HYDROSEEDING OF FOREST ROAD SLOPES FOR EROSION CONTROL AND RESOURCE PROTECTION

by

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ABSTRACT

Soil erosion resulting from logging road construction is a serious problem affecting physical stream water quality and road stability in British Columbia. This study investigates slope re-vegetation by hydroseeding to alleviate this problem.

Laboratory tests on the effect of fertilizer slurry contact on seed germination show a 30% loss in *Trifolium repens* germination after a 60-minute exposure to a solution of 90 kg 10-30-10 fertilizer per m^3 of water (750 lbs fertilizer per 1000 gallons water). Although there was no significant effect of such exposure on *Rhizobium* inoculum, care must be taken to limit seed soaking time in the hydroseeder and to keep slurry fertilizer concentration as low as possible.

Field hydroseeding tests show no significant advantage from separate applications of seed then fertilizer, nor from the use of a mulch in connection with slurry application. The effect of seed-fertilizer contact in the slurry did not appear to be operationally significant. Mulching did not have a significant effect on the composition of the vegetative cover established nor on the effectiveness of the plant cover in erosion control. All hydroseeding treatments yielded satisfactory vegetative cover (averaging 65%) and similar vegetative composition. Soil on untreated control plots eroded an average depth of 2.3 cm (0.9 in) from September 1976 to April 1977. This translates to 256 m^3 of eroded soil material per km of logging road (540 cu yd per mile), assuming 1.5 ha of exposed side slope per km (6 acres per mile). The vegetation not only was successful in halting erosion from the vegetated areas, but it also acted as a

catchment for soil particles brought into these areas from upslope by gravity and water erosion.

The one-step slurry application of seed-fertilizer-soil binder and water was as effective in vegetation establishment and erosion control as the other hydroseeding treatments and much cheaper. Based on 1976 costs, it would take approximately $2000 to hydroseed a kilometer of logging road ($3000 per mile) by this method. This is a small investment for road-side revegetation that can protect the integrity of a forest road (which may initially cost upwards of $60,000/km), reduce road maintenance costs, and greatly benefit the adjacent aquatic environments.

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INTRODUCTION

Soil erosion from forest road construction is a major management-related cause of forest stream turbidity and sedimentation (Figure 1). A newly constructed forest road can have from 0.5 to 3.0 ha of exposed soil and surficial material per km (2 to 12 acres per mile) that are extremely vulnerable to the erosive forces of frost and water (Personal communication, R. P. Willington 1976). Fredricksen (1965) found a 250-fold increase in stream turbidity and sedimentation during the first rain storms following construction of forest road on a small Oregon watershed.

Not only does road bank erosion cause degradation of the physical quality of stream waters, but it also plays a significant role in road stability problems. Reduced ditch drainage capacity and culvert blockage (Figure 2), undercutting of road banks (Figure 3), and undermining of the road surface (Figure 4) are all causes of road instability problems that can be traced to soil erosion. The use of a vegetative cover on forest road banks not only decreases stream sedimentation, but can also aid in prolonging road life and reducing maintenance costs. The recent studies of Dyrness (1975) and Megahan (1975) have quantified significant reductions in soil erosion achieved by revegetation of bare slopes beside forest roads. A plant and litter cover of 70 to 80% can effectively reduce soil erosion from both dry ravel and water erosion (Berglund 1976). The important functions of a vegetative cover are as follows (Berglund 1976):

Figure 1. Stream sedimentation and turbidity from forest road construction at Koksilah, 1976, before hydroseeding.

Figure 2. Culvert blockage from cut-bank erosion.

Figure 3. Erosion undercutting forest road bank.

Figure 4. Gully formation cutting into road surface.

1) Vegetation protects the soil particles from direct impact of raindrops. Raindrop energy will be dissipated on vegetation instead of on the soil particles.
2) Grasses and legumes can reduce the velocity of surface runoff, which also dissipates the erosive energy and allows more time for infiltration.
3) Grass can rapidly develop a fine, extensive root system that stabilizes soil particles by increasing resistance to erosive forces.
4) Established vegetation will trap eroding soil particles and prevent them from moving down the entire slope length.
5) The addition of organic matter to the soil not only makes soil more resistant to erosion but also is important in soil development.

The following are additional functions of a vegetative cover:

1) A well established grass cover can effectively slow (if not prevent) the invasion of red alder (Alnus rubra) on road edges, which would otherwise be held in check with herbicides or costly pruning (Becker 1971).
2) Revegetation of slopes with grasses and legumes can aid in the recovery of at least part of the roadside area removed from forest production, by improving soil properties (fertility and moisture holding capacity) and protecting the seedling from erosive damage.

The art of roadside revegetation has been developed and refined by various highway departments throughout the United States and Canada. Their work provides an excellent basis for forest revegetation and should be used in development of forestry methods. The most widely used revegetation practice is the direct seeding of road slopes with grasses or grass-legume mixtures. Direct seeding has been proven effective in cover establishment and lends itself to mechanization.

Hydroseeding or hydrograssing is the application to soil of a seed and water slurry that may contain fertilizer, a chemical soil binder, and/or a mulch (Figure 5). Materials can be combined in one slurry for a single application or some components can be applied separately for a multiple-step application (Figure 6). Either method provides effective spreading on slopes. Hydroseeding is not labor-intensive and therefore is one of the more cost-efficient methods of roadside revegetation.

The objectives of this study were to answer the following questions concerning hydroseeding as related to its cost-effectiveness and use in the forest environment.

A. Since Rhizobium inoculum is needed if legumes are to fix nitrogen, what is the effect of fertilizer concentration on Rhizobium viability?

B. What is the effect of fertilizer salts on seed germination in the one-step slurry application, where seed is exposed to a concentrated fertilizer solution in the hydroseeder tank?

C. What species of grasses and legumes are most suitable for hydroseeding on forest lands at two southern Vancouver Island locations?

D. Is a one-step slurry application, including both seed and fertilizer, better than a two-step (or separate) application of seed then fertilizer? The trade-off may be reduced seed germination

Figure 5. Small (950-liter capacity) hydroseeder used in experiments.

Figure 6. Hydro-slurry containing seed, fertilizer, binder, and mulch.

versus higher cost.

E. Are the benefits of mulching justified by its added cost?

F. How much soil erodes from forest road slopes and what reduction is possible as a result of hydroseeding?

G. How do the costs of different hydroseeding treatments compare?

BACKGROUND

Hydroseeding as a method of grass-legume establishment has only been practiced about 15 years. The development of new equipment and slurry amendments is proceeding rapidly. These advances contribute greatly to the economic and operational advantages of hydroseeding over dry seed application on steep slopes.

