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Salt Tolerance in Short Stature Grasses

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16. Abstract (Limit: 200 words)

In this project, researchers used extensive laboratory, greenhouse, and field studies to determine the relative salt tolerance of select native grasses and forbs used to re-vegetate rights-of-ways within four meters of the pavement edge.

The studies found that grasses prove relatively tolerant to salt, but show poor survivability in the field during over-wintering. In contrast, forbs generally are sensitive to salt in their environment. Planting success of monocultures and mixtures of grasses near the pavement edge was poor. Observed percent coverage after two years ranged from about 10 to 20 percent over all tested species.

Monitoring of longer established sites also shows that native species do not increase as a stand ages. Soil amendments including gypsum, potash, and potassium nitrate were only minimally effective in alleviating salt stress in sodic soils, although gypsum may have some promise in further field testing. The application of salt during winter salting operations also permanently and negatively impacts soil chemistry, which in concert with other plant stress factors such as soil compaction and infertile roadside soils, will continue to limit the success of establishing desirable vegetation on the inslopes of heavily salted roadways in Minnesota.

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SALT TOLERANCE IN SHORT STATURE GRASSES

Final Report

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Executive Summary

This study was undertaken to determine the utility of using short-stature native grasses along the edge of heavily traveled highways in Minnesota whose soils can be described as being sodic, compacted, dry, low in nutrients, and subjected to frequent disturbance. These short statured species may be ideal for this area of the right-of-way since they are short and require less mowing and they have been thought to be relatively salt (NaCl) and drought tolerant. Extensive laboratory, greenhouse, and field trials show that these grasses are relatively salt tolerant but perform poorly in the field. Poor ability to overwinter in combination with competition from weedy annuals in the field appears to be the primary factors in limiting establishment of these species within four meters of the pavement edge. Establishment of tested grass species at newly established sites, and at longer established sites, is observed to be in the range of about 10 to 20% coverage after two or more years. Forbs, in contrast, are generally sensitive to salt in their environment and my be effected by aerial dispersion of salt at greater than 4 meters from the pavement edge. One species, *Puccinellia distans*, is very tolerant of sodic soils near pavements although it acts more like an annual species than a perennial species in this environment. It should be used in all mixtures being planted on the inslope and may have great value as a cover crop species since it is not competitive in more fertile soils of ditch bottoms or outslopes. Our studies of another commonly used roadside species, *Poa pratensis* (Kentucky bluegrass) indicate that it should never be used where soils are likely to be heavily salted. Of the Minnesota Department of Transportation (Mn/DOT) mixtures tested in this study, mixture 30A was found to be most effective for re-vegetation of the soils near the pavement.

Soils were also studied extensively at our sites to determine the impact of salting operations on soil chemistry. Salt permanently and negatively impacts soil chemistry causing further difficulties in establishing plant populations on sodic soils.

Previous studies have suggested that salt stress might be alleviated by the addition of soil supplements or ammendments to roadside soils. This study determined that soil ammendments including gypsum, potash, and potassium nitrate were only minimally effective in alleviating salt stress in sodic soils. However, one of these ammendments, namely gypsum did show some promise for further field testing in sodic areas. Highly sodic roadside soils, which are often recognized in the field by having a salt crust on them, or because they support only a limited population of halophytes ("salt loving plants") or are even devoid of plants, will have to be reclaimed or planted to species that are tolerant of highly saline soils. Salt will continue to cause probems in establishing plant populations near heavily salted roadways in Minnesota.

Chapter 1. Laboratory and Field Studies of Salt Tolerance in Native Grasses; Monitoring of Field Sites; Aerial Dispersion of Salt; and Characterization of Sodic Soils

Abstract

Laboratory and field studies were used to evaluate the relative salt tolerance of native and non-native species used in roadside plantings for their ability to tolerate the levels of salt typically found in Minnesota roadside soils and provide adequate vegetative cover along the first 4 meters of highway inslopes. The results of the laboratory studies showed that all of the grass species were able to easily tolerate NaCl concentrations of 1000 ppm (µg/g). Forbs were much more sensitive to NaCl than the grasses. The relative salt tolerances of the species varied depending on the life stage (germination, seedling, and mature) and on what parameter was considered for indication of salt tolerance (% germination, delay in germination, seedling survival, or biomass). Generally, the native plantings along the shoulders and inslopes were found to be minimally successful with only about a 10-20% cover of the desirable native species present and an indication that the native species are not increasing as the stand ages. Although germination and seedling establishment were initially high, large losses of desirable species occurred within 1 meter of the pavement edge after the first winter with the exception of the non-native grass *Puccinellia distans*. This reduction of the desirable species appears to be unrelated to NaCl levels in the soil during the growing season since there were no statistically significant differences in Na and Cl concentrations in the soil between 1 and 4 meters of the inslope. The high disturbance, especially by snowplow blades, along the first meter of inslope seems to be a probable cause of this species decline, although the potentially high NaCl levels in soil during the winter months when the soil is frozen and the plants are dormant has not been ruled out as a causal factor. Similar to previous studies, the soil monitoring at the Cambridge field site showed a significant increase of exchangeable and soluble Na in the soil after only two winter seasons, a seasonal pattern of higher Na and Cl levels in early spring followed by a decline throughout the growing season until a resumption of salting operations in late fall, and higher levels of Na and Cl in the upper most 10 cm of soil with less at the lower depths. Based on the results of this study, Mn/DOT mix 300 (presently called 30A), which contains native species as well as the non-native *Puccinellia distans*, was most successful at providing vegetative cover along highway inslopes in this region.

Introduction

While it is important to have highway inslopes vegetated to control soil erosion, reduce hazards, improve highway appearance, and improve water flow to ditches or drainages, the roadside environment presents extremely poor growing conditions for vegetation. An inspection of vegetation within 1 to 3 meters of rights-of-way of high volume roadways in the cities of Minneapolis/St. Paul in Minnesota indicates that these areas are either largely devoid of vegetation, or that grasses planted along roadways have been replaced by undesirable, weedy species (see Appendix A). The decline in vegetative cover along roadsides can in part be attributed to the applications of sodium chloride (NaCl) to roadways for removal of snow and ice during the winter months.

Introduced, cool season grasses such as *Bromus* or *Poa* spp., have traditionally been planted adjacent to improved roadways in Minnesota. More recently, native shortgrass prairie species are being used by the Minnesota Department of Transportation (Mn/DOT) for this application because these species have characteristics that would possibly make them more suitable for roadside use. These characteristics include the ability to grow in poor soils under hot, dry conditions, the germination of seedlings or an initial flush of growth from over-wintering plants that typically occurs in late May and early June after roadside salt accumulations and debris have been flushed from soil by spring rains, and a short stature that eliminates the need for frequent mowing.

In order to maintain adequate vegetative cover along roadsides exposed to varying amounts of salt, the present Mn/DOT seed mixes must be tested and possibly modified with the addition of appropriate salt tolerant species or artificially selected lines. The purpose of this research is to evaluate the native shortgrass prairie species presently used in Mn/DOT roadside seed mixtures for their ability to germinate and provide adequate vegetative cover in the highly sodic, poor soils of highway inslopes; and to test the effects of different chemical ammendments in ameliorating sodic soils on rights-of-way.

The research includes laboratory screening of species tolerant to high NaCl concentrations and field testing of both single species and Mn/DOT seed mixtures along Minnesota roadsides.

Materials and Methods

The effects of salt on germination of select species

A germination experiment was designed to test the relative salt tolerance of six grasses and five prairie forbs in a controlled growth environment. The species included: a) the four native prairie grasses *Bouteloua gracilis, Buchloe dactyloides, Sporobolus cryptandrus*, and *Agropyron trachycaulum*:; the two non-native grasses *Poa pratensis* 'Park', and *Puccinellia distans*; and five prairie forbs which included *Ratibida columnifera, Asclepias tuberosa, Allium stellatum, Petalostemon purpureum,* and *Coreopsis palmata.* Prairie forb seeds were collected on October 27, 1994 from a local prairie garden, placed separately into plastic bags containing sterilized, water-saturated vermiculite, and cold stratified at 3°C for 10 weeks. Seed for the grass species were obtained from Prairie Restorations Inc., PO Box 327, Princeton, MN 55371; Mohn Seed Co., RR1, Box 152, Cottonwood MN 56229; and Agassiz Seed and Supply, 4121 1/2 So. University Dr., Fargo, ND 58104. The grass seeds were not stratified prior to the experiment.

Styrofoam blocks (Mini - Hahn 408 Block, Stuewe and Sons Inc., 2290 SE Kiger Island Dr., Corvallis, OR 97330) plugged with cotton, and filled with washed silica sand (size 40, Wedron Silica Co., PO Box 119, Wedron, Il. 60557) were used for the experiment. Each block was 24 x 17 inches and contained 408 individual cells, each with 4.1 inch depth, 0.66 inch diameter, and 1.0 $inch^3$ capacity. A nylon mesh was stapled to the bottom of the block to retain the cotton plugs. A single seed was placed into each cell. Each 24 cell row was considered one repetition for all species except *Asclepias tuberosa.* Seeds of *Asclepias tuberosa* were limited for this experiment and only 8 seeds were considered one repetition for this species. For each of the eleven species there were four repetitions of each salt treatment. The salt treatments were as follows in ppm and conductivity: 0 ppm (1.2 µS); 1000ppm NaCl (1947 µS); and 5000ppm NaCl (9870 µS) made up in double distilled water (DDW).

The seeded blocks were placed in a controlled environment chamber at a setting of LD 15:9, temperature 30°C:20°C. Light intensity was 200 $\mu Em^{-2}s^{-1}$ photosynthetic photon flux. Humidity was 50%. Each individual cell was watered daily with approximately 1.0 ml of the treatment solution using a plastic 50 ml syringe. After one week, the germinants began to receive 0.5 ml of 1/2 strength Hoaglands nutrient solution, following the daily salt treatment application. After 30 days the seedlings were harvested, rinsed with DDW, and dried at 60°C. After drying, the root and shoot portions for each repetition were separated and weighed for mean dry weight determination. Analysis of variance, Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests, and regression analyses were performed using StatView SE+ Graphics software package (Abacus Concepts, Inc., Berkeley, CA, 1987).

The Amelioration of Salt Effects by Calcium Sulfate

Since calcium sulfate ($CaSO_4$, gypsum) has been shown to be beneficial in ameliorating the deleterious effects of high NaCl (Kent and Lauchli 1985, Hansen and Munns 1988), a second germination experiment was designed to determine if calcium sulfate could improve NaCl tolerance in *Bouteloua gracilis.* Calcium sulfate at 0, 5, and 10 mM were tested in combination with NaCl at 0, 1000, 3000, and 5000 ppm in a 3 x 4 factorial experiment with 6 repetitions. Plastic mini-flats (12 x 8 x 5.5 cm) were lined with paper towelling and filled with washed silica sand. One hundred seeds of *Bouteloua gracilis,* obtained from Prairie Restorations Inc., were sprinkled evenly into each flat followed by a layer of vermiculite to retain moisture. Each mini-flat was watered with approximately 80 ml of the appropriate treatment solution at the start of the experiment, covered with clear plastic wrap, and placed in a controlled environment chamber at a setting of LD 15:9, temperature 25°C:20°C. Light intensity was 200 $\mu Em^{-2}s^{-1}$ photosynthetic photon flux and 70% relative humidity. Flats were watered with 50 ml of additional treatment solutions as needed throughout the 20 days of the experiment. After 10 days the clear plastic wrap was removed to decrease damping off caused by fungal growth. Germination of seeds were recorded throughout the length of the experiment. At the end of the experiment, the survived germinants were harvested, rinsed with DDW, blotted dry between paper toweling, and dried at 62°C for 8 days for dry weight determination. Analysis of variance and Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests were performed.

The Effects of Salt on Established Species

A laboratory experiment was designed to test the relative salt tolerance of mature, well established, grasses in a controlled growth environment. Four native prairie grasses, *Bouteloua gracilis, Buchloe dactyloides, Sporobolus cryptandrus*, and *Agropyron trachycaulum,* and two non-native grasses; *Poa pratensis* 'Park', and *Puccinellia distans* were grown in 4 in^3 Conetainers™ (Stuewe and Sons Inc., 2290 SE Kiger Island Dr., Corvallis, OR 97330) in washed silica sand. The seed was obtained from Prairie Restorations Inc., Mohn Seed Co., and Agassiz Seed and Supply. Cotton was used to plug the conetainer drainage holes to keep the sand from escaping. The Conetainers™ were placed in a controlled environment chamber at a setting of LD 15:9, temperature 30°C. After one month the temperature was lowered to a constant 25°C. Light intensity was 210 $\mu Em^{-2}s^{-1}$ photosynthetic photon flux. After germination the grasses were watered as needed with 1/2 strength Hoaglands nutrient solution. Periodically distilled water was used to flush out any build up of salts and to reduce the blue green algae which had become established on the sand surface.

After eleven weeks, the most vigorous plants were divided up evenly by species, into three separate treatment groups; 0 (distilled water), 1000, and 5000 ppm of NaCl. The sample sizes for *Bouteloua gracilis, Buchloe dactyloides, Sporobolus cryptandrus, Agropyron trachycaulum, Poa pratensis* 'Park', and *Puccinellia distans* were 8, 19, 31, 25, 22, and 26, respectively. The shelf in the growth chamber was lowered to accommodate the larger sized grasses which reduced the light intensity to 105 $\mu Em^{-2}s^{-1}$ photosynthetic photon flux. The plants received the salt treatments daily during the week and distilled water during the weekend. On Tuesdays and Thursdays of each week, the plants received 1/2 strength Hoaglands nutrient solution in their NaCl treatment. This treatment regime was continued for the nine weeks of the experiment after which the remaining live plants were removed from the Conetainers™, rinsed with distilled water to remove the sand, and dried at 65°C. After drying, the shoot and root portions of each plant were weighed separately for biomass determination. Analysis of variance and Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests were performed.

Field Testing of Individual Species and Mixtures at Cambridge, MN

One mile of inslopes along the newly constructed Highway 65 in Cambridge, MN, (see Appendix A) were used to field test the Mn/DOT native shortgrass prairie roadside seed mixes. The highway was newly opened and the inslopes seeded by Mn/DOT with a temporary cover in June of 1994. The temporary cover consisted of Regreen (winter wheat x slender wheat grass, 20 lbs/acre), annual ryegrass (10 lbs/acre) and oats (40 lbs/acre). Experimental plots were established, each 100 m in length and within the first 6 m of the inslope, and seeded using a Truax seed drill with some supplemental hand broadcasting. The Cambridge-Fall and Cambridge-Spring plots were seeded on October 19, 1994, and May 24, 1995, respectively. These two field sites were similar in seed treatments (see Appendix Table B1) but differed in the time of planting. Three of the seed treatments, mix 300, mix 400, and mix 350, are Mn/DOT roadside seed mixes (Jacobson 1994). The seed was obtained from Prairie Restorations Inc., Mohn Seed Co., and Agassiz Seed and Supply. The seed lot differed between the Cambridge-Fall and Cambridge-Spring plantings.

The vegetation was monitored in June and August during the 1995 and 1996 growing seasons. Percent cover of the vegetation was determined for each treatment plot using the point method as described in Barbour *et al.* (1980) along five permanently marked transects perpendicular to Highway 65. Thus, the same series of points were sampled in successive observations to reduce the variance and allow any changes in the vegetation to be better estimated as recommended by Goodall (1952). The vegetative and bareground cover was determined at 1, 2, 3, and 4m from the pavement edge. Analysis of variance and Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests were performed.

Field Testing of Individual Species and Mixtures at Eden Prairie, MN

The experiment at Cambridge was replicated at Eden Prairie. Another section of roadway, located on the northbound entrance ramp to I-494 in Eden Prairie, MN, was also used to field test the Mn/DOT native shortgrass prairie roadside seed mixes and individual species. This roadway is heavily salted during the winter and was being revegetated by Mn/DOT because of the poor quality of the existing vegetation. The field experiment was set up as in the Cambridge field site with both a fall and spring planting and using the same seed treatments (Appendix Table B1), but with a smaller plot size of 30 m long and 5 m of the inslope. The inslope along the west side of the ramp was seeded on October 25, 1995, and along the east side of the ramp on May 29, 1996. The seed lot used was the same used for the Cambridge-Spring planting. The inslopes were herbicided with glyphosate and 2,4-D 10 days prior to each of the seedings. The fall planted site also was disked after the herbicide treatment.

The vegetation was monitored during the 1996 growing season and the data analyzed as described above for the Cambridge field sites.

St. James Field Site

The St. James field site is located northbound along T.H. 60 near St. James, MN. This site had been seeded in July of 1993, as part of another study by Stenlund and Jacobson (1994). A complete site history and detailed methods are presented in Stenlund and Jacobson (1994). Appendix Table B2, of the present study, shows the components and rates of the native seed mixes used.

The inslope vegetation at 1m from the pavement edge was monitored in June and August during the 1995 and 1996 growing seasons. Only the first meter was monitored since the 1993 planting of the inslope was only 2 m, or 1 tractor pass, wide. Percent cover of the vegetation was determined using the point method applied five times within each treatment plot. The sampling points could not be permanently marked at this site so that successive observations were not taken at the same locations each time as for the other field sites. The vegetative and bareground cover was determined and the data analyzed as described above for the Cambridge field sites.

The 1993 data collected from the original study by Stenlund and Jacobson (1994), was reanalyzed into the same percent cover categories as for the present field experiments for better comparison. The number of repetitions of percent cover determinations for the August 1993 data set (n=30) and the September 1993 data set (n=15) were each grouped and then averaged to create five repetitions for each treatment plot. The reworked data was subjected to analysis of variance and Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests.

Crosstown Field Site

The crosstown site is located westbound along T.H. 62 in Minneapolis, MN. The inslopes to this heavy traffic roadway had been seeded on September 24 of 1993 by Mn/DOT as part of the Crosstown Prairie Restoration Project to reduce the invasion of non-native species into the adjacent prairie remnant (Biesboer and Jacobson 1994, Appendix B). The site was sprayed with Transline herbicide in mid-August of 1993 followed by glyphosate and 2,4-D applied in mid-September to remove the existing weedy vegetation. Appendix Table B3, of the present study, shows the components and rates of the native seed installed at the Crosstown site.

The vegetation was monitored in June and August during the 1995 and 1996 growing seasons and the data analyzed as described above for the Cambridge field sites.

I-94 Loop Site

On August 28, 1996, the inslope vegetation was sampled at five different sites around the Twin Cities metro area I-94 system to compare native and non-native roadside plantings. Two sampling sites were along 494, two along 694, and one along 94. Because the non-native grasses could not be destinguished from the weedy grasses, only the percent cover of bareground and weedy dicot species were determined. The point method was used along five transects at 1, 2, 3, and 4m from the pavement edge at each sampling site.

For analysis, the data was lumped with the August 1996 data for the non-native mix 400 from the Cambridge sites and compared with the native vegetation data from the Crosstown, St. James, and mixes 300 and 350 from the Cambridge sites. The combined data was subjected to analysis of variance and Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests.

Salt Spray Study

Three transects were established perpendicular to the newly constructed Highway 65 in Cambridge, MN to monitor the aerial deposition of salt during the winter months. Uncovered 2 gallon polyethylene buckets, diameter of 21.5 cm, were set on the ground secured with rebar posts at 2, 5, 10, 15, and 20 meters from the road edge. The contents of the buckets were collected periodically, after winter storm and salting events, and placed into plastic bags.After transport to the laboratory, the precipitation was allowed to melt, the total volume measured, and a subsample removed for analysis of Na and Cl. A Hach One Laboratory pH/ISE meter and Hach ion selective electrodes (Hach Company, P.O. Box 389, Loveland, CO. 80539) were used for Na and Cl determinations according to the procedures outlined in the Hach instruction manuals. Sodium chloride input (g $NaCl/m^2$) was calculated and subjected to analysis of variance and Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests.

JES Pond Monitoring

Water samples were collected from "JES" pond, located in the southwest corner of the intersection of Highway 65 and County 30 in Cambridge, MN, (see Appendix A), to monitor the NaCl levels in this newly constructed pond. The roadway run-off from both Highway 65 and County 30 drains directly into this pond. Water samples were collected near the shoreline at the north culvert, east culvert, and south end of the pond and analyzed for pH, Na, Cl, and conductance back at the lab. A Hach One Laboratory pH/ISE meter and Hach ion selective electrodes were used for pH, Na, and Cl determinations. An Oakton Conductivity/Temperature Meter model WD-35607-10 was used to measure the conductance. The September 1994 sample represents baseline values for each of the parameters since the new highway and pond had not yet experienced any winter salting events. Analysis of variance and Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests were performed.

Soil Analyses

The Cambridge-Fall site was the primary focus for studying the effect of NaCl on roadside soils since this site was newly constructed and thus had no prior history of NaCl applications. Soils were collected at 1m, 2m, 3m, and 4m from the pavement edge to determine any differences in soil chemistry with respect to distance from the roadway, and at three depths, 0-10 cm, 11-20 cm, and 21-30 cm (collected at the 2m distance) to monitor the movent of NaCl within the soil profile. Soils were first collected in September of 1994 prior to the soils experiencing any winter salt applications to determine baseline values for the soil parameters. Soil was collected monthly from April to October during the 1995 season and in the months of April, June, and September during the 1996 season to determine any phenological patterns. Six soil cores were collected using a 21" Oakfield soil sampling probe and combined into one composite sample at each collection location. This was repeated at four locations within the Cambridge-Fall site. Four composite soil samples were also collected, as described above, in April of 1996, 2m from the pavement edge, to a depth of 10 cm at both the Cambridge sites, St. James, Crosstown, and Eden Prairie-Fall sites for comparison among sites.

Soil samples were air dried in the laboratory and passed through a 2 mm sieve. Hydrogen ion activity was determined using a Hach One Laboratory pH/ISE meter with a Ag/AgCl combination pH electrode, according to the method of McLeon (1982). The soluble plus exchangeable Na was determined by an ammonium acetate extraction as described by Thomas (1982) followed by measurement of the Na concentration in the soil extract according to the procedure outlined in the instructuion manual for the Na ion selective electrode (Hach Company). Soluble Na, Cl, and electrical conductivity were determined on the saturation extract using a slightly modified procedure from that described in Rhoades (1982). The procedure digressed from Rhoades (1982) in that the saturated soil-water paste was extracted after standing for only 2 hours and sodium hexametaphosphate was not added to the extract after filtration. Electrical conductance of the extract was measured immediately after filtration using an Oakton conductivity/temperature meter. The extract was then diluted to 50 ml with deionized water and used for Na and Cl analyses as described above. All concentration values were determined on a oven dry basis. Exchangeable Na was calculated by subtracting the soluble Na concentration from the soluble plus exchangeable

Na concentration. Analysis of variance, Fisher's Protected Least Significant Difference (PLSD) multiple comparison tests, and regression analyses were performed.

Additional soil parameters were measured from one composite sample from each of the field sites. Soil texture was determined by sedimentation using a LaMotte Soil Texture Unit (LaMotte Company, PO Box 329, Chestertown, Maryland 21620). Percent nitrogen (Kjeldahl nitrogen without nitrate reduction), percent organic matter, cation exchange capacity (by ammonium saturation/displacement), and inductively coupled plasma atomic emission spectroscopy for total elemental analysis (digestion by microwave with 25% nitric acid) were determined by the University of Minnesota Department of Soil, Water, and Climate, Research Analytical Laboratory (135 Crops Research Building, University of Minnesota, St. Paul MN 55108).

Results

Laboratory screening of NaCl tolerant species.

