainder of the seed was dry applied or hydroseeded, at the option of the contractor.

During the site review, the most conspicuous element was the ground surface, which appeared to be moving - from the incredible rodent population. Evidently the rodents had moved in from the surrounding agriculture fields, and with the seed in the straw and the erosion control mix, they had a population explosion. At first it appeared there was no alfalfa, but upon close examination many small tufts of stems were found. After other food supplies were consumed, the rodents devoured the alfalfa. At other nearby sites that had received similar seed mixes, the alfalfa had grown several inches high but had died from lack of moisture in the ongoing drought.

Numerous sites were visited in San Diego County where the most extensive use of legumes in the state has occurred. On sites where the legumes, in particular rose clover, had been used as the primary erosion control cover, there was generally either very good clover cover or the native vegetation that had been

planted with the clover was dominant. Many wildflowers are also able to compete with the clover. A very successful native semishrubby legume often used in native shrub seed mixes is deerweed, (Lotus scoparius).

The San Diego Experience

The soils in much of the San Diego area are granular, infertile and highly erosive. The variable rainfall pattern makes the establishment of vegetation difficult. Prior to the use of legumes, seeding for roadside erosion control relied on annual grasses with massive applications of nitrogen fertilizers. When there was ample rainfall there would be excessive amounts of grassy vegetation that would prevent wild flowers and native shrubs from establishing. The excessive vegetation also presented a fire hazard. For the grasses to persist, periodic refertilization was required.

In the early 1970s it was becoming more apparent that the exclusive use of grasses for erosion control was not providing long-term effectiveness. There was also a growing aesthetic concern over the visual difference between vegetation on the right-of-way and that on the other side of the fence.

The indigenous vegetation of the San Diego area is primarily coastal sage scrub along the sea shores, the southern coastal mesas and the coastal valleys. Chaparral grows on the northern coastal mesas and up into the mountains(1, 2). These plant communities provide the long-term and self-sustaining vegetative cover for this area. To generate a similar type of vegetation on the highway right-of-way, it was necessary to learn to establish these native species while preventing erosion.

Many of the native shrubs of the area are relatively easy to establish by direct seeding. California buckwheat (Eriogonom fasciculatum) is particularly easy and has been extensively used in erosion control seed mixes. However, most woody plants do not compete well with a heavy cover of grass (20,28,69). The annual grasses used for erosion control grow in the fall with the onset of the rainy season. The shrubs usually germinate later in the season, often not until spring. They must develop a deep root system to prepare for the summer drought before developing much top growth. By then however, the grasses dominate, and out-compete the shrubs for sunlight and moisture. For the shrubs to succeed, an alternative slope protection cover was necessary.

At about the same time that interest was developing in seeding native shrubs, highway planting trials were run in San Diego County to evaluate clover varieties for their ability to establish and persist. They were compared with commonly used grasses for erosion protection and soil building in critical areas (26). These studies showed that the Hykon variety of rose clover outproduced both annual rye grass and blando brome in both

biomass and ground cover during the first year. In following years, as the clover plots produced nitrogen and organic matter, the production increased. As the grasses consumed the nitrogen that was applied at seeding, their production declined each year.

It was later found that native shrubs planted from seed were able to compete very satisfactorily with the clovers. This is assumed to be due to the lower stature and early maturity and death of the annual clovers which leaves available moisture for the shrubs. With the seeding of clover and native shrubs, it became possible to establish a dominant cover of native woody vegetation in as little as five years. This practice has become the standard in erosion control for highway construction in San Diego County.

Rose Clover

The extensive use of legumes for erosion control by Caltrans began in the San Diego area. Legumes had been used as a minor component of seed mixes for a long period of time throughout the state, but not as the principal vegetative cover. Rose clover, Trifolium hirtum, has become the primary legume used in Caltrans erosion control mixes in low elevation and arid areas. It originated in the Mediterranean region of North Africa, Asia Minor and Europe where it survives harsh conditions on poor rocky soil and low rainfall. It was first planted in California by Dr. Milton Love in 1944 near Wilton, Sacramento County. The progeny of that planting later became certified as Wilton rose clover. Since then, numerous other strains have been discovered or developed in Australia that are more flexible for varied climatic conditions. Many range trials have been conducted throughout the state to evaluate their adaptation, and persistence for range improvement. It is now commonly recommended for dry land range seeding in California (13,24,25,26,50,56).