Soil binders

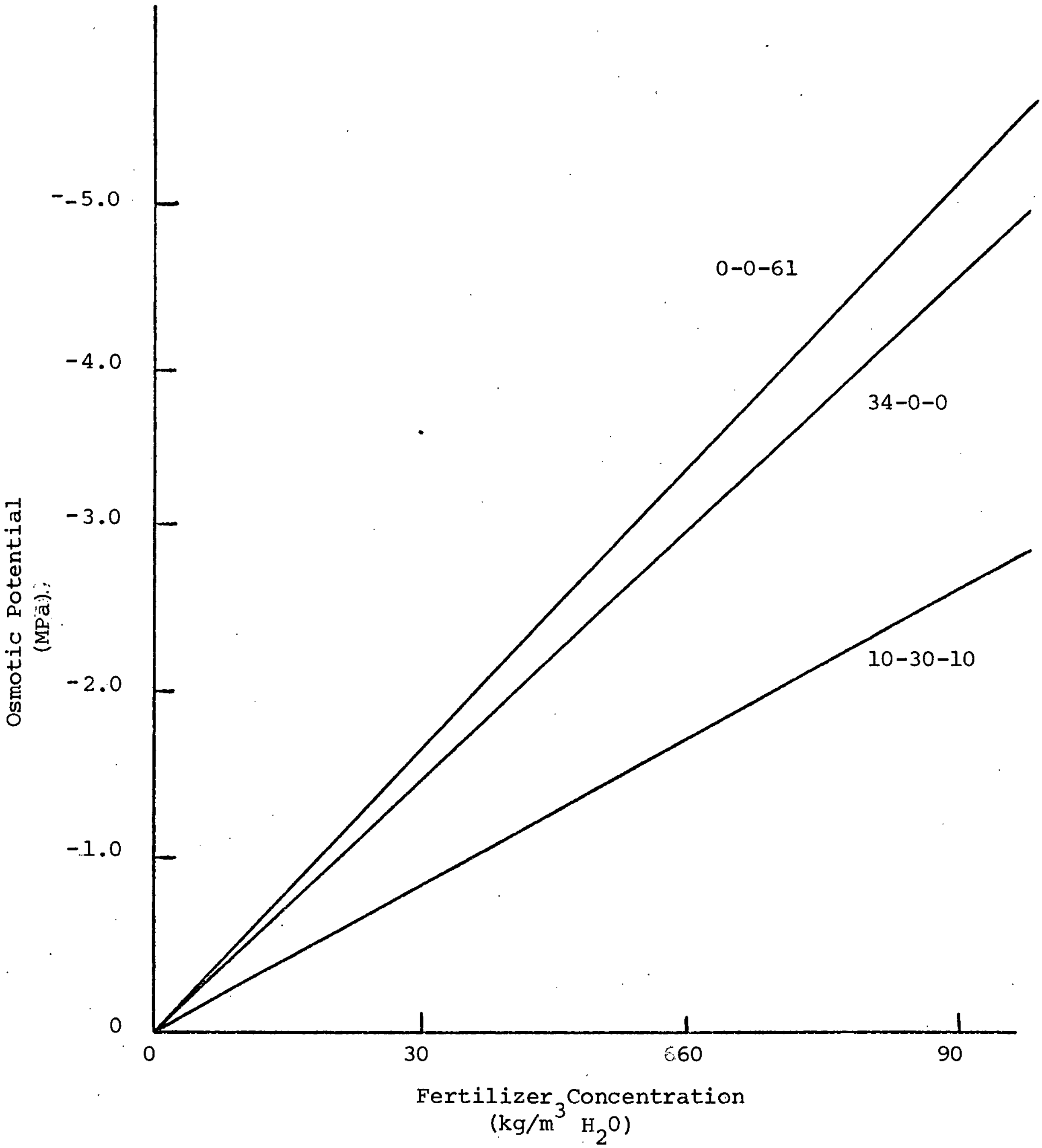
One of the more recent and most significant advances in hydroseeding has been the development of chemical soil binders. The soil binder is an organic or inorganic substance added to a slurry to give temporary soil cohesion, holding the seed and surface soil particles in place on steep slopes. Where wind and water would normally remove seed and other soil amendments from the slope in a dry seed application before germination is secured, the binders, which can last up to 3 months (Armbrust and Dickerson 1971, Kay 1976) hold the seed in place to help ensure even cover establishment.

Fertilizer

The addition of fertilizer to a slurry is an excellent method of site fertilization that is inexpensive, requiring little additional time and no extra equipment. This liquid application of soluble fertilizers provides an even distribution of fertilizer on infertile road cut and fill slopes that are not accessible to conventional non-aerial spreading methods. Also, once dissolved, the nutrients may be readily available to the fast germinating species, e.g., *Lolium* spp. and *Trifolium* spp. These advantages however, may be partially offset by loss of seed germination and plant vitality, induced by immersion of seeds in high concentrations of fertilizer slurries.

In soil, soluble fertilizer salts are dissolved in the soil solution surrounding the zone of application, which becomes quite concentrated. Excessive concentration of soluble salts in contact with roots or germinating seed causes injurious effects, e.g., plasmolysis, restriction of available moisture, or actual salt toxicity (Tisdale and Nelson 1966). The increase in salt concentration and resulting depression of osmotic potential of the soil solution will vary depending upon fertilizer grade and mix. Radar *et al*. (1943) found, for a 448 kg/ha (400 lb/acre) application of fertilizer, decreases in osmotic potential in the soil ranging from .019 to 3.966 bars. In hydroseeding, however, there is no soil to buffer the salt solution concentration and osmotic potentials incurred are much lower. Osmotic potential as a function of fertilizer type and concentration is shown in Figure 7. At the highest concentration of 90 kg of fertilizer per m^3 of water (750 lbs. per 1000 gallons) or the equivalent of a 420 kg/ha application of fertilizer, potentials incurred range from -2.48 to -5.10 MPa. The fertilizers 0-0-61 and 34-0-0 are high in potassium and nitrogen salts respectively, which are major contributors to the decrease in osmotic potential. Fortunately, if the soil is moist, the exposure of seed to such high concentrations is limited to the time between mixing and application. Even this limited exposure may be the cause for loss of legume vitality and seed germination.

Figure 7. Graph of Osmotic Potential as a function of Fertilizer concentration and type.



Brooks and Blazer (1963) showed that after a 30 minute exposure to a solution of 108 kg of 10-20-10 fertilizer per m^3 water (900 lbs. per 1000 gallons water), germination of Kentucky 31 fescue (*Festuca elatior*) was reduced from 98% to 61%. Personal communication with landscape contractors (L. Barberry of Barberry Bros. Sod Inc. 1975 and P. Sahlstrom of Terrisol Hydrograss Ltd. 1976) appears to substantiate this with observations that some species in a seed mix never appear, although they had previously been used successfully. Part of this problem may be attributed to mechanical damage from the hydroseeder pumping system (Kay 1976), but it appears that fertilizer salt contact may also be a significant contributor.

Fertilizer salt contact may also account for a lack of legume vitality observed by Kay (1976) after prolonged soaking in a hydroseeder. The problem is a lack of legume nodulation by *Rhizobium* bacteria that are included with the seed in the hydroseeder. The bacteria, in a humus base, are coated on the seed with a sticking agent to help ensure sufficient organisms in the soil for infection and nodulation. Without the nitrogen-fixing bacteria, legume establishment and vitality are definitely retarded (Lother and McDonald 1973), unless nitrogen deficiencies are absent. The cause for this lack of nodulation in the hydroseeding may be initial low viability of *Rhizobium*, separation of the seed and bacteria, *Rhizobium* mortality from soaking in the fertilizer salt solution, or repression (by available nitrogen) of infection.

New seed coating procedures ensure better and longer seed-inoculum contact, thus removing this problem. However, the presence of excessive nitrogen in the soil has been shown to repress legume nodulation (Dart and

Wildon 1970; Richardson, Jordon, and Gerrard 1957; Tanner and Anderson 1963). The temporary exposure to a nitrogen fertilizer may be enough to repress nodulation. There is also the possibility of Rhizobium mortality from plasmolysis caused by exposure to low osmotic potentials in a fertilizer solution.

Mulch

The use of mulch is often recommended with direct roadside seeding. Mulch is non-living material offering instantaneous protection to the soil surface (Berglund 1976). Mulch may also improve the microenvironment of the seed by moderating evaporation and soil moisture content, and modifying soil and air temperatures (Brink and Maxwell 1965). Dyrness (1967) found mulches to be important in his forest roadside revegetation study.

There are a number of mulching materials available, such as excelsior matting, jute netting, straw, and paper or plastic coverings (Dueck 1967; Kay 1976). These mulches, however, can be expensive or labor intensive, and/or require special application equipment. The cost of these materials is generally prohibitive in the forest environment. There has been recent development of hydro-mulches which are applied in slurry form with seed or separately. The most common hydromulch is a cellulose fiber by-product from the pulping industry (e.g., Silvafiber, Conwed, Spra-mulch). More recently, pelletized grass seed wastes (Jacklin Organic Mulch) has been added to the list of mulches that are applied in slurry form. All are adequate mulching agents that provide the ease of slurry application, which makes them relatively inexpensive compared to other types of mulches.