The results of the experiment to test the ability of several grasses and forbs to germinate and survive under NaCl levels typically found in roadside soils during early spring are presented in Figures 1-11, and Tables 1 and 2. All species experienced reduced germination with the 1000 ppm and 5000 ppm NaCl treatments. The 5000 ppm NaCl treatment also resulted in a 5 to 10 day delay in germination for *Buchloe dactyloides* (Figure 1), *Agropyron trachycaulum* (Figure 5), *Asclepias tuberosa* (Figure 8), and *Coreopsis palmata* (Figure 9). *Sporobolus cryptandrus* (Figure 3), *Allium stellatum* (Figure 10), and *Ratibida columnifera* (Figure 11) had such low germination in the control treatment that the salt tolerance could not be adequately determined. The forb species generally were more sensitive to NaCl than the grass species since germination was reduced to below 1% at the 5000 ppm level (Figures 7-11) and survival of the germinants was significantly reduced even at the 1000 ppm NaCl level (Table 1). The NaCl treatments did not significantly effect survival of the grass germinants except for *Buchloe dactyloides* at the 5000 ppm NaCl level (Table 1). The shoot and root biomass of the surviving germinants show a significant reduction in biomass due to 1000 ppm NaCl only for *Coreopsis palmata* (Table 2). Of the four grasses which had survived the 5000 ppm NaCl treatment, *Puccinellia distans* was the only species which did not have significantly reduced biomass for both shoot and root.

The ability of calcium sulfate to ameliorate the detrimental effects of NaCl on germination and seedling survival of *Bouteloua gracilis* (Table 3) could not adequately be determined because of the interference of vermiculite in the growing medium which has a high cation exchange capacity and seedling mortality due to damping off. This experiment was not repeated. The effect of calcium sulfate to ameliorate the detrimental effects of NaCl on germination was further tested in the field and is described in Chapter 2.

The results of the experiment to test the ability of mature grasses to tolerate elevated NaCl levels are presented in Table 4. There were no significant changes in shoot biomass for *Bouteloua gracilis, Sporobolus cryptandrus,* and *Poa pratensis* , and in root biomass for *Buchloe dactyloides* and *Bouteloua gracilis* with the increasing concentrations of NaCl. For *Buchloe dactyloides, Agropyron trachycaulum,* and *Puccinellia distans,* there was actually a significant increase in shoot biomass at the 1000 ppm NaCl level. *Puccinellia distans* was the only species with a shoot biomass significantly less at the 5000 ppm level compared to the 0 ppm. *Sporobolus cryptandrus* and *Puccinellia distans* showed a significant reduction in root biomass only at the 5000 ppm treatment whereas *Poa pratensis* root biomass was affected even at the 1000 ppm NaCl level. The root biomass data for *Agropyron trachycaulum* was difficult to interpret because of the problem in removing all the growing media from the root tissue at time of harvest, especially for those plants grown at the 5000 ppm NaCl level.

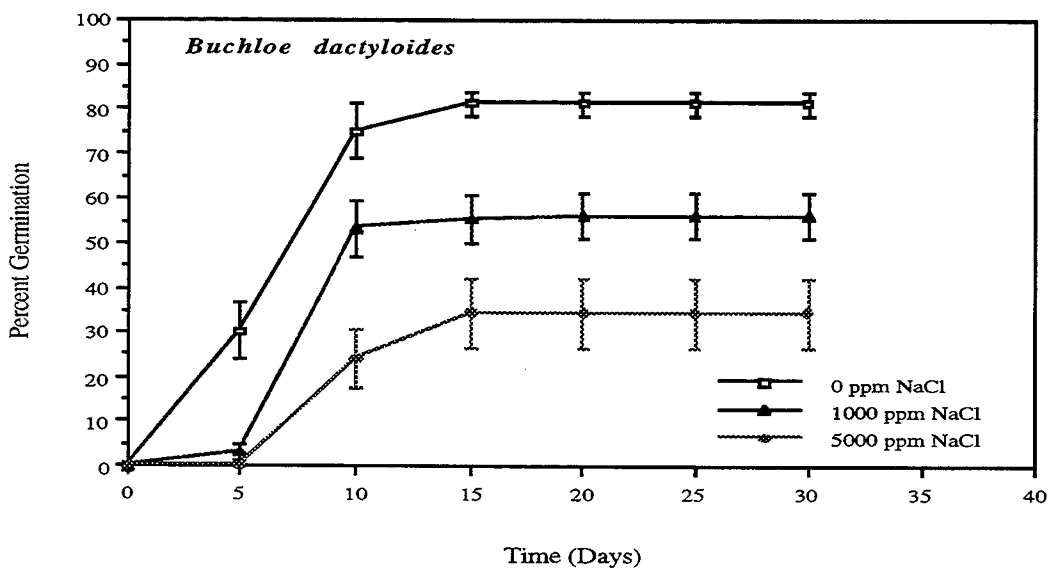


Figure 1. Effect of NaCl on the germination of *Buchloe dactyloides*

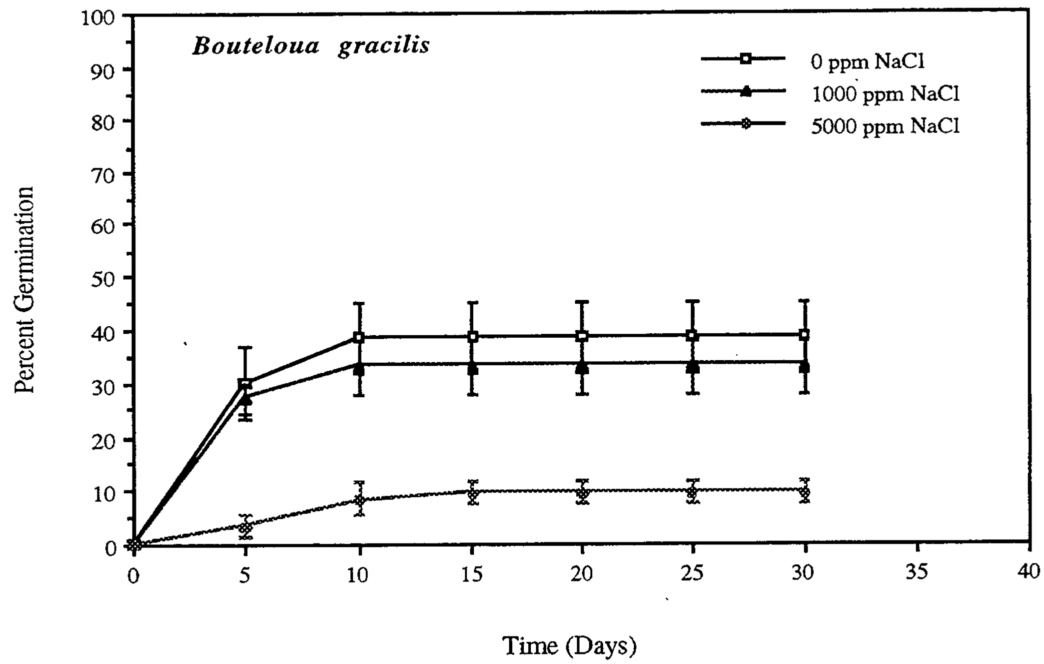


Figure 2. Effect of NaCl on the germination of *Bouteloua gracilis*

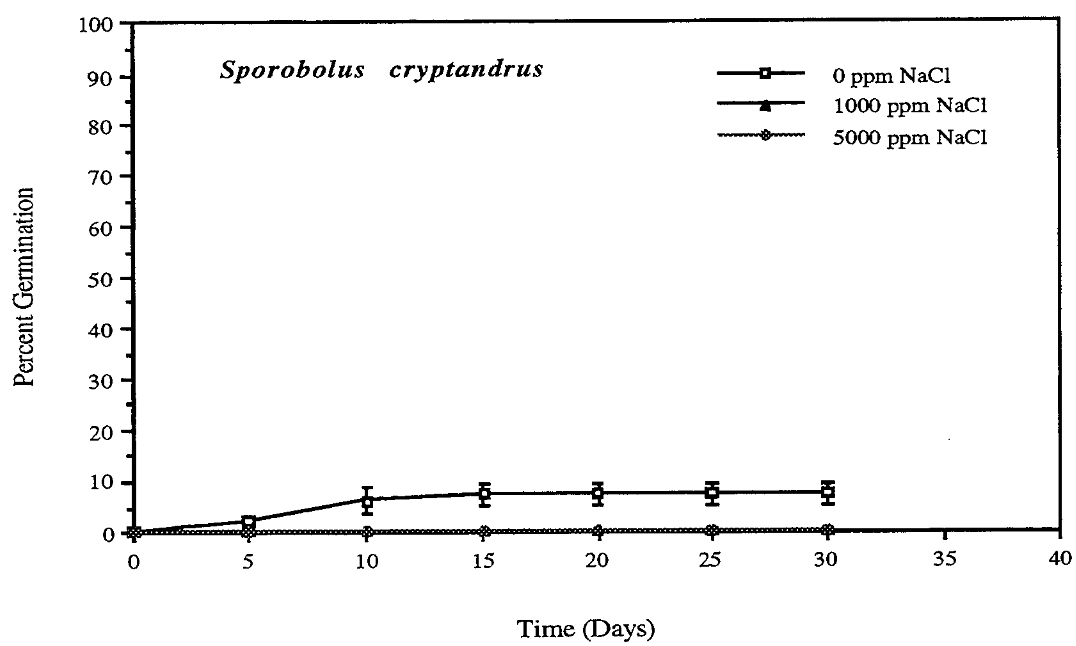


Figure 3. Effect of NaCl on the germination of *Sporobolus cryptandrus.*

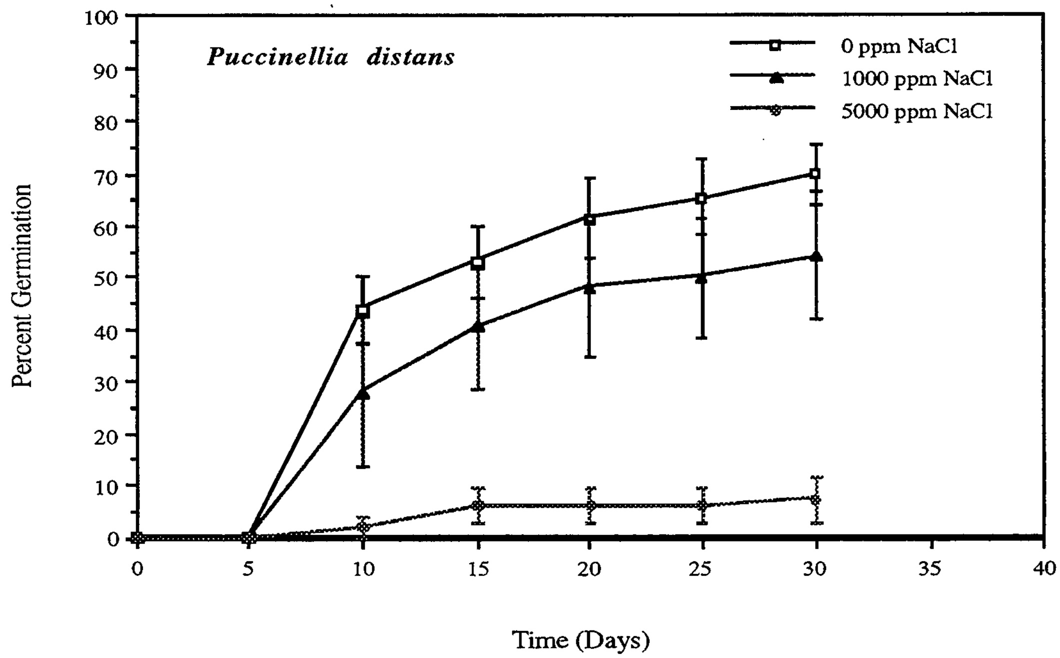


Fig. 4. Effect of NaCl on the germination of *Puccinellia distans*.

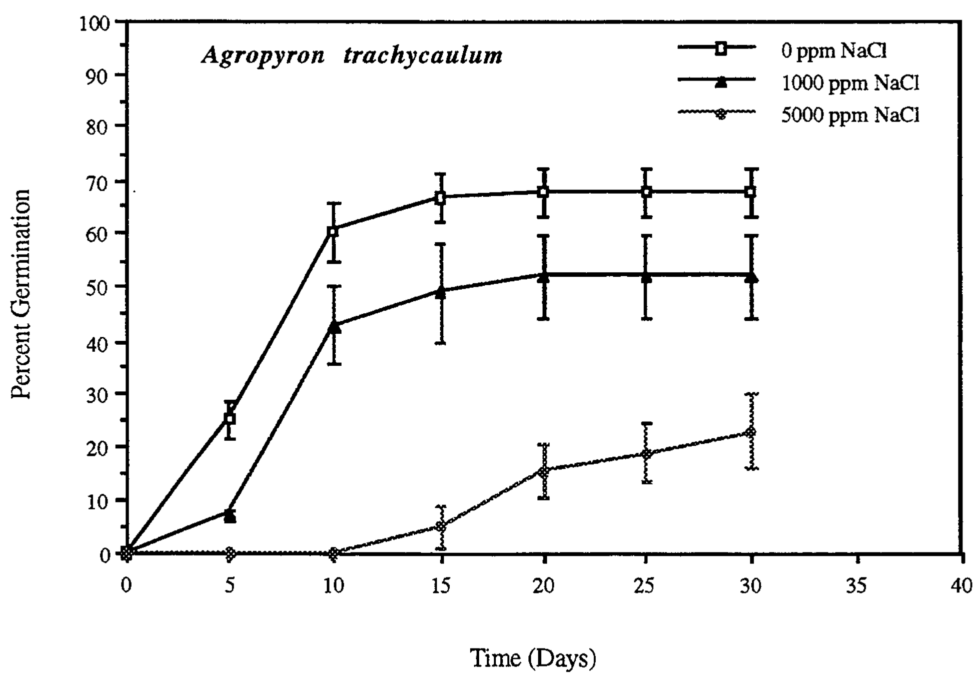


Fig. 5. Effect of NaCl on the germination of *Agropyron trachycaulum*.

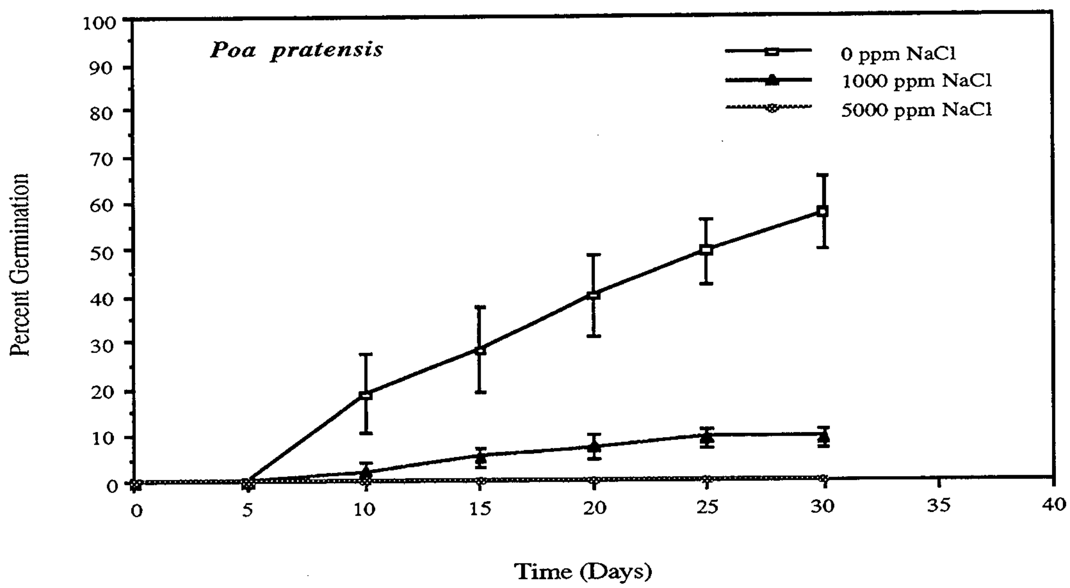


Figure 6. Effect of NaCl on the germination of*Poa pratensis.*

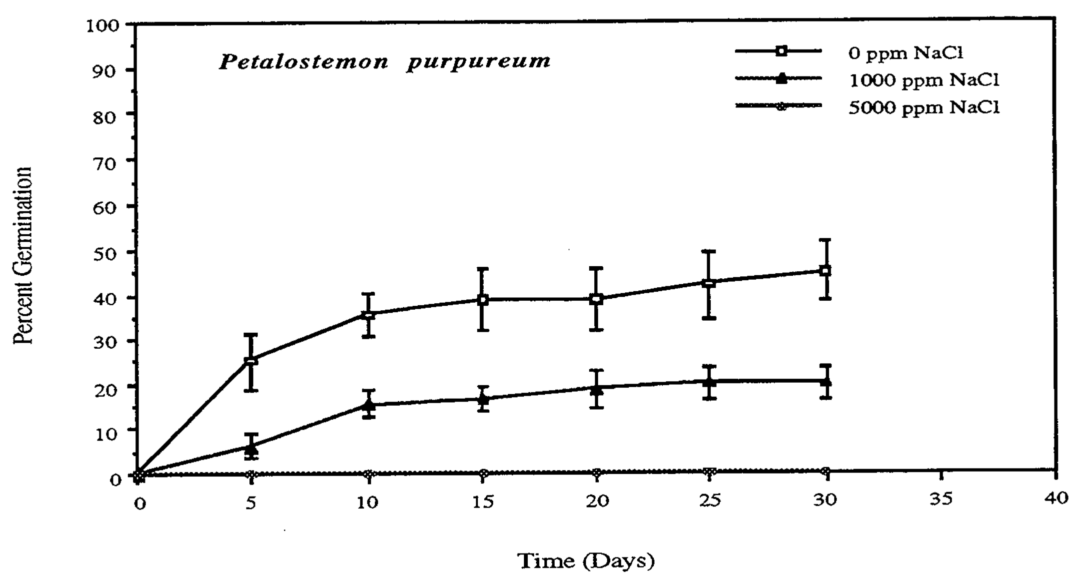


Fig. 7. Effect of NaCl on the germination of *Petalostemon purpureum.*

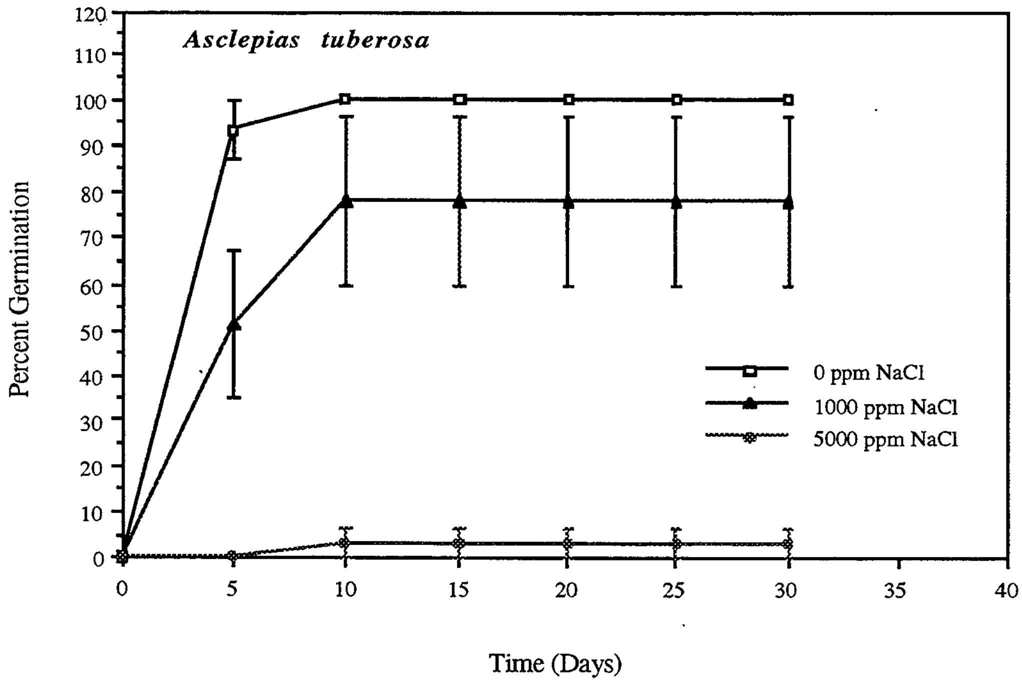


Fig. 8. Effect of NaCl on the germination of *Asclepias tuberosa*.

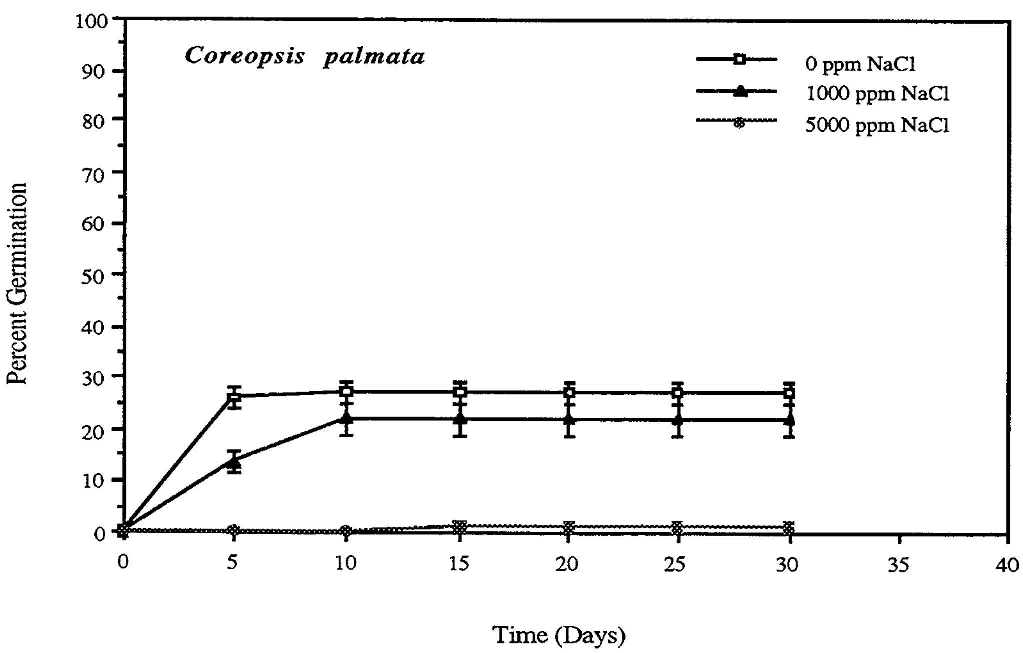


Fig. 9. Effect of NaCl on the germination of *Coreopsis palmata*.

