EROSION CONTROL WITH VEGETATION IN HIGHWAY CORRIDORS

by

David Lee Wright

Thesis submitted to the Graduate Faculty
of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY
in
Agronomy

APPROVED:

Chairman, Dr. R. E. Blaser

Dr. T. B. Hutcheson, Jr.

Dr. D. C. Martens

Dr. D. D. Wolf

Dr. L. H. Aung

March 1977

Blacksburg, Virginia

ACKNOWLEDGEMENTS

The author would like to thank Dr. R. E. Blaser for his patience and help as well as serving as an inspiration and an invaluable advisor in preparing this manuscript. Appreciation is also expressed to Dr. D. C. Martens, Dr. D. D. Wolf, Dr. L. H. Aung, and Dr. T. B. Hutcheson, Jr., for their encouragement and guidance throughout the program and for serving on the author's committee.

Gratitude is expressed to the Virginia Department of Highways and Transportation Research Council and to the Agronomy Department of Virginia Polytechnic Institute and State University for funds made available to conduct the research.

A special appreciation is given to for her secretarial help and to and for help in establishing and collecting data from experiments. Gratitude is also expressed to for his thoughts and assistance in conducting useful experiments.

Greatest appreciation is expressed to the author's wife, , for her patience and support throughout the investigations and manuscript preparation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In recent years, there has been strong support to clean up our environment including the air, water and land. More stringent controls have been placed on construction contractors, and especially those contractors who gain state highway contracts, to minimize erosion and sedimentation. Developing principles of slope preparation methods, varying seed components with season, providing soil amendments for the desired type of vegetation and use of mulches has caused a great demand for this type of information and its effectiveness for reclamation of drastically disturbed land.

Slopes in the highway corridors are most erosive when initially denuded because of loose soil material which is an ideal seedbed for establishing vegetation. Therefore, short intervals between construction and seeding are desired.

Few areas of the United States have had long term research programs in the area of revegetation of drastically disturbed lands; conventional grading methods, seed mixtures, and soil amendments used for revegetation in these critical areas have failed or resulted in inadequate or high maintenance vegetation. These practices also lead to vast amounts of soil loss and siltation with much of the vegetation being non-persistent, making costly renovation necessary 2 to 5 years after the initial seeding, at state expense. Research findings have shown that persistent vegetation can be obtained by employing practices of proper seedbed preparation, soil amendments, seed mixtures, and mulches.

Because of the interest in minimizing pollution from sediments in the highway corridors, this dissertation was written to accomplish the following objectives: 1) to bring together principles of establishing vegetation in highway corridors from early and recent research work through an interpretative summary; 2) to ascertain the emergence of 12 grasses and legumes under four moisture stresses and two temperatures, for seeding in various seasons; and 3) to determine the need for topsoiling and the influence of surface conditions of topsoil and subsoil on the microenvironment and establishment of grasses and legumes.

GENERAL RESEARCH METHODS

Sites for experiments in highway corridors were selected on slopes with uniform subsoil materials, aspect, steepness, and height. The plots with imposed treatments were perpendicular to the slopes to obtain similar environments for various treatments. Experiments were established on soil derived from different geological formations in the Appalachian, Piedmont, and Coastal Plains regions.

All experiments were designed in accordance with modern statistical methods to remove personal bias and to obtain reliable data; e.g., the experimental treatment variables were randomly assigned to blocks replicated two to four times to ascertain the statistical significance of various data to make valid biological interpretations. Each experiment generally provided data for two or more factors or objectives. The treatments were often factorial combinations or of split-plot designs to evaluate interactions among various factors. The experimental layouts were generally randomized complete blocks or split-plot designs along highways and were generally completely random in greenhouse studies.

Experiments in highway corridors were established with seeding and mulching equipment (hydro-mulchers and straw blowers) commonly used by contractors and highway departments. Seed mixtures, fertilizers, mulches, soil chemical binders, and certain straw tacking agents were usually applied with a hydroseeder to a straw blower equipped with a pump for applying fluid binding agents.

Data obtained from each experiment varied, depending upon the specific objectives, soil materials, moisture conditions, and rate of plant growth. Data from experiments along highways generally included: populations of plant species, plant heights, vegetative cover, components in vegetative cover, general appearance of vegetation, persistence of mulches and binders, mulch stability, and amount of erosion. All data were analyzed statistically with significant differences for individual or group means given at the 5% level. A check (no treatment) was generally used as a standard for comparing treatments in an experiment.

Diagrams of the original experimental layouts, with all treatments, replications, dates of establishing and location, are permanently filed at Virginia Polytechnic Institute and State University for future reference to observe changes in plant succession.

AN INTERPRETATIVE REVIEW:

PERSISTENT LOW MAINTENANCE VEGETATION FOR EROSION CONTROL AND AESTHETICS IN HIGHWAY CORRIDORS

Environments in old or newly constructed highway corridors in the U.S.A. vary in climax vegetation from semi-tropical with forest-grass, humid-temperate with forest, prairie with tall to short grasses, and semi-arid, arid, and desert regions with sparse vegetative cover.

From the viewpoint of erosion, pollution, and aesthetics, two major problems are encountered in highway corridors: 1) erosion by wind and water during the construction phase before stabilization with vegetation, and 2) concurrently controlling erosion and plant succession to a persistent vegetative cover requiring little or no maintenance. Due to the recent fuel crisis and high costs of labor, materials, equipment, and repairs; cultural practices must be implemented to obtain vegetative covers that require little or no fertilizer or mowing maintenance subsequent to establishment. New construction disturbs natural contours, drainage areas and climax vegetation to cause potential wind and water erosion and pollution. Erosion control practices to minimize off-site pollution from construction sites in highway corridors depend on grading methods, slope preparation, soil surface conditions, soil amendments, mulches, species selection for mixtures, and obtaining a desirable, persistent vegetation through plant succession.

Principles on preparing cut, fill, and median slopes; mulching and tackifying processes; soil amendments; seed mixtures; water control in drainageways; and special siltation control measures during and subsequent to construction will be described as used in the Appalachian and Piedmont regions. The principles will generally apply to all highway corridors of the U.S.A. The procedures for obtaining a persistent vegetative cover by plant succession that requires little or no soil amendments subsequent to establishment or the necessity for mowing will especially apply to regions with sufficient precipitation to promote adequate vegetative growth to prevent and/or minimize erosion.

Arresting Erosion During New Construction

The grading operations for new highways or other construction activities cause uncontrolled water flows initially from small bare soil areas. Subsequently, the combined and uncontrolled flows from many small areas carry soil particles with the amount enlarging at momentous proportions with increasing distance from the initial erosion sites. Thus, the many small localized disturbed areas with seemingly insignificant movements of water and soil within the initial grading operations often assemble massive and rapid flows of water with coarse and fine sediments, causing severe damage in highway corridors as well as flooding and contaminating downstream drainage systems. Even the initial slow flows of clear water from many small sites, when grading is initiated in a highway contract, cause progressively larger erosive flows of water. Thus, it is imperative to minimize water flow at the very first mini-sites of initial grading operations.

Although macroclimatic environments cannot be changed, the microclimatic environment may be altered by grading and construction procedures (Goss, Blanchard, and Melton, 1970; Green, Blaser, and Perry, 1973; Wischmeier, 1973; Wright et al., 1975). Increased water infiltration to reduce erosion and pollution by runoff water during construction can be controlled or minimized in four primary ways: 1) grade slopes as shallow as practical; 2) employ grading and soil management to encourage water infiltration and reduce runoff; 3) establish vegetative covers as the slopes are being constructed to hold soil materials in place and encourage water infiltration; and 4) use rock or concrete drains for containing and removing concentrated flows of water. It is estimated that it costs about twice as much to maintain 45° (1:1) slopes as 27° (2:1) slopes because of seeding, fertilization, refertilizing, removing sloughed material from ditches and drainage recepticles. Therefore, initial construction planning, especially the design and grading of slopes, should consider both the short and long range maintenance programs and pollution problems that could potentially be encountered and/or eliminated for the duration of the highway.

Cut, fill, and median slopes should be as shallow as practical as the amount and speed of runoff water and potential erosion during and after torrential rains is directly allied with the steepness and length of slopes. The shallowness of slopes depends on many factors (right-of-way, soil material, and cost of construction operations). Micaceous and sandy soils are usually more erodable than heavy textured soils due to the weakness of the shear plane and lack of cohesiveness; hence, such slopes should be shallow. During winter even light precipitation can cause severe rilling and erosion on shallow bare slopes.

Grading Cut Slopes: For long sloping cuts, the grading operation should begin with establishing diversion ditches at the apex of cuts to impede and disburse water from slopes above the area to be graded (Fig. 1). Slopes should generally be no steeper than 33° (1-1/2:1), because the shallower slopes are less erosive and easier in which to establish vegetation. The steepness of cut slopes should be determined by the length of grade, the soil and rock materials, topography, width of highway corridor, and the ease of establishing vegetation. For example, it is more difficult to establish vegetation on "hot" sunny slopes than on "cool" shaded slopes; hence, shallow slopes on sunny exposures would facilitate the establishment of vegetation (Wright et al., 1975). Conversely, undecomposed rocky materials on cuts may be nearly vertical.

Slopes steeper than 18° (3:1) should be stair-step graded, left rough, or grooved. Stair-step grading may be used on any materials soft enough to be ripped with a dozer. Slopes steeper than 27° (2:1) should be stair-step graded (Fig. 2). The ratio of the vertical cut distance to the horizontal distance should be less than one with the bench and vertical wall forming an acute angle to catch sloughing soil, increase infiltration, and reduce runoff. The individual vertical cuts should generally not be more than 60 to 90 cm on soft soil materials and not over 100 cm in rocky materials (Blaser and Perry, 1975; Green et al., 1974; Perry et al., 1974; Wright et al., 1975). The heights and widths of the steps may vary within a cut.

Figure 1. Long hard and smooth cut slopes cause vegetative covers to develop slowly. The low infiltration causes high rates of uncontrolled water flows and severe rilling and erosion.

Figure 2. Top: Stair-step grading of cut slopes encourages infiltration and impedes water flow to minimize erosion and sedimentation in ditch lines.
Bottom: This grading method creates a favorable environment for establishing vegetation while construction proceeds.

Soft rock with subsoil material is ideal for stair-step grading and establishing vegetation during grading operations. Areas in the mountainous region of the western United States use topsoil on such stair-steps where vegetation is desired, because the infertile granite material weathers slowly and allows little water infiltration (Foote et al., 1970).

The numerous steps improve water infiltration and generally nullify sheet erosion, rilling, and pollution of runoff waters (Blaser et al., 1975). Sloughing and falling materials and precipitation intercepted by horizontal steps cover much of the lime, fertilizer, and seeds to promote germination, seedling growth, and enhances the establishment of a vegetative cover. Stair-step grading also augments encroachment of persistent leguminous vegetative cover, as crownvetch (Wright et al., 1975). Note on Figure 2 that stair-step grading prevented an accumulation of mud and water at slope bases that usually occurs in drainageways with conventional smooth, hard grading on cut slopes and also with bench grading (Fig. 3).

The surface of cut slopes less than 27° (2:1) should be "rough" and undulating with stones left in place (Fig. 4). High and low places giving variable microenvironments speed up the establishment of vegetative cover because of some coverage of seed and fertilizer and improved moisture.

The detrimental practice of constructing slopes with smooth, hard surfaces gives a false impression of "finished grading" and a job well done, but vegetation often fails (Fig. 5). Rough slope surfaces with rocks left in place give an "ugly" appearance to the novice, but

Figure 3. Top: Bench grading with broad benches to catch falling materials creates very steep back slopes, making it difficult to obtain protective vegetation.
Bottom: Erosion and sedimentation into ditches are serious problems. Sediment dams were made with rocks to reduce clogging of drains and culverts.

Figure 4. Slopes 27° (2:1) or flatter should be roughened and loosened leaving ridges and furrows perpendicular to the slope to increase water infiltration and to promote vegetative growth.

Figure 5. Conventional smooth grading and hard surfaces of steep slopes make it difficult to establish seedlings and vegetation due to little water infiltration and severe erosion. Such slopes should have special mulch treatment as straw tacked with woodfiber.

encourages water infiltration, speeds up establishment of vegetation, and decreases the rate of water flow into drainageways. The increased water infiltration and populations of both cereal rye and Kentucky 31 fescue plants from rough as compared to smooth slope surfaces is given in Tables 1 and 2. Roughened surfaces with topsoil or subsoil increased soil moisture and decreased soil surface temperature which increased germination, plant density, height, and protective cover (Woodruff and Blaser, 1970). When comparing rough graded subsoil with topsoil placed over the smooth subsoil, there was a four-fold improvement in vegetative cover for the rough graded subsoil 3 months after seeding (Table 2).

Slopes along highways with smooth hard surfaces should be grooved or roughened to aid in establishing vegetation before the application of seed, soil amendments, and mulch. The grooves should be 8 to 15 cm deep, parallel to the highway, spaced 38 to 60 cm apart (Fig. 6). Such grooves collect sloughing soil, seed, and soil amendments, and enhance the rate of obtaining a protective vegetative cover (Perry et al., 1975).

Of the four types of slope surfaces discussed, rough slope surfaces or stair-step grading are more desirable than smooth slope surfaces with or without lateral grooves for obtaining a vegetative cover quickly.

Grading Fill Slopes: It is generally easier to obtain vegetative covers for erosion control on fill slopes than on cut slopes because less compacted rock and soil material encourages water infiltration and root growth (Fig. 7). However, the common practice of blading and/or tracking fill slopes with a dozer is usually objectionable because

Table 1. Soil moisture, plant populations and heights as influenced by surface conditions of a 2:1 fill slope. The experiment was established on 9/24/74 and data obtained 26 days later.1/

Slope surface condition	Kentucky 31 fescue2/		Cereal rye		Soil moisture, %
	Plants/dm^2	Height (cm)	Plants/dm^2	Height (cm)	
Smooth and hard3/	6.8b	3.8b	.7b	10b	10.5b
Rough and loose	13.3a	7.5a	1.3a	15a	13.6a

1/ Seed mixture included Kentucky 31 fescue at 56 and cereal rye at 45 kg/ha.

2/ Means in a column followed by different letters are significantly different at the 5% level of probability.

3/ Conventional hard and smooth surface "finish grading" and tracking.

Table 2. The influence of surface conditions of a subsoil with and without topsoil on plant density, vegetative cover, and height of cool season grasses.[1]

	15 cm topsoil over subsoil					Subsoil alone				
	5/30/75				7/20/75	5/30/75				7/20/75
Graded surface	Plants/ dm^2	Vegetative cover, %	Ht. cm.	Soil temp.C	Vegetative cover, %	Plants/ dm^2	Vegetative cover, %	Ht. cm.	Soil temp.C	Vegetative cover, %
Rough and furrowed[2]	11.4a	39a	8.3a	25a	100a	15.2a	38a	8.8a	22a	100a
Smooth finish grading	2.6b	10b	4.8b	30b	25b	4.0b	7b	3.8b	28b	21b

1/ Means in a column followed by different letters are significantly different at the 5% level of probability.

2/ Traversed perpendicular to slopes with a road grader with tiller feet. Lime, fertilizer, seed and mulch were uniformly applied on the surface. The experiment was established on 4/25/74.

Figure 6. Grooving of hard smooth cuts improves seedling establishment and growth of grasses and legumes. The entire area had a uniform surface application of lime, fertilizer, and soil. The hard and smooth areas between the grooves allowed little water infiltration and growth.