The addition of a hydro-mulch to a single-step slurry application does, unfortunately, at least double the cost of basic hydroseeding by increasing both material costs (Table 1) and time of application (Table 2). Kay (1977) believes that proper time of seed application and good

TABLE 1

COST COMPONENTS BASED ON ACTUAL FIELD OPERATION WITH 1200 GALLON HYDROSEEDER (1976)

Material	Rate per Hectare	Cost per Hectare
Seed	94 kg	$125
Fertilizer	440 kg	100
Mulch	1100 kg	250
Binder	22 kg (with mulch)	150
	or	
	11 kg (without mulch)	75
Equipment Operation	Variable with treatment	Variable (based on $150/hour)

TABLE 2

TOTAL COST PER HECTARE

Treatment	Steps	Hours	$
Unmulched	1 - step	3	750
	2 - step	6	1200
Mulched	1 - step	6	1550
	2 - step	9	2000

(Based on 50 hectare operation) (1976)

agronomic practices will give better results than relying on mulching to offset any problems that may arise. Also the possibility of inducing early seed germination in an unfavorable macro-environment is eliminated. Personal communication with people that are involved with hydroseeding (J. Morrow of N.W. Stabilization Chemicals 1977 and L. Barberry 1975) indicates that in the long run, there appears in many cases to be no significant cover difference where mulched and unmulched areas are compared. The instantaneous soil protection of mulches may be somewhat superfluous with the use of a chemical soil binder.

Seed Mix

The method and timing of seed application are important considerations in roadside revegetation, but most important is the selection of a proper seed mix for the area in question. Without proper species selection and combination, no amount of precaution or sophistication of application techniques will aid in cover establishment. A proper seed mix should contain species that are suitable to the soil and surficial materials, topography, and climate of the treatment area. Species chosen should be compatible (aggressive species avoided), with at least one rapidly establishing, short-lived species to provide quick cover while the slower developing but long-lived perennials develop (Brink 1964).

As to actual species selection for revegetation in western Canada and northwestern U.S., papers by Brink (1964), Hafenrichten (1963), MacLaughlan (1966), U.S. Environmental Protection Agency (1975), and Berglund (1976) all give excellent ecological descriptions of species adapted to this area. The paper by Berglund (1976) is recommended, for it deals specifically with hydroseeding in the forest environment. With some judicious consideration, his seeding recommendations for Oregon can be modified for use in British Columbia. Also, the B.C. Department of Highways can be helpful in more localized grass-legume selection.

Soil Erosion

Surface soil erosion is not as spectacular or obvious as mass wasting. However, over the life of a road system and especially during the first few years after construction, it can be a very serious problem affecting physical stream quality and road stability. Unfortunately, this problem is seldom given proper consideration by the B.C. forestry community. The Federal Fisheries Act, section 33.1, provides regulations and fines for excessive stream sedimentation. The B.C.F.S. supplemental road design standards, SS-648, also provide regulation for erosion control. Both of these are seldom enforced (partially due to low work forces), and the erosion damage continues.

Fredricksen (1965) found a 250-fold increase in stream sedimentation during the first rainfalls following construction of 2.5 km (1.65 miles) of logging road on a 100-hectare (250-acre) watershed in the Willamette National Forest in Oregon. Sediment levels continued to be higher than a companion undisturbed watershed for the next two years. Dyrness (1970), by measuring the profile of a 7.6-m-high, 1:1 backslope, found a 1.14-cm (0.45-inch) soil loss over the first winter after road construction from water erosion. This is roughly equivalent to 102 t/ha (45 tons/acre) of soil lost. Soil loss by dry ravelling over the summer was almost as great as the rain-caused loss, amounting to 1.2 cm (0.4 inches) of soil loss. These two losses total a 2.16-cm (0.85-in.)

soil loss over the first year, or approximately 193 t. of soil lost per hectare (85 tons per acre). After five years, the annual loss was 0.51 cm (0.2 in.), still accounting for a soil loss of 45 t/ha (20 tons/acre). Although a large portion of this eroded soil temporarily comes to rest in the road drainage system, e.g., ditches and culverts, road drainage water and continual grader activity (sidecasting) eventually transports most of this soil to neighboring streams. While in the road drainage system, this soil reduces effective water-carrying capacities of the drainage structures, jeopardizing road stability.

SCOPE OF THE STUDY

The purpose of this study, as stated in the objectives, was to answer some questions and problems pertaining to the use of hydroseeding in the forest environment. Five experiments, two in the laboratory and three in the field, were undertaken to fulfill these objectives. The laboratory experiments deal with the problems associated with fertilizer salts. The field experiments pursue the effectiveness of operational hydroseeding.

The project was funded by British Columbia Forest Products Ltd. B.C.F.P. has large timber holdings on southern Vancouver Island, which includes some watersheds with high fishery value. Due to the increase in sedimentation resulting from road construction and possible damage to this fishery resource, field hydroseeding trials were concentrated in this area. Two test locations were chosen on southern Vancouver Island, representing two of the three major precipitation zones of the island (Figure 8).

The Koksilah site is located near Shawnigan Lake in an area of 180 cm (70 inch) of rainfall. The chosen road cut-slopes are on a very erodible fine-textured till material, with a thin clay layer 1.5 to 1.8 m (5 to 6 feet) from the surface. Recent heavy siltation of the Koksilah River has been traced to the cut and sidecast slopes of this 3-year-old road (Figures 9 and 10).

The Caycuse site, near the west end of Cowichan Lake, receives in

Figure 8. Location of study areas on southern Vancouver Island.

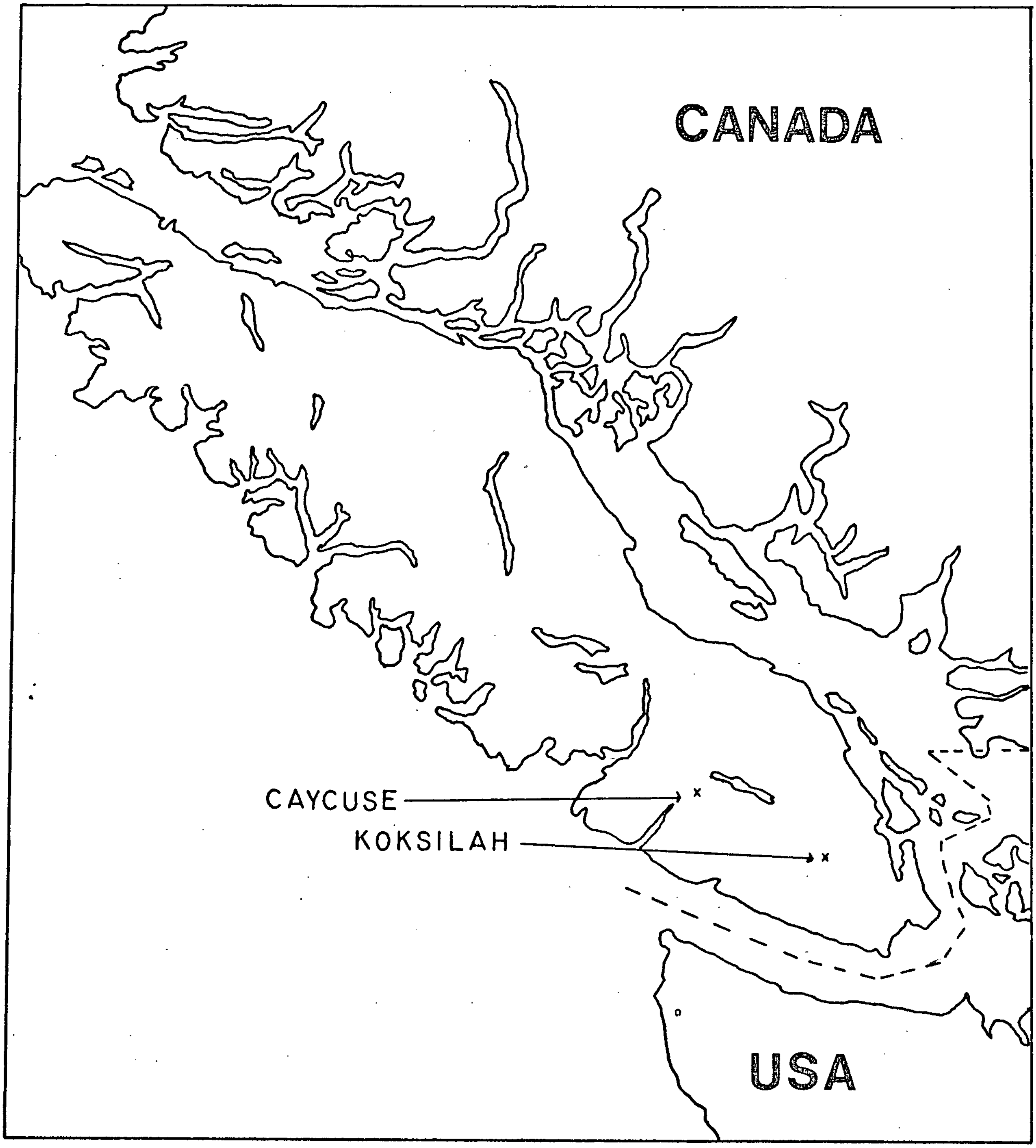


Figure 9. Koksilah sidecast slope before treatment, Sept. 1976.