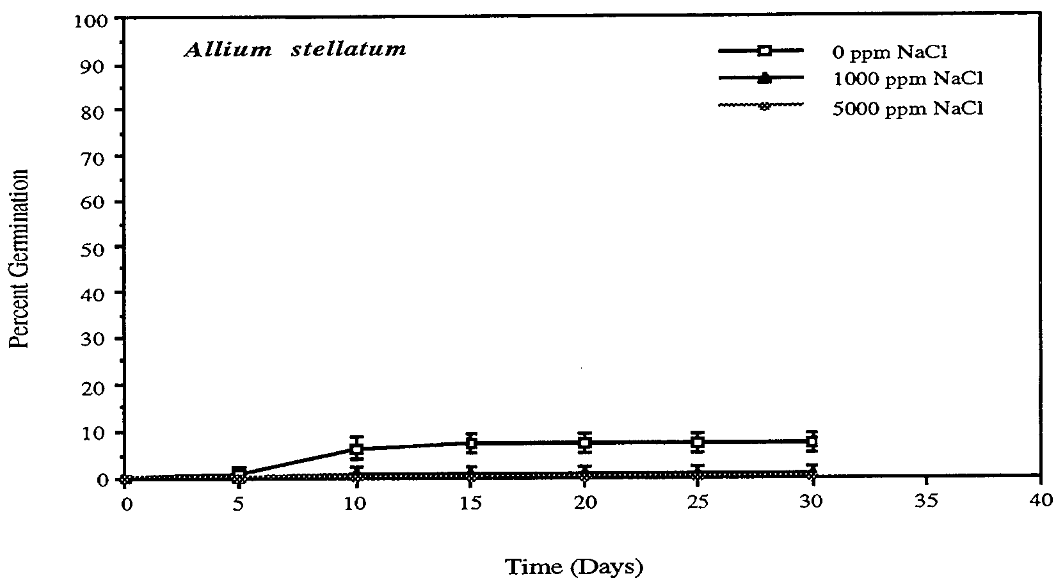


Fig. 11. Effect of NaCl on the germination of *Allium stellatum.*

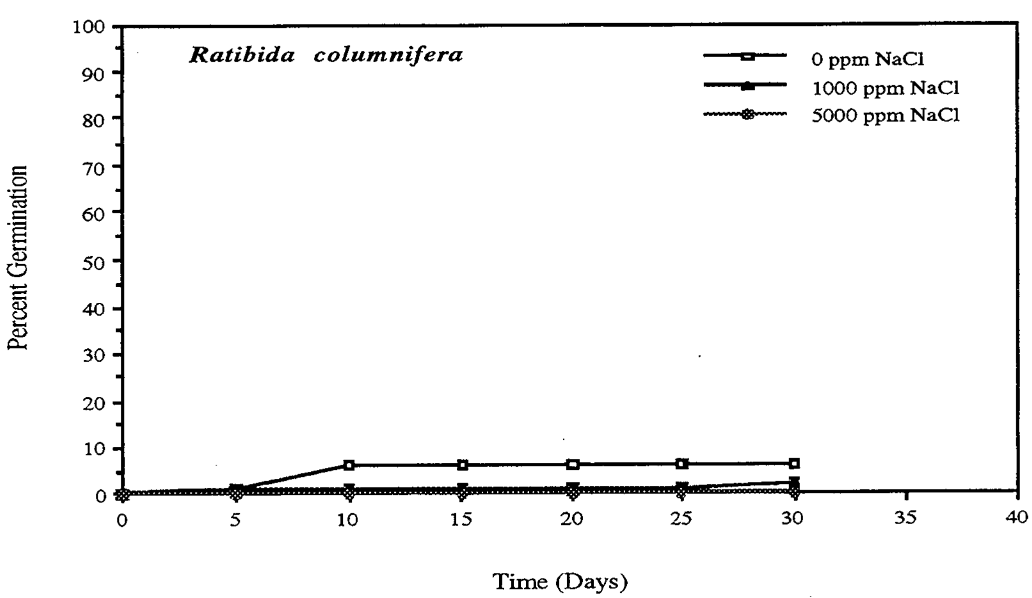


Figure 10. Effect of NaCl on the germination of *Ratibida columnifera.*

Table 1. Percent survival of germinants exposed to NaCl treatments after 30 days. Mean survival was determined from N=4 repetitions of 24 seeds per repetition.

Species	% Survival		
	0 ppm NaCl	1000 ppm NaCl	5000 ppm NaCl
Buchloe dactyloides	94 a*	88 a	44 b
Bouteloua gracilis	48 a	36 a	25 a
Sporobolus cryptandrus	92	-	-
Puccinellia distans	99 a	98 a	100 a
Agropyron trachycaulum	97 a	98 a	79 a
Poa pratensis 'Park'	100 a	100 a	-
Petalostemon purpureum	77 a	29 b	-
*Asclepias tuberosa***	97 a	56 b	0 c
Coreopsis palmata	93 a	66 a	0 b
Allium stellatum	100	0	-
Ratibida columnifera	50	50	-

*Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance. Some of the data could not be statistically compared due to having no or too few germinants.
**For *Asclepias tuberosa* N=4 repetitions of 8 seeds per repetition were used.

Table 2. Shoot and root biomass of germinants exposed to NaCl treatments after 30 days.*

	Shoot Biomass (mg/plant)			Root Biomass (mg/plant)		
	0 ppm	1000 ppm	5000 ppm	0 ppm	1000 ppm	5000 ppm
Buchloe dactyloides	7.8 a**	6.4 a	2.5 b	2.0 a	1.7 a	0.4 b
Bouteloua gracilis	2.6 ab	4.0 a	0.7 b	0.8 a	0.9 a	0.1 a
Puccinellia distans	0.5 a	0.4 a	0.3 a	0.4 a	0.4 a	0.2 a
Agropyron trachycaulum	6.2 a	6.4 a	0.7 b	3.8 a	4.0 a	0.2 b
Poa pratensis 'Park'	0.8 a	0.6 a		0.6 a	0.3 a	
Petalostemon purpureum	5.1 a	3.6 a		1.6 a	0.8 a	
Asclepias tuberosa	25.3 a	15.7 a		19.8 a	9.3 a	
Coreopsis palmata	9.3 a	4.5 b		1.8 a	0.7 b	

*Mean values were determined from repetitions of varying numbers of survived plants. Due to a low survival rate for some species under some treatments, the means were determined from less than 4 repetitions.

**Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

Table 3. The effect of calcium sulfate on blue grama (*Bouteloua gracilis*) germination and survival exposed to sodium chloride. N=6 repetitions of 100 seeds each for each treatment combination.

	CaS04		
	0 mM	**5 mM**	**10 mM**
NaCl	**% Germination - Day 6**		
0 ppm	22.5	21.7	17.5
1000 ppm	19.0	17.7	18.2
3000 ppm	15.0	20.2	14.3
5000 ppm	16.7	16.0	15.3
	Mean Number of Survived Germinants - Day 20		
0 ppm	4.2	3.2	3.0
1000 ppm	2.0	1.5	1.5
3000 ppm	1.2	2.2	1.3
5000 ppm	1.2	1.2	2.0
	Mean Dry Weight (mg/plant)		
0 ppm	0.80	0.69	0.78
1000 ppm	0.73	1.07	0.75
3000 ppm	1.09	0.74	0.56
5000 ppm	0.88	0.75	0.75

Table 4. Root and shoot biomass of mature grasses exposed to NaCl treatments*.

	Shoot Biomass (mg/plant)			Root Biomass (mg/plant)		
NaCl	**0 ppm**	**1000 ppm**	**5000 ppm**	**0 ppm**	**1000 ppm**	**5000 ppm**
Buchloe dactyloides	706 a (8)**	946 b (16)	694 a (19)	301 a	262 a	266 a
Bouteloua gracilis	312 a (5)	318 a (8)	441 a (5)	67 a	146 a	148 a
Sporobolus cryptandrus	1269 a (23)	1246 a (30)	1130 a (31)	339 a	313 a	220 b
Agropyron trachycaulum	227 a (17)	347 b (25)	378 b (25)	424 a	255 b	662 c
Puccinellia distans	546 a (26)	668 b (26)	397 c (26)	555 a	677 a	251 b
Poa pratensis 'Park'	418 a (19)	333 a (22)	340 a (22)	638 a	197 b	170 b

* Eleven week old grasses were subjected to 9 weeks of salt treatments before harvesting.
**Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance. Numbers in parentheses are sample sizes for both shoot and root biomass determinations.

Vegetation establishment in experimental field sites.

The vegetational composition resulting from native roadside plantings does vary according to site but generally can be expected to have only a 10-20% cover of the desirable native species (Table 5). In spring the majority of the cover is bareground (60%) which becomes filled in by the weedy grasses and dicots which represent the dominant cover (50%) by August (Table 5). Some non-native roadside plantings around the metro area were additionally sampled for comparison with our native plantings and show that the native plantings do result in significantly less dicot weeds but more bareground than the non-native roadside plantings (Table 6). The weedy grasses could not be distinguished from the non-native grasses at these sampling sites so were not included in the analysis although they do represent a large component of the roadside vegetation (Table 6).

Within the two years that the native plantings were being monitored, the percent cover of desirable vegetation either remained about the same or decreased between the successive August samplings (Table 7). The percent cover of desirable vegetation is low in June 1995 at the Cambridge sites since the newly planted grasses were just beginning to germinate at this time (Table 7).

Since there were spring and fall plantings of the seed treatments at both Cambridge and Eden Prairie, a comparison could be made to determine if time of planting would influence the resulting vegetational composition (Table 8). During the first growing season the cool season grasses (mix 300 in part, mix 400, *Agropyron trachycaulum*, *Puccinellia distans*, and *Poa pratensis*) establish significantly better when fall planted whereas the warm season grasses (mix 350, *Buchloe dactyloides*, *Bouteloua gracilis*, and *Sporobolus cryptandrus*) establish similarly regardless of planting season. This difference diminished by the second growing season at the Cambridge sites.

The roadside vegetation is greatly influenced by proximity to the roadway (Tables 9 and 10). There is significantly less desirable grasses and significantly more bareground within 1 meter of the pavement edge as compared to distances further down the inslope (Table 9). This lack of desirable grasses is not due to poor germination and establishment at this location (Table 10). It appears that the loss of desirable species occurs after the first winter and is particularly dramatic for *Poa pratensis*. In contrast, *Puccinellia distans* is able to survive and actually has the highest percent cover within the first couple meters of the inslope.

Table 5. Vegetational composition of roadside native plantings.

	% Cover					
	Desirable grasses		Weedy grasses and dicots		Bareground	
	Jun. '96	Aug.'96	Jun. '96	Aug.'96	Jun. '96	Aug.'96
Cambridge-Fall						
mix300*	53	49	8	27	41	33
mix400**	51	34	15	48	37	23
mix350	16	21	29	31	40	38
Cambridge-Spring						
mix300	20	20	8	22	74	59
mix400	25	26	19	32	55	42
mix350	16	25	17	25	69	74
St. James***	12	15	70	84	22	6
Crosstown	6	11	42	39	40	26
Eden Prairie-Fall						
mix300	9	15	7	52	85	39
mix400	20	21	16	61	68	30
mix350	1	5	32	66	67	31
Eden Prairie-Spring						
mix300	1	5	1	59	95	35
mix400	2	0	4	67	93	31
mix350	2	15	5	66	90	24
Mean % cover ± SE	**13.6 ± 4.8**	**18.1 ± 4.0**	**21.9 ± 6.9**	**47.1 ± 6.7**	**62.3 ± 7.9**	**34.5 ± 4.7**

*mix 350 is primarily a native mix but does contain a large non-native component-alkaligrass which is included in the desirable grass % cover value.
**mix400 is a non-native seed mix and therefore was not included in the overal mean percent cover.
*** The data for all 6 plots were combined for the St. James site, thus giving a sample size of 30, measured at 1 m from the pavement edge. Each of the other sites had a sample size of 20, measured within 4m from the pavement edge.

Table 6. Comparison of native and non-native vegetation along Minnesota roadside plantings.*

Vegetation Type	% Cover - August 1996	
	bare ground	**dicot weeds**
native	33.8 a (130)**	15.7 a (130)
non-native	18.0 b (140)	26.1 b (140)

*The native vegetation included the following sites: Crosstown, St. James, Cambridge-Spring and Cambridge-Fall plots "mix300" and "mix350". The non-native vegetation included the following sites: Cambridge-Spring and Cambridge-Fall plots "mix400", and 5 sites along the Twin Cities metro area I-94 system.

**Means within a column followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance. Numbers in parentheses are sample sizes.

. **Table 7.** Vegetational changes in roadside plantings as the stand ages.

	% Cover of Desirable Vegetation*					
	Aug.'93	Sep.'93	Jun '95	Aug.'95	Jun '96	Aug.'96
Cambridge-Fall						
mix300			38 a**	57 a	53 a	49 a
mix400			12 d	64 a	51 b	34 c
mix350			0 c	37 a	16 b	21 b
Cambridge-Spring						
mix300			0 b	27 a	20 a	20 a
mix400			0 b	18 a	25 a	26 a
mix350			2 b	36 a	16 b	25 ab
St. James* **						
MR-1	16 bc	32 a	26 ab	28 ab	4 c	4 c
MR-2	24 ab	31 a	18 abc	8 cd	10 bcd	2 d
MR-3	22 bc	40 ab	6 c	56 a	14 c	26 bc
MR-4	18 b	34 ab	10 c	52 a	4 c	14 bc
MR-5	20 a	11 a	0 a	24 a	8 a	10 a
MR-6	17 c	41 b	2 c	76 a	32 b	36 b
Crosstown			6 a	4 a	6 a	11a

*Mean % cover of desirable vegetation for each plot was determined from a sample size of 5, measured at 1 m from the pavement edge for St James, and a sample size of 20, measured within 4m at Cambridge-Fall, Cambridge-Spring, and Crosstown sites.
**Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.
***The 1993 data set for St. James was reanalyzed from a previous study: Stenlund, D.L. and R.L. Jacobson. 1994. Establishment of short and mid-height grasses on roadway inslopes. Final Report to the Minnesota Department of Transportation

Table 8. Comparison of spring and fall plantings of roadside vegetation. N=20.

	% Cover of Desirable Vegetation		
Sites	**Cambridge**		**Eden Prairie**
Treatment Plots	**After 1 growing season (August 1995)**	**After 2 growing seasons (August 1996)**	**After 1 growing season (August 1996)**
Mn/DOT mix 300			
fall planted	57 a*	49 a	15 a
spring planted	27 b	20 b	5 b
Mn/DOT mix 400			
fall planted	64 a	34 a	21 a
spring planted	18 b	26 a	0 b
Mn/DOT mix 350			
fall planted	37 a	21 a	5 a
spring planted	36 a	25 a	15 a
Buchloe dactyloides monoculture			
fall planted	26 a	4 a	0 a
spring planted	19 a	2 a	3 a
Bouteloua gracilis monoculture			
fall planted	11 a	10 a	2 a
spring planted	8 a	2 b	4 a
Sporobolus cryptandrus monoculture			
fall planted	-	-	0 a
spring planted	2	0	0 a
Agropyron trachycaulum monoculture			
fall planted	25 a	24 a	0 a
spring planted	0 b	4 b	0 a
Puccinellia distans monoculture			
fall planted	35 a	18 a	19 a
spring planted	16 b	29 a	0 b
Poa pratensis 'Park' monoculture			
fall planted	47 a	10 a	0 a
spring planted	3 b	20 a	0 a

*Means within a column, for each treatment plot, followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

Table 9. Effect of distance from pavement edge on vegetational composition of roadside plantings. N=180.*

Distance from edge of pavement	August 1996 % Cover		
	Desirable grasses	Weedy grasses and dicots	Bareground
1 meter	4.2 a**	44.1 a	47.5 a
2 meters	13.1 b	47.2 ab	33.8 b
3 meters	11.8 b	50.5 bc	28.9 c
4 meters	14.4 b	54.6 c	29.3 bc

*All plots in Cambridge-Fall, Cambridge-Spring, Eden Prairie-Fall, Eden Prairie-Spring, and Crosstown sites, were combined for determination of the mean.
**Means within a column followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

Table 10. Effect of distance from pavement edge on establishment of selected grass species in roadside plantings. N=5.

Monoculture Plots	% Cover of Desirable Vegetation at Cambridge-Fall Site*			
	June 1995	Aug.1995	June 1996	Aug.1996
Cambridge-Fall				
Buchloe dactyloides				
1 meter	16 ab**	36 a	0 b	0 b
2 meters	4 b	34 a	0 b	0 b
3 meters	2 a	16 a	2 a	14 a
4 meters	2 a	18 a	0 a	0 a
Bouteloua gracilis				
1 meter	0 a	0 a	0 a	0 a
2 meters	4 a	14 a	2 a	2 a
3 meters	0 a	18 a	14 a	14 a
4 meters	4 a	12 a	12 a	24 a
Agropyron trachycaulum				
1 meter	2 a	12 a	0 a	2 a
2 meters	10 a	22 a	34 a	44 a
3 meters	0 a	14 a	26 a	26 a
4 meters	4 b	50 a	38 a	26 ab
Puccinellia distans				
1 meter	44 a	40 a	20 a	24 a
2 meters	28 a	34 a	48 a	42 a
3 meters	46 a	38 a	24 a	4 a
4 meters	10 ab	26 a	12 ab	0 b
***Poa pratensis* 'Park'**				
1 meter	22 b	62 a	0 c	0 c
2 meters	18 b	52 a	4 b	6 b
3 meters	6 b	54 a	22 b	14 b
4 meters	8 a	18 a	22 a	20 a

*Data from Cambridge-Spring site showed very similar trends.
**Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

NaCl inputs and the influence on soil properties.

Sodium chloride inputs and resulting concentrations in the soil throughout the growing season were closely monitored at the Cambridge-Fall field site. The amount of NaCl from winter spray and splash was dependant upon the distance away from the road (Table 11). The majority of the NaCl landed within the first 5 meters of the inslope with a sharp reduction further down the inslope (Table 11). There were no statistically significant differences in resulting soil concentrations of Na or Cl within the first 4 meters of the inslope during the growing season (Table 12). Temporally, exchangeable Na, soluble Na, Cl, conductivity, and pH were all higher in soils collected during the 1996 season as compared to the 1995 season (Figures 12-14) especially for exchangeable Na (Figure 12). There were statistically significant increases in both exchangeable and soluble Na levels in soils after only two winter seasons (Table 13). Soil conductivity and Cl concentrations had also increased during the two years since road opening but these increases were not statistically significant (Table 13). Within the seasons there also was a general pattern of higher soil concentrations of Na and Cl and total conductivity during the spring with subsequent decline throughout the season (Figures 12 and 13). This was also true for concentrations of Na and Cl in "JES" pond where levels were significantly greater during the May sampling (Table 14). The large drop in soil pH during August of 1995 (Figure 14) appeared to be related to the heavy rains which had occurred during that same time (Figure 15).

Each of the soil parameters were measured at three different depths during both the 1995 and 1996 growing seasons (Figures 16-20). Exchangeable Na, soluble Na, Cl, and soil conductivity were all higher within the top 10 cm and decreased at greater depths. The pattern of seasonal decline for each soil parameter was similar at each depth except during August of 1995 when there was a transitory peak at the lower depths.

Comparing the soil parameters among all the field sites, Eden Prairie had the highest values for the soluble ions (conductivity, Cl, and soluble Na) followed by Crosstown, St. James, and Cambridge (Table 15). The Eden Prairie and St. James sites were generally the most fertile with greater levels of nutrients, organic matter, and cation exchange capacities (Table 16).

Table 11. Amount of NaCl (g/m^2) in aerial salt spray collection transects along highway 65 at the Cambridge-Fall site. N=3.

Collection Dates	NaCl Input (g NaCl/m^2) Distance from pavement edge (m)				
	2	5	10	15	20
12-02-94	45.36 a	53.67 a	4.91 b	0.05 b	0.04 b
12-13-94	53.90 a	17.32 b	1.05 c	0.80 c	0.62 c
12-19-94	131.71 a	163.38 a	1.23 b	0.91 b	0.48 b
1-10-95	18.39 a	16.72 a	4.42 a	0.83 a	0.44 a
1-19-95	35.05 a	14.00 b	5.57 b	2.45 b	1.20 b
2-16-95	95.44 a	58.93 a	0.85 b	0.35 b	0.28 b
3-10-95	138.63 a	82.28 b	13.20 c	2.24 c	1.35 c
4-27-95	20.47 a	9.37 b	5.28 bc	1.49 cd	0.69 d
Seasonal Total	**538.95**	**415.67**	**36.51**	**9.12**	**5.10**

*Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

Table 12. Effect of distance from pavement edge on measured soil parameters at Cambridge-Fall site. N=36.*

Distance from edge of pavement	pH	Exchangeable Sodium (µg/g soil)	Soluble Sodium (µg/g soil)	Chloride (µg/g soil)
1 meter	8.1 a	172 a	65 a	33 a
2 meters	8.2 a	147 a	57 a	19 a
3 meters	8.1 a	182 a	67 a	33 a
4 meters	8.0 a	159 a	60 a	19 a

*Monthly data from April - October of 1995, June and September of 1996 were combined for determination of the seasonal mean values.

**Means within a column followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

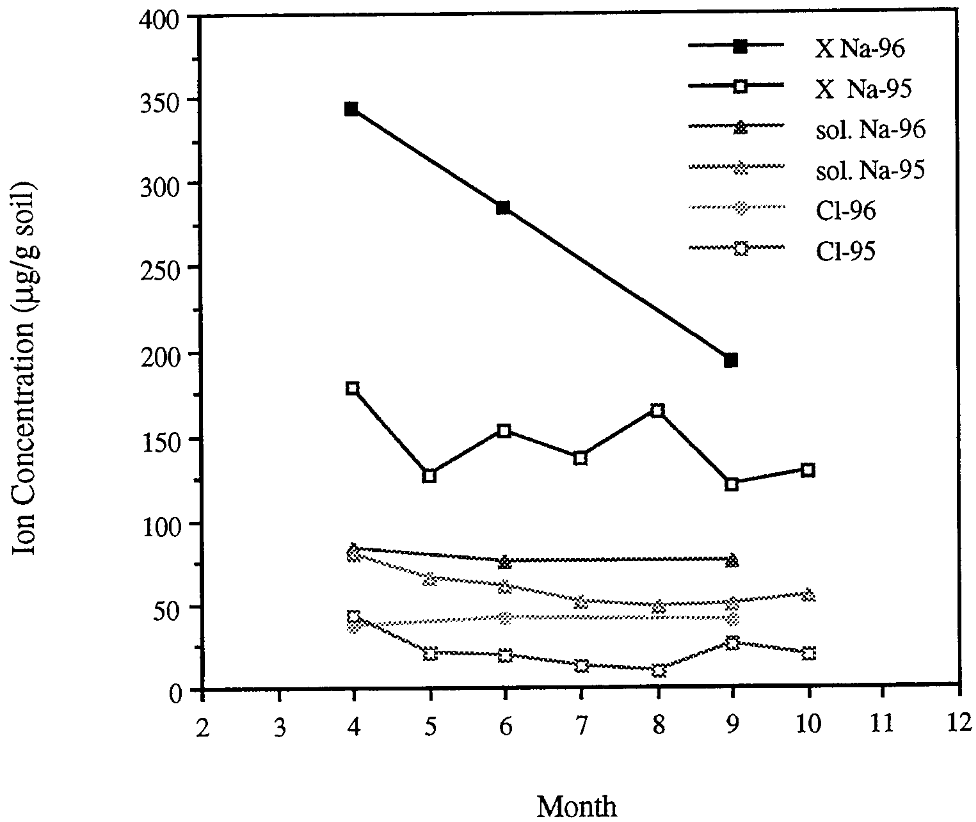


Figure 12. Sodium and chloride concentrations in soil during the 1995 and 1996 seasons at the Cambridge-Fall field site. Soil samples were collected within 4 m from the pavement edge, to a depth of 10 cm. Each data point represents the mean value from 16 soil samples. "X Na", "sol. Na" refer to exchangeable sodium and soluble sodium, respectively.

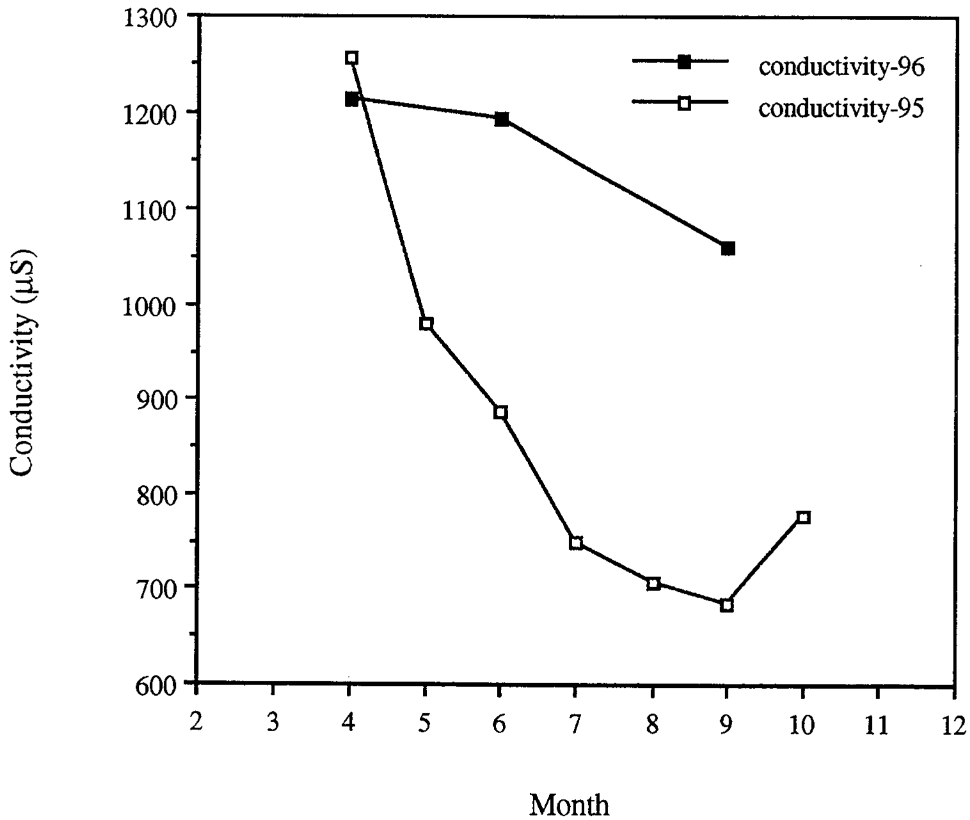


Figure 13. Soil conductivity during the 1995 and 1996 seasons at the Cambridge-Fall field site. Soil samples were collected within 4 m from the pavement edge, to a depth of 10 cm. Each data point represents the mean value from 16 soil samples.

