Development of Salt Tolerant Grasses for Roadside Use

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16. Abstract

Roadsides in Rhode Island and elsewhere are planted to mowed turfgrass in order to prevent erosion, improve aesthetics, maintain visibility, and provide a safe means of stopping errant vehicles. However, there are a number of ways in which mowed turfgrass is failing to meet the expectations of highway managers and the traveling public. Regular mowing and turf maintenance is expensive. Use of non-native plants has resulted in problems with invasive species. Most importantly, the seeded turfgrasses are not surviving in the roadside environment and so are failing to prevent erosion.

Solving this problem requires answering two questions: why are the seeded turfgrasses dying? And how can this be fixed given severe limitations on funding? The purpose of this study was to seek answers to the first question, and then generate possible solutions to the second. The initial hypothesis was that high levels of deicing salt were responsible for the damage. We proposed to test this hypothesis by establishing test plots of 21 grass varieties selected for tolerance to salt in the high-salt zone at two locations: I-95 North in Hopkinton, and I-295 North in Lincoln. The grass variety trial was combined with a test of two potential low-cost soil amendments: yard waste compost and biosolids. We also proposed to monitor salt deposition over two winters at six sites to determine how much salt the grass was being exposed to, and how long the salt persisted in the root zone. Persistence is important because the grass is more sensitive to salt damage when it is actively growing (April-October) than during the winter months. At the same time we proposed to survey the vegetation on established, mowed roadsides to determine which plant species were surviving, as these might be good candidates for inclusion in a modified seed mix.

We found that salt tolerant grasses showed no improvement in survival over the grass varieties already in use, even though the salt tolerant grasses had shown significantly better survival in greenhouse salt screening trials. This suggested that the salt was not the primary cause of vegetation failure; the finding that the salt did not persist in the root zone at levels high enough to cause plant damage past early April further supported this hypothesis. Soil amendment, however, had a dramatic effect on turfgrass survival. Perennial vegetation cover on plots amended with biosolids remained above 50% throughout the two-year study, and beyond.

At the beginning of this study it was assumed that most of the vegetation surviving on mowed roadsides was the turfgrasses seeded by RIDOT or weeds such as quack grass, sheep sorrel, and crab grass. However, in surveys of seven sites in mowed areas along limited access highways in Rhode Island we found a total of 80 plant species, approximately half of which are native to Rhode Island.. Our results suggest that the seed mix used by RIDOT is not persisting on the roadside, but that it is gradually being replaced by native or naturalized species. Reductions in mowing would further this process, as they would permit more of these naturally-occurring plants to mature seed, filling in gaps created by vehicles and other disturbances.

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Executive Summary

Roadsides in Rhode Island and elsewhere are planted to mowed turfgrass in order to prevent erosion, improve aesthetics, maintain visibility, and provide a safe means of stopping errant vehicles. This tradition dates back to the parkways of the early 20th century, and remains most prevalent on limited-access roads.

However, there are a number of ways in which mowed turfgrass is failing to meet the expectations of highway managers and the traveling public. Regular mowing and turf maintenance is expensive. Mowed grass resembles a uniform green carpet, especially when viewed at highway speeds, lending a boring sameness to roadsides everywhere. Use of non-native plants has resulted in problems with invasive species. Most importantly, the seeded turfgrasses are not surviving in the roadside environment and so are failing to prevent erosion.

Solving this problem requires answering two questions: why are the seeded turfgrasses dying? And how can this be fixed given severe limitations on funding? The purpose of this study was to seek answers to the first question, and then generate possible solutions to the second. Studies elsewhere in the United States and in Europe suggested that high levels of de-icing salt were causing failure of roadside grass plantings. These suggestions were supported by the pattern of the damage, which was worst within 10 feet of the pavement, and by the damage worsening along I-95 after RIDOT began using pure salt for de-icing, rather than a mix of salt and sand.

We proposed to test this hypothesis by establishing test plots of 21 grass varieties selected for tolerance to salt in the high-salt zone at two locations: I-95 North in Hopkinton, and I-295 North in Lincoln. The grass variety trial was combined with a test of two potential low-cost soil amendments: yard waste compost and biosolids. Amending the soil with organic matter generally enhances plant growth, but it can also intensify salt damage. We also proposed to monitor salt deposition over two winters at six sites to determine how much salt the grass was being exposed to, and how long the salt persisted in the root zone. Persistence is important because the grass is more sensitive to salt damage when it is actively growing (April-October) than during the winter months. At the same time we proposed to survey the vegetation on established, mowed roadsides to determine which plant species were surviving, as these might be good candidates for inclusion in a modified seed mix.

We found that salt tolerant grasses showed no improvement in survival over the grass varieties already in use, even though the salt tolerant grasses had shown significantly better survival in greenhouse salt screening trials. This suggested that the salt was not the primary cause of vegetation failure; the finding that the salt did not persist in the root zone at levels high enough to cause plant damage past early April further supported this hypothesis. Soil amendment, however, had a dramatic effect on turfgrass survival. Perennial vegetation cover on plots amended with biosolids remained above 50% throughout the two-year study, and beyond (Figure 1). Soil nutrient analysis showed that the unamended soil was deficient in all the major nutrients (nitrogen, potassium, phosphorous, calcium, and magnesium) required for plant growth. One-time incorporation of biosolids to create a 50/50 mix in the top six inches of the root zone significantly increased the levels of all these nutrients while lowering the levels of bioavailable lead and other metals.

Improving the fertility of the soil improved the survival of conventional turfgrasses. However, there is significant public pressure to use native species on roadsides, and to have roadside plant communities reflect the natural vegetation of the area. At the beginning of this study it was assumed that most of the vegetation surviving on mowed roadsides was the turfgrasses seeded by RIDOT or weeds such as quack grass, sheep sorrel, and crab grass. However, in surveys of seven sites in mowed areas along limited access highways in Rhode Island we found a total of 80 plant species, approximately half of which are native to Rhode Island. Only four of these species had been deliberately planted: red fescue, Kentucky bluegrass, perennial ryegrass, and birdsfoot trefoil. Mean coverage of these species ranged from 38% over 4 locations for red fescue to only 3% at one location for perennial ryegrass. Our results suggest that the seed mix used by RIDOT is not persisting on the roadside, but that it is gradually being replaced by native or naturalized species. Reductions in mowing would further this process, as they would permit more of these naturally-occurring plants to mature seed, filling in gaps created by vehicles and other disturbances.

Most of the 32 introduced species found in the survey are benign; in many cases they have been here for centuries and cause no problems in natural areas. However, some are invasive weeds of agricultural areas and urban landscapes, and others have potential to invade natural landscapes. The most common of these weed species was smooth crabgrass, which is an annual species that colonizes where perennial species have died. More troubling weed species are quackgrass, spotted knapweed, purple loosestrife, and crown vetch. All of these are perennial, and are listed as invasive species either in New England or at the federal level. Spotted knapweed, purple loosestrife, and crown vetch were each found at only one location, and represented by only one or two plants, so they are unlikely to persist on the mowed roadside. However, quackgrass is widespread. This tall, fast-growing grass is extremely well adapted to roadside conditions and very aggressive. It is spreading rapidly along highways in Rhode Island, probably through use of erosion control “straw” bales which contain quackgrass seed heads. Quackgrass greens up sooner than other grasses, and grows faster, particularly in April and May, creating an untidy appearance on the roadside. It displaces native plants and turfgrasses, even when they are healthy and growing in fertile soil.

Based on the results of this study, we suggest that RIDOT incorporate the following management practices to improve survival of roadside vegetation:

- Incorporate biosolids or other nutrient-rich organic matter into plantable soil, particularly between the pavement and the swale.
- Continue to choose turfgrass varieties based on cost of seed.
- Encourage establishment of native plants by reducing mowing frequency to only once or twice per year, and permitting native species to mature seed before mowing.
- Discontinue the use of “straw” bales for erosion control. Mesh bags filled with compost are a possible substitute that would enrich the soil while avoiding introduction of weeds.

