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# ROADSIDE VEGETATION ESTABLISHMENT BY SEEDING OF HERBACEOUS SPECIES UNDER SUBOPTIMAL CONDITIONS

J. B. Masiunas
P. L. Carpenter

PURDUE UNIVERSITY

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J. B. Masiunas

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Interim Report

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TO: H. L. Michael, Director
Joint Highway Research Project

FROM: P. L. Carpenter

April 6, 1982

Project: C-36-48H

File: 9-5-8

Attached is an Interim Report on the HPR Part II Study titled "Techniques to Increase Survival of New Highway Plantings". This Interim Report is the second one on the portion of the Study concerned with plant establishment by seeding. The Report is titled "Roadside Vegetation Establishment by Seeding of Herbaceous Species Under Suboptimal Conditions".

The Report is submitted for review and acceptance as partial fulfillment of the objectives of the Study. A very limited number of copies of the Report will be published using color photographs in some of the illustrations as they better illustrate the points being discussed. All published copies will not have such prints as their inclusion makes the copies very costly.

A Final Report on this portion of the Study is in preparation and will be available about June 1982.

Respectfully submitted,

P. L. Carpenter / HLM

P. L. Carpenter

PLC:ms

cc: A. G. Altschaeffl
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G. D. Gibson
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S. R. Yoder

INTERIM REPORT

# ROADSIDE VEGETATION ESTABLISHMENT BY SEEDING OF HERBACEOUS SPECIES UNDER SUBOPTIMAL CONDITIONS

by

John B. Masiunas
Philip L. Carpenter
Department of Horticulture
Purdue University

Joint Highway Research Project
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16. Abstract

In seeding trials, fall seedings performed better than spring seedings. Legume establishment was best in the spring, as long as adequate weed control measures were used.

The soil temperature of north and south facing slopes was strongly influenced by mulching. Straw mulching reduced surface temperatures by an average of 5°C. The north facing slope averaged 5°C cooler than the south facing slope and temperature differences due to mulching were not as great.

Laboratory studies on the effect of temperature on radicle (root) growth showed a difference between cool season (C-3) and warm season (C-4) grasses. The optimal temperature for radicle growth was lower for C-3 grasses, and no growth occurred at 37°C when compared to C-4 grasses. Alternating temperatures caused a stunting of growth compared to radicle growth under constant temperatures. Polyethylene glycol induced moisture stress also caused a decrease in the amount of radicle growth.

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# HIGHLIGHT SUMMARY

Seeding studies were conducted on two roadsides and one farm site to evaluate the effectiveness of various seed mixtures on the rapidity of establishment. Fall seedings performed better than spring seedings with the latter having severe weed problems. In June seedings seed mixtures containing warm season grasses and legumes provided the most rapid cover. The effect of treatment was not statistically significant. The effectiveness of mulches in improving seedling survival was also tested. Wheat straw performed best.

A soil temperature study was conducted on north and south facing slopes using mulched and nonmulched plots. The maximum temperature observed was 51°C at 2 pm on July 13 on the south slope's surface. A straw mulch modified the temperature by an average of 5°C. The north facing slope averaged 5°C cooler than the southern exposure. Differences between mulched and nonmulched plots on the northern exposure were not as great. *Coronilla varia* L. regrowth after hoeing occurred on the northern slopes but not the southern slope.

Laboratory studies were conducted using pregerminated seed of 12 common herbaceous erosion control species. In the first series of experiments seedlings were grown for 48 hours, and the increase in radicle length was measured. Measurements were made at 5°C increments between 12 and 37°C and at 47°C. Negligible growth occurred at 47°C. Radicle growth was slight between 12 and 17°C. Optimal growth occurred at 22°C for *Lolium multiflorum* Lam., at 27°C for *Bromus inermis* Leyss., and at 32°C for *Panicum virgatum* L., *Andropogon gerardii*

Vitman., and *Lespedeza stipulacea* Maxim. In the other species optimal growth occurred over the 22-32°C range. Radicle growth at 37°C was significant for C-4 warm season grasses, while for the C-3 cool season grasses no growth occurred.

Seedlings of *L. multiflorum*, *L. stipulacea* and *Bouteloua curtipendula* (Michx.) Torr. were grown in 12 hour alternating temperature regimes of 10/18°C. 18/26°C, 24/32°C, 30/38°C and 36/44°C. The optimum radicle growth of *Lolium multiflorum* was at 24/32°C and 30/38°C, and for *B. curtipendula* it was in the 30/38°C regime. Radicle growth of all species was stunted compared to that occurring at the constant temperatures of the previous experiment.

Growth of the same three species was also studied in 3 different concentrations of polyethylene glycol 20000 (20g solute/100 ml distilled water, 25g solute/100 ml distilled water, and 30g solute/100 ml distilled water) at 22, 27, 32, and 37°C. Radicle growth rate decreased as the concentration of poyethylene glycol increased. Polyethylene glycol induced osmotic stress also caused a shift in temperature at which optimum growth occurred. Optimum temperature for radicle growth was increased from 22°C to 27°C for *L. multiflorum* and decreased for *B. curtipendula* and *L. stipulacea* from 27-37°C to 27-32°C.

# INTRODUCTION

In establishing mixtures of herbaceous species along roadsides seeding times do not always coincide with the optimal time for germination and growth (Duell, 1969). It is especially hard to successfully establish cover in late fall or in late spring to early summer. During both these periods germination may occur, but subsequent conditions are often unfavorable for continued growth. Thus seedling mortality is high (Green et al., 1974).

During early summer and late fall, temperatures are often extreme, especially for soil surface layers in which seeds actually germinate (Blaser et al., 1961). Besides temperature being a problem, moisture availability varies greatly depending both on temperature and number of sunny days. Thus although conditions allowing germination may occur during late fall or late spring to early summer, environmental conditions must remain favorable for subsequent seedling growth (Curry, 1980).

Disparate groups of grasses can be expected to perform differently during various seasons. This has led to the division of grasses into two categories, cool and warm season, based on observations of when their growth occurs. Warm season grasses could have promise during the critical late spring to early summer periods.

Inclusion of legumes in seeding mixtures is important for long term coverage and ease of maintenance. Commonly used legumes have a low maintenance requirement, but are also slow to establish (Wright et al., 1978a). Thus, it is important to select species whose growth is favored by the prevailing environmental conditions present.

The objectives of these studies were to determine the following:

- The ability of various mixtures of herbaceous species to establish during late fall or spring.
- The effect of seed treatments, fertilization, and mulch on establishment of seeding mixtures.
- The persistence of herbaceous vegetation along highways and at an experimental farm location.
- Temperature conditions present on north facing and south facing highway slopes during the summer in Indiana.
- Radicle growth of common erosion control species in constant or alternating temperatures.
- Effect of the interaction of temperature and polyethylene glycol-induced moisture stress on radicle growth of selected species.

# CHAPTER I

# REVIEW OF LITERATURE

## The Importance of Vegetative Cover Establishment on Roadsides

Erosion control on roadside slopes has been a major problem since the 1920's when the first extensive system of all-weather road surfaces was established (National Research Board, 1970). Since then road construction has reshaped thousands of acres annually, exposing subsoils whose properties were generally unfavorable to plant growth (Turelle, 1973).

In providing erosion control it is of major importance to rapidly establish a vegetative cover (Duell, 1969). Economic considerations often determine the plant cover to be established. The considerations include a desire to protect the investment made in the road surface and the surrounding drainage facilities (Foote and Kill, 1968). Recently, ease of maintenance has become important in the selection of vegetation to use. Because of maintenance, departments now prefer legumes, like *Coronilla varia*, in many slope situations. Also, with a two or three cycle mowing regime, low growing grasses such as some varieties of *Poa pratensis* are desirable (Morre, 1977; Daniel and Michael, 1977).

Problems remain in establishing vegetative cover, which is the critical phase in slope stabilization (Duich, 1964; Beard et al., 1971). Establishment problems exist because of the vast array of microclimates and the physiographic and biologic limitations of the plant species in use (Donahue and Bennett, 1975). Thus, the proper plant species, the needed amounts of nutrients, the physical and chemical structure of the soil, the microclimate and even the engineering features must be manipulated to rapidly establish vegetative cover (Foote et al., 1978).

Besides requiring a definite knowledge of both plant and environment parameters, long term planning is needed because severe erosion can occur if perennial vegetation is declining, during the second or third year (Jensen, 1977). This decline and subsequent failure of the vegetative stand coupled with failures that occur in the period between six weeks and a year lead to large amounts of erosion (Mausbach et al., 1972). According to Diseker and Richardson (1961), the worst time period for erosion is March, April and early May when it is hard to establish vegetative cover on roadsides, and frost action and slumping are most active. Thus erosion can result in loss of up to several hundred cubic yards of material per exposed acre (Turelle, 1973; Diseker and Richardson, 1961).

## Environmental Factors Affecting Vegetative Cover

Many roadside microclimatic factors affect the attainment of vegetative cover (Stark, 1966). According to Jensen (1977) factors affecting vegetation establishment can be grouped into the three following categories: lack of available soil moisture during the critical period, failure to stablize the seedbed, and failure to provide a suitable protective microclimate for developing seedlings.

Soil moisture is a major factor affecting the growth and survival of grass seedlings (Rosenthal, 1976). Soil moisture, soil temperature and light intensity are interdependent, thus, determination of any one factor as being the most important is superfluous. Thermal conductivity and volumetric heat capacity of the soil depend upon soil moisture content. Soil temperature influences the evaportion rate of water. Radiation impeding on the soil surface causes changes in both moisture content and temperature of soil (Denmead, 1972; Unger, 1978). Interations between light, moisture and temperature were most evident at the soil surface. Ash et al. (1975) found that by the 15 cm depth, fluctuations of both moisture and temperature were no longer of an amplitude to affect root growth of Festuca arundinacea.

The importance of soil moisture should not be underestimated, because as Asher and Ozanne (1966) stated, "if a seedling's growth was to proceed unchecked from germination onward, a continuous supply of moisture is needed." During seeding of roadside slopes, unless some modification of the site is undertaken, the soil surface is likely to be droughty (Spedding and Diekmahns, 1972). Because of this, conditions for surface seeded or shallow seeded plants are much more severe than those experienced by more deeply buried seed (McWilliam and Dowling, 1970).

Walter and Jensen (1970) stated that soil moisture can be readily modified to achieve optimal levels for plant growth. Two methods were used in modifying the moisture content of highway slope soils. One method involved establishing a temporary nurse crop using an annual species from either the Secale or Lolium genera (Carpenter et al., 1976; Donahue and Bennette, 1975). Nurse crops stabilized the critical area, but were competitive with more permanent species. Another method of modifying soil moisture and stabilizing critical sites was by using a mulch. The advantages of a mulch have been discussed by various authors, including Gilbert and Davis (1967), Carpenter (1975), Carpenter et al. (1976), USDA (1967), Shearman et al. (1979) and Barkley et al. (1965). All have shown that adequate mulching modified soil temperature, conserves moisture and prevents crusting. Thus it moisture content and temperature of soil (Denmead, 1972; Unger, 1978). Interations between light, moisture and temperature were most evident at the soil surface. Ash et al. (1975) found that by the 15 cm depth, fluctuations of both moisture and temperature were no longer of an amplitude to affect root growth of *Festuca arundinacea*.

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A mulch modifies the soil temperature of the root zone of the plant by conserving water loss. Also, the soil temperature has a direct effect on water absorption by roots and on the moisture available to them. Davidson (1969) demonstrated this with *Eragrestis curvula*, *Lolium perenne*, and *Poa pratensis*. All plant species had optimum soil temperature ranges for various plant functions (Unger, 1978; Ohlenbush, 1966). Deviations from these optimal, especially the extremes, reduced seed germination and plant growth (Chang, 1968). Thus, soil temperature was a major environmental factor governing development of plants found in a particular area, and was more ecologically significant than was air temperature (Johnson et al., 1965; Chang, 1968).

Soil temperature varies in both a diurnal cycle and a seasonal trend. Temperature of the soil surface was coldest in the early morning and the warmest in the early afternoon. Rosenburg (1974) stated that the warmest soil temperatures lag behind the peak time for incoming radiation due to the balance between incoming and outgoing radiation. The seasonal trend was approximately in phase with the level of incoming radiation. As soil depth increases, maximum soil temperatues are reached later in the year and the seasonal changes are smaller (Russell, 1973; Cooper, 1961).

Seasonal trends are affected by the aspect of the slope. On north and south facing roadside slopes, microclimate extremes varied from cool and moist at the bottom of the north slope to warm and dry at the top of a south slope (McKee et al., 1965). Cooper (1961), found that summer temperatures were consistantly higher by 4-5°C on south facing slopes. The higher temperatures encountered on southern exposures were due to higher light energy intercepted and heating of those slopes (Mckee et al., 1965; Duell, 1969). Maximum interception of solar energy occurs when solar radiation strikes at a right angle to the soil surface (Johnson et al., 1965). On overcast days, differences were not as great between north and south facing slopes because there are no direct solar effects (Chang, 1968). Establishment failures occur more frequently on south facing slopes than on north facing slopes, because of moisture and temperature differences (Iurka et al., 1955; Walker, 1964; Richardson et al., 1963).

Besides problems with moisture and temperature during highway slope seeding, the physical properties of the soil also can cause seeding failures. Slope angle and fertility of subsoils encountered are important in determining the success of seeding. Soil materials are often finely divided and readily form a crust, thus preventing the penetration of seedling roots (Jackobs et al., 1967). Also, soil nutrients and soil pH contribute to the success of a seeding (Palazzo and Duell, 1974; Foote and Johnson, 1965). Sodium chloride and calcium chloride which are used for deicing, can accumulate to toxic levels. And soil salinity tends to decrease the availability of water (Berstein, 1958). Thus according to Duell and Schmit (1975), frequently poor grass performance along roadsides may be attributed in part to soil conditions that can be amended.

The Characteristics Desired in Herbaceous Species

In deciding which plant species to use for a given site, many plant characteristics must be considered. A plant must have the ability to thrive under conditions present at the site (Donahue and Bennett, 1975). As McKell (1972) noted, differences among grass species are well known and have been attributed to differential plant response to environmental conditions. Plant establishment is especially dependent on microclimate (Blaser and Ward, 1958; Foote and Kill, 1968). Summer et al. (1972) in studying the establishment of a *Trifolium* sp. found that the successful introduction and persistence of a species depended on an understanding of the interactions of the plant with its environment. Thus, the ability of plants to grow in an environment was determined, to a great extent, by the inherent characteristics of the plant and their expression in a given situation (Turelle, 1973).

Sprague (1943), found that the effects of weather were critical during the period of germination and early seedling development in determining species survival. This is manifested in the effect of seeding date on the successful establishment of herbaceous species. Weather conditions encountered are complicated because seedings are often made over an extended time period as construction disturbances of the site proceed and erosion control becomes critical (Laskey and Wakefield, 1978). Federal law now requires that sites be seeded within 30 days after construction is completed (Green et al., 1974). Thus seeding cannot be delayed until the season is favorable for establishment of permanent vegetation.

Anslow and Green (1967) concluded with *Lolium perenne* and *Festuca arundinacea* that grass growth follows different annual patterns. Thus the season of seeding is important. Wray (1974) found similar results, but noted that a particular grass species has an individual growth pattern.

## Warm Season and Cool Season Grasses

Since grasses and legumes are the most economical means of preventing or controlling erosion, their growth has to be encouraged by selecting the species most adapted to the location (Foote and Kill, 1968). Evans et al. (9164) noted that festucoid perennial grasses (grasses of the subfamily Pooideae) grew relatively well in low temperatures, and had an optimal temperature for growth below 27°C. Festucoid grasses are included in the traditional range management classification of cool season grasses. Cool season grasses start growth at 5-7°C, have a temperature maximum for growth between 29-33°C, and remain semi-dormant during hot dry periods (Vengris, 1969). Warm season grasses are the other category in the range management system. Their growth does not start until soil tempertures approach 16°C, and they are unchecked by hot weather as long as water and nutrients are available (Vengris, 1969).

The category in which a species belongs is determined to a large extent by the climate of its origin (Foote and Kill, 1968). Cooper (1963) lists two major types of environment from which grass species originated. The first is the Mediterranean environment. Here the major limiting fator is a summer drought, and winter is the most favorable growing season. Many of the more common cool season species have originated in this type of environment (Hartley and Williams, 1956). The other type of environment is a continental climate in which cold temperatures are limiting, growth and often seed dormancy prevents autumn germination (Cooper, 1963). Many of the warm season species originated in this type of climate. Thus the choice of which type of grass to use is important. If a cool season grass is not strong and vigorous by summer, it will be invaded by summer annuals, while warm season grasses are apt to be invaded by winter annuals (Foote and Kill, 1968).

## C-3 andC-4 Grasses

The photosynthetic pathway of a grass seems to be important in determining seasonal growth patterns. Williams and Markley (1973) stated that plants with different biochemical pathways have different physiological responses to their environment. It is probable that the growing season of grasses with a 3-carbon photosynthetic pathway (C-3) coincides with cool moist months, whereas the physiological traits of 4-carbon photosynthetic pathway (C-4) grasses allows them to grow during hotter drier months (Waller and Lewis, 1979; Williams and Markley, 1973). In support of this idea Teeri and Stowe (1976) found that high minimum temperatures during the growing season strongly correlates with the relative abundance of C-4 grass species in a regional flora. Locations with normal July minimum temperatures below $8^{o}$C had few or no C-4 grass species. Many tropical C-4 species are unable to withstand cold temperatures. This is thought to be due to failure of chilling sensitive C-4 grasses to hydrolyze and translocate starch on cold nights (Ku et al., 1978).

Besides differences in seasonal growth patterns, C-4 grasses are found on drier soils than are C-3 species (Teeri and Stowe, 1976). This characteristic is important in highway slope seeding. Thus, McKee et al. (1965) observed estalishment of Cynodon dactylon, a C-4 grass, on a south slope and Festuca arundinacea, a C-3 grass, on the opposite north slope.

The seasonal growth pattern of a grass is related to its appearance, which according to Mayer (1972) and Vengris (1969) is an important consideration. Because of low maintenance programs now in use by the Indiana State Highway Department, a grass having a low compact uniform growth without unsightly seedhead formation is desirable (Daniel and Michael, 1977). Also the longevity of the species, its ability to withstand the specialized management practices employed, and its resistance to disease and pests affect appearance.

## Plant Vigor

Fast emergence and establishment is important in determining which plants to use at a site. Related to rapidity of emergence is the seedling vigor, Duell andSchmit (1974) suggested that seedling characteristics affect subsequent plant develoment especially in unmowed turf. The importance of seedling vigor in subsequent plant establishment depends on the other species present. Foote and Johnston (1965) found that Coronilla varia has poor seedling vigor, with attainment of complete cover taking 2-3 years, yet once established it has excellent erosion control characteristics. There is considerble variation in seedling vigor among varieties of legumes, especailly Lotus corniculatus (Seany and Henson, 1970).

Seedling vigor, rate of moisture imbibition, and the rate of germination all determine rate of emergence (Wright et al. 1978b). According to Duell and Schmit (1974), rate of emergence, although it does effect the ease of establishment, is too often stressed by many researches. Thus, species like Festuca arundinacea are often suggested, without consideration of their maintenance requirements Duell, 1969).

Root characteritics of a given species are also important. The soil binding ability of a root is a major consideration in erosion control (Kislev et al., 1979). The rate of root growth determines the ability of a plant to obtain moisture (Briske and Wilson, 1978). How deep a plant is rooted determines its soil holding capacity. Thus, Coronilla varia and Medicago sativa are popular because their deep roots serve to prevent surface creep types of erosion (Zak et al., 1972b).

A major consideration in deciding what species to seed in how long it can survive on the roadside. Annuals that develop late in the spring (summer annuals) and die with the first frost offer little protection during most of the year and compete with permanent plants (Hottenstein, 1969). Competition is especially important when legumes are used for permanent establishment. Zak et al. (1972b) had a problem with competition when using the winter annual, Lolium multiflorum with the legume Coronilla varia. The annual established rapidly, but inhibited C. varia growth, so when L. multiflorum died, a permanent species was not present to replace it.

## Common Erosion Control Species

Carpenter et al. (1976) pointed out that along Indiana roadsides the number of legumes and grasses used is limited. Thus, rapid and complete cover is not always obtained. Roadside seeding contracts typically name only the species and not the variety to be used (Duell and Schmit, 1975). If no variety is stated, the contractor's natural inclination is to use common types because they are usually cheaper (Duell and Schmit, 1974). For example if the variety of *Poa pratensis* is not specified then the seed lot is likely to be Newport or some other high seed yielding variety that did not pass purity standards (Duell and Schmit, 1975).

## Cool Season Grasses

Two types of cool season grasses were used on highway slopes: annual species for temporary quick cover and perennial species for intermediate to long term cover. The most commonly used annual species is *Lolium multiflorum*. Its growth occurs in the early spring and late autumn. *L. multiflorum* only flourishes in fertile nonacidic soils (Hanson et al., 1969; Vengris, 1969; Spedding and Diekmahns, 1972). A major problem is competitiveness toward other species in a mixture (Wright et al., 1978a; Spedding and Diekmahns, 1972). The second category of temporary grasses are the *Secale* spp. including *Secale cereale* 'Abruzzi'. They are less competitive than are *Lolium multiflorum* (Richardson and Diseker, 1961).

Numerous perennial grasses have been used for seeding. Two popular cool season perennial grasses for slope seeding are *Festuca arundinacea* and *Festuca elatior* 'Arundinacea' (Kentucky 31 tall fescue). *F. elatior* `Arundinacea' obtains better coverage of the ground than does *Dactylis glomerata* and *Bromus inermis* (Richardson and Diseker, 1961; Dieseker and Richardson, 1962). *F. elatior* `Arundinacea' is a bunch grass, but is not as aggressive as the *Lolium* spp. Its establishment the first year is mediocre, although Carpenter et al. (1976) gave it a high rating by the second year. *Festuca* spp. prefer cool dry slopes, but will tolerate soils ranging from droughty to poorly drained (Augustine, 1967). They resist high temperatures, heavy wear and have a strong fibrous root system that binds and holds the soil in place (hanson et al., 1969; Vengris, 1969).

*Poa pratensis* is another popular cool season perennial grass. It requires a more fertile soil and less extreme moisture conditions than do *Festuca* spp. *P. pratensis* is the most popular turf grass species in use (Younger, and Nudge, 1976). The Indiana State Highway Department found that *P. pratensis* was the dominant grass on roadsides, and tried to select varieties that are easily maintained (Daniel and Michael, 1977). Two varieties are popular with the Indiana State Highway Department. The first popular variety is `Bark', which was first selected by the Minnesota Agriculture Experiment Station because of its resistance to rust, its superior seedling growth and its vigor (Hanson, 1959). The second variety, just introduced, is `Wabash', which was selected at Purdue University because of its rapid and agressive rhizome growth, its low growth habit and its plant disease resistance (Daniel and Michael, 1977).

*Poa pratensis* is fine textured and produces a dense sod under favorable conditions (Hanson et al., 1969). It is relatively resistant to dry soils but requires moderate fertility and a relatively high phosphorous level (Carroll, 1943). Duell and Schmit (1974) found *P. pratensis* emergence and establishment barely adequate on less productive sites and complete soil coverage was never obtained, even with additional fertilizer.

*Lolium perenne* contains many ecotypes and cultivars (Spedding and Diekmahns, 1972). *L. perenne* is a very aggressive species, which did not give adequate cover until the second year in a study by Carpenter et al. (1976). Satisfactory establishment of *L. perenne* is dependent on adequate soil moisture (Spedding and Diekmahns, 1972). *L. perenne* commonly persisted only two to three years under no mow, low fertilization management. Its initial competition with less vigorous seedlings resulted in appreciably weaker stands of *Festuca rubra* or *Poa pratensis* (Duell and Schmit, 1972; Duell and Schmit, 1974).

The use of *Festuca rubra* is gaining popularity. Duell and Schmit (1974) in New Jersey found that spreading fescues reduced the amount of maintenance that is required. *F. rubra* requires good to moderate drainage and grows on poor, droughty or acid sites (Hanson et al., 1969). *F. rubra*, due to its tolerance of shade is often included in mixtures with *Poa pratensis*.

*Bromus inermis*, *Agrostis alba* and *Dactylis glomerata* are also popular in roadside slope seeding. But these species are neither as persistent as other common species nor can they supply cover as rapidly (Richardson and Diseker, 1965). *B. inermis* is the best of three; it is a coarse-textured sod forming grass whose major region of adaptation corresponds to the corn belt. It is extremely resistant to drought and high tempertures (Hanson et al., 1969).

## Warm Season Grasses

Warm season grasses are also used in controlling roadside erosion. *Eragrostis curvula* is often used as a nurse crop for spring seedings of *Coronilla varia* (Zak et al., 1976; Richardson and Diseker, 1961; Woodruff and Blaser, 1970; Richardson et al., 1970). *E. curvula* used for this purpose is seeded at a low rate with a low nitrogen level to prevent it from smothering slower growing species (Richardson and Diseker, 1961; Richardson et al., 1970). *E. curvula* germinates swiftly, obtaining rapid cover and slope protection during the summer period (Woodruff et al., 1972). There are advantages in using *E. curvula* as a cover crop for slower growing legumes. It has an erect growth habit which permits considerable light penetration into the canopy. Also *E. curvula* starts growth later in the spring than do most legumes. *E. curvula* is killed during most winters in Indiana. Thus, if permanent species have not established, then cover will depend on *E. curvula* reseeding each year (Hanson et al., 1969).