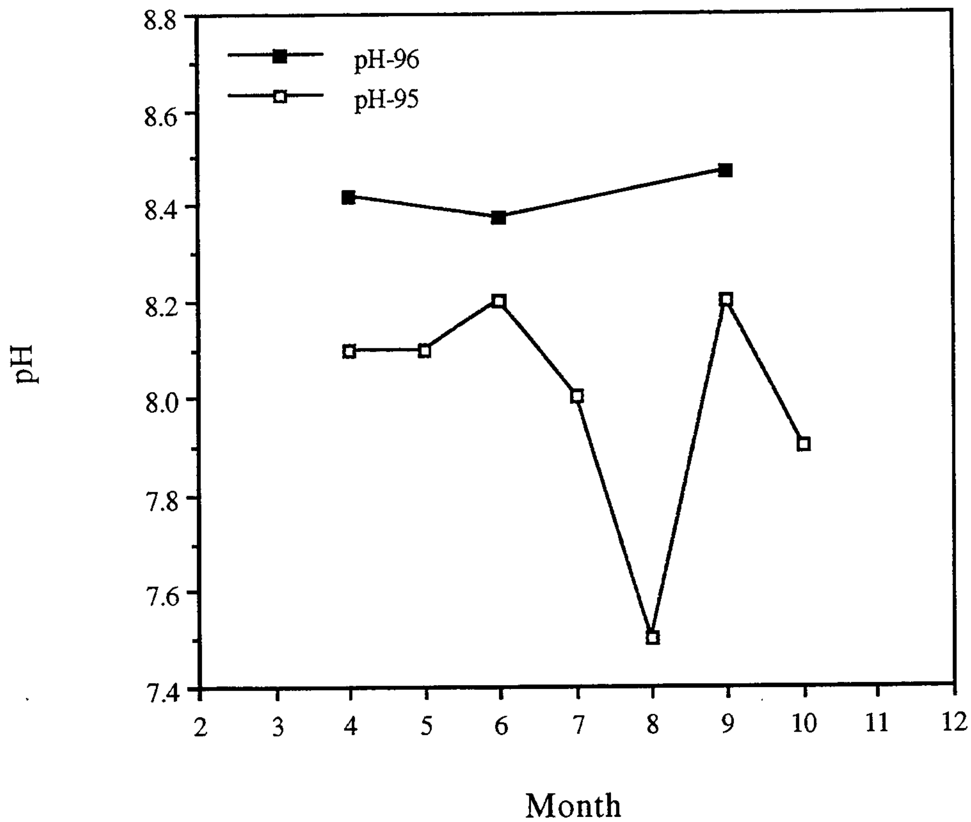


Figure 14. Soil pH during the 1995 and 1996 seasons at the Cambridge-Fall field site. Soil samples were collected within 4 m from the pavement edge, to a depth of 10 cm. Each data point represents the mean value from 16 soil samples.

Table 13. Three year comparison of soil parameters for the Cambridge - Fall site. Soil samples were collected in September, within 4m from the pavement edge, to a depth of 10 cm

Sampling Date	September 1994	September 1995	September 1996
Sample Size	3*	16	16
Conductivity (µS)	831 a**	683 a	1060 a
Cl (µg/g soil)	5 a	25 a	40 a
Exchangeable Na (µg/g soil)	22 a	120 ab	193 b
Soluble Na (µg/g soil)	22 a	49 ab	75 b

*Each 1994 sample represents a composite sample of 4, collected prior to any road salt use.
**Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

Table 14. "JES" Pond Water Analysis.

Date	sample size	pH	Conductance (µS)	Na (mg/l)	Cl (mg/l)	Cl/Na
Sep. 1994*	8	8.0 a**	452 a	5.24 a	7.30 a	1.22 a
Dec. 1994	4	8.5 a	502 a	5.82 a	7.34 a	1.08 a
May 1995	3	8.5 a	601 a	15.63 c	26.83 b	1.59 a
Aug 1995	3	7.8 a	419 a	7.40 ab	13.44 ab	1.76 a
May 1996	3	8.2 a	452 a	12.02 bc	25.43 b	2.00 a
Aug. 1996	3	8.9 a	309 a	5.60 a	10.19 ab	1.80 a

*Sep. 1994 samples were collected prior to any roadsalting of Highway 65.
**Means within a column followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

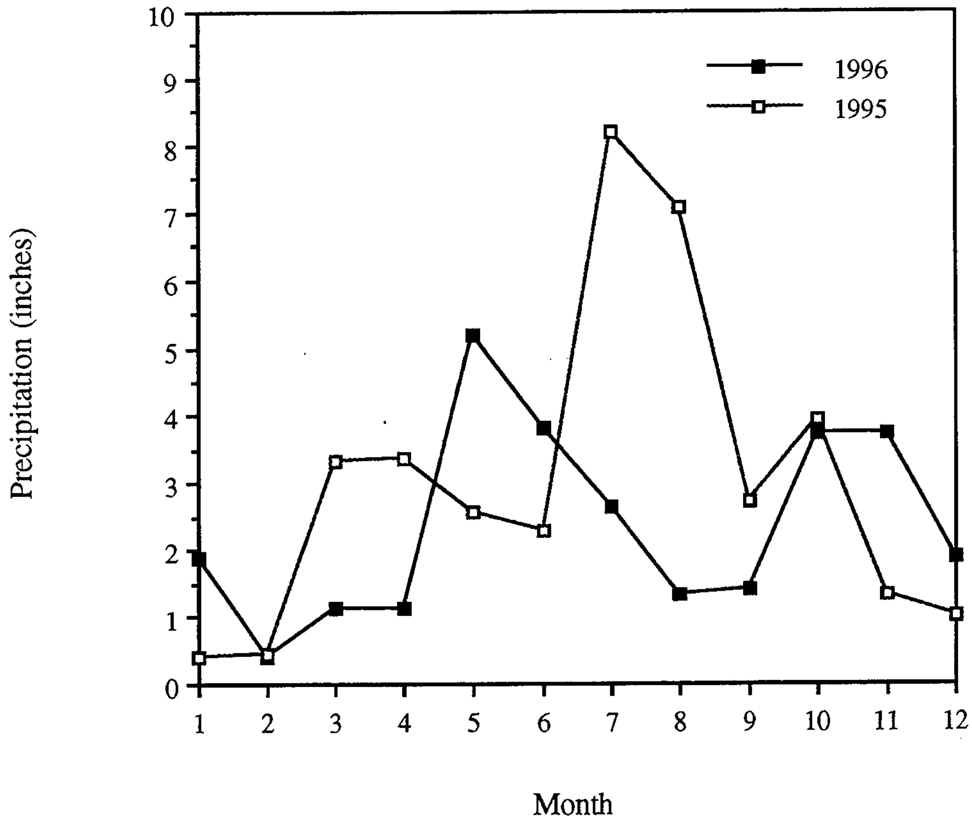
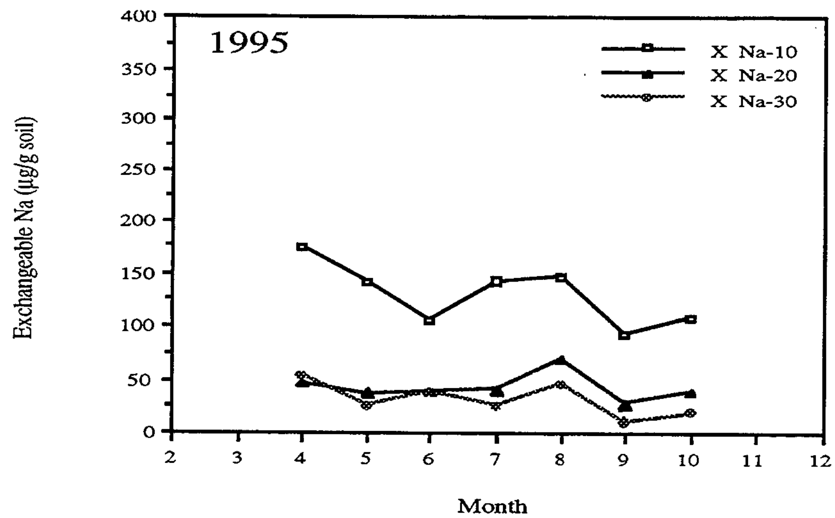


Figure 15. Precipitation totals for Cambridge, MN during the 1995 and 1996 seasons. The data was obtained from The State Climatology Office, Division of Waters, Minnesota Department of Natural Resources.



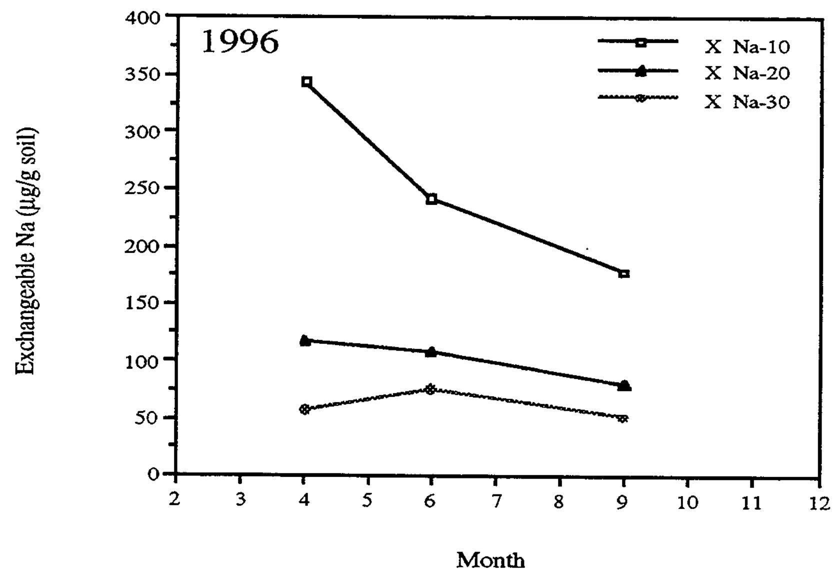
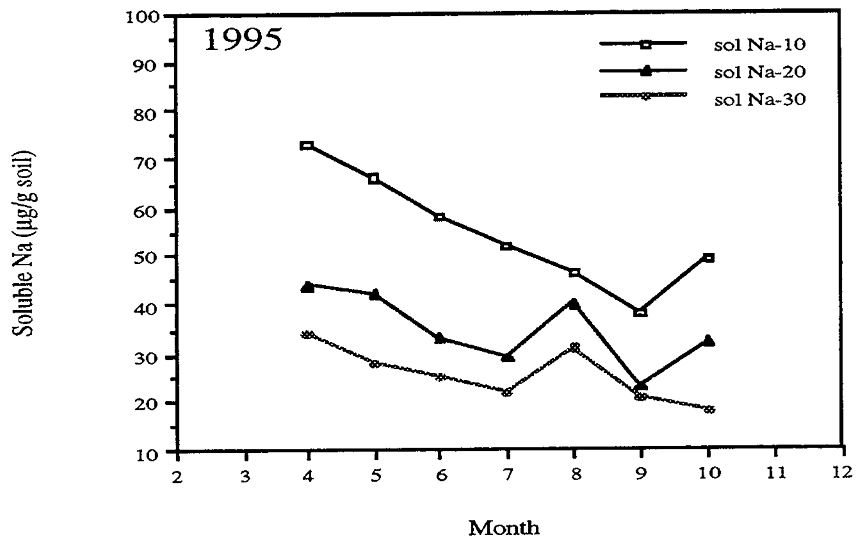


Figure 16. Exchangeable Na levels in Cambridge-Fall soils at differing depths during the 1995 and 1996 seasons. Soil samples were collected at 2 m from the pavement edge at depths of 1-10 cm, 11-20 cm, and 21-30 cm. Each data point represents the mean value from 4 soil samples.



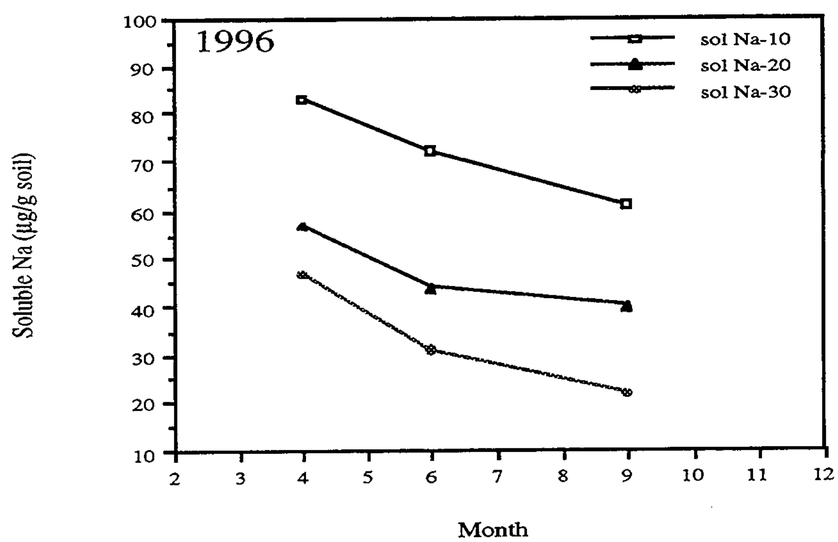
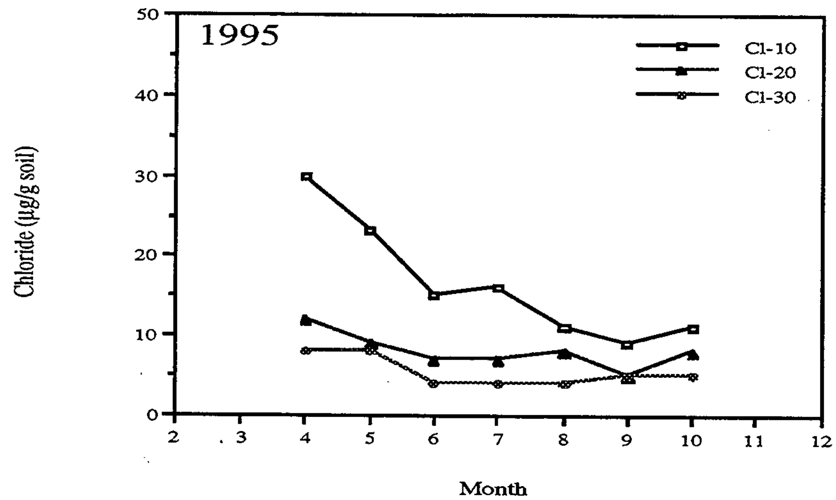


Figure 17. Soluble Na levels in Cambridge-Fall soils at differing depths during the 1995 and 1996 seasons. Soil samples were collected at 2 m from the pavement edge at depths of 1-10 cm, 11-20 cm, and 21-30 cm. Each data point represents the mean value from 4 soil samples.



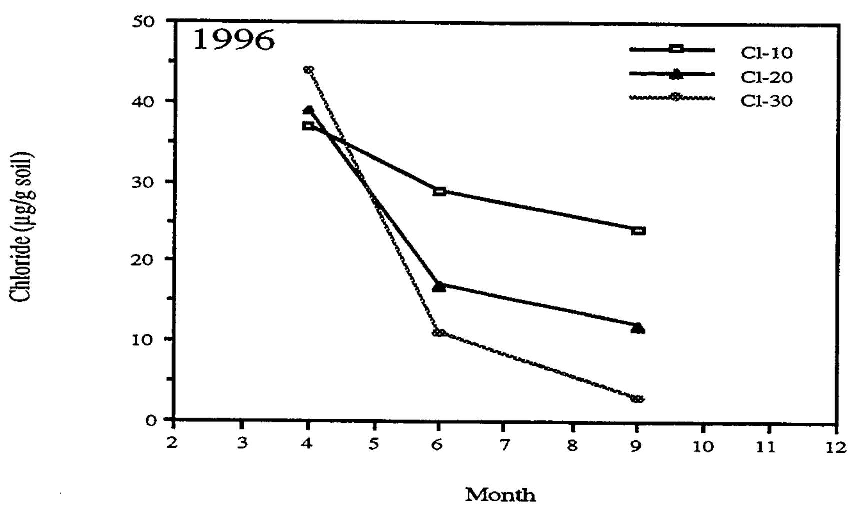
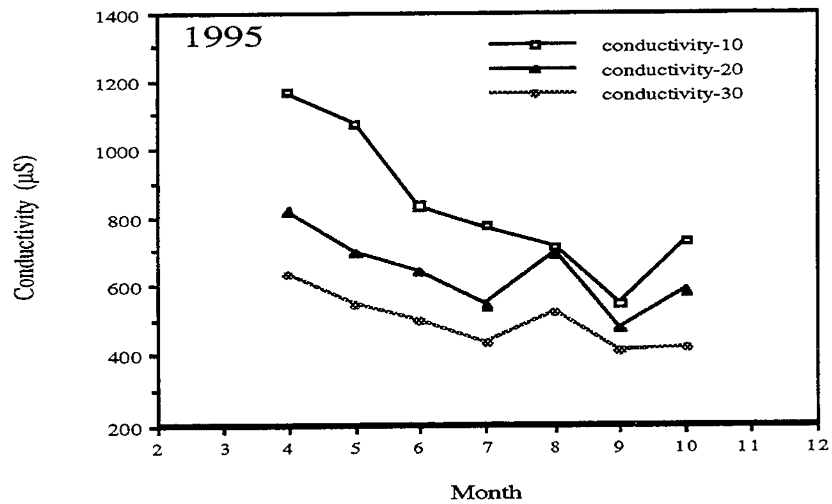


Figure 18. Chloride levels in Cambridge-Fall soils at differing depths during the 1995 and 1996 seasons. Soil samples were collected at 2 m from the pavement edge at depths of 1-10 cm, 11-20 cm, and 21-30 cm. Each data point represents the mean value from 4 soil samples.



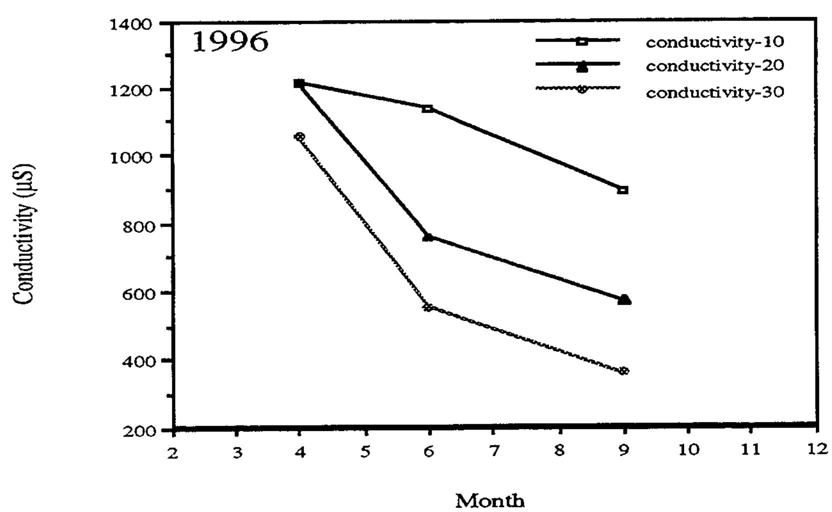
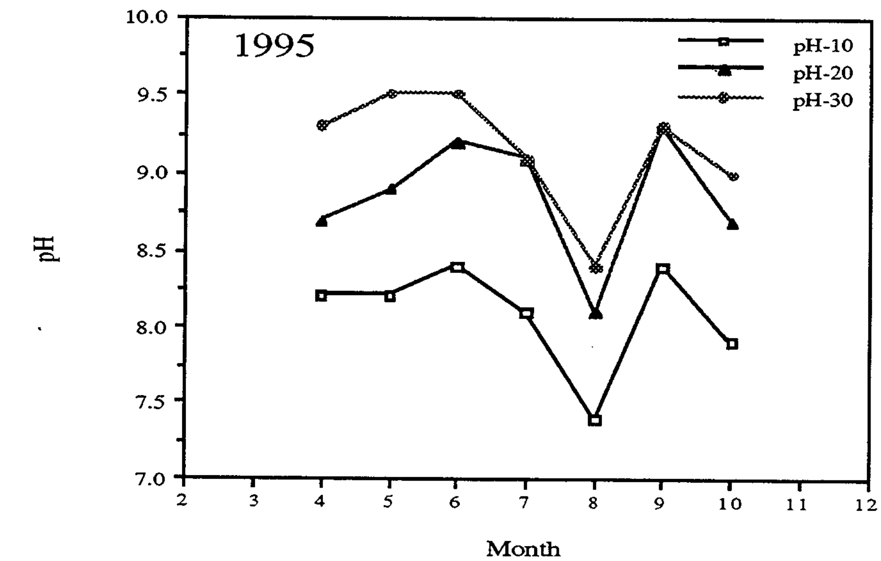


Figure 19. Conductivity in Cambridge-Fall soils at differing depths during the 1995 and 1996 seasons. Soil samples were collected at 2 m from the pavement edge at depths of 1-10 cm, 11-20 cm, and 21-30 cm. Each data point represents the mean value from 4 soil samples.



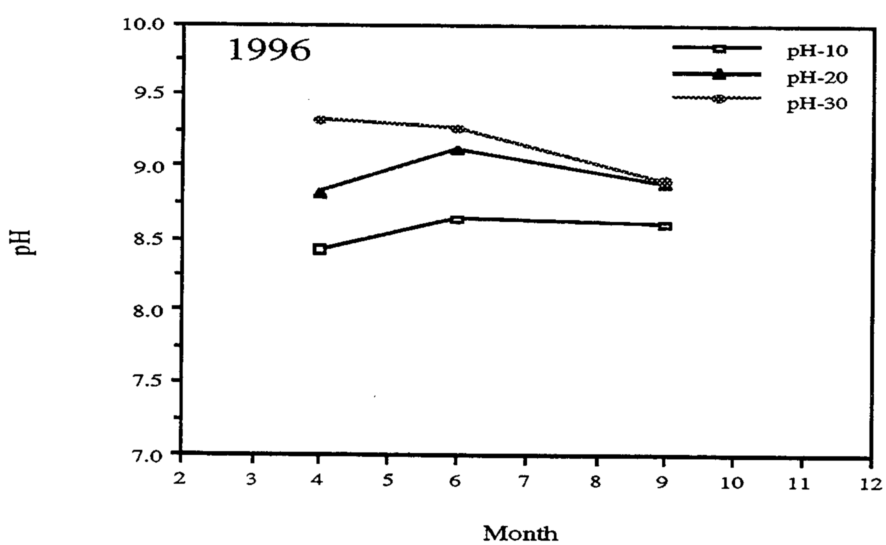


Figure 20. pH of Cambridge-Fall soils at differing depths during the 1995 and 1996 seasons. Soil samples were collected at 2 m from the pavement edge at depths of 1-10 cm, 11-20 cm, and 21-30 cm. Each data point represents the mean value from 4 soil samples.