Figure 1 The roadside trial sites in Google Earth images from April 20, 2010. The I-95 site is on top, and I-295 underneath. The I-295 compost treatment was split to clear the lightpost; the lightpost in the biosolids treatement was installed after the plots were in place.

Table of Contents

Introduction

Description of Problem

The primary concern in the design and management of roadways is the safety of the traveling public. The health of the roadside ecosystem and its ability to support plant growth is, by necessity, of lesser importance. However, the roadside is generally planted to perennial vegetation to prevent erosion, filter storm water, reduce dust, and increase aesthetics. For safety reasons, every effort is made to keep the roadway free of water, ice, and snow. The pavement is crowned to drain water to the vegetated shoulder, which is itself engineered to rapidly drain water into the swale leading either to storm drains or to ponds. When weather is below freezing, salt is applied to roadways so that ice and snow will melt and drain from the pavement. All of the water and salt, along with other pollutants, flows through the roadside soil, negatively affecting its chemical composition and physical structure. At the same time, heat reflected from the pavement and the constant wind from passing vehicles create a microclimate hostile to plant growth. For safety reasons, the area of the vegetated shoulder closest to the pavement (clear zone) is maintained as low-growing herbaceous vegetation – usually mowed grasses. These plants live entirely within the hostile microclimate. The result is that the first 10-15 feet of the vegetated shoulder are often bare of vegetation or dominated by annual weeds, and the shoulder fails to provide the intended functions of erosion control and improved aesthetics.

To improve the survival of perennial vegetation on the shoulder it is necessary to identify the specific stresses limiting vegetation growth, and then to either identify plants which can tolerate those stresses or identify ways to ameliorate the stresses while still maintaining safety. The "dead zone" generally corresponds with the area of greatest salt deposition, suggesting that high salinity is a limiting factor. The turfgrass species used on roadsides generally receive regular applications of fertilizer and irrigation when used in lawns, suggesting that drought and/or nutrient stress may be limiting factors. The objectives of this study were to determine which of these factors are more significant in Rhode Island, and identify ways to mitigate the impact of the stress. We addressed salt stress by monitoring the salt levels in soil pore water, runoff, and snow over two years, and by testing the performance of 21 turfgrass varieties developed for salt tolerance against the common red fescue used on roadsides. We addressed drought and nutrient stress by testing the effects of amending roadside soil with yardwaste compost and biosolids on the performance of the 22 turfgrass varieties, and by surveying the vegetation community at seven roadside sites.

Literature Review

Impacts of salt on roadside environment

The use of rock salt for highway deicing is standard practice in areas where winter weather regularly includes snow and ice. Rock salt is the most economical and cost-effective deicer available (Salt Institute, 2004). However, its use can lead to negative environmental impacts, particularly in areas of heavy use. Chemically rock salt is almost pure sodium chloride. Both sodium and chloride are toxic to plants at high concentrations. In addition sodium can alter the water-holding capacities of soils and can interfere with plants' ability to take up water and maintain proper turgor pressure within cells. Plants differ in their sensitivity to sodium and chloride. Some, such as maples and many conifers, are damaged by exposure to low levels of salt. Others, such as alkaligrass, can tolerate very high levels. Many trees are quite sensitive to chloride poisoning, while grasses tolerate much higher levels of chloride and are more likely to be damaged by desiccation from high levels of sodium (Cordukes and Parups 1971).

Soil

The rate at which salt accumulates in soil and the effects on soil structure depend on the basic soil type (Warrence et al., 2002). Chloride is a negatively-charged ion, and does not bind to soil particles, so it is quickly flushed below the root zone. However, sodium can bind to soil particles and may accumulate to high levels, resulting in sodic soil. Sodicity is most likely in soils high in clay or organic matter, as they have a high cation exchange capacity. In these soils sodium ions displace the calcium and magnesium ions on the surface of soil particles, increasing the soil pH and causing the soil particles to aggregate into larger particles (Warrence et al., 2002). Soils with larger particles can hold less water than soils with smaller particles, increasing drought stress on plants. This stress is increased in clay soils as sodium causes the clay particles to swell when the soil water is less saline than the soil aggregates, such as during rainstorms. The swelling reduces the permeability of the soil and leads to runoff rather than water infiltration (Warrence et al., 2002). In addition, when precipitation is less than evaporation both sodium and chloride can accumulate on the soil surface. The presence of salts in the soil water increases the osmotic potential of the soil solution, making the water less available to plants.

Several studies have shown that soil salt levels are highest within five feet of the pavement and decrease with increased distance from the road (Bryson and Barker 2002, Prior and Berthouex, 1967, Hutchinson and Olson 1967). The overall width of the impacted area depends on the soil type, the traffic speed, roadway drainage patterns, and wind direction. A study at the Morton Arboretum near Chicago detected significant sodium deposition at ground level up to 400 feet from the edge of Interstate 88 (Kelsey and Hootman 1992). A Swedish study found that 90% of the salt was deposited within 130 feet (40 m) of the pavement (Blomqvist and Johansson 1999). Salt levels are highest in the winter months, and decrease over the course of the growing season. In areas where winter storms are followed by thaws or rain, salt levels peak during each salting event and then decline during the thaw, exposing plants to alternating high and low levels of salt (Prior and Berthouex 1967). Soil salt levels reach much higher concentrations in areas where the ground remains frozen all winter. Salt concentrations of 20,000 ppm were reported as typical along Chicago-area expressways in April, with levels reaching 50,000 ppm in the medians (Hughes et al. 1975). Sensitive species are damaged by levels below 1,000 ppm, and few plants can tolerate levels of 50,000 ppm. While much of the salt leaches from the roadside soil each spring, the growing season minimums do increase over time (Hutchinson and Olson 1967). The rate of increase is largely determined by the type of soil and the annual precipitation. Soils with high cation exchange capacities (CEC) and high levels of calcium readily bind sodium and can accumulate high levels. In contrast, low CEC soils bind relatively little sodium and significant levels are unlikely to persist if precipitation levels are sufficient for leaching. In much of New England low CEC soils and abundant rainfall combine to keep growing season sodium levels below 1000 ppm even after decades of salt application (Hutchinson and Olson 1967, Bryson and Barker 2002).

Salt applied to the roadway reaches planted areas as runoff and as airborne spray. The amount of salt reaching the roadside in a given storm event is determined by the amount of salt applied to the roadway, moisture levels, the amount of traffic, and the speed of the traffic. The slope of the land and the direction of prevailing winds are also important. Generally salt damage is worse in areas that are downhill or downwind from the roadway (Patenaude 1989). Berms or other structures designed to protect areas adjacent to highways from noise and air pollution can cause the cloud of salt spray to reach heights of more than 60 feet (18 meters) above the road surface (Kelsey and Hootman 1992). Woody plants are sensitive to damage from winter salt spray as they maintain their above-ground tissues from one year to the next. Evergreens are particularly sensitive to desiccation and toxicity from salt accumulating on their leaves, but twigs and buds of deciduous species can also be killed (Hofstra et al. 1979). Grasses are only minimally affected by salt spray as their vertical leaves trap spray poorly and most species replace all above-ground tissues annually (Bryson and Barker 2002). In addition, grasses are more likely to be covered by snow during salt applications.

Salt mixes with snow to form brine which soaks into the soil along the road, primarily within the top 6-18 inches of the soil profile and up to 60 feet from the edge of the road. If soils have high CEC or are poorly drained high salt levels may persist throughout the growing season and increase from one year to the next (Roberts and Zybura 1967, Biesboer et al. 1998). Sodium that remains in the soil when plants are actively growing may be taken up by the plants, causing sodium toxicity in leaves and shoots. High sodium levels also interfere with plant uptake of the essential nutrients potassium and calcium, leading to nutrient deficiencies and stunted growth. Shallow-rooted plants, plants growing in shallow soil, and plants which leaf out or flower early in the spring are particularly sensitive to damage. Many species are unable to germinate in sodic soils even when the adult plants are salt tolerant, creating difficulties in revegetating roadsides. High levels of sodium in the soil is the major cause of salt damage to grasses; it is also significant on shallow-rooted trees such as sugar maples.