Prairie grasses are gaining popularity in Indiana and neighboring states for erosion protection. Robocker and Miller (1953) found that certain species native to the tall grass prairies of the eastern Great Plains and the north Central States are outstanding for erosion control and restoration of soil surfaces. Prairie grasses are particularily useful in areas of high erosion potential and on droughtly soils of low fertility (Aikman, 1960). Thus, they are ideal for use along roadsides (Dolling and Landers, 1969).

Two species that have received extensive testing for highway slope use are *Sorghastrum nutans* and *Andropogon scoparius*. McCreey et al. (1975) in establishment studies on roadsides in Georgia found that *S.*

*nutans* was too tall for use on shoulders or front slopes, and it attained adequate coverage at a relatively slow rate. Thus its widespread use along roadsides was extremely questionable. McCreey and Spaugh (1977) reported that *A. scoparius* showed an excellent potential for highway seeding, especially with its adaptation to the drier environments of Texas, Oklahoma, and Kansas.

*Bouteloua curtipendula* and *Bouteloua gracilis* are used extensively to control erosion in the western Great Plains. *B. curtipendula* is often found in association with *Andropogon* spp., on more favorable locations, and is replaced by *B. gracilis* on the drier, droughtier sites (Hanson et al., 1969). A problem with *Bouteloua* spp., especially *B. gracilis* is that the crowns are near the soil surface. If adventitious roots do not extend from the crowns before the seedling is nine weeks old, then it will die (Hyder et al., 1975).

## Legumes

Legumes are often used for seeding highway slopes. *Coronilla varia* is the most popular legume for use on infertile, easily eroded slopes. According to Ruffner (9164), within its adaptable limits, *C. varia* is far superior to any other herbaceous or woody plant in producing continuous cover with a minimum of man hours required for establishment. *C. varia* persists on well drained calcareous soils (Hawk and Shrader, 1964; McKee and Langile, 1967). *C. varia* has a densely branching root system, and a greater proportion of its root network deeper in the soil profile (Duich et al., 1955; Zak et al., 1972a). A deep root system insures better soil binding, especially on slopes where breakouts of subsoil water are a problem (Foote and Johnson, 1965). Penngift, which was released in 1954 by the

Pennsylvania State Agricultural Experimental Station, is a popular variety because of its seedling vigor (Baylor et al., 1969; Foote and Johnson, 1965). The biggest problem with C. varia is that it requires at least three years to become established under conditions commonly occurring along highways (Ruffner, 1964; Button, 1964; Carpenter and Hensley, 1976). Other problems are a high percentage of hard seed, poor inoculation and competition from grasses and weeds are often severe. Also adequate cover and persistence are obtained only on soils of pH above 5.5, with high potassium levels (McKee and Langile, 1967).

Two other popular leguminous species are Medicago sativa and Lotus corniculatus. The root system of M. sativa, with a stout tap root and a few large, lateral roots, has excellent soil holding capacity (Spedding and Diekmahns, 1972). Also M. Sativa has better emergence through a soil surface crust than do most other legumes (Jensen et al., 1972). A problem with M. sativa is its persistence. Carpenter and Hensley (1976) found that M. sativa was declining and C. varia was taking over in the third year after seeding. A popular variety of M. sativa is Vernal which is bred and recommended for use in humid northern areas of this country (Ueno and Smith, 1970). Lotus corniculatus is better adapted than C. varia to less permeable, poorly drained soils (Hawk and Shrader, 1964; Hawk, 1964). Although, L. corniculatus is useless on unfertile, droughtly subsoils, its drought tolerance is improved if the soil is adequately limed and fertilized (Duich et al., 1955; Ruffner, 1964; Wheaton, 1965). L. corniculatus develops a strong tap root with numerous lateral branches (Wheaton, 1965; Seany and Henson, 1970). It possesses little competitive ability, thus establishment is irregular. It should be used in simple mixtures with nonaggressive species (Duich et al., 1955; Seany and Henson, 1970; Cheverett et al., 1960). The lack of competitive ability has impeded the widespread use of L. corniculatus (Twamley, 1967).

Other legumes have been tried for roadside seeding, including clovers (Trivolium spp.), but they lack persistence under conditions encountered on Indiana roadsides. Another popular leguminous genus for erosion control is Lespedeza. Both are used only as nurse crops, because they are not winter hardy in Indiana.

## Designing Seeding Mixtures

Very seldom is just a single species seeded for highway slope erosion control, rather seeds of selected species are mixed together. Chances of obtaining cover with a mixture of herbaceous species are improved. Green et al. (1974) suggested using mixtures of Secale cereale `Abruzzi´, Festuca elatior `Arundinacea´, and Festuca rubra to obtain vegetative cover under low temperature conditions in Virginia.

The germination, growth and survival of grasses and legumes differ with the microclimate of a seedling community. Thus the best situation is to alter mixtures for the conditions expected (Blaser, 1962).

In designing a seeding mixture, the species included in the mixture should provide the best appearance for most of the year with the least amount of maintenance (Duell and Schmit, 1974). Carter et al. (1974) felt that both the permanence and ability to establish rapidily are important considerations in choosing herbaceous species. The best mixtures contain only selected varieties from a few species (Duell and Schmit, 1974; Blaser, 1962). The use of a mixture serves to broaden the genetic base, which increases the probability of obtaining pest resistance, and tolerance to environmental stresses (Neihaus, 1976). There are wide variations present both interspecifically and intraspecifically, and these are important in the design of roadside seeding mixtures, because a fairly close correlation exists between the genetic variation within a species and the spatical and temporal variation within the environment (Niehaus, 1976). Rhodes (1970) demonstrated the importance of genotypic variation when he found that the most productive mixtures of *Lolium perenne* included two phenotypes, one was of prostrate habit, the other erect.

The tendency on old highway sites is plant succession leading to a diversity of plant material. Thus, Jensen and Sindelar (1979) felt that it is desirable to include the climatic species of an area in a planting. Seeding mixtures which include climatic species tend to contain many species, and are referred to as "shotgun mixtures" (Duell, 1969). They are used in the hope that at all sites some species will be sufficiently adapted to provide plant coverage (Duell, 1969). There is a large magnitude of seedling mortality in the grasses as Johnston (1961) discovered with a simple mixture containing *Festuca scabrella*, *Danthonia parvyi* and *Bromus pumpellianus*. Seedling mortality is especially pronounced in late fall seedings and is increased by the complexity of a mixture (Green et al., 1974).

## Competition

A major problem with seeding mixtures is seedling mortality due to competition. Competition among seedlings is important in establishing the desired species (Blaser et al., 1961). They stated that certain plant species were aggressive toward other species because of differences in emergence and subsequent rates of seedling growth. In contrast, Donald (1963) reported that there is lack of competition at the seed or seedling stage. Laskey and Wakefield (1978) stated that Lotus corniculatus is an example of a species that is adversely affected by competition. There is an adverse effect of competition on the growth of other legumes including Medicago sativa (Allison, 1972). Some mixtures of legumes and grasses are more compatible than are other combinations (Chamblee, 1958).

Competition arises from many plant interactions. Two types of plant interactions are important. Competition for light involves any factor affecting stature or the ability of a species to shade differentially in relation to its neighbors (Rhodes and Stern, 1977). Ludow (1977) stated that the survival and success of an individual grass plant depended on how well it intercepted, competed for and responded to light. A factor of importance in competition for light among seedlings or mature plants is the photosynthetic pathway a plant possesses. Because a C-4 plant does not become light saturated at full sunlight it has an advantage where high light intenesities are encountered such as on south facing slopes (Ludlow, 1977).

Plant interactions involving the root system also occur. Root competition was entirely responsible for the suppression of Festuca spp. when grown in association with Lolium perenne (Rhodes, 1968; Crocker and Martin, 1964). In seedling development competition below ground is more important than competition above ground (Snaydon, 1977). Below ground competition usually involved two factors, water and nutrients (Roberts and Olson, 1942; Donald, 1963). According to

Hall (1977), species differ in their ability to absorb a particular resource such as water or nutrients due to differences in root distribution.

The importance of competition in determining the composition of the vegetative cover on a highway slope should not be underestimated. Evans and Young (1972), stated that competition determined the relative ecological structure of grassland communities. In grass seedings about ten percent of the plants survive the establishment year (Snaydon, 1977). In mix cropping of grasses and legumes the degree of success of the mixture is dependent on the compatibility of the associated plants (Roberts and Olson, 1942). Turkington et al. (1977) found *Medicago sativa* never in association with *Trifolium repens*, whereas *M. sativa* was found in association with three grasses, each of which occupied different soil environments.

## Stages of Mixture Establishment

In designing a seeding mixture, it is common to plan for several stages of establishment (Wright et al., 1978b). Thus, a seedling mixture usually contained annuals for rapid establishment, with perennials and self seeding annuals for permanent establishment (Carter et al., 1974). In the primary stage mulch protects the bare soil until temporary species can become established. The temporary species can be a legume such as *Lespedeza stipulacea*, which provided a fast inital cover for erosion control (Daniel and Freebourg, 1980). Problems can occur if a high seeding rate of the temporary species are used (Iurka et al., 1955). Cullen (1964) reported mixtures containing high rates of *Lolium multiflorum*, a popular temporary species, were the most productive mixtures the first year. Later they were not and undoubtedly the presence of *L. multiflorum* led to the suppression of more slowly establishing species. These temporary species, although optimally adapted for establishment under severe conditions are poorly adapted to perpetuate themselves (McIntosh, 1970).

During the second stage, temporary vegetation is replaced by a perennial grass. The three perennial grasses commonly used are *Festuca arundinacea*, *Poa pratensis*, and *Festuca rubra*. They can be the base grass of a seeding mixture if the soil is fertile (Bowmer, 1967). But their establishment is slower than companion or temporary grasses (Blaser, 1962; Bowmer, 1967). Besides maintaining these grasses through soil fertilization two other alternatives are possible. One alternative is to allow natural vegetation to return. A serious drawback occurs when slopes are infertile and have received extensive modifications, because often no vegetation establishes naturally.

The second alternative is to include persistent legumes which require little or no maintenance (Wright et al., 1978b). McCloud and Mott (1952) reported that the best mixtures they studied contained a legume.

Thus, in seeding slopes to control erosion, there are two common types of mixtures used, those containing only grasses and those containing both grasses and legumes. Foote et al. (1978) found a mixture containing *Bromus inermis*, *Medicago sativa* and *Poa pratensis* to provide the best surface cover on sandy loam soils. The Pennsylvania Highway Department favors mixtures containing *Coronilla varia* for controlling erosion (McKee, 1964). The Illinois Department of Highways has had success with mixtures containing *Lespedeza stipulacea*

(Andrews et al., 1964). Beard (1972) reported that the highest ranking mixtures in their tests were those containing Poa pratensis, Festuca rubra and Lolium perenne. The same grass mixture was ranked best by Schery (1970). However with the adoption of low maintenance practices, mixtures containing legumes as the climatic species for highway slope stabilization are gaining popularity.

## Methods to Improve Establishment

Seed treatments can be used to ensure a seed the best possible chance to establish during favorable periods, by increasing its rate of both germination and growth. To be feasible for highway seeding these treatments have to be inexpensive and rapid. Two easy techniques to improve the rate of seed germination include scarification and preimbibing. The latter may include stratification.

Legumes often are hard seeded due to a layer of macrosclerid cells forming a palisade layer in the testa which is impermeable to water (Rolston, 1978). Impermeable seed coats allow germination and seedling development to distributed in time as well as space. Thus only a part of a seed population becomes permeable to water and germinates. McKee et al. (1977) showed the importance of a treatment to allow rapid imbibition of water by Coronilla varia. C. varia pierced to a depth of 98 m takes two days to swell, whereas those pierced to a depth of 82 m or less require nine days or more to swell. Seed scarification may not be important in highway seeding mixtures, because most legumes are used as climax species, and rapid germination is not important (Wright et al., 1978a).

Rapid germination and seedling growth is especially important for warm season grasses. Warm season grasses often have a moist-chilling rquirement preventing mature seed from germinating until it has overwintered. Stratification is the procedure of exposing seed to low temperatures under moist conditions, with temperatures between 2 and $7^{o}$C being best (Hartmann and Kester, 1975; Mayer and Poljakoff-Mayber, 1975). Seeds having a moist-chilling requirement usually contain dormant embryos, and the moist-chilling allows changes to occur, including embryo growth, and activation of enzymes that effect metabolism (Mayer and Poljakoff-Mayber, 1975). Stratification of warm season grasses may be necessary to achieve a high percentage of germination.

Stratification is needed to increase germination of prairie forbs. Prairie grasses can be established with relative ease when compared with the requirements of prairie forbs (Sorensen and Holden, 1974). Voigt (1977) found in a study of 20 species of forbs, that three species germinated without any seed treatments, four required scarification and the other species germinated after two months of moist-cold treatments. For prairie forbs to be used in highway mixtures some type of moist-chilling treatment will be required.

Other more commonly used herbaceous species are not as demanding in their requirements. An early study reported that most species of grass had growth acceleration from presoaking, but this advantage may be negligibly small under adequate soil moisture conditions (Chippindale, 1934). Soaking seeds of Cynodon dactylon for 16 hours at $10^{o}$C and 8 hours at $40^{o}$C accelerated germination the most (Young et al., 1977). They felt this presoaking treatment had an excellent application to hydroseeding. Beard and Anda (1975) found the most beneficial seed treatments for Poa pratensis `Merion' were either soaking at 25°C for 168 hours or soaking at 10°C for 48 hour, both followed by air drying. The best treatment for Festuca rubra 'Pennlown', was soaking at 25°C for 6 hours or at 5°C for 48 hours, and with Lolium perenne 'Manhattan' no treatments were better than the untreated control. Curry (1980) found presoaking to accelerate emergence of Andropogon scoparius, Sorghastrum nutans, Aselepias tuberosa, Aster novae-angliae, Coreopsis palmata, Echinacea purpurea and Liatris aspera.

Advantages obtained from seed treatments are more pronounced as conditions for seed establishment deteriorated (Keller et at., 1970). Thus seed of Agropyron desertorum, exposed to moisture for 50-60 hours at 17°C emerged faster than did controls in suboptimal conditions (Keller et al., 1970). Similar responses were also found for Agropyron spp. and Elumus junceus with moist seed stored at 17°C (Bleak and Keller, 1974). They felt the principal advantage of pre-plant seed treatment was temperature rather than drought related. In another study Bleak and Keller (1972) reported that Agropyron spp. Bromus tectorum, and Elymus junceus preplant treated by wetting seeds at selected temperatures and periods had hastened seedling emergence, but this advantage was quickly overcome as treated seed approached maximum emergence.

Although preplant treatment is advantageous in increasing the rate of emergence, some reports have claimed other responses. An increase in drought tolerance or a hardening was reported for Festuca arundinacea, Lolium perenne, Trifolium alexandrium and Medicago sativa (A-As-Saqui and Corleto, 1978). They soaked seed at room temperature for 24 or 36 hours, then dried them. Waisel (1962), studying other species, found there was no true increase in frost, drought, or heat hardening as a result of soaking at room temperature.

Other work has been done with soaking seed in water containing either nutrients or growth regulators. *Coronilla varia* and *Lotus corniculatus* soaked in 100 to 500 ppm of ethephon (2-chloroethyl-phosphoric acid) for 6 hours prior to planting, germinated faster than other seed treatments (Larson, 1978). He also reported *Festuca arundinacea*, *Eragrostis curvula*, *Dactylis glomerata* and *Bromus inermis* had accelerated germination with a water presoak. The rate of germination of *Dactylis glomerata* was significantly increased by a soaking treatment using potassium nitrate. Both *B. inermis* and *D. glomerata* germination rates were increased by 500 ppm of ethephon (Larson, 1978). Thus his study concluded that presoaking appears the best treatment to increase the rate of germination and allow the seedling to respond to the favorable conditions that should be present at the time of seeding.

## Environmental Effects on Seedling Growth

### Seedling Development

According to Plummer (1943) germination and the early stages of seedling development are critical periods in the life of grasses. He felt that once a plant adapted to a site had lived through its seedling stage it could be expected to endure the fluctuations of that environment. An important component of seedling establishment is that the maximum amount of root growth occurs during the preemergence stage, thus ensuring that the seedling root reaches the relatively moist subsurface layers before the emerging plant becomes subject to atmospheric moisture stress (Tadmor and Cohen, 1968; Troughton, 1957). The root system of turfgrasses is a dynamic system influenced by many environmental variables, the most important of which is root temperature (DiPaola and Beard, 1978). Root growth affects both establishment and the competitive ability of seedlings. Rhodes (1968) found *Festuca arundinacea* to be suppressed by *Lolium perenne* because *L. perenne* had a greater rate of nodal root production.

A seedling has three phases of development, and establishment is not considered successful until the plant has developed an adequate root system and leaf area to sustain a high rate of growth (McKell, 1972). The first stage in seedling growth is the heterotrophic stage (Whalley et al., 1966; Qualls and Cooper, 1968; McKell, 1972). This phase commences with imbibition of water by the seed, and is completed when the first leaves emerge above the soil surface and photosynthesis begins. It is followed by the transition phase when the endosperm reserves remaining are exhausted. Since reserves are present the seedling utilizes organic compounds both from photosynthesis and from storage products (Qualls and Cooper, 1968). The final stage is the autotrophic phase when the seedling utilizes organic compounds that are entirely the products of photosynthesis (Whalley et al., 1966).

The sensitivity and degree of response of a seedling to the environment depends on its stage of development. Also Dotzenko et al. (1967) using *Bromus* spp. found the type of environmental response to be dependent on species, ecotypes, and varieties. In seedling growth and development, the amount of reserves present, the rapidity with which they are mobilized, and the efficiency of their metabolism are all important (Qualls and Cooper, 1968). Tadmor and Cohen (1968) reported these factors to be important in coleoptile growth and radicle enlongation during the heterotrophic stage.

Herbaceous species possess two distinct types of root systems (Troughton, 1957). The first is the primary or seminal root system consisting of a small number of main roots and their branches. The second type, the adventitious root system develops from the lower internodes of the shoot. Seminal root production is important in the successful establishment of a species (Asher and Ozanne, 1966). Briske and Wilson (1978) studied the importance of seminal root development and the initiation of adventitious roots in *Bouteloua gracilis*. They found the seminal root of *B. gracilis* was very delicate and easily broken, and adventitious roots would fail to develop when the soil surface was dry (Wilson and Briske, 1978; Wilson and Sarles, 1978).

Adventitious roots can be of two different types (Aberg et al., 1943). They can be annual roots which are regenerated each year, with the old roots decaying shortly after the new roots become established. *Bromus inermis* contains this type of root system. The second category includes species with perennial root systems. Maximum root production occurs during the first year, and most roots remain functional for more than one year (Aberg et al., 1943). *Medicago sativa* is a species containing a perennial root system.

In deciding the value of a species for roadside use the speed of germination and emergence are important (Davis, 1961). Emergence is dependent on shoot (coleoptile) growth, and the depth from which emergence can occur is primarily determined by the amount of endosperm reserves (Jones, 1972). There is a close relationship between the rate of root development and subsequent plant growth (Plummer, 1943). Thus, the speed of a root in following the moist substrate and keeping ahead of the drying of the upper soil layer critically affects establishment under highway slope conditions. Seminal root growth is important in penetrating the soil surface when herbaceous species are hydroseeded or broadcast seeded. McWilliam and Dowling (1970) found that the problem of surface penetration is more pronounced in Medicago sativa than in Lolium perenne because legumes have thicker radicles and an epigeal mode of germination not adapted to surface conditions.

Seedling root elongation is correlated with seedling vigor. Seedling vigor refers to a vigorous growth habit that involves a more rapid size increase than that of competing plants of the same age (Cooper, 1977). Inherent seedling vigor of a variety may manifest itself as early as the heterotrophic stage of development (Qualls and Cooper, 1968). Vigor has a biochemical basis because a seedling with the fastest root and top growth must be supported by efficient enzyme systems that mobilize food reserves in the endosperm (McKell, 1972). Seed size and weights are important characteristics associated with seedling vigor. Kneebone and Cremer (1955) found that within seed lots of Buchloe dactyloides, Sorghastrum nutans, Bouteloua curtipendula and Panicum virgatum the best seedlings were obtained from the largest seed. They found that between species seed size and seedling vigor are not related, although Henderlong (1971) claimed to have found a significant relation. The importance of seed size was demonstrated with legumes having slow establishment, such as Lotus corniculatus or Coronilla varia (Cooper et al., 1979; Henson and Tayman, 1961). Carleton and Cooper (1972) found a seed size correlation with seedling growth in *L. corniculatus* but not in the faster establishing legume *Medicago sativa*. Also, the effect of seed weight on the vigor of a herbaceous plant decrease with time after emergence (Thoma, 1965).

Temperature Effects on Seedling Develpment

Temperatures are often a limiting factor in establishing herbaceous species on highway slopes. Donahue and Bennett (1975) in their report on erosion control noted that temperature was the limiting factor in fifty percent of the sites in the United States that intensive research has been conducted. Soil temperatures are frequently more important in determining establishment success than air temperature, because root temperatures are always close to soil temperatures (Evans et al., 1964); Davidson, 1977). Soil surface temperatures are important because the greatest root density is near to the surface, and the shoot apicies and tiller buds lie close to the surface (Christian, 1977: Evans et al., 1964). High surface temperatures limit further development of root primorida, or after they are formed limit their development into fully functional roots (Garwood, 1968).

For a plant, three cardinal soil temperatures exist. The first is the minimum temperature for growth to occur. Above this temperature the growth rate increases to a maximum level as temperature rises (Russell, 1973; Casnoff, 1978). The optimum temperature is the second point, and is where the growth rate is the most rapid (Troughton, 1957). Finally, as temperature increases the rate of root growth starts to decrease until a temperature is reached which is the maximum at which growth occurs. Different species have various temperature requirements for optimal root growth, and not all species react similarly to temperature changes (Troughton, 1957). Temperate grasses have an optimum temperature about 20°C, while tropical grasses have an optimum about 35°C (Russell, 1973; Donahue and Bennett, 1975). Also the optimum temperature varies depending on what stage of development a species is in (Pfeiffer, 1966).

Growth is the complicated summation of a number of individual processes each influenced by temperature (Pfeiffer, 1966). The effect of temperature on plant development is very complex. According to Morrow and Power (1979) there is a general lack of information relating soil temperature to the development of perennial grasses. Most of the temperature studies concentrate on a controlled air temperature and allow root temperature to vary accordingly. The studies done using air and soil temperatures cite various causes for the observed variation in growth rate at different temperatures. One cause of variations in the growth rate are changes in the rate of chemical reactions. Nielsen (1974) stated that an increase in temperature almost invariably increases the chemical reaction rate. Prescht et al. (1973) stated that changes in the growth rate of Bromus spp. occurred because enzyme mechanisms in the seed were not furnishing enough carbohydrates which were not being rapidly translocated to furnish meristems with adequate energy for growth. In early growth of seedlings, the breakdown and exhaustion of endosperm carbohydrates are important. Later, available energy can arise from the breakdown of protein and cellular material (hayes, 1976). It is interesting that stages in the life of a plant characterized by high rates of development are generally susceptible to extreme temperatures. Cohen and

Tadmor (1969) felt that higher temperatures were not all detrimental and they increase the mobilization rate of seed reserves, thus enhancing root elongation before emergence.

The degradation of metabolites both in the endosperm and in the radicle meristem are important (Langridge, 1963). Cellular respiration is involved in much of the metabolite breakdown. Barkley et al. (1965) stated that simulated respiration is related to problems of herbaceous species establishment at high temperatures because as temperature increases carbohydrates may be utilized at a faster rate than they are synthesized. Respiration rates increase exponentially with a rise in temperature, thus decreasing yields obtained, especially for C-3 species of grasses like Lolium multiflorum (Nielsen and Cunningham, 1964; Prescht et al., 1973). The importance of respiration rate was shown by Watschke and Schmit (9170) with Poa pratensis cultivars. Those with the largest yield at high temperatures had the highest carbohydrate content. Cool season grasses that are adversely effected by high temperatures have little accumulation of food reserves (Baker and Jung, 1970). At higher temperatures there is an increase in the respiration rate causing carbohydrate utilization faster than synthesis can occur. The amount of storage products a young seedling has then becomes important. Thus, Barta (1978) claimed that Lotus corniculatus' lack of stress tolerance may have resulted from a carbohydrate deficiency which made the plants susceptible to attach by pathogens.

Increased temperature stimulates plant respiration in Poa pratensis because photorespiration and oxidative phosphorylation are influenced (Watschke et al., 1970). With root growth of young seedlings, the rate of oxidative phosphorylation is important. Also significant at high temperatures is the solubility of gases, because water solubility of gases decreases as temperature increases (Pfeiffer, 1966). As solubility decreases the diffusion coefficient of a gas through liquids increases (Letey et al., 1962; Jensen, 1960). Thus, according to Letey et al. (1961), there is a net increase in the supply of oxygen to the root as temperature increases. The results of Cameron (1973) and Heinrichs (1972) with flooding tolerance of Medicago sativa seem to indicate that an increased supply of oxygen to a root at a high temperature is not adequate to meet increased respiration demands, since M. sativa at high temperatures is less tolerant of wet soil conditions.