Rose clover is a many branched winter growing annual that will persist in dry infertile soils that many other plants can't survive in. It grows from three-to sixteen-inches tall. The flower heads are rose colored, spherical, about 3/4-inch across and covered with stiff, white hairs (47). The Hykon strain is particularly early maturing and drought tolerant. It will grow and set seed by March with about ten inches of precipitation. It was initially limited to about 3000-foot elevation, but recent strains have been found surviving up to the 4500 to 5000-foot elevation. Rose clover has the ability to produce some seed even under extremely adverse conditions.

Rose clover produces a high percentage of hard seed to carry it through even the driest years. Some seed survives in the ground for years before there is enough rainfall for it to germinate. Hard seed is live seed that will not take in water because of an impermeable seed coat (45). In one investigation of seed viability, manure chips were collected from cows that had foraged on rose clover pasture. The dried chips were isolated from other

seed sources in containers. Each fall, the chips were placed outdoors where the seasonal rains germinated some of the seeds. As the plants matured, the blossoms were removed to prevent any additional seed from forming. This procedure took place from 1957 until 1981-82 with some plants germinating from the initial seed each year for 15 years. In a similar study at UC Davis, the hard seed constituted 85% of the total amount of seed; only 5% of the available seed germinated the first year (31).

These percentages of hard seed appear to be extremes. To demonstrate the hard seed content of commonly available legume seed, S&S Seeds of Carpenteria CA, provided results from their recent seed tests. Results from six Hykon rose clover tests gave hard seed percents of 18, 13, 22, 13, 27 and 38. Wilton rose clover tested at 20 and 23 percent hard seed. The hard seed content for the rose clovers are moderate compared to crimson clover which tested at 1 and 3 percent, and strawberry clovers which tested at 63, 56, 64, 72 and 72 percent.

The hard seed content should be considered in the seeding rate, which is also influenced by the purpose of the seeding. Seeding rates for dryland range improvement are one to ten pounds per acre (50). For broadcast or hydroseeding, the Soil Conservation Service recommends about 30 pounds minimum. Because of the variability of the weather and the use of rose clover as the primary erosion control cover, the San Diego Caltrans office specifies 60 to 100 pounds of seed. Other districts use from 10 to 40 pounds, depending on the density of cover desired and other species included in the seed mix.

Inoculation and Nodulation

The great importance of legumes in agriculture and erosion control is their ability to fix nitrogen. The air is comprised of 78% uncombined nitrogen along with oxygen, carbon dioxide and other gases. Legumes can't absorb the nitrogen directly from the air. They must have a symbiotic association with an effective strain of Rhizobium bacteria which forms nodules on the roots of the legumes. In the nodules, the bacteria use carbon furnished by the growing plants along with oxygen to provide the energy to convert the atmospheric nitrogen to ammonia. The ammonia is incorporated into organic compounds by the plant without being released into the surrounding soil. Most of the nitrogen from the symbiotic fixation process is initially available only to the legume; only a very small part is released into the soil. The remainder eventually becomes available through decomposition of plant and animal residues.

In agriculture, legume seed inoculation represents an attempt to introduce a new organism into an established, complex microfloral community. Nodule formation and effectiveness is the result of response by the host roots to invasion by specific rhizobia (57). An abundant soil population of invasive resident rhizobia will

nodulate young legume roots as soon as they start to grow. For each legume, there are specific strains of rhizobia that are effective, or more effective than others, in fixing nitrogen. There are many other rhizobia present in soils which support native legumes that will cause nodulation, but they are likely to be ineffective in fixing nitrogen on an introduced species.

For many erosion control applications, inoculation is often an attempt to establish a microfloral community on a substrate that has never sustained life. One index of success of inoculation is the degree to which the inoculant forms nodules on the intended host plant. If there is little competition from other rhizobia, the number of bacteria necessary to achieve inoculation may be very small. But as naturalized soil populations of rhizobia increase in number, compensating higher rates of rhizobia are required to get effective nodulation. If the legume seed carries only a few rhizobia of the desirable strain, they may not be able to compete with large numbers of resident soil rhizobia, and ineffectively nodulated plants may result. It is desirable to obtain the maximum possible numbers of viable inoculant rhizobia per seed at sowing (14,15,63).

Nodule formation begins with the infection of a root hair or epidermal cell. As rhizobia enter into a root hair, they form an infection thread containing the bacteria that penetrates into the body of the root where a tumor-like proliferation of root cells results. Within the young nodule, bacteria are released from the infection thread into the cytoplasm of root cells. The plant surrounds these invasive bacteria with a membrane, and the rhizobia differentiate into strangely shaped cells called bacteroids that are capable of fixing atmospheric nitrogen.