Both salt spray and runoff are worst in the areas closest to the road, including shoulders and medians. These areas are often planted to grass. The grass prevents erosion which can damage the roadbed, while not obstructing visibility or presenting a safety hazard. However, salt levels within 10 feet of the pavement are often high enough to restrict grass growth (Roberts and Zybura 1967). In grasses new shoots and roots originate from the crown, which is located at the soil surface. This is a different growth pattern from that of trees, where new growth originates at the tips of the old growth. During the winter roadside grasses may be submerged in salt-laden slush or saltwater. Examining grasses in the median of a highway near Amsterdam, Liem et al. (1984) found that two days after the application of deicing salts the sodium level on the leaves was 6-12 times higher than on the leaves of control plants 30 meters from the road. High salt conditions can persist for quite some time if frozen or compacted soil prevents the salt from leaching out of the root zone.

Plants

Salinity stress to plants takes two forms: osmotic stress and ion toxicity. Osmotic stress refers to the fact that it is more difficult for roots to absorb water when the soil solution is high in salts. Ion toxicity occurs when high levels of sodium, chloride, and other ions accumulate in cells and disrupt their normal functioning. Ion toxicity can be avoided by sequestering the ions in vacuoles (compartments) within the cell, but this creates osmotic stress at the cellular level. Grasses deal with the osmotic stress by producing the secondary compound glycinebetaine which has similar osmotic effects as the ions without the toxicity. However, production of glycinebetaine requires adequate levels of nitrogen and carbohydrates. In general grasses are more sensitive to ion toxicity than to osmotic stress, and tolerate salt by excluding toxic ions from the shoots (Marcum 2009b). Sodium (Na^+) is more of a problem than chloride (Cl^-) for grasses because sodium competes with the essential nutrient potassium (K^+) for uptake into the plant. Salt-tolerant grasses are able to regulate the K^+/Na^+ ratio in their cells by selectively absorbing K^+ while excluding Na^+(Marcum 2009b); however, this ability depends on sufficient K^+ levels in the soil.

Many grasses commonly used on lawns will be severely weakened or killed by high salt levels, particularly if soil remains high in sodium during the growing season. However, grasses which are adapted to high-salt areas such as salt marshes, seaside dunes, and salt flats are more tolerant. There is an increasing body of research identifying the grass species best suited to use on roadsides exposed to deicing salts. Much of the research has focused on high CEC soils that are prone to sodicity and compaction. When not damaged by sodium these soils are generally fertile, have a neutral to alkaline pH, and hold water well. Grasses grow very well in these soils. In contrast, many of the soils in Rhode Island are lighter in texture, with low CEC. These soils are not prone to compaction and do not retain high levels of sodium. However, these soils are also acidic, infertile, and prone to drought – conditions which do not favor grasses. Differences in salt tolerance are most pronounced in grasses grown with an abundance of nitrogen and other nutrients, and may disappear when grasses are nitrogen deficient (Bowman et al. 2006a). At the same time, salinity decreases the ability of the grass to absorb nitrogen from the soil, potentially exacerbating nitrogen deficiency (Bowman et al. 2006b). Lack of nutrients prevents grasses from regrowing leaves and roots lost to winter salt exposure and summer drought, leading to death of the plants. Considerable work has been done on identifying salt tolerant grasses, and grasses suited to low-maintenance sites. However, little has been done on tolerance of grasses to both stresses simultaneously.

Tolerance of grasses to salt

Trials

Agronomists and plant breeders use trials to determine which grasses are most likely to succeed under salt or saline conditions, and to develop new cultivars with improved performance under these conditions. There are three basic types of trials: germination trials, salt bath trials, and field trials. Each type of trial has advantages and disadvantages, and measures a different aspect of salt tolerance.

Germination Trials

Germination trials evaluate the ability of seeds to germinate under high-salt conditions. Many grasses are more susceptible to salts as germinating seedlings than as established plants (Westing 1969). The ability to germinate under saline conditions is important in areas where the irrigation water is saline, where soil is persistently saline, or where salt-damaged roadsides need to be re-seeded in the spring before the salt has leached from the soil. Germination trials require little time or space to conduct. However, they are not good predictors of a cultivar's ability to tolerate high salt levels as a mature plant.

Salt Solution Trials

Salt solution trials are frequently used to evaluate the salt tolerance of mature turfgrass plants. These trials are generally conducted in the greenhouse. The plants are either grown in a hydroponics system to which the salt is added or in pots which are irrigated with a salt solution. Salt solution trials permit plants to be evaluated under carefully controlled conditions using known salt mixtures. The salt solution may be sodium chloride, or it may be designed to mimic the range of salts found in seawater or in saline soil or irrigation water. Salt solution trials are an efficient way to evaluate individual plants or cultivars for salt tolerance, and to select the most tolerant individuals from a segregating population. However, the conditions in the salt bath may differ significantly from conditions in the landscape. In particular, salt solution trials are usually conducted using actively growing plants; road salt exposure usually occurs when the grass is semi-dormant.

Established Plant Field Trials

Field trials are the most accurate way to evaluate turfgrass performance. However, they can be quite expensive to conduct, and so are rarer than greenhouse trials. It is difficult to monitor or control salt exposure in roadside trials. In addition it is difficult to separate the effects of salt from other factors such as drought, soil fertility, disturbance, and soil compaction in field trials; this makes it difficult to apply results across a range of environments.

Trial Reports and Currently Available Material by Species

Alkaligrass (*Puccinellia distans*) is generally considered the most salt-tolerant of the cool-season grasses. However, it is not generally considered to be a turf grass, and few cultivars exist. Some of the fineleaf fescues are also highly salt-tolerant, particularly the slender creeping red fescues (*Festuca rubra* ssp. *litoralis*). Ryegrass (*Lolium perenne*) and tall fescue (*Festuca arundinaceae*) are considered moderately salt tolerant, as is strong creeping red fescue (*Festuca rubra* ssp. *rubra*). The demand for salt tolerant ryegrass for overseeding salt-tolerant warm season turf in the southern United States has led to the development of many new ryegrass cultivars with much-improved salt tolerance. Kentucky bluegrass (*Poa pratensis*) is generally considered to be quite susceptible to salt damage, but there is significant variation among cultivars. Chewings fescue (*Festuca rubra* ssp. *commutata*), sheeps fescue (*F. ovina*) and hard fescue (*F. trachyphylla*)are tolerant of low fertility but generally sensitive to salt. Among the bentgrasses some cultivars of creeping bentgrass (*Agrostis stolonifera*) are highly salt tolerant as long as water and fertility are sufficient. Colonial bentgrass (*A. capillaris*) tolerates drought and low fertility but is very sensitive to salt.

Turf Species

Red fescues:

Torello and Symington (1984) examined the ability of the slender creeping red fescue cultivars 'Dawson' and 'Checker' to germinate and establish on tissue culture medium amended with sodium chloride up to 170 mM (approximately 10,000 ppm). Germination of 'Checker' ranged from 100% at 85 mM NaCl to 80% at 170 mM NaCl. Germination was as good as alkaligrass at 170 mM, and better than alkaligrass at the lower salt levels. 'Dawson' germinated almost as well as 'Checker', ranging from 86% at 43 mM NaCl to 70% at 170 mM. High levels of salt did not significantly affect leaf or root growth of either cultivar, and both grew slightly better than the alkaligrass. Liem et al. (1985) found that the chewings fescue cultivar 'Mary' germinated as well when soaked in a solution of 10 g/l sodium chloride as when soaked in plain water, and that exposure to 20 g/l NaCl reduced germination by less than 50%. In contrast, germination of the chewings fescue ‘Moncorde’ and the sheeps fescue Biljart decreased by about 10% at 10 g/l and by 90% at 20 g/l.

Corduke and Parups (1971) studied chloride uptake of turfgrasses in salt solution culture; they found ‘Pennlawn’ strong creeping red fescue to be moderately tolerant, with better tolerance than Kentucky bluegrass but less than tall fescue.