The rate of translocation both of nutrients and of organic compounds at a particular temperature is important in determining the rate of seedling growth (Troughton, 1957). Both cell division and elongation at the growth points of grass seedlings is dependent on efficient translocation systems (McKell, 1972). Not only is the translocation rate significant but also the partitioning of compounds between the shoot and root meristems is important in determining their relative growth rates. Wray (1974) found the growth pattern of a grass root is primarily influenced by soil temperature and the supply of carbohydrates translocated to it. At low temperatures, M. sativa the physiological activities of the plant decreased and the partitioning of carbohydrates to underground parts was decreased (Ueno and Smith, 1970).

The translocation of both organic and inorganic compounds, and the absorption of nutrients are all effected by temperatures. Also, nutrient uptake of seedlings occurs before they have completed their heterotrophic stage of development. Thus, Smith (1969) found a reduced uptake and translocation of potassium by _M. sativa_ 'Vernal' in a cycle of 18°C for 12 hours and 10°C for 12 hours. Possington et al. (1964) studying _Trifolium subterraneneum_ reported a reduction in the amount of nitrogen in the plant as the temperature was increased above 30°C, partially because of a temperature effect on nitrogen fixation.

## Examples of Temperature Effects

According to McWilliam (1977), the optimal growth of grass roots tended to occur at lower temperatures than did shoot growth. Growth response to temperature is one of the reasons for classifying grasses into cool season (or festucoid) and warm season (or nonfestucoid) (Evans et al., 1964). Cool season grasses have optimal growth below 27°C, and grow poorly at temperatures around 35°C, while the warm season grasses grow vigorously at 35°C and extremely slowly at temperatues below 15°C.

Weihing (1963) found that no growth of _Lolium multiflorum_, a cool season grass, occurred when the soil temperature was less than 6°C. In the early stages of development _Lolium perenne_ and _L. multiflorum_ growing in either a constant temperature of 25°C or an alternating temperature of 25°C day and 12°C night, had higher relative growth rates than plants in a constant 12°C temperature.

The temperature response of _Poa pratensis_ has been extensively studied. Younger and Nudge (1976) studying mature _P. pratensis_ reported the greatest root elongation occurred at 18°C and the least occurred at 27°C. Watschke et al. (1970) found _P. pratensis_ grows poorly at the temperature regime of 35/20°C and best at a 27/18°C temperature regime. Root elongation of the variety Merion was impaired at 27°C and the optimum temperature for root growth is 5°C below shoot growth (Aldous and Kaufmann, 1979).

Other researchers have studied P. pratensis along with other species. Paspalum dilatatum, Cynodon dactylon, axonopus affinis and P. pratensis had the greatest growth at 27-32°C and the three species whose yields were highest were warm season grasses (Lovvorn, 1945). In another early study P. pratensis made the greatest increases in dry matter accumulation at a temperature range of 13-22°C (Spraque, 1943). This study also found Bromus inermis, Festuca elatior, Dactylis glomerata, Agrostis tenuis, Phleum pratense and P. pratensis, all cool season grasses, were injured by temperatures of 30 to 38°C. Another early study found that grass root growth has a narrower environment requirement than shoot growth (Sullivan and Spraque, 1949). They also found Poa compressa, P. pratensis and D. glomerata all had lower optimum temperatures than those obtained for cynodon dactylon. Baker and Jung (1968) found yields of Poa pratensis decreased when temperatures were increased from 22 to 25°C.

Jackobs et al. (1967) studying cool season grasses, found Bromus inermis and Festuca elatior had best emergence at temperatures between 29 and 38°C, while the best temperature for emergence of Dactylis glomerata, Phleum pratense and Poa pratensis was 18-29°C. Dubetz et al. (1962) conducted a study of cool season grasses including Bromus inermis, Phleum pratense, Agropyron desertorum and Festuca rubra. The best emergence of F. rubra was at 18°C whereas P. pratense had the best emergence at the moderate temperatures of 13 or 18°C. The percentage emergence of the other species were not affected by the temperatures in their study. Casnoff (1978) in an extensive study of the environmental effects on Festuca arundinacea seedling growth found a significant increase in total length of F. arundinacea roots as temperature increased from 7 to 16°C.

Morrow and Power (1979) in a study of prairie grasses, Bouteloua curtipendula, Bouteloua gracilis, Andropyron spp. and Elymus spp. found the optimum root zone temperature for plant indigenous to warm climates are greater than those for temperate species. Bokhari et al. (1974) found with the two native warm season species, Bouchloe dactyloides and Bouteloua gracilis and the cool season species Agropyron tricophorum, that the rate of germination of the two warm season species was faster at 30/18°C, while for the cool season grass, it was fastest at the 24/13°C regime. The longest roots for Andropogon scoparis were obtained at a soil temperature of 27°C. This temperature was also the best for root growth of Bromus inermis, but Festuca rubra had its best growth at 18°C (Smoliak and Johnston, 1968). Briske and Wilson (1977) reported the greatest total length of adventitious roots for Bouteloua gracilis was produced at 30°C.

The response of Medicago sativa to temperature has been extensively studied. Physiological studies indicated that low midsummer yields of M. sativa could be attributed to high temperatures (McLaughlin, 1977). Nielsen et al. (1960) found the best temperature for root growth of M. sativa was 19°C except for plants growing without phosphorous, where 27°C was the best temperature. Evenson (1979) was able to semi-independently control root, crown and top temperatures. He found that the lowest root production occurred with a 40°C crown temperature, and the maximum top growth occurred with a crown temperature in the range of 32-40$^{o}$C. Thus the optimum temperature for different portions of _M. sativa_ plants varies.

There are marked variety differences in root response of _Medicago sativa_ to temperature (Heinrichs and Nielsen, 1966). And these differences are more pronounced for root growth than for other characteristics. For the varieties Dupits and Kodak, root growth increased more in the temperature range from 10 to 18$^{o}$C than from 18 to 26$^{o}$C (Levesque and Ketcheson, 1963). Pearson and Hunt (1972) reported the most rapid dry matter accumulation for _M. sativa_ 'Vernal' and 'Moapa' occurred in the temperature regime of 15/10$^{o}$C and 20/15$^{o}$C. Harada (1975) reported that with Vernal, Cody and Florida 66 the greatest dry weight increases were obtained in a 21/15$^{o}$C temperature regime.

Nelson and Smith (1968) studies both _Lotus corniculatus_ and _Medicago sativa_. They found that with _L. corniculatus_, high temperatures were detrimental in terms of root and crown diseases and carbohydrate storage when compared with _M. sativa_. Another study tested _L. corniculatus_ and _M. sativa_ in alternating temperatures and reported each had similar rates of germination (McElgunn, 1973). Gist and Mott (1957) found _L. corniculatus_ seedlings grew only a third as fast as _M. sativa_. They noted that both species showed a similarity in response to temperature, with a decrease in root growth as temperature increased from 16 to 33$^{o}$C. Kunelius and Clark (1970) conducted a study of the response of three strains of _L. corniculatus_ to various root temperatures. Their results showed the strain 'Empire' had a lack of vigor, but all three strains had an optimum temperature for growth in the range of 18 to 24°C.

Smith (1970), in a study of the effects of temperatures on the growth of legumes, found growth lowest at the temperature regime of 32/27°C and highest at the regime of 15/10°C. He studied Trifolium hybridum, Trifolium pratense, Lotus corniculatus, and Medicago sativa. In that study, L. corniculatus produced the least amount of growth.

Temperature and Moisture Interactions

Every species is characterized by its own temperature optimum for water absorption. According to Prescht et al. (1973), there is a close connection between the temperature prevailing in the natural habitat of a plant and its temperature optimum of water uptake. Morrow and Power (1979) found soil temperatures in the range of 13 to 23°C were most favorable for efficient use of water by cool season plants. Thus, during a period of heat these plants are not only endangered by high temperatures but also by the accompanying dehydration (Prescht et al., 1973). Temperature effects are modified and masked by other environmental factors such as moisture status encountered by the seedling root in the soil environment (Rosenquist and Gates, 1961).

McGinnies (1960) reported in a study with Bromus inermis, Elymus junceus and 4 species of Agropyron that as moisture levels decreased, germination was delayed and its rate reduced. In a study of Andropogon barbinodis, Bouteloua curtipendula, and Leptochloa dubia as moisture tension increased, emergence within a temperature decreased (Ohlenbush, 1966). He stated that the ability of a seedling to survive and grow is dependent on its developing root system utilizing moisture stored in the soil. Rosenquist and Gates (1961) found that temperature affects the rate of water absorption of *Agropyron inerme*, *Festuca ovina*, *Poa ampla*, and *Dactylis glomerata* seeds and seedlings. Stone et al. (1979) reported that the effect of osmotic potential on *Medicago sativa* germination was dependent on cultivar and temperature. McWilliam et al (1970) in a study using polyethylene glycols as the osmotic agent found that *Lolium perenne* was superior in its ability to germinate under the osmotic potentials studied.

Thus soil moisture tensions and soil temperatures are major factors influencing both plant growth and the partitioning of organic compounds between plant parts (Davidson, 1977). These two factors are interconnected especially on highway slopes, because soil moisture modifies temperature. Both these soil conditions have to be at adequate levels to allow germination and seedling establishment. Although a time can be chosen when conditions of soil moisture and soil temperature are favorable, it is not always possible to predict how long it will last.

# CHAPTER II. FIELD STUDIES ON THE ESTABLISHMENT AND PERSISTENCE OF HERBACEOUS SPECIES

## Abstract

Field studies were conducted at two sites to test the establishment and persistence of various seed mixtures when sown either in late spring or in the fall. Two seed treatments were used, dry seed and moist-chilled seed. In June seedlings, mixtures that contained warm season grasses and legumes (especially *Medicago sativa*) performed the best. Above ground biomass production was better on the fertilized than the nonfertilized plots.

Fall seedings were better than spring seedings, with the latter having a severe weed problem. The seed treatment effect was not significant. The warm season-cool season grass mixture, when seeded in the fall, provided the least number of shoots the following spring; otherwise mixture effects were not consistent. *Lolium multiflorum*, *Lolium perenne*, and *Festuca arundinacea* or *Festuca rubra* performed well in all mixtures. Above ground biomass peaked at the end of June, then declined.

A field study was conducted to determine the effect of mulch on seedling survival of late fall seeded mixtuers. Straw increased survival in comparison with no mulch or to a hardwood mulch.


## Introduction

Roadside seeding traditionally occurs either during the fall, from September to mid-October, or the spring, from late April to early June. Construction activities may not coincide with these optimum seeding seasons (National Highway Research Board, 1970). Since severe erosion could result from unseeded plots, government regulations require seeding no later than 30 days after completing construction.

Thus, vegetation establishment could be attempted nearly year-round (Green et al., 1974).

During late fall and early summer, vegetation establishment has a low probability of success. Seeds might germinate, but seedling mortality is considerable because of excessive hot or cold periods and/or low moisture availability (Duell, 1969). One method to increase the success of seeding during these periods is to increase the seeding rate (Green et al., 1974).

A second method is to vary the components of a mixture as species performance changes. For example, it is difficult to establish cool-season perennial grass during the late spring and summer (Woodruff et al., 1972). Specific annuals, such as Eragrostis curvula for summer, or Lolium multiflorum for late fall, are included in seeding mixtures as well as the desired perennial species (Carter et al., 1974; Hottenstein, 1969). Since annuals grow rapidly they provide surface protection while the desired perennial species, which usually grow slower, become established (Blaser, 1962).

Rapidness and uniformity of establishment are extremely important in stabilization and maintenance of the slope surface (Beard et al., 1971). Rapid establishment which minimizes erosion must be balanced against species aggressiveness (Duell and Schmit, 1975). Seed treatments are a method to increase the speed of establishment. The usefulness of a treatment depends on its cost. Also, results obtained have to be immediate, and the treatment in the long term cannot be detrimental to the permanence of the cover achieved. Presoaking seed at 4°C appears promising because of the low cost, and it can be used in hydroseeding, where seed is applied in a water scurry (Curry, 1980;

Larson, 1978). The presoak cannot be for a long period, because both cost and logistical problems would escalate.

The purpose of these experiments was to test the rapidity of establishment and the persistence of seedling mixtures during seasons when conditions encountered were likely to be unfavorable for growth. The experiments also were designed to test the effects of a seed presoak on establishment and subsequent performance, as well as the importance of mulch on germination and survival.

## Materials and Methods

### Experiment 1. The Establishment of Herbaceous Species Mixtures During the Spring and Fall

Establishment experiments were conducted at two locations. The first was a research farm west of Purdue University, and the second was a west facing highway slope south of Linden in Montgomery County, on Indiana 231. The soil of the research farm was prepared during the beginning of October, whereas the highway site was prepared by a contractor during the last week of October. At both sites the soil was harrowed, limed, and fertilized. Soil samples were taken after all seeding was completed and the results were given in Appendix C.

The seed mixture components are listed in Table II-1. One half of each mixture was stored dry inside a polyethylene bag at a room temperature. The other half was placed in a beaker and mixed with .5 ml distilled water per gram of seed until thoroughly moistened. The moistened seed was placed inside a polyethylene bag and stored at approximately 5$^{\circ}$C until seeding. The seed mixtures for the October 25 seeding at Horticulture farm were moist-chilled for 5 weeks prior to

Table II-1. Seed mixtures used in seeding at Horticulture Farm and Linden.

| Mixture 1: Legume-Cool Season Grass | kg/ha | % of mixture by seed number |
|---|---|---|
| 1. *Medicago sativa* L. | 9.1 | 7.7 |
| 2. *Coronilla varia* L. | 18.2 | 8.2 |
| 3. *Lolium multiflorum* Lam. | 5.1 | 4.6 |
| 4. *Festuca arundinacea* Schreb. | 58.4 | 53.3 |
| 5. *Lolium perenne* L. | 28.1 | 26.2 |
| | 19 | |
| **Mixture 2: Warm Season-Cool Season Grass** | | |
| 1. *Lolium multiflorum* Lam. | 5.1 | 4.7 |
| 2. *Festuca arundinacea* Schreb. | 39.0 | 36.0 |
| 3. *Lolium perenne* L. | 11.2 | 10.6 |
| 4. *Sorghastrum nutans* (Michx.) Nash. | 22.4 | 15.0 |
| 5. *Andropogon gerardii* Vitman. | 22.4 | 16.3 |
| 6. *Panicum virgatum* L. | 11.2 | 11.9 |
| 7. *Sporobolus heterolepis* Gray. | 5.1 | 5.5 |
| | 116 | |
| **Mixture 3: Proposed Highway** | | |
| 1. *Lolium multiflorum* Lam. | 11.2 | 2.3 |
| 2. *Festuca rubra* L. | 28.1 | 11.3 |
| 3. *Poa pratensis* L. 'Park' | 22.4 | 40.3 |
| 4. *Poa pratensis* L. 'Wabash' | 22.4 | 40.3 |
| 5. *Lolium perenne* L. | 28.1 | 5.8 |
| | 112.2 | |
| **Mixture 4: Current Highway** | | |
| 1. *Festuca arundinacea* Schreb. | 44.9 | 21.1 |
| 2. *Lolium perenne* L. | 28.1 | 13.5 |
| 3. *Poa pratensis* L. | 11.2 | 47.0 |
| 4. *Lolium multiflorum* Lam. | 39.3 | 18.4 |
| | 123.5 | |

use. All other seed mixtures were moist-chilled for one week.

Seeding was conducted on October 25, November 5, and May 7, at Horticulture farm, and November 1 and May 27 at Linden. On each date a randomized block design was used with blocks 5x3 m in size. Both mixtures and seed treatments were completely randomized with three replications. The seed was hand-broadcasted, and then mulched with wheat straw at 3.3t/ha. Erosion netting was applied on top of the straw mulch to hold it in place. At Horticulture farm the plots were located sequentially with each seeding date adjacent to the previous seeding. A different design was used at Linden, because of abrupt changes in soil types that occurred (Appendix B). There, the May 27 seeding replications were alternated with the November 1 seeding replications. Also, before the spring seeding at Linden, the soil surface was reworked with a rototiller due to slight gully and rill erosion.

The fall seeded plots were checked on November 12 and no germination had occurred for either the November 1 seeding at Linden or the November 5 seeding at Horticulture farm. The number of seedings with at least one leaf in an upright position within a randomly thrown $.1m^2$ quadrat were counted for the October 25 seeding at Horticulture farm. A final fall count for all seedings was conducted on December 4. Counts were taken the following spring from the beginning of May through the beginning of June. Also the May 7 seeding at Horticulture farm and the May 27 seeding at Linden were counted at 1, 2, and 4 weeks after seeding.

Once coverage reached a stage where counts were no longer feasible, fresh weights were used as a ranking method (Appendix D).

Samples were taken by throwing an .1m$^2$ quadrat, then removing and weighing the above ground tissue. Sampling started on May 21 for the November and October seedings at Horticulture farm, and on June 4 at Linden for the November seeding. Shoot fresh weight were taken again on June 4 at Horticulture farm and at approximately monthly intervals thereafter until September. Fresh weights were obtained for the May 7 seeding at Horticulture farm on July 1 and August 23, but were discontinued because of substantial weed problems. For the May 27 seeding at Linden, shoot fresh weights were obtained on August 12 and September 12.

Because of weed problems in the spring seeding, and to simulate actual highway maintenance practices, the seedings at Horticulture farm were mowed to approximately 15 cm height during the last week of August. This mowing caused residual weed material to remain on top of the May 7 seeding.

Experiment 2. The Effects of Mulch Treatments on Late Fall Performance of Seeding Mixtures

The experiment was conducted on a southwest facing slope at the Interstate 65 and Route 43 interchange immediately north of Lafayette. Four of the mixtures were the same as those used at Linden and Horticulture farm. Two others used were suggested by the Indiana Highway Department for wildlife use (Tale II-3). The experiment was a randomized block design with three replications. Seeding was conducted October 7, 28 and November 6. Areas of the slope lacking vegetation were selected, and 1m$^2$ plots staked out. Preweighed fertilizer was applied at 880kg/ha. After fertilizer application the seed mixtures were spread by hand over the surface of the plots. Then one of

Table II-2. Proposed seeding mixtures to be used on bridge projects for the benefit of wildlife.

| Mixture 6: Legume | kg/ha | % of mixture by seed number |
|---|---|---|
| 1. *Lespedeza stipulacea* Maxim. | 8.9 | 1.8 |
| 2. *Trifolum hybridium* L. | 8.9 | 4.4 |
| 3. *Lotus corniculatus* L. | 8.9 | 3.7 |
| 4. *Poa pratensis* L. | 35.6 | 75.4 |
| 5. *Festuca rubra* L. | 26.7 | 12.6 |
| 6. *Lolium multiflorum* Lam. | 9.0 | 2.1 |
| | 98 | |
| **Mixture 7: Cool Season Grass** | | |
| 1. *Bromus inermis* Leyss | 13.4 | 1.7 |
| 2. *Dactylis glomerata* L. | 8.9 | 4.8 |
| 3. *Poa pratensis* L. | 35.6 | 77.3 |
| 4. *Festuca rubra* L. | 26.7 | 12.9 |
| 5. *Lolium multiflorum* Lam. | 13.4 | 3.3 |
| | 98 | |

three treatments was applied: no mulch (control), hardwood bark ($.01m^3$ bark/$m^2$), and straw (3.35t/ha). Seedlings within a randomly tossed $.1m^2$ quadrat were counted at one week intervals until the first week of December.

## Results and Discussion

### Experiment 1. The Establishment of Herbaceous Species Mixtures During the Spring and Fall

Horticulture Farm

Seed presoaking resulted in a negligible increase in the rate of germination and the number of seedlings obtained for either of the fall seedings. Presoaking also appeared to be detrimental to legume survival. Legumes greminated during late fall, but were killed by low temperature injury during the winter. The same result has been observed with a wide variety of legume species (Allison, 1972; Woodruff and Blaser, 1970; Jensen and Sindelar, 1979; Laskey and Wakefield, 1978; Fribourg and Stand, 1973).

In November, the effect of seed treatment for the October seeding depended on the mixture (Table II-3). As Figure II-1 shows, the current highway mixture had more seedlings emerged than any other mixture. By December, no significant differences occurred between either mixtures or treatments. A large variability between replications occurred which may contribute to the finding of nonsignificance. Shoot counts for mixtures seeded in November were significantly different, with the current highway mixture containing the highest number of seedings (Figure II-2; Table II-3). This was because it contained the highest percentage of *Lolium multiflorum*, a winter

Table II-3. Mean shoot counts obtained at the Horticulture Farm seeding.

| Sampling Date** | | Seeding Date: 10-25-79 Mixture | | | 11-5-79 Mixture | | | | 5-7-80 Mixture | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Nov. 12 | wet | 190a* | 430ab | 250a | | | | | | | | |
| | dry | 170a | 75a | 795b | | | | | | | | |
| Dec. 4 | | 1780 | 2055 | 2243 | 130a | 70a | 240a | 455b | | | | |
| May | wet | 835a | 1040ab | 450a | 740b | 360a | 960b | 810b | 295 | 150 | 180 | 245 |
| | dry | 1030ab | 2040b | 1160ab | | | | | | | | |
| June 6 | | 1562 | 1712 | 1277 | 994b | 599a | 1130b | 1005b | 840 | 570 | 840 | 940 |

** Where two means are given for a sampling date the treatment effect was significant. The May sampling dates were on May 8 for October's seeding, May 4 for November's seeding and May 15 for May's seeding.

* Means (shoots/$m^2$) which are the average of three replications, within a sampling date and seeding date followed by a different letter are significantly different by the Duncan Multiple Range Test at the .05 level.

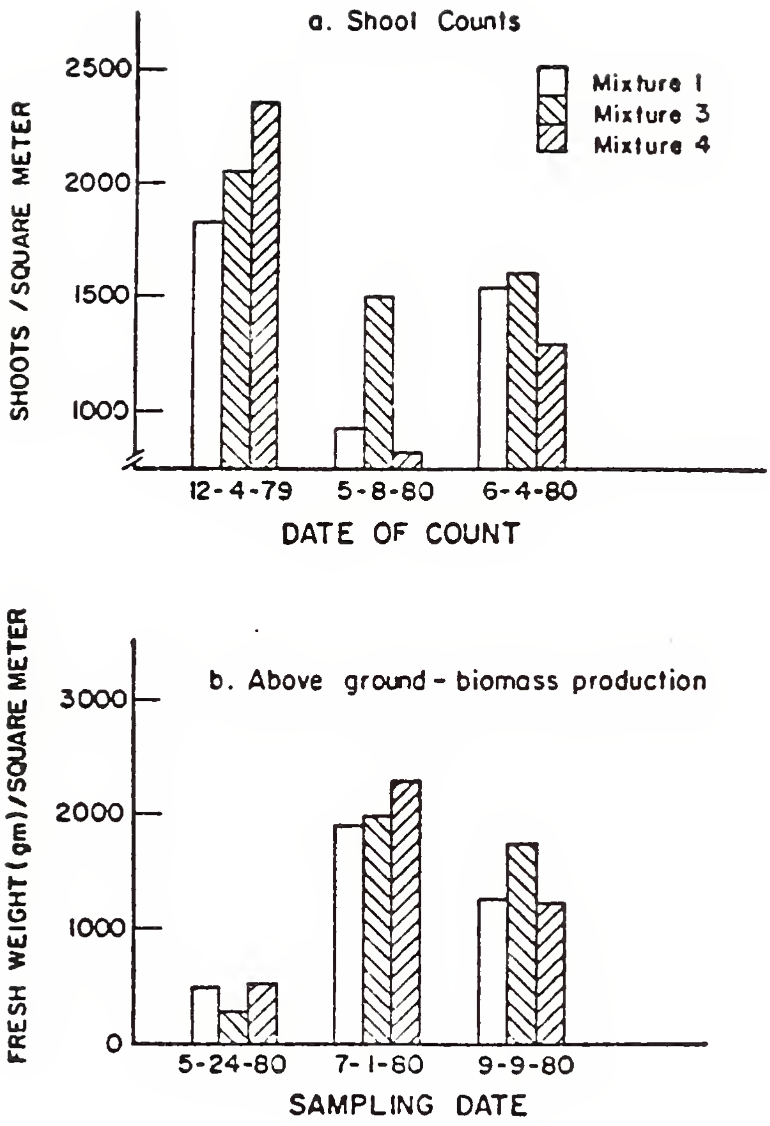
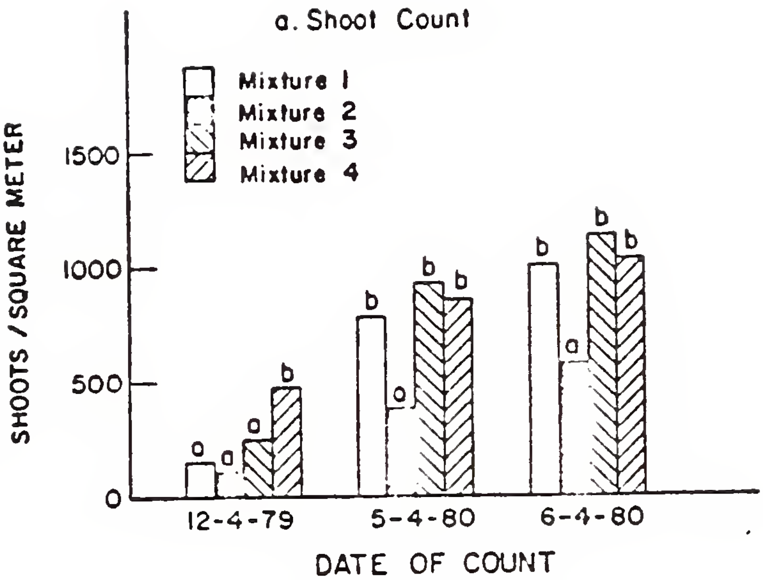



Figure II-1. Shoot counts and fresh weights for the October seeding at Horticulture Farm.