Table 15. Comparison of soil parameters among all field sites. Soil was collected in April 1996, 2m from the pavement edge, to a depth of 10 cm. N=4.

Field Sites	Cambridge -Fall	Cambridge -Spring	St. James	Crosstown	Eden Prairie-Fall
pH	8.4 a*	8.4 a	7.9 b	8.5 a	7.7 b
Conductivity (µS)	1212 a	1325 a	2452 a	4988 b	8555 c
Cl (µg/g soil)	37 a	47 ab	204 bc	345 c	1076 d
Exchangeable Na (µg/g soil)	343 b	197 a	173 a	540 c	286 ab
Soluble Na (µg/g soil)	83 a	80 a	111 a	309 b	531 c

*Means within a row followed by the same letter are not significantly different according to Fisher's PLSD multiple comparison test at a 95% level of significance.

Table 16. Comparison of soil parameters among all field sites. Four soil samples were collected in April 1996, 2m from the pavement edge, and pooled into one composite sample per site for analyses.

Field Sites	Soil Depth (cm)	Cambridge -Fall	Cambridge -Spring	St. James	Crosstown	Eden Prairie-Fall
Soil Texture	10 20 30	sandy loam loamy sand loamy sand	loamy sand	sandy loam	loamy sand	loamy sand
% Organic Matter	10 20 30	1.2 1.0 0.4	0.8	3.1	2.9	6.2
C.E.C. (meq/100 g)	10 20 30	5.9 3.3 1.4	4.2	19.5	8.2	13.4
% Nitrogen	10 20 30	0.04 0.02 <0.01	0.03	0.16	0.12	0.27
Phosphorus (µg/g soil)	10 20 30	396 343 230	363	419	431	552
Potassium (µg/g soil)	10 20 30	533 579 266	701	1654	877	1013
Calcium (µg/g soil)	10 20 30	4791 11350 14910	6486	24380	11510	35500
Magnesium (µg/g soil)	10 20 30	2074 3313 4139	3086	9139	5929	10970

Discussion

Two non-native grasses were used to determine the relative salt tolerance of native grass species. These two non-native species, *Puccinellia distans* and *Poa pratensis* were chosen because *Puccinellia distans* has previously been shown to exhibit high tolerance to salt (Hughes *et al.*, 1975) and *Poa pratensis* has been shown to have relatively poor tolerance to salt (Greub *et al.*, 1985). Although many authors have produced lists of species ordered their ability to tolerate salt, our study clearly indicates that tolerance of salt varies depending upon life stage (ability to germinate, seedling stage, or mature plants) or according to which parameter is considered for indication of the degree of salt tolerance (% germination, delay in germination, 30 day survival, shoot or root biomass, or salt concentration).

Some concrete observations can be noted about salt tolerance in our tested grasses and forbs. Salt concentration of 1000 ppm and greater significantly delay germination of native grasses (Figs. 1- 6). More importantly, salt decreases the percentage of seeds that can germinate if salt is not present in the environment. This reduction, often in the range of 10 to 50% at the lowest tested concentration of 1000 ppm NaCl, is significant because if native grasses are seeded to even moderately saline soils, a significant proportion of the total number of seeds planted will be lost due to inhibition of germination. Higher concentrations of salt at 5000 ppm and above completely inhibit germination of *Sporobolus cryptandrus* and *Poa pratensis* (Figs. 3 and 6). Certainly, sodic soils delay and decrease germination in the field which partially accounts for the poor establishment and growth of native species near the roadside. In addition, *Poa pratensis*, a grass commonly used alone, in seeding mixes, or as sod on roadsides, is not tolerant of high salt conditions and should not be considered for use along heavily traveled and salted highways.

In contrast, survivability of germinated seeds was not significantly impacted across salt concentrations except for *Buchloe dactyloides* (Table 1). Seedlings that survive exposure to salt for 30 days also show little significant change in shoot or root biomass except when grown at the relatively high concentration of 5000 ppm NaCl (Table 2). The same conclusion can be reached for mature grasses exposed to salt (Table 3). Significant reductions of shoot and root biomass generally only occur at 5000 ppm. Seedlings or rapidly growing mature plants can safely tolerate moderately saline soils. This observation is further supported by our studies at Cambridge (below) that show that in soils not yet exposed to winter salting operations, that establishment and growth in the first season is very high, with rapid declines occurring only after over-wintering occurs.

Forbs were must less tolerant of salt than native grasses. But as was observed for the grasses, salt will delay germination, and decrease the percentage of germinating seeds (Figs. 7-10). More importantly, percent survivability decreased significantly for all species at the relatively low concentration of 1000 ppm and killed germinated seedlings at 5000 ppm (Table 1). As observed for the tested grasses, reduction of shoot and root biomass was not significantly different for plants grown at the low concentration of 1000 ppm NaCl except for a single species, *Coreopsis palmata.*

Based on these studies, it becomes difficult to rank the testes grass species in order of high to low salt tolerance. For example, although *Puccinellia distans* clearly germinated at percentages that were much higher than other species, and survived well with no biomass reductions at the seedling stage; it was the only species that exhibited a significant reduction in shoot biomass at the mature plant stage when grown in an environment containing 5000 ppm NaCl. In contrast, a concentration of 5000 ppm NaCl is lethal to *Poa pratensis*; however, this species did not show significant reductions in shoot biomass (but did show significant reductions in root biomass) when salt is applied at the mature stage. These observations are similar to those of Wu and Lin (1994) who found salt tolerance to be greater for young shoots separated from established plants than for seedlings of *Buchloe dactyloides*.

Generally, the tested species of grasses but not the forbs, could germinate and survive in our laboratory tests and at our field sites where concentrations of NaCl do not exceed 1000 ppm. Although significant delays and a 10 to 50% decrease in germination can occur at this concentration, surviving seedlings can establish and grow under these saline conditions. At our field sites, soil concentrations only slightly exceeded 1000 ppm NaCl (*i.e.,* total Cl, exchangeable Na, and soluble Na, ug/g=ppm) at the Crosstown and Eden Prairie sites during early spring. At Cambridge, where soils were very sandy and thus pervious to water, salt concentrations never exceeded 500 ppm during the spring.

Based on our observations, testing of salt tolerance followed by ranking of species as to their level of salt tolerance is very difficult to do based on laboratory trials. Tolerance to salt depends on the life stage of species and other factors that, in conjunction with sodic soils, will limit plant growth within several meters of the pavement edge. *In our opinion, salt tolerance of different plant species under consideration should be determined by long-term field studies and observation of species planted directly to sodic soils along heavily traveled highways.*

The difficulty of establishing and maintaining vegetation in proximity to highway pavements is strikingly illustrated by Table 1 in Appendix A. Table 1 (Appendix A) is a survey of vegetation found at 1, 2 and 3 m^2 from the pavement edge on the heavily traveled highways of Highways 36, I-494, and I-694 within the metropolitan area of Minneapolis-St. Paul. Several conclusions can be made from this survey. a) Salt damage, as evidenced by "salt-burned" vegetation (i.e., dead) or even bare, salt-encrusted ground, may extend several meters from the pavement edge and is especially prevalent in medians and blind drainages where salty water will be trapped and pool during the winter and early spring. b) Plant indicators of sodic soils such as obligate halophytes (*Suaeda* spp.) or wild barley (*Hordeum jubatum*) are often found within the first 3 meters of the pavement. c) The percentage of cover in the few 2 meters of the pavement is often very low. d) Most notably, the vegetation consists principally of weedy dicots and weedy grasses. Desirable plants such as *Bromus inermis* or other purposefully planted species are usually completely absent or only occasionally present within 3 meters of the pavement edge. Appearances are deceiving because even though the roadside appears to be vegetated, the vegetation is often sparse and usually not what is intended to be established at the roadside edge.

The vegetational observations of the roadside survey are reflected in the results of this large field study of salt tolerance in grasses. Table 5 shows percent cover and vegetational composition for standard MN/DOT grass mixtures and monocultures after two years of establishment at our experiment sites (Cambridge, MN; Eden Prairie, MN) and at two longer established sites (St. James, MN; the Crosstown Prairie). Mean percent cover across all sites to 4 meters from the pavement edge in August of 1996 shows that approximately 18% of the vegetation is desirable vegetation, 47% is weeds, and 34% is bare ground. Much time and effort is aimed at establishing successful plantings on the inslopes of highly traveled rights-of-way, but we suspect that very few plantings have been successful on the sodic, compacted, nutrient poor, disturbed soils of inslopes across the state.

However, despite the fact that native vegetation is difficult to establish within 4 meters of the pavement edge, one advantage of using native vegetation is that percent coverage of dicotyledonous weeds decreases from approximately 26% to 15% after two years when natives do become established. Native grasses are more competitive against weeds across all newly established and previously established plantings.

This study has quantitatively proven that it is surprisingly difficult to establish native vegetation along the shoulders and inslopes of roadsides despite the fact that native vegetation (grasses in particular) is surmised to have characteristics such as drought tolerance and adaptations to nutrient poor soils. Although the results of our laboratory studies and others (Roberts and Zybura 1967, Hughes *et al*. 1975, Greub *et al.* 1985, Mueller and Bowman 1989, Biesboer and Jacobson 1994) have shown that high salt concentrations can be detrimental to the germination and/or establishment of grasses, the initial germination and first season of plant growth of native grasses is very good, perhaps leading to the belief that these plantings will be successful. This high rate of early success in germination and early establishment also occurred within the first meter of the pavement edge. This early success is diminished rapidly by the second year which correlates with the findings of Stenlund and Jacobson (1994) who noted that increasing the seeding rate in native grasses plantings did not result in an increase in percent cover in following years.

At the Cambridge research site, where germination and early establishment was high, nearly all the monocultures or mixtures planted failed within the first meter from the edge of the pavement after the first winter. An exception was *Puccinella distans*. The most notable loss was *with Poa pratensis*, a species that has a long history as both a turf grass and is often utilized along the right-of-way. Since the soil sodium and chloride concentrations with the first meter of pavement were not significantly different form the soils further down the inslope, it should again be reiterated that *Poa pratensis* should not be used on inslopes on salted highways.

Salt appears to have its greatest effect on plantings during the winter months. In a study by Biesboer and Jacobson (1994), extremely high salt concentrations >20,000 ppm were occasionally found adjacent to pavements in the winter months. Salt damage probably occurs during this period of time with both exposure to high salt levels and frequent freeze-thaw cycles that damage the root systems of perennial plants on the inslope. This is especially evident at Cambridge where establishment of all mixtures and monocultures was very high followed by a rapid decline after one winter. Sandy soils, as found at the Cambridge site, probably contribute to plant damage during the winter because increased filtration of salty water occurs during the winter in sandy soils vs. soils having a higher content of silt or clay (Stoeckeler and Weitzman, 1960).

Table 9 is a particularly important data summary for this report. Examination of data across our experimental sites that were planted in both spring and fall, and at the established Crosstown site, it can be seen that grasses establish most poorly within one meter of the pavement but at greater distances out to 4 meters, they establish at a low and statistically insignificant different rate from the pavement edge. Weedy grasses and dicots are certainly problematical within 4 meters of the pavement edge with cover expected to be approximately 50% after two or more years.

Based on the data in this report as well as many years of personal observation of plantings on the inslopes of rights-of-way, the poor establishment and /or reductions of plant populations over time within the first 4 meters of the pavement are due to many factors. These factors include: a) High salt concentrations in soils which appears to damage established plants principally during the winter months. b) Very high localized concentrations of salt that cause plants to die after an initial flush of growth in the spring ("salt burn") or that result in bare-ground in blind drainages or slowly draining areas where salt-laden water will collect, then slowly percolate into the soil or evaporate (usually recognized by a salt crust at the surface of the soil even into late June in our area). c) Very nutrient poor soils that are especially low in nitrogen and have poor ion exchange capacity because of a low percentage of organic carbon (Table 16). d) High amount of disturbance from snow plowing operations which scrape the soil surface near the pavement exposing root systems directly to salt. e) Compaction caused by motor vehicles and highway maintenance equipment driven on the first two meters of soils near the pavement edge. f) A soil chemistry that is permanently changed by the addition of salt to roadside soils.

There is no doubt that the roadside environment is a highly disturbed environment. In this study, we examined the ability of grasses to establish and grow on a newly constructed highway (Cambridge), on an established highway (Eden Prairie), and at other longer established sites. These highly disturbed soils at all sites favor annual weeds but certainly do not favor the establishment of native species such as prairie grasses. In this environment, we found only a single species, *Puccinellia distans*, that performed well close to the pavement edge (Table 8; Table 10). This perennial species behaves like an annual species exhibiting fast growth and prolific seed production that allowed it to quickly propagate disturbed soils near the pavement. Another species that performed well at least within 2 meters of the pavement edge was *Agropyron trachycaulum*. Both should be increased in total percentage in mixes that are used near pavements (*e.g.*, the first pass by the seed drill). In addition, MN/DOT mix 300 (currently designated as 30A) which contains both native species and the non-native *Puccinellia distans* performed most satisfactorily in the near roadside environment on the tested inslopes.

The levels of Na and Cl measured in the soils from our field sites are well within the range found by previous studies which have also documented Na and Cl levels in soils adjacent to highways (Hutchinson and Olson 1967, Prior and Berthouex 1967, Zelazny and Blaser 1970, Langille 1976, Hofstra *et al.* 1979, and Hsu 1984). We also found that salt is very "mobile" in the environment moving in large quantities via aerial dispersion from the pavement surface and impacting soils many meters away from the road bed (Table 11) .

Similar to the findings of other studies, at our Cambridge field site there was a significant increase of exchangeable and soluble Na concentrations in the soil after only two winter seasons (Hutchinson and Olson 1967, Zelazny and Blaser 1970, Langille 1976, and Hsu 1984), and a seasonal pattern of higher Na and Cl levels in early spring followed by decline throughout the growing season until salting resumed again (Tables 12 and 13; Prior and Berthouex 1967, Zelazny and Blaser 1970, and Patenaude 1989). Although studies by Hutchinson and Olson (1967), Zelazny and Blaser (1970), Hofstra *et al.* (1979), Hsu (1984) and Patenaude (1989) all found Na and Cl concentrations in soils to decrease at greater distances (up to 200 ft) from the roadway, we had found no such distance effect within the first 4 meters from the roadway at the Cambridge site probably because of the relatively small distance range from which we were measuring. The concentrations of Na and Cl, as well as soil conductivity, were all higher in the top 10 cm of soil as compared to the lower depths which is in agreement with other reports (Table 13; Prior and Berthouex 1967, Hutchinson and Olson 1967, and Zelazny and Blaser 1970). The transitory peak in each of the soil parameters during August of 1995 at the lower depths was probably due to the unusually heavy rains which had leached the ions from the uppermost layers of soil. Buschena and Sucoff (1980) had also attributed a downward transport of Na in the soil profile to heavy summer rains during the 1979 season.

As part of this study, we also monitored salt contamination of the "JES" holding pond immediately adjacent to our study sites at Cambridge beginning with a sample taken prior to the first winter salting operation at this site, and ending nearly 2 years later. Samples were taken at three stations established at the north and south ends of the pond and a point midway between. The highest salt loads were observed in May of both 1995 and 1996 when spring rains flushed salt into this drainage basin. This was strictly a monitoring effort and the effects of increased salt load on biota of the pond were not explored.

In comparing our field sites, it is evident that the performance of native plants at any given site will be difficult to predict because of the differences in salt use, traffic volume, soil chemistry, nutrient levels, and other factors among the different sites. Although both the St. James and Eden Prairie field sites contained soils which would be more favorable for plant growth (higher organic matter content, cation exchange capacity, plant nutrients), the detrimental effects of Na upon the physical properties of soil as well as the rate of accumulation in soil is greater for soils with higher organic matter, higher exchange capacities, and higher amounts of clay since the ions would be retained more in comparison to poorer soils in which both Na and Cl would be more readily leached (Ratner 1935, Patenaude 1989, Eppard *et al.* 1992).

The long-term trends of our roadside plantings could not be adequately determined because of the short duration of this study, although the vegetation data from the previously established St. James and Crosstown sites definitely indicate that the native species are not increasing along the roadsides as the stand ages. The duration of the present study also involved two growing seasons that were very different from each other when we examine the data from our experimental sites. The year 1995 was very wet and 1996 was very hot and dry making some comparisons between years difficult (Fig.15). The relatively poorer establishment of the plantings at the Eden Prairie site may well be because of the drought conditions that occurred during that year of planting and not necessarily due to the relatively higher levels of Na and Cl found in the Eden Prairie soils during the spring of 1996. Precipitation from year to year will also have a great influence on salt levels in the environment. Since salt is very soluble, increases in precipitation during the spring and summer will most likely decrease salt in roadside soils leading to better establishment and survivability of plantings. Much longer term studies are always needed to effectively monitor long-term success of roadside plantings.

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Appendix A. Vegetative survey of select sites adjacent to the highway.

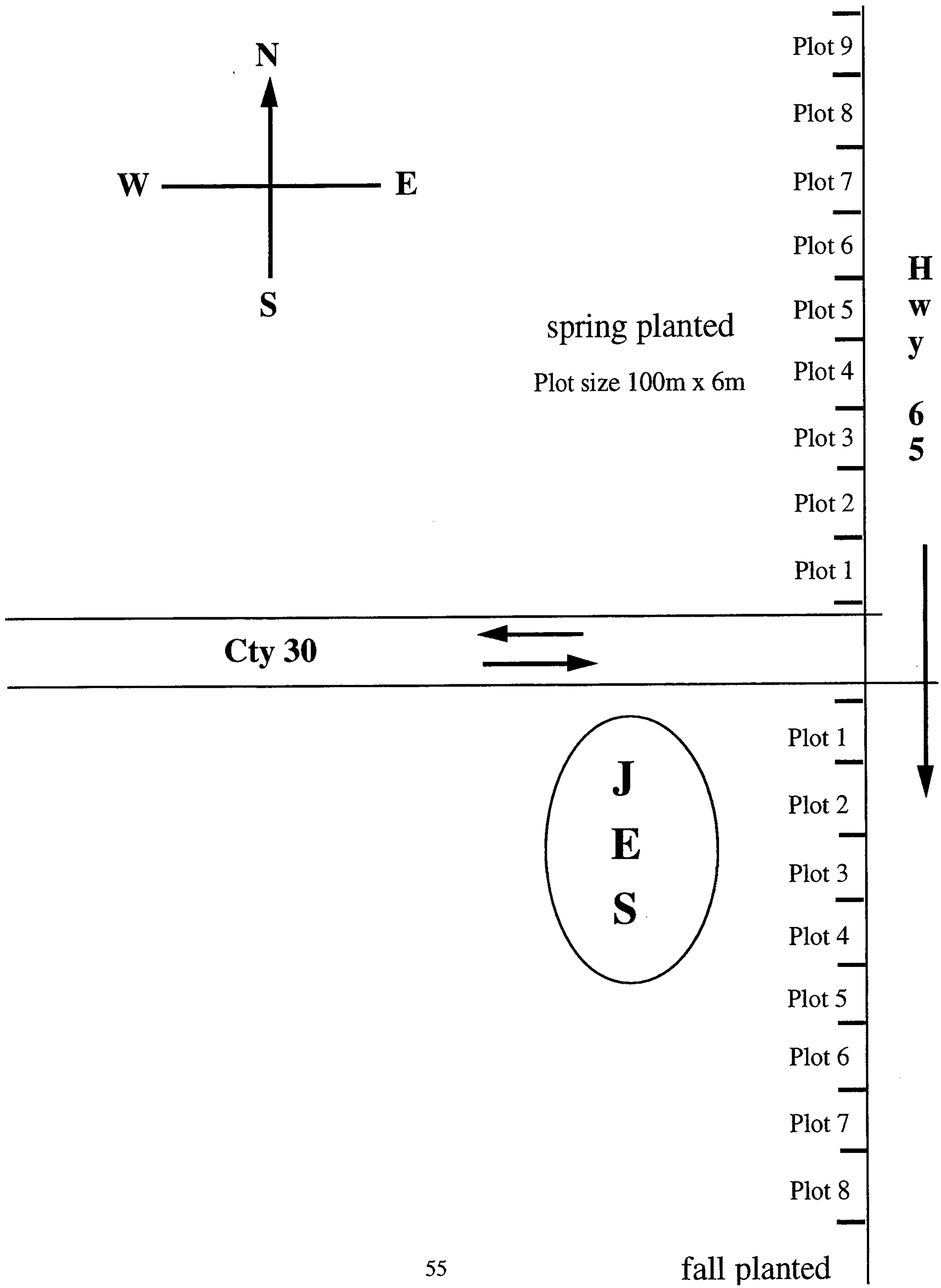
Table 1. Vegetative survey of select sites at 1.0, 2.0, and 3.0 m^2 from the pavement edge on or near the Highway 494 and 694 beltline in the Minneapolis-St. Paul metropolitan area. Values are for % cover of vegetation followed by the % composition of that plants present in the plots (e.g., at 3 m^2 in the first entry, the plot had only 40% coverage, and that coverage was composted of 70% *Polygonum* and 30% *Digitaria*.