Figure 10. Koksilah cut-slope during treatment, Sept. 1976.

excess of 250 cm (100 inches) of precipitation annually. The predominant soil material in this area is a very clayey glacial till which, through heavy surface erosion from cut-slopes (Figure 11), is resulting in road stability problems and high road maintenance costs. A comparison of the two sites is presented in Table 3.

TABLE 3

SITE COMPARISON

Location:	Koksilah	Caycuse
Elevation:	305 m	305 m
Rainfall:	180 cm	250+ cm
Soil Material	Fine textured till (with clay blanket)	Clayey glacial till (40-50% clay)
Aspect:	S to SE	SE
Slope:	70 - 90%	80 - 90%
Av. Slope Length:	15 - 20 m	12 m
Treatment Blocks:	2 cut-slopes 2 fill/sidecast slopes	3 cut-slopes

Figure 11. Caycuse cut-slope before treatment, Sept. 1976.

METHODS AND MATERIALS

Laboratory Experiments

The two laboratory experiments deal with the problem of high concentrations of fertilizer salts in the hydroseeder and their effect on seed germination (Brooks and Blazer 1965) and legume vitality (Kay 1976). The testing criteria for each experiment are based on operational hydroseeding maxima. A contact time of 60 minutes and fertilizer concentration of 90 kg of 10-30-10 fertilizer per m^3 (750 lbs/1000 gallons) of water were deemed as a maximum seed contact time and slurry concentration that should occur in the field operation of hydroseeding. This time and concentration were used initially for both experiments.

Experiment 1: The effect of fertilizer salts on *Rhizobium* inoculum viability. The objective of this experiment was to evaluate the effect of temporary exposure to a salt solution on *Rhizobium* viability and subsequent legume nodulation. The test was run using commercially available *R. trifolii*, white clover inoculum. Two salt solutions were used, each equivalent to an osmotic potential of -2.5 MPa. The first salt solution was prepared with KCl according to Wiebe *et al* (1975). The other was prepared with 10-30-10 fertilizer: 90 kg/m^3 of solvent. In this manner, both the *Rhizobium* mortality from salt toxicity or plasmolysis, and the influence of nitrogen on nodulation (Dart and Wildon 1970) were tested. A sterile buffer was the third solution used, serving as a control.

The method used for determining the number of viable Rhizobium cells per gram of inoculum was the plant-infection technique prepared by Dr. Lucien M. Bordeleau, of the Agriculture Canada Research Station at Sainte Foy, Quebec, for the Production and Marketing Branch of Canada Agriculture, Plant Products Division. The procedure is based on J. Brockwell's 1963 work with the plant-infection method for determining Rhizobium numbers. Basically, this method is a most-probable-number (MPN) technique, with a series of five-fold dilutions of inoculum. Samples of each dilution are then placed in test tubes containing a growth medium and sterile legume seeds. Any observed nodulation is a positive test at that dilution level. By counting the number of positive tests at each dilution level and referring to a MPN table, as in Brockwell (1963), the number of viable Rhizobium cells per gram of tested inoculum is obtained.

In my study, the only deviation from the Bordeleau (1976) procedure was with the initial inoculum dilution. The initial inoculum dilution, for both of the salt treatments, was agitated for 60 minutes in the respective salt solution before subsequent dilutions with a sterile buffer. The control treatment was agitated for 10 minutes initially in a sterile buffer. All subsequent dilutions were with the sterile buffer and 10 minutes of agitation.

Experiment 2a: The effect of fertilizer-slurry contact on seed germination. Although Brooks and Blazer (1965) showed that fertilizer-seed contact could reduce seed germination, the objective of this study was to try to establish a rating system of species' susceptibility to such fertilizer contact. After a 60 minute exposure to a fertilizer-slurry concentration of 90 kg 10-30-10 fertilizer per m^3 water, each of the grass and legume species tested (Table 4) was washed and germinated according to the 1966 International Seed Testing Association guidelines. Each germination test consisted of three 100-seed samples. Species exhibiting a negative germination response to the initial fertilizer concentration would be tested at lower levels of fertilizer, 60 kg/m^3 then 30 kg/m^3, (500 lbs. per 1000 gallons, then 250 lbs.).

TABLE 4

SPECIES USED IN FIELD TRIALS AND GERMINATION TEST

Grasses	Legumes
Phleum pratense - timothy	Trifolium repens - white clover
Agrostis alba - redtop	Trifolium pratense - red clover
Lolium perenne - perennial ryegrass	Trifolium hybridum - alsike clover
Lolium multiflorum - annual ryegrass	
Dactylis glomerata - orchardgrass	
Festuca rubra - chewings fescue (var. commutata)	
Festuca arundinacea - tall fescue	
Festuca rubra - creeping red fescue	

Experiment 2b: The effect of a residual fertilizer coating (from slurry soaking on seed germination. In the first part of experiment 2, fertilizer-seed contact was ended after the 60 minute exposure to the slurry by washing the seed. This variation was designed to see if continued fertilizer-seed contact from a residual fertilizer coating produced any additional negative effects on seed germination. Due to limited space, only four species would be tested, two that would show an effect in the first part and two that would not. The only change in procedure was that seeds were not washed between the slurry exposure and germination tests.

Field Experiments

The three field experiments were performed on hydroseeding test plots at the two chosen Vancouver Island locations, Koksilah and Caycuse. The overall design of the field plots was a randomized complete block, with four blocks (slopes) treated at Koksilah and three blocks treated at Caycuse. Each block consisted of four hydroseeding treatments and a control. The plots were 15.24 m (50 feet) in width. The hydroseeding specifications and treatment descriptions are presented in Table 5. The treatments are a combination of one and two-step applications (seed and fertilizer together or applied separately) and the use or non-use of a mulch. The special seed mix was made up of the eight grasses and three

TABLE 5

TREATMENTS

	No Mulch	Mulch
1-Step	Seed + Fertilizer + Binder	Seed + Fertilizer + Binder + Mulch
2-Step	Seed + Binder, followed by Fertilizer + Binder	Seed + Binder, followed by Fertilizer + Binder + Mulch

Specifications

Seed Rate:	100 kg/ha	Special Mix
Mulch:	670 kg/ha	Jacklin Organic Mulch
Fertilizer:	450 kg/ha	10-30-10
Binder:	11 kg/ha (without mulch) or 33 kg/ha (with mulch)	Terra Tack I

Applicator: 950 liter hydroseeder (recycling agitation)
Terrisol Hydrograssing Ltd., Vancouver

legumes in Table 2, plus Festuca ovina (hard fescue) and Lotus corniculatus (birdsfoot trefoil). The field experiments deal with species composition of established vegetative cover, per cent plant cover established, and the amount of erosion from the plots.

Experiment 3: Species composition of established vegetation. The species composition of the established vegetative cover was estimated by a frequency test. This method is basically a listing of all vegetation present within a small circular sample frame. In this study, a 0.035 m^2 circular hoop was used and five random samples were taken in each plot. A species was assigned a frequency of 20% for each of the five samples in which it occurred. For example, if Trifolium pratense was present in three out of five random samples, it would be assigned a 60% frequency. The higher the frequency of a particular species, the more widespread the species is, and the more likely it is to contribute significantly to total plant cover.