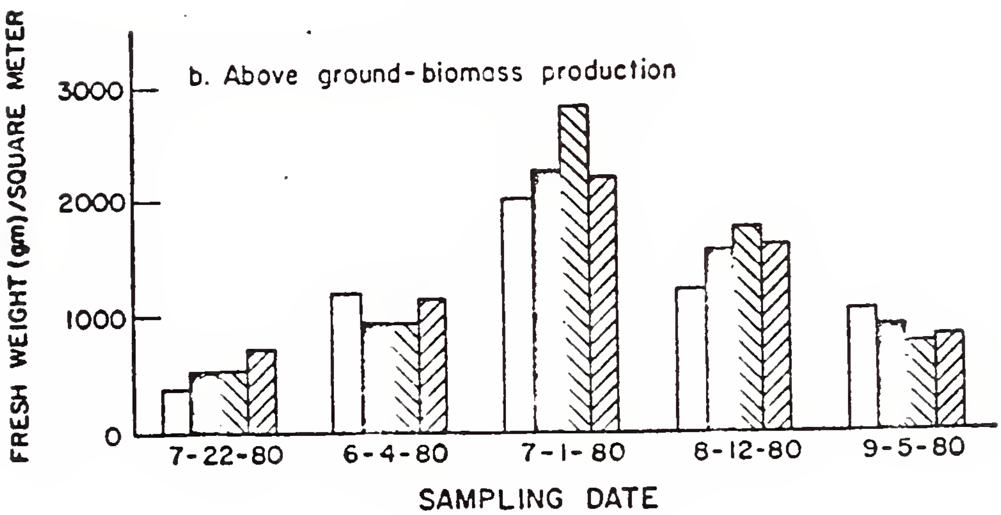




Figure II-2. Mixture means for the November seeding at Horticulture Farm*.

*Means within a sampling date followed by a different letter differ significantly by Duncan's Multiple Range Test at the .05 level.

Table II-4. Percentage establishment of fall seedings on December 4 and May 22.

| | October seeding | | November seeding | |
|---|---|---|---|---|
| | Dec. | May | Dec. | May |
| Mixture 1 | 31* | 10 | 2 | 13 |
| Mixture 2 | --** | -- | 1 | 6 |
| Mixture 3 | 8 | 3 | 1 | 4 |
| Mixture 4 | 22 | 9 | 4 | 7 |

* The percentage is the number of seedlings counted per the number of seed per square meter.

** Mixture 2 was not seeded in October.

annual, commonly used as a rapid establishment species during late fall and early spring (Foote and Kill, 1968).

The percent establishment was higher for the October seeding than the November seeding (Table II-4). Beard et al. (1971) reported that establishment of vegetation was progressively less successful with each ten day interval after September 6. In December the mixtures with the highest percent establishment were those that contained the least amount of Poa pratensis. Poa pratensis has a slower rate of germination than either Lolium spp. or Festuca spp. (Appendix E). By May, percent establishment had decreased for the October seeding, due to the unsuccessful overwintering of many young seedlings. The November seeding had a low perentage of seedlings established by December, but an increase in the percent establishment occurred by the May 22 count as more seed germinated in early spring.

In spring, the number of seedlings from the dry seed treatment were significantly greater than for the presoaked seed treatment in the October seeding. Presoaking could have contributed to increased low temperature injury. Results from the mixtures seeded in November indicated that the warm season-cool season grass mixture had fewer seedling than any other mixture. This was probably because it consisted of approximately half warm season grasses, whose germination due to low temperature is limited during early spring and late fall. The contribution of legumes to cover was negligible. In May, a further decline in the number of seedlings present from October seeding occurred, while the November seeding stabilized. An increase in the number of shoots for the October seeding occurred between May 22 and

Table II-5. Mean shoot fresh weight obtained from the Horticulture Farm seedings.

| Sampling Date | Seeding Date 10-25-79 Mixture 1 | 3 | 4 | 11-5-79 Mixture 1 | 2 | 3 | 4 | 5-7-80 Mixture 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5-21 | 480a* | 290a | 625b | 400 | 530 | 515 | 1445 | | | | |
| 6-4 | 1075 | 700 | 1220 | 1220 | 870 | 950 | 1180 | | | | |
| 7-1 | 1870 | 1990 | 2320 | 2050 | 2275 | 2840 | 2210 | 980 | 1420 | 1450 | 835 |
| 8-12 | 950 | 1030 | 890 | 1240 | 1590 | 1790 | 1645 | 1785b | 1345ab | 920a | 795a |
| 9-5 | 790 | 1250 | 790 | 1060 | 930 | 775 | 822 | | | | |

* Means ($g/m^2$) are an average of two seed treatments over three replications. Means within a seeding date and a sampling date followed by a different letter are significantly different using Duncan's Multiple Range Test at the .05 level.

July 3

October 6

a. October seeding

July 6

b. November seeding

Figure II-3. An overview of the October and November seedings at Horticulture Farm.

June 4. This appeared to result from mature plants tillering and not from an increase in the number of plants present.

Fresh weights of the shoots, shown in Table II-5, were also used to determine mixture performance. On May 21, for the October seeding, the legume-cool season grass mixture and the current highway mixture had a greater shoot fresh weight than the proposed highway mixture. One explanation for this is that the proposed highway mixture is over eighty percent *Poa pratensis*, which has a thinner blade than either *Festuca arundinacea* or the *Lolium* spp. Also, this mixture contained the least amount of *Lolium multiflorum*, which produced the most growth at this time. After May there were no statistically significant differences for neither mixtures, treatments, nor their two-way interactions for either fall seeding. There was an increase in fresh weights with the peak in production occurring in early July. During this period, the cool season grasses *Lolium perenne*, *Lolium multiflorum*, and *Festuca arundinacea* were flowering. Growth of these cool season grasses almost ceased by July 1 (Hanson et al., 1969). The only mixture containing warm season grasses was the warm season-cool season grass mixture whose performance was similar to the other mixtures. As Figure II-3 illustrates, the well established cool season grasses probably competed with and inhibited the establishment of later germinating warm season species.

For the May 7 seeding at Horticulture farm, a negligible difference in shoot numbers occurred between either seed mixtures, seed treatments or their two way interactions. There was a large increase in the number of shoots that occurred between May 22 and June 4, but the plants were fewer and smaller than those from the fall seedings.

a. The weed problem encountered in July.

b. The seeding's performance in October after an August mowing.

Figure II-4. An overview of the May seeding establishment and performance during the first year after seeding.

Percent establishment one month after seeding ranged from 14% for the legume-cool season grass mixture, to 3% for the proposed highway mixture. The percent establishment was approximately the same as for the October and November seedings after overwintering.

Weed growth in the May seeded plots was extensive (Figure II-4). The weeds, especially Chenopodium album and Cirsium arvense, competed detrimentally with the desired plants. Besides shading the young grass seedlings, the weeds also used nutrients and water thus making them unavailable to the desired species. Thus, weed growth contributed to a lower fresh weight production in the spring seeding compared to either of the fall seedings.

For the spring seeding on August 12, the shoot fresh weight of the legume-cool season grass mixture was significantly greater than for either the current highway mixture or the proposed highway mixture, although it was not significantly different than the warm season-cool season grass mixture. The only difference between the mixtures was that the legume-cool seson grass mixture contained legumes while the others did not. However, legumes were not an appreciable part of coverage. Although spring is the most favorable time for seeding legumes, establishment is successful only if weeds are controlled (Fribourg and Stand, 1973; Allinson, 1972; Jensen and Sindelar, 1979). Another explanation for depressed levels of cover in mixtures containing cool season species is that establishing cool season perennials during the late spring and summer is difficult because of adverse temperatures and drought (Woodruff et al., 1972).

The fall seedings shown in Figure II-3 were virtually weed free with a complete coverage of the soil surface. In September, when final fresh weight samples for the fall seedings were taken, those of the spring seeding were not obtained because of the extensive amount of dead weeds laying on its surface.

Linden

At Linden, as for Horticulture farm, the fall seeding had better results than those obtained from the spring seeding. The November seeding showed no significant differences due to either treatments, mixtures or their interactions (Table II-6). Most of the seedlings that established by the beginning of December were either *Lolium multiflorum* or *Lolium perenne*. The contribution to cover by the legumes was negligible. Although *Medicago sativa* germinated, it was not present the following spring.

In December, the warm season-cool season grass mixture tended to have the smallest number of seedlings, probably because it contained about fifty percent warm season grasses, which would not grow at this time. However, even this mixture prevented erosion. This differs from Beard et al. (1971) finding that dormant or extremely late fall seedings on slopes were prone to washing and soil erosion by late winter and early spring rains. The results of Green et al. (1974) also indicated an inability of normal seeding mixtures to establish at this time. Thus, our results as shown in Figure II-4 differ from their results. However, the fall and early winter of 1980 were unusually mild.

No significant differences in fresh weight occurred between mixtures in either the spring or summer. In the spring, there was an increase in the number of shoots because individual plants were larger. The percent establishment was similar to that of Horticulture

Table II-6. Mean shoot counts and shoot fresh weight production at the Linden highway seedings.

a. Shoot counts (shoots/$m^2$).

| Mixture | November seeding Sampling date | | | May seeding Sampling date | | |
|---|---|---|---|---|---|---|
| | 12-4 | 5-4 | 6-3 | 6-3 | 6-12 | 6-26 |
| Mix 1 | 235* | 585 | 475 | 290 | 2940 | 635 |
| Mix 2 | 75 | 440 | 525 | 370 | 1580 | 720 |
| Mix 3 | 245 | 545 | 505 | 165 | 1200 | 830 |
| Mix 4 | 295 | 510 | 700 | 39 | 1965 | 850 |

b. Fresh weights (gm/$m^2$).

| Mixture | November seeding Sampling date | | | | May seeding Sampling date | |
|---|---|---|---|---|---|---|
| | 6-3 | 6-26 | 8-8 | 9-4 | 8-8 | 9-4 |
| Mix 1 | 465* | 655 | 540 | 500 | 430 | 660 |
| Mix 2 | 575 | 955 | 550 | 580 | 315 | 440 |
| Mix 3 | 330 | 550 | 420 | 550 | 385 | 615 |
| Mix 4 | 510 | 870 | 370 | 360 | 460 | 475 |

* Means are the average value of two treatments over three replications. No means within a sampling date were significantly different by Duncan's Multiple Range Test at the .05 percent level.

a. The site immediately after seeding on November 1.

b. The site on August 21.

Figure II-5. November seeding establishment at the Linden highway site.

farm's November seeding. In fresh weight samples the proposed highway mixture tended to be the lowest, probably because of the large amount of *Poa pratensis* it contained. As Figure II-6 shows, this trend is still evident on June 26, but not on either of the two later sampling dates. A peak in fresh weight production occurred on June 26, as *Festuca arundinacea*, *Lolium perenne*, and *Lolium multiflorum* matured. Their inflorescences gave an unsightly appearance during the late sampling dates, but could easily be removed by mowing. *Medicago sativa* had an increased contribution to coverage as the grass species matured. This trend could be from *M. sativa* competing for moisture near the surface to the detriment of the grasses, while also obtaining water at deeper soil depths through its tap root (Christian, 1977).

The results obtained from the spring seeding are shown in Table II-6. There were no significant differences for either treatments or mixtures for the first two sampling dates. The number of shoots peaked during the second week after seeding. By later sampling dates the temperature had increased, the soil was drier, and plant size was larger, causing competition to be greater, and the number of plants to decline. On June 26, the number of shoots present for dry seed treatments were greater than those for moist treatments, possibly because either more dry seed germinating over a longer time period or from the wet seeded plots declining earlier.

As shown in Figure II-7, a major weed problem occurred in the May seeding. The major weed species present were *Chenopodium album* and *Polygonum hydropiper*. These weeds competed with the grasses and legumes, especially in the replications where soil fetility was higher (Appendix C).

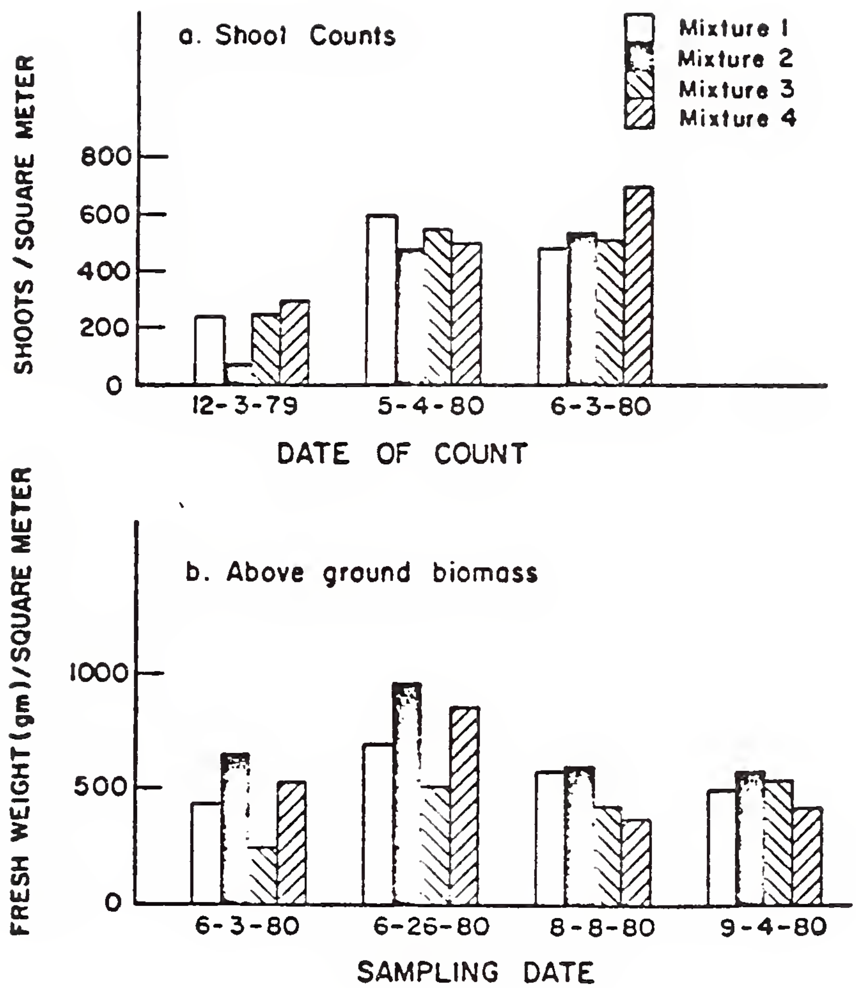
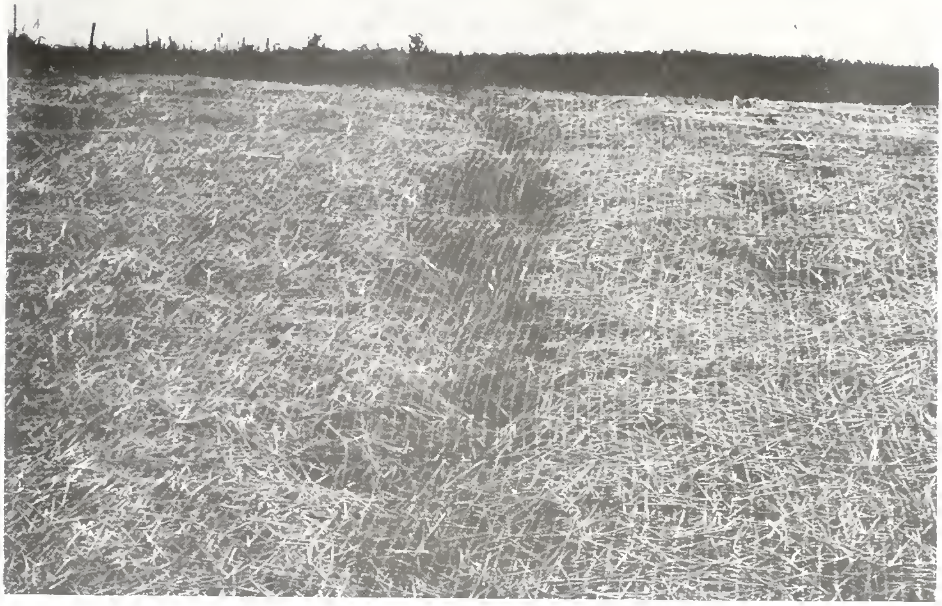



Figure II-6. Mixture means for the November seeding at Linden.



a. Gully erosion at the site from the soil being bare over the winter.

b. Severe weed problems present August 21.

Figure II-7. Problems encountered at the Linden highway site for a May seeding.

Thus there were no consistent differences between either mixtures or treatments at either site. At both Horticulture farm and Linden severe weed problems were encountered in spring seeding. Delaying late fall seeding until a favorable time the next spring does not appear advisable under these circumstances. As Figure II-7 illustrates, not only were weeds a problem, but gully erosion was encountered when seeding was delayed until spring.

Experiment 2. The Effects of Mulch Treatments on Late Fall Performance of Seeding Mixtures

Seed failed to germinate for the later two seeding dates, but for the October 7 seeding, mulch treatment had a significant effect on the amount of plants present for all mixtures by the November 25 count (Figure II-8). The straw mulch improved the germination and survival of all mixtures tested. This is probably because straw modified the temperature extremes encountered by the germinating seedlings and improved the moisture content of the soil surface layers. The hardwood bark treatment was not significantly different from the control, which was without mulch. This was caused by the rate of hardwood bark mulch being too low, thus not adequately modifying the extreme environmental conditions encountered. Also due to dark surface color of the mulch, soil temperatures would be higher under it during the day, thus contributing to larger temperature fluctuations.

Seeding mixtures all performed the same in this experiment because the majority of plant cover was from temporary nurse crop species like Lolium multiflorum which was included in all the mixtures used.

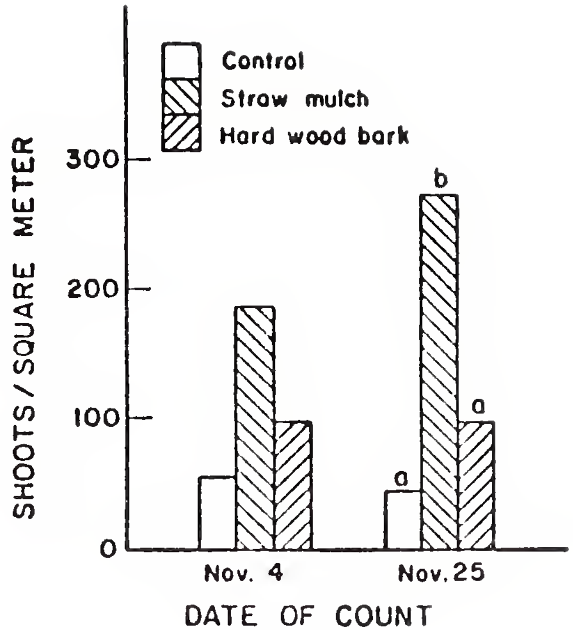



Figure II- 8.   Effect of mulch treatments on seedling establishments.*

* Means within counting dates with the same letter are not significantly different by the Duncan Multiple Range Test, .05 level.

## Conclusions

Prairie forbs did not contribute substantially to the cover obtained, and due to economic constraints they probably should not be used in mixtures except in special situations such as roadside rest areas, where an aesthetically pleasing landscape is important.

Seeding mixtures containing warm season grasses should not be used in late fall, because most of their growth occurs between June and September. But warm season species have a great potential for use in seeding during late spring and early summer. *Eragrostis curvula* was especially promising at the Covington highway site where it is very tolerant of hot, dry summers (Perry et al., 1975).

Other species that deserve consideration for use in special situations are *Lespedeza stipulacea* and *Lotus corniculatus*. *L. corniculatus* has been used elsewhere and has relatively poor seedling vigor, along with an inability to establish during late summer and early fall (Laskey and Wakefield, 1978; Allinson, 1972).

Besides species selection proving to be important, proper fertilization was critical in obtaining cover with grass species. In seeding legumes, rates of fertilizer have to be controlled to favor them over the grasses in the mixture.

In order to establish some grasses like *Poa pratensis*, high levels of fertility and maintenance are required. Results indicated that *Poa pratensis* containing mixtures are extremely wasteful of seed. In early establishment, these mixtures were dominated by *Festuca* spp. and *Lolium* spp., which produce an unsightly inflorescence in early June. Since seed production by these species is undesirable, some method of controlling flowering such as mowing should be attempted. The fresh weight of the shoot peaks when these species flower and then declines before leveling off. This could be of importance in scheduling maintenance operations.

Although germination and emergence in the fall is slower than in the spring, seeding operations should not be delayed from late fall until early spring. The level of seedling mortality was high whether seeding occurred in the spring or late fall, which is consistent with the findings of Green et al. (1974). Some method to improve percentage establishment would be desirable. Presoaking does not seem to be the answer. Although presoaking had an immediate effect, presoaking may have been deleterious in long term establishment because it allowed seeds to germinate when conditions were unfavorable.

Legume establishment from fall seedings is slight, probably from lack of overwintering ability. Thus, most legume seeding should be done in the spring with a weed control program (Jensen and Sindelar, 1979). Weed control is especially important on more fertile soils where weed species out compete legumes.

Adequate mulching with wheat straw appears to be the most promising treatment to allow the germination and survival of seedings in the late fall. Thus a straw mulch with species adapted to environmental conditions present at seeding time appears to offer the most hope for establishment of grasses and legumes in late fall.

# CHAPTER III. THE MODIFICATION OF SLOPE SOIL TEMPERATURE BY MULCH AND VEGETATIVE GROWTH

## Abstract

A soil temperature study was conducted on north and south facing slopes along I-74 at Veedersburg, Indiana. Soil temperatures were taken at the surface and an 8-12cm depth on bare soil and mulched plots. The maximum temperature, 51°C, was observed on July 13 on the surface of the south slope. A straw mulch modified the temperature. The temperature found at the 8-12cm depth was less extreme than the surface, and the fluctuations were not as great. The north facing slope averaged 5°C cooler than the south facing slope, and smaller temperature fluctuations were observed. Differences between mulched and nonmulched plots on the north facing slope were not as great. Regrowth of *Coronilla varia* occurred on the north facing slope and not on the south facing slope. The regrowth occurred first on the mulched plots, then on the nonmulched plots. It was concluded that the only hope of successfully establishing vegetation on the south facing slope was to seed in early spring or late fall.


## Introduction

In determining the suitability of a species, the climate and microclimate existing along a roadside are of major significance (Walker, 1964). Two of the more important environmental factors are temperature and the amount of moisture present. Soil temperatures influence growth of herbaceous species more than do air temperature, mainly because shoot apices and tiller buds lie close to the soil surface (Evans et al., 1964). Soil temperature also determines the rate of germination and the rate of seedling growth, two growth factors to consider when trying to control roadside erosion. Germination and growth tend to be negligible below a certain temperature, rise to a maximum, and then decrease as soil temperature rises (Russell, 1973).

A major factor determining soil temperature encountered along a roadside is slope exposure. In the middle and high latitudes of the northern hemisphere, southern exposures receive more direct sunlight of a higher intensity than northern facing slopes, which intercept light at a low angle and reflect much of it (Chang, 1968).

Not only is soil temperature greater on south facing slopes, but increased water evaporation occurs. These two factors cause an increased difficulty in vegetative establishment on south facing slopes in comparison to north slopes (Duell, 1969; Iurka et al., 1955; Walker, 1964). For example, south facing slopes will frequently dry out, resulting in stand failures and/or reduced plant growth. Conditions on northern exposures can also be severe especially during winter when slope surfaces are exposed to extreme winter cold and the heaving action of frost (Richardson et al., 1963). Because of the different conditions that exist on slopes with a northern exposure and those with a southern exposure, different categories of grasses would be expected to grow on each. McKee et al. (1965) reported that cool season grasses will grow on a north facing slope, and warm season species are adapted to southern exposures.

Although the macroclimate present at a site can not be modified, the microclimate may be. Soil moisture is the climatic factor that can be most readily modified to achieve the optimum for plant growth. Soil temperature for the most part is unchangable in the field (Walter and Jensen, 1970). Rosenthal (1976) found that modification of only soil moisture was adequate to improve establishment, because most factors he studied which influenced growth and survival were those which affected soil moisture. Geiger (1966) showed that the climate of slopes facing in different directions was affected to a large degree by moisture conditions.