For prompt effective nodulation, the rhizobia must multiply around the legume root adequately for infection of a majority of the first available areas of infection. These infection areas are available for a limited time and change position with the growing root tip. For subsequent infections, the rhizobia must be able to move down the rhizosphere with the root tip. If the soil environment is not suitable for rhizobial multiplication, there may be insufficient infections to satisfy the nodule requirement of the plant.

Only a certain percent of infections develop into nodules. This proportion can vary greatly with each host species and rhizobial strain. In the field where the establishing plant is dependent on an early nodulation for its nitrogen supply, any delay in the formation of nodules will reduce the chances of the plant becoming established. This is why such emphasis is placed on the number of rhizobia in the inoculant and on the survival of the rhizobia on the seed.

Pellet Inoculation

In early work with inoculants, many methods were explored to keep the rhizobia alive when the legume seeds were planted. The rhizobia are very susceptible to dying from desiccation or exposure to sunlight . It was found that finely ground peat was a good carrier for the inoculum. A slurry made from inoculum, peat and water gave some protection from dehydration for a short period of time. If the seeds were planted within a couple of days on a moist prepared seed bed, reasonable infection of the germinating seed could be expected.

Additional protection was provided by the technique of pelleting the seed by coating it with lime. Lime pelleting is an effective two step inoculation process. It consists of sticking rhizobial inoculum to the seed with an adhesive and drying the wetted seed with a finely pulverized limestone. Of the many adhesives used, gum arabic has given the best rhizobial survival. The limestone both separates and coats the seed. The lime pelleting protects the inoculum from detrimental effects of acid soils or fertilizers and promotes survival of the inoculum on the seed during storage by minimizing desiccation.

The University of California Agricultural Extension Service has published a succession of bulletins describing the pellet inoculation of legume seed. The first of these publications was AXT-200, Seed Pelleting--As an Aid to Legume Seed Inoculation. This was followed by AXT-280, Pellet Inoculation of Legume Seed. AXT-280 is referred to in the current Caltrans Standard Specifications for the formula of inoculating seed. The next revision was Bulletin 842, Range-Legume Inoculation and Nitrogen Fixation by Root-Nodule Bacteria(33) which was followed by the most recent publication with the same name(63) but now called Bulletin 1842 (available from A N R Publications, Univ. of CA, 6701 San Pablo Ave., Oakland CA, 94608-1239 for $1.00. Make checks payable to U.C. Regents.) The latest bulletin has some newer techniques for inoculating seed as well as lime coating.

The inoculation technique given in the university publications for pelleting seed is a simple method designed to be used on the farm. It can be as easily done by a seed supplier or the erosion control contractor. The materials required are a good quality inoculant for the specific legume to be treated, the adhesive, and coating material. A minimum of four times the amount of inoculant as recommended on the package is suggested. Gum arabic powder should be used as the adhesive. It is available at laboratory chemical supply companies. The coating is a finely ground calcium carbonate product such as lime, calcite, enamel whiting or 280 whiting.

To prepare the pellets, the gum arabic is dissolved in warm water and allowed to cool. The inoculum is added to the gum arabic solution and stirred until it is a smooth slurry. The seed is then added and stirred until it is well coated with the gum

arabic-inoculant mixture. Then the calcium carbonate material is added and stirred until all the seed is coated. The calcium carbonate sticks to the gum arabic to provide a protective coating and prevent the seeds from sticking together. If the coated seed is allowed to age for twenty-four hours, the pellets will be firmer. A cement mixer is more convenient than hand mixing when large quantities of seed are being handled.

In a study by Date (15), a number of mixtures using various sources of lime were tested. As shown in the table below, the seed inoculated without a coating gave significantly better initial survival than any of the coated seed. The lower survival with the no lime coat after 42 and 84 days was assumed to be due to less severe desiccation than in the lime coated treatments. After 84 days of storage, better survival of the inoculant was found on the lime coated than on the noncoated. Although a marked improvement in rhizobial survival during storage can be obtained with pelleting, it is advisable to sow pelleted seed as soon as possible to capitalize on the higher rhizobial counts.