Ahti et al. (1980) evaluated 18 cultivars of fineleaf fescue for salt tolerance using a salt solution system with clay loam soil. Unlike the sand usually used, clay loam will bind salt, causing salinity levels to increase over the course of the experiment. Ahti et al. found that the slender creeping red fescue cultivars ‘Dawson’ and ‘Golfrood’ showed the most salt tolerance, with little apparent damage when grown for 71 days at approximately 20,000 ppm NaCl. The strong creeping red fescue cultivars ‘Ruby’, ‘Ranier’, ‘Steinacher’ and ‘Illahee’ had intermediate tolerance. They all survived the salt stress, but lost more than half their leaves. These cultivars were not able to grow new leaves under the high-salt conditions. ‘Scaldis’ and ‘Centurion’ hard fescues, ‘Pennlawn’ and common strong creeping red fescues, and ‘Atlanta’ chewings fescue (*F. rubra* var. *commutata*) had fewer than 50% of the plants surviving after 71 days. The most susceptible cultivars were ‘Wintergreen’, ‘Waldorf’, and ‘Jamestown’ chewings fescues, ‘Firmuala’ and ‘Barok’ sheeps fescues, and ‘Durar’ hard fescue. The six cultivars were severely damaged by only a few weeks of salt, and there were no surviving plants after 71 days.

Humphreys (1982) evaluated the salt tolerance of 15 slender creeping red fescue populations from around Britain. He found that some coastal populations survived salt levels five times higher than seawater, while inland populations were killed at much lower salt levels.

Brod and Preusse (1980) conducted salt solution tests and field tests in Germany during the winters of 1975-76 and 1976-77. They evaluated sward density as percent green matter for four fineleaf fescue cultivars and three seed mixes with fineleaf fescue as a major component. The cultivars were the red fescues ‘Dawson’, ‘Topie’, and ‘Ensylva’ and *F. vallesiaca* ‘Gruber’. Two of the mixtures contained ‘Ensylva’; the third contained ‘Topie’ and *F. ovina* ‘Biljart’. ‘Topie’ was salt sensitive, with 35% of the sward density lost following exposure to 0.5 kg salt/m^2/year and 90% lost following exposure to 1.0 kg salt/m^2/year. ‘Ensylva’ was slightly more tolerant, with sward density losses of 10% and 70% respectively. Like ‘Topie’ ‘Ensylva’ was completely killed at 2.0 kg salt/m^2/year. ‘Dawson’ and ‘Gruber’ were quite salt tolerant. Neither cultivar lost sward density at 0.5 kg salt/m^2/year. Treatment with 1.0 kg salt/m^2/year reduced sward density only 20% in ‘Gruber’ and 25% in ‘Dawson’. ‘Dawson’ retained 35% cover at 2.0 kg salt/m^2/year, the most of any cultivar in the study. *F. ovina* ‘Biljart’ did not exhibit any salt tolerance.

Greub et al. (1985) evaluated the red fescue cultivar ‘Ruby’ in a greenhouse salt trial. They found that five weeks of treatment with 20 ml per week of a 2.65 M sodium chloride solution did not significantly reduce the shoot growth of ‘Ruby’ but did result in significant injury to the turf. The final salt level was approximately 10,000 ppm. The three slender creeping red fescue entries had the best resistance.

Researchers at Pure-Seed Testing evaluated the survival of 36 cultivars or breeding populations of fine fescue in a salt bath at 10,000 ppm sodium chloride. ‘Seabreeze GT’, ‘Dawson E’, and ‘Seabreeze’ all had better than 95% survival after seven weeks, and better than 90% survival after 10 weeks. ‘Seabreeze’ declined significantly by 12 weeks, with only 72% survival. ‘Seabreeze GT’ had 95% survival. ‘Dawson E’ had 87% survival; it was not statistically different from ‘Seabreeze GT’. Brown (2008) found that ‘Seabreeze GT’ retained acceptable green cover at 17,500 ppm sodium chloride and was able to survive two weeks at 20,000 ppm. 'Epic' strong red fescue retained acceptable green color at 15,000 ppm sodium chloride and was able to survive two weeks at 22,500 ppm.

Salt-tolerant fine fescue cultivars on the market at this time include 'Dawson E', 'Seabreeze GT', 'Florentine GT', 'SeaLink', 'Shoreline' and 'Epic'.

Kentucky bluegrass:

Kentucky bluegrass is relatively sensitive to salt. Liem et al. (1985) found that a solution of 5000 ppm sodium chloride reduced germination of Kentucky bluegrass seed by 50%, and 10,000 ppm reduced germination practically to zero. Mature plants are somewhat more tolerant. Greub et al. (1985) tested the salt tolerance of six 1970's-era Kentucky bluegrass varieties grown in a clay loam soil. 'Park' showed the most salt tolerance and 'Marion' the least, but growth of all six varieties was less than that of perennial ryegrass, rough stalk bluegrass, or creeping bentgrass at the same salt levels. Torello and Symington (1984) tested the salt tolerance of five Kentucky bluegrass cultivars and found that 'Adelphi' and 'Ram' were more tolerant than 'Baron'. All five varieties were less tolerant than alkaligrass or creeping red fescue, but 'Adelphi' and 'Ram' had similar tolerance to 'Jamestown' chewings fescue. Rose-Fricker and Wipff (2001) screened 65 Kentucky bluegrass varieties for survival after six weeks in a hydroponic solution of 10,000 ppm mixed salts. Damage ranged from ~30% loss of green tissue in the tolerant variety 'Northstar' to 75% loss of tissue in the sensitive varieties 'P-105' and 'KenBlue'. In field and greenhouse studies exposing Kentucky bluegrass varieties to salt levels in the range of 2000 – 5000 ppm Bonos et al. (2009) found that 'Eagleton', 'Liberator', 'Cabernet', 'Diva', 'Argos', and 'Rhythm' showed the most salt tolerance while 'Baron' and 'Julia' showed the least. Robins et al. (2009) evaluated the salt tolerance of 93 Kentucky bluegrass accessions and found that five accessions had tolerance as good as or better than the tall fescue and perennial ryegrass accessions. Commercially available Kentucky bluegrass varieties developed for salt tolerance include 'Moonlight SLT', 'Moonbeam', and 'Northstar'. However, no current Kentucky bluegrass is as salt tolerant as the salt tolerant red fescues.

Perennial ryegrass:

Perennial ryegrass is popular for use on roadsides because it germinates very quickly and effectively controls erosion. Ryegrass has moderate levels of salt tolerance, better than most Kentucky bluegrasses but poorer than alkali grass. However, ryegrass is often short-lived and has little tolerance for low fertility or drought stress (McKernan et al. 2001). Liem et al. (1985) found that a salt level of 20,000 ppm reduced germination of 'Lamora' perennial ryegrass seed by 50%. Rose-Fricker and Wipff (2001) found that germination of 'Charger II' was affected less by salt than germination of 'Manhattan II'. Greub et al. (1985) found that irrigation with salt water for five weeks caused visible injury to 'NK 200' but did not decrease shoot growth. Hughes et. al. (1975) had found that shoot growth in common-type perennial ryegrass decreased by almost 50% relative to controls when grown in soil amended with 20,000 ppm sodium chloride. Tissue survival among 45 cultivars grown for nine weeks at 17,000 ppm salinity ranged from a high of 84% to a low of 25% (Rose-Fricker and Wipff 2001). Cultivars 'Brightstar SLT', 'Manhattan 3', 'Catalina' and 'Fiesta III' were in the most tolerant group while 'Allsport', 'Buccaneer', 'Premier', 'Promise', 'Linn', 'Ascend' and 'Wilmington' were highly sensitive. Perennial ryegrass varieties currently marketed as salt tolerant include 'SaltEase', 'Brightstar SLT', 'Graystar', and 'Salinas'.