Experiment 4: Estimate of percent plant cover. Each treated plot was photographed using 35-mm color-infrared positive slide film and a Wratten 12 filter. (Color-infrared film was used to accentuate the soil-vegetation contrast as illustrated by Figures 12 and 13). Once developed, slides were projected onto a 200-dot grid, and percent plant cover was determined. Care was taken to assure, approximately, the same sampling intensity per unit area for each slide.

The ideal photograph of each plot would have been vertical (to avoid "shadow" effects by taller vegetation). However, this was not possible due to slope length and steepness. Therefore, each treatment block was photographed from the same angle (as similar between blocks as possible) in order to maintain uniform overestimation within each set

Figure 12. Plot photographed with normal color film, April 1977.

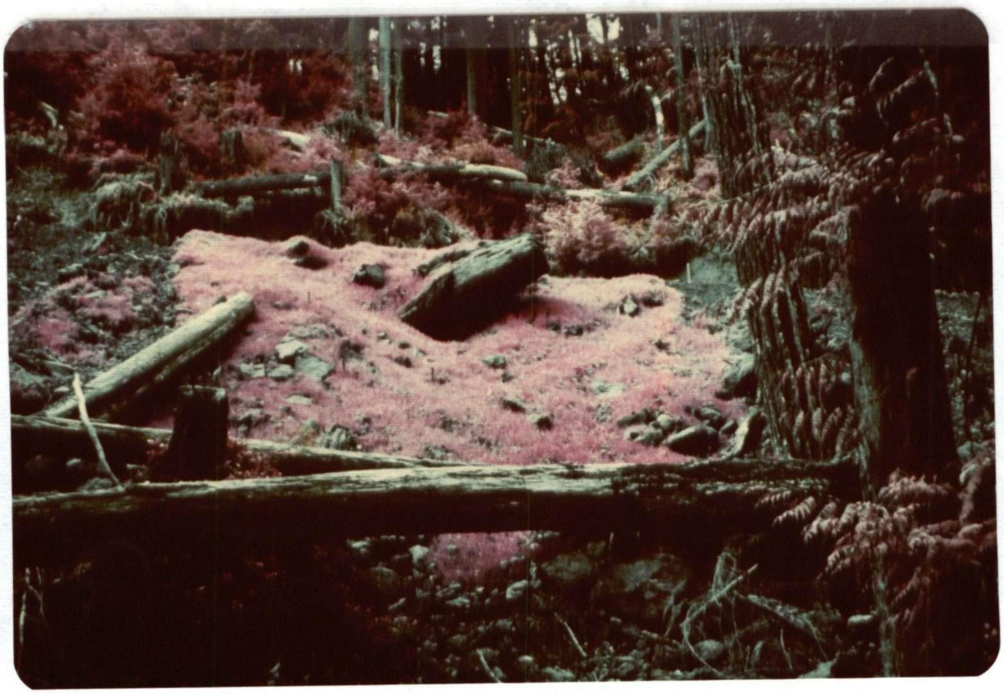


Figure 13. Plot photographed with color-infrared film, April 1977.

of plots. By using the block design, the overall comparison between treatments within the blocks was expected to be valid.

Experiment 5: Measure of soil erosion. The basic methodology for the erosion measurement is the same used by Dyrness (1967), a measure of slope profile change over a period of time being a measure of erosion. Mr. Don McCool (agricultural engineer with the U.S. Soil Conservation Service at Pullman, Washington) has developed a rill-meter for measuring surface rill erosion. The rill-meter consists of a set of pins lowered from a portable apparatus to define a ground contour. The pins are photographed, and by digital analysis and reconstruction of the original ground contour, an estimate of rill erosion can be made. For this study, an estimate of both rill and sheet erosion was needed since both contribute to road cut and fill slope degradation. Upon recommendations by Mr. McCool, a modification of the original rill-meter was made. By establishing two permanent pipes in the slope, vertical measurements from a standard bar could be made, thus defining the ground contour. A comparison of ground contours measured before (Figure 14) and after treatment (Figure 15) would give a measure of net soil erosion.

The modified rill-meter was constructed from a 5.08 cm × 7.62 cm × 0.64 cm (2" × 3" × ¼") channel aluminum bar. The bar was 1.25 meters (50") in length with 25 permanent slots established to allow vertical measurement to the ground surface with a hand micrometer. The bar had adjustment bolts and cross-levels on each end to insure a true vertical measurement to the ground surface. Between the cross-levels and the slots constructed for the rill-meter to fit onto the pipes, any pipe movement (e.g., from frost heaving, grader interference, falling rocks) would be discovered. There were three sets of randomly located

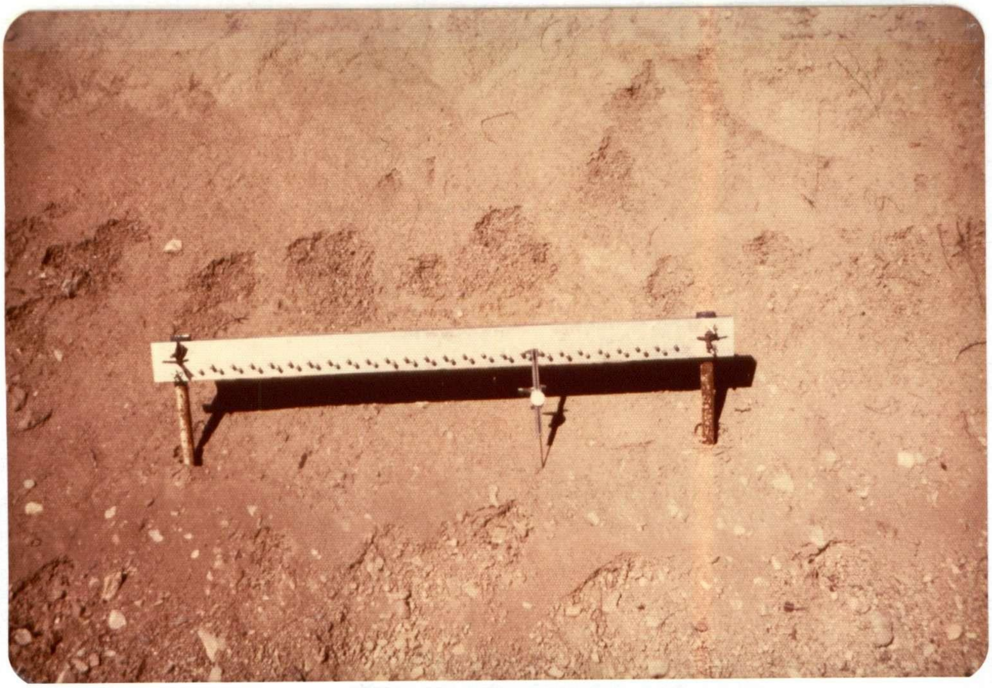


Figure 14. Rill-meter in use at Koksilah, September 1976.

Figure 15. Rill-meter in use at Koksilah, April 1977.

pipes per plot. Any contour pipe suspect of movement was cause for that contour to be eliminated from the sample. The sum of the differences between the September 1976 and April 1977 measurements for the 25 points would represent the contour in the statistical analysis.

RESULTS AND DISCUSSION

Experiment 1: The effect of fertilizer salts on *Rhizobium* inoculum viability. The minimum acceptable number of viable *Rhizobium* cells per gram of commercial legume inoculum, according to Bordeleau (1976), is 1.0×10^6 cells. For both salt treatments and the control, the final counts yielded at least 1.0×10^6 viable cells per gram of inoculum tested (Table 6). This suggests that neither the temporary

TABLE 6

RHIZOBIUM VIABILITY PER GRAM OF LEGUME INOCULUM

Treatment		Thousands of Viable Cells per Gram	
		21 days	31 days
Sterile Buffer:	A	540	1090
	B	540	1090
KCl:	A	1410	4100
	B	820	2690
10-30-10 Fertilizer:	A	218	1410
	B	380	1090

subjection of the inoculum to high salt concentration nor the exposure to the nitrogen of the fertilizer had any effect of practical significance on *Rhizobium* viability and subsequent nodulation. Thus, it would appear that poor legume vitality, caused by hydroseeding effects on nodulation (Kay 1976), is not a function of *Rhizobium* mortality induced by salts, if the initial inoculum viability is adequate. Instead, it may reflect other factors, e.g., separation of inoculum from the seed.