Two methods are commonly used to improve the amount of soil moisture present on a slope. One method is to grade such that there is a rough surface with rocks left in place. This type of slope surface encourages water infiltration by decreasing the rate of downhill water flow (Wright et al., 1978b). The second method is to use a mulch. Wheat straw at 3.3 t/ha is popular. An important function of mulch in reducing the rate of evaporation is to hold a layer of relatively still air near the surface. This layer of still air serves to insulate the soil against extremes of temperature (National Highway Research Board, 1970). Thus, soil temperatures and humidity in the germination and early growth zones are more uniform (Turelle, 1973). The soil under a mulch commonly is cooler during the day and warmer during the night by as much as 3-8°C (Spraque, 1943; Jurka et al., 1955).

## Materials and Methods

The experiment was established on north and south facing slopes along I-74 near Veedersburg, Indiana. The angle of incline on both slopes was between 20° and 25° from the horizontal. A section of each slope with similar amounts of *Coronilla varia* was selected. The existing vegetation was removed with a hoe leaving the underground portions of the plants intact. Plots $1m^2$ were staked out in cleared areas and 10cm sections of 12mm conduit tubing were buried in the middle of each plot to allow for the measurement of soil temperature at an 8-12cm depth. A $50cm^2$ piece of cardboard was then placed over the exposed opening of the conduit tubing.

A 12-12-12 (N,P,K) fertilizer was applied to each plot at the Indiana State Highway Department suggested rate of 880kg/ha. The preweighed seeding mixture, shown in Table III-1, and/or mulch (wheat straw at a rate of 3.3t/ha) were applied to selected plots to give the following treatments: mulched, bare surfaced, bare surfaced that was seeded, and a mulched surface with seed. There were four replications on each slope.

Initial soil temperature readings were taken on July 3, on the surface and at the bottom of the piece of conduit tubing (8-12cm) using a telethemometer and calibrated thermocouples. The readings at the bottom of the conduit tubing were compared to readings taken with thermocouples buried at an 8-12cm depth, and a negligible difference was noted between the two. Temperature readings were conducted at 2 day intervals for July, then twice a week in August and once a week during September and October. The temperature readings were taken during the early afternoon between 1 and 3 pm, and air temperatures (30-40cm) were also recorded. The experiment was terminated on October 7.

## Results and Discussion

The seeding mixture, consisting of species which looked promising at Covington, failed to germinate. A similar failure was reported by Perry et al. (1975) in early summer seedings of a variety of species. They attributed the failure of vegetative establishment to high soil temperatures and a lack of available moisture. On the south facing

Table III-1. The seeding mixture used at the Veedersburg experimental plots.

| Species | kg/ha | % of seed in mixture |
|---|---|---|
| 1. *Bromus intermis* Leyss. | 72 | 30 |
| 2. *Eragrostis curvula* (Schrad.) Nees. | 12 | 30 |
| 3. *Sorghastrum nutans* (Michx.) Nash | 22 | 20 |
| 4. *Bouteloua gracilis* (H.B.K.) Lag. ex. Steud. | 24 | 20 |

plots temperatures of approximately 50°C were reported throughout the month of July (Figure III-1). The high temperatures appeared to be the major explanation for the failure of the seeding mixture.

As can be seen in Figures III-1 and III-2, mulch modified the temperature on both slopes. This modification occurred at both the surface and the 8-12cm depth. The reduced temperatures appeared to be from the mulch maintaining higher levels of surface moisture. Differences between the mulched and nonmulched treatments were not as great or nonexistant immediately after a rain such as on August 12. Diseker and Richardson (1961) reported similar findings with mulch retaining moisture a little longer than nonmulched soil, thus aiding in germination. Differences between the mulched and nonmulched plots were also not as great later in the season when the mulch started to decompose.

For the 8-12cm depth of both slopes the temperatures were lower and the extremes were not as great as those occurring on the soil surface. The soil temperature decreased later at the 8-12cm depth than at the surface. Russell (1973) reported the seasonal changes in temperature being smaller and the time at which the maximum temperature is reached becoming later in the year at deeper soil depths. Temperatures at 8-12cm on both slopes in July were at levels which would be within the range of temperatures where growth of warm season grasses would occur.

Soil temperatures on the north facing slope were not as great as those on the southern exposure. Soil temperature fluctuations also were less on the northen exposure, due possibly to its higher level of soil moisture. The temperature found on the north facing slope averaged 5°C cooler than the midsummer temperatures recorded on southern exposures.

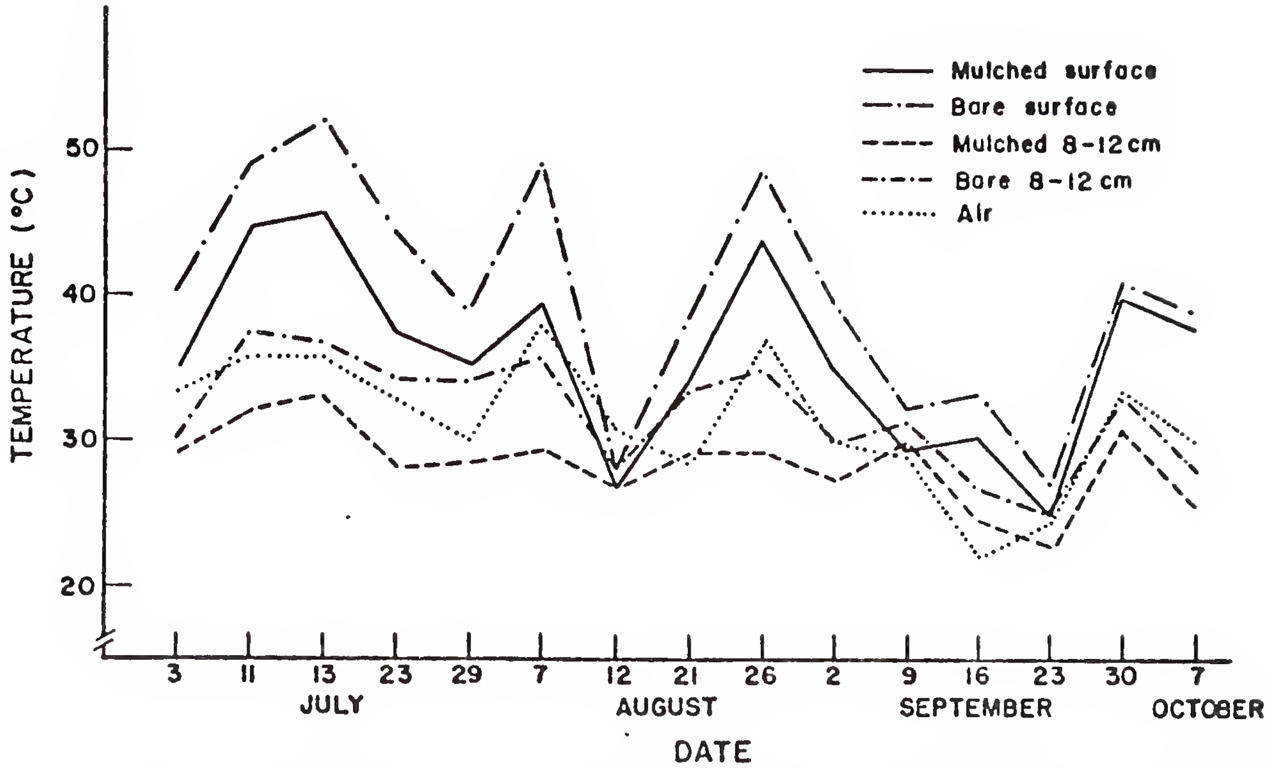



Figure III-1. Soil temperatures encountered on a southern exposure at Veedersburg, Indiana on selected dates.

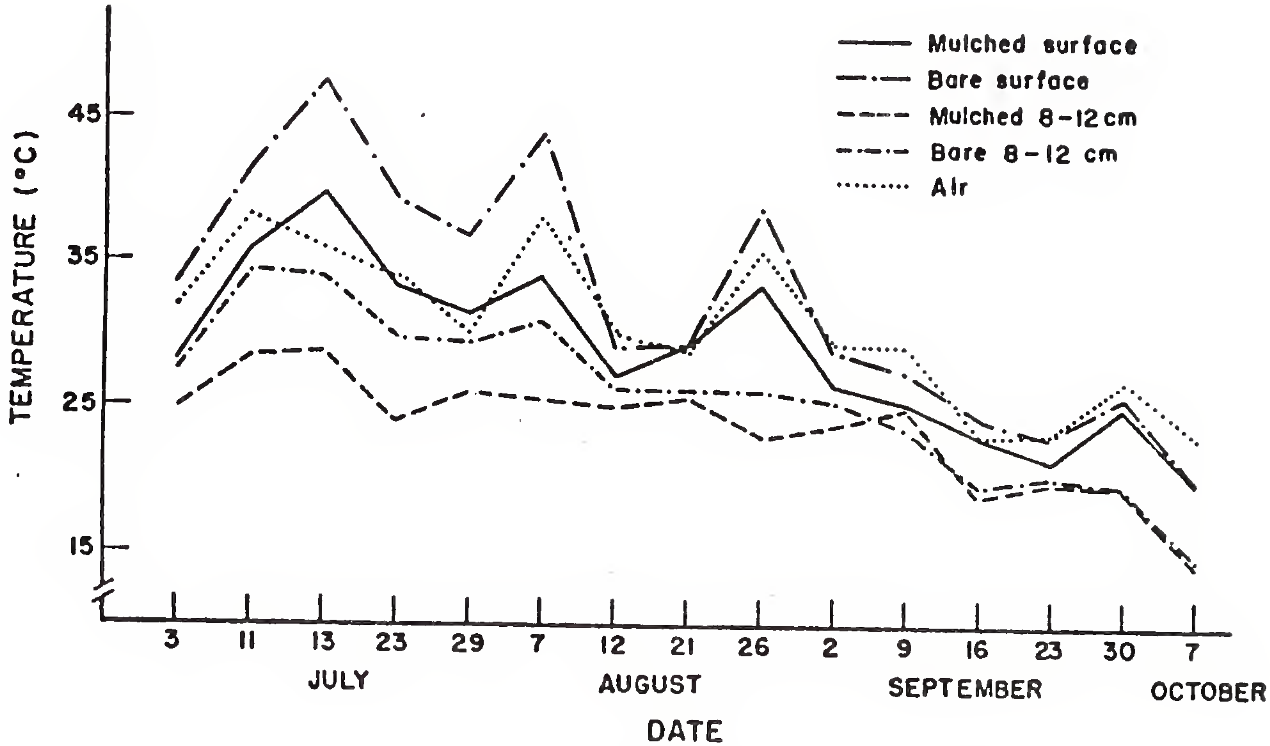



Figure III-2. Soil temperatures found on a north facing slope at Veedersburg, Indiana on selected dates.

As shown in Figure III-2 the differences between mulched and nonmulched plots were also not as great.

Another difference between the slope with a southern exposure and the one with a northern exposure was that the latter had regrowth of Coronilla varia (Figure III-3). Regrowth was observed first on August 7 for the mulched plots and then on August 21 for the nonmulched plots. An early regrowth on the mulched plots may be due to the mulch conserving soil moisture as Barkley et al. (1965) found. The growth of C. varia appeared to modify the temperature found on the north slope (Figure III-4). In July and August the average monthly temperature for the north bare surface was comparable to that for the south mulched surface. In September, the temperature on the bare surface of the north slope, where a significant amount of C. varia regrowth had occurred, was similar to the mulched plots of the north slope.

Thus, the temperatures found on a southern or northern exposure during the month of July would not appear to allow growth of vegetation. Conditions existing on the south-facing slope would not allow vegetative growth during most of the study period. Temperatures encountered there were outside the normal range of temperatures for plant growth, which Donahue and Bennett (1975) reported to be 10°C-40°C. For successful seeding on a south facing slope, an attempt would have to be made to seed earlier in the spring or later in the fall than a north facing slope.

## Conclusions

Temperature conditions existing on the south facing slope in the summer are too extreme to allow for the growth of common herbaceous

a. The plots on July 3, two days after the treatments were applied.

b. Coronilla varia regrowth occurring on October 3.

Figure III-3. Northern facing plots on July 3 and on October 3 showing the regrowth of Coronilla varia.

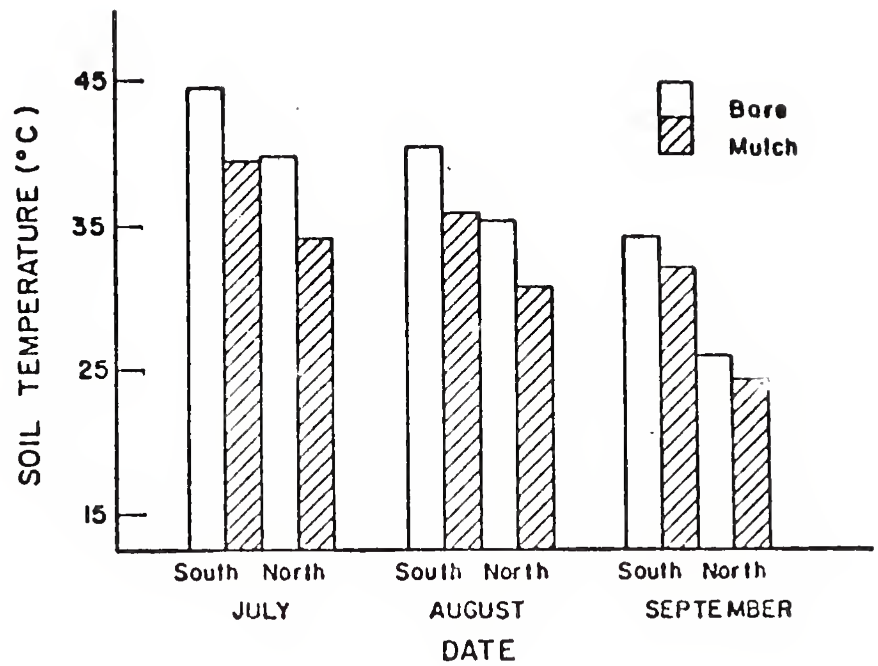



Figure III-4. Monthly mean surface temperatures recorded at the Veedersburg experiment plots.

species. It is doubtful whether microclimate conditions on the south-facing slope could be modified to allow for successful seeding. Thus, to obtain successful vegetative cover requires seeding in early spring or late fall when favorable environmental conditions would occur.

On the northern exposure, conditions were not as extreme, and vegetative growth occurred. Seeding on this slope could be expected to be successful during August as long as some method to retain moisture was used.

# CHAPTER IV. THE RESPONSE OF RADICLE GROWTH TO FIXED TEMPERATURE

## Abstract

Pregerminated seeds of *Andropogon gerardii* Vitman., *Panicum virgatum* L., *Sporobolus heterolepis* Gray., *Bouteloua curtipendula* (Michx.) Torr., *Bouteloua gracilis* (H.B.K.) Lag. ex. Steud., *Lolium multiflorum* Lam., *Lotus corniculatus* L. 'Empire', *Bromus inermis* Leyss., *Lespedeza stipulacea* Maxim., *Trifolium hybridum* L., *Medicago sativa* L. 'Vernal', and *Poa pratensis* L. 'Park' were placed between the glass of a test tube and a sheet of moistened filter paper. The initial root length was marked and the seeds were grown at a constant temperature for 48 hours. Then root growth was measured. The experiment was conducted at 5°C increments between 12°C and 37°C and at 47°C. A negligible amount of radicle growth occurred at 47°C for all species. The seminal root growth of all species remained low between 12°C and 17°C. Optimum growth occurred at 22°C for *L. multiflorum*, 27°C for *B. inermis*, and 32°C for *P. virgatum*, *A. gerardii*, and *L. stipulacea*. In the other species optimum growth occurred over a range of temperatures from 22°C to 32°C. *P. pratensis*, *L. multiflorum*, and *B. inermis*, cool season C-3 grasses, had negligible growth at 37°C, whereas *B. curtipendula*, *P. virgatum*, *A. gerardii*, and *B. gracilis*, warm season C-4 grasses, had significant radicle growth at that temperature.


## Introduction

Soil temperature and soil moisture are decisive factors in determining if plant establishment will be successful. Optimum temperature and moisture conditions are especially important in areas where vegetative growth is limited, such as highway slopes and stripmine spoils (McKee et al., 1965). Adequate soil temperature and

and moisture conditions may persist long enough to allow germination, but their continued presence is also required for a seedling to complete its heterotrophe stage of growth. At the same time, the rapidity with which this stage of grass establishment is completed closely corresponds to the early growth characteristics of the species or variety (Henderlong, 1971). Since the surface layers of soils tend to have a low moisture content and wide temperature fluctuations, the characteristic ability of a species to cope with broad temperature ranges and the speed of its root growth to soil layers with a higher moisture content becomes extremely important (Curry, 1980; Geiger, 1966; McWilliam, 1977).

According to McWilliam (1977), the temperature a grass encounters is even more important than rainfall in determining its relative abundance in a particular location. Temperature effects all processes, especially those involving active growth such as early seedling development. According to Cohn and Tadmor (1969) the temperature response varies depending on the species. The dependency of temperature response on the species is evident in the adaptation of grasses to different climates and to different growth cycles (Hughes, 1965). Morrow and Power (1979) found that in a study involving Bromus inermis, Bouteloua spp., Agropyron spp. and Elymus spp. that cool season grasses grew taller and more rapidly at a lower soil temperature than did the warm season grasses.

Besides temperature being important in determining the rate of seedling growth other factors are involved. Seed size is an important factor in deciding the amount or rate of seedling growth in many herbaceous species. Grasses with larger seed sizes have more radicle growth than do smaller seeded species (Curry, 1980). If seed size determines the amount of radicle growth, then by using larger seeded species, early seedling growth could be improved.

The purpose of this study was to evaluate the effects of a constant temperature on radicle growth of plants commonly used in erosion control along roadsides.

## Materials and Methods

Seed of Andropogon gerardii Vitman., Panicum virgatum L., and Sporobolus heterolepis Gray. were placed in a plastic 9cm petri dish on top of two pieces of Whatman #1 9cm filter paper, moistened with 2ml distilled water. Two more pieces of filter paper also moistened with 2ml distilled water were placed on top of the seed. A piece of freezer tape was then run across the top of the petri dish to hold it together. The petri dishes were sealed inside polyethylene bags, which allowed limited gas exchange (Hartman and Kester, 1973). They were stored in a refrigerator at 4°C. Seed of S. heterolepis, A. gerardii, and P. virgatum were stratified for 7, 8, and 9 weeks, respectively.

The stratified seed and untreated seed of Bouteloua curtipendula (Michx.) Torr., Bouteloua gracilis (H.B.K.) Lag. ex. Steud., Lolium multiflorum Lam., Lotus corniculatus L. 'Empire', Bromus inermis Leyss., Lespedeza stipulacea Maxim., Trifolium hybridum L., Poa pratensis L. 'Park' and Medicago sativa L. 'Vernal' were sized according to weight (Table IV-1). The B. curtipendula seed were cleaned of chaff before weighting. A procedure similar to that for stratification was followed in germinating the seed. Fifty seeds per 9cm petri dish were placed on top of two pieces of moistened filter paper, and two more moistened pieces of filter paper were used to cover the seed. The petri dishes were sealed inside polyethylene bags, placed in a laboratory drawer, and the seed allowed to germinate.

The petri dishes were opened when the radicles of the germinated seeds were approximately 5mm long. The petri dishes were opened after 36 hours for Bouteloua curtipendula, Andropogon gerardii, Panicum virgatum and Lespedeza stipulacea, 48 hours for Bouteloua gracilis, Medicago sativa, Lolium multiflorum, Bromus inermis, and Trifolium hybridum, 3 days for Sporobolus heterolepis, and 4 days for Poa pratensis and Lotus corniculatus. Selected seedlings were placed in 65mm x 15mm Kimax test tubes, between the glass of the test tube and a 5.5cm x 5.5cm piece of rolled Whatman #1 filter paper moistened with .5ml of distilled water. The test tubes were then sealed with rubber serum stoppers and the initial root length marked on the glass.

Test tubes containing seed were set in holes 1.8cm in diameter by 6cm deep drilled in a 91x21x8cm solid aluminum bar, so that all but the top 12mm of the tube were in the block. As Figure IV-1 shows, there were 56 holes in the bar spaced 4 per row for a total of 14 rows. Spacing within the row was 4.5cm apart and between the rows it was 5.0cm. Two 1.5cm circulating ports were drilled through the width of the bar at one end and interconnected with insulated Tygon tubing (Hensley, 1978). The desired temperature was maintained by passing deionized water heated or cooled by a Lauda/Brinkmann R-3 circulator (temperature range -20 to 100°C) through the circulation ports drilled

Table IV-1. Species, location where the seed was produced and seed size used in the fixed temperature aluminum bar experiment.

| Latin name | Common name | Location of seed production | Seed size used (mg) |
|---|---|---|---|
| 1. *Andropogon gerardii* | big bluestem | Illinois | 6.5* |
| 2. *Bouteloua curtipendula* | sideoats grama | Kansas | .5** |
| 3. *Bouteloua gracilis* | blue grama | Colorado | .5** |
| 4. *Bromus inermis* | smooth brome | Kansas | 3.0** |
| 5. *Lespedeza stipulacea* | Korean lespedeza | Montana | 2.2** |
| 6. *Lolium multiflorum* | annual ryegrass | Oregon | 2.7** |
| 7. *Lotus corniculatus* | empire birdsfoot trefoil | Canada | 1.5** |
| 8. *Medicago sativa* | vernal alfalfa | Idaho | 2.0** |
| 9. *Panicum virgatum* | switchgrass | Illinois | 2.5** |
| 10. *Poa pratensis* | park Kentucky bluegrass | Minnesota | .5** |
| 11. *Sporobolus heterolepis* | northern dropseed | Illinois | 2.3* |
| 12. *Trifolium hybridum* | alsike clover | Canada | .9* |

* ±.5mg The seed was stratified for 7 to 9 weeks at 4°C.

** ±.2mg

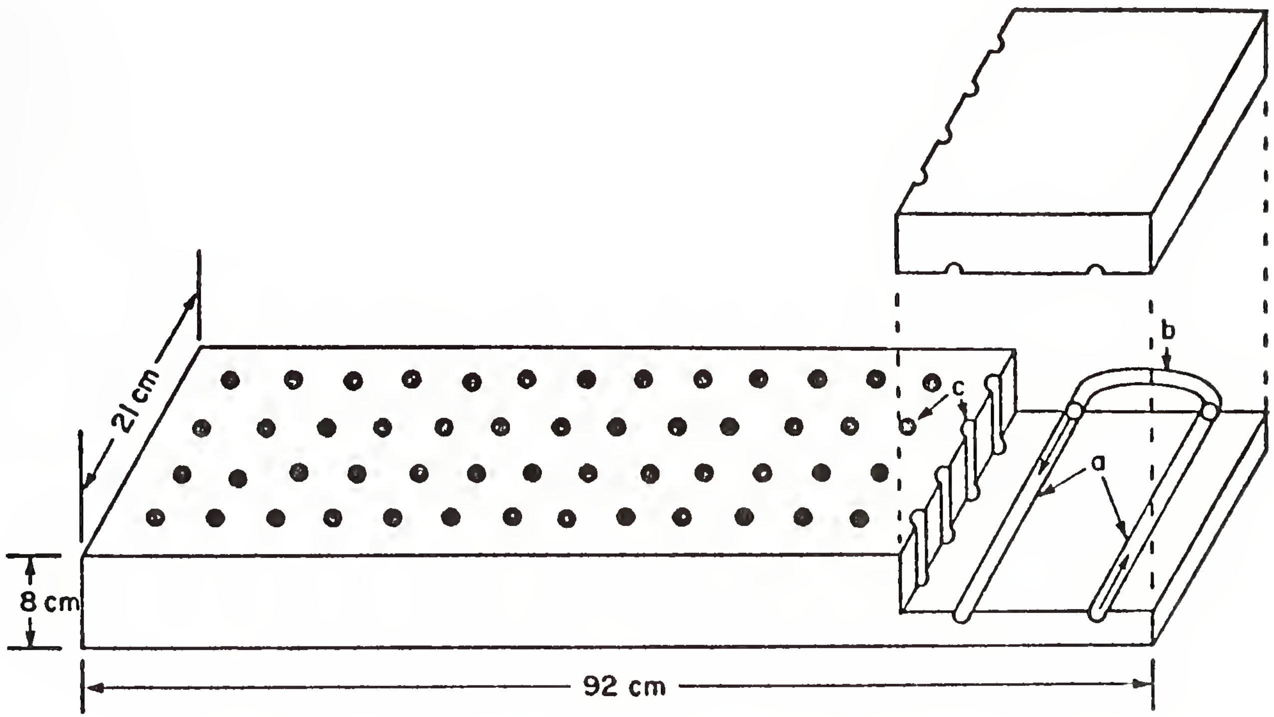



Figure IV-1. Cut-away view of the aluminum bar used to maintain a constant temperature showing: ports for circulation of water (a), tygon tubing (b), and holes for the test tubes containing seedlings (c).