EFFECTS OF COATING MATERIAL ON THE SURVIVAL OF RHIZOBIA TRIFOLII ON PELLETED SUBTERRANEAN CLOVER SEED (15)

Coating	Rhizobia surviving per seed from 10,000 after 7 days	21 days	42 days	84 days
Gum Arabic				
No Coating*	13000	4470	1380	178
Microfine Lime	4780	2510	1100	332
Plasterers Whiting	4270	1860	725	295
Calcium Carbonate	5130	2090	660	219

(*The article cites no explanation for the discrepancies of the numbers)

A newer system of inoculating seeds has been developed that provides large numbers of viable rhizobia to the seed in which a lime coating is not used. The "Pelinoc-Pelgel" system is a proprietary system (Lephatec Inc., formerly Nitragin Co.) of inoculating seed using a sticker with a gum arabic base and peat moss inoculum for coating and drying instead of a calcium carbonate product. The sticker is called "Pelgel" and the inoculum "Pelinoc". This system is designed to supply 25,000 to 50,000 viable bacteria to the seed just prior to planting. This method appears to be more effective than lime pelleting when the seed is sown promptly after inoculation. Jones(42) found the effectiveness of the adhesives in descending order were: Pelinoc-Pelgel, gum arabic-lime, methylcellulose-lime, and sugar-lime.

Graves(23) used the following table to exalt the merits of the Pelinoc-Pegel over lime pelleting inoculation:

EFFECTS OF INOCULATION ON SUB CLOVER FOLIAGE YEILDS (23)

		Lime Pelleting	Pelinoc-Pelgel
Hopland Field Station	Vassar	4114	6446
	Middle	2112	4169
	Orchard	616	1342
Johnson ranch, second year		1650	2970
Daley Ranch		1806	2577

Based upon the above information, it appears the most effective inoculation technique is the Pelgel-Pelinoc. This is especially true if the seed is planted in a prepared seed bed soon after it has been inoculated, and at the most appropriate time of year. No research has been found that compares the viability of the bacteria on lime-pelleted versus the Pelgel-Pelinoc inoculated seed in storage or long periods on the ground before germination. Phillips(63) didn't think there would be much difference unless the seed was to be sown on acid soils. Other research, referred to above, has shown greater longevity of the rhizobia with lime coating.

Caltrans' special provisions allow the use of the Pelinoc-Pelgel inoculation with the approval of the construction engineer. The intent is to have the contractor inoculate the seed at the project site immediately before sowing. However, the seed suppliers began using this method to inoculate the seed before it was delivered. This created a problem because in the activity of handling and transporting, the inoculant was dislodged from the seed. Most of the inoculant was in the bottom of the bag. It is likely that the Pelgel-Pelinoc method will continue to be allowed for Caltrans erosion control, but only if the inoculation is done by the contractor immediately prior to applying.

Preinoculation

Most commonly used legume seed is available to contractors or seed dealers as preinoculated seed. Preinoculation implies that there is a period of storage between the time the seed is inoculated and sold. The length of storage time can greatly affect the amount of live bacteria available on the seed.

There have been concerns raised about the viability of the rhizobia on preinoculated seed. The primary supplier of preinoculated seed in California, Celpril Industries in Manteca, CA, claims their coated preinoculated seed carries sufficient live rhizobia for up to one year when stored in their temperature-controlled storage facility. The results of a study done by Vincent and Smith (75), suggest that many retail samples of pre inoculated seed did not carry optimum levels of viable rhizobia. They also found that during storage of preinoculated seed, the viability of inoculant decreased faster on uncoated seed than on coated seed. In Australia, Brockwell(5) found no detectable rhizobia on three of the 48 samples of preinoculated seed they examined, 22 others carried very low numbers, and all but one fell below standards derived from the Australian Inoculant Research and Control Service requirements. The longer the seed has been inoculated, the more likely that competition from native rhizobia will hinder effective infection due to the low rhizobial numbers on pretreated seed

Preinoculated seed is commonly used on Caltrans projects. Seed suppliers normally inoculate the lesser-used legumes themselves due to the high cost of having small quantities commercially inoculated. The legumes that are used in large quantities are generally sent to Celpril for inoculation. Based on field reviews, most plantings of commercially inoculated seed appear to carry sufficient live rhizobia for effective nodulation. However, there are also a number of projects where the seeded legume was not successful. These can't necessarily be cited as the fault of the inoculation, but that suspicion is raised. When large amounts of inoculated seed are ordered by the suppliers, the last of it may be held in storage a long time before it is sold. This length of storage can have a detrimental effect on the survival of the rhizobia. It is also possible that handling after purchase, method or time of application, site characteristics, fertilizer, competition, weather, or other factors may have influenced the failure. We have no conclusive data at this time.