Figure 7. Rocks and uneven surfaces on fill slopes impede water flow off and enhance vegetative establishment by creating favorable microenvironments. Straw applied to rough slopes need not be tacked. A vegetative cover established quickly to control erosion.

compaction inhibits water infiltration and aeration, causing poor growth. Also, seeds and fertilizer on such hard surfaces are apt to wash away. Tracking clayey and silty soil materials, especially when wet, causes severe surface compaction which augments water runoff and erosion. The weight and downslope slippage of dozers cause soil materials to form hard clods between the cleats that are severed from soil contact. These conditions cause water to flow around and under the "cleated clods;" hence, during heavy rains surface water accumulates and the massive downflows on slopes cause severe sheet and gully erosion (Fig. 8). The xeric environments associated with the severed "clods" make it difficult to establish vegetative cover. Tracking sandy materials may be desirable if the tracks leave indentations perpendicular to the slope. Tracking parallel to the slope is especially objectionable as the vertical rills, inadvertantly occurring with such operations, leave channels for accelerated water movement down slopes.

When constructing fill slopes, berms and down troughs (rock, plastic or other material) should be constructed on each side of the fill lift to direct water movement off the slope. As lifts of the fill slope are constructed, the soil and rock materials falling naturally onto the slope surface should not be removed. Variable steepness, looseness, and undulations within a fill slope create desirable mini-environments for establishing and maintaining vegetation. Also, by allowing materials to fall naturally, the variable contours inhibit water runoff. Colluvial materials "flow" when supersaturated and should not be used in highway fills (Fig. 9). During fill slope construction, the slope area should be properly designed and constructed from the onset to make regrading of

Figure 8. Tracked, compacted fill slopes on clay and silt material restrict water infiltration resulting in rilling and erosion from hard rains. Such slopes need to be reseeded, but it is difficult to establish seedlings in rills.

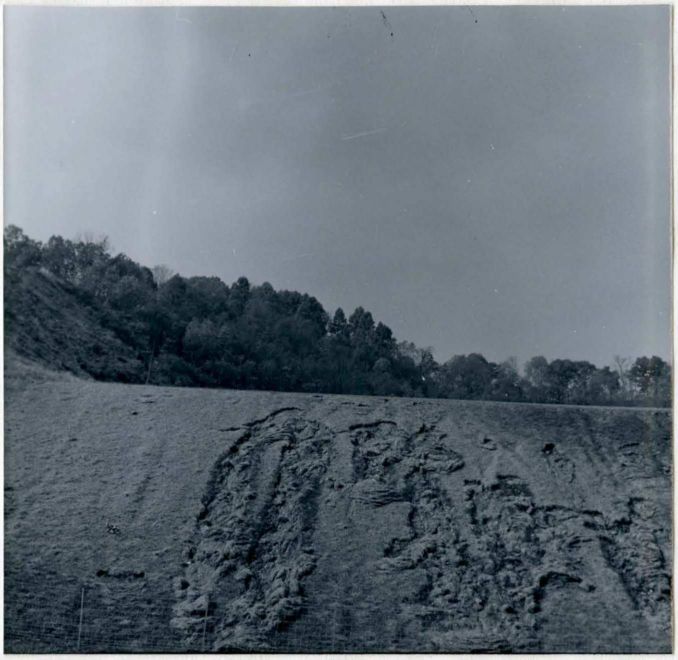

Figure 9. Sloughing often occurs where soils were tracked and compacted. Undulations and rocks left in place usually prevent sloughing.

slopes unnecessary after seeding. Seedings should be made every week or whenever the lift is elevated 3 to 4.5 m. The vegetation established at the base will settle suspended soil by slowing water movement from above as construction proceeds. Excellent vegetative cover to nullify erosion usually occurs from one seeding on rough loose fill slopes; however, tracked compacted fill slopes usually have sparse vegetation due to rilling and erosion and require several seedings and refertilizations to establish satisfactory vegetative covers.

Smoothing of fill slopes may be justified where mowing is necessary. However, fill slopes steeper than 2:1 should never be mowed. Leaving fill slopes very rough with rocks falling naturally is desirable as it will often prevent movement or flow of soil material.

Grading Medians: Highway medians constructed in mountainous topography often become severely eroded because of the accelerated flows of water concentrated in "V" bottom drainageways, making it virtually impossible to establish a vegetative cover to reduce or prevent erosion. This accelerated flow of water causes severe gullying in drainageways and often plugs culverts and causes downstream pollution.

The slopes of medians with little or slow water movement in drainageways should generally be shallow (less than 15°; 4:1) to reduce hazards to motorists. The compacted surfaces of finished medians are poor environments for water control and seedling establishment (Allmaras et al., 1973; Blaser, 1963; Carson and Blaser, 1962; Dickens and Orr, 1969; Green et al., 1973; Hottenstein, 1969; Willis and Amemiya, 1973; Woodruff and Blaser, 1970; Woodruff and Blaser, 1970a). Thus, the slopes should be loosened and roughened with a spiked dozer blade or strong cultivation tool to leave furrows 5 to 10 cm deep and 15 to 25 cm apart, paralleling the drainageway. This will encourage water infiltration and establishment of vegetation (Fig. 10).

Results from many experiments show vastly improved vegetation and erosion control with rough versus smooth surfaces. The drainageways in medians should be constructed with flat bottoms 90 cm wide, rather than the conventional "V" shaped ditches. The latter concentrate and accelerate the flow of water, encourage erosion, and make it difficult to establish vegetation.

Medians and drainageways in level topography may be seeded, fertilized, and mulched without special erosion control measures. Lime and fertilizer should be incorporated into the soil to a depth of 10 to 15 cm; seed and mulch should then be surface applied.

In medians where considerable water flow is expected (generally not to exceed a depth of 5 cm), the ditch may be straw mulched using 4480 to 6720 kg/ha of straw tacked with 1270 to 1695 liters of asphalt.

For slopes in drainageways where rather fast water flow is expected, special precautions must be used for stabilization. Where massive and fast flows of water are expected, the only solution is the construction of concrete or asphalt ditches or the equivalent.

The best and surest way of establishing vegetation in drainage ditches where high velocities of water are expected is by direct sodding. It is recommended that the sod be high quality bluegrass-Kentucky 31 fescue mixture, being at least 25% bluegrass or creeping red fescue in

Figure 10. Top: Foreground shows conventional smooth hard grading with little vegetation; background shows rough, loose tillage with vigorous seedlings.
Bottom: A closeup of the roughened, cloddy subsoil shows excellent stands and growth of seedlings 21 days after seeding.

the northeast. Fertilization, watering, and cultural practices should be used for laying sod.

Jute matting or excelsior materials are superior to asphalted straw but inferior to direct sodding for establishing vegetation in water ways in medians (Fig. 11). The best way to use jute matting is: 1) incorporate soil amendments and leave rough surfaces; 2) apply seed to surface; 3) apply straw at 4480 kg/ha; and 4) install jute or other appropriate netting over the straw. Instructions for installing jute or other matting should be rigidly followed.

Topsoiling: Topsoiling is necessary for establishing vegetation in the following situations:

1. Xeric rocky environments;

2. To cover and restrict root contact as with soil materials containing high amounts of pyrites;

3. Where special ornamentals that demand especially good soil fertility and aeration are to be planted;

4. Where a quality turfgrass lawn is wanted as at rest areas, and highway corridors adjacent to urban areas;

5. Where good topsoil would otherwise be discarded; it may be used in medians and shoulders.

Excluding number 5, when applying topsoil to the previously described areas, it should be applied from 25 to 50 cm in depth.

The slopes should be as shallow as possible; topsoil will not usually adhere in place on slopes steeper than 2:1 (Blaser and Woodruff, 1968; Jacobs et al., 1967; Smith, 1973). The slopes should be rough

Figure 11. Excelsior matting in a ditch along a new highway facilitates growth of seedlings, while controlling erosion. Similar results may be obtained with properly installed jute matting.

graded, stair-stepped, or grooved with undulations perpendicular to the slope. This encourages some mixing of the topsoil with the subsoil material to form a bond between the two. The stair-steps or grooves also reduce soil and water runoff. Topsoil should be applied to a depth of about 10 cm, leaving the final surface roughened. Another alternative is to apply the topsoil and then till it with grooves perpendicular to the slope and to a depth of 15 to 20 cm to insure bonding with the subsoil (Wright et al., 1975).

The economics and the potential problems commonly associated with topsoiled areas must be considered. Topsoiling is expensive, costing $5,000 to $10,000/ha, and its use usually delays seeding operations, which increases the possibility of erosion and pollution. Also, most topsoil contains weed seeds which cause dense weed canopies that shade out desirable species unless reseeded or herbicides are applied. Also, topsoils in humid regions are usually of poor quality (low in pH, fertility, and organic matter).

Potentially beneficial effects from topsoils on sloping cuts, fills and medians in highway corridors are often nullified and are usually associated with less than desirable slope surface preparation and topsoil application practices. On slopes with hard smooth surfaces and those with vertical rills from prolonged exposure, topsoiling is often useless because of severe sloughing and erosion. Supersaturation at the soil-subsoil interface cause massive sloughing of the loose topsoil (Fig. 12).

The need for topsoiling should be limited to the five areas mentioned previously as good vegetative covers can be established quickly

Figure 12. Topsoil placed over smooth, hard subsoil material on cuts is subject to flow off as shown above. The subsoil should be roughened before applying topsoil.

on properly amended slopes with surfaces composed of subsoil-rock materials.

Grading and preparing subsoil materials as discussed earlier often give more desirable seedbeds than topsoils. As compared with topsoil, the clay content of subsoils provides high moisture availability, deters leaching because of cation retention, and the lower silt content often reduces sealing of surface pores, thereby reducing runoff due to increased water infiltration.

Experiments show that rough graded subsoil slopes can be superior to topsoil for grass and legume establishment (Table 3). The better soil moisture in the subsoil rather than the topsoil material (Table 2) was a primary factor responsible for the improvement in plant density. Clayey clods from a roughened subsoil resisted breakdown and crusting to slow down surface water movement allowing better infiltration than for the topsoiled slope. Rough grading of subsoil materials created a loose soil environment as noted by a decrease in bulk density and an increase in porosity when compared to the compacted subsoils for "finished" grading (Table 3).

Establishing excellent leguminous-grass canopies avoids degeneration of grassy vegetation due to the low organic matter-N fertility in subsoil materials. In the humid southern region, winter annuals such as crimson and white clover and summer legumes such as lespedeza are widely adapted and serve as N suppliers to perpetuate grass-legume covers (Woodruff and Blaser, 1971).

Legumes such as crownvetch, alfalfa, red clover, and white clover are broadly adapted to a wide range of central and northern latitudes

Table 3. Established 5/22/72. Plant populations (plants/dm^2) and vegetative cover as influenced by subsoil conditions, topsoiling, and fertilizer incorporation.

Treatments	Data on 7/22/72					
	Crown-vetch 2/	Grass	Vegetative cover %	Bulk density 3/ gm/cm	Total porosity 3/ %	Crownvetch cover after 2 years, %
a) Subsoil smooth and hard with lime, fertilizer, mulch and seed surface applied (conventional method)	.02c	1.6d	22c	1.76	42.1	100
b) Subsoil roughened and loosened with tiller feet of a road grader, then lightly rototilled leaving a cloddy surface other treatments as in a).	.44a	8.0a	72a	1.38	51.4	100
c) Same as b) except lime and fertilizer applied first	.48a	9.3a	74a	1.44	59.9	100
d) Same as a) but with 10 cm of topsoil and all treatments surface applied	.18b	6.8b	66b	1.42	53.0	100

1/ The subsoil pH was 5.3 at the date of seeding. The treatments were: seed mixture - Kentucky 31 fescue at 84, redtop at 2.24, annual ryegrass at 5.6, and crownvetch at 22.4 kg/ha; a 10-20-10 fertilizer at 1120 kg/ha, lime at 4480 kg/ha, and woodfiber mulch at 840 kg/ha.

2/ Means in a column followed by different letters are significantly different at the 5% level of probability.

3/ Bulk density (weight/volume) and total porosity (pore space in %) were made on the 0-3 cm soil layer.

and altitudes on subsoil materials that are properly graded and amended in the more humid regions (Blaser and Ward, 1970; Brooks and Blaser, 1964; Carson, 1963; Donald, 1963; Shoop et al., 1961; Wright et al., 1975; Zak et al., 1972). In the Appalachian and Piedmont regions, crownvetch or sericea lespedeza have persisted for two decades on various subsoil materials without any maintenance treatments. The longevity is attributed to supplying needed lime and nutrients before seeding and the recycling of the various essential nutrients.

Soil Amendments: Controlling erosion from bare soil areas during highway construction is achieved quickly and economically by establishing a protective vegetative cover. Such covers cannot be obtained without adequate and balanced fertility and a favorable pH. The lime and nutrient requirements vary with soils and for species; hence, soil materials should be sampled and analyzed by competent laboratories for making lime and fertilizer recommendations for soils and species adapted to various regions.

The native species and natural woody vegetation in humid regions are generally tolerant of low soil acidity and fertility; however, they establish slowly and require long periods to develop dense protective vegetation (Blaser and McKee, 1967; Hill, 1965; U.S. Forest Service, 1948; Zak et al., 1972). The introduced and improved grasses and legumes that develop protective vegetative covers quickly in highway construction projects generally require relatively high fertility and soil pH conditions.

Soil N is the primary limiting nutrient and most costly for grass growth; thus, soil amendments should be planned to grow legumes where adapted. Legume-grass associations eliminate the need of costly N fertilization to maintain dense vegetative canopies for erosion control (Woodruff et al., 1970a).

Where adapted, successful growth of legumes requires a favorable soil pH and mineral balance. Semi-tropical legumes such as lespedeza species are tolerant of the high acidity, low Ca, low P, high Al complex common in soils in the humid southeastern region (McKee et al., 1965; Wright et al., 1975). Conversely, legumes of temperate origin require medium to high soil pH values with low Al availability and medium to high values for P, Ca, Mg, and K. Except for a few environments, other nutrients such as S and micronutrients are usually adequate. Although applying certain elements may stimulate growth, the objective is to obtain a persistent protective cover of desirable botanical components rather than high yield. Excessive growth is objectionable because of diseases, rodents, and increased mowing and other management problems.

However, liberal applications of lime and P, when needed, are essential for maintaining a protective cover of persistent leguminous species requiring little or no maintenance. Liberal applications of lime have long-lasting residual effects for supplying Ca and Mg and counteracting soil acidity. Phosphorus is generally very low in soils in humid regions and low in availability under high soil pH conditions in the arid regions. Liberal applications are desirable and necessary because the release of P for plant growth is often slow due to chemical fixation with Fe, Al, or Ca, depending on pH. Leaching of P is nil and very low for Ca and Mg; with the recycling (canopies and roots to soil to canopies) of these nutrients, high rates of applications last for decades and are relatively inexpensive. Thus, applications of 2 to 10 metric tons/ha of lime, pending soil properties, and 200 to 350 kg/ha of P as P_2O_5, have maintained persistent and invading legumes such as crownvetch in the Piedmont and Appalachian regions for decades (Blaser et al., 1975).

Mulches, Nets and Binders: Mulch materials are used for temporary erosion control of bare soils and to simultaneously improve the soil environment for establishing vegetation quickly by augmenting germination and seedling growth. Organic mulches, straw-like materials, wood-fiber products, chips and bark moderate soil temperatures and improve moisture relationships; plastic-type materials are generally ineffective (Barkley et al., 1965; Blaser, 1962; McCreery et al., 1975; McKee et al., 1964). The many experiments with various organic and inorganic nets on steep cut slopes in the Appalachian and Piedmont areas have usually resulted in seeding failures. It is practically impossible to establish a continuous soil-net contact; therefore, water flows under nets causing serious erosion (Fig. 13).