	Distance from pavement edge		
Location and Field Notes	1 m^2	2 m^2	3 m^2
Highway 36 at Fairview ramp eastbound, south side. No desirable grasses present.	0% coverage	0% coverage	40% coverage *Polygonum* -70 *Digitaria* -30
Highway 36, median at Lexington. Salt damage extends to 4 meters on either side of the median. Some smooth brome present at 3 meters.	0% coverage	10% coverage *Suaeda* - 70 *Chenopodium* - 30	50% coverage *Polygonum* - 20 *Puccinellia* - 50 *Bromus* -20 *Ambrosia* - 10
Highway 36 at Arcade St. south side. Salt damage extends to 4 meters from pavement edge. Some smooth brome present at 3 meters.	30% coverage Sporobolus - 99 *Amaranthus* - 1%	80% coverage *Sporobolus* - 40 *Polygonum* - 20 *Sonchus* - 10 *Setaria* - 10 *Panicum* -10 *Ambrosia* -5 *Portulaca* - 5	100% coverage *Bromus* - 50 *Setaria* - 20 *Chenopodium* -10 *Lolium* -10 *Sonchus* -5 *Ambrosia* - 5
Highway 36 at Hadley, south side. Some smooth brome present at 2 and 3 meters.	80% coverage *Panicum* - 80 *Sporobolus* - 10 *Setaria* - 10	100% coverage *Sporobolus* - 40 *Bromus* - 20 *Panicum* - 10 *Portulaca* - 10 *Panicum* - 5 *Setaria* - 5	100% coverage *Bromus* - 50 *Setaria* - 50

Highway 494 at Cty Rd 5, both sides of median at salt plots. Salt damage extends across median. No desirable vegetation present. Halophytes found at 2 and 3 meters	100% coverage *Sporobolus* - 100	50% coverage *Sporobolus* - 50 *Polygonum* - 30 *Chenopodium* - 10 *Suaeda* - 10	80% coverage *Sporobolus* - 50 *Polygonum* - 30 *Suaeda* - 10 *Chenopodium* - 10
Highway 494 at 15th St., N. Oakdale. Small percentage of smooth brome at 2 and 3 meters.	40% coverage *Sporobolus* - 95 *Digitaria* - 5	75% coverage *Setaria* - 40 *Digitaria* - 40 Panicum - 10 *Bromus* - 10	80% coverage *Setaria* - 30 *Panicum* - 30 *Digitaria* - 10 *Bromus* - 10 *Phalaris* - 10 *Echinocloa* -5 *Poa* - 5
Highway 494 at Carver Ave, west side. Small percentage of smooth brome present at 2 and 3 meters.	0% coverage	80% coverage *Lolium* - 60 *Poa* - 30 *Bromus* - 10	100% coverage *Lolium* - 60 *Poa* - 30 *Bromus* -10
Highway 494 at Route 52, north side. *Hordeum*, an indicator of high salt concentrations in soils, at 3 meters. No desirable vegetation present.	50% coverage *Polygonum* - 50 *Kochia* - 25 *Setaria* - 20 *Panicum* - 5	40% coverage *Polygonum* - 50 *Kochia* - 25 *Setaria* - 20 *Panicum* - 5	40% coverage *Setaria* - 80 *Bromus* - 10 *Echinocloa* - 5 *Hordeum* - 5
Highway 494 at Pilot Knob Road, north side. Smooth brome present at 2 and 3 meters.	5% coverage *Portulaca* - 40 *Chenopodium* - 30 *Setaria* - 30	100% coverage *Bromus* - 50 *Setaria* - 50	100% coverage *Bromus* - 90 *Setaria* - 10
Highway 494 at 12 Avenue, S., north side Smooth brome predominates at 2 and 3 meters.	50% coverage *Sporobolus* - 95% *Polygonum* *Setaria* *Plantago* *Chenopodium* *Portulaca*	70% coverage *Bromus* - 75 *Panicum* - 10 *Echinocloa* - 5 *Ambrosia* - 5 *Digitaria* - 5	100% coverage *Bromus* - 100
Highway 494 at Bush Lake Road, north	0% coverage	90% coverage	100% coverage

side. No desirable vegetation present.		*Setaria* - 50 *Bromus* - 20 *Polygonum* - 20 *Lolium* - 10	*Lolium* - 50 *Setaria* - 30 *Poa* - 20
Highway 494, 0.5 mi south of Highway 7, eastside. No desirable vegetation present.	30% coverage *Panicum* - 70 *Chenopodium* - 20 *Setaria* - 5 *Polygonum* - 5	80% coverage *Chenopodium* - 70 *Setaria* - 10 *Lolium* - 10 *Bromus* - 10	90% coverage *Lolium* - 50 *Bromus* - 40 *Poa* - 10
Highway 494, south of highway 12, east side. Smooth brome predominates at 2 and 3 meters.	25% coverage *Chenopodium* - 80 *Sporobolus* -10 *Setaria* - 10	90% coverage *Bromus* - 90 *Lolium* - 10	90% coverage *Bromus* - 80 *Poa* - 10 *Phalaris* - 10
Highway 494 at Rockford Road, east side. *Suaeda*, a halophyte and *Hordeum* an indicator of sodic soils present at 1 and 2 meters. Some smooth brome at 3 meters.	70% coverage *Chenopodium* - 40 *Polygonum* - 35 *Sporobolus* - 20 *Suaeda* - 5	70% coverage *Bromus* - 50 *Chenopodium* - 45 *Hordeum* - 5	90% coverage *Bromus* - 60 *Lolium* - 40
Highway 694 at Highway 61, south side. *Suaeda*, a halophyte present at 1 meter. Smooth brome predominates at 3 meters.	10% coverage *Suaeda* - 50 *Sporobolus* - 20 *Chenopodium* - 20 *Panicum* - 10	90% coverage *Ambrosia* - 50 *Lotus* - 40 *Setaria* - 10	90% coverage *Bromus* - 70 *Lolium* - 20 *Ambrosia* - 10
Highway 694 at Sahdy Creek Blvd, south side. Smooth brome present at both 2 and 3 meters.	70% coverage *Ambrosia* - 50 *Panicum* - 25 *Chenopodium* - 20 *Sporobolus* - 5	80% coverage *Setaria* - 40 *Bromus* - 30 *Chenopodium* - 20 *Lactuca* - 10	90% coverage *Bromus* - 70 *Lolium* - 20% *Setaria* - 10

Appendix B. Map of the Cambridge field site area.


N
W
E
S
spring planted
Plot size 100m x 6m
Plot 9
Plot 8
Plot 7
Plot 6
Plot 5
Plot 4
Plot 3
Plot 2
Plot 1
Hwy 65
Cty 30
JES
Plot 1
Plot 2
Plot 3
Plot 4
Plot 5
Plot 6
Plot 7
Plot 8
fall planted

Appendix C. Components of seed mixtures used in experimental field plots.

Table C1. Components of seed mixtures used at the Cambridge-Fall, Cambridge-Spring, Eden Prairie-Fall, and Eden Prairie-Spring field sites.

	Seeding Rate (PLS lbs/acre)								
	mix 300	mix 400	mix 350	BUF	BG	SD	SLW	ALK	KB
Warm season natives									
Schizachyrium scoparium	6		6						
Buchloe dactyloides			6	40					
Bouteloua gracilis	10		10		40				
Bouteloua curtipendula	8		8						
Sporobolus cryptandrus	1		2			3			
Cool season natives									
Koeleria macrantha			1						
Agropyron trachycaulum	3		2				20		
Cool season introduced									
Puccinellia distans	8	20						60	
Poa compressa	10								
Poa pratensis 'Park'		20							60
Lolium perenne		10							
Festuca rubra 'Dawson'		20							
Cover crops*									
Lolium italicum	2		2	2	2	2	2	2	2

*Oats were used in the spring plantings at an undetermined seeding rate.

Table C2. Components of seed mixtures used at the St. James field site.*

	Seeding Rate (PLS lbs/acre)					
	MR-1	MR-2	MR-3	MR-4	MR-5	MR-6
Warm season natives						
Schizachyrium scoparium	6	13	4	9		4
Buchloe dactyloides			4	8	10	4
Bouteloua gracilis	5	10	4	8	10	4
Bouteloua curtipendula	6	12	4	9		4
Sporobolus cryptandrus	1	2	1	2		1
Cool season natives						
Koeleria macrantha			1	2	5	1
Agropyron trachycaulum	2	4	2	4		2
Cool season introduced						
Puccinellia distans						9
Poa compressa					15	9
Cover crops						
Lolium italicum	3	3	3	3	3	3
Avena sativa	14	14	14	14	13	14

*This information was obtained from: Stenlund, D.L. and R.L. Jacobson. 1994. Establishment of short and mid-height grasses on roadway inslopes. Final Report to the Minnesota Department of Transportation.

Table C3. Components of seed mixtures used at the Crosstown field site.*

Species	Seeding Rate (PLS lbs/acre)
Warm season natives	
Schizachyrium scoparium, little bluestem	4.0
Bouteloua gracilis, blue grama	4.4
Bouteloua curtipendula, sideoats grama	4.4
Cool season natives	
Koeleria macrantha, june grass	1.0
Agropyron trachycaulum, slender wheat grass	1.6
Elymus canadensis, Canada wild rye	1.4
Cover crop	
Regreen (hybrid between slender wheat x winter wheat)	4.0

The following species were collected from the crosstown prairie remnant and installed with the above native grasses. Seeding rate is undetermined for these species.

Warm season natives	**Flowers**
Schizachyrium scoparium, little bluestem	*Zizea* sp., Alexanders
Bouteloua curtipendula, sideoats grama	*Gallium* sp., bedstraw
Andropogon gerardii, big bluestem	*Monarda fistulosa,* bergamot
Sorghastrum nutans, indian grass	*Rudbeckia hirta,* black-eyed susans
Sporobolus heterolepsis, prairie dropseed	*Euphorbia corrollata,* flowering spurge
	Ratibida pinnata, grey-headed coneflower
Cool season natives	*Pycnathemum virginianum,* mountain mint
Panicum virgatum, switch grass	*Liatris aspera,* rough blazingstar
	Helianthus rigidus, stiff sunflower
	Anemone cylindrica, thimbleweed

*This information was obtained from: Biesboer, David D. and Robert Jacobson. 1994. Screening and selection for salt tolerance in native warm season grasses. Minnesota Department of Transportation Report Number 94-11.

Chapter 2. Potential Alleviation of Salt-Induced Stress on Seed Germination Using Soil Amendments - Greenhouse and Field Studies.

Abstract

Concentrations of sodium (Na) and chloride (Cl) ions build up in roadside soils as a result of winter deicing practices. Excessive Na delays or inhibits seed germination and consequently decreases plant establishment leaving roadside soils susceptible to erosion. Restoring ionic balance in the soil can alleviate the stress. Greenhouse and field experiments were designed to assess the abilities of three soil amendments, gypsum ($CaSO_4$), potash (KCl), and potassium nitrate (KNO_3), to alleviate NaCl-induced stress on seed germination. Three study species, Kentucky bluegrass (*Poa pratensis*), blue grama (*Bouteloua gracilis*), and alkali grass (*Puccinellia distans*), were selected to represent a range of salt tolerance in plant species, low, medium, and high tolerance, respectively. Amendment solutions were repeatedly applied to seeds in saline soil culture in the greenhouse experiments. A single amendment treatment coinciding with seed planting was used in the field experiments. Alleviation of NaCl stress varied among plant species, amendment compounds, and study sites. NaCl stress on Kentucky bluegrass was alleviated to various degrees by the different amendments in the greenhouse, but not in the field; Kentucky bluegrass is not a good candidate for planting in sodic roadside soils. Alkali grass had the greatest establishment and persistence of the three study species in the field. The limited success of a single amendment application at alleviating NaCl stress in roadside soils suggests more extensive reclamation may be necessary on highly sodic sites. Gypsum was the most effective soil amendment. Potassium compounds showed some alleviation effect in greenhouse experiments, but were largely ineffective as soil amendments. However, adding KCl to sand-salt mixtures as a chemical deicer may offset Na stress on seed germination.

Introduction

The accumulation of sodium (Na) and chloride (Cl) ions in soils adjacent to roadsides is a primary factor limiting seed germination and plant growth and survival in these areas. The accumulation of these ions is a direct result of winter de-icing procedures (see Chapter 1; Roberts and Zybura, 1967; Patenaude, 1989; Kelsey and Hootman, 1992; Biesboer and Jacobsen, 1994). High concentrations of ions can persist in the soil into late spring. Absolute concentrations of salt and the duration of high salt levels depends both on climate (precipitation and temperature during the spring and in the preceding winter) and on soil properties (especially hydraulic conductivity, organic matter content, and cation exchange capacity). However, concentrations are often at their highest during spring months when plants begin to emerge from dormancy (Hutchinson and Olson, 1967; Prior and Berthouex, 1967; Zelazny and Blaser, 1970; Biesboer and Jacobsen, 1994).

Excessive ion concentrations have both short- and long-term effects on plant growth (Munns and Termaat, 1986). The immediate effect is water stress; the additional ions decrease osmotic potential in the soil which limits water uptake by plants and seeds. Restricted water uptake by seeds (imbibition) delays germination and, therefore, early plant development (Bernstein, 1975; Sinha et. al., 1982). Long-term effects are cumulative ion toxicities, or specific ion effects. High concentrations of specific ions can irreversibly inhibit seed germination, tamper with plant development by altering enzyme activity and interfering with the uptake of essential ions, and decrease plant growth rates (Greenway and Munns, 1980; Fitter and Hay, 1987; Hardegee and Emmerich, 1990). These effects are specific to different plant species and varieties and to the particular ions involved (Munns and Termaat, 1986).

Seed germination is a life cycle phase that is relatively sensitive to salt (Bernstein, 1975). Sodium chloride (NaCl) delays, decreases, or inhibits seed germination in many plant species (see Chapter 1; Knipe, 1968; Macke and Ungar, 1971; Ungar, 1974; Hughes et al., 1975; Sinha et. al., 1982; Cluff and Roundy, 1988; Myers and Couper, 1989). A delay in seed germination along roadsides is problematic. It alters the phenology of new plants delaying their development until later in the spring season when temperature and precipitation are less favorable for seedling growth. Set-back or failure of seedling establishment leaves the soil susceptible to erosion.

Although high concentrations of NaCl in the soil solution do affect the osmotic balance between seed and soil, it is generally the cumulative ion toxicity that affects seed germination (Hyder and Yasmin, 1972; Romo and Haferkamp, 1987). In roadside soils, the specific and toxic ions are Na and Cl. Primary effects of excess Na are often defined in terms of the alteration of the ionic ratio in plant cells. For example, an increase in the sodium/calcium (Na/Ca) ratio induces a change in membrane permeability. More specifically, this causes an efflux of potassium and a reduction in the uptake of essential nutrients (Kent and Lauchli, 1984; Allan and Trewavas, 1987; Mansour and Stadelmann, 1994). The subsequent increase in the sodium/potassium ratio causes the inactivation of enzymes which inhibits the production of photosynthates, proteins and other structural compounds and compromises basal metabolic processes (Flowers et. al., 1977; Larcher, 1991).

The purpose of these experiments was to study the potential alleviation of NaCl stress on seed germination by restoring ionic balance in the seedbed. Many studies over many years have shown that the addition of exogenous ions can alleviate NaCl stress on germination. These studies have predominantly been germination trials of seeds placed in ionic solutions in petri dishes (Hyder and Greenway, 1965; Younis and Hatata, 1971; Hyder and Yasmin, 1972; Ryan et al., 1975; Myers and Couper, 1989; Hardegee et. al., 1990). Some studies have included plants in soil, but these have targeted seedling stages (Macke and Ungar, 1971; Ungar, 1974). However, few have looked at seed germination in soil culture. Sinha et. al. (1982) used soil culture to study the effects of alkalinity on germination. The experiments of this report were all performed in soil culture and used soil amendments both as ionic solutions (greenhouse studies) and dry, pelletized form (field studies).

Greenhouse and field studies were initiated to compare the ability of three soil amendments, calcium sulfate ($CaSO_4$; gypsum), potassium chloride (KCl; potash), and potassium nitrate (KNO_3) to alleviate salt stress on the germination of three grass species, Kentucky bluegrass (*Poa* *pratensis*), blue grama (*Bouteloua gracilis*), and alkali grass (*Puccinellia distans*). The amendments were chosen for their cation content and low cost. Gypsum is an amendment suggested for the reclamation of salt-affected soils (US Salinity Laboratory Staff, 1954; Mathur et. al., 1983; Gupta and Abrol, 1990; Alcordo and Rechcigl, 1993; Liang et. al., 1995; Suhayda, 1997). Gypsum reduces the amount of Na in the soil and provides calcium for plant uptake. Potash is a chloride salt. Therefore, in addition to its use as a fertilizer to amend low potassium levels in soil, it is also an alternative chemical de-icer (D'Itri, 1992). The potassium may offset excess Na levels in the soil, adjusting the sodium/potassium ratio available to plants. Potassium nitrate is a common fertilizer that adds potassium to offset Na and provides a source of nitrogen for newly emerging plants. Treatment or pre-treatment with potassium nitrate has also been shown to increase seed germination (Williams, 1983; Goudey et. al., 1988).

The three grass species were selected from Minnesota Department of Transportation (MN/DOT) seed mixes on the basis of their range of reported salt tolerance in the scientific literature. Kentucky bluegrass is a component of most non-native seed mixes that are widely used in urban areas. Although salt resistant cultivars have been developed, Kentucky bluegrass is salt-sensitive relative to many other species (Hughes et. al., 1975; Greub et. al., 1985). Blue grama is a native species of the short-grass prairie. It is drought tolerant (Knipe, 1968) and is considered to be moderately salt tolerant (Bernstein, 1958). Alkali grass is a non-native species first introduced in northeastern Canada and the United States. It has spread rather rapidly to the interior of the country following increasing salinity along roadsides (Cusick, 1982; Scott and Davidson, 1985; Gleason and Cronquist, 1991; Garlitz, 1992; Swink and Wilhelm, 1994). Alkali grass has repeatedly been shown to tolerate high salinity (Hughes et. al., 1975; Greub et. al., 1985; Ashraf et. al., 1986). Thus, these three grass species were chosen for their relative salt tolerance.

Materials and Methods

Greenhouse experiments

Experimental Design Each grass species was treated with each individual soil amendment in a two-factor factorial design. Five repetitions of fifty seeds were planted in sterilized greenhouse soil in 3-inch pots. Seeds were covered with vermiculite-perlite mixture and treated twice per week with solutions of NaCl and of $CaSO_4$, KNO_3, and KCl in concentrations that were equal to 0.5, 1, and 2 times the molar equivalent of 5000 parts per million (ppm) NaCl. The species-salt-treatment combinations were arranged in a complete, randomized block design. Each pot was placed on a riser to prevent contamination from the surrounding treatments. The experiment was completed in the greenhouse of the Plant Biological Sciences at the University of Minnesota in September, 1997. Daylength was extended to 16:8 hour light:dark conditions using 1000W sodium-halide lamps. Germination was recorded every five days for thirty days; germinated seeds were removed upon counting.

Data Analysis: Percent germination of all species under all treatments were transformed using an arcsine square root function to achieve normality and to stabilize the variance of the data (Sokal and Rohlf, 1981). Separate analyses were performed on four different subsets of the full data set (containing percent germination of each species under each salt-amendment combination). Factorial ANOVAs were run for each grass species to assess its germination response to salt treatment and to amendment treatment, and whether the different amendments alleviated salt stress differently. Two-way analyses of variance (ANOVA) were performed on the full factorial data set for each species-amendment combination (i.e. Kentucky bluegrass-gypsum, blue grama-KNO_3, alkali grass-KCl, etc.) to assess the affect of NaCl on each species ("salt" row of Table 1). To assess the direct affect of each individual amendment on seed germination and to assess the alleviation of NaCl stress by each amendment, one-way analyses of variance were run on subsets of the species-amendment combination datasets. To test the effect of the amendments themselves, the data from the pots without NaCl treatment was used, thus three concentrations of amendment were compared to a zero amendment control ("treatment" row of Table 1). To assess the alleviation of NaCl stress on seed germination, the data from pots with NaCl treatment, and alleviation defined as a significantly positive effect ("salt*treatment" row of Table 1). (The control group for this analysis was pots treated with NaCl and no amendment.) All analyses were run on each species-amendment combination. Significant effects of NaCl, amendment, or salt-amendment interaction were assessed at $\alpha=0.05$. Multiple comparisons of means for significant models were assessed using a Bonferroni experimentwise-correction, $\alpha=0.05/6=0.0083$. Further, polynomial regression was used to define the relationship of the chemical compounds on seed germination; linear, quadratic, cubic, and zero slope relationships were tested for the treatment and salt*treatment subsets of the species-amendment combinations.

Field Experiments.

Site Preparation and Planting. Two study sites along roadways in the Twin Cities metropolitan area were selected for the implementation of field experiments. The roadways were selected for the high rate of salt application based on observational information and technical advice from the MN/DOT. The sites were established in 1.) Eden Prairie, along the on-ramp to northbound Interstate-494 from westbound Highway 212, and 2.) Oakdale, in the median of 5th Street between Interstate-694 and Hadley Avenue (Figure 1). Each study site was divided into areas for fall planting (October, 1995) and spring planting (April, 1996). The planting areas were sprayed with Round-Up herbicide 7 days prior to planting and rototilled one day prior to planting at each site. Monocultures of three grass species, *Poa pratensis*, *Bouteloua gracilis*, and *Puccinellia distans*, were planted in 2m x 2m plots arranged in two rows adjacent to the pavement (Figure 1). Seeding rate was 120 lbs/acre for *Poa* and *Puccinellia* and 80 lbs/acre for *Bouteloua,* twice the recommended Mn/DOT seeding rate for each species. Seed was broadcast by hand and raked evenly over the plots to ensure an even distribution throughout the plots and aid in seed-soil contact. Three different soil amendments, potassium nitrate (KNO_3), potash (KCl), and gypsum ($CaSO_4$), were applied and raked into the selected plots.

Figure 1a. Eden Prairie field site layout.

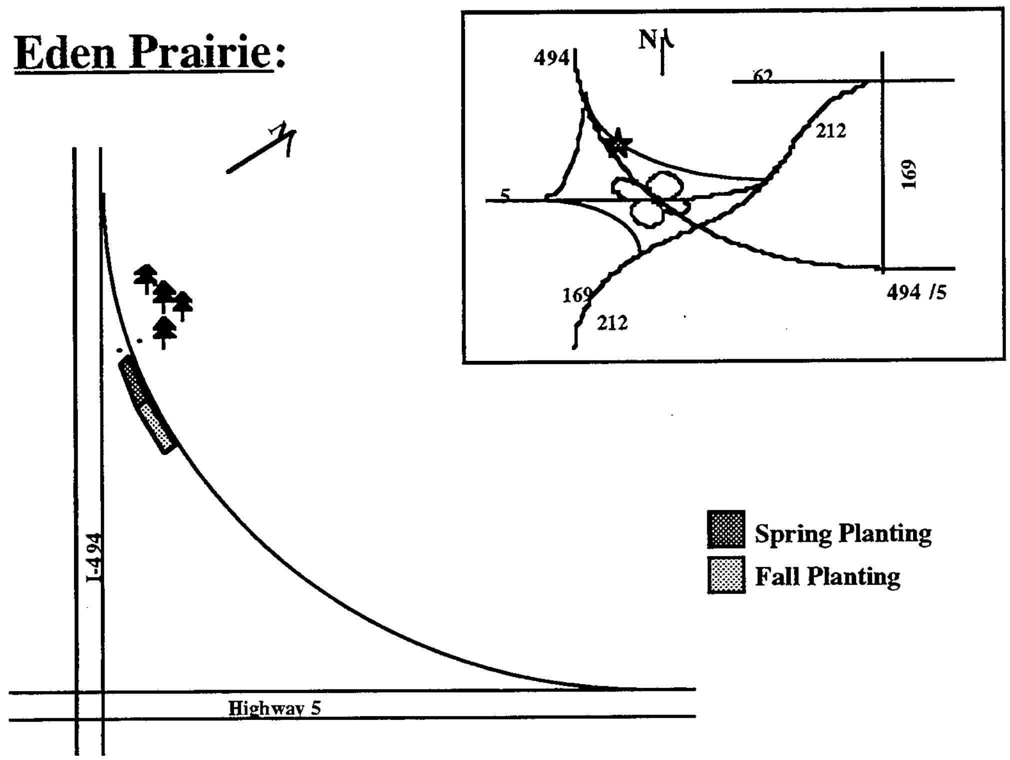
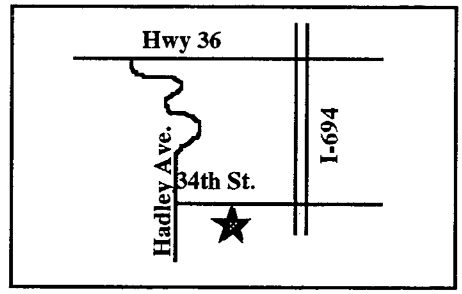
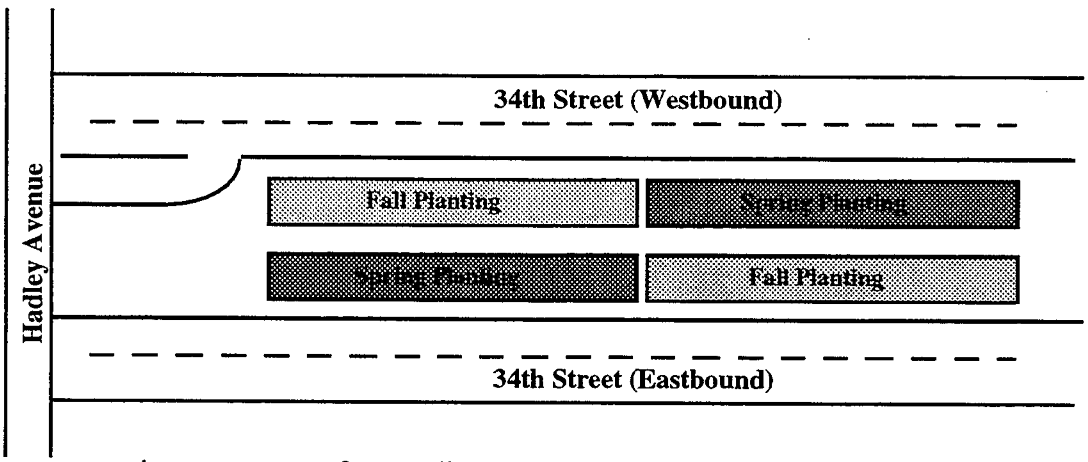


Figure 1b. Oakdale field site layout.