Tall fescue:

Tall fescue is moderately salt tolerant, with 50% reduction in shoot growth occurring around 6,000 ppm. It is one of the most heat-tolerant of the cool-season turfgrasses, and has been widely used for lawns and roadsides in the region from New Jersey south to North Carolina and west to Iowa and Nebraska. Roberts and Zybura (1967) found that 'Kentucky 31' tall fescue was the most salt tolerant of ten species considered for use on salt-impacted soils along I-80 in Iowa. 'Kentucky 31' was only slightly injured when exposed to 5050 ppm sodium chloride, which is equivalent to 48,000 lb salt per lane-mile. Greub et al. (1979) found that the tall fescue cultivars 'Kentucky 31' and 'Alta' had visual quality similar to Nutall alkaligrass (*Puccinellia airoides*) when grown in soil receiving 2.24-8.96 mt/ha/wk sodium chloride for 5 weeks. Kobayashi et al. (2004) found that the tall fescue cultivar 'Southern Cross' was the most tolerant of six cool-season species tested to calcium chloride, magnesium chloride, and sodium chloride. Fifty percent reduction in dry matter occurred at 4800 ppm for calcium chloride, 3900 ppm for calcium chloride, and 9000 ppm for sodium chloride. Alshammary et al. (2004) found that 'Arid' tall fescue was more salt tolerant than 'Challenger' Kentucky bluegrass but less tolerant than alkaligrass or saltgrass (*Distichlis spicata*) and that 50% reduction in tall fescue shoot growth occurred between 6400 and 9000 ppm NaCl. Wipff and Rose-Fricker (2003) tested survival of 45 tall fescue varieties at 25,000 ppm NaCl. The top performer was 'Tarheel II' which had 86% survival after 15 weeks and only 50% loss of green cover. Other varieties with comparable tolerance were 'Pure Gold', 'Dynamic', 'Kentucky 31', and 'Plantation'. Krishnan (2010) found that 'Pure Gold' retained 76% cover after two weeks at 12500 ppm NaCl and 59% cover after two weeks at 15000 ppm; tolerance was comparable to the best of 27 red fescues tested. Newer varieties have greatly superior turf quality relative to 'Kentucky 31' and 'Alta'; varieties with comparable or better salt tolerance include 'Tarheel II', 'Pure Gold', and 'Corona'.

Bentgrasses:

Creeping bentgrass is the most salt tolerant of the turf bentgrasses, tolerating up to 10,000 ppm NaCl (Marcum 2009a). However, it requires high fertility and abundant moisture; most cultivars were developed for use on golf courses and are unsuited to roadside use. Colonial bentgrass and highland bentgrass tolerate drought, low fertility, and acid soil. Very little salinity testing has been done on these species but they are generally considered to be very sensitive to salt. Greub et al. (1979) found that 'Astoria' colonial bentgrass was severely damaged by the equivalent of 2.4 mt/ha/wk of sodium chloride. Gibeault et al. (1977) evaluated the colonial bentgrass cultivars 'Astoria', 'Highland', and 'Holfior' on a golf course with a soil salinity of 7000 ppm. Performance of the three cultivars was similar, and none of them had acceptable turf quality.

Tolerance of grasses to low fertility and low maintenance

Fertilization is a standard component of turfgrass maintenance, so most studies of performance on infertile soils are conducted under low maintenance conditions, with the grass receiving no irrigation and minimal mowing or pesticide application. Roadsides typically receive even less maintenance than low-maintenance lawns, so these studies are applicable. However, the studies conflate drought tolerance with tolerance to low fertility, making it difficult to apply results from low rainfall areas to more mesic climates such as New England. The fine fescues, creeping bentgrass and colonial bentgrass have the lowest nitrogen requirements of the standard turfgrasses, although the variation within species is considerable (Liu et al. 2009). In particular most commercial bentgrass varieties were developed for golf course use under high fertility levels. Tall fescue and fine fescues tolerate drought well, while creeping bentgrass is drought-sensitive (McCann and Huang 2008). Colonial bentgrass tolerates drought by going dormant; it is generally considered to be drought-sensitive because summer dormancy is not acceptable on golf courses.

McKernan et al. (2001) evaluated the performance of 23 species of turfgrasses and native grasses for establishment and persistence under low maintenance at two locations in Alberta. They found that 'Aurora' and 'Spartan' hard fescues and 'Nakiska' sheeps fescue had the best persistence of the turfgrasses in southern Alberta and that 'Dawson' red fescue had the best persistence in the more mesic climate of central Alberta. 'Fults' alkaligrass and 'Blazer' and 'Fiesta' perennial ryegrasses had the least persistence. Diesburg et al. (1997) evaluated 12 species for tolerance to low-input maintenance at sites throughout the Upper Midwest. They found that sheeps fescue and 'Alta' tall fescue had the best persistence across all locations. 'Durar' hard fescue, 'Exeter' colonial bentgrass, 'Colt' rough bluegrass, and redtop bentgrass were well-adapted in some locations but did poorly in others. The authors mention that colonial bentgrass did particularly well on the less fertile soils. Mintenko et al. (1999) evaluated 12 species of native grasses for use as turfgrasses in Manitoba. 'Barkoel' prairie junegrass had the highest quality of any of the commercially available entries. 'Nortran' tufted hairgrass and 'Golfstar' Idaho bentgrass established well and showed promise but were damaged by disease. Dernoeden et al. (1998) evaluated the performance of 'Flyer' creeping red fescue, 'Jamestown II' chewings fescue, 'Bighorn' sheeps fescue, 'Reliant' hard fescue and 'Rebel II' tall fescue under mowed low-input conditions in Maryland. When the grass was mowed at a height of 3 in. the hard fescue and tall fescue plots had the best quality. The sheeps fescue also gave good quality once established. The authors concluded that creeping red fescue and chewings fescue were not good choices for low-input turf in their area. Wakefield et al. (1974) evaluated persistence of a number of turf and native grasses on roadside sites throughout Rhode Island. They found that red fescue (common or 'Pennlawn') and tall fescue gave the best coverage one year after seeding. Two years after seeding 'Exeter' colonial bentgrass, 'Pennlawn' red fescue, common creeping red fescue and fine-leaved sheeps fescue has the best cover. Fine-leaved fescues, 'Exeter' colonial bentgrass, and 'Park' Kentucky bluegrass were still providing adequate groundcover five years after seeding, although the Kentucky bluegrass only persisted on the moister, more fertile sites. A 5-year low-input lawn trial at the University of Rhode Island found that hard fescue, prairie junegrass, red fescue, colonial bentgrass, and tall fescue had the best persistence while perennial ryegrass, tufted hairgrass, and Kentucky bluegrass died out (Brown, unpublished data).

Impacts of amendments on soil quality

Composted Yard Waste

Composted yard waste is made from a mix of grass clippings, leaves, and wood chips. These components are common in urban and suburban areas, so are a good source of organic matter for use on urban and suburban roadsides. Many DOTs use compost as mulch to reduce erosion on slopes; it has been shown to be more effective than hydromulch and silt fences and provides a way to recyle organic wastes rather than landfilling them (Barkley 2004, Middleton and King 2002). Compost applied as a surface mulch is effective at controlling surface erosion from construction sites. Faucette et al. (2005) reported that hydroseeded plots equipped with a silt fence lost 3.5 times as much solids as plots mulched with compost in a storm event occurring immediately after seeding, and 16 times as much solids during a storm event three months after seeding.

Properly finished yard waste compost provides significant quantities of soil organic matter (SOM) but relatively few nutrients. The chemical makeup of compost depends on the feedstocks and the composting method used to produce the compost. However, Grebus et al. (1994) reported that a finished compost of grass clippings, brush, and woodchips had a cation exchange capacity of 30 meq $100g^{-1}$, a C:N ratio of 12, and a total nitrogen content of 1.8. Per gram of compost there was 0.7 mg phosphorous, 7 mg potassium, 6 mg calcium and 1.2 mg magnesium. In a review of the use of municipal solid waste compost in agriculture Hargreaves et al. (2008) reported that compost increased the pH, buffering capacity, water holding capacity and aggregate stability of soil. They also reported that while the compost was not an effective source of nitrogen, it did supply significant quantities of plant-available phosphorous, potassium, calcium, and magnesium. Roadside soils are generally of much poorer quality than agricultural soils, and it can be difficult to establish vegetation. A FHWA study in Washington, DC found that the use of composted yard waste significantly improved fescue establishment on roadsides compared to routine hydroseeding (EPA 1997). In Florida the incorporation of compost into roadside soil significantly improved establishment and persistence of bahiagrass and bermudagrass (Miller et al. 2002).