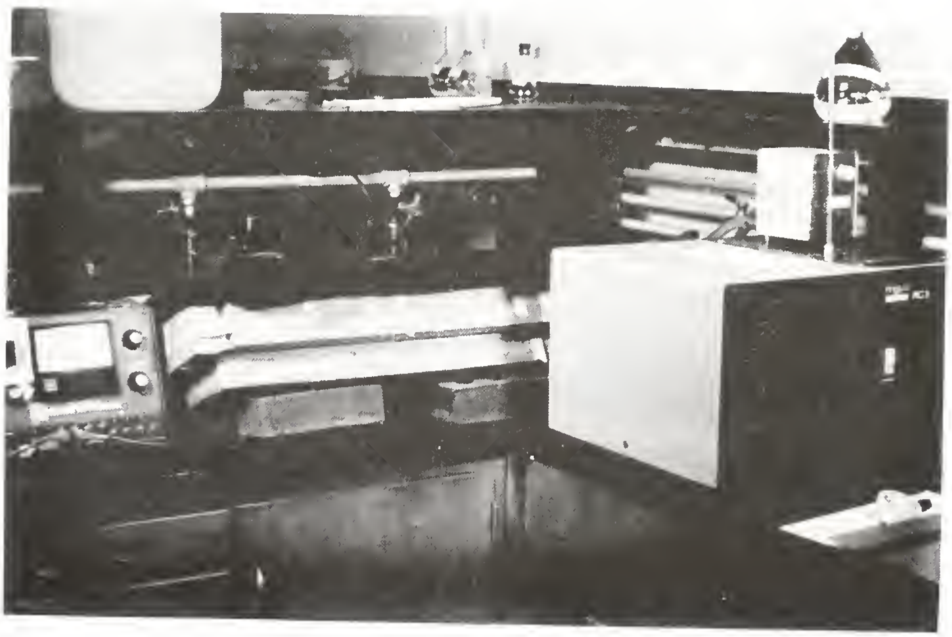


Figure IV-2. Overview of the aluminum bar, with insulation and the circulator.

in the bar (Figure IV-2). The bottom and sides of the bar were insulated with 3.5cm and 5cm of Styrofoam, respectively. The top was insulated with 2.5cm of Styrofoam, into which holes had been drilled to allow placement and extraction of test tubes. A 1.5cm thick covering of black cloth was then placed on top of the Styrofoam insulated bar to limit circulation of air into the holes and to ensure that the seedlings were in darkness. The bar was placed at a 22° angle from the horizontal.

The aluminum block was large enough to contain three replications of twelve seedlings (two per test tube) of three species. The experiment was a split plot design with replications and species within the split plot. The experiment was conducted at 5°C increments between 12°C and 37°C, and at 47°C. The bar temperature was monitored in two test tubes at approximately one-third and two-thirds the length of the bar using thermocouples with periodic readings of a telethermometer. The largest observed variation in temperature was ± 1.0 at 47°C. After 48 hours the test tubes were removed from the bar and the amount of radicle growth measured.

## Results and Discussion

The temperature-species interaction was found to cause significant differences in radicle growth. The response of early root development to a particular temperature was dependent on species as was also noted by Cooper (1977) who correlated the seedling growth response to temperature with seedling vigor. The general trend was that the rate of radicle growth was negligible below a certain temperature, rose to a maximum, and then declined as temperature continued to increase.

Similar temperature responses have been noted for other growth processes such as seed germination, seedling growth and root growth (Russell, 1973).

Negligible growth for all species was observed at 47°C, as can be seen in Figures IV-3 and IV-4 and Tables IV-2 and IV-3. At this temperature, the roots of the cool season species, Bromus inermis, Lolium multiflorum, and Poa pratensis appeared brown. This temperature was below the 50°C that Gist and Mott (1957) reported to be the lethal temperature for grasses.

Radicle growth was retarded until temperatures rose above 17°C. As Casnoff (1978) noted each plant species has a soil temperature at which root elongation ceases. Poor root growth at low temperatures has been reported to limit the distribution of C-4 warm season grasses (Teeri and Stowe, 1976). Within the category of warm season grasses, some grow better than others at lower temperatures, as is shown in comparing the amount of radicle growth of Bouteloua curtipendula to that of Panicum virgatum in the 12°C to 17°C temperature range (Figures IV-3 and IV-4). Ku and Edwards (1978) reported P. virgatum to be tolerant of cold night temperatures.

Between 17°C and 22°C there was a significant increase in the amount of radicle growth observed after 48 hours for each species. This increase can be seen by the change in slopes of the lines in Figures IV-3 and IV-4. A large increase in the amount of growth between 17°C and 22°C is different from that Levesque and Ketcheson (1963) reported for mature plants of Medicago sativa. They found root growth increasing more as temperature increased in the 10-18°C range than in the 18-26°C range.

Table IV-2. Mean** radicle growth in 48 hours for the six herbaceous species in Figure IV-3.

| Species | Temperature (°C) 12 | 17 | 22 | 27 | 32 | 37 | 47 |
|---|---|---|---|---|---|---|---|
| | | | | mm | | | |
| *Bouteloua curtipendula* | 1.3ab* | 1.3a | 24.5c | 29.7d | 39.2d | 27d | 0.5a |
| *Bouteloua gracilis* | 1.9ab | 3.6ab | 9.5a | 14.4b | 13.9b | 5.6b | 0.1a |
| *Lolium multiflorum* | 8.0c | 8.6c | 39.5d | 32.9e | 17.8c | 1.0a | 0a |
| *Lotus corniculatus* | 3.0b | 5.1b | 10.3a | 11.3a | 11.9b | 5.6b | 0.2a |
| *Medicago sativa* | 8.1c | 12.4d | 20.5b | 24.6c | 17.5c | 8.7c | 0.1a |
| *Poa pratensis* | 1.1ab | 3.0ab | 7.8a | 9.5a | 6.9a | .2a | 0a |

** Means are the average value of three replications of 12 observations each.

* Means within columns (temperatures) followed by the same letter are not significantly different by the Duncan Multiple Range Test at the .05 significance level.

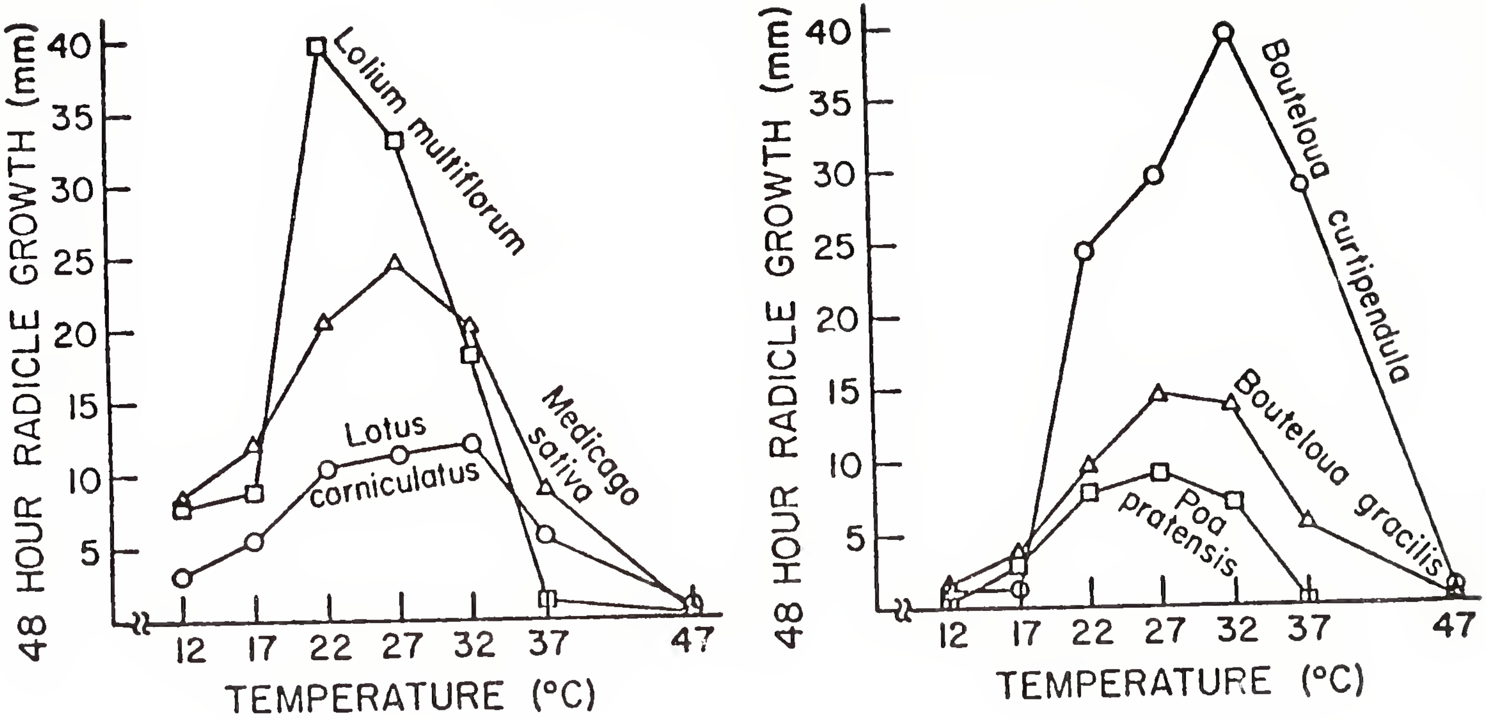



Figure IV-3. Temperature response* of seedling radicles during a 48 hour period.

* The temperature response is the mean radicle growth in mm, which is the average of 3 replications of 12 observations each.

Table IV-3. Mean** radicle growth in 48 hours for the species in Figure IV-4.

| Species | Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|---|
| *Andropogon gerardii* | 2.2abc* | 6.0b | 16.9b | 28.4d | 28.4c | 19.5c | 0a |
| *Bromus inermis* | 5.8d | 9.8c | 19.3b | 30.3d | 15.5b | 1.2a | 0a |
| *Lespedeza stipulacea* | 4.8cd | 9.6c | 23.3c | 28.2a | 35.5d | 30.6d | 0a |
| *Panicum virgatum* | 1.4ab | 3.9ab | 15.8b | 22.9c | 30.4c | 22c | .1a |
| *Sporobolus heterolepis* | 0.6a | 1.9a | 5.9a | 8.1a | 6.2a | 2.8a | 0a |
| *Trifolium hybridum* | 3.9bc | 6.8b | 14.9b | 16.2b | 19.9b | 9.9b | .1a |

** Means are the average value of 3 replications of 12 observations each.

* Means within columns (temperatures) followed by the same letter are not significantly different by the Duncan Multiple Range Test at the .05 significance level.

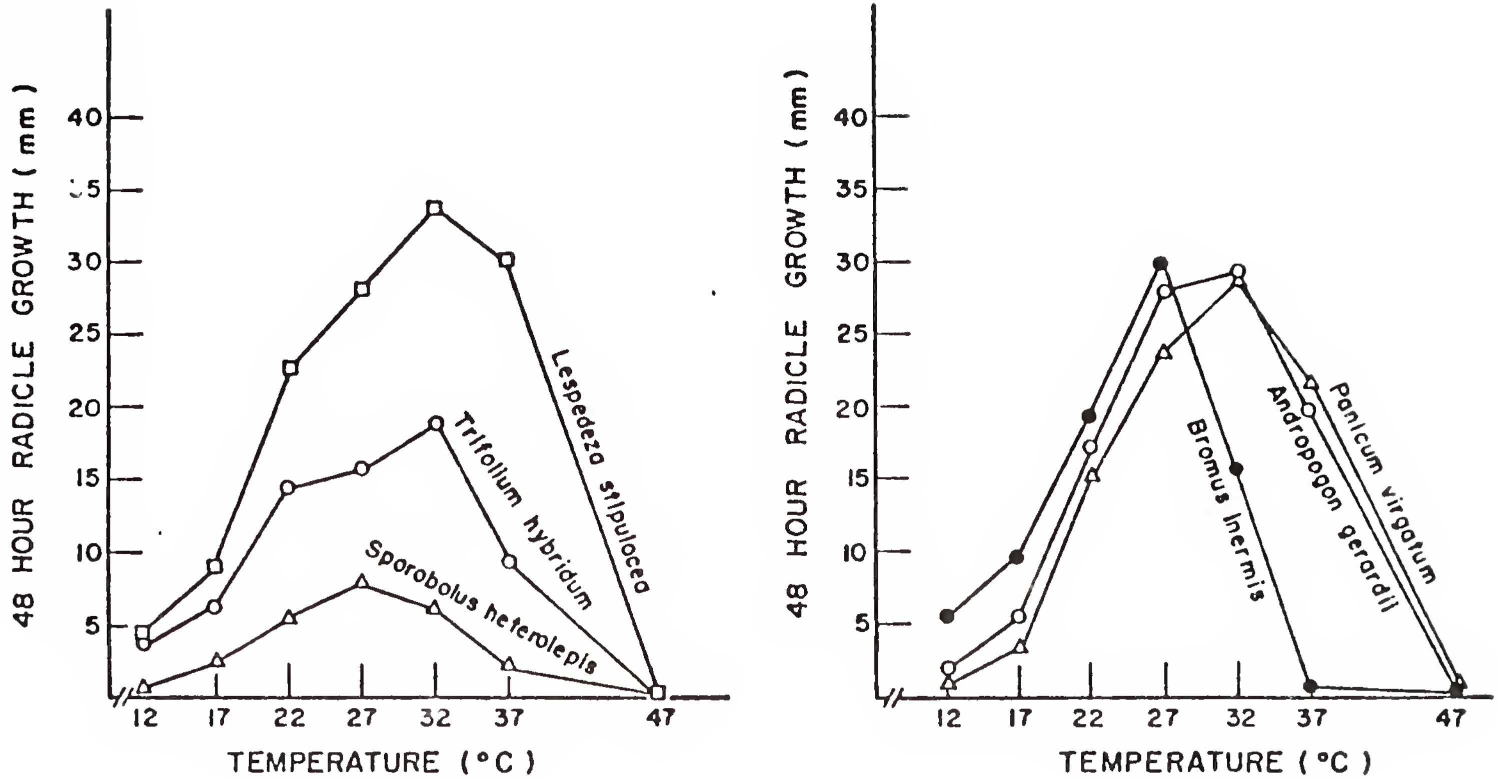



**Figure IV-4.** Temperature response* of seedling radicles during a 48 hour period.

* The temperature response is the mean radicle growth in mm, which is the average of 3 replications of 12 observations each.

The importance of an increase in temperature from 17°C to 22°C can be observed in the substantial increases that took place in the growth of *Lolium multiflorum* and *Bouteloua curtipendula*. Since an increase in growth was observed for all species it is doubtful that this temperature response is due to a species specific temperature lesion (Ketellaper, 1963; Langridge, 1963). The similarity in response of *L. multiflorum* and *B. curtipendula* to the change from 17°C to 22°C is especially interesting in light of differences in their genotypes. *L. multiflorum* is a cool season grass that has a C-3 photosynthetic pathway, while *B. curtipendula* is a warm season grass with a C-4 photosynthetic pathway. The legumes used also showed a significant, although less dramatic response to the increase in temperature from 17°C to 22°C. The response of radicle growth tends to support the idea that the reason for the increase in the rate of radicle growth at 22°C over that at 12°C to 17°C was due to some general physical change occurring within the plant's cells.

At 22°C, *Lolium multiflorum* reaches its peak amount of radicle growth per 48 hour period. This optimum temperature is similar to that observed by Neilsen (1974) for the growth of many temperate crops. It corresponds to temperatures encountered in the early spring and late fall. Spedding and Diekmans (1976) reported that in spring and late fall much of the growth of *L. multiflorum* occurred. Also, at 22°C, *Lotus corniculatus*, *Poa pratensis*, *Trifolium hybridum*, and *Sporobolus heterolepis* reached a plateau in the amount of seminal root growth. This is near 24°C, where Kunelius and Clark (1970) observed a peak of root growth for mature plants of *L. corniculatus* 'Empire'.

Kunelius and Clark (1970) also noted that lack of vigor and competitive ability of Lotus corniculatus compared to other legumes, manifests itself in the early non-photosynthetic stages of development. It is interesting that the four species with the least amount of radicle growth observed, Sporobolus heterolepis, L. corniculatus, Poa pratensis, and Bouteloua gracilis are the hardest to establish. But with B. gracilis the rate of radicle growth is not related to drought tolerance, because it has an excellent ability to withstand droughts. Smoliak and Johnston (1968) stated that species that germinated well under a wide range of temperature and moisture conditions and that are easy to establish did not withstand drought when mature. This statement is an oversimplification especially when legumes like Medicago sativa are considered.

Above 22°C the rate of seminal root growth observed for L. multiflorum decreases rapidly, whereas that for the remaining species is either increasing or constant. At 27°C, Bromus inermis had its optimum rate of radicle growth. Also, 27°C was the temperature Smoliak and Johnston (1968) reported to produce the longest roots in mature plants of B. inermis. As Cooper (1977) found, each legume has its own specific optimum growth temperature. Lespedeza stipulacea had its optimum rate of radicle growth occurring at 32 and 37°C. The 32-37°C range was the highest optimum temperature noted for any of the species used, and could indicate that this species has promise for warm season seeding. The results for Medicago sativa were consistent with the findings of Nielsen et al. (1960), who found the optimum temperature for root growth of mature plants was at 19 to 27°C.

Medicago sativa, Trifolium hybridum, Lotus corniculatus, Bouteloua gracilis, and Poa pratensis did not exhibit the sharp peak in amount of radicle growth as was observed for Bromus inermis, Lolium multiflorum and Bouteloua curtipendula. The latter three species had a narrow range in which optimum radicle growth was observed. Thus, a change of 5°C for those species could cause a large change in the amount of radicle growth occurring in a 48-hour period. This type of temperature response may have implications in the establishment of B. inermis, L. multiflorum, and B. curtipendula in either the early spring or late fall, when soil surface temperatures can fluctuate widely.

The C-4 warm season grasses had optimal growth at higher temperatures than did the C-3 cool season species. Vengris (1969) reported that cool season grasses stopped growth at 35°C, whereas warm season grasses grew unchecked at that temperature. Thus, for example, B. gracilis had its optimum radicle growth between 27°C and 32°C. A similar optimum temperature has been observed for seed germination and adventitious root growth, all processes occurring early in the life cycle of the plant (Bokhari et al., 1974; Briske and Wilson, 1977). Optimum root temperatures similar to this range also have been noted for tropical crops such as sorghum and cotton (Morrow and Power, 1979; Russell, 1973). Differences in optimum temperatures for growth are especially important in trying to design compatible seeding mixtures (Henderlong, 1971).

The difference between C-3 and the C-4 grasses was most evident at 37°C, where the amount of radicle growth for Lolium multiflorum, Bromus inermis, and Poa pratensis was negligible, whereas a significant amount of growth was observed for Andropogon gerardii, Panicum virgatum, Bouteloua curtipendula and Bouteloua gracilis. Since seedlings were in the hetertrophic stage of growth, photosynthetic differences could not have occurred between the two categories of grasses, and definitely suggested the possibility of genetic differences leading to biochemical dissimilarities. According to McWilliams (1977), exposure to prolonged temperatures above 35°C is usually lethal for cool season grasses, but following emergence most species become increasingly heat tolerant. The species specific response to high temperature appears to be different than the general response of all species to a change in temperature from 17°C to 22°C. As noted the latter response is possibly due to a physical change in the cells themselves.

The response of a plant to temperature varies immensely. One factor of importance is the climatic adaptation of a species. Most plants exhibit an underlying genetic adaptation to the thermal environment of their origin (McWilliams, 1977). Thus, for example, species like Bouteloua curtipendula, B. gracilis, Andropogon gerardii, and Panicum virgatum, all native to the American plains, require adequate seminal root growth when the soil temperature is warm to keep up with the drying of the soil. The climatic adaptation of a species can be important in the use of popular turfgrasses like Poa pratensis in areas where they are not normally adapted (Younger and Nudge, 1976).

Not only does the optimum temperature for a species depend on its climatic adaptation, but it also varies depending on a plant's stage of development, the tissue or organ of concern, and the strain or variety used (Beever and Cooper, 1964; Dotzenko et al., 1976). For example, radicle growth of Poa pratensis 'Park' was optimum between 22 and 32°C, whereas Baker and Jung (1968) reported a narrower range (27-32°C) optimal for herbage growth of Poa pratensis, with varieties varying considerably.

Seed size between species does not seem to be important in the initial rate of seminal root growth. This is evident in the amount of growth the small seeded Bouteloua curtipendula had at its optimum temperature for radicle growth, which was 39.2mm at 32°C. It was not significantly different than the amount Lolium multiflorum, a larger seeded grass, had its optimum temperature, which was 39.5mm at 22°C. Thus, even though L. multiflorum has larger seeds the total length of its radicle was not significantly different from B. curtipendula when growth at their respective optimum temperatures were compared. Seed size is probably more related to the amount of time over which growth can occur before reserves are exhausted. The amount of growth in 48 hours would be correlated with the ability and rate of mobilization of endosperm reserves more directly than to the actual reserves present (Asher and Ozanne, 1966).

## Conclusions

Radicle growth response to temperature varies depending on the species. Lolium multiflorum reaches its peak rate of radicle growth in a 48-hour period at 22°C. Bromus inermis has an optimum temperature for radicle growth at 27°C, and Bouteloua curtipendula reaches its peak radicle growth at 32°C. All three species have a narrow range of temperatures at which optimum growth occurs. A change in temperature of as little as 5°C will cause a large change in seminal root growth thus restricting establishment. The general trend is that at the cooler temperatures (12-17°C) root growth is inhibited. As the temperature increases, the rate of radicle growth increases until an optimum temperature is reached. Above that point the rate of radicle growth decreases as temperature increases.

The C-4 grasses Bouteloua curtipendula, B. gracilis, Panicum virgatum, and Andropogon gerardii had a significant amount of growth at 37°C, whereas the C-3 grasses Lolium multiflorum, Bromus inermis, and Poa pratensis had a negligible amount of growth. Root growth differences could be important in the summer seeding of grasses.

The legumes used, Lespedeza stipulacea, Lotus corniculatus, Medicago sativa, and Trifolium hybridum, generally had a broad range of temperatures over which optimal radicle growth occurred. L. stipulacea is especially interesting, because it has an optimal temperature for radicle growth between 32°C and 37°C. Thus, L. stipulacea may have potential for use in summer seeding.

Poa pratensis, Bouteloua gracilis, Lotus corniculatus and Sporobolus heterolepis are hard to establish through seeding, and they also have the least amount of radicle growth. Thus, radicle growth may have an influence on the ease of establishment of a species.

Seed size is of little importance in the rate of seminal root growth. Instead ability to mobilize storage products at a rate fast enough to supply the processes involved in radicle growth is probably important. Thus trying to select species with large seed size to improve the rate of seminal root growth would not be important.

Instead selection should depend on those species whose seminal root growth is optimum at the temperatures encountered.

# CHAPTER V. RADICLE GROWTH OF SELECTED SPECIES UNDER VARYING ENVIRONMENTAL CONDITIONS

## Abstract

Seedlings of Lolium multiflorum, Lespedeza stipulacea, and Bouteloua curtipendula were grown in 12 hour alternating temperature cycles of 10/18°C, 18/26°C, 24/32°C, 30/38°C, and 36/44°C. L. multiflorum had its optimum radicle growth at 24/32°C, whereas the optimum growth of L. stipulacea was at 24/32°C and 30/38°C and the optimum growth of B. curtipendula was in the 30/38°C regime. Radicle growth of all species was stunted when compared to that occurring at similar constant temperatures.

Seedlings of the same three species were also grown at 22, 27, 32, and 37°C in three different concentrations of polyethylene glycol 20,000 (average molecular weight 15,000-20,000): 20g solute/100ml distilled water, 25g solute/100ml distilled water, and 30g solute/100ml distilled water. Radicle growth rate decreased with increasing levels of polyethylene glycol. Radicle growth was less at 32°C and 37°C than at cooler temperatures for L. multiflorum and L. stipulacea. Polyethylene glycol induced water stress also caused a shift in the temperature for optimal radicle growth in comparison to the optimal temperature in distilled water. The shift was from 27-37°C to 27-32°C for L. stipulacea, from 22°C to 27°C for L. multiflorum, and from 32-37°C for B. curtipendula.

## Introduction

In surface or shallow seeding of herbaceous species on roadsides fluctuating or alternating temperatures are encountered by germinating seeds. These fluctuating temperatures are from the rapid heating and cooling of the soil surface layers due to a variety of environmental influences (Bokhari et al., 1974). Alternating temperatures would be expected to have a different effect on plant growth then if a constant temperature has been maintained. McElgunn (1973) found with Medicago sativa, Lotus corniculatus, and a Melilotus sp. that cold alternating temperatures such as those encountered in the spring reduced both rate of germination and total germination of these species, whereas cold constant temperatures reduced only rate of germination. Jackobs et al. (1967) reported that the germination rate of Cynodon dactylon was increased under alternating temperatures compared to the rate under constant temperatures.

As with most plant regulating factors, temperature is modified and sometimes masked by other enviromental parameters (Rosenquist and Gates, 1961). One of the more important of these is soil moisture. Often an emerging radicle is not only exposed to unfavorable soil temperature regimes, but also to low levels of available moisture. Temperature also will affect the rate of water uptake, thus intensifying any existing problems (Rosenquist and Gates, 1961). Soil temperature is a critical factor in water uptake, because each species is characterized by its own temperature optimum for water absorption. Also, biological processes of different species or cultivars cease at differing temperatures. Thus, Stone et al. (1979) found with Medicago sativa that the osmotic potential at which germination ceased depended both on cultivar and on temperature.