Oakdale Site:





plots as a one-time treatment after seeding in a randomized incomplete block design. Application rate was 200 lbs/acre following Minnesota Department of Transportation (Mn/DOT) fertilizer application specifications. Further, plots planted in the fall were divided into a fall and spring times of application of soil amendment treatment. One half of each fall-planted treatment plot received amendment application in the fall on the same day as seed was sown (fall/fall), the remaining half of the plot received amendment application in the spring (fall/spring). Spring plots received soil amendment over the entire plot area on the day of planting (spring).

The spring planting was repeated at both sites in 1997 to assess long-term persistence of plots following the loss of spring planted seedlings to drought-like conditions during the summer of 1996.

Vegetation Data. Percent cover of sown species was estimated in each plot. A 100-square grid with a total area of 0.25 m^2 was placed in the center of each plot. Percent cover was estimated in each square of the grid and the 100 values were summed into a single percent cover value for the 0.25 m^2. Percent cover of non-sown species (grasses and forbs) was evaluated using estimates of percent cover within each quarter section (25 squares) of the grid and the four estimates were summed for a single percent cover value for the 0.25 m^2.

Soil Analysis. Soil samples were collected at two-week intervals at each site throughout the spring of 1996 and 1997. Samples were pooled from six soil cores of the top 10 cm taken within blocks of eight plots. Sodium and chloride levels, electrical conductivity, and pH were measured for each block sample. Samples were air-dried and passed through a 2mm sieve before analysis. Total sodium (soluble and exchangeable) was measured from an ammonium acetate extract (Thomas, 1982) using a Hach One Laboratory pH/Ion Selective Electrode (ISE) meter and a sodium ion probe (Hach Company, Loveland, CO). Soluble sodium, soluble chloride, and electrical conductivity was measured from a saturation paste extract (200 g soil saturated using distilled water, vacuum-filtered after 2 hours; following a procedure modified from Rhoades, 1982). Soluble sodium and chloride were measured using Hach sodium (model 44520) and combination chloride (model 50255) electrodes. Electrical conductivity of the extract was measured immediately after filtration using an Oakton hand-held conductivity/temperature meter. Soil pH was measured from a 1:1 soil:water solution.

Data Analysis. Factorial ANOVAs were used to define the variability in germination of each species and of each species treated with each soil amendment for 1996 data collected at each site. The parameters selected for the species-amendment combination analyses included the soil amendment treatment (treatment), and the combination of planting time-soil amendment application (time of application; e.g. fall/fall, fall/spring, spring) as fixed effects and soil salinity as a random effect. Analyses for each species included type of amendment (amendment) as a fixed effect. Both a mixed model and a fixed effects model were analyzed. Second- and third-order interactions were not significant for any of the analyses and were dropped from the models. Data collected in 1997 at Eden Prairie was analyzed separately using a mixed model with soil amendment treatment as a fixed effect and soil salinity as a random effect. Germination data was transformed with an arcsine square root, log, or square root function to fulfill normality assumptions and to stabilize variance.

Significant effects were defined by a p-value less than or equal to 0.10 given the highly variable and un-controllable nature of roadside conditions.

Results

Greenhouse Experiments.

Means of proportion of seed germination for each species and amendment are shown in Table 1. Without the addition of amendment compounds, NaCl significantly decreased overall germination of each species (Table 2, "salt" row). Germination of Kentucky bluegrass was decreased by more than fifty percent: germination in NaCl treatment replicates was 54% and 85.3% in the controls. Blue grama and alkali grass respectively had 38.8% and 80.9% germination under salt treatment compared to 44.1% and 87.6% germination in controls. Treatment with an amendment compound had various effects on the different species ("treatment" row), and the different amendment compounds had differing effects on each species ("amendment"

Table 1. Greenhouse Experiment: Means of proportion of seed germination.

		Species					
	Amendment	*Poa pratensis*		*Bouteloua gracilis*		*Puccinellia distans*	
Amendment	concentration	control	NaCl	control	NaCl	control	NaCl
$CaSO_4$	0	0.780a	0.444a	0.472a	0.468a	0.888a	0.696a
	0.5	0.776a	0.624ab	0.472a	0.488a	0.916b	0.932b
	1	0.832a	0.612ab	0.488a	0.336a	0.924b	0.920b
	2	0.812a	0.828b	0.476a	0.412a	0.892a	0.788a
KNO_3	0	0.896a	0.556a	0.444a	0.256a	0.880a	0.904a
	0.5	0.820ab	0.688a	0.428a	0.364a	0.860a	0.840a
	1	0.704b	0.460a	0.408a	0.296a	0.872a	0.852a
	2	0.592b	0.564a	0.304a	0.272a	0.712a	0.816a
KCl	0	0.884a	0.620 a	0.408a	0.440a	0.860a	0.824a
	0.5	0.812ab	0.760 a	0.448a	0.352a	0.916a	0.780a
	1	0.584b	0.680ab	0.352a	0.420a	0.904a	0.824a
	2	0.592b	0.464 b	0.388a	0.306a	0.828a	0.716a

Values with the same letter are not significantly different.

row). In the absence of salt there was a general trend in the collective seed germination of each plant species treated with different amendments. Seed germination of all species was greater with gypsum than with potash than with potassium nitrate (Figure 2).

Figure 2. Differences in percent germination of study species between different amendments. (Amendments connected by a line are not significantly different.)

Poa	$CaSO_4$	>	KCl	>	KNO_3
Bouteloua	$CaSO_4$	>	KCl	>	KNO_3
Puccinellia	$CaSO_4$	>	KCl	>	KNO_3

Poa pratensis.

The species level model for Kentucky bluegrass was significant (Table 2). NaCl decreased seed germination in each model of each species-amendment combination. Multiple comparisons showed greater seed germination in the lower treatment levels of the amendments. Salt*treatment interaction was significant due to the alleviation of NaCl stress by each amendment (see Table 3)

Table 2. Greenhouse Experiments: p-values of main effects and interactions of species-amendment combinations.

Species	Effect	Amendment $CaSO_4$	Amendment KNO_3	Amendment KCl
Poa pratensis	salt (model)	**0.0069** (.005)	**0.0001** (.0001)	**0.0191** (.0001)
	treatment	0.8753	**0.0055**	**0.0018**
	salt*treatment	**0.0056**	**0.0265**	**0.0044**
Bouteloua gracilis	salt (model)	0.1455 (.33)	**0.0022** (.01)	0.5690 (.51)
	treatment	0.9846	0.0634	0.5467
	salt*treatment	0.3458	0.3350	0.3346
Puccinellia distans	salt (model)	**0.0154** (.001)	0.4575 (.31)	0.0407 (.29)
	treatment	0.8753	0.0891	0.3784
	salt*treatment	**0.0350**	0.7749	0.6064

Bold values denote significant effects.

Table 3. Greenhouse Experiments: p-values of main effects for each species.

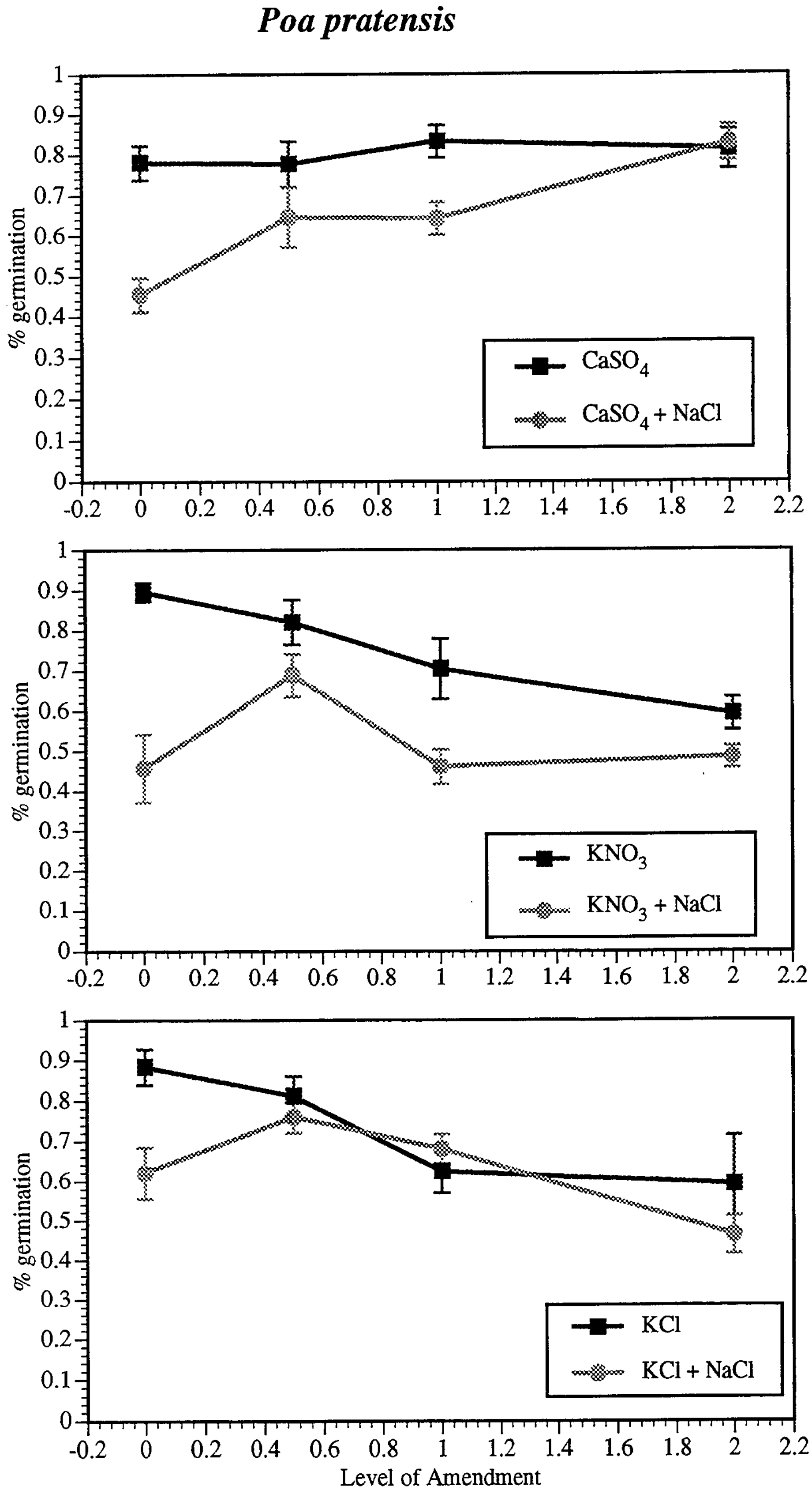
Effect	Species		
	Poa pratensis	*Bouteloua gracilis*	*Puccinellia distans*
model (R^2)	**0.0001** (.39)	**0.0003** (.24)	**0.0137** (.17)
salt	**0.0001**	**0.0052**	**0.0372**
treatment	**0.0098**	**0.0506**	**0.0044**
salt*treatment	**0.0012**	0.9655	0.6975
amendment	**0.0072**	**0.0003**	0.3067

Bold values denote significant effects.

with gypsum as the most effective amendment, followed by potash, followed by potassium nitrate. Alleviation by gypsum was significantly greater than alleviation by potassium nitrate, but not significantly different than potash, and the effect of potash was not significantly different than the effect of potassium nitrate (Figure 3).

In the Kentucky bluegrass -gypsum experiment NaCl significantly decreased seed germination (Table 3). Control replicates had greater germination than those treated with NaCl. Gypsum alone had no effect on seed germination, but it significantly alleviated salt stress on seed germination in a positive, linear relationship. The higher the concentration of gypsum, the greater the alleviation with complete alleviation at the highest concentration (Figure 3).

Figure 3. Alleviation graphs for Kentucky bluegrass experiments.



In the potassium nitrate experiment, both NaCl and KNO_3 significantly decreased germination (Table 3). Potassium nitrate alone decreased germination in a significantly negative, linear relationship. But, the presence of both salts ameliorated the decrease in germination by KNO_3 alone and the decrease in germination due to NaCl (NaCl*KNO_3 interaction was significant). Further, NaCl stress was alleviated only at low concentration (0.5 level) of KNO_3; the relationship had a significant cubic function (Figure 3).

Again, NaCl significantly decreased seed germination in the Kentucky bluegrass-potash model, and again amendment alone decreased germination in a significantly negative, linear relationship (Table 3). There was alleviation of NaCl stress only at the low concentration (0.5 level) of potash that did not occur at the higher treatment levels (Figure 3).

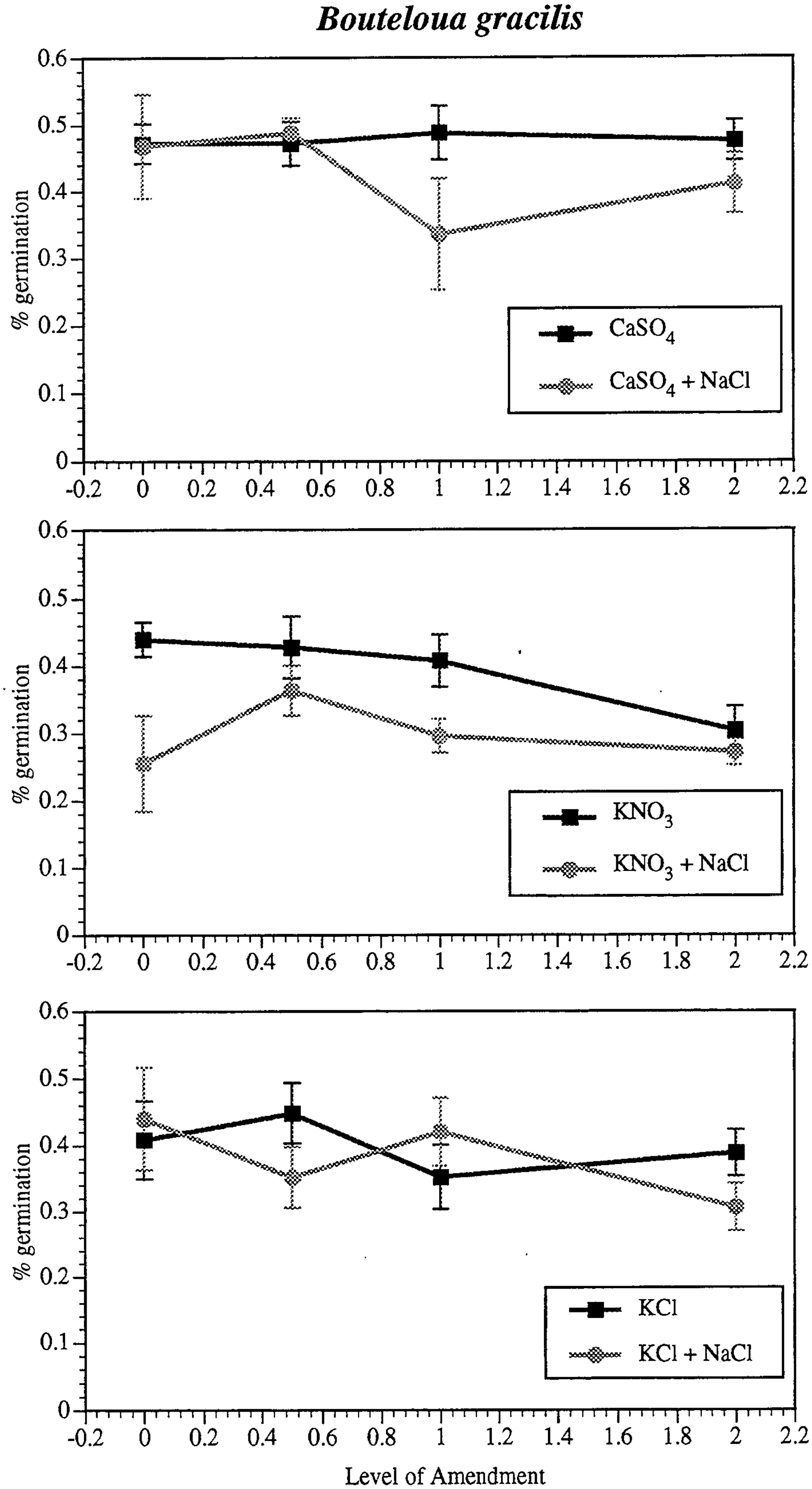
Bouteloua gracilis.

The species-level model for blue grama was significant due to the main effects of NaCl, the treatment level of an amendment, and differences in alleviation by the different amendments (Table 2). NaCl decreased germination in the species-level as a result of NaCl stress in the KNO_3 experiment. The level of treatment level was significant ($p=0.0506$) with low concentrations of amendments (0.5 level) yielding higher germination than higher concentrations (levels 1 and 2). There was greater germination in the gypsum experiment than in the potash or potassium nitrate experiments (Figure 2).

The KNO_3 experiment had the only significant model among the blue grama experiments (Table 3). This was due to a negative effect of NaCl on germination (in a significant linear relationship). The effect of treatment level showed a general trend of decreasing germination with increasing KNO_3 concentration (Figure 4).

There were no definable relationships in the potash model. In the gypsum model, gypsum alone showed no effect on blue grama germination (significant zero slope). But, there was no definitive relationship for the gypsum-NaCl interaction. (Figure 4).

Figure 4. Alleviation graphs for blue grama experiments.



Puccinellia distans.

The species-level model for alkali grass was significant due to main effects of NaCl and main effects of the treatment level of an amendment (Table 2). The effect of NaCl resulted from a significant decrease in germination in the gypsum model (see Table 3). Multiple comparisons showed that treatment with an intermediate level of an amendment compound (levels 0.5 and 1) produced higher germination than treatment with high concentration (level 2) or with no amendment. This significant treatment effect again is due to its significance in the gypsum model (see Table 3). The effects of the individual amendments were not significantly different from one another (Figure 2).

The gypsum experiment had the only significant model for alkali grass . In this experiment gypsum alone had no effect on germination (zero slope) and NaCl had a negative effect on seed germination. The NaCl-$CaSO_4$ interaction term was significant and had a quadratic relationship; NaCl stress was alleviated only by intermediate concentrations (levels 0.5 and 1) of gypsum (Figure 5).

The potash model had no significant effects, nor did the KNO_3 model. However, increasing concentrations of potassium nitrate decreased alkali grass germination. This negative trend was alleviated by the addition of KNO_3 (Figure 5).

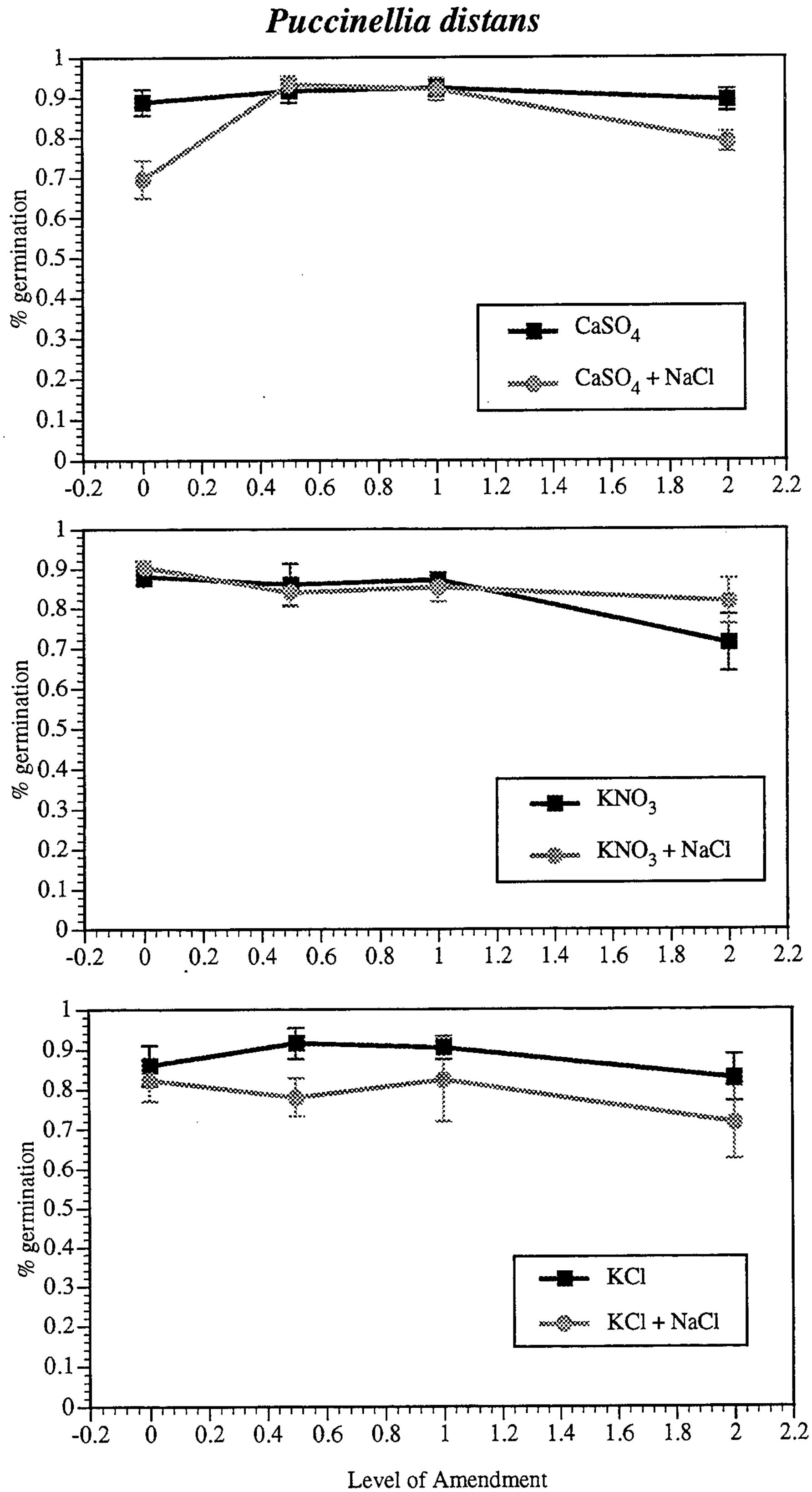
Field Experiments--1996.

Percent cover of the species-treatment plots are shown for Eden Prairie and Oakdale sites (Tables 4a and 4b). Established cover was very low for both Kentucky bluegrass and blue grama at both sites. Kentucky bluegrass and alkali grass had greater overall germination at Eden Prairie than at Oakdale in both fall and spring plantings. Blue grama had very little establishment at either site.

Poa pratensis.

The species level ANOVA models were significant for both study sites (Table 5). At Eden

Figure 5. Alleviation graphs for alkali grass experiments.



Prairie, only soil sodicity caused significant variation in the percent cover. At Oakdale, treatment with an amendment, the particular amendment, soil sodicity, and time of application caused significant variation in percent cover. Treatment with soil amendments significantly increased percent cover with gypsum and potash having greater effects than potassium nitrate. Spring plantings had significantly greater bluegrass percent cover than fall plantings.

Table 4a. Eden Prairie, 1996. Percent cover within plots.

Species	time of application	control	Amendment $CaSO_4$	Amendment KNO_3	Amendment KCl
Poa pratensis	fall/fall	0.17a	0.17a	0.13a	0.15a
	fall/spring	0.13a	0.36a	0.34a	0.11a
	spring	0.83b	2.37b	1.97b	1.74b
Bouteloua gracilis	fall/fall	0.54a	0.40a	0.41a	0.84a
	fall/spring	0.40a	0.50a	0.49a	0.82a
	spring	0.55a	0.50a	0.62a	0.11a
Puccinellia distans	fall/fall	6.47a	25.80c	20.86c	15.75c
	fall/spring	14.95a	23.29c	24.68c	17.48c
	spring	0.99b	6.27d	10.89d	10.57d

Values with different letters within a species are significantly different.