Of approximately 15 chemical binders and soil stabilizers used in highway corridors on many soil and subsoil materials, all have proven unsatisfactory when used alone for erosion control and seedling establishment (Perry et al., 1974; Wright et al., 1975). With the exception of asphalt, the materials now on the market for binding organic mulches have been ineffective or of such short duration as to make them

Figure 13. Nets for slope stabilization are undesirable because of labor involved in installation. Poor net-soil contact causes erosion under the nets resulting in seeding failures.

impractical and economically unfeasible. Laboratory tests show desirable results from some binders, but experiments on slopes along highways have nullified such favorable laboratory results. Binding straw on slopes with 840 kg/ha of woodfiber has given exceptionally good and prolonged straw stabilization, being superior to any binder and avoiding pollution possibilities (Fig. 14) (Wright et al., 1975). Tacking straw with woodfiber gives excellent results in a two-step operation: a) apply straw, and b) apply the seed-woodfiber-soil amendment slurry. This procedure has been similar to the three-step operation: a) applying the seed-soil amendment slurry, b) applying straw, and c) tacking with woodfiber.

It is imperative to apply mulches liberally in harsh environments as on smooth, hard slopes, "hot" slope exposures, and to provide prolonged mulch stabilizations as with straw tacked with woodfiber for midsummer or winter seedings (Blaser et al., 1961; McCreery et al., 1975; McKee et al., 1964; and McKee et al., 1965). High rates of mulch materials are less important for rough, loose graded slopes since the roughness _per se_ creates favorable microenvironments by coverage of seed and fertilizer, aiding germination and growth (Fig. 15).

Mulch materials and rates of application vary with season. For example, straw, woodbark, and woodchips are superior to woodfiber during stress periods when germination and seeding development are slow.

1. _During favorable spring or late summer seeding seasons_: Mulch with 3360 kg/ha of straw, 1350 kg/ha of woodfiber, or 30 m^3 of woodbark or woodchips. If slopes are stair-step graded or in a rough loose condition, the mulch rates may be reduced or even omitted on cool

Figure 14. Straw tacked with 840 kg/ha of woodfiber stabilizes straw for prolonged periods, aids in vegetative establishment, and avoids pollution and contamination that could occur with chemical tacking agents.

Figure 15. Sloughing soil material from the vertical walls of a 25 cm stair-step grading facilitates coverage of seed and soil amendments creating favorable microenvironments for germination and growth. Excellent seedling stands occurred on horizontal steps. Area with poor vegetation and sloughing in foreground was left smooth.

(shaded) slopes. Chemical binders need not be used during these favorable seasons, although straw may be tacked with 840 kg/ha of woodfiber on steep slopes.

2. Mulches for the late spring-summer season: Moisture stress and high air and soil temperatures make straw, woodbark or woodchips superior to woodfiber for conserving moisture and moderating temperatures to enhance germination and the establishment of seedlings. Straw on smooth hard slopes and flat areas should generally be tacked as with asphalt at 210 liters/ha or preferably woodfiber at 840 kg/ha. When applied to rough loose soil surfaces, straw need not be tacked unless the areas have high winds, traffic, air currents, or steep slopes. Woodbark or woodchips should not generally be used on slopes steeper than 2:1 and do not need binders. Woodfiber at 2240 kg/ha should be used on slopes steeper than 1-1/2:1 and may be substituted for straw and woodbark when they are unavailable. Rates of applying mulches for summer seedings are:

a. Straw or grass hay free of weed seeds at 3360 to 4480 kg/ha.

b. Woodbark or woodchips at 90 to 140 m^3/ha.

c. Woodfiber at 1680 to 2240 kg/ha.

3. Mulches for winter: Prolonged soil stabilization during winter (November to March) is imperative since protection from vegetative cover is not likely to be attained until spring. Persistent mulches under hard freezing and thawing conditions are favorable. Specifications are:

a. Straw at 4.5 metric tons/ha tacked with 840 kg/ha of woodfiber.

b. Straw at 4.5 metric tons/ha tacked with asphalt at 2800 liters/ha, or other suitable chemical binders yet to be ascertained.

c. Woodbark or woodchips at 140 m^3/ha without binders.

It is best to reserve woodbark or woodchips for the most difficult environments as for winter stabilization.

Hydro- versus Other Seeding and Fertilizer Techniques: The hydro-method is the most practical method for applying mulch, seed and soil amendments on steep slopes. However, surface applications of seed, lime, and P, especially on smooth hard slope surfaces, are inferior to incorporating these materials. It is especially desirable to incorporate lime and P as these materials are positionally fixed, with movement into soil and subsoil materials being slow. Thus, on traversable slopes it is economical and desirable to apply soil amendments in dry form, and incorporate them into the surface 10 to 20 cm. Seeding with a grain drill or other machines for seed coverage improves moisture status in the soil-seed zone. Also, passing over straw mulch to partially imbed it into soils with a cut-away disk is an excellent means of stabilization.

Designing Seed Mixtures: Erosion is minimized during grading and denuding operations in highway corridors by establishing a fast developing vegetative cover. Dense plant canopies reduce raindrop impact onto the soil surface and avoid soil deflocculation and clogging of pores, encouraging water infiltration, thereby reducing runoff waters that cause erosion. The roots of rapidly developing plant covers bind soil materials and increase soil granulation and porosity.

When designing seed mixtures within regions in the U.S.A., it is necessary to alter species components and ratios of seeding for seeding at all seasons to minimize erosion as construction proceeds (Blaser et al., 1968; Duell and Schmidt, 1974; Powell et al., 1967; Schmidt et al., 1967; Schmidt and Blaser, 1969). The changing environments, differential adaptations of species and seedling vigor for different seasonal seedings must be concurrently considered in designing mixtures. Furthermore, the species and seeding rates in mixtures should be planned to give a series of changing species; e.g., plant succession shifting from fast developing temporary species such as cereal grains, ryegrasses, and German millet, to secondary species such as the fescues, bluegrass, and lovegrass, to persistent species that develop slowly such as crownvetch, sericea lespedeza, and woody species (Woodruff et al., 1972).

For example, the seed mixtures in the Appalachian and Piedmont regions are designed to obtain a protective cover by mulching and a succession of species as follows:

Primary stage: Bare soil protected with mulch → temporary vegetation from companion annual grasses, that germinate quickly and produce vigorous seedlings during specific seasons, such as annual ryegrass and cereal rye during the cool seasons or German millet during summer (Fig. 16).

Secondary stage: Temporary vegetation → perennial grasses, such as tall fescue, creeping red fescue, and bluegrass. These perennial grasses are often short-lived unless they are mowed and fertilized, especially with N.

Figure 16. Excellent crownvetch was established into an undisturbed cereal rye canopy. Winter or summer annuals provide excellent *in situ* mulch for overseeding persistent legumes. Dense competitive, temporary canopies may be killed by applying herbicides concurrently with seed to eliminate competition.

Final stage, Alternative I: Perennial grasses → perennial persistent legumes requiring little or no maintenance, such as sericea lespedeza and crownvetch. These occur with restricted or preferably no mowing.

Final stage, Alternative II: Perennial grasses → woody perennials, if left unmowed and unfertilized to reduce canopy competition from grasses. The succession period to woody species may require many years, pending species and natural or artificial seeding. Legume species are excluded to reduce canopy competition.

Final stage, Alternative III: Perennial grasses → conditioned stage by mowing managements and N fertilization.

Competition from dense canopies of fast growing annual species is lethal to desirable persistent species; hence, after annuals die, erosion occurs. All desirable species giving persistent covers have rather poor seedling vigor; thus, the density of the quick developing canopies should be controlled by using low seeding rates to minimize competition. The major species, seeding rates and seasons of seeding for various states are given in Table 4.

Multi-step Seeding and Fertilization: Seeding contracts should specify a 75 to 95% vegetative cover with 50% of the botanical components being persistent legumes or 80% persistent grasses where legumes are not adapted nor desired. This assumes that a persistent vegetative cover requiring no additional seed and fertilizer will develop through plant invasion and succession. Presently a large percentage of the initial contract seedings have a rapidly degenerating grassy vegetation

Table 4. Species and rates of and seasons of seeding in states in various regions.

	Rate of seeding kg/ha	Seeding season			
		Spring	Summer	Fall	Winter
A. Ohio, Indiana, Illinois, Michigan, Wisconsin, Iowa, Missouri, and Minnesota.					
Ky 31 fescue	50	X	X	X	X
Perennial ryegrass	28	X	X	X	X
Kentucky bluegrass	34	X		X	
Annual ryegrass	7	X		X	X
Redtop	11	X		X	
Ladino clover	7	X			
Creeping red fescue	45	X	X	X	X
Winter vetch	45			X	X
Crownvetch	22	X	X	X	
Birdsfoot trefoil	22	X			
Cereal rye	100			X	X
German millet	28		X		
Alsike clover	14	X		X	
B. Virginia, West Virginia, Tennessee, North Carolina, Kentucky, Arkansas, Missouri, Maryland, southern Ohio, Indiana, and Illinois.					
Ky 31 fescue	56	X	X	X	X
Redtop	5	X			
White clover	7	X			
Annual lespedeza	22		X		
Weeping lovegrass	7		X		
Bermudagrass (common)	8		X		
Annual ryegrass	7	X		X	X
Crimson clover	22				X
Crownvetch	22	X	X	X	
Sericea lespedeza	40	X	X	X	
Bluegrass	55	X		X	
Red fescue	45	X		X	X
Perennial ryegrass	28	X		X	X
Cereal rye	100				X
German millet	28		X		

Table 4. Species and rates of and seasons of seeding in states in various regions. (continued)

	Rate of seeding kg/ha	Seeding season			
		Spring	Summer	Fall	Winter
C. Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, New York, Pennsylvania, Connecticut, and New Jersey.					
Ky 31 fescue	50	X	X	X	X
Perennial ryegrass	11	X	X	X	X
Creeping red fescue	45	X	X	X	X
Red clover	11	X			
Birdsfoot trefoil	17	X		X	
Crownvetch	22	X	X	X	
Annual ryegrass	7	X		X	X
Cereal rye	100				X
White clover	6	X			
Bentgrass	6	X			
Redtop	10	X		X	
Weeping lovegrass	11		X		
German millet	28		X		
Kentucky bluegrass	33	X		X	
D. Central and southern Louisiana, Mississippi, Alabama, Arkansas, Georgia, South Carolina, Florida, west Tennessee, east Texas, and Coastal Plains of North Carolina and Virginia.					
Annual lespedeza (Kobe or Korean)	22	X	X		
Bahiagrass (Pensacola or Wilmington)	45	X	X	X	
Bermudagrass (common)	11		X		
Brunswickgrass	45		X		
Crimson clover	28	X		X	X
Abruzzi rye	78			X	X
Sericea lespedeza	40		X		
Crownvetch	22	X		X	
Tall fescue (Ky 31)	45	X		X	X
Weeping lovegrass	7	X	X		
German millet	28		X		
White clover	7	X			
Sudangrass	28		X		
Redtop	8	X		X	

Table 4. Species and rates of and seasons of seeding in states in various regions. (continued)

	Rate of seeding kg/ha	Seeding season Spring	Summer	Fall	Winter
E. Arizona, New Mexico, Nevada, southern California, and west Texas.					
Yellow bluestem	3.0	X		X	
Weeping lovegrass	6.7	X	X		
Lehman lovegrass	2.2	X	X		
Sand dropseed	1.1	X	X		
Sacaton	22	X	X		
Black gramagrass	2.2		X		
Siberian wheatgrass	2.2	X		X	
Blue grama	3.3	X			
Indian ricegrass	2.2			X	
Yellow sweet clover	3.3	X		X	
Crested wheatgrass	5.6	X		X	
Smooth brome	5.6	X	X	X	
F. Eastern Washington and Oregon, Idaho, northern Nevada, and Utah.					
Crested wheatgrass	5.6	X		X	
Smooth bromegrass	11	X		X	
Slender wheatgrass	5.6	X		X	
Streambank wheatgrass	8.9	X		X	
Hard fescue	13.4	X		X	
Big bluegrass	11.2	X			
Western wheatgrass	8.9	X		X	
Pubescent wheatgrass	4.4	X		X	
G. Western Washington, Oregon, Alaska, and northwest California.					
White clover	4.4	X		X	
Colonial bentgrass	3.3	X	X	X	
Red fescue	22	X	X	X	
Perennial ryegrass	8.9	X	X	X	
Chewings fescue	16.8	X		X	
Kentucky bluegrass	5.6	X		X	
Annual ryegrass	112		X	X	X
Barley	112				X
Crownvetch	28	X			

Table 4. Species and rates of and seasons of seeding in states in various regions. (continued)

	Rate of seeding kg/ha	Seeding season			
		Spring	Summer	Fall	Winter
H. North Dakota, South Dakota, Montana, Nebraska, Kansas, Wyoming, Colorado, Oklahoma, central Texas, and western Minnesota.					
Bromegrass	14	X		X	
Intermediate wheatgrass	7.8	X		X	
Crested wheatgrass	14	X		X	
Kentucky bluegrass	30	X		X	
Perennial ryegrass	3.3	X		X	
White clover	5	X		X	
Reed canarygrass	2.2	X		X	
Switchgrass	2.2		X		
Indiangrass	2.2		X		
Sideoats grama	2.2		X		
Little bluestem	1.1		X		
Alfalfa	7.8	X		X	
Red clover	5.6	X		X	
Hairy vetch	14	X		X	
Buffalograss	4.5		X		
Blue grama	1.1		X		
Slender wheatgrass	7.8	X		X	
Green needlegrass	2.2	X		X	
Western wheatgrass	5.6	X		X	
Green sprangletop	4.5		X		
Weeping lovegrass	4.5		X		
Sericea lespedeza	28	X		X	
Cereals (wheat, rye, oats, barley)	90	X		X	
Ky 31 fescue	28	X		X	
Bermudagrass	7		X		

that must be reseeded because of short-lived species and inadequate soil amendments.

It is usually impossible to obtain a satisfactory vegetation from one initial seeding because of the rigorous environments in highway corridors; the soil-biotic-climatic complex cannot be sufficiently manipulated. The principle of multi-step seeding is to apply specified seed and soil amendments in two to three applications at dates ranging from 2 to 12 months apart to take advantage of favorable conditions for establishing or stimulating desirable species when initial seedings fail to provide a protective vegetation of desirable persistent species. The second or third step operations, pending vegetation from initial seeding, may include fertilizer, when suitable species degenerate, rhizobia inoculants when nodulation of legumes fail, seed if soil amendments are suitable, or a seed-soil amendment-woodfiber slurry for areas with poor vegetative cover.

The multi-step principle used in the Appalachian and Piedmont regions has been very successful for obtaining desirable persistent vegetative covers requiring little or no maintenance. Exhibits for multi-step applications are:

1. For seeding in all seasons during construction operations:

a. Step I. Establish a temporary canopy during summer with a German millet-fertilizer-woodfiber slurry.

Step II. Apply cool season species with additional fertilizer during late summer-early fall. Frost or maturity kills millet, providing an <u>in situ</u> non-competitive mulch canopy.

b. Step I. Establish a temporary canopy during winter with a cereal rye-cool season species-fertilizer-woodfiber slurry over a straw mulch.

Step II. Apply a light application of fertilizer with either crownvetch or sericea lespedeza and perennial grasses if needed in March. Alternative Step II. Add paraquat to slurry if cereal rye canopy is dense and tall (aggressive).

2. Favorable spring season, one or two-step operations:

a. One-step procedure. Use recommended rates as 110 kg seed, 1700 kg of a 10-20-10 fertilizer, and 1700 kg/ha of woodfiber.

b. Two-step procedure. Step I. Apply woodfiber at 100% of the rate and other materials at 75% of the rate in Alternative a. above. Step II. Apply the rest of the materials during late summer, pending stands, applying materials at higher rates where vegetation is sparse.