In an effort to insure adequate rhizobia numbers, the maximum length of time that seed can be inoculated before sowing is controlled. Caltrans' Standard Specifications require the seed be inoculated within 90 days of application or be reinocluated. This reinoculation requirement is being be viewed skeptically because there is no known information that indicates any success of reinoculating seed after it has already been inoculated.

Effects on Inoculation in Hydroseeding Legumes

Much of the seeding done for erosion control throughout the country is done by hydroseeding, either as a total erosion control solution or as a method of evenly distributing seed and fertilizer along with other protective measures. For a number of years, there have been questions about hydroseeding inoculated legume seed. Specific questions that have been considered are the effect of fertilizers on the inoculant and the possibility of washing the inoculant off the seed in the hydroseeder.

Prior to the pelleting system, the inoculant was added to the seed in several ways. In many cases it was simply dumped directly into the hydroseeder with the seed and fertilizer. In Zak's(79) research on crownvetch, he described various methods of inoculation, including mixing the inoculant with water to form a slurry before mixing it with the seed. An alternative was to sprinkle the seed with a small amount of sugar water before mixing in the inoculant to make it stick to the seed. When hydroseeding legumes, he recommended that the inoculant should be increased by three to four times. However, he evidently was not comfortable with hydroseeding because all his test plots were hand seeded and raked or drilled. In Maine(51), the inoculated seed was applied by hand prior to hydroseeding other materials. In Virginia(78), it was recommended that 10 times the recommended amount of rhizobia be used if the seed was to be hydroseeded. Because of the prevalence of acidic soils, lime was often applied by hydroseeder along with the seed and fertilizer .

In other research of seed viability in hydroseeding slurries, Brooks and Blaser(6) found that high concentrations of fertilizer salts affected seed germination. Field and laboratory results showed that high analysis fertilizers had less effect on the seed than those with low analysis because of lower salt concentration. Triple superphosphate (0-45-0) didn't seriously inhibit germination even though seeds were in contact with it. Ordinary superphosphate (0-20-0, 0-25-0) caused serious retardation in germination under moisture stress because of the high gypsum content. With nitrogen fertilizers, similar results were found where concentrated forms of fertilizers caused less burning than less concentrated forms. Organic and urea formaldehyde sources of nitrogen did not inhibit germination.

Carr and Ballard(10) found that the osmotic effects of fertilizer in hydroseeding slurries may reduce the germination of seed and kill rhizobia, both in the hydroseeding tank and after application. They suggest that if the fertilizer effects are minor, the seeding rates can be increased. If the effects are critical it may be necessary to apply seed and fertilizer in either separate or more dilute applications. They recommend pellet coating the inoculated legume seed to prolong seed-inoculum contact, or to broadcast the seed prior to hydroseeding the other materials.

The Nitragin Company(57) found fertilizer concentrations of up to 800 pounds of 10-20-20 in 1000 gallons of water were not highly toxic to crown vetch rhizobia unless the slurry was acid. In a fertilizer slurry with a pH above 5.0, approximately 25% of the rhizobia added were still viable after 2 hours in solution. With a pH lower than 5.0, most rhizobia were dead within thirty minutes. The pH of the slurry can be raised by adding lime, but limestone and $CaCO_3$ go into solution too slowly to neutralize the acid. Calcium hydroxide is more effective. In contrast to Brooks and Blasers' work, Nitragin found fertilizers with high nitrogen content were more toxic than those with lower nitrogen.

Brown and Wolf(7) also studied the survival of rhizobia in hydroseeding slurries. The typical slurry used in mined areas consisted of seed, 350 lb 16-12-12 fertilizer, and 350 gallons of water per acre. Mulch was not included and the inoculant was dumped into the slurry. The fertilizer components used in their research were combinations of ammonium nitrate, muriate of potash and either diammonium phosphate or triple superphosphate to simulate the typical 16-12-12. Diammonium phosphate (DAP) and triple superphosphate were the only fertilizers to influence the pH of the slurry. The DAP had a pH of greater than 7.0 either by itself or with N and K fertilizer and had little effect on the survival of the inoculant. Again in contrast with Brooks and Blaser, Brown and Wolf found the triple superphosphate resulted in very acid slurries that are detrimental to rhizobia survival. Inoculum viability was greatly reduced after 30 minutes exposure to pH of 6.0 and lower. The effects of the low pH compares favorably with Nitragin's results.