Although the final Rhizobium counts were all satisfactory, the difference between the first and second counts does prove interesting. The control treatment showed a 2-fold increase, the salt treatment a 3-fold increase, and the fertilizer treatment a 4-fold increase in apparent Rhizobium numbers derived from resulting nodulation. This may suggest a "shock" effect on the bacteria from being subject to such a low osmotic potential, causing delay in the nodulation process. There may also be a further delay in legume nodulation from the temporary nitrogen exposure. This is consistent with the observation of Dart and Wildon (1970), that nitrogen presence delays nodulation of the legume *Vigna sinensis* within the first three weeks but has no effect on subsequent nodulation.

Experiment 2a and 2b: The effect of fertilizer-slurry contact and residual fertilizer coating on seed germination. In part one of the germination experiment, three species show a statistically significant reduction in germination as a result of 1 hour contact with the solution containing 90 kg of 10-30-10 fertilizer per m^3 of water (Table 7). *Festuca rubra* var. *commutata*, *Festuca arundinacea*, and *Trifolium repens* exhibited decreases in germination, with *T. repens* decreasing most (14%). Further testing with a solution containing 60 kg fertilizer per m^3 of water showed no further reduction in germination of these three species. Therefore, *F. rubra* var. *commutata*, *F. arundinacea*, and *T. repens* should be considered slightly sensitive to fertilizer contact.

TABLE 7

SEED GERMINATION: SEEDS WASHED

Species	Control		Percent Germination Level 1[1]	Level 2[2]
Phleum pratense	82±5		82±6	-
Agrostis alba	72±8		72±7	-
Lolium perenne	93±5		88±7	-
Lolium multiflorum	99±1		96±3	-
Dactylis glometata	90±4		96±3	-
Festuca rubra var. commutata	46±4	*	37±2	42±2
Festuca arundinacea	88±2	*	77±2	85±4
Festuca rubra	93±3		89±5	-
Trifolium pratense	75±6		71±10	-
Trifolium repens	78±3	*	64±5	79±5
Trifolium hybridum	78±3		73±11	-

[1]Level 1 = 90 kg 10-30-10 fertilizer/m^3 of water.

[2]Level 2 = 60 kg 10-30-10 fertilizer/m^3 of water.

*denotes a significant reduction in germination at alpha = 0.05.

In the variation of this experiment, residual fertilizer was not rinsed from the seed after the 1-hour soaking period. The seeds were germinated with the residual fertilizer coating in order to duplicate field conditions. This time, two out of the four species tested showed a significant negative germination response (Table 8). Festuca rubra was added to the list of sensitive species, and T. repens exhibited an additional negative response over the same fertilizer level in the first part. The combined effect of these germination tests is an approximately 30% reduction in T. repens germination, indicating the high sensitivity of this species to fertilizer slurry contact.

It is noteworthy that all three fescues tested were sensitive to fertilizer contact. This agrees with Brooks and Blazer (1963), who

TABLE 8

SEED GERMINATION: SEEDS UNWASHED

Species	Percent Germination Control		Level 1[1]
Lolium multiflorum	99±1		97±2
Festuca arundinacea	88±2		73±7
Festuca rubra	93±3	*	81±1
Trifolium repens	78±3	**	48±8

[1]Level 1 = 90 kg fertilizer/m^3 of water.

*denotes a significant reduction in germination from the control at alpha = 0.05.

**denotes an additional negative response over the seeds washed test (Table 7).

also found a fescue (Festuca elatior) sensitive to fertilizer slurry contact. In their study, a 40% loss of germination was observed, whereas my experiment revealed only a 10% loss. The difference is probably due to the different species used, type of fertilizer, and fertilizer concentration.

In my experiments with operational test criteria, although the 10% loss in fescue germination from fertilizer slurry contact is statistically significant, it should not be considered operationally significant. Such a small loss would not justify special treatment (e.g., separate and more expensive application) of fescues or exclusion of these species from future seed mixes. The Festuca genus includes some of the most important and widely used grasses for erosion control. Simply by allowing for such a loss in germination when making up the seeding specifications should compensate for this problem with insignificant extra cost.

The negative effect on the legume germination is not so readily dealt with. The 30% loss of white clover (T. repens) poses a more serious problem, especially since this widely used legume is important to the nitrogen budget of developing vegetative cover. This and the other Trifolium spp. seeds are not afforded the protection of the palea or lemma as are most grasses. Their seed coat is completely exposed, probably the cause for the greater negative effect of fertilizer on T. repens germination.

Separate application of leguminous species is a possibility. A separate broadcast application of legume seeds, in connection with the regular hydroseeding, would rather inexpensively solve this problem and aid in assuring good legume establishment. Another possibility is the use of seed pelletizing. Some promising new seed coating agents have been developed that increase seed germination (Vartha and Clifford 1969). These coatings also increase legume nodulation and vitality by prolonging seed and inoculum contact, which would be of benefit as indicated by experiment 1.

Experiment 3: Species composition of established vegetation. Only rapid-establishing, fall-winter species were present in early April 1977 when the frequency test was done. These are very important species in the seed mix since they provide initial erosion control and slope stabilization over the first winter. With the slope intact, the cover can continue to develop toward a more permanent and stable plant community over the following spring.

The results from the cover composition frequency sampling are summarized in Tables 9 and 10. Table 9 represents the cover composition

TABLE 9

SPECIES FREQUENCY BY BLOCK
(Av. % frequency of
all treatments)

	Blocks					
	Koksilah				Caycuse	
	Sidecast		Cut-slope		Cut-slope	
Species	Culvert	Bridge	Culvert	C-5000	II	III
Grasses						
Lolium multiflorum	100	100	100	100	100	100
Lolium perenne	100	100	100	100	100	100
Festuca ovina	100	100	100	100	100	100
Festuca rubra	100	100	100	100	100	100
Dactylis glomerata	100	65	60	85	95	65
Legumes						
Trifolium repens	60	60	20	30	30	30
Lotus corniculatus	35	25	0	5	5	15
Trifolium pratense	15	5	5	5	0	20
Trifolium hybridum	0	0	0	0	55	30

TABLE 10

SPECIES FREQUENCY BY TREATMENT
(Av. % frequency of all blocks)

	Treatment			
	No Mulch		Mulch	
Species	one-step	two-step	one-step	two-step
Grasses				
Lolium multiflorum	100	100	100	100
Lolium perenne	100	100	100	100
Festuca ovina	100	100	100	100
Festuca rubra	100	100	100	100
Dactylis glomerata	90	70	70	80
Legumes				
Trifolium repens	45	45	20	45
Trifolium pratense	15	10	5	10
Lotus corniculatus	25	10	5	10
Trifolium hybridum	5	10	10	20

of each block (slope), the average of the four seeding treatments per block. The cover frequency according to hydroseeding treatment is summarized in Table 10, which is the average species frequency over all blocks. Only six of the original seven treatment slopes are accounted for. Caycuse cut-slope I was lost when the overhanging roots collapsed, destroying the vegetative cover present.

As can be seen in Tables 9 and 10, the grass component of the vegetative cover was very consistent between both blocks (slope type and location) and hydroseeding treatment. Lolium perenne and multiflorum, and Festuca rubra and ovina were the dominant grasses on all plots. Dactylis glomerata was present on all plots but comprised a lesser portion of the grass-legume stand. These grasses, typically, are rapid-establishing and adaptable to a wide range of climates.

On the cut-slopes at Koksilah, the importance of these early establishing species was particularly evident. These slopes were subject to severe frost heaving which increased their erodibility (Figure 16). Although the upper portion of the vegetative mat was disrupted, the lower slope remained fully vegetated. This intact vegetation acted as a catchment for slough material from the upper portion of the slopes, which prevented this material from reaching the road drainage ditch. These grasses are now providing a source for re-establishing full vegetative cover to the slope.