An alternative for Step 2 is to apply around 200 kg/ha of P as P_2O_5 and 20 kg/ha of crownvetch when grass cover is sufficiently protective. It is assumed that lime is not needed due to a favorable pH. Fertilizer recommendations used with multi-step seeding in the Virginias are given in Table 5.

When using the multi-step seeding procedure with a given amount of seed or fertilizer, the chances of arresting erosion and obtaining a persistent cover are better than for a single application because:

1. Environmental risk for generating cover is minimal with seeding dates for the multi-step applications.

2. The risk of stand failure from unexpected catastrophy such as torrential rains, drought, and freezing is reduced. There is invariably

Table 5. Recommendations for several-step fertilization in different seasons for erosion and siltation control. 1/

Seeding seasons	Recommendations
A. Favorable spring, cool-moist environments	Apply 1100 kg/ha 10-20-10/A at seeding and 550 kg/ha 10-20-10/A the next fall
B. Late spring-mid summer	(a) With weeping lovegrass-perennial species, use 1100 kg/ha 10-20-10/A at seeding, 550 kg/ha the following spring. (b) With German millet use 850 kg/ha 10-20-10 at seeding and 850 kg/ha in the fall.
C. Favorable cool moist periods, summer-early fall	Apply 1100 kg/ha 10-20-10/A at seeding and 550 kg/ha next spring
D. Mid-late fall	Apply 1100 kg/ha 10-20-10/A at seeding and 550 kg/ha the following spring
E. Winter seedings	Apply 1100 kg/ha 10-20-10/A at seeding and 550 kg/ha the next spring

1/ Lime should be applied according to soil test recommendations.

2/ The actual dates within each seeding period vary with physiographic regions.

3/ Perennial grasses and legumes should be used during all seasons as discussed previously and used as recommended for various management practices and slope conditions.

some soil, seed, and fertilizer movement down slopes, even on shallow ones due to torrential rains or channeling of accumulated water from rainfall. Thus, with one-step methods some soil areas will be left without seed and fertilizer; hence, no vegetative cover. Such bare areas become enlarged in subsequent years and soil and water movement may become serious. This can be avoided with multi-step principles.

3. The mortality of seedlings from surface concentrations of N and K salts is reduced by the lighter applications (Verghese et al., 1970).

4. There is a chance of saving materials as the initial application may produce a satisfactory vegetative cover, making the second application unnecessary.

5. The multi-step procedures almost assure excellent productive covers as a responsibility by contractors.

6. Degeneration of young stands often starts 6 months after seeding in subsoil materials before legumes become established; hence, a two or three step method would improve growth, persistence, and longevity of vegetation.

7. The competition from grasses that suppresses legumes can be controlled by applying no N in Step 2.

8. When desirable species seeded in Step 1 are depressed by weed competition, Step 2 can be made later when weed competition is not serious as in the fall season.

9. The multi-step method is desirable when grassy covers are to be mowed and maintained. Step 2 could be composed of primarily a slowly available source of N to prolong its longevity.

Improving Sparse Vegetation: Sparse vegetation in highway corridors is common in all regions of the U.S.A. because of inadequate lime and fertility, use of unadapted and short-lived species, the low soil N status, absence of legumes, competition from aggressive weeds or companion species, catastrophies such as flooding, and poor unacceptable stands from initial one-step seeding operations.

The soils should be tested to apply nutrients to obtain persistent species, especially legumes. Renovation of sparse canopies with legumes should be initiated while grass cover is adequate to control erosion without applying N. Nitrogen stimulates grasses causing moisture and light competition. This depresses legumes, causing them to fail. Lime, P, and K applications, if needed, stimulate legume seedings and their invasion (Blaser et al., 1968; Blaser et al., 1975).

For example, slopes with a 50% grass cover or greater have given excellent crownvetch stands when seeded at about 40 kg/ha alone with 170 kg/ha of P as P_2O_5 and 850 kg/ha of woodfiber.

For sparse grass stands of 30 to 50% cover, it is usually necessary to apply 50% of the recommended grasses, around 300 kg of P as P_2O_5 and 60 kg/ha of N, along with woodfiber at 1680 kg/ha and full legume seeding rates.

When maintaining grassy vegetation, fertilizers, especially N, should be applied before degeneration and erosion occur. Rates of N should be as low as possible to avoid overstimulation of growth and problems with mowing management and maintaining vegetation. Autumn season N applications thicken shoot density, decrease weeds and avoid overstimulation of growth in spring (Blaser and Perry, 1975).

Conclusions

Many areas of this broad arena of roadside revegetation need additional research. There is a demand from the highway departments to find adapted, persistent low growing legumes that require little or no mowing or maintenance fertilizer application. Two legumes, flat pea (Lathyrus sylvestris), and sweet pea (L. latifolius), are promising in the southeast region. Also, there is a need for short growing cool and warm season grass species for use around guardrails along many miles of interstate highways. Other cool season annual and perennial species are needed for seeding in the winter season when erosion is very critical.

Maintenance requirements of many slopes could be reduced by encouraging woody species and shrub development through direct seeding and other methods. Attempts to establish woody species from seed have led to inconclusive and erratic results.

Designing seed mixtures with season to obtain vegetative cover under high and low temperatures as well as at several moisture levels led to the experiment presented next in Area I. Also, alternate methods of establishing vegetation without topsoil were examined for regions of Virginia and are presented in Area II.

SPECIFIC RESEARCH AREAS

WITH LITERATURE REVIEWS, RESULTS AND DISCUSSION

AREA I:

TEMPERATURE AND MOISTURE TENSIONS AS RELATED TO SEEDLING EMERGENCE

Seeding denuded slopes at all seasons of the year to control erosion is important in highway corridors where steep slopes make it necessary to use a hydroseeder to spray seed-fertilizer or seed-fertilizer-woodfiber slurries onto the slope to obtain vegetative covers. Such surface applications leave many seeds exposed to adverse moisture and/or temperature stresses. Species vary in degree and rate of germination and seedling development under harsh environmental conditions. The seedling survival and vegetative cover often depend on seedling size and speed of emergence with limited moisture and/or degree of tolerance to prevailing environmental factors.

Soil water stress at about -6 bars or above reduces germination of most plant species (Ayers, 1952; Doneen and MacGillivray, 1943; Evans and Stickler, 1961; Hughes et al., 1966; Hunter and Erickson, 1952; McGinnies, 1960; Parker and Taylor, 1965; and Wanjura and Buxton, 1972). Phillips (1968) found water uptake of several field crop seeds to decrease with increasing soil moisture tension at 28 C. The highest germination of six cool season grasses occurred at 20 C; germination started sooner at 30 C but was less than at 20 C; 10 C delayed germination more than 20 C or 30 C, but total germination was higher after 28 days for 10 C than at 30 C (McGinnies, 1960).

Because of variations in temperature and moisture, seeding seasons have pronounced effects on germination and growth rate of grass and legume species. Also, species with fast emergence and development are competitive toward slow emerging and slow growing seedlings (Blaser et al., 1956).

Water absorption for germination varies with species and temperature (Evans and Stickler, 1961; McGinnies, 1960). Many crop seeds germinate under severe moisture stress; corn, rice, soybeans, and segmented sugar seets do not germinate at moisture tensions exceeding -12.5, -7.9, -6.6, and -3.5 bars, respectively (McGinnies, 1960). As moisture stresses from mannitol solutions increased, wheat germination was delayed and reduced (Helmrich and Pfeifer, 1954). Both germination and early growth of side oat gramma and sand bluestem declined as moisture stress increased (Kneebone, 1957). Strains of the grasses with superior establishment characteristics germinated fastest and produced largest seedlings when subjected to soil water stress of less than -7.5 bars (Kneebone, 1957). Seeds in soil with inadequate water for germination are often subject to fungal damage and young seedlings are subject to dessication. Vigor and yield potential of cotton were found to be closely related to the time required for emergence; vigor of plants declined with delays in emergence (Wanjura et al., 1969).

Most of the research cited was conducted with soils where endeavors were made to maintain control of moisture stress. However, it is difficult to maintain specific moisture availabilities in soils (Hendrickson and Veihmeyer, 1941; Richards and Loomis, 1942).

The objectives of this research were to ascertain the influence of various temperature and moisture regimes on emergence rate of several plant species. Results from these experiments should aid in selecting adapted species for seed mixtures for various seasons because of expected moisture and temperature stresses. The need of obtaining vegetative cover on bare soil areas at all seasons makes it necessary to vary components of seed mixtures that are more adapted to the prevailing environmental conditions.

Methods and Materials

Moisture tension curves were determined by the pressure membrane method on a Groseclose subsoil classified as a Typic Hapludult, clayey, mixed, mesic, from a highway cut slope. Four kilograms of oven dry soil were placed in plastic airtight containers and distilled water was added to give moisture tensions of -1/3, -3, -6, and -9 bars (28.5, 18.7, 16.8, and 15.9% total water, respectively). This soil with different moisture tensions was sealed in plastic containers and stored for 60 days to reach equilibrium before starting the emergence experiment.

Twelve grasses and legumes (cultivars for some of the species) were used in the experiment. The highest percent emergence at either temperature and generally the most favorable moisture over the 19-day period was taken to be 100% emergence for that species. They are as follows with the optimum emergence given in percent: Abruzzi rye (*Secale cereale* L.) 92, perennial ryegrass (*Lolium perenne* L.) 98, annual ryegrass (L. *multiflorum* Lam.) 88, redtop (*Agrostis alba* L.) 81, Kentucky 31 fescue (*Festuca arundinacea* Schreb.) 74, German millet (*Setaria italica* L.) 92, weeping lovegrass (*Eragrostis curvala* Schrad. Nees.) 54, creeping red fescue (*Festuca rubra* L.) 66, Kentucky bluegrass (*Poa pratenses* L.) 54, sericea (*Lespedeza cuneata* G. Don.) 20, crownvetch (*Coronilla varia* L.) 57, and common bermudagrass (*Cynodon dactylon* L.) 14 (Table 6). These highest emergence values were used to determine the rate per day of emergence in percent for the different moisture tensions and temperatures.

Table 6. Rates (percent total emerged per day) of seedling emergence at 21 C and 28 C and four moisture tensions determined on a daily basis.

	Emergence period, days after seeding at 21 C							Emergence	
	1-2	3-4	5-6	7-8	9-10	11-12	13-19	Total, %	Relative[1/]
				-1/3 bar					
Abruzzi rye	36	10	0	0	0	0	0	80	92
German millet	39	6	1	0	0	0	0	84	91
P. ryegrass	1	42	5	0	0	0	0	94	96
A. ryegrass	9	36	5	0	0	0	0	88	100
Weeping lovegrass	15	15	8	2	2	0	0	46	85
Redtop	-	-	-	-	-	-	-	--	--
Creeping red fescue	0	15	23	5	0	3	1	66	100
Kentucky 31 fescue	0	7	16	13	3	0	0	54	80
Kentucky bluegrass	0	6	28	11	4	0	0	54	100
Crownvetch	0	16	12	9	5	4	1	57	100
Sericea	0	0	5	10	11	11	2	19	100
Common bermudagrass	0	7	7	0	9	9	0	10	71
				-3 bars					
Abruzzi rye	38	4	4	1	0	0	0	86	93
German millet	33	16	1	0	0	0	0	92	100
P. ryegrass	0	30	13	3	4	0	0	98	100
A. ryegrass	0	26	15	0	0	0	0	72	82
Weeping lovegrass	0	11	11	4	2	0	0	30	56
Redtop	0	18	6	7	1	0	0	51	63
Creeping red fescue	0	0	13	10	6	9	0	51	77
Kentucky 31 fescue	0	4	11	22	8	1	0	68	92
Kentucky bluegrass	0	0	6	24	6	3	0	42	78
Crownvetch	0	2	2	2	3	0	0	10	18
Sericea	0	0	0	0	9	7	5	14	74
Common bermudagrass	0	0	0	0	8	7	0	5	36

1/ Rates and relative values of emergence were based on the highest emergence obtained by each species which was generally at -1/3 bar of soil water potential.

Table 6. Rates (percent total emerged per day) of seedling emergence at 21 C and 28 C and four moisture tensions determined on a daily basis. (continued)

	Emergence period, days after seeding at 21 C							Emergence	
	1-2	3-4	5-6	7-8	9-10	11-12	13-19	Total, %	Relative[1]
				-6 bars					
Abruzzi rye	15	17	1	4	6	1	0	82	88
German millet	0	21	10	8	4	1	0	82	89
P. ryegrass	0	5	29	10	2	1	0	92	94
A. ryegrass	0	0	8	5	4	2	1	36	41
Weeping lovegrass	0	0	0	4	1	1	1	10	19
Redtop	0	0	12	3	5	1	0	35	43
Creeping red fescue	0	0	0	8	8	6	1	38	58
Kentucky 31 fescue	0	0	0	8	2	3	2	30	41
Kentucky bluegrass	0	0	0	2	7	2	1	16	30
Crownvetch	0	0	0	0	0	0	4	12	21
Sericea	0	0	0	0	0	0	10	12	63
Common bermudagrass	0	0	0	0	0	0	0	0	0
				-9 bars					
Abruzzi rye	0	19	6	6	4	2	0	70	76
German millet	0	0	15	9	6	4	0	66	72
P. ryegrass	0	0	22	15	4	1	0	82	84
A. ryegrass	0	0	0	2	3	2	1	20	23
Weeping lovegrass	0	0	0	0	0	1	0	2	3
Redtop	0	0	0	6	5	2	0	22	27
Creeping red fescue	0	0	0	0	2	1	2	14	21
Kentucky 31 fescue	0	0	0	2	2	3	1	18	24
Kentucky bluegrass	0	0	0	0	0	1	3	12	22
Crownvetch	0	0	0	0	2	0	0	0	0
Sericea	0	0	0	0	0	0	7	9	45
Common bermudagrass	0	0	0	0	0	0	0	0	0

Table 6. Rates (percent total emerged per day) of seedling emergence at 21 C and 28 C and four moisture tensions determined on a daily basis. (continued)

	Emergence period, days after seeding at 28 C							Emergence	
	1-2	3-4	5-6	7-8	9-10	11-12	13-19	Total, %	Relative[1]
				-1/3 bar					
Abruzzi rye	42	8	0	0	0	0	0	92	100
German millet	2	24	6	1	3	1	0	68	74
P. ryegrass	10	26	6	1	0	0	0	84	86
A. ryegrass	23	14	9	0	0	0	0	82	91
Weeping lovegrass	29	17	4	0	0	0	0	54	100
Redtop	0	27	9	0	14	0	0	81	100
Creeping red fescue	0	23	14	3	3	1	0	56	89
Kentucky 31 fescue	2	24	14	7	3	1	0	74	100
Kentucky bluegrass	0	11	12	14	2	0	0	42	78
Crownvetch	0	2	3	3	3	0	1	16	28
Sericea	0	0	3	4	10	10	6	20	100
Common bermudagrass	0	21	7	7	8	5	0	14	100
				-3 bars					
Abruzzi rye	34	4	2	2	1	0	0	79	86
German millet	43	1	0	1	0	0	0	82	89
P. ryegrass	4	32	4	0	3	1	0	86	89
A. ryegrass	0	27	8	3	1	0	0	68	77
Weeping lovegrass	20	19	2	2	0	0	0	46	85
Redtop	0	13	4	3	2	1	1	42	52
Creeping red fescue	0	2	3	2	0	0	0	9	14
Kentucky 31 fescue	0	0	7	4	4	9	0	42	57
Kentucky bluegrass	0	0	2	0	2	1	1	8	15
Crownvetch	0	0	0	0	0	0	1	3	5
Sericea	0	0	0	5	11	5	3	13	65
Common bermudagrass	0	0	7	16	0	6	0	9	64

Table 6. Rates (percent total emerged per day) of seedling emergence at 21 C and 28 C and four moisture tensions determined on a daily basis. (continued)

	Emergence period, days after seeding at 28 C							Emergence	
	1-2	3-4	5-6	7-8	9-10	11-12	13-19	Total, %	Relative[1/]
				-6 bars					
Abruzzi rye	27	12	0	2	1	0	0	76	83
German millet	39	2	3	4	2	0	0	88	100
P. ryegrass	0	24	12	4	4	0	0	76	88
A. ryegrass	0	8	2	4	1	1	0	28	34
Weeping lovegrass	0	0	6	8	9	1	1	30	56
Redtop	0	4	2	3	1	0	0	15	19
Creeping red fescue	0	0	0	0	0	1	0	2	4
Kentucky 31 fescue	0	0	0	2	0	1	0	6	8
Kentucky bluegrass	0	0	0	1	0	1	0	2	5
Crownvetch	0	0	0	0	0	0	0	0	0
Sericea	0	0	0	0	0	0	0	0	0
Common bermudagrass	0	0	0	0	0	3	6	6	43
				-9 bars					
Abruzzi rye	18	5	8	2	2	1	0	66	72
German millet	29	3	3	2	1	0	0	70	76
P. ryegrass	0	8	7	2	1	0	0	34	37
A. ryegrass	0	0	0	0	0	1	0	2	2
Weeping lovegrass	0	0	0	2	2	1	0	6	11
Redtop	0	0	1	0	2	0	0	5	6
Creeping red fescue	0	0	0	0	0	0	0	0	0
Kentucky 31 fescue	0	0	0	0	0	0	0	0	0
Kentucky bluegrass	0	0	0	0	0	0	0	0	0
Crownvetch	0	0	0	0	0	0	0	0	0
Sericea	0	0	0	0	0	0	0	0	0
Common bermudagrass	0	0	0	0	0	2	1	2	14

One hundred seeds of each species were sown on top of 2 cm of soil and then covered with a thin soil layer no deeper than 0.5 cm in each of two replications in plastic containers. The containers were sealed to prevent evaporation and then placed at constant temperatures of 21 or 28 C. Redtop at 21 C and -1/3 bar of soil water potential was mishandled and omitted from the study.