Enviromentalists and water quality experts have expressed concerns that widespread use of compost could increase problems with leaching of nitrogen and phosphorous and increase the salt and heavy metal contents of soils. Amlinger et al. (2003) reviewed the agricultural use of compost as a nitrogen source in Europe. They reported that most of the nitrogen present in yard waste compost was immobilized, with only 2.1% mineralizable nitrogen. Nitrate leaching was correspondingly low, only 8.5% of applied nitrogen for urban compost and 0% for brushwood compost. Faucette et al. (2005) reported that the loss of nitrogen and phosphorous from hydroseeded slopes was significantly greater than from slopes mulched with compost even though the compost contained more nitrogen and phosphorous. This is likely due to the water-soluble inorganic fertilizer in the hydroseed mix; most of the nitrogen and phosphorous in the compost is bound in insoluble organic matter.

Since contamination by salts and heavy metals is already a problem on many roadsides, adopting soil amendment practices that increase these contaminants could be problematic. He et al. (1992) reported that composts generally have higher levels of trace metals than agricultural soils, although yard waste compost has significantly lower levels than sewage sludge. When Glanville et al. (2004) tested nutrient loss from compost used to control erosion on highway slopes they found that the nutrient concentration was much greater in runoff from compost plots, but that significantly more precipitation was required to produce runoff from the composted plots than from the native soil plots. As a result the native soil plots produced 5 times as many soluble contaminants and 33 times as many adsorbed contaminants than the compost plots. In addition, Hargreaves et al. (2008) reported that the humic material in mature composts effectively binds trace metals, further reducing leaching. Improved vegetation cover will also decrease leaching and runoff of contaminants as erosion is reduced and contaminants are incorporated into plant tissue. Hargreaves et al. (2008) also reported that composts generally have higher salt content than agricultural soils, and that their use could increase soil salinity to phytotoxic levels. However, they noted that salt levels in compost could be controlled with the correct choice of feedstocks and composting methods. Compost incorporation did increase soil salt content on roadsides in Florida (Miller et al. 2002) but that the levels returned to normal after 3 months as the salts were absorbed by vegetation or leached by rainfall.

Biosolids

Biosolids are composed of the solid waste remaining after sewage is processed in a wastewater treatment plant. The resulting sludge is high in nitrogen, phosphorous, and organic carbon. Processed sludge is approximately 50% organic matter. The nitrogen content ranges from 2-8% and the phosphorous content from 1-4% (Epstein et al. 1976). Biosolids are much higher in these essential nutrients than is yard waste compost. In addition the level of mineralizable nitrogen in biosolids can be as high as 40% of total nitrogen, although it depends greatly on the processing method used (Epstein et al. 1978, Parker and Sommers 1983). While biosolids are also high in phosphorous, much of it may be bound in inorganic molecules and inaccessible to plants (McCoy et al. 1986). This is particularly true if aluminum or iron was used to precipitate phosphorous during sewage treatment.

Since the 1970s municipalities have been looking for environmentally and economic ways to dispose of biosolids. Many studies have shown that biosolids are similar to animal manures in their suitability as agricultural fertilizers, and that they can be used without undue risk of contaminating surface and groundwater with nitrate and phosphate as long as good agronomic practices are followed. However, there continues to be widespread concern about the use of biosolids in agriculture because they often contain more heavy metals than agricultural soil or animal manure and have a greater likelihood of containing human pathogens. There are concerns about the heavy metals accumulating in the food supply, and about exposure to dust from fields fertilized with biosolids. Hoette et al. (1995) measured the concentration of several heavy metals in biosolids from Missouri. They reported the following ranges, all in milligrams of metal per kilogram of dry biosolids: lead 40-950, zinc 170-13,000, and copper 45-5200. Mean values were 145 mg/kg for lead, 390 mg/kg for copper, and 1200 mg/kg for zinc. Roadside soils are already contaminated with these and other heavy metals. For example, Turer et al. (2001) tested soil from the shoulder of I-75 near Cincinnati, OH and reported 15-1980 mg/kg for lead, 58-1207 mg/kg for zinc, and 21-401 mg/kg for copper. Imperato et al. (2003) reported even higher levels of lead (3420 mg/kg) and zinc (2550 mg/kg) in roadside soils in Naples, Italy. While biosolids could increase the heavy metal content of roadside soils, the use of class A biosolids low in heavy metals at agronomic levels would be unlikely to cause significant increases. Furthermore, biosolids would increase the organic matter levels of the roadside soil both directly and by enhancing vegetation growth. Turer et al. (2001) reported that insoluble organic matter effectively bound heavy metals, reducing water contamination. The combination of biosolids and vegetation has also been shown to enhance degredation of petroleum hydrocarbons in soil (Dickinson and Rutherford, 2006).

Literature Cited

Ahti K., Moustafa A., Kaerwer H. (1980) Tolerance of turfgrass cultivars to salt. Proceedings of the Third International Turfgrass Research Conference 3:165-171.

Alshammary S.F. (2004) Growth response of four turfgrass species to salinity. Agricultural water management 66:97.

Amlinger F., Götz B., Dreher P., Geszti J., Weissteiner C. (2003) Nitrogen in biowaste and yard waste compost: dynamics of mobilisation and availability--a review. European Journal of Soil Biology 39:107-116.

Barkley T. (2004) Erosion Control with Recycled Materials, Public Roads, Federal Highway Administration. pp. unpaginated.

Biesboer D.D., Neid S., Darveaux B. (1998) Salt Tolerance in Short-Statured Native Grasses, Minnesota University, St Paul; Minnesota Department of Transportation.

Blomqvist G., Johansson E.-L. (1999) Airborne spreading and deposition of de-icing salt -- a case study. The Science of The Total Environment 235:161-168.

Bonos S.A., Koch M., Honig J.A., Gianfagna T., Huang B. (2009) Evaluating cool-season turfgrasses for salinity tolerance: Rutgers University scientists continue to unravel this important trait for future turfgrass cultivars. USGA Green Section Record 47:6-9.

Bowman D., Cramer G., Devitt D. (2006a) Effect of Salinity and Nitrogen Status on Nitrogen Uptake by Tall Fescue Turf. Journal of Plant Nutrition 29:1481-1490.

Bowman D., Cramer G., Devitt D. (2006b) Effect of Nitrogen Status on Salinity Tolerance of Tall Fescue Turf. Journal of Plant Nutrition 29:1491-1497.

Brod H.G., Preusse H.-U. (1980) The influence of deicing salts on soil and turf cover. Proceedings of the Third International Turfgrass Research Conference:461-468.

Brown R.N. (2008) Salt Tolerance of Native Grasses with Potential for Use oon Roadsides in New England, in: W. C. Stringer, et al. (Eds.), Managing an Ecosystem on the Edge, Clemson University, Columbia, SC. pp. 70-81.

Bryson G.M., Barker A.V. (2002) Sodium accumulation in soils and plants along Massachusetts roadsides. Communications in Soil Science and Plant Analysis 33:67-78.

Cordukes W.E., Parups E.V. (1971) Chloride uptake by Various Turfgrass Species and Cultivars. Canadian journal of plant science 51:485-490.

Dernoeden P.H., Fidanza M.A., Krouse J.M. (1998) Low Maintenance Performance of Five Festuca Species in Monostands and Mixtures. Crop Sci. 38:434-439. DOI: 10.2135/cropsci1998.0011183X003800020027x.

Dickinson S.J., Rutherford P.M. (2006) Utilization of Biosolids during the Phytoremediation of Hydrocarbon-Contaminated Soil. J. Environ. Qual. 35:982-991. DOI: 10.2134/jeq2005.0253.