As in the Nitragin study, Brown and Wolf also used pulverized agricultural lime to counteract the acidity from the use of the triple superphosphate. They also found the slow solubility of the calcium carbonate increased the pH very little. The addition of highly soluble hydrated lime (calcium hydroxide) did increase the pH to tolerable levels. To neutralize the effect of the acidity of the superphosphate, they recommend a minimum of 40% of the phosphate be derived from diammonium phosphate. And, since with hydroseeding the rhizobia are spread over the entire land rather than being concentrated close to the seed, additional rhizobia should be added. They also recommend the slurry be maintained above a pH of 6.0 and the time of exposure in the slurry be as short as possible after the inoculum is added.

To determine if rhizobia are washed off the seed in the hydroseeding process, Kay and Jones(44) compared the seeding of subclovers by hydroseeding and by dry applying. Seeds were pellet inoculated by the method described in Bulletin AXT-280. The slurry contained a per acre equivalent of 2625 gallons water, 875 lb wood fiber mulch, 612 lb of 0-36-0-20 (triple superphosphate fortified with elemental sulfur) and 35 lb clover seed. Samples of the hydroseeded applications were sprayed on a prepared seed bed after 1, 10, 20, 30, 60, and 120 minutes in the hydroseeder. These were compared with the same seed, inoculated

and noninoculated, and dry applied at 20 lb per acre with 500 lb of the same fertilizer. Stands were rated on a 1 to 10 basis, from no plants nodulated to all plants effectively nodulated. Numbers followed by the same letter indicate no significant difference.

Time in hydroseeder	Mt. Barker	Woogenellup
1 minute	10a	9a
2 minutes	9a	9a
10 minutes	8a	8a
20 minutes	8a	8a
30 minutes	8a	8a
60 minutes	4b	8a
120 minutes	1c	2b
Dry Pellet	8a	8a
No inoculation	1c	1b

Their conclusion was that pellet-inoculated seed (calcium carbonate coated) will remain effectively inoculated in a hydromulching slurry if seeded within 30 minutes. As shown in the above table, both species were as successful as the dry applied seed.

Kay has since changed his position (personal communication, 1989) based on the work of W. Graves in southern California. In a 1985 letter to E. Kress, Caltrans Chief Landscape Architect, he stated that a coating had not been found that will not wash off. The seed should be dry applied as the first of a two-step process, then the mulch and fertilizer added in step two.

Walter Graves has long been an advocate of using legumes for erosion control. He is also fairly adamant in them being applied by a dry method as opposed to hydroseeding. The following table shows the results of one test comparing hydroseeded and dry applied clover.

Establishment of Early maturing subclover Strains Under Pellet Inoculation Dryspread and Hydromulched Seeded Conditions (San Diego, Seed Spread 6-15-82) (22)

Seeded Condition	Above ground production (kg/ha)	Cover (%)	Number plants (0.25m)
Pellet inoculated seed, dry spread	3123	96	29
Pellet inoculated seed, hydroseeded	105	10	2

Gum-arabic-coated inoculant at the rate of 5 kg inoculant to 100 kg raw seed. Plants sampled 5-19-83. Average of 10 samples.

No other information accompanied this table to explain the conditions of the test or the results. As such, the results must be viewed skeptically. The seed was inoculated with the Pelgel-Pelinoc method so it did not have a calcium carbonate coating. Whether fertilizer was applied or how long the seed was in the hydroseeder was not reported. It is also not known if the dry applied seed was raked in or covered with a mulch. These, and other factors, could have significantly affected the germination and establishment of these clovers. These test results appear to be unsubstantiated in supporting the conclusion that legumes should not be hydroseeded.

For many years, most Caltrans projects had seed applied by hydroseeding. As discovered in this research project, many of these projects were successful; some were not. There can be many reasons why a particular erosion control treatment failed. The time of year, method of application, weather, quality and choice of materials, proper species selection and the reliability and conscientiousness of the contractor all contribute to the success of a project. If hydroseeding alone was significantly detrimental to the rhizobia, few successes should be reported.

In a recent large project reviewed for this research, the erosion control was applied in the fall in a three-step process where the seed, primarily legumes, was applied by hydroseeding, straw was blown on at a rate of two tons per acre and then 'tacked' or glued down with a tackifier and fiber. The fertilizer was applied in the third application with the tackifier. Because of unusually cool temperatures, the cover was slow to establish, but by spring there was a thick green carpet of clover. In a few areas though, the clover plants were tinged with red which is an indication of nitrogen deficiency. These plants were not sufficiently nodulated to produce their own nitrogen. From a recent discussion with the contractor, it was learned that he added the pelleted legume seed to the agitating water in the hydroseeding tank prior to loading the fiber. The seed was in the slurry considerably longer than thirty minutes. It is probable that some of the inoculant was washed off.