It must be remembered that these grasses (especially Lolium spp.) are fairly short-lived. A proper seed mix must contain slower-developing, longer-lived species, in addition to the rapid-establishing species. Continual monitoring of species succession is important for a complete evaluation of the experimental seed mix.

Figure 16. Frost action on Koksilah cut-slope, Jan. 1977.

Legume establishment was generally spotty and overall, low frequencies were incurred when measurements were taken in early April 1977. This is to be expected since the legume species used are typically spring establishers. On recent visits to the research plots, legumes appear to be contributing much more to the vegetative cover and seem very healthy.

There are, however, several trends developing in the early observations. Trifolium repens appeared to be the most dominant legume at all areas and treatment plots. Lotus corniculatus had a start on most plots, and should improve, for it is a slow but strong establisher. T. pratense had a consistently low frequency value of establishment on all plots. It would appear that this legume should be removed from future seed mixes and its percentage of the seed given to one of the better establishing legumes. T. hybridum was conspicuously absent at Koksilah and a co-dominant with T. repens at Caycuse. A possible explanation of this is that the Koksilah area was subject to long periods of repeated freeze-thaw. T. hybridum, being very subject to winter-kill, may have been totally destroyed in this area. More testing with this species is necessary, for it appears that T. hybridum may be an erosion control legume of limited climatic adaptability.

In comparing the different slopes treated, the cut-slopes at Koksilah had relatively poorer legume establishment than the other slopes. These slopes, as previously stated, were subject to heavy frost damage and the legumes used in this seed mix are subject to winter-kill (Hafenrichter 1964). With fall seed applications, a supplemental spring sowing of leguminous species may be necessary if the following winter was harsh. A small cyclone seeder could inexpensively achieve this.

One treatment, the one-step mulch application (1-M), definitely had lower legume frequencies than the other treatments. In the laboratory germination experiments, white clover (T. repens) was shown to be very susceptible to continued fertilizer contact. The 1-M treatment could result in the longest seed-fertilizer contact, for the mulch might slow the leaching of fertilizer from the micro-environment of the seed, thus extending the contact time. Once again, a separate legume application may be advisable if a single-step mulching application is the chosen method of hydroseeding. The prolonged exposure to fertilizer could also have a deleterious effect on the accompanying legume inoculum (Rhizobium spp).

Experiment 4: Estimate of percent plant cover. The estimates of percent plant cover are summarized in Table 11. From the Duncan's

TABLE 11

PERCENT PLANT COVER

Block		Treatment				
		No Mulch		Mulch		
		one-step	two-step	one-step	two-step	Ave.
Koksilah						
Cut-slope:	culvert	50	40	40	45	44 a*
	C-5000	35	50	45	60	48 a
Sidecast:	culvert	75	80	75	75	76 b
	bridge	65	85	65	90	68 b
Caycuse						
Cut-slope:	II	70	70	65	65	68 b
	III	85	40	90	60	69 b
Average		63 c	61 c	63 c	66 c	

*Averages followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level of probability.

Multiple Range test (alpha = 0.05), there were no significant differences in cover establishment associated with differences in application method (treatment). All hydroseeding treatments averaged 61-66% plant cover. The two cut-slopes at Koksilah (blocks 1 and 2) had reduced cover establishment (averaging 44% and 48%, respectively) from the frost damage, and this is borne out by the Duncan's test for blocks. Fortunately, the bottom portion of these two slopes remained fully revegetated and the vegetation is starting to spread over the entire slope. The remaining four slopes (blocks) averaged 68-76% plant cover, this being within the Berglund (1976) criteria for vegetative cover for successful erosion control. Figures 17 and 18, 19 and 20, and 21 illustrate the amount of plant cover obtained by hydroseeding.

Although there was no significant effect on plant cover establishment from the use of mulch, early observations of seed germination and seedling establishment tend to substantiate the fears of Kay (1977) that mulch can adversely affect plant establishment. On the cool, shaded cut-slopes at Koksilah, the modification of surface soil temperatures by the mulch appears to have kept the surface temperatures of these plots lower than unmulched plots. This lower surface temperature caused a delay in seed germination on these plots, which may have been a serious problem if cold weather had begun earlier and the seedings were not yet hardy enough to survive.

Experiment 5: Measurement of soil erosion. A summary of the amount of erosion per treatment is given in Table 12. Only three out of the four blocks at Koksilah were measured due to breakage of the two adjustment bolts on the right side of the rill-meter preventing accurate bar placement on the permanent pipes. Also, only two contours per plot

Figure 17. Koksilah cut-slope in September 1976.

Figure 18. Same cut-slope in April 1977.

Figure 19. Koksilah sidecast that caused the stream sedimentation seen in Figure 1 (Sept., 1976).

Figure 20. Same sidecast slope in April 1977. Note untreated control area between hydroseeded plots.

Figure 21. Caycuse cut-slope, treatment and control, April 1977.

TABLE 12

MEASURED EROSION (cm)

Blocks		Treatment: No Mulch one-step	No Mulch two-step	Mulch one-step	Mulch two-step	control
Koksilah						
Sidecast:	culvert	-1.2[1]	-0.1	0.3	0.0	1.8
	bridge	0.4	-0.4	-2.3	-1.8	3.1
Cut-slope:	culvert	-2.4	-1.9	-2.0	-3.1	2.0
Average		-1.1 a*	-0.8 a	-1.3 a	-1.6 a	2.3 b

[1]Negative erosion means a net accumulation of soil material.

*Averages followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level of probability.

were used in the analysis of variance. Most of the plots only had two sets of pipes left undisturbed from falling rocks, frost heave, animal interference, or grader activity. On plots where three contours were intact, all were measured and one randomly removed from the sample before analysis. The reduced data produced meaningful results in the statistical testing at alpha equal to 0.05.

The amount of soil erosion from these slopes averaged 2.3 cm (0.9 inches) of slope profile loss, which is significantly greater than the 0.5 cm (0.2 inch) loss observed by Dyrness (1975). Assuming the following:

a. 1 cm/ha soil depth amounts to 89 t/ha (1 in/acre = 100 tons)
b. 1.5 ha of bare side slope per km of logging road (6 acres per mile)
c. 1 m^3 of soil material has a mass of 1.2 t (1 cu yd = 1 ton),

this 2.3-cm (0.9-inch) slope loss is equivalent to 256 m^3 per km (540 cu yd per mile) of soil erosion on the Koksilah road system from April to September. Since erosion is usually greater in the first years after road construction (Dyrness 1970; Fredricksen 1965), the total erosion to date for this 3 year-old road system would be at least 768 m^3/km (1620 cu yd/mile). This measure does not include dry ravel over the summer, which in the Dyrness (1970) study matched water erosion. This amount of soil movement, much of which may eventually enter the Koksilah River, can have a deleterious effect on the water quality, fisheries potential, and aquatic environment of this watershed. In combination with the effect on road slope stability, drainage ditch capacity, and road surface integrity, there is no doubt that surface soil erosion is a serious although not highly visible problem.

Fortunately, the slopes treated by hydroseeding of a grass-legume seed mixture showed a definite halt of this problem. The establishment of a vegetative cover not only controlled surface erosion, but in most cases (9 out of 12) acted as a filter or catchment for soil particles carried into the vegetation from outside of the established cover. This was most obvious on the cut-slopes which had only a partial vegetative cover on the lower half of the slope. From the data, the 2.0 cm (0.78 inches) of erosion (from the cut-slope control) was halted on the lower part and apparently most of the eroded material from the top part was accounted for by soil accumulation in the vegetated area. The establishment of a vegetative cover seems to be a very effective and fast way of alleviating the problems associated with surface soil erosion.

Once again, there was no significant difference between the various hydroseeding treatments in their effectiveness for controlling erosion. The addition of mulch, and the extra soil binder of this treatment, to the seeding operation did not significantly reduce erosion.