Counts of emerging seedlings were made at 1 to 3 day intervals during 19 days to determine rate and percent of emergence. Analyses of variance were made to study temperature, moisture and date interactions of the species.

Results and Discussion

Emergence rates of the different species and cultivars were grouped into intervals of 2 or more days in the table to simplify the presentation of the data. The highest total emergence of each species, usually obtained at the lowest soil water potential, was used to base emergence of all species on a relative scale. The relative values may be used to determine the difference within and among species at different moisture levels and temperatures. Rates of emergence per day as given in Table 6 are important when designing seed mixtures and rates for different seeding seasons, since short periods of favorable moisture under field conditions is a more common occurrence than extended moist conditions.

Temperature, moisture levels, and their interactions resulted in differences ($P < 0.05$) as measured by rate and total emergence among species or cultivars. Increased moisture stress decreased emergence of all species (Table 6). German millet and Abruzzi rye generally had faster and higher total emergence at 21 and 28 C than other species at all moisture tensions (Table 6). These two species required the least amount of water to initiate germination, having an emergence rate of 39 and 42%, respectively, for the first 2-day interval under the favorable moisture and temperature. At 21 C and -1/3 bar of soil water potential, German millet and Abruzzi rye had about 80% of their total emergence by day 2, whereas aggressive species such as annual and perennial ryegrass had rates of 9 and 1% (16 and 2% total), respectively, by day 2. Total emergence of lovegrass after day 19 was no more than 50%, but the rate of emergence was high at -1/3 bar of soil water potential and it had a higher emergence rate than annual or perennial ryegrass at -1/3 bar of soil water potential during the first 2-day interval.

Among species with intermediate total emergence values, lovegrass was the only species to emerge by day 2 at 21 C (Table 6). Creeping red fescue, crownvetch, Kentucky bluegrass, or Kentucky 31 fescue emerged either after day 3 or 4, having emergence rates ranging from 6 to 15% per day at 21 C and -1/3 bar. At this environment by day 19, the total emergence of these four species ranged from about 55 to 65% (Table 6). At 21 C and -1/3 bar, bermudagrass on day 4 and sericea on day 6 had less than 3% total emergence but had rates of emergence of 10% per day for days 7 through 13 for sericea and about 10% emergence for bermudagrass for days 9 through 13.

At 21 or 28 C, increasing moisture stress from -1/3 to -9 bars generally affected emergence of all species in two ways: 1) rate of emergence declined and was delayed as moisture stress increased, and 2) total emergence decreased with water stress (Table 6). Significant interactions ($P < 0.05$) were noted among species at different moisture levels (Figure 17). The high as compared to the low temperature generally caused delays and decreases in total emergence, especially at the higher moisture stresses of -6 and -9 bars. The sharpest response for total emergence was made with crownvetch at -1/3 bar of soil water at 21 as compared to 28 C. The emergence rate was 16% for days 3 and 4 at 21 C as compared to 2% for 28 C. At 21 C the rate and total emergence of crownvetch was several fold higher than for sericea and bermudagrass and is classed as an intermediate emerging species with favorable moisture. At 28 C, however, the rates of emergence of sericea and crownvetch were very low and affected more than bermudagrass, with all values for total emergence being similar and low. Low values for total emergence of sericea and crownvetch may partly be explained by their hard seed. At 28 versus 21 C, Kentucky bluegrass total emergence dropped 12%, while Kentucky 31 fescue increased 20% by day 19. Also, the rate of emergence was higher for bluegrass on days 3 through 6 at 21 than at 28 C and fescue was best at 28 C at -1/3 bar of soil water tension. This indicates that Kentucky 31 fescue may be seeded during higher temperature periods as in summer as compared to spring or early fall for bluegrass. Near maximum emergence was reached by day 13 for all species (Table 6). Crownvetch, sericea, and bluegrass at 28 C and common bermudagrass at 21 C had very poor or no emergence by day 19 at -6 and -9 bars of soil water potential.

Suitable temperature and moisture are important for seedling emergence, although some species imbibed water at faster rates than others. For example, at 28 C Abruzzi rye had an emergence rate of 18 and 5% for the first two 2-day intervals at -9 bars of soil water potential, while sericea required 5 days to emerge at favorable moisture (-1/3 bar) (Table 6). Favorable moisture during reasonable long periods is a very important factor in seedling emergence; also, insufficient moisture may result in damage or lethal effects to seedlings from pathogens. Grasses that emerged at the higher moisture tensions generally gave the highest and fastest emergence rates at both temperatures and all moisture levels. Abruzzi rye, German millet and perennial ryegrass were the only aggressive species for rate and total emergence at -9 bars of soil water potential. Figure 17 illustrates how rapidly the emergence of annual ryegrass dropped at -6 and -9 bars of soil water potential as compared to perennial ryegrass and Abruzzi rye. At 21 C and -9 bars of soil water potential at day 19, perennial ryegrass had a relative emergence value of 84%, followed closely by Abruzzi rye with 76% and German millet with 72%. On day 19 at -9 bars of soil water potential, annual ryegrass, a very aggressive grass with favorable environmental conditions, had 4 and 17 fold less emergence than perennial ryegrass at 21 and 28 C, respectively. However, on days 3 through 6 at -1/3 bar of soil water potential, emergence of annual and perennial ryegrasses had similar and high emergence rates at both 21 and 28 C. Also, at favorable moisture (-1/3 bar) for both temperatures, annual ryegrass had two to eight fold more seedlings on day 2 than perennial ryegrass. Thus, with favorable moisture, as is common for spring seedings, annual ryegrass is very aggressive as compared to perennial ryegrass and other species. The vigorous seedlings also make annual ryegrass an aggressive species (Blaser et al., 1956).

With favorable moisture and temperature, based on rate and total emergence, the 12 species or cultivars may be classified into three groups and are generally arranged in this order in Table 6:

<u>Aggressive</u>: Perennial and annual ryegrasses, German millet, redtop, weeping lovegrass, and Abruzzi rye had the highest rates of emergence at both 21 and 28 C; maximum rates of emergence occurred from days 1 through 4 with near maximum emergence values occurring by day 6 under favorable moisture.

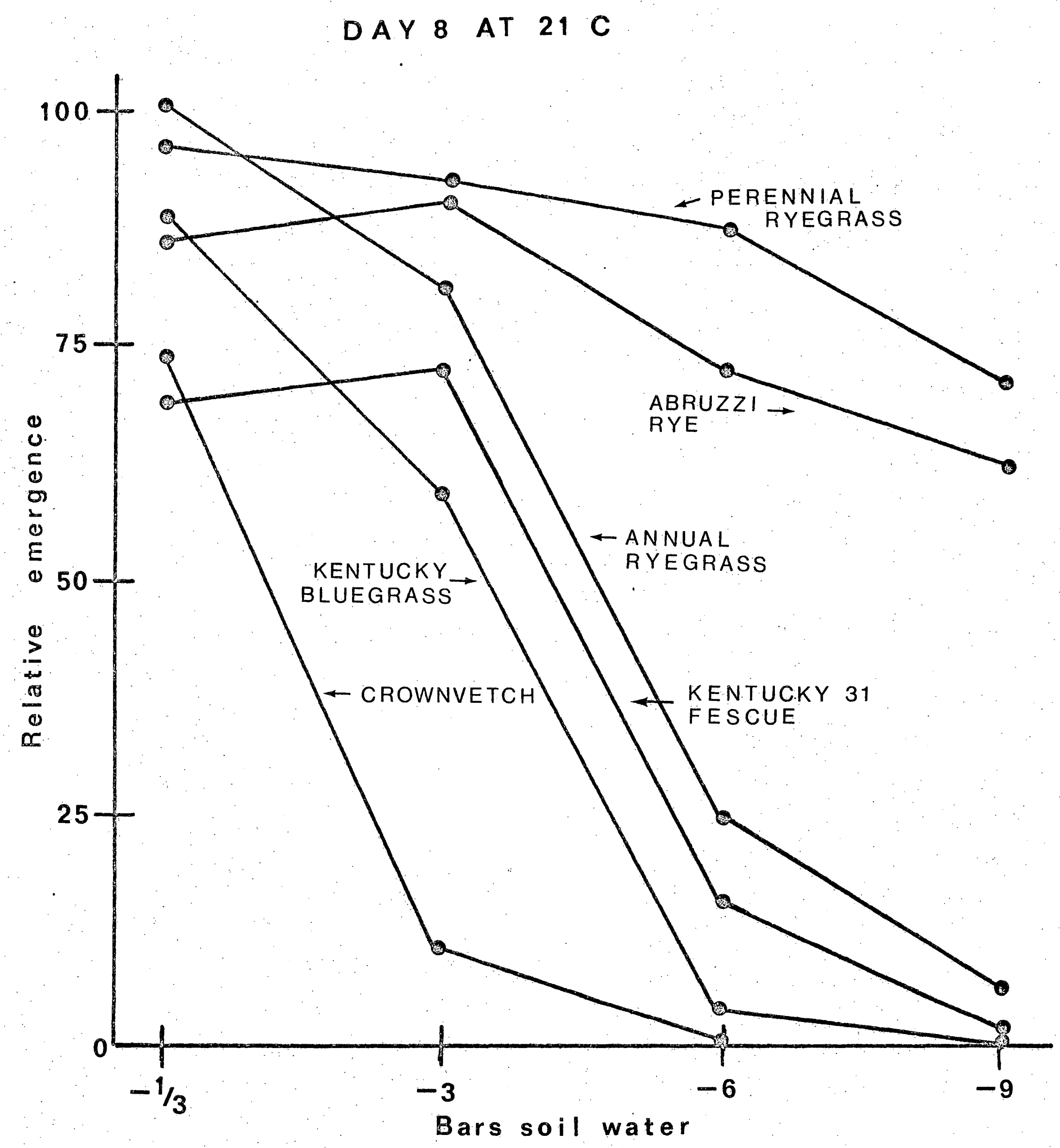

Figure 17. Relative emergence of six plant species at different moisture tensions at 21 C.

Intermediate: Crownvetch at 21 C and creeping red fescue, Kentucky bluegrass and Kentucky 31 fescue at both temperatures had intermediate emergence rates; maximum emergence rates occurred for days 3 through 8 with near maximum emergence occurring by day 8 under favorable moisture.

Non-aggressive: Crownvetch at 28 C and sericea and common bermudagrass at both temperatures had lowest and slowest emergence; maximum emergence rates occurred between days 3 and 13 with near maximum emergence occurring between day 10 and day 13. Parks and Henderlong (1967) reported similar results for some of the species.

At high moisture stress at either 21 or 28 C, only perennial ryegrass, Abruzzi rye, and German millet were aggressive species for rate and total emergence. Redtop and annual ryegrass were generally aggressive only under low moisture stress and the cooler temperature. Field studies show that cool season grasses are not aggressive competitors with warm season species under the high temperature of summer seeding conditions (Blaser et al., 1956). Creeping red fescue, Kentucky bluegrass, and Kentucky 31 fescue had intermediate values for total seedling emergence.

Controlling erosion on newly constructed highway slopes with year-round construction requires special seed mixtures for the sharply different seasonal temperature and moisture extremes. Seedling emergence that develops vegetative covers quickly for erosion control cannot be obtained from a single perennial grass or legume species subjected to widely varying environments; hence, temporary species that are adapted to certain harsh environments are used with slower developing persistent species. Later, through plant succession when growth conditions become favorable, the initially slow developing species dominate.

Seed mixtures should be designed to provide a fast initial cover of temporary grassy vegetation that will shift to perennial grasses and legumes and then finally to a persistent leguminous canopy. The data indicate that this may be accomplished by seeding an aggressive summer species such as German millet with an intermediate emerging species such as Kentucky 31 fescue and crownvetch, a non-aggressive legume that finally dominates. Such a summer seeding mixture gives a cover of German millet quickly; later it is killed by frost, while fescue and crownvetch continue growth during the autumn season. Crownvetch generally requires a year for good root and crown development before prolific top growth begins to shade out the Kentucky 31 fescue, with low nitrogen fertilization and no mowing.

Abruzzi rye readily emerges at 21 or 28 C at high moisture stress. This cultivar is generally used as a companion species with slower developing species as Kentucky 31 fescue or creeping red fescue with late fall and winter seeding. Abruzzi rye seeded during late fall-winter season at high rates matures and dies during the subsequent late spring, thereby allowing the cool season perennial species to become dominant. The early spring growth and dense, tall canopies of cereal rye often become very competitive to slower developing cool season perennial grasses and legumes. Mowing or treating the rye canopies with Paraquat reduces its aggressiveness which encourages growth of persistent grasses and legumes. Excellent stands of crownvetch have been obtained by an application of a slurry of inoculated crownvetch seed, Paraquat, and fertilizer onto rye with a hydroseeder in spring (Blaser et al., 1975). The data suggests that Abruzzi rye could be seeded in summer mixtures as it emerged at 28 C at high moisture stress. With summer seedings, aggressive rye seedlings may develop adequate canopies for erosion control before dying due to adverse physiological and pathological conditions; thus, rye may be a suitable companion crop for developing persistent grass and legume canopies since competition for light and moisture would be limited during the critical summer months.