Caltrans generally requires a two-step application for hydroseeding. In the first application the seed is applied with 500 pounds of fiber per acre. This fiber rate cushions the seed as it passes through the hydroseeder's pump gears, puts the seed as close to the ground as possible, and allows the operator to visually monitor the application to provide even coverage. It is very important to have the seed in contact with the soil. The critical period for all germinating seed is from sprouting until the radicle enters the soil. Any delay increases the danger of the radicle drying or being affected by pathogens or insects. A second application of 1000 to 1500 pounds of fiber covers the seed and helps insulate it from the sun and aridity. The additional fiber also provides surface erosion protection. A mulch of 3000 pounds of straw is generally considered more effective than the second application of fiber. If fertilizer is

applied with the second fiber application, or with the straw tack, it reduces the potential of the inoculant being killed by the acid hydromulch solution. This is a sound procedure for hydroseeding all seed varieties because it prevents the seed from long exposure to a potentially toxic solution.

There are potential problems in hydroseeding legumes, as there are in hydroseeding any seed. Pelleted seeds left in hydroseeding solution too long will likely have the inoculant removed from seed. If the seed is applied on a site without competitive rhizobia and at a time of year that the seed will sprout in a short time, there is still a reasonable chance of success. However, if the inoculant is removed from the seed and spread over the surface of the ground where it is exposed to sun and aridity, it will result in poorly inoculated or noninoculated seed. By requiring the seed to be pellet inoculated and limiting the amount of time the seed is in the hydroseeder, these problems can be minimized. If the seed is applied in separate applications the problem of fertilizer toxicity is lessened.

The most adverse conditions for the survival of the rhizobium are age, aridity, acidity and heat. If these factors can be controlled, there is a good chance that there will be effective nodulation. Dry applying legume seed alleviates some of these problems, but it does increase the cost slightly by requiring an additional application. Whether legumes are applied dry or hydroseeded depends on the specifiers confidence in getting quality products and application.

There are locations where dry application is not feasible. It is often not physically possible to walk on steep rocky slopes to sow seed. Pellet inoculated legume seed is like a small marble. When it is dry applied to a steep slope, much of it ends up in the gutter at the bottom. Application by drilling is generally not possible because of the degree of slope. There is technology to pneumatically apply seed(30) and fertilizer, but that requires additional equipment and has some range of throw limitations.

Of more importance than the method of application is getting the most specific rhizobium for the species being planted and using fresh inoculant. It is also important to pellet the seed with a calcium carbonate coating unless it will be planted immediately and at a time of year that germination will be prompt. Caltrans will continue to dry apply legumes on many erosion control projects where legumes are the predominate vegetative cover and where the timing of the application cannot be controlled. We will also continue to hydroseed legumes given the right controls.

Fertilization

As with any other crop, legumes need essential nutrients to be able to grow and reproduce. Of more than 100 chemical elements known today, only 16 have been shown to be essential for plant growth(8). Of those 16, oxygen, carbon and hydrogen are taken primarily from air and water. The remaining nutrients are absorbed by the plant roots from the soil. For legumes, the exception to this is nitrogen, which is also absorbed from the air. If any of the essential nutrients are not available, the plants will not be able to survive.

Deficiencies of mineral nutrients affect the growth of legumes by affecting the photosynthesis process, the formation of nodules, or the fixation of nitrogen in the nodule. A legume suffering from a deficiency of any nutrient other than nitrogen cannot benefit fully from inoculation. Boron and calcium are necessary for nodule formation. The elements needed for nitrogen fixation are calcium, cobalt, copper and molybdenum. Elements that are required for the healthy metabolism that enables a legume to utilize fixed nitrogen are boron, calcium, copper, phosphorus, potassium, sulfur and zinc(33).

The elements most commonly deficient for legume production in California soils are phosphorus and sulfur(42). Without one or both of these elements, legumes can't synthesize protein even with an ample supply of nitrogen. For this reason, phosphate fertilizers are generally recommended for use on legume crops.

The most commonly available and used phosphate fertilizer in the agriculture market is triple-superphosphate. This fertilizer is made by mixing ground phosphate rock with phosphoric acid(8). The end product contains about 46 percent P205. Because of the high analysis, this fertilizer is economical to transport and apply. Sulfur is generally applied in the fields separately. Normal or single superphosphate is made by reacting sulfuric acid with the ground phosphate rock. The end product usually contains twenty to twenty-five percent available P205 and eight to twelve percent sulfur, respectively. This has been a good mixed fertilizer for use with legumes for erosion control.