The general trend is that as moisture tension increases, emergence of a species and its ability to survive decreases. One reason is that a large amount of early seedling growth involves cell elongation with water uptake by preformed cells. Thus, adequate levels of soil moisture and temperature are required for seedling growth. Ohlenbush (1966) reported that rain, even at low soil temperatures, aided in the emergence of *Andropogon barbinodis*, *Leptochola clubia*, and *Bouteloua curtipendula*, whereas McGinnies (1960) found that as moisture stress (from mannitol) increased, germination was delayed or reduced.

In germination studies, numerous agents have been used to create an osmotic potential in a solution. Solutes used include sodium chloride, sucrose, mannitol, glycol, and polyethylene glycols (carbowax). The germination of seed in contact with an aqueous solution of one of the solutes depends on the extent of permeability of the seed coat to the solute, and whether the solute is toxic (Manohar, 1966). A major criticism of much of the work with sodium chloride, glycol, sucrose, and mannitol is that these solutes penetrate the germinating seed (McWilliam et al., 1970; Manohar, 1966). The solutes enter the seed through the micropyle, whereas the micropyle acts as a semipermeable membrane to polyethylene glycols above 4000 molecular weight (Manohar, 1966; McWilliam et al., 1970). For this reason polyethylene glycols are most widely used as an osmotic agent in germination studies (Thrill et al., 1979). Two major problems exist with polyethylene glycols. First of all there is a reduction in osmotic potential of dilute polyethylene glycol solutions with time, and secondly the relationship of osmotic potential to concentration is curvilinear, unlike mannitol (Thrill et al., 1979).

Thus, in trying to predict the effect of temperature on radicle growth, it is important to consider alternating temperatures and the interaction of temperature with other environmental parameters, such as moisture availability. The purpose of these two experiments was to expand on the data obtained in the previous experiment. Also, for the alternating temperature experiment, an objective was to see if suboptimal temperatures would have a residual effect on radicle growth. The purpose of the polyethylene glycol experiment was to determine the response of the three species to the interaction of polyethylene glycol induced osmotic stress and temperature.

## Materials and Methods

### Experiment 1. Effects of Alternating 12-Hour Temperature Cycles on the Amount of Radicle Growth in a ~~47~~ 48-Hour Period.

Sized seeds of *Bouteloua curtipendula*, *Lolium multiflorum*, and *Lespedeza stipulacea* were germinated using a previously explained method (described in Chapter III). Two germinated seed were then selected for uniformity and placed inside a test tube which contained a rolled square of Whatman #1 filter paper, moistened with .5ml distilled water. Test tubes were sealed with rubber serum stoppers and placed inside the aluminum temperature gradient bar (described in Chapter III).

To minimize fluctuations from temperature changes across the length of the bar, only the two-thirds of the bar furthest from the circulation ports was used. There were enough holes in this section of the bar to allow for two replications of each species with six test tubes per species (two seed per test tube). Each alternating temperature regime was then replicated twice over time. Thus the experiment was a split-split plot design.

The temperature of the bar was maintained by a Lauda/Brinkman R-3 circulator whose temperature setting was manually altered every 12-hours. The circulator gave temperature regimes of 10/18°C, 18/26°C, 24/32°C, 30/38°C, or 36/44°C. Figure V-1 is an example of the actual temperature regimes obtained in comparison with those found for a 20cm depth of bare surfaced soil at the Purdue University Agronomy Farm. Temperatures were monitored continuously throughout the course of the experiment using a thermocouple recorder with 5 calibrated thermocouples evenly spaced throughout the length of the bar. Periodic temperature readings also were taken using a telethermometer. The largest temperature variation found was ± 2°C, obtained when the bar temperature setting was altered. At 10°C, 38°C, and 44°C, there was also a gradiation of temperature as can be seen in Figure V-1. This gradiation was at most ± 1°C.

The germinated seeds were grown for 48 hours under an alternating temperature regime. After this period, the test tubes were removed from the bar and the increase in radicle growth was measured.

Experiment 2. The Interaction of Constant Temperatures and Polyethylene Glycol Induced Water Stress on the Amount of Radicle Growth in a 48-Hour Period

Three solutions of polyethylene glycol (PEG) 20,000 (average molecular weight 15,000-20,000) were prepared according to the method described by Thrill et al. (1979). The concentrations used were 20g PEG/ 100ml distilled water, 25g PEG/ 100ml distilled water, and 30g PEG/ 100ml distilled water to give solutions with osmotic potentials of approximately 4, 7, and 9 bars respectively (Thrill et al., 1979;

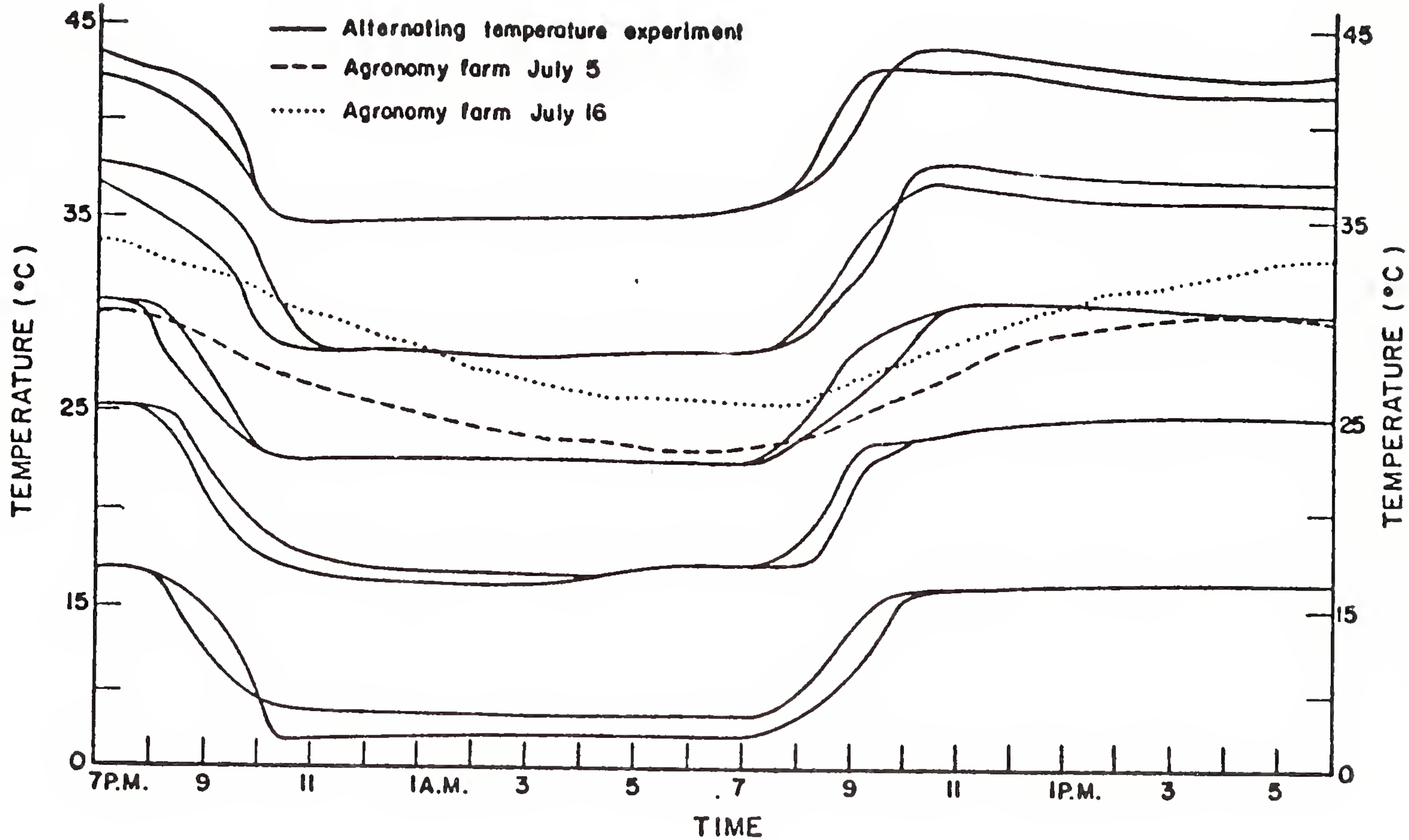



Figure V-1. Twenty-four hour temperature cycles for the alternating temperature experiment and a bare soil at the Purdue Agronomy Farm.

Manohar, 1966). These solutions were then used to moisten a $3m^2$ piece of Whatman #1 filter paper, which was rolled inside a 65mm x 15mm Kimax test tube.

Seeds of Bouteloua curtipendula, Lolium multiflorum, and Lespedeza stipulacea were germinated between pieces of moistened filter paper inside petri dishes sealed in polyethylene bags. Seedlings were then placed betweeen the rolled piece of filler paper and the test tube wall. Tubes were placed in the bar at a constant temperature of either 22°C, 27°C, 32°C, or 37°C. Temperatures were monitored with three thermocouples placed at one-quarter intervals the length of the bar and periodically read with a telethermometer. The last two rows of holes closest to the ports for the circulation of water were not used in effort to minimize the temperature variation observed over the length of the bar. The largest temperature variation observed was ± 1.2°C at 37°C. The section of the bar used was large enough to allow for ten seedlings (2 seedlings/ test tube) of each species to be exposed to each concentration of PEG. There were three replications of each bar temperature over time. The experiment was a split plot design. The seedlings were allowed to grow for 48 hours and then the increase in radicle length was measured.

## Results and Discussion

### Experiment 1. The Effects of Alternating 12-Hour Temperature Cycles on the Amount of Radicle Growth in a 48-Hour Period

The interaction between species and alternating temperature regimes was found to be significant with the rate of radicle growth dependent on the alternating temperature regime. The general trend was that as the temperature regime increased, the amount of radicle growth in a 48-hour period increased until a certain temperature regime, then the amount decreased in higher temperature regimes (Table V-1 and Figure V-2).

The rate of radicle growth for Bouteloua curtipendula, Lespedeza stipulacea and Lolium multiflorum was similar in the 10/18°C temperature regime, with radicle growth appearing to be stunted by the low temperatures. In the 18/26°C termperature regime, the growth of Lolium multiflorum was significantly greater than that of either of the other two species. This temperature regime is similar to the 18/27°C regime which Watschke et al. (1970) found best for root production of Poa pratensis another cool season C-3 grass.

The most radicle growth in a 48-hour period for both Lolium multiflorum and Lespedeza stipulacea occurred in the 24/32°C regime. The rate of radicle growth for Bouteloua curtipendula was still stunted at this temperature regime, and was not significantly greater than the amount of radicle growth in a 48-hour period observed in the 18/26°C temperature range. Bokhari et al. (1974) reported a temperature regime (18/29.5°C) intermediate to these regimes as the best for Bouteloua gracilis germination.

In the 30/38°C temperature regime there was a substantial decrease in the amount of radicle growth of Lolium multiflorum, whereas the amount of radicle growth of the other two species remained the same or increased. The most root growth of Bouteloua curtipendula occurred under this regime. In the highest temperature regime (36/44°C), B. curtipendula performed best of the three species but the high temperatures

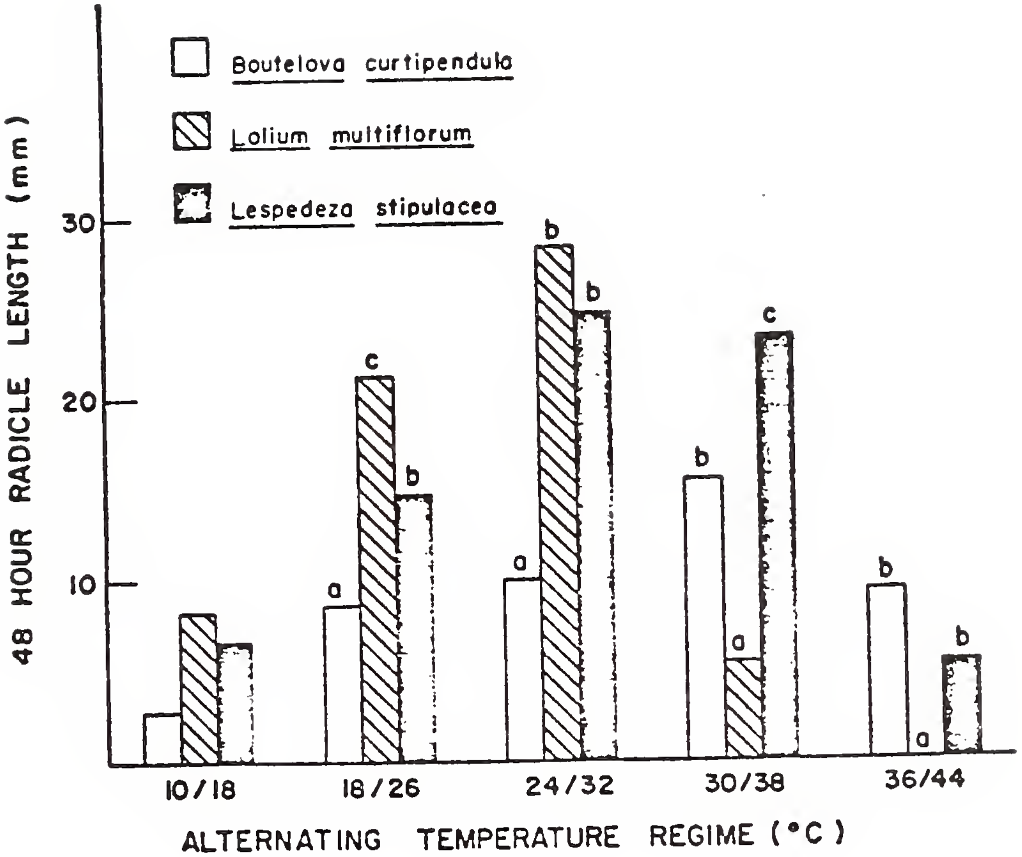



Figure V-2. Effect of alternating temperature on radicle growth of three selected species*.

* Mean separation within temperature regimes by Duncan's Multiple Range Test at the .05 level.

Table V-1. Radicle growth in a 48-hour period under five alternating temperature regimes.

| Species | Alternating Temperature Regime (°C) 10/18 | 18/28 | 24/32 | 30/38 | 36/44 |
|---|---|---|---|---|---|
| | | | mm | | |
| Bouteloua curtipendula | 5a* | 9ab | 10b | 16c | 9ab |
| Lolium multiflorum | 8b | 21c | 28d | 8d | 0a |
| Lespedeza stipulacea | 7a | 15b | 25c | 24c | 8a |

* Means are the average value of four replications 12 observations per replication rounded to the nearest whole mm. Means within rows followed by the same letter are not significantly different by the Duncan Multiple Range Test at the .05 level.

had an inhibitory effect on the amount of seedling root growth.

Figure V-3 compares the results obtained under constant temperatures to those obtained under alternating temperatures. The amount of radicle growth was less in the alternating regimes than that obtained in the constant temperature regimes. The differences were especially evident that the optimal temperatures for radicle growth of each species. In the constant temperature regime at their optimal temperature Lolium multiflorum and Bouteloua curtiphendula both had approximately 40mm of radicle growth in a 48-hour period, whereas with alternating temperatures the greatest radicle growth was 28mm for L. multiflorum and 16mm for B. curtipendula. Thus, alternating temperatures appeared to retard radicle growth. This could be due to some residual effect of the extreme (or most unfavorable) temperature of the regime, or just form a slower growth rate occurring at the most unfavorable temperatures of the regime.

At the coldest alternating temperatures (10/18°C) the rate of seminal root growth was similar to that at either 12 or 17°C constant temperatures. This observation indicates that radicle response to temperature over this range is fairly constant. Also the temperature optimum is shifted in alternating temperatures. The optimal alternating temperature regime for radicle growth of Lolium multiflorum is higher, while the optimal regimes for root growth of Lespedeza stipulacea is still in the same range as the best constant temperatures.

Thus the response of the selected species to alternating temperature was different than from the constant temperature regimes. Not only was the amount of radicle growth less in the alternating had an inhibitory effect on the amount of seedling root growth.

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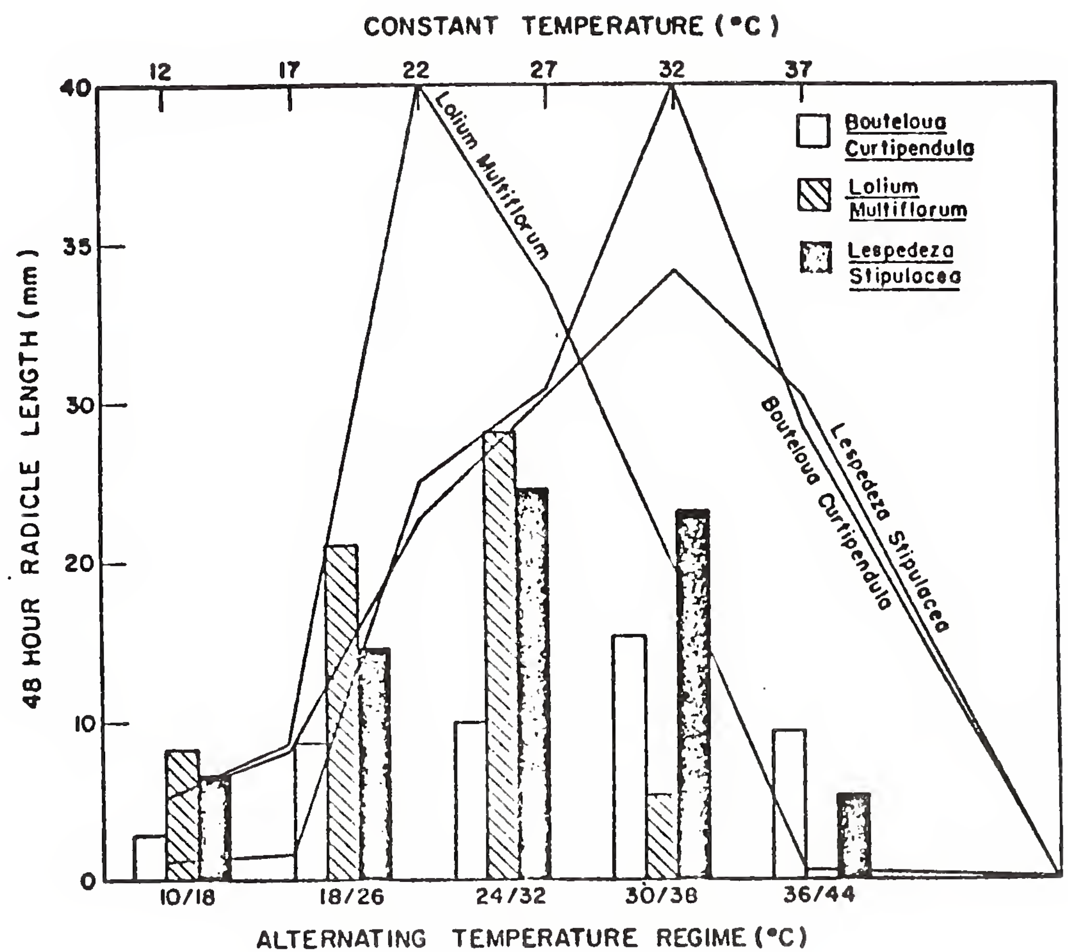


Figure V-3. Comparison of radicle growth obtained using an alternating temperature regime with that obtained using a constant temperature regime.

temperature regimes, but also for Lolium multiflorum the optimum temperature range for radicle growth was shifted.

### Experiment 2. The Interaction of Constant Temperatures and Polyethylene Glycol Induced Water Stress on the Amount of Radicle Growth in a 48-Hour Period

The interaction of temperature and PEG induced water stress was found to have a significant effect on the rate of radicle growth in a 48-hour period. Increasing concentrations of PEG caused radicle growth to decrease. The concentration of PEG also shifted the temperature at which optimal radicle growth occurred (Table V-2).

Figure V-4 shows the results for Lespedeza stipulacea. The lowest concentration of PEG did not cause a significant decrease in radicle growth compared to growth in distilled water. At 22°C and 27°C radicle growth in the 25g/100ml concentration of PEG was similar to growth in the distilled water control. The similarity in growth rates could be due to the higher temperature placing more of a moisture requirement on the seedling or hampering its ability to obtain moisture, while at cooler temperatures the seedling was able to obtain an adequate level of moisture.

The results for Bouteloua curtipendula were different as is seen in Figure V-5. At 22°C, 27°C, and 32°C none of the PEG concentrations allowed as much growth as did distilled water. As the temperature increased, the amount of radicle growth for the 20g/100ml concentration of PEG improved in comparison to distilled water. Thus at 37°C it appears that temperature was more inhibitory to radicle growth than was low amounts of PEG induced moisture stress.

Table V-2. Effect of temperature and polyethylene glycol induced water stress on radicle growth of three species.

<u>Lespedeza stipulacea</u>

| Concentration* | Temperature (°C) 22 | 27 | 32 | 37 |
|---|---|---|---|---|
| | | mm | | |
| distilled water | 22a** | 28ab | 35b | 30b |
| 20 | 16a | 24b | 36c | 23ab |
| 25 | 11a | 24b | 25b | 13a |
| 30 | 9a | 13ab | 17b | 10ab |

<u>Bouteloua curtipendula</u>

| Concentration | Temperature (°C) 22 | 27 | 32 | 37 |
|---|---|---|---|---|
| | | mm | | |
| distilled water | 26a | 30a | 40b | 27a |
| 20 | 10a | 18b | 20b | 23b |
| 25 | 10a | 22b | 13a | 12a |
| 30 | 6a | 15bc | 17c | 11ab |

<u>Lolium multiflorum</u>

| Concentration | Temperature (°C) 22 | 27 | 32 | 37 |
|---|---|---|---|---|
| | | mm | | |
| distilled water | 40d | 32c | 18b | 1a |
| 20 | 20c | 35d | 10b | 0a |
| 25 | 14c | 22d | 7b | 0a |
| 30 | 10c | 14c | 5b | 0a |

* The concentration is in g polyethylene glycol/100ml distilled water.

** Means are the average value of three replications, 10 observations rounded to the nearest mm. Means within rows followed by the same letter are not significantly different by the Duncan Multiple Range Test at the .05 level.

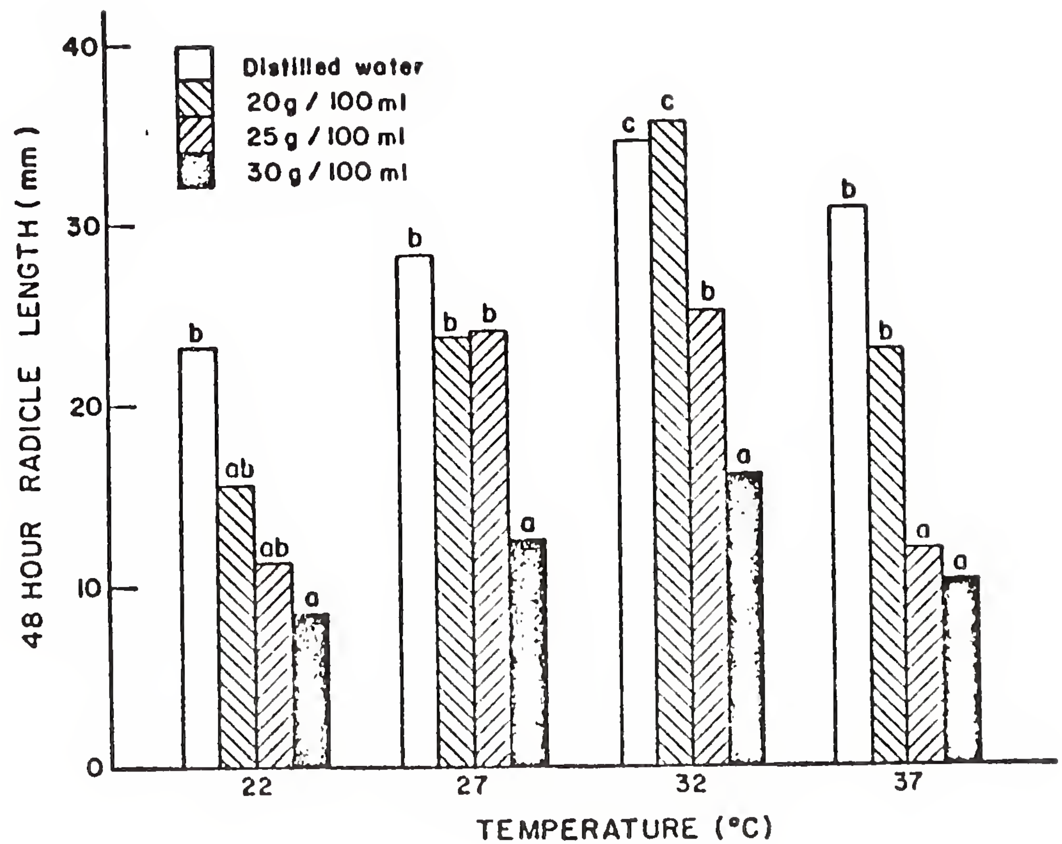


Figure V-4. Effect of temperature and polyethylene glycol induced osmotic stress on radicle growth of Lespedeza stipulacea*.

* Means within temperature denoted by the same letter are not significantly different by the Duncan Multiple Range Test, .05 level.