Diesburg K.L., Christians N.E., Moore R., Branham B., Danneberger T.K., Reicher Z.J., Voigt T., Minner D.D., Newman R. (1997) Species for Low-Input Sustainable Turf in the U.S. Upper Midwest. Agron. J. 89:690-694. DOI: 10.2134/agronj1997.00021962008900040024x.

EPA. (1997) Innovative Uses of Compost, United States Environmental Protection Agency. pp. 8.

Epstein E., Taylor J.M., Chancy R.L. (1976) Effects of Sewage Sludge and Sludge Compost Applied to Soil on some Soil Physical and Chemical Properties1. J. Environ. Qual. 5:422-426. DOI: 10.2134/jeq1976.00472425000500040021x.

Epstein E., Keane D.B., Meisinger J.J., Legg J.O. (1978) Mineralization of Nitrogen from Sewage Sludge and Sludge Compost1. J. Environ. Qual. 7:217-221. DOI: 10.2134/jeq1978.00472425000700020013x.

Faucette L., Jordan C., Risse L., Cabrera M., Coleman D., West L. (2005) Evaluation of stormwater from compost and conventional erosion control practices in construction activities. Journal of Soil and Water Conservation 60:288.

Gibeault V.A., Hanson D., Lancaster D., Johnson E. (1977) Final research report: Cool season variety study in high salt location. California Turfgrass Culture 27:11-12.

Glanville T., Persyn R., Richard T., Laflen J., Dixon P. (2004) Environmental effects of applying composted organics to new highway embankments: Part 2. Water quality. Transactions of the American Society of Agricultural Engineers 47:471-478.
Grebus M., Watson M., Hoitink H. (1994) Biological, chemical and physical properties of composted yard trimmings as indicators of maturity and plant disease suppression. Compost Science & Utilization 2:57-71.
Greub L.J., Drolsom P.N., Rohweder D.A. (1985) Salt tolerance of grasses and legumes for roadside use. Agronomy Journal 77:76-80.
Hargreaves J.C., Adl M.S., Warman P.R. (2008) A review of the use of composted municipal solid waste in agriculture. Agriculture, Ecosystems & Environment 123:1-14.
He X.-T., Traina S.J., Logan T.J. (1992) Chemical Properties of Municipal Solid Waste Composts. J. Environ. Qual. 21:318-329. DOI: 10.2134/jeq1992.00472425002100030003x.
Hoette G.D., Brown J.R., Arnold K. (1995) Activity and Movement of Plant Nutrients and Other Trace Substances in Soils, in: U. o. M. Extension (Ed.).
Hofstra G., Hall R., Lumis G. (1979) Studies of salt-induced damage to roadside plants in Ontario. Journal of Arboriculture (UK).
Hughes T.D., Butler J.D., Sanks G.D. (1975) Salt tolerance and suitability of various grasses for saline roadsides. Journal of Environmental Quality 4:1975.
Humphreys M. (1980) Response to Salt Spray in Red Fescue and Perennial Ryegrass. Proceedings of the Fourth International Turfgrass Research Conference 4:47-54.
Humphreys M.O. (1982) The genetic basis of tolerance to salt spray in populations of Festuca rubra L. New Phytologist 91:287-296.
Hutchinson F.E., Olson B.E. (1967) The relationship of road salt applications to sodium and chloride ion levels in the soil bordering major highways. Highway Research Record 193:1-7.
Imperato M., Adamo P., Naimo D., Arienzo M., Stanzione D., Violante P. (2003) Spatial distribution of heavy metals in urban soils of Naples city (Italy). Environmental Pollution 124:247-256.
Kelsey P.D., Hootman R.G. (1992) Deicing salt dispersion and effects on vegetation along highways, in: D. I. F. M. (Ed.), Chemical De-icers and the Environment, Lewis Publishers, Inc., Chelsea, Michigan. pp. 253-282.
Kobayashi H. (2004) Tolerance of Grasses to Calcium Chloride, Magnesium Chloride and Sodium Chloride. Plant production science 7:30-35. DOI: 10.1626/pps.7.30.
Krishnan S. (2010) Physiology and Genomics of salt Tolerance in Lolium and Festuca, Environmental Science, University of Rhode Island, Kingston, RI.
Liem A.S.N., Hendriks A., Kraal H., Loenen M. (1985) Effects of de-icing salt on roadside grasses and herbs. Plant and Soil 84:299-310.
Liu H., Baldwin C., Luo H., Pessarakli M. (2009) Enhancing Turfgrass Nitrogen Use under Stresses, in: M. Pessarakli (Ed.), Handbook of Turfgrass Management and Physiology, CRC Press, Boca Raton, FL. pp. 557-601.
Marcum K. (2009a) Physiological Adaptations of Turfgrasses to Salinity Stress, Handbook of Turfgrass Management and Physiology, CRC Press.
Marcum K. (2009b) Relative Salinity Tolerance of Turfgrass Species and Cultivars, Handbook of Turfgrass Management and Physiology, CRC Press.
McCann S., Huang B. (2009) Turfgrass Drought Physiology and Irrigation Management, in: M. Pessarakli (Ed.), Handbook of Turfgrass Management and Physiology, CRC Press, Boca Raton, FL. pp. 431-445.
McCoy J.L., Sikora L.J., Weil R.R. (1986) Plant Availability of Phosphorus in Sewage Sludge Compost1. J. Environ. Qual. 15:403-409. DOI: 10.2134/jeq1986.00472425001500040016x.
McKernan D., Ross J., Tompkins D. (2001) Evaluation of grasses grown under low maintenance conditions. Int. Turfgrass Soc. Res. J 9:25-32.
Middleton L.M., King M. (2002) Innovative Use of Compost in Highway Construction, in: F. H. Administration (Ed.), Sevierville, TN.

Miller G.L., Harrell M.S., Kidder G., Black R. (2002) Composted Materials on Florida Roadsides, in: U. o. F. I. Extension (Ed.), Gainesville, FL.

Mintenko A., Smith R. (1999) Evaluation of native grasses for low-maintenance turf. Golf Course Management 67:60-63.

Parker C.F., Sommers L.E. (1983) Mineralization of Nitrogen in Sewage Sludges. J. Environ. Qual. 12:150-156. DOI: 10.2134/jeq1983.00472425001200010028x.

Patenaude R.W. (1989) Investigation of Road Salt Content of Soil, Water, and Vegetation Adjacent to Highways in Wisconsin, in: W. D. o. Transportation (Ed.).

Prior G.A., Berthouex P.M. (1967) A study of salt pollution of soil by highway salting. Highway Research Record 193:8-21.

Roberts E.C., Zybura E.L. (1967) Effect of sodium chloride on grasses for roadside use. Highway Research Record 193:35-42.

Robins J.G., Bushman B.S., Waldron B.L., Johnson P.G. (2009) Variation within Poa Germplasm for Salinity Tolerance. HortScience 44:1517-1521.

Rose-Fricker C., Wipff J. (2001) Breeding for salt tolerance in cool-season turfgrasses. Int. Turfgrass Soc. Res. J 9:206-212.

Salt_Institute. (2004) Highway Salt and Our Environment, Alexandria, VA. pp. 28.

Torello W., Symington A. (1984) Screening of turfgrass species and cultivars for NaCl tolerance. Plant and Soil 82:155-161.

Turer D., Maynard J., Sansalone J. (2001) Heavy Metal Contamination in Soils of Urban Highways Comparison Between Runoff and Soil Concentrations at Cincinnati, Ohio. Water, Air and Soil Pollution 132:293.

Wakefield R.C., Bell R.S., Jagschitz J.A., Clapham A.J., Dore A.T., Nielsen A.P., Laskey B.C. (1974) Establishment of Roadside Vegetation in Rhode Island, Rhode Island Agricultural Experiment Station Bulletin.

Warrence N., Bauder J., Pearson K. (2002) Basics of salinity and sodicity effects on soil physical properties, Montana State University Bozeman.

Westing A. (1969) Plants and salt in the roadside environment. Phytopathology 59:1174-1180.

Chapter 1: What plant species survive and thrive on the mowed roadside in Rhode Island?