Most of the literature on inoculation or legume seeding cautions against the use of nitrogen fertilizers with legumes. Well-nodulated legumes do not need any nitrogen from the soil. Even at very low levels, soluble nitrogen prevents root nodule formation (63). Nitrogenous fertilizers also generally give grasses a competitive advantage over most legumes.

Caltrans rarely tests soil to determine the required amounts of nutrients for erosion control applications. Most projects are left with a surface of subsoil rather than topsoil. It is reasonable to assume that this material is relatively sterile. For many years, 500 pounds of 0-25-0 was specified for use with legume seeding based on the recommendations of Kay and Graves.

However, in early 1987, this formulation of single superphosphate was no longer being manufactured. There was not much demand for it in the agriculture market and use by Caltrans was not sufficient to make its manufacture economical. It was also difficult for the suppliers to store because the acidity would deteriorate the bags. Later, a 0-20-0 superphosphate became available with a sulfur content of about 8 percent. This fertilizer is now also difficult to obtain.

In the meantime, another phosphate fertilizer was found to replace the superphosphate. A local supplier is blending a 0-36-0-19s from 0-45-0 and 'popcorn' sulfur. 'Popcorn' sulfur is pure sulfur which has been expanded to give it more surface area. It breaks down slower and lasts longer than ground sulfur. Initially, this blend was available only as a bulk product and had to be purchased in quantities of one ton or more. This was adequate for large projects but not suitable when only a few hundred pounds were needed. It is now being bagged and is available statewide from at least two suppliers.

IMPLEMENTATION

Implementation of the results of this project will be accomplished by the revision of specifications, additional research on legume species, distribution of this report and articles prepared for trade journals and publications.

The specifications will be made more explicit regarding the Pelgel-Pelinoc inoculation. This inoculation method is meant to be done immediately before sowing. A memorandum to construction inspectors will be sent to notify them that this method shall be done only by the contractor on the project site. Seed-supplier-applied inoculant by the Pelgel-Pelinoc method will not be in compliance. All legume seed not inoculated by the contractor shall have a calcium carbonate coating.

An inoculation specification will be prepared that will detail the requirements of inoculation. This will replace the existing system of referring to a University of California publication. Reinoculation will be deleted for seed that has exceeded the specified time limitation for inoculation. An attempt will be made to specify a minimum number of rhizobia per seed rather than by weight of inoculant. Workshops will be held with inoculant manufacturers, seed coating companies, seed suppliers, academia and Caltrans specification writers to determine the most practicable inoculation specifications and determine the benefits or limitations of preinoculated seed. It is anticipated that these workshops will result in industry agreement for standards and specifications for inoculation of legume seed, time of storage, preinoculation, and probable effects of hydroseeding.

A memorandum will be prepared and sent to Caltrans Districts detailing the information that should accompany inoculated seed. This information will include the date of inoculation, the

species of Rhizobia used and the expiration date as listed by the manufacturer, and the amount of inoculant and inert material. This information will also be sent to the seed suppliers so they will know what will be expected for Caltrans' projects.

Additional research is needed to find new species of legumes for more difficult sites. The implementation of this has already been started by contracting with the Soil Conservation Service in the Lake Tahoe area to do additional research to find species for high altitude areas. The Plant Materials Center for the Soil Conservation Service in Lockford is also reviewing legume species for erosion control and revegetation. A relationship will be maintained with them to help find additional species for use by Caltrans. As new species become available, the Districts will be encouraged to establish test plots on erosion control plantings to evaluate these new species.

EFFECTIVENESS OF LEGUME SEEDING
FOR EROSION CONTROL

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The materials historically used for erosion control have required high inputs of fertilizer to obtain a cover. That cover provided abundent fuel for fires, delayed the invasion of desireable plants and often did not persist.

Legumes, in association with Rhizobia, have the ability to produce their own nitrogen. As erosion control covers they re-fertilize sterile construction site soils, help re-establish soil profiles and allow the invasion or re-establishment of desireable woody vegetation. They can also produce sufficient biomass to provide surface erosion protection.

This research project reviews the use of legumes for erosion control on Caltrans projects, problems of inoculation and nodulation, pellet inoculation, pre-inoculation, hydroseeding of legumes and fertilization practices.