Table 4b. Oakdale, 1996 Percent cover within plots (listed as proportions).

Species	time of application	control	Amendment $CaSO_4$	Amendment KNO_3	Amendment KCl
Poa pratensis	fall/fall	1.52a	2.87a	0.19c	1.29a
	fall/spring	1.90a	2.21a	0.46c	2.26a
	spring	3.71b	1.17b	2.19b	3.71b
Bouteloua gracilis	fall/fall	0.23a	0.29a	0.08c	0.38a
	fall/spring	0.17a	0.11a	0.43a	0.66a
	spring	0.42a	0.65b	0.14a	0.36a
Puccinellia distans	fall/fall	32.85a	18.75a	25.56a	26.05a
	fall/spring	26.95a	15.24a	20.27a	23.85a
	spring	12.54b	10.90b	15.30b	6.65b

Values with different letters within a species are significantly different.

Table 5. Field Experiments: p-values of main effects for species ANOVAs.

Effect	Eden Prairie			Oakdale		
	P. pratensis	*B. gracilis*	*Pu. distans*	*P. pratensis*	*B. gracilis*	*Pu. distans*
model (R^2)	**0.0057** (.60)	0.1314 (.50)	**0.0001** (.70)	**0.0001** (.71)	**0.0006** (.76)	**0.0001** (.69)
treatment	0.7172	0.2490	**0.0001**	**0.0932**	0.3992	**0.0672**
amendment	0.4860	0.6971	0.5673	**0.0007**	0.6337	0.4478
sodium	**0.0019**	0.0740	**0.0001**	**0.0001**	**0.0002**	**0.0001**
time of application	0.9971	0.6884	0.1201	0.7101	0.2235	0.3251

Bold values denote significant effects.

Table 6. Field Experiments, 1996: p-values of main effects of species-amendment combination[1].

Species	Effect	Eden Prairie			Oakdale		
		$CaSO_4$	KNO_3	KCl	$CaSO_4$	KNO_3	KCl
Poa pratensis	model (R^2)	0.1727 (.65)	0.4585 (.62)	**0.0043** (.88)	**0.0006** (.88)	**0.0853** (.69)[2]	**0.0730** (.70)
	treatment	0.5121	0.6515	**0.0418**	0.3205	**0.0392**	0.3853
	time of application	0.3825	0.7700	0.1540	0.7499	**0.0132**	0.4009
	sodium	0.3399	0.9084	**0.0480**	**0.0002**	0.4757	**0.0788**
Bouteloua gracilis	model (R^2)	0.5160 (.77)	**0.0055** (.76)	**0.0422** (.73)	**0.0241** (.99)	**0.0097** (.73)	**0.0086** (.80)
	treatment	0.6109	0.2898	0.3077	0.3770	0.1265	0.8676
	time of application	0.5578	0.8957	0.8907	**0.0716**	**0.0533**	0.1671
	sodium	0.5134	**0.0024**	**0.0542**	**0.0196**	**0.0077**	**0.0047**
Puccinellia distans	model (R^2)	**0.0001** (.92)	**0.0004** (.92)	**0.0042** (.75)	**0.0160** (.74)	0.1759 (70)	**0.0022** (.85)
	treatment	**0.0001**	**0.0919**	**0.0505**	**0.0107**	0.7969	0.6436
	time of application	**0.0950**	**0.0945**	0.2529	**0.0051**	0.5497	0.6204
	sodium	**0.0014**	**0.0066**	0.2159	0.1504	0.2212	**0.0054**

[1] p-values calculated from type III sums of squares. Bold values denote significant effects.
[2] Poa pratensis-KNO_3 germination data was just below normality cut-off values, type I sum of squares used to calculate p-values.

Potash was the only amendment with significant effects at both study sites (Table 6). At Oakdale, the variation in soil sodicity had a significant effect on seed germination. Further, there was a significant negative correlation between soil sodium and seed germination. At Eden Prairie, treatment and soil sodicity had significant effects. Treatment had a significant positive effect on seed germination (Table 4a). Soil sodicity showed a significant negative correlation with germination. Also, removal of NaCl effects from the model resulted in a significant effect of planting time with spring plantings having greater percent cover.

The potassium nitrate and gypsum models were significant at Oakdale, but not at Eden Prairie. At Oakdale, treatment with potassium nitrate had a significant negative effect on seed germination. Spring plantings again had significantly more seed germination than fall plantings. In the gypsum experiment, only soil sodicity had a significant negative effect (Table 5).

Bouteloua gracilis.

The species level ANOVA model was significant only for the Oakdale site (Table 5). Further, soil sodicity was the significant variable causing a negative effect on percent cover. At Eden Prairie, species-amendment models were significant for potash and potassium nitrate, again because soil sodicity had a negative effect on seed germination. Removing NaCl from the model resulted in a significant treatment-time of planting interaction; treatment added to plots planted in the spring had significantly less germination than treatment plots planted in the fall. At Oakdale, all species-amendment models were significant. In the gypsum experiment, both soil sodicity and treatment had a significant negative effects; control plots had greater cover than treatment plots. For potassium nitrate, sodicity had a significant negative effect and time of application was significant with fall plantings having greater cover than spring plantings. The potash model was significant due to the negative effect of sodium.

Puccinellia distans.

The species level ANOVAs for Oakdale and Eden Prairie sites were both significant (Table

5), but produced opposing results (Table 4a and 4b). At Oakdale, treatment with a soil amendment was significant, but the effect was negative. Control plots had greater percent cover than treatment plots and there was a significant negative correlation with sodium ($r = -0.25$, $p = 0.04$). At Eden Prairie, however, treatment with a soil amendment had a significantly positive effect on germination; treatment plots had greater cover than control plots and there was a positive correlation of germination with sodium ($r = 0.63$, $p = 0.0001$). After removing NaCl from the model, time of application had a significant effect at both sites. Fall-planted plots had greater percent cover than spring-planted plots (Oakdale: $p = 0.0245$; Eden Prairie: $p = 0.0001$).

The species-amendment models were significant at both sites for gypsum and potash, and for potassium nitrate at Eden Prairie. In the gypsum models, significant treatment effects were opposite at the sites. At Oakdale treatment had a negative effect whereas it had a positive effect at Eden Prairie. Time of application was also significant at both sites with fall plots having greater cover than spring plots. Further, at Eden Prairie, soil sodium was significant and had a positive correlation with germination ($r = 0.80$, $p = 0.0001$). In the potassium nitrate experiment there were significant treatment, time of application, and sodicity effects at Eden Prairie. Treatment plots had greater cover than control plots, fall plots had greater cover than spring plots, and sodium was positively correlated with germination ($r = 0.74$, $p = 0.0001$). The potash models were, again, significant at both sites. At Eden Prairie, treatment had a significant positive effect and there was a positive correlation between sodium and germination ($r = 0.48$, $p = 0.01$). Also, when fall-planted plots (fall/fall and fall/spring application) were lumped together, time of application was significant and fall plots had greater cover than spring plots. At Oakdale, the potash model was significant due to the negative effects of sodium.

Field Experiments--1997.

Percent cover was low for both Kentucky bluegrass and blue grama with an average across all plots of 7.7% and 6.8%, respectively, whereas alkali grass had an average of 26.3% (Table 7). Of the nine species-amendment combination models, only two were significant: Kentucky bluegrass -potassium nitrate and alkali grass -gypsum (Table 8). In both models soil sodium had significant main effects. In addition to soil sodium, treatment with amendment had a significant negative effect on the germination of alkali grass .

Table 7. Field Experiments, 1997: Percent cover in plots.

		Amendment		
Species	control	$CaSO_4$	KNO_3	KCl
Poa pratensis	5.26	15.37	6.20	3.97
Bouteloua gracilis	8.66	7.65	6.58	4.46
Puccinellia distans	28.77	**21.92**	30.79	23.67

Bold values denote significant difference from control.

Table 8. Field Experiments, 1997: p-values of main effects.

		Amendment		
Species	Effect	$CaSO_4$	KNO_3	KCl
Poa pratensis	model (R^2)	0.1369 (.85)	**0.1004** (.88)	0.4294 (64)
	treatment	0.1476	0.3882	0.5033
	sodium	0.1329	**0.0754**	0.3630
Bouteloua gracilis	model (R^2)	0.3057 (.72)	0.1104 (.87)	0.3810 (.67)
	treatment	0.7619	0.4019	0.2869
	sodium	0.2305	0.0831	0.3799
Puccinellia distans	model (R^2)	**0.0020** (.99)	0.4139 (.65)	0.1663 (.82)
	treatment	**0.0221**	0.8010	0.7896
	sodium	**0.0015**	0.3200	0.1203

Bold values denote significant effects.

Discussion

Greenhouse Experiments

NaCl decreased the germination to some degree in each study species. As expected, the effect was the most profound for Kentucky bluegrass ; NaCl significantly decreased germination in each of the three experiments. NaCl decreased the germination of blue grama and alkali grass in only one experiment each. This was not unexpected for Bouteloua (Weiler and Gould, 1983; Bowman et. al.; 1985). The effect of NaCl on alkali grass was similar to the results of Greub et. al. (1985). However, they found that although germination was decreased by NaCl, alkali grass passed all the screening trials for salt tolerance. Ashraf et. al. (1986) also showed that NaCl decreased germination in alkali grass, but it responded quickly to selection, with plants in the second generation unaffected by NaCl stress.

Of the three soil amendments, gypsum had the greatest effect in alleviating NaCl stress. Gypsum alone did not affect the germination of any of the study species (Figures 3-5). This is attributable to the very low solubility of gypsum, at neutral pH it is a non-ionic compound inducing no osmotic nor specific ion effects (Lindsay, 1979). Gypsum alleviated NaCl stress on Kentucky bluegrass in a linear fashion, as gypsum concentrations increased, germination increased with complete alleviation of NaCl stress at the highest concentration of amendment. Calcium has also been shown to alleviate NaCl stress in cotton (Cramer et. al., 1985; Kent and Lauchli, 1987), corn (Maas and Grieve, 1987), and other grasses (Suhayda et. al., 1997). An increase in the Na/Ca ratio corresponded to decreased calcium and a marked decrease in potassium levels in plant tissues. These alterations are caused by Na ions displacing calcium ions from membranes altering electrochemical potential leading to an efflux of potassium (Hauser et. al, 1976; Cramer et. al., 1985). Potassium is an integral ion involved in maintaining the osmotic pressure (turgor pressure) of plant cells and is a coenzyme in many metabolic processes (Marschner, 1993; Taiz and Zeiger, 1991). The addition of calcium (or the decrease in Na/Ca ratio) restores membrane integrity which prevents the loss of potassium (Allan and Trewavas, 1987). Maintaining the Na/Ca ratio has been shown to prevent the alteration of structural components of cell membranes (Choukr-Allah and Markhart, 1989; Suhayda et. al., 1994). Further, there is some evidence that suggests the addition of calcium may prevent sodium uptake in some plant species (beans: Lahaye and Epstein, 1969; rice: Muhammed et. al., 1987).

The germination of alkali grass was effected by the interaction between gypsum and NaCl. Gypsum alleviated NaCl stress at intermediate concentrations, but interfered with germination at high concentrations. The initial alleviation of stress by low concentration of gypsum is likely an aberration in the data. Germination of *P. distans* in NaCl alone was significantly lower in the gypsum experiment than in the remaining experiments. Pooling of the data for the no-amendment pots from all three experiments made the initial alleviation non-significant. However, the interference of gypsum at high concentrations was significant. Calcium perhaps interfered with the uptake of Na by alkali grass which is perhaps an element used for ionic adjustment. It has been shown that alkali grass germination is inhibited more by non-ionic osmotic stress (induced by PEG or mannitol) than by saline solutions of the same osmotic potential (*P. nuttalliana* : Macke and Ungar, 1971; *P. ciliata* : Myers and Couper, 1989). Flowers et. al. (1977) listed the optimal salinity level for *P. nuttalliana* to be 128mM salt, principally as NaCl.

Unlike the findings of Williams (1983) and Goudey et. al. (1988), potassium nitrate alone had a significantly negative effect on the germination of Kentucky bluegrass. There were also non-significant decreases in the germination of blue grama and alkali grass with increasing potassium nitrate. For bluegrass the effect is likely due to increasing osmotic stress germination which decreased linearly as KNO_3 increased. Although NaCl alone and KNO_3 alone caused significant decreases in germination, in combination the decrease in germination imposed by NaCl was alleviated, especially at the 0.5 level of amendment. It is likely that this treatment level provided an optimal sodium/potassium selectivity ratio to induce a high affinity potassium uptake system (System I) in cell membranes. This system is induced by low potassium and is unaffected by Na. At higher concentrations of potassium the low affinity potassium uptake system (System II) is induced. With System II uptake, Na/K selectivity is less pronounced leading to a higher Na/K and resultant Na stress (Jeschke, 1984).

Na/K selectivity is implicated by other treatments with potassium compounds. NaCl-induced decreases in blue grama and Kentucky bluegrass germination was affected by KNO_3 and KCl respectively. This is likely to be further evidence for the induction of System I and System II potassium uptake and the resultant Na/K selectivity.

Although salt seemingly had a significant effect on germination in the potash-alkali grass experiment ($p = 0.0407$), the ANOVA model was not significant ($p = 0.29$) which makes the interpretation of significant factor effects dubious (Cody and Smith, 1997).

Field Experiments

The results from the two study sites differ in terms of the alleviation of salt stress on plant establishment by adding amendments to the soil. Where amendments were effective at Eden Prairie the effect was a positive one. However, each significant treatment effect at Oakdale was negative; applying soil amendments decreased seed germination. These results were most likely a function of the different edaphic conditions at the study sites (Table 9). The soil samples used to illustrate the edaphic properties at the study sites were taken in July after soil sodicity is naturally diminished by seasonal precipitation, and they were taken five to seven meters from the pavement, where impacts of deicing salts are less (see Chapter 1). Both soils could be classified as saline-sodic (Gupta and Abrol, 1990). The soil at Oakdale had a slightly higher pH, lower soil moisture, organic matter, and available nitrogen than the soil at Eden Prairie. The concentrations of elements and of heavy metals were variable, but Oakdale soils had, in general, lower concentrations of cations and higher concentrations of heavy metals. However, throughout the spring growing season (during the field experiments), soil sodicity within the first four meters of the road was greater at Oakdale (figure 6).

The low soil moisture at Oakdale exacerbated the negative effects of deicing salts on soil water potential. Lower soil water potential decreases the amount of water available for imbibition, the first step in seed germination. Lower soil moisture, higher pH, and lower concentrations of cations and available nitrogen in Oakdale soil are likely associated with the low organic matter. Organic matter provides both buffering and water-holding capacities to adsorb excess sodium and increase soil water potential. Excess sodium also affects soil structure by dispersing clay particles. This decreases the rate of hydraulic conductivity, and, therefore, available water for imbibition. Further, deicing salts mobilize both organic matter and heavy metals, promoting the loss of organic matter and the availability of heavy metals in the soil solution (Amrhein et. al., 1994) which would compound the poor soil conditions at Oakdale.

Table 9. Physical properties of soil at field sites.

	Eden Prairie	*Oakdale*
pH	8.2	8.5
Soil moisture (%)	1.65	0.54
Organic matter (%)	5.85	2.5
Total nitrogen[1] (%)	0.21	0.09
SAR	9.5	8.0
Boron[2] (ppm)	5.4	5.0
Calcium[2] (ppm)	21380	15430
Magnesium[2] (ppm)	8271	8596
Manganese[2] (ppm)	308	215
Sodium[2] (ppm)	1153	881
Phosphorus[2] (ppm)	359	289
Potassium[2] (ppm)	583	581
Heavy metals[2]:		
Aluminum (ppm)	5139	5250
Iron (ppm)	10270	12470
Zinc (ppm)	73.6	84.7
Copper (ppm)	17.8	24.4
Lead (ppm)	142	164
Nickel (ppm)	12.6	10.7
Chromium (ppm)	21.7	28.0
Cadmium (ppm)	0.56	0.56

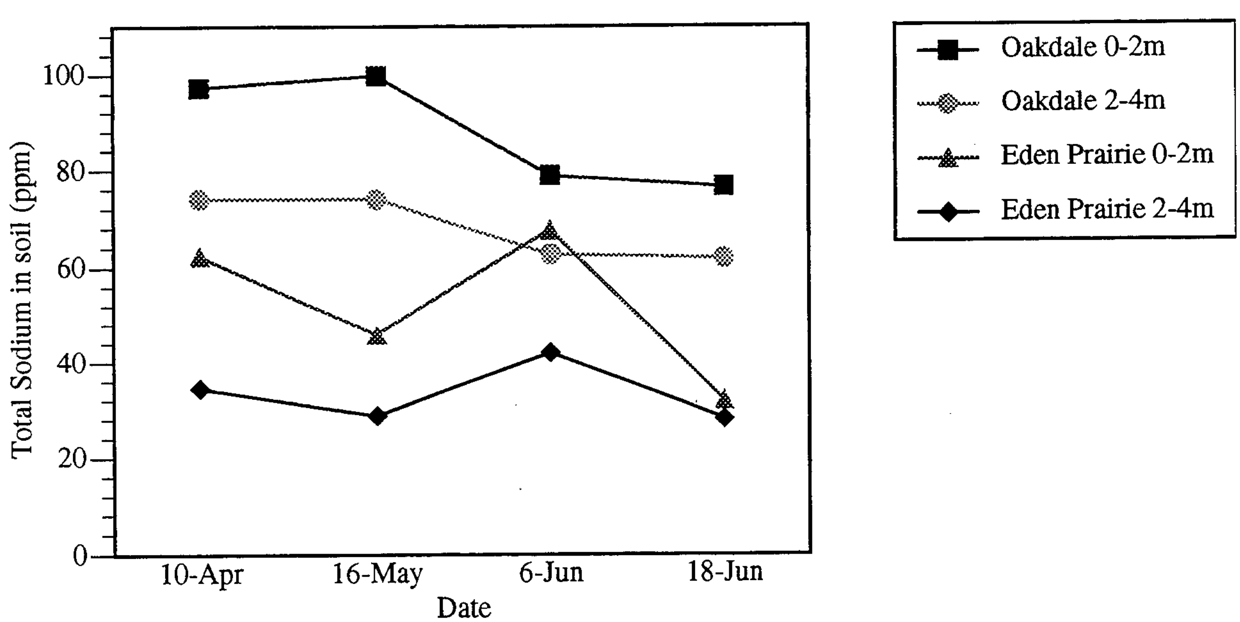
[1] Kjeldahl process.
[2] Inductively-Coupled Plasmolysis (HNO_3 digestion).

The greater sodicity also would explain the differences seen in plant response at the two sites. Of the nine experiments at Oakdale, six had significant negative effects of sodium. (Also, all three species-level analyses showed a negative effect of sodium.) At Eden Prairie, five of the nine experiments had a significant effect of sodium. However, two of these five were significant effects in alkaligrass experiments where the effect was positive.

Of the three study species the performance of alkali grass illustrates the differences between the sites most effectively. As predicted Kentucky bluegrass was negatively affected by soil sodicity, and this occurred at both sites. Blue grama had consistently low germination in all plots at both sites. This is most likely attributable to low viability of the seed batch used in the planting; thus results of amendment application alleviating NaCl stress on blue grama are largely inconclusive. The results of the alkali grass experiments were unexpectedly inconsistent between the two sites. Seed germination was positively correlated with soil sodicity at Eden Prairie (as expected), but negatively correlated with sodicity at Oakdale. Control plots at Eden Prairie showed remarkably low germination (table 6a). This may be attributable to exacerbating effects of high percent cover of weedy forbs in control plots relative to the treatment plots (data not shown). Alkali grass germination was negatively correlated with forb cover which was negatively correlated with sodicity; less sodicity allowed greater forb cover which decreased the germination of alkali grass. Conversely, the control plots at Oakdale had significantly higher germination than treatment plots. (Weedy forb cover was not significantly different in control vs. treatment plots at Oakdale.) The addition of amendments at Oakdale may have further increased osmotic stress and decreased germination.

Although soil sodicity was the primary cause of low germination, the time of planting was significant for both Kentucky bluegrass and alkali grass. Kentucky bluegrass had significantly greater establishment when planted in the spring and alkali grass had greater establishment when

Figure 6. Total sodium in soils at each field site, 1996.



planted in the fall. This illustrates the release of NaCl-induced inhibition on alkali grass germination. After removing inhibitory NaCl concentrations *Puccinellia nuttalliana* germination has been shown to recover 87.6% (Macke and Ungar, 1971). Similar results have been shown for other grasses (Ungar, 1991). *Puccinellia distans* is able to imbibe water as soon as the water melts, despite the high NaCl content. Conversely, seeds of Kentucky bluegrass are likely unable to recover the ability to germinate after exposure to toxic levels of NaCl.

The success of amendment use can also be illustrated by the persistence of treated plots beyond the first growing season. Toward this end, persistence was defined by exhibiting greater than 25% cover within a plot. Interestingly, more plots persisted at the Oakdale site than at Eden Prairie. Nearly 100% of the alkali grass plots survived at both sites. The one alkali grass plot that did not persist at Oakdale were in the west end of the northwest block of fall plots (see Figure 1) where no other plots persisted with the species planted in them. This area consistently had the highest sodium concentrations and electrical conductivity across both sites. Ironically, alkali grass seeded into the entire east half of the northwest block despite not being originally planted in that area. Blue grama sporadically persisted where it was planted throughout the Oakdale site and was not observed outside the plots. Several Kentucky bluegrass plots persisted, however, only if they had received an amendment treatment. No control plots of Kentucky bluegrass persisted. At Eden Prairie persistence only occurred in fall-planted plots. Although there was significant germination in the spring-planted plots, the 1996 growing season had only one significant rainfall event between mid-June to mid-October and a number of days and nights with recording-breaking temperatures. The emerged seedlings died by the end of July. In the fall-planted plots, all alkali grass plots persisted but one which had high forb cover. No blue grama plots persisted, but a several Kentucky bluegrass plots persisted in the row two to four meters from the pavement. All of the persistent Kentucky bluegrass plots were treated with an amendment.

Due to the demise of a majority of spring-planted plots in 1996, the spring planting was repeated in 1997. Seeds did germinate in 1997, however, climatological circumstances again were taxing. The 1997 growing season began with near-drought conditions between mid-April to late

June. However, the near-drought ended shortly thereafter as nearly eight inches of rain fell in three storm events within one week. Preceding the deluge, however, blue grama sporadically emerged at Oakdale (planted with a new seed batch) but not at Eden Prairie. Kentucky bluegrass and alkali grass germinated at Eden Prairie, but not at Oakdale. Following one of the storm events, data was collected at Eden Prairie. However, it was not collected before road construction work nearly obliterated a quarter of the plots. For those plots, cover data was taken over a smaller area and extrapolated. Therefore, the significance of the decrease in alkali grass germination in the gypsum-treated plots is perhaps dubious.

Conclusions

- The overwhelming effects of soil sodicity and the variability between study sites suggest that a single application of amendment compound (i.e. simultaneously with seed planting) is insufficient to alleviate NaCl-induced stress on germination. Multiple applications may offset NaCl stress, as implied by the greenhouse experiments.
- Soils at Oakdale (and other similar sites) will require reclamation before successful plant establishment can occur. Treatment with calcium amendment compounds and flushing the soil with freshwater may be successful. However, total soil replacement is probably necessary in order to establish plants at these sites.
- Certain species have greater establishment when planted in the fall vs. the spring. Alkali grass establishment was greater in fall plantings. The study also suggests that Kentucky bluegrass is more successful when planted in the spring. However, percent cover of even the spring plots was very low and the persistence of Kentucky bluegrass plots was poor. It can be concluded that Kentucky bluegrass, even relatively salt tolerant lines, are not good candidates for roadside soils in Minnesota.

- Although KCl is not necessarily successful when used as a soil amendment, it is a chemical deicing compound. Adding KCl to the salt-sand mixtures may enhance plant establishment at a relatively low cost and without jeopardizing highway travel.

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