Seeds of annual and perennial ryegrasses, creeping red fescue, Kentucky bluegrass, and Kentucky 31 fescue are used in various combinations for turf or for lawns. Rate of emergence and seedling size and growth under various temperature and moisture stresses are important factors for designing seed mixtures. For example, the data show that emergence of Kentucky bluegrass as well as creeping red fescue declined sharply at the higher temperature. This indicates that even under irrigation or favorable moisture, cool temperatures as in the spring or fall are required for satisfactory emergence and growth. Although high temperatures did slightly increase the speed of emergence of bluegrass at the high moisture levels, the values were extremely low. Kentucky 31 fescue also needs high water availability over prolonged periods and cool temperatures for rapid and high seedling emergence; however, a higher and faster emergence rate was noted for Kentucky 31 fescue than for either creeping red fescue or Kentucky bluegrass at 28 C and high moisture stress.

The data show that the aggressive species of annual and perennial ryegrasses would be very competitive in seed mixtures to slower developing perennial grasses; hence, these species should be seeded at low rates when water availability and temperatures are favorable as in the spring or autumn seasons. However, under moisture stress and especially at high temperatures, annual ryegrass is non-aggressive as compared to perennial ryegrass, which maintains excellent emergence rates at high moisture stress. High rates of aggressive species as for ryegrasses should never be seeded with bluegrass or creeping red fescue since successful establishment of a bluegrass turf depends on cool temperatures and high moisture availability. The latter factors make the ryegrasses aggressive. Thus, modifications of seed mixtures depend on the season of seeding and type of vegetation desired. Special precautions should be taken when seeding mixtures of aggressive species with slow developing species when conditions favor rapid emergence and growth.

AREA II:

ESTABLISHING VEGETATION ON SUBSOILS WITH AND WITHOUT TOPSOIL

Topsoil is invaluable where vegetation is desired as over xeric rock or when concentrations of certain elements in subsoils are toxic to plants. Topsoil applied 10 cm deep on medians and fill slopes in highway corridors is currently recommended in some contract specifications by the Virginia Department of Highways and Transportation. However, the specifications are often waived because of high costs of hauling and spreading topsoil, coupled with seeding delays, contamination with weed seeds and undesirable grasses and inability of writing suitable specifications for quality topsoil. Thus, investigations were initiated for establishing vegetation on subsoil materials on highway slopes.

After grading cuts, the exposed B and C horizons and parent materials are usually smooth and compact, making them impervious to water infiltration. Woodruff and Blaser (1970) observed more flow off and erosion from smooth cut slopes as compared to slopes with stair-steps constructed parallel to the roadway. Grasses and crownvetch (*Coronilla varia* L.) established more quickly on roughened slopes and provided a better protective vegetative cover than on glazed hard surfaces for conventional grading.

Immediately after construction, compacted soils on steep inclines are vulnerable to sheet erosion and severe rilling from water channels that make vegetative establishment nearly impossible (Blaser, 1963). Taylor and Burnett (1964) observed that roots of cotton grew horizontally when the soil was compacted with a road roller. This caused shallow rooted plants, subject to dessication. The physical resistance of the compacted soil reduces water infiltration and restricts root growth and exploration.

The glazed surfaces with pan grading and bulldozing cause shallow roots that grow somewhat horizontally because of severe compaction. Air exchange is nearly nullified in compacted soils, resulting in a depletion of soil oxygen and a concurrent increase in CO_2 concentration, which limits respiration for root growth processes (Labanauskas et al., 1971).

Findings show that soil oxygen concentrations near the atmospheric content (20.6%) are optimum for root growth of many plants (Huck, 1970). Stolzy, Letey, Szuszkiewicz and Lunt (1961) found optimum root growth of snapdragons at 8 to 21% soil oxygen. Tillage operations to 15 to 26 cm were often necessary to modify soil structure, improve aeration, moisture-temperature relationships, and to reduce soil strength for root penetration.

Many freshly graded slopes in the Coastal Plains and Southern Piedmont regions of Virginia with smooth glazed surfaces are topsoiled because engineers have observed better vegetative cover. The better vegetative cover may be attributed to two factors: 1) better moisture and aeration, and 2) covering the acid subsoil materials high in soluble aluminum which restricts growth of many plants (Shoop et al., 1961).

Topsoil specified in many contract seedings on fill slopes and medians prior to seeding does not meet specific fertility standards and may be inferior to the subsoil. The vast amounts of topsoil needed in Virginia highway corridors, along with the high costs and delays in seeding, led to the establishment of experiments with and without topsoil in the Appalachian and Coastal Plains regions. Applying adequate fertilizer, lime and seed on glazed hard surfaces as compared with rough grading of the subsoil and smooth and roughened topsoil was investigated to determine the necessity of topsoiling for establishing vegetation.

Methods and Materials

Two experiments with similar objectives were established. Experiment 1 was established in May 1972 near Blacksburg in the Appalachian region on a freshly graded 3:1 cut slope exposing a Groseclose subsoil classified as Typic Hapludult, clayey, mixed, mesic, with the following properties: pH - 5.0; CaO - L+; MgO - M-; P_2O_5 - L-; K_2O - L; and organic matter nil as determined by the Virginia Polytechnic Institute and State University soil testing laboratory. The slopes had a hard glazed condition as for conventional grading. A randomized block design with three replications had soil, subsoil and slope preparation treatments as follows: 1) applying lime and fertilizer on the surface of the glazed subsoil; 2) roughening the glazed subsoil to a 15 cm depth with a tractor tiller and then applying lime and fertilizer on the surface; 3) applying lime and fertilizer to the glazed subsoil and then roughening as in 2); and 4) applying 10 cm of topsoil over the glazed subsoil and applying lime and fertilizer on the surface. The origin of the topsoil is unknown but was thought to be from a nearby Groseclose soil. A slurry of seeds (Kentucky 31 fescue (*Festuca arundinacea*) at 84, redtop (*Agrostis alba*) at 2.2, annual ryegrass (*Lolium multiflorium*) at 5.6, and crownvetch at 22.4 kg/ha) and woodfiber at 1680 kg/ha was applied uniformly with a hydromulcher.

Bulk density and total porosity of the soil and subsoil were measured on the 0-3 cm surface layer by the core method described by Blake (1965), and porosity by the method described by Komocil (1965). Data on legume and grass stands were taken at random within three strata of each plot. Data on density of vegetative cover and erosion ratings are mean values of independent ratings by three persons.

Experiment 2 was established on a freshly graded median in the Coastal Plains region near Gloucester, exposing a yellow-brown Lenior silty clay loam subsoil classified as Aeric Paleaqualt, clayey, mixed, thermic, with the following chemical properties: pH - 5.2; CaO - L; MgO - L+; P_2O_5 - L; and K_2O - L+ as determined by the Virginia Polytechnic Institute and State University soil testing laboratory. The treatments for this split-split plot experiment were: main plots - 1) glazed subsoil, and 2) subsoil covered with 15 cm of topsoil; subplots - 1) roughened subsoil, 2) glazed subsoil, 3) roughened topsoil, and 4) smooth topsoil; and sub-subplots were three fertilizer rates (N-P-K in kg/ha) - 1) 168-146-139, 2) 112-98-93, and 3) 84-73-70.

For the subplots, half of the topsoil and subsoil was roughened to a depth of 15 cm by tiller feet of a road grader. The topsoil was not mixed with the subsoil. For the roughened subsoil, a rototiller was used to break the large clods to sizes ranging from 3 to 10 cm. The sandy topsoil had small clods when tilled with the road grader; hence, no additional tilling was needed on the loose topsoil. The smooth topsoil and glazed subsoil areas were left in conditions conventional for contract seedings during highway construction.

The entire experimental area was limed and seeded with a slurry (rate kg/ha) of lime at 3360, Kentucky 31 fescue at 67, annual ryegrass at 11, crownvetch at 22, and white clover at 3.4.

Populations of grasses and legumes were obtained as described for experiment 1; data on percent vegetative cover and erosion ratings are means of three visual estimates. Soil moisture is the difference of wet and oven dry weights at 100 C for 48 hours in a forced air oven (Gardner, 1965). Soil temperatures were obtained with a copper-constantine thermocouple with recorder powered by a portable generator (Taylor and Jackson, 1965).

Results and Discussion

Thirty-five days after seeding, there were nearly four-fold more plants per unit area and five-fold better vegetative cover on the roughened yellow-brown Lenior subsoil as compared to the glazed subsoil. Plant heights were also doubled by rough grading in the 5-week period (Table 7). Grass and legume plant populations were affected similarly, having .9 crownvetch, .77 white clover, and 11.6 grass plants per dm^2 on the roughened subsoil as compared to .13, .03, and 2.6 plants per dm^2 for the respective species on the "conventional" glazed subsoil where the soil amendments, seed, and mulch were surface applied (Table 8). These increases of 543% in vegetative cover and 269% in plant size (Table 7) occurred 35 days after seeding. About 90 days after establishing the experiment, the vegetative covers were 21 and 100% for the glazed and roughened subsoils, respectively.

Roughening the subsoil improved the available soil moisture substantially at the 0 to 5 and 5 to 20 cm depths (Table 9). This is attributed to increased water infiltration caused by lower bulk densities, 1.38 as compared to 1.76 gm per cm^3, and higher porosity, 51.4 as compared to 42% for the glazed subsoil (Table 10). Also, the stability of the clay clods in rough subsoils, having a lower erosion rating as compared to smooth glazed subsoils, slowed water movement and moderated the microenvironment by creating "mini-slopes" or environments (Tables 9 and 10).

Even though woodfiber mulch had been applied to moderate temperatures, the subsoil surface temperatures differed sharply, being 28 C

Table 7. Roughened and glazed Lenior subsoil as compared with topsoiling with smooth and rough surfaces on plant development and erosion in a median. The experiment was established on 4/25/74.1/

	Topsoil, 15 cm					Glazed subsoil, no topsoil				
	5/30/74			7/20/74		5/30/74			7/20/74	
	Plants/ dm^2	Cover %	Ht. (cm)	Vegetative cover, %	Erosion rating2/	Plants/ dm^2	Cover %	Ht. (cm)	Vegetative cover, %	Erosion rating
Roughened	11.4a	39a	8.3a	100	1.8	15.2a	38a	8.8a	100	1.7
Glazed or smooth	2.6b	10b	4.8b	25	3.8	4.0b	7b	3.8b	21	7.2

1/ Means in a column followed by different letters are significantly different at the 5% level of probability.

2/ Estimates made for areas receiving 1.2 cm of artificial rain at a rate of 5 cm per hour. Erosion ratings were made on a 0 to 10 scale with 0 being nil and 10 being severe rill and/or sheet erosion.

Table 8. Legume stands obtained on a Lenior subsoil with and without topsoiling, each left smooth and roughened by tillage. The experiment was established on 4/25/74; data collected 35 days later.

N-P-K kg/ha	Topsoil, 15 cm[1]						Subsoil[1]					
	Roughened			Smooth			Roughened			Glazed		
	CV[2]	WC[2]	Grass	CV	WC	Grass	CV	WC	Grass	CV	WC	Grass
	plants/dm^2			plants/dm^2			plants/dm^2			plants/dm^2		
168-146-139	.6b	.7c	12.1a	0b	.2b	2.2a	.7c	.7b	11.5a	.1a	.1a	2.7a
112-98-93	.6b	1.0b	10.7a	0b	.4a	1.5a	.9b	.7b	10.3a	.1a	0b	2.4a
84-73-70	.9a	1.7a	13.9a	.1a	.2b	2.0a	1.1a	.9a	12.9a	.2a	0b	2.6a
Average	.7	1.13	12.1	.03	.27	1.9	.9	.77	11.6	.13	.03	2.6

1/ Means in a column followed by different letters are significantly different at the 5% level or probability.

2/ CV = crownvetch; WC = white clover.

Table 9. Effects of roughened versus glazed Lenior subsoils and topsoiling on temperature and moisture on slopes of a highway median. The experiment was established on 4/25/74 (data taken 35 days later).[1/]

	Topsoil, 15 cm deep				Subsoil			
	Rough surface		Smooth surface		Rough surface		Glazed surface	
Depth (cm)	Soil moisture %	Temp. C	Soil moisture %	Temp. C	Soil moisture %	Temp. C	Soil moisture %	Temp. C
0-5	13.9	25	11.6	30	15.3	22	11.2	28
5-20	16.1		12.8		18.9		12.4	

1/ Moisture due to depths and temperatures over both top and subsoil were different at the 5% level of probability.

Table 10. Plant populations and vegetative cover as influenced by surface conditions of a Groseclose subsoil were examined with topsoiling and incorporation and surface application of lime and fertilizer. This experiment was established 5/22/72.

Seedbed preparation	7/22/72						6/20/74
	Crownvetch	Grass	Vegetative cover, %	Bulk density gm/cm^3	Total porosity, %	Erosion rating[3/]	Crownvetch cover, %
	Plants/dm^2						
Glazed subsoil, lime and fertilizer surface applied[1/]	.02c	1.6d	22c	1.76	42.1	3.7	100
Roughened-loose subsoil, lime and fertilizer surface applied	.44a	8.0a	72a	1.38	51.4	1.2	100
Rough-loose subsoil, lime and fertilizer and then roughened	.48a	9.3a	74a	1.44	59.9	1.4	100
10 cm topsoil on subsoil lime and fertilizer surface applied[1/]	.18b	6.8b	66b	1.42	53.0	0.4	100

[1/] Practices commonly specified and used by grading contractors during highway construction.

[2/] Means in a column followed by different letters are different at the 5% level of probability.

[3/] Estimates made for areas receiving 1.2 cm of artificial rain at a rate of 5 cm per hour. Erosion ratings were made on a 0 to 10 scale with 0 being nil and 10 being severe rill and/or sheet erosion.

for the glazed versus 22 C for the roughened surface. The lower subsoil temperatures for roughened surfaces may be attributed to factors directly related to increased water infiltration: 1) high soil moisture requiring more energy to elevate temperatures than for soil air or low soil water; 2) soil shading caused by the faster developing plants; 3) mini-slopes or shade created by clay clods causing some cooling; and 4) more evapotranspiration causing a cooling effect.

The experiment on the Groseclose subsoil had 5 and 24 fold more grass and legume plants, and 72 versus 22% vegetative cover on the roughened as compared to glazed subsoil (Table 10). Crownvetch seeded in this experiment gave a 100% slope cover 2 years after seeding. Incorporating the soil amendments did not significantly increase plant populations or vegetative cover. However, incorporation is usually allied with increased rooting depths of plants since surface applied lime and phosphorus move into soil very slowly because of positional fixation.

Roughening the topsoil had desirable effects comparable to roughening the subsoil (Table 7). Plant stands and percent soil cover with vegetation were increased by a factor of about four by roughening versus smooth topsoil. Plant heights were nearly doubled in the 35-day period, being 8.3 and 4.8 cm tall for the roughened versus the smooth topsoil, respectively. About 90 days after establishing the experiment, the smooth topsoil had only a 25% vegetative cover as compared to a 100% cover for the roughened topsoil. Plant populations of white clover, crownvetch, and grass were substantially increased by the roughened versus the smooth topsoil (Table 8). A 10 cm layer of topsoil applied topically to the Groseclose subsoil that was not roughened had about a 70% vegetative cover 2 months after seeding and had 100% crownvetch cover 2 years after seeding.

The topsoil applied over the Groseclose subsoil and left smooth had a low erosion rating of 0.4 as compared to 3.7 for the glazed subsoil. However, where topsoil was applied to the Lenior subsoil and roughened, approximately one-half the amount of erosion occurred as where the topsoil was left smooth (Table 10).

Roughened versus smooth topsoil surfaces increased the available soil water by 16 and 20.1% at the 0 to 5 and 5 to 20 cm depths, respectively (Table 9). Such increases in infiltration to augment water availability increase the amount of germination and subsequent seedling growth (Doneen and MacGillivray, 1943). Thus, many of the increases in plant populations and vegetative cover may be attributed to higher water availability due to roughening of soils to slow water movement, thereby increasing the chance for infiltration.