This is contrary to the Dyrness work (1967, 1970, 1975), where mulch was important in vegetation establishment and erosion control. From my study, mulching would be important in erosion control only where climatic and soil conditions suggest moisture or temperature problems that would interfere with successful vegetation establishment, and not as a general specification with hydroseeding. The vegetative cover is the key to effective erosion control, not a temporary soil covering. This is borne out by experiments 3, 4, and 5. All treatments resulted in the same plant cover composition, percent plant cover, and as would follow, all treatments were equally effective in controlling erosion.

SUMMARY

A. The effect of fertilizer salts on legume inoculum, *Rhizobium spp*.

Temporarily subjecting *R. trifolii* to high fertilizer salt solutions did not affect cell viability or subsequent successful plant infection and nodulation. The presence of nitrogen in the fertilizer solution, at concentrations used in operational hydroseeding, did not affect final nodulation but may have caused a delay in early nodulation, which would agree with Dart and Wildon (1970).

B. The effect of fertilizer salts on seed germination

The temporary exposure to a -2.5 MPa fertilizer solution for 60 minutes did cause a loss of seed germinance for the three fescues tested and white clover (*Trifolium repens*). Although the fescues lost approximately 10% germination, this is not operationally significant and can be compensated for by applying extra seed (over-seeding). The 30% loss of white clover germination is very serious and appropriate precautions should be taken. By limiting seed soaking time in the slurry, using a seed coating agent, using high analysis fertilizers to reduce fertilizer salt concentrations in the slurry, and applying extra seed, a separate seed application may be avoided (resulting in considerable savings).

C. Early establishment of grass and legume species

Five grasses dominated the vegetative cover after seven months

and provided important erosion control over the first winter after seed application. Lolium multiflorum, Lolium perenne, Festuca rubra, Festuca ovina, and Dactylis glomerata were the major components of this early plant cover. Legume establishment was fairly low but has been improving since the spring. Trifolium repens and Lotus corniculatus appeared to be the most important leguminous species of this seed mix. T. hybridum was an excellent species at Caycuse and absent at Koksilah, suggesting that this legume may be limited in its climatic adaptability. T. pratense does not appear to be an effective erosion control legume where seed application is by hydroseeding. Legume establishment was very poor on cut-slopes that were subject to severe frost damage. These species of legumes, not being cold-tolerant and being subject to winter-kill, may require a supplemental spring application after a severe winter.

Follow-up of the plant succession on these plots is necessary to evaluate the whole seed mix for the slower-developing species have yet to appear. The grasses and legumes mentioned above should be given serious consideration for erosion control seed mixes to provide a quick plant cover and protect the site while longer-lived species develop.

D. One-step slurry application versus multiple-step application

There was no significant difference in vegetation establishment, composition, or effective erosion control due to separate seed application (multiple-step slurry application). Although experiment 2 (seed germination) would suggest a difference, a shorter fertilizer contact time, lower fertilizer concentration, and over-seeding seem to have compensated for any negative effects that may have affected cover establishment. The single-step slurry application is safe as long as contact time, fertilizer concentration and grade, and seed mix selection are given proper consideration. When leguminous species are proposed to be a substantial part of the eventual cover, seeds could be coated to help overcome any possible residual fertilizer coating effect on germination.

E. <u>The effect of mulching</u>

The use of mulch did not result in more successful plant cover establishment or erosion control. Since mulching can more than double the cost of hydroseeding, care should be taken in choosing areas to be mulched. Mulch should be used where climatic or soil conditions suggest moisture or temperature problems for establishing vegetation. The use of a chemical soil binder can in many places provide temporary erosion resistance and aid in uniform cover establishment at less cost. Also, any possible negative effects on plant cover establishment from the use of a mulch may be avoided.

F. <u>The amount of soil erosion from forest roads and possible reductions</u>

The use of a vegetative cover successfully halted erosion from forest road cut and sidecast slopes that have eroded 2.3 cm in seven months. The grass-legume cover not only prevented erosion but also acted as a filter and catchment for soil particles brought into the vegetated area from upslope by gravity, wind, and water. Erosion at the Koksilah test area was equivalent to 256 m^3 of sediment and soil material per kilometer (540 cu yd per mile) of logging road from September 1976 to April 1977, most of which could be eliminated by slope revegetation. This erosion has been taking place for 3 years, at probably higher rates, and the costs to the aquatic environment and road stability, although not tangible, must be extremely great.

G. The cost of hydroseeding

The basic cost for hydroseeding a large area, in excess of 50 acres, is approximately $720/ha ($300/acre), based on 1976 prices (Table 2), for a one-step slurry application without mulch. This type of application proved to be just as effective in erosion control and plant cover establishment as the more expensive treatments. Mulching can at least double the basic cost of hydroseeding and should only be used where vegetation establishment is expected to be difficult.

The cost for hydroseeding a kilometer of logging road can range between $1100 and $2000 ($2000-$3000/mile) depending on the size of the operation and acreage per kilometer. This can greatly reduce the high amount of eroded soil being deposited in adjacent stream systems. This is an external diseconomy that has tremendous impact on physical water quality and fishery potentials. The effect on road stability and road maintenance costs is more tangible and directly affects the licensee responsible for the road. Two thousand dollars is a small investment when compared to road building costs upwards of $62,000 per kilometer ($100,000 per mile) and road maintenance costs of $1200-3000 per kilometer ($2500-5000 per mile) annually. This investment can save a large portion of the road maintenance costs, help maintain the road surface and slope stability thus protecting the initial investment of road construction, and greatly benefit the environment. Moreover, hydroseeding can often be confined to limited areas of high erosion risk, reducing the cost per kilometer of hydroseeding. The chance to put back into production part of the acreage lost during road construction by enhancing soil development should also be considered.

Roadside revegetation by hydroseeding can be very effective in controlling soil erosion from cut and sidecast slopes beside forest roads. With proper planning of the seed mix and other specifications, an effective vegetation cover should result. The cost of hydroseeding is small when compared to the tangible and intangible costs involved in forest road construction, road maintenance, and stream degradation.

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APPENDIX I

Percent Plant Cover

Analysis of Variance

Treatment Blocks	Treatments
1. Koksilah : cut-slope @ culvert	1. one-step
2. " " @ C-5000	2. two-step
3. Koksilah : sidecast @ culvert	3. one-step with mulch
4. " " @ bridge	4. two-step with mulch
5. Caycuse : cut-slope II	
6. " " III	

Analysis of Variance Table at alpha = 0.05

term	d.f.	sum sq.	mean sq.	F	prob.	
block	5	4.06E-01[1]	8.12E-02	4.87	.0077	*
treat	3	7.50E-03	2.50E-03	0.15	.93	ns
error	15	2.50E-01	1.67E-02			
total	23	6.63E-01				

*denotes significant test at 5 percent level.

[1] 4.06E-01 is equivalent to 4.06×10^{-1}.

Duncan's Multiple Range Test at 5 percent level

Treatment Blocks : (1,2)

(5,6,3,4)

Treatments : (4,3,1,2)

(Subsets of elements, no pair of which differ by more than the shortest significant range for a subset of that size.)

APPENDIX II

Measure of Soil Erosion

Analysis of Variance

Each of the contours measured is represented by the sum of the differences between the Sept. and April measurements for the 25 points.

Treatment Blocks

1. Koksilah : cut-slope @ culvert
3. " : sidecast @ culvert
4. " : " @ bridge

Treatments

1. one-step
2. two-step
3. one-step with mulch
4. two-step with mulch
5. control (no treatment)

Analysis of Variance Table at alpha = 0.05

term	d.f.	sum sq.	mean sq.	F	prob.	
block	2	9352.9	4676.4	2.15	.15	ns
treat	4	38807	9701.7	4.48	.014	*
b × t	8	9583.4	1197.9	0.55	.80	ns
error	15	32501	2166.7			
total	29	90244				

*denotes significant test at 5% level

Duncan's Multiple Range Test at 5 percent level

Treatment Blocks : (3,4,1)

Treatments : (4,3,1,2)

(5)

(Subsets of elements, no pair of which differ by more than the shortest significant range for a subset of that size.)