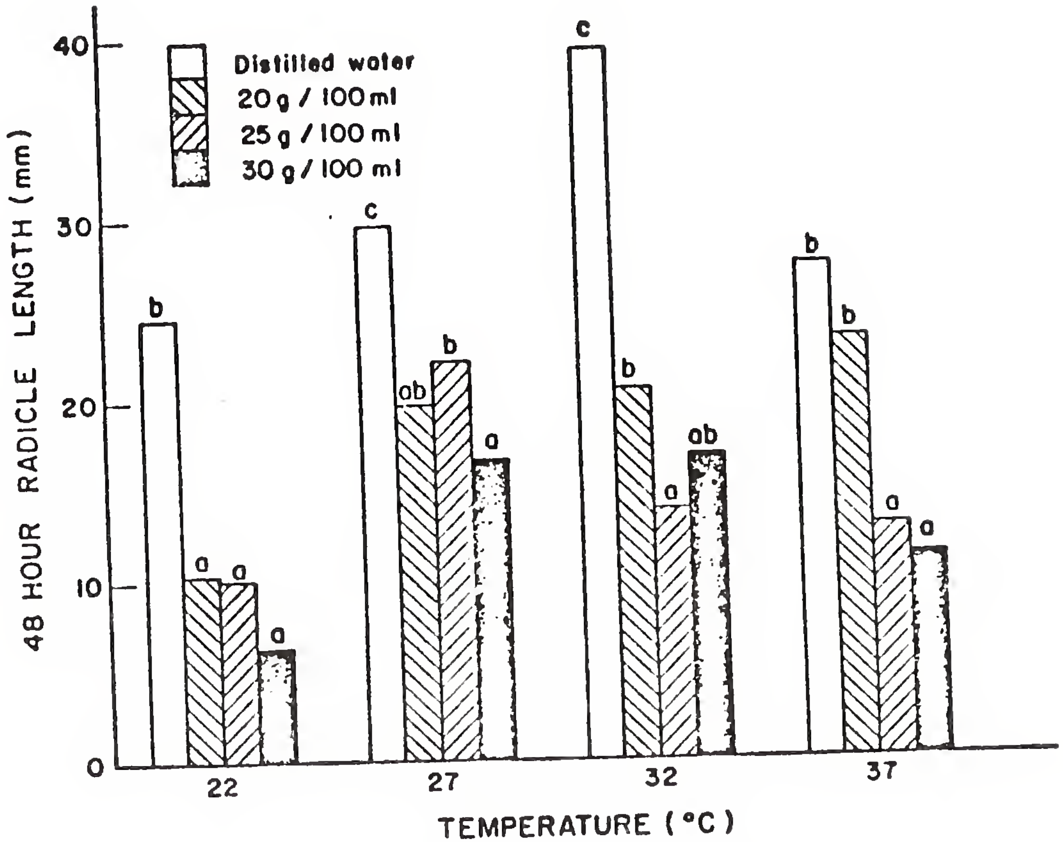


Figure V-5. Effect of temperature and polyethylene glycol induced osmotic stress on radicle growth of Bouteloua curtipendula*.

* Means within temperatures denoted by the same letter are not significantly different by the Duncan Multiple Range Test, .05 level.

For Lolium multiflorum, the results are shown in Figure V-6. At 22°C and 27°C, the amount of radicle growth in the PEG solution of the lowest concentration is significantly greater than at the other two PEG concentrations. And at 27°C the amount of radicle growth in the 20g/100ml solution is not significantly different than it is in distilled water. There are no significant differences in the amounts of radicle growth between any of the three PEG solutions at 32°C, and the amount of radicle growth in each is significantly less than in distilled water. Greater moisture requirement at the higher temperatures could have caused radicle growth of each PEG concentration to be similar.

Polyethylene glycol induced moisture stress also causes a shift in the temperature at which optimum radicle growth of a species occurs. As Table V-2 shows this shift tends to be toward lower temperatures for a species whose optimum radicle growth is at high temperatures and in the opposite direction for a species whose optimum growth is at a low temperature. Thus for Lespedeza stipulacea the optimal temperature became 27-32°C as the concentration of PEG increased, while the optimum temperature for radicle growth of Lolium multiflorum shifted from 22°C to 27°C in the 20 and 25g/100ml concentrations of PEG.

## Conclusions

Alternating temperatures had a significant effect on radicle growth of Bouteloua curtipendula, Lespedeza stipulacea and Lolium multiflorum, with their growth stunted in comparison to the amount of radicle growth found for each in the constant temperature experiment. The difference between the cool season C-3 grass L. multiflorum and

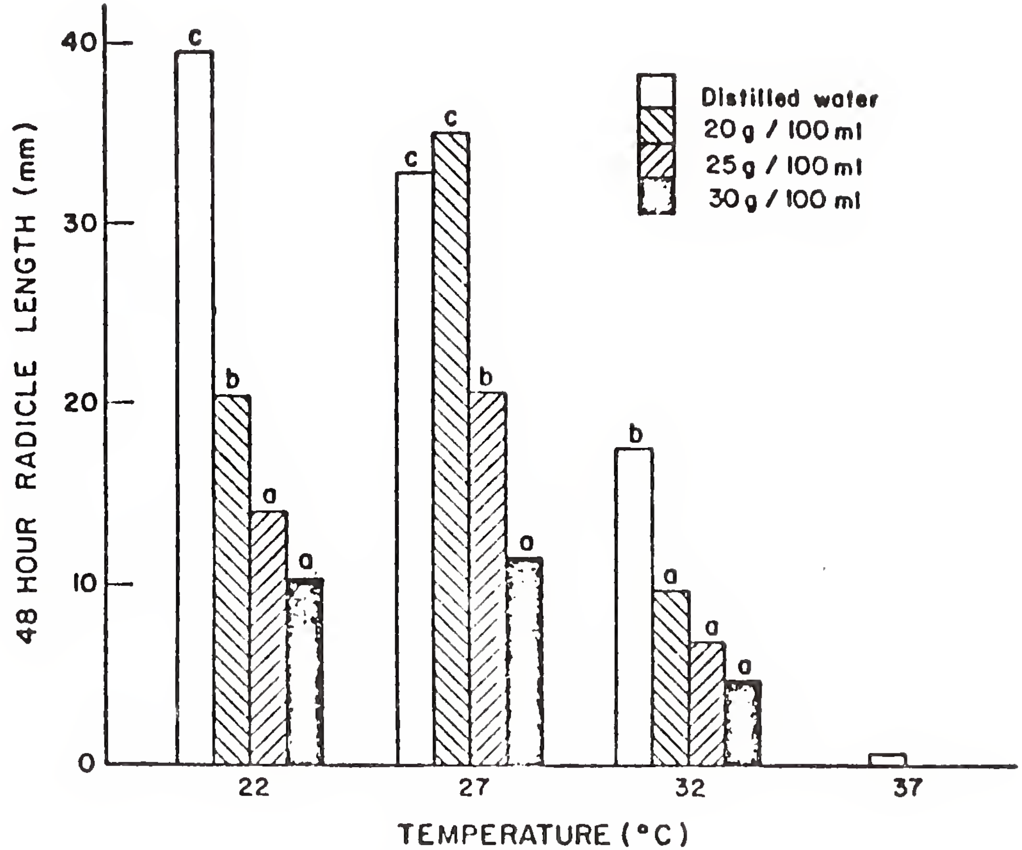


**Figure V-6.** Effect of temperature and polyethylene glycol induced osmotic stress on radicle growth of *Lolium multiflorum**.

* Means within temperature denoted by the same letter are not significantly different by the Duncan Multiple Range Test, .05 level.

the warm season C-4 grass *B. curtipendula* were still as pronounced, with the latter having a significant amount of radicle growth in the 36/44°C regime, whereas the former had a negligible amount.

Polyethylene glycol induced water stress caused a significant decrease in the amount of radicle growth. It also caused a shift in the optimum temperature of radicle growth for each species. Thus, in attempting to extrapolate results found in laboratory experiments to field studies, it is important to consider the interrelations of environmental factors.

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# APPENDICES

# APPENDIX A: CHARACTERISTICS OF THE HERBACEOUS SPECIES USED

Table A-1. Characteristics of the grass used.

| Latin Name | Common Name | Seasonal growth Class. | Experiment Used in | seed/g | Origin | Photosynt. Pathway | Climatic Adapt. | Soil Adapt. |
|---|---|---|---|---|---|---|---|---|
| 1. Andropogon gerardii Vitman. | big bluestem | warm | 1,2[1] | 420[2] | native[2] | C-4[3] | Cm,Cd[2,4] | S,1,W[2,5] |
| 2. Gouteloua curtipendula (Michx.) Torr. | sideoats grama | warm | 1 | 314 | native | C-4 | Cm,Cd,Wd | S,1,a |
| 3. Bouteloua gracilis (H.B.K.)Lag.ex.steud. | blue grama | warm | 1,2 | 1566 | native | C-4 | Cm,Cd,Wd | S,1,a |
| 4. Bromus inermis Leyss. | smooth brome | cool | 1,2 | 275 | introduced | C-3 | Cm,Cd* | S,1,W |
| 5. Dactylis glomerata L. | orchard grass | cool | 2 | 1188 | introduced | C-3 | Cm,Cd* | S,1,W |
| 6. Eragrostic curvula (Schrad.) Wees. | weeping lovegrass | warm | 2 | 3218 | introduced | C-4 | Cd,Wd | S,1 |
| 7. Festuca arundinacea Schreb. | tall fescue | cool | 2 | 532 | introduced | C-3 | Cm,Cd | 1,c,a,w |
| 8. Festuca rubra L. | red fescue | cool | 2 | 1054 | introduced | C-3 | Cm,Cd | 1,c |
| 9. Lolium multiflorum Lam. | annual ryegrass | cool | 1,2 | 530 | introduced | C-3 | Wm | 1 |
| 10. Lolium perenne L. | perennial ryegrass | cool | 2 | 543 | introduced | C-3 | Cm,Cd | S,1,W |
| 11. Lolium perenne L. 'Manhattan' | Manhattan perennial ryegrass | cool | 2 | 540 | | | | |
| 12. Panicum virgatum L. | switchgrass | warm | 1,2 | 611 | native | C-4 | Cm,Cd | S,1,W |
| 13. Poa pratensis L. | Kentucky bluegrass | cool | 2 | 4740 | introduced | C-3 | Cd,Cm | S,1,W |
| 14. Poa pratensis L. 'Park' | park KY bluegrass | cool | 1,2 | 4700 | | | | |
| 15. Poa pratensis L. 'Wabash' | Wabash KY bluegrass | cool | 2 | 4800 | | | | |
| 16. Sorghastrum nutans (Michx.)Nash | Indiangrass | warm | 2 | 385 | native | C-4 | Cm,Cd | S,1,W |
| 17. Soroboius heterolepis Gray. | northern dropseed | warm | 1,2 | 625 | native | C-4 | Cm,Cd | S,1,W |

1. laboratory experiments = 1; field studies = 2.
2. from Donahue and Bennett (1975).
3. determination of whether a species possess a C-3 or a C-4 photosynthetic pathway is from Waller and Lewis (1979).
4. cold moist winters - Cm; cold dry winter = Cd; warm moist winters = Wn; warm dry winters = Wd.
5. sandy = s; loam = 1; clay = C: alkali or salty = a; wet = w.

* limited ability to adapt to these conditions.

Table .-2. Characteristics of the legumes used.

| Latin Name | Common Name | Experiment Used in | Seed/g | Origin | Climatic Adapt. | Soil Adapt. |
|---|---|---|---|---|---|---|
| 1. *Coronilla varia* L. 'Penngift' | pennigift crownvetch | 2[1] | 262[2] | Introduced | Cm,Cd[2,3] | S,1[2,4] |
| 2. *Lespedeza stipulacea* Maxim. | Korean lespedeza | 1,2 | 454 | Introduced | | |
| 3. *Lotus corniculatus* L. 'Empire' | empire birdsfoot trefoil | 1,2 | 920 | Introduced | Cm,Cd* | S,1,W |
| 4. *Medicago sativa* L. 'Vernal' | vernal alfalfa | 1,2 | 495 | Introduced | Cd,Cm* | S,1,C |
| 5. *Trifolium hybridum* L. | alsike clover | 1,2 | 1110 | Introduced | Cm,Cd* | S,1,W |

1. laboratory experiments = 1, field studies = 2.

2. from Donahue and Bennett (1975).

3. cold moist winters = Cm; cold dry winters = Cd; warm moist winters = Wm; warm dry winters = Wd.

4. sandy = s; loam = 1; clay = c; alkali or salty = a; wet = w.

* Limited ability to adapt to these conditions.

# APPENDIX B: COMMON NAMES OF SOME HERBACEOUS SPECIES

Appendix B. Common Names of some Herbaceous Species

| Latin Name | Common Name |
| --- | --- |
| 1. *Agrostis alba* | red top |
| 2. *Andropogon scoparius* | little bluestem |
| 3. *Bouteloua curtipendula* | sideoats grama |
| 4. *Bouteloua gracilis* | blue grama |
| 5. *Bromus inermis* | smooth bromegrass |
| 6. *Coronilla varia* | crownvetch |
| 7. *Cynodon dactylon* | Bermudagrass |
| 8. *Dactylis glomerata* | orchard grass |
| 9. *Eragrostis curvula* | weeping lovegrass |
| 10. *Festuca arundinacea* | tall fescue |
| 11. *Festuca elatior* 'Arundinacea' | Kentucky 31 tall fesuce |
| 12. *Festuca rubra* | creeping red fescue |
| 13. *Lespedeza stipulacea* | Korean lespedeza |
| 14. *Lolium multiflorum* | annual ryegrass |
| 15. *Lolium perenne* | perennial ryegrass |
| 16. *Lotus corniculatus* | birdsfoot trefoil |
| 17. *Medicago sativa* | alfalfa |
| 18. *Panicum virgatum* | switchgrass |
| 19. *Phleum pratense* | timothy |
| 20. *Poa pratensis* | Kentucky bluegrass |
| 21. *Secale cereale* 'Abruzzi' | Abruzzi rye |
| 22. *Sorghastrum nutans* | Indiangrass |
| 23. *Trifolium hybridum* | Alsike clover |
| 24. *Trifolium repens* | red clover |

# APPENDIX C: SOIL TEST RESULTS

| Sample Location | Date Sampled | Texture | pH | %OM | P Kg/ha | K Kg/ha | % Total N |
|---|---|---|---|---|---|---|---|
| 1. Linden (north)* | 5-13-80 | clay loam | 6.9 | 0.61 | 40 | 150 | .06 |
| 2. Linden (south)* | 5-13-80 | clay loam | 7.2 | 2.57 | 39 | 131 | .13 |
| 3. Covington | 5-13-80 | silty clay loam | 5.9 | 0.45 | 28 | 160 | .05 |
| 4. Horticulture Farm | 5-13-80 | clay loam | 5.8 | 1.96 | 31 | 158 | .12 |
| 5. West Lafayette; I-65 | 7-3-80 | loam | 8.3 | 0.74 | 3 | 131 | .07 |
| 6. Veedersburg (north) | 7-3-80 | loam | 8.1 | 2.03 | 3 | 128 | .05 |
| 7. Veedersburg (south) | 7-3-80 | loam | 8.1 | 0.86 | 3 | 120 | .13 |

* The north sample is from the end of the plot closest to Linden, while the south sample is from the end of the plot furthest from Linden.

# APPENDIX D: METHODS TO RANK MIXTURE PERFORMANCE

Ranking seeding mixtures is extremely difficult, because it is an attempt to qualify the performance of a mixture which consists of many variables, such as blade color, percent coverage, general appearance of the vegetation, and even relative growth rates. To complicate matters further, different situations require different types of performance. Thus in initial erosion control on highway slopes, rapid growth is extremely important, while for established vegetation Daniel and Michael (1977) have stressed the importance of slower growth for ease of maintenance.

In erosion control and initial establishment studies, three ranking methods are commonly used: (1) visual rankings, (2) counts of the number of plants per unit area, or (3) some type of weight measurement (either fresh or dry weight). The most popular method of ranking mixtures in seeding studies has been visually. Foote et al. (1964) used two or three evaluators and claimed satisfactory results. There are many problems with visual rankings methods, especially when a scale of one to ten is used and individual estimates are averaged to one decimal place. Thus a scale is created from one to one hundred. Also visual ratings are extremely subjective and thus hard to repeat. The other two ranking methods, weights or counts, are used largely to improve the objectiveness of the rating system thus improving repeatability.

We used either a seedling count or when the plants are too large a fresh weight ranking system. One major problem with using both ranking systems is that an inverse relationship exists between plant size and density (Christian, 1977). Thus, to use both systems the scale has to be relative to some standard. In using the count method, a problem exists in distinguishing individual plants, especially grasses, so that counts of older plants are of shoots and not single plants.

Both fresh and dry weight ranking methods have their disadvantages. Dry weight ranking methods require the drying of large volumes of tissue and does not consider the dead tissue present. In fresh weight ranking methods, the moisture content and thus the weight varies depending on the moisture status of the plant. Thus, comparisons of one mixture to another are only possible within a specific sampling date. Ranking systems using weight also give no true indication either of the number of plants present or the quality of the mixture. Weight methods are good when coverage is of prime importance, especially when plants are all of the same relative height, which is common for herbaceous plants in their vegetative phases of growth.

# APPENDIX E: GERMINATION OF COMMONLY USED SPECIES AND SEEDING MIXTURES

## Abstract

Germination studies were conducted for Coronilla varia, Festuca rubra, Panicum virgatum, Poa pratensis, Poa pratensis 'Park', Poa pratensis 'Wabash', Sporobolus heterolepis, Andropogon gerardii, Festuca arundinacea, Lolium multiflorum, Lolium perenne, Lolium perenne 'Manhattan', Medicato sativa, Sorghastrum nutans and four mixtures consisting of these species. The individual species or varieties could be divided into high and low germination percentage categories, with the latter seven of the above species or varieties having a high germination percentage. The germination percentage of the mixture was as good or better than that would be predicted from the performance of their individual species. Thus, indications are that no allelopathic relationships inhibiting germination existed.

## Introduction

In establishment of vegetation along roadsides, the germination percentage of the species used can be an important determinate in the success of the seeding. According to Davis (1961), grasses that germinate in the shortest time make the most rapid seedling growth. Thus, if a species is to be successful in a seeding mixture its rate of germination and total germination percentage have to be comparable to that obtained from other species in the mixture.

Besides differences in competitiveness of a species being important, some species may be allelopathic to others. Allelopathy occurs when substances produced by one organism negatively influence another (Salisbury and Ross, 1978). Allelopathy may occur as some growth inhibitor is leached from the seed of one species and inhibits the germination of seed of neighboring species.

Since allelopathy would be an undesirable characteristic of species used in a seeding mixture, one purpose of this experiment was to study percentage germination of seed used in previous experiments. A second purpose was to compare the predicted germination percentage of four mixtures with the actual percentage, as an indication of any allelopathic relationships inhibiting mixture germination.

## Materials and Methods

Seed of *Coronilla varia*, *Festuca rubra*, *Panicum virgatum*, *Poa pratensis*, *Poa pratensis* 'Park', *Poa pratensis* 'Wabash', *Andropogon gerardii*, *Festuca arundinacea*, *Lolium multiflorum*, *Sorobolus heterolepis*, *Lolium perenne*, *Lolium perenne* 'Manhattan', *Medicago sativa*, and *Sorghastrum nutans* were selected for uniformity of size. One hundred seeds of each were then placed on top of two layers of 9cm Whatman #1 filter paper which was moistened with 2ml distilled water within a 9cm in diameter, glass petri dish. Two more pieces of filter paper moistened with 2ml of water were placed on top of the seed and the petri dish closed. Samples were made of each of the four mixtures used at Horticulture farm and Linden experimental plots (Table II-1) by proportionally adding seed of each species or variety in the mixture to give one hundred total seeds. The mixtures were placed inside petri dishes as described for the individual species or varieties.

There were three replications, and the petri dishes were randomly placed inside a Narco incubator at 27°C. After two days, the petri dishes were opened and the number of seeds germinated in each was counted. Germinated seed were then discarded. The petri dishes were returned to the incubator and counts of germinated seeds were taken daily for a one week period. Distilled water was added to the filter paper as needed to remain an adequate moisture level. On the tenth day the remaining nongerminated seeds were counted and the experiment terminated.

## Results and Discussion

### Germination Percentage

The germination percentages of the individual species are presented in Table D-1, and fall into one or another of two categories. Sporobolus heterolepis not only had a low germination percentage but fungal contamination also occurred. This species and Panicum virgatum require stratification to improve their rate of germination.

Poa pratensis varieties have a low germination rate. In preliminary studies, it was found that if the petri dishes containing the seed were sealed inside polyethylene bags, the germination percentage was improved. The differences in germination percentages would seem to imply that the build-up of some volatile compound, possibly a gas is important for germination of P. pratensis.

The group with a high germination percentage contained Lolium multiflorum and Lolium perenne which were commonly used as nurse crops. These two species germinated fastest and had the highest germination percentage of any species or variety tested. Davis (1961) had similar findings, with Lolium multiflorum emergence occurring rapidly within three days after seeding.

Table E-1. Germination percentage of fourteen selected species.

a. Species with a low germination percentage.

| Species | % Germination |
| --- | --- |
| 1. *Coronilla varia* | 10 |
| 2. *Festuca rubra* | 27 |
| 3. *Panicum virgatum* | 20 |
| 4. *Poa pratensis* | 2 |
| 5. *Poa pratensis* 'Park' | 15 |
| 6. *Poa pratensis* 'Wabash' | 17 |
| 7. *Sporobolus heterolepis* | 3 |

b. Species with a high germination percentage.

| Species | % Germination | Days until 50% Germination |
| --- | --- | --- |
| 1. *Andropogon gerardii* | 89 | 5 |
| 2. *Festuca arundinacea* | 63 | 7 |
| 3. *Lolium multiflorum* | 95 | 2 |
| 4. *Lolium perenne* | 94 | 2 |
| 5. *Lolium perenne* 'Manhattan' | 82 | 4 |
| 6. *Medicago sativa* | 86 | 3 |
| 7. *Sorghastrum nutans* | 82 | 5 |

Seed Mixture Germination

Seed mixture germination, shown in Figure D-1, was as good or better than that predicted by multiplying the germination percentage of the individual species by their percentage in the mixture. The performance of the legume-cool season grass mixture, the warm season-cool season grass mixture and the proposed highway mixture (mixtures 1, 2, and 3) were approximately what was predicted. The germination percentage of the proposed highway mixture (mixture 3) was low because it contained over 80% Poa pratensis 'Wabash' and 'Park', whereas the other two mixtures contained more species with high germination percentages.

The germination percentage of the current highway mixture (mixture 4) was more than expected, because a higher percentage of Poa pratensis germinated than predicted. One possible explanation is that germinating seeds of the other species released some stimulatory compound. The comparison of mixture performance to predicted values would seem to indicate that no allelopathic compound that affects germination percentage of the mixture is released by germinating seeds into the filter paper.

## Conclusions

Although half of the species tested had low percentage germination, this may not be indicative of how they would perform in other environmental conditions. In many germination tests, seeds were exposed to alternating temperatures, and germination percentages would be different than what was found with constant temperature.

In comparing the germination percentages found for the four mixtures to those expected, there were no indications of any allelopathic relationships.

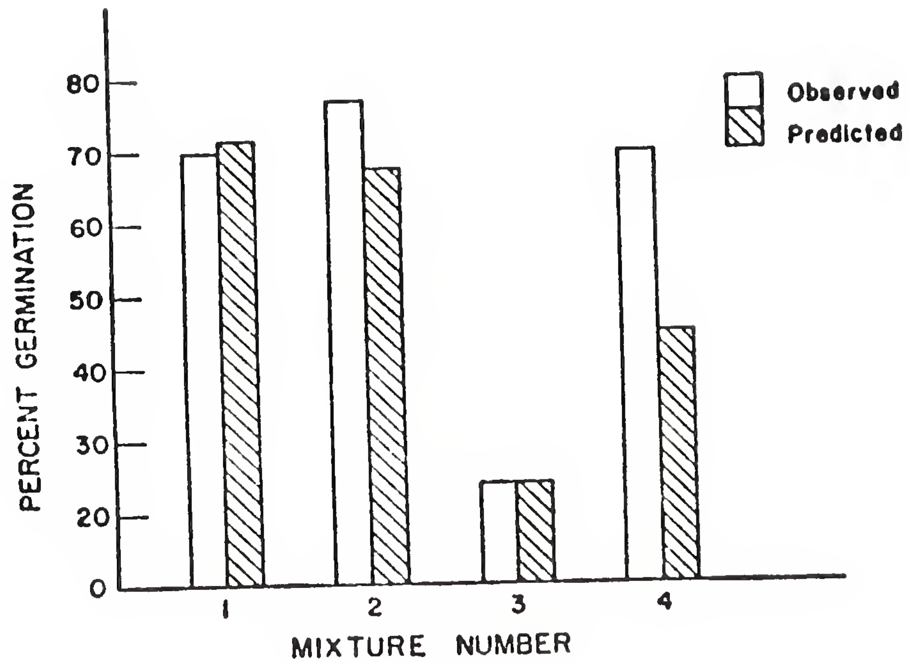


Figure E-1. Percent germination of four seeding mixtures relative to predicted values.

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