The temperature of the roughened topsoil was 5 C cooler than for the smooth topsoil (Table 9). This temperature differential is mainly attributed to moisture differences, more water infiltration with rough versus smooth surfaces.

When comparing plant populations of grasses and legumes, their height, and total vegetative cover (Tables 7, 8, and 10), results for roughened topsoils and subsoils were similar. Rough graded subsoil vastly increased plant stands, 584% better than smooth topsoil. However, when comparing glazed subsoils with roughened topsoils, the plant populations were better for the roughened topsoil (11.4 versus 4.0

plants per dm^2 (Table 7)). These findings indicate that satisfactory vegetative covers may be assured for either the topsoil or subsoil substrata by preparing the soil surface to increase water infiltration and creating favorable microenvironments with "mini-slopes" from clods and surface undulations.

Available water was higher by 10 and 15% in the 0 to 5 and 5 to 20 cm depths, respectively, of the rough graded subsoil as compared to the roughened topsoil; whereas with smooth topsoil versus the glazed subsoil, the available water was higher in the topsoil. This is attributed to the higher porosity of the topsoil (53%) as compared to 42.1% for glazed subsoil. It is assumed that water infiltration was higher on the roughened soil areas due to the combined influence of higher porosity and lower bulk density than for the glazed subsoil (Table 10). The lower available moisture in the roughened topsoil versus the roughened subsoil is attributed to high silt content of top-soil that often results in surface sealing, causing increased water runoff and reduced infiltration. Such crust formations for topsoil may be alleviated by deep tillage to mix the more stable clay subsoil material with the topsoil, which may also increase root development. Burwell et al. (1966) showed that random roughness and total porosity were controlling factors for increasing water infiltration from tillage induced structural conditions. Clod stability and roughness of surface materials are factors that restrict water movement and erosion from slopes. Likewise, infiltration seems to be dependent on the depth to which the soil is loosened by mechanical means. Other factors that influence infiltration are the amount and intensity of rainfall, infiltration capacity of the surface layer, soil texture, and moisture conductivity of lower horizons, and the amount of water which the soil profile will retain at its field capacity (Baver, 1972).

Temperatures were 22 and 28 C for the roughened and glazed subsoil as compared to 25 and 30 C for the roughened and smooth topsoil. The lowest temperature occurred with the highest soil water content while the highest temperature occurred with the topsoil, although it contained slightly more soil water than the glazed subsoil. The high temperature of the topsoil was partly attributed to absorption of higher amounts of radiant energy by the dark colored organic matter as compared to the light yellowish-brown color of the subsoil.

The subsoil with numerous clods 3 to 10 cm in size provided adequate soil-seed contact for excellent germination and subsequent growth. The ridges in the roughened topsoil served much the same function as the clay clods but many weed seeds germinated causing severe competition to developing grass and legume seedlings.

Increases in legume stands as fertilizer application rates were lowered were attributed to declines in grass vigor as the nitrogen increment in the fertilizer rates declined. There were no differences in grass stands with fertility rates. Roughening either the topsoil or subsoil increased legume stands more than five-fold over smooth topsoil or glazed subsoil (Table 8). Legume and grass stands were poor on the smooth topsoil and glazed subsoil; roughening the soil surface had a substantially greater effect on plant populations than fertilizer rates.

These findings show that rough and loose grading of slope surfaces with or without topsoil should be implemented to provide favorable microenvironments for germination and seedling development to establish vegetative covers quickly for erosion control. Clods and undulations create mini-slopes that shade and slow wind movement at the soil surface as well as minimizing erosion by slowing water runoff.

Vegetative cover produced by roughened subsoils properly amended and mulched was equal to or superior to similarly treated topsoil. Available topsoil is often of low quality and fertility, requiring amendments, mulches, and seeds similar to those for subsoil to obtain satisfactory vegetative covers. The delays in seeding, weed seed contamination, and cost make topsoiling undesirable and unnecessary when subsoils are rough graded and suitable for plant culture. Subsoil material is generally suitable for culturing persistent legumes.

GENERAL SUMMARY AND CONCLUSIONS

The summary and conclusions are discussed in three sections as the objectives are given. These three sections are: 1) an interpretative review of present and past research for establishing vegetation in highway corridors; 2) an experiment on the influence of four moisture stresses and two temperatures on the rate of emergence of 12 grasses and legumes over time; and 3) experiments of establishing vegetation on clayey subsoils with and without topsoil and with roughened versus conventionally graded surfaces.

Section 1: Grading to leave smooth or glazed surfaces and a "finished" grading appearance, a common practice with cut slopes during highway construction in Virginia, often causes seeding failures. Water infiltration and adsorption on glazed surfaces are low resulting in poor seedling germination, growth and canopy development and potential erosion and pollution because of inadequate vegetative cover.

Stair-step or rough grading to leave loose surfaces or grooving of cut slopes create favorable microenvironments for rapid germination, growth, and plant succession to leguminous persistent canopies to arrest erosion. Such slope surfaces reduce the mulching and seeding rates and make plants more responsive to given rates of mulch, seed, and fertilizer. Rough grading practices do not increase construction costs and decrease costs of establishing and maintaining vegetation.

Slopes steeper than 2.5:1 should be stair-step graded. The vertical wall in the stair-step design should be no more than 50 cm, with the width of the horizontal step equal to or exceeding the height of vertical walls. Cuts 2.5:1 or flatter that are rough graded or tilled to leave furrows parallel to the road increase water infiltration and modify soil temperatures. Better vegetative covers have been obtained on rough tilled areas without mulch than on smooth areas with mulch. Excellent growth on loose, rough slope surfaces was attributed to seed and fertilizer coverage, increased water infiltration, reduced erosion, and a more favorable microenvironment than for smooth slopes.

Widening old highway corridors, especially secondary roads, often results in steep, smooth cut slopes. Grooving such slopes, with grooves 45 to 65 cm apart and 10 to 20 cm deep, has resulted in a four-fold increase of vegetation as compared to smooth surfaces. The grooves collect sloughing soil, seed, and soil amendments as well as water which enhances establishment of vegetative covers. Grooves are the least desirable of rough grading methods since smooth areas between the grooves are conducive to water flow off and erosion.

Protective vegetative covers are more easily established on fill than cut slopes due to less compaction of the rock and soil materials. Establishing grass and legume cover on tracked slopes was slower than for roughened slopes. Poor vegetative development on tracked fill slopes is attributed to compaction from cleats which inhibited water infiltration; this often causes severe erosion.

Fill slopes can be prepared in two ways to minimize erosion and hasten the establishment of vegetation: 1) let materials fall naturally and undisturbed as the lift is constructed; or 2) leave roughened surfaces with a sheeps foot roller.

Roughened subsoils in medians gave many fold better vegetative cover than seedings on glazed subsoils. Establishing a vegetative cover quickly in the roughened median reduced erosion as water infiltration was much better than for glazed surfaces. The moisture improvement and lower soil temperatures caused faster establishment of legumes.

Topsoil is unnecessary on roughened subsoils that are liberally limed and fertilized. Properly treated subsoils produced excellent vegetative cover and legumes as sericea lespedeza and crownvetch have persisted for many years without maintenance fertilizer. Topsoil is necessary in some xeric areas and where special vegetation may be desired.

Erosion control is achieved by establishing a vegetative cover quickly that develops into a persistent vegetation through plant succession. Obtaining vegetative covers depends on applying adequate soil amendments and adjusting the pH to a favorable level by liming. Subsoil and rock material on slopes in highway corridors of Virginia are nearly devoid of organic matter and nitrogen, low in calcium, magnesium and phosphorus, usually low in pH, and high in soluble aluminum. Low soil nitrogen causes slow growth and degeneration of grassy vegetation.

A 10-20-10 fertilizer at 1120 kg and lime at 5 metric tons/ha furnishes adequate amounts of nitrogen, phosphorus and potassium to promote plant succession from temporary grass to perennial grass to persistent legumes during a 2 to 3 year period when combined with other good cultural practices of slope preparation, seed mixtures, and mulches.

Nitrogen at rates higher than 140 kg/ha caused failure of legumes due to light and water competition from annual ryegrass and other aggressive grasses. The legumes currently used in highway corridors develop slowly and have high seedling mortality with high levels of nitrogen application.

Seedling survival and spread of crownvetch, flat pea, and perennial sweet pea was best when soils had a pH above 6.0 and high available phosphorus or when highly acid infertile soils had liberal applications of lime and phosphorus. Responses to potassium were generally low or nil. Sericea lespedeza growth responded to phosphorus when soils were very infertile.

In the Coastal Plain region, crownvetch and sericea lespedeza required 3 to 5 years for developing dense canopies as compared to 1 to 3 years in the Piedmont or Appalachian regions; conversely, results with flat pea are excellent and those with perennial sweet pea are promising. Flat pea crowded out dense stands of fescue in about 1 year in the Coastal Plains. All four of the persistent legumes generally developed good protective vegetation on various subsoils on slopes in the Piedmont and Appalachian regions. Flat pea generally developed a complete vegetative cover more rapidly than sericea, crownvetch, or perennial sweet pea.

Straw, woodbark, and woodfiber moderate soil temperatures and improve moisture relations and improve germination and seedling growth. Woodbark and straw are superior to woodfiber for erosion control for seedings during unfavorable seasons. Woodfiber at 840 kg/ha applied over straw gave prolonged stabilization under a wide array of climatic conditions and was especially suitable for winter or summer seedings. Woodfiber with straw aids in the establishment of vegetation by the added effects of another mulch. It was found that a simple two-step seeding operation--1) blowing straw on slopes, and 2) tacking the straw with a slurry of seed-lime-fertilizer and woodfiber--gave results similar to three-step operations--1) applying a seed-fertilizer slurry, 2) applying straw, and 3) applying woodfiber tack. The woodfiber does not create pollution and may be washed from buildings or sidewalks if the spray has been misguided. The straw-woodfiber combination maintained better cover and stability than the straw-asphalt combination.

Chemical binders alone have no mulch properties for moderating soil temperatures or conserving moisture and have usually resulted in vegetative covers similar to no mulch. The vegetation from woodfiber-chemical binder combinations was usually no better than for woodfiber alone. Poor results have been attained with nets on slopes for erosion control because of poor net-soil contact. Properly installed jute or excelsior matting is satisfactory for erosion control and vegetative establishment in median ditches with expected water flow.

Cereal rye, annual and perennial ryegrasses, German millet, and weeping lovegrass develop temporary vegetative covers quickly, lovegrass being persistent. Cereal rye and annual and perennial ryegrass seeded at heavy rates gave winter vegetative cover when seeded during late autumn, rye being best for mid-winter seeding. German millet and weeping lovegrass gave excellent cover for summer seedings when high temperatures and drought were encountered.

Seeding temporary species for initial vegetative cover concurrently with perennial grasses and legumes has usually given persistent legume covers at later dates. Summer seedings of German millet give excellent canopies for intercepting raindrops and slowing water runoff; later cool season species develop as frost kills the millet which then serves as an excellent in situ mulch.

Dense canopies of cereal rye killed with Paraquat and concurrently seeded with persistent legumes were conducive for developing crownvetch and flat pea cover. Temporary canopies of annual ryegrass, rye, or German millet serve for erosion control more effectively than mulches for temporary access roads or other areas where erosion control is needed.

Slopes with degenerating grasses along highways (interstate, primary and secondary) are potential sites for erosion. Crownvetch may be established in these sparse grass covers by applying phosphorus and lime with crownvetch seeds during a favorable seeding season. With sparse grass cover, light applications of nitrogen stimulate growth and persistence of grasses to avoid erosion. Woodfiber at 840 kg/ha with phosphorus and lime helps establish legumes when grass cover is 50% or less.

Section 2: The 12 species differed sharply in rate and total emergence. German millet and Abruzzi rye seedlings had high emergence 2 days after seeding; bluegrass and bermudagrass required 4 days for emergence under favorable conditions. Based on rate and total emergence the species were placed into three categories: aggressive species that had maximum emergence by day 6 included perennial and annual ryegrasses, weeping lovegrass, German millet, redtop, and Abruzzi rye; the intermediate species that had near maximum emergence by day 8 included crownvetch at 21 C, and creeping red fescue, Kentucky bluegrass, and Kentucky 31 fescue at both temperatures; and the non-aggressive species that had near maximum emergence between day 10 and day 13 included crownvetch at 28 C, sericea and common bermudagrass at both temperatures.

Rates and total emergence of species differed with moisture stress and temperature. German millet, Abruzzi rye and perennial ryegrass gave the fastest and highest emergence under the high temperature and -9 bars of soil water. The aggressive species, annual ryegrass and redtop, were no better than intermediate species under high moisture stress at 21 or 28 C, while weeping lovegrass maintained fairly high emergence rates but lower than rye, German millet and perennial ryegrass. The perennial cool season grasses and legumes generally required favorable moisture, -1/3 or -3 bars of soil water, for high and rapid emergence.

These data may be applied to designing seed mixtures for various seasons of seeding as described in the discussion.

<u>Section 3</u>: The population and height of plant species and subsequent vegetative covers obtained in two experiments were as good or better with roughened subsoils as for topsoiling the same subsoils; however, the vegetative cover for glazed subsoils as with conventional grading was very poor. With roughened subsoil, incorporation of lime

and fertilizer was no better than surface applications. The rapid establishment of vegetative cover on roughened versus glazed subsoils is attributed to favorable moisture from high infiltration encouraged by the low bulk density and increased porosity.

Application of topsoil to subsoils enhanced the physical properties by lowering bulk density and increasing total porosity, giving growth and vegetative covers similar to those for the roughened subsoils. Application of topsoil did not reduce fertilizer requirements as growth responses and vegetative covers were similar for roughened subsoils and topsoiling. Weediness tended to be severe on the topsoiled areas.

Hauling and spreading of topsoil often delays seedings that prolong bare slope exposure and may enhance erosion and cause failures in establishing satisfactory vegetative covers because of late seeding. Roughened subsoil with recommended soil amendments, seed mixtures, and mulches usually gives desirable soil cover at roughly 1/3 the cost of topsoiling.

LITERATURE CITED

Allmaras, R. R., A. L. Black, and R. W. Rickman. 1973. Tillage, soil environment, and root growth. In Conservation tillage. Soil Cons. Soc. Amer., Ankeny, Iowa. pp. 62-87.

Ayers, A. D. 1952. Seed germination as affected by soil moisture and salinity. Agron. J. 45:82-84.

Barkley, D. G., R. E. Blaser, and R. E. Schmidt. 1965. Effect of mulches on microclimate and turf establishment. Agron. J. 57: 189-192.

Baver, L. D., W. H. Gardner, and W. R. Gardner. 1972. Soil structure - evaluation and agricultural significance. In L. D. Baver (ed.), Soil physics. John Wiley and Sons, Inc. pp. 178-223.

Bicher, E., and C. Y. Ward. 1971. Roadside vegetation. Terminal report for Mississippi State Highway Department and Federal Highway Administration.

Blake, G. R. 1965. Bulk density. In C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger, F. E. Clark (ed.), Methods of soil analysis. Agronomy 9:299-314. Amer. Soc. Agron., Madison, Wisconsin.

Blaser, R. E. 1962. Methods of maintaining and reseeding deteriorated highway slopes. The Department of Landscape Architecture, Ohio State University, and the Ohio Department of Highways. pp. 87-93.

Blaser, R. E. 1962a. Soil mulches for grassing. National Acad. of Sci., Highway Res. Bd., Roadside Development. Wash., D. C. 1030: 15-20.

Blaser, R. E. 1963. Principles for making up seed mixtures for roadside seedings. National Acad. of Sci., Highway Res. Bd., Roadside Development. Wash., D. C. 1120:79-84.

Blaser, R. E., J. T. Green, Jr., and D. L. Wright. 1975. Establishing vegetation for erosion control in the Piedmont region. Chap. 7. Spec. National EPA Handbook on Erosion Control.

Blaser, R. E., and W. H. McKee, Jr. 1967. Regeneration of woody vegetation along roadsides. National Acad. of Sci., Highway Res. Bd., Roadside Development. Wash., D. C. 161:104-116.

Blaser, R. E., and H. D. Perry. 1975. Establishing vegetation for erosion control along highways in the Appalachian region. Chap. 8. Spec. National EPA Handbook on Erosion Control.

Blaser, R. E., T. Taylor, W. Griffith, and W. Skrdla. 1956. Seedling competition in establishing forage plants. Agron. J. 48:1-6.

Blaser, R. E., G. W. Thomas, C. R. Brooks, G. J. Shoop, and J. B. Martin. 1961. Turf establishment and maintenance along highways. National Acad. of Sci., Highway Res. Bd., Roadside Development. Wash., D. C. 928:5-17.

Blaser, R. E., and C. Y. Ward. 1958. Seeding highway slopes as influenced by lime and fertilizer and adaptation of species. National Acad. of Sci., Highway Res. Bd., Roadside Development. Wash., D. C. 613:21-39.

Blaser, R. E., and J. M. Woodruff. 1968. The need for specifying two- or three-step seeding and fertilization practices for establishing sod on highways. National Acad. of Sci., Highway Res. Record. Wash., D. C. 246:44-49.

Blaser, R. E., D. L. Wright, and H. D. Perry. 1975. Erosion control during highway construction. Rural and Urban Roads. 13(4):38-40.

Brooks, C. R., and R. E. Blaser. 1964. Effect of fertilizer slurries used with hydroseeding on seed viability. National Acad. of Sci., Highway Res. Record. Wash., D. C. 53:30-34.

Buckman, H. O., and N. C. Brady. 1969. Liquid losses of soil water and their control. In N. C. Brady (ed.), The nature and properties of soils. Macmillan Co., Collier-Macmillan, Ltd., London. pp. 209-240.

Burwell, R. E., R. R. Allmaras, and L. L. Sloneker. 1966. Structural alteration of soil surface by tillage and rainfall. J. Soil Water Cons. 21:61-63.

Carson, E. W., Jr., and R. E. Blaser. 1962. Establishing sericea lespedeza on highway slopes. National Acad. of Sci., Highway Res. Bd., Roadside Development. Wash., D. C. 1030:3-14.

Dickens, R., and H. P. Orr. 1969. Roadside vegetation and erosion control. HPR Report No. 44. Auburn University School of Agriculture, in cooperation with Alabama Highway Department and Federal Highway Administration.

Donald, C. M. 1963. Competition among crop and pasture plants. Adv. in Agron. 15:1-118.

Doneen, L. D., and J. H. MacGillivray. 1943. Germination (emergence) of vegetable seed as affected by different moisture conditions. Plant Physiol. 18:524-529.

Duell, R. W., and R. E. Schmidt. 1974. Grass: grass varieties for roadsides. Proc. 2nd Inter. Turfgrass Res. Conf. pp. 541-551.

Evans, W. F., and F. C. Stickler. 1961. Grain sorghum seed germination under moisture and temperature stresses. Agron. J. 53:369-372.

Fairbourn, M. L., and H. R. Gardner. 1975. Water-repellent soil clods and pellets as mulch. Agron. J. 67:377-380.

Foote, L. E., D. L. Kill, and H. Bolland. 1970. Erosion prevention and turf establishment manual. Office of Materials Construction Division, Minnesota Department of Highways.

Gardner, W. H. 1965. Water content. In C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger, F. E. Clark (ed.), Methods of soil analysis. Agronomy 9:82-127. Amer. Soc. Agron., Madison, Wisconsin.

Goss, R. L., R. M. Blanchard, and W. R. Melton. 1970. The establishment of vegetation on non-topsoiled slopes in Washington. Final Report Y-1009. Prepared jointly by Washington State Highway Commission and Washington State University Agricultural Research Center in cooperation with Federal Highway Adminsitration.

Greb, G. W., D. E. Smika, and A. L. Black. 1970. Water conservation with stubble mulch fallow. J. Soil and Water Cons. 25:58-62.

Green, J. T., Jr., R. E. Blaser, and H. D. Perry. 1973. Establishing persistent vegetation on cuts and fills along West Virginia highways. Final report for the West Virginia Department of Highways and the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. Project 26, Phase II.

Green, J. T., Jr., H. D. Perry, J. M. Woodruff, and R. E. Blaser. 1974. Suitability of cool and warm season species for dormant winter seedings. Proc. 2nd Inter. Turfgrass Res. Conf. pp. 557-568.

Green, J. T., Jr., J. M. Woodruff, and R. E. Blaser. 1973. Stabilizing disturbed areas during highway construction for pollution control. Final report for the Virginia Department of Highways, Virginia Highway Research Council, U. S. Department of Transportation, and Federal Highway Administration.

Helmrick, R. H., and R. P. Pfeifer. 1954. Differential varietal responses of winter wheat germination and early growth to controlled limited moisture conditions. Agron. J. 46:560-562.

Hendrickson, A. H., and F. J. Veihmeyer. 1941. Moisture distribution in soil containers. Plant Physiol. 16:821-826.

Hill, W. O. 1965. Direct seeding of shrubs and trees in soil and water conservation districts in the northeast. In H. G. Abbott (ed.), Direct seeding in the Northeast, a symposium.

Hottenstein, W. L. 1969. Highway roadsides. In A. A. Hanson and F. V. Juska (ed.), Turfgrass science. ASA Monograph 14:603-637.

Huck, M. G. 1970. Variation in taproot elongation rate as influenced by composition of the soil air. Agron. J. 62:815-818.

Hughes, T. D., J. F. Stone, W. W. Huffine, and J. R. Gingrich. 1966. Effect of soil bulk density and water pressure on emergence of grass seedlings. Agron. J. 58:549-553.

Hunter, J. R., and A. E. Erickson. 1952. Relation of seed germination to soil moisture tension. Agron. J. 44:107-109.

Jacobs, J. A., O. N. Andrews, Jr., C. L. Murdock, and L. E. Foote. 1967. Turf establishment on highway right-of-way slopes--a review. National Acad. of Sci., Highway Res. Record. Wash., D. C. 161: 71-103.

Kneebone, W. R. 1957. Selection for seeding vigor in native grasses under artificial moisture stress. Agron. Abstracts. p. 55.

Labanauskas, C. K., L. H. Stolzy, L. J. Klotz, and T. A. DeWolfe. 1971. Soil carbon dioxide and mineral accumulation in citrus seedlings (Citrus sinensis var.). Plant Soils 35:337-347.

Little, T. M., and F. J. Hills. 1972. Statistical methods. Agr. Ext., University of California. p. 50.

McCreery, R. A., E. G. Diseker, and R. M. Lawrence, Jr. 1975. Mulch treatments. GDOT Research Project No. 6907, Department of Agronomy, University of Georgia.

McGinnies, W. J. 1960. Effects of moisture stress and temperature on germination of six range grasses. Agron. J. 52:159-162.

McIntyre, D. S. 1958. Soil splash and the formation of surface crusts by rainfall impact. Soil Sci. 85:261-266.

McKee, W. H., R. E. Blaser, and D. W. Barkley. 1964. Mulches for steep cut slopes. National Acad. of Sci., Highway Res. Record. Wash., D. C. 54:35-42.

McKee, W. H., R. E. Blaser, A. J. Powell, Jr., R. B. Cooper, U. Yadar, and P. Bosshart. 1965. The establishing and maintenance of vegetation on various environments along interstate highways. Annual report, Virginia Agric. Exp. Sta., in cooperation with the Virginia

Council of Highway Investigation and Research and U. S. Bureau of Public Roads. p. 60.

McKee, W. H., A. J. Powell, Jr., R. B. Cooper, and R. E. Blaser. 1965. Microclimate conditions found on highway slope facings as related to adaptation of species. National Acad. of Sci., Highway Res. Record. Wash., D. C. 93:38-43.

Parker, J. J., Jr., and H. M. Taylor. 1965. Soil strength and seedling emergence relations. I. Soil type, moisture tension, temperature, and planting depth effects. Agron. J. 57:289-291.

Parks, O. C., Jr., and P. R. Henderlong. 1967. Germination and seedling growth rate of ten common turfgrasses. Proc. West Virginis Acad. of Sci. 39:132-140.

Perry, H. D., D. L. Wright, and R. E. Blaser. 1975. Project 40: Producing vegetation on highway slopes concurrently with and subsequent to highway construction. Final report submitted to West Virginia Department of Highways.

Phillips, R. E. 1968. Water diffusivity of germinating soybeans, corn, and cotton seed. Agron. J. 60:568-591.

Powell, A. J., Jr., R. E. Blaser, and R. E. Schmidt. 1967. Physiology and color aspects of turfgrass with fall and winter nitrogen. Agron. J. 59:303-307.

Powell, A. J., Jr., R. E. Blaser, and R. E. Schmidt. 1967a. Effect of nitrogen on winter root growth of bentgrass. Agron. J. 59: 529-530.

Richards, L. A., and W. E. Loomis. 1942. Limitations of auto-irrigators for controlling soil moisture under growing plants. Plant Physiol. 17:223-235.

Schmidt, R. E., R. E. Blaser, and M. T. Carter. 1967. Evaluation of turfgrass for Virginia. Res. Div., Virginia Polytechnic Institute and State University Bul. 12.

Schmidt, R. E., and R. E. Blaser. 1969. Ecology and turf management. In A. A. Hanson and F. V. Juska (ed.), Turfgrass science. ASA Monograph 14:217-239.

Shoop, G. J., C. R. Brooks, R. E. Blaser, and G. W. Thomas. 1961. Differential responses of grasses and legumes to liming and phosphorus fertilization. Agron. J. 53:111-115.

Smith, N. 1973. On preserving topsoil. In Conservation tillage. Soil Cons. Soc. Amer., Ankeny, Iowa. pp. 217-219.

Stolzy, L. H., J. Letey, T. E. Szuszkiwicz, and O. R. Lunt. 1961. Root growth and diffusion rates as functions of oxygen concentrations. Soil Sci. Soc. Amer. Proc. 25:463-466.

Taylor, H. M., and E. Burnett. 1964. Influence of soil strength on the root-growth habits of plants. Soil Sci. 98:174-180.

Taylor, S. A., and R. D. Jackson. 1965. Temperature. In C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger, F. E. Clark (ed.), Methods of soil analysis. Agronomy 9:331-344. Amer. Soc. Agron., Madison, Wisconsin.

Verghese, G. K., R. E. Hanes, L. W. Zelazny, and R. E. Blaser. 1970. Sodium chloride uptake distribution in grasses as influenced by fertility and complimentary ion competition. National Acad. of Sci., Highway Res. Record. Wash., D. C. 335:13-19.

Vomocil, J. A. 1965. Porosity. In C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger, F. E. Clark (ed.), Methods of soil analysis. Agronomy 9:299-314. Amer. Soc. Agron., Madison, Wisconsin.

Wanjura, D. F., and D. R. Buxton. 1972. Water uptake and radicle emergence of cotton seed as affected by soil moisture and temperature. Agron. J. 64:427-431.

Wanjura, D. F., E. B. Hudspeth, Jr., and J. D. Bilbro, Jr. 1969. Emergence time, seed quality, and planting depth effects on yield and survival of cotton. Agron. J. 61:63-69.

Willis, W. O., and M. Amemiya. 1973. Tillage management principles: soil temperature effects. In Conservation tillage. Soil Cons. Soc. Amer., Ankeny, Iowa. pp. 22-42.

Wischmeier, W. H. 1973. Conservation tillage to control water erosion. In Conservation tillage. Soil Cons. Soc. Amer., Ankeny, Iowa. pp. 133-141.

Woodruff, J. M., and R. E. Blaser. 1970. Establishing and maintaining turf on steep slopes along Virginia highways. Annual report for the Virginia Department of Highways and U. S. Bureau of Public Roads.

Woodruff, J. M., and R. E. Blaser. 1970a. Establishing crownvetch on steep slopes in Virginia. National Acad. of Sci., Highway Res. Record. Wash., D. C. 335:19-28.

Woodruff, J. M., and R. E. Blaser. 1971. Stabilizing disturbed areas during highway construction for pollution control. Interim report. HPR Code 0754, Department of Agronomy, Virginia Polytechnic Institute and State University, Research Division.

Woodruff, J. M., J. T. Green, Jr., and R. E. Blaser. 1972. Weeping lovegrass for highway slopes in the Virginias. National Acad. of Sci., Highway Res. Record. Wash., D. C. 411:7-14.

Wright, D. L., H. D. Perry, J. T. Green, Jr., and R. E. Blaser. 1975. Manual for establishing a vegetative cover in highway corridors of Virginia. Virginia Polytechnic Institute and State University, Blacksburg.

Zak, J. M., J. Troll, J. R. Havis, H. M. Yegian, P. A. Kaskeski, W. W. Hamilton, and L. C. Hyde. 1972. The use of adaptable plant species for roadside cover in Massachusetts. Final report, 23-R5-Roadside Development. University of Massachusetts, Amherst.

The vita has been removed from the scanned document

EROSION CONTROL WITH VEGETATION IN HIGHWAY CORRIDORS

by

David Lee Wright

(ABSTRACT)

Grading operations in highway corridors disturb the natural vegetation and land contours, thereby causing erosion and pollution. Minimizing erosion is predicated on the principle of maximizing water infiltration to reduce massive runoff of water. This depends on grading and soil preparation methods, augmented temporarily by mulches, but perfected by developing a vegetative cover quickly. The speed of developing a vegetative cover and shifts in plant biota to persistent covers depend on grading and subsoil preparation, soil amendments, mulches, and specially designed seed mixtures for seeding at various seasons. The management of these factors, through plant succession, results in persistent vegetative covers of legumes like crownvetch (*Coronilla varia* L.) or sericea (*Lespedeza cuneata* G. Don.), requiring little or no mowing or fertilizer maintenance. In difficult environments or in adverse seeding seasons, multi-step seeding and fertilization is usually required.

Erosion from slopes with sparse grassy vegetative covers in highway corridors can be minimized or eliminated by overseeding with persistent legumes and the application of needed soil amendments.

Topsoiling is not needed nor recommended on properly graded subsoil materials with adequate lime and fertilization, especially when the final botanical component is a persistent legume. Soil moisture was higher and temperatures lower for rough graded subsoil as compared to roughened topsoil, providing a more favorable microenvironment for plant growth with subsoils. Stands and vegetative covers were similar, although weed growth on topsoil materials was more severe than on subsoils. Roughened topsoil or subsoil surfaces sharply enhanced growth and vegetative cover as compared to the smooth topsoil or glazed subsoil. This was attributed to better infiltration and higher soil moisture, allied with improved bulk density and porosity.

Twelve species of grasses and legumes were grouped into three categories according to total emergence. Perennial (Lolium perenne L.) and annual (L. multiflorum Lam.) ryegrasses, German millet (Setaria italica L.), redtop (Agrostis alba L.), and Abruzzi rye (Secale cereale L.) had the highest rate and total seedling emergence with maximum emergence obtained by day 6 under favorable moisture conditions. Crownvetch at 21 C, creeping red fescue (Festuca rubra L.), Kentucky bluegrass (Poa pratenses L.), Kentucky 31 fescue (Festuca arundinacea Schreb.), and weeping lovegrass (Eragrostis curvula Schrad. Nees.) at both temperatures had intermediate rates and total emergence with maximum emergence obtained by day 8. Crownvetch at 28 C and sericea and common bermudagrass (Cynodon dactylon L.) at both temperatures had the slowest rates and least emergence, obtaining maximum emergence between days 10 and 13.