Introduction

Grasslands and open shrublands are a traditional and culturally important component of the landscape in coastal New England. However, these open lands were primarily a result of deforestation and agricultural activities; they did not exist on a significant scale prior to European settlement (Foster and Motzkin 2003). As agriculture declined during the Twentieth Century, grasslands were replaced by forests and urban development, and many grassland species have become rare (Neill 2007). Lawns and mowed roadsides have become the predominant grasslands. In 1995 there were an estimated 805,000 acres of residential lawns in southern New England (Vinlove and Torla 1995). The area in lawns has undoubtedly increased in the past 15 years, and this estimate does not include parks, golf courses, or other managed turf areas. In addition, there is an estimated 4 acres of mowed roadside for every mile of limited access highway in southern New England (K. Berger, University of Rhode Island, personal communication). Mowed roadsides have significant potential as preservation sites for native grassland and shrubland plant species because they receive no fertilizer, pesticides, or irrigation and experience minimal foot traffic. National policy favors the encouragement of native species on roadsides, while safety concerns justify the expense of sufficient mowing to prevent the land from reverting to forest.

The same turfgrasses used for lawns are used to seed roadsides (RIDOT 2004) and it has been generally assumed that roadsides are similar to lawns in being almost devoid of ecological value (Foreman et al. 2003). However, the roadside is a harsher environment than most lawns, and receives less maintenance. Thus the survival of cultivated turfgrasses on roadsides may be significantly different than for lawns; one objective of this study was to determine what species were actually present in roadside grasslands.

Field Site Description

We surveyed 7 randomly-selected sites alongside limited-access highways in Rhode Island. The location of each site is shown in figure 1; GPS coordinates are provided in table 1. The survey area at each site was defined as a rectangle with a width of 10 m running perpendicular from the edge of the pavement and a length of 300 m running parallel to the road. All of the roads are classified as urban/suburban and have similar traffic levels. No sites were chosen in the more urban areas of Providence because those roads either lack vegetated shoulders and medians or have steeply sloping shoulders which cannot be safely accessed without blocking traffic. The initial date of vegetation establishment for each site is listed in table 1; all sites have been reseeded repeatedly but none had been seeded within the previous 5 years. The right-of-ways for all seven sites are maintained by RIDOT crews. Vegetation is mowed with large tractor-mounted rotary mowers every 3-4 weeks from late June through October. Clippings are not removed. Plantings

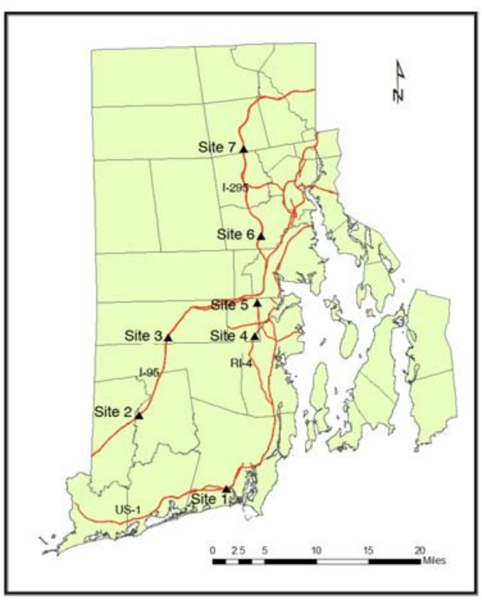

Figure 2 Location of survey sites. All sites are along urban/suburban limited access highways and are maintained by the Rhode Island Department of Transportation.

Site	Location	GPS Coordinates	Initial Seeding
1	US-1 median, Matunuck	41°23’N, 71°32’W	1950s
2	I-95 shoulder, Hopkinton	41°29’N, 71°42’W	1953
3	I-95 median, West Greenwich	41°36’N, 71°39’W	1969
4	RI-4 shoulder, North Kingstown	41°36’N, 71°29’W	1988
5	RI-4 median, East Greenwich	41°39’N, 71°29’W	1972
6	I-295 median, Cranston	41°45’N, 71°28’W	1968
7	I-295 median, North Providence	41°52’N, 71°30’W	1975

Table 1 Locations and initial seeding dates for survey sites. Dates are from Anderson (2009).

receive no other inputs or maintenance. Sanding and salting of the roads for ice control is done by RIDOT crews; a standard application rate is used state-wide. However, salt exposure may vary by location as inland areas receive more precipitation as snow or freezing rain than coastal areas do. Salt levels in runoff and soil water are quite high during the winter but decrease rapidly in March and April to levels unlikely to harm any but the most sensitive plants.

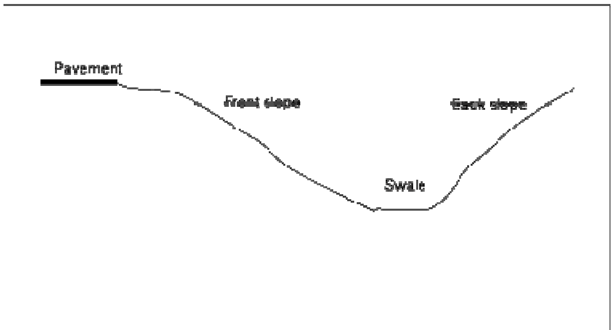

Figure 3 Cross-section of a standard engineered roadside showing location of front slope, swale, and back slope.

Roadsides are engineered environments; the basic terrain is a front slope stretching down from the pavement to a drainage swale and a backslope stretching up from the swale (fig. 2) However, the specific terrain of each site was shaped by the geology of the larger area. Sites 2 and 4 are located on the shoulder, with a paved break-down lane separating the vegetation from the travel lane. The other sites are located in medians. The front slope of site 1 is nearly flat and the swale runs at an angle to the pavement such that the eastern end of the survey site has no front slope and the western end is mostly front slope. The south-facing back slope is quite steep at the eastern end and decreases to the west. Site 2 is the driest site, with very sandy soil. The front slope is wide and nearly flat, with the shallow swale located more than 10 m from the pavement. Site 3 is entirely on the front slope which declines gradually from the pavement to a swale 15-20 m away. Site 4 most resembles the basic roadside, with a gentle front slope leading to a swale approximately 5 m from the pavement and a steep mowed backslope. Site 5 is a 10-15 m-wide median on a north-facing slope ending in a wetland; it has 2 front slopes rather than a back slope. Site 6 is similar to site 5 but the cross-section of the median is nearly flat, and the site is more uniform than the others. Site 7 is similar to site 3.

Methods

Surveying

Surveying was done using a one meter square quadrant divided into 100 sections each 10 cm x 10 cm (figure 3). Each site was divided into 3.3 m wide zones running parallel to the pavement. These zones were based on the pattern of salt spray deposition, which is heaviest within 3.3 m of the pavement and declines to near zero beyond 6.6 m (Bryson and Barker 2002). The initial quadrant location was selected randomly within each zone. Subsequent quadrants were spaced 50 m apart. Each site had three zones except site 5, which had only two as the entire median was within 7 m of pavement. Each species present within the quadrant square was identified and recorded. Frequency and relative cover were combined into a single value estimated by counting the number of sections that contained a particular species. This method permitted us to compensate for the large differences in plant size among species and the layers of overlapping vegetation. Each site was surveyed on a single date between June 25 and August 15, 2008.

Figure 4 Counting species in a quadrant

Species Identification

All plants were identified to genus, and to species and subspecies wherever possible. Phillips (1962) was used to identify mowed grasses based on vegetative characteristics. The Flora of North America volumes 22-25 (FNA 1993) and Gleason and Cronquist (1972) were used to identify plants for which flowers were available. Grasses, sedges and rushes that could not be identified beyond the genus without flowers or fruit were transplanted to the research farm and permitted to flower. We also returned to the survey sites in June 2009 before the first mowing to confirm species identifications. Scientific names are based on the Flora of North America; determination of native status is based on the PLANTS database (USDA-NRCS 2009).

Data Analysis

Each site was represented by five or six quadrants within each zone. Homogeneity among sites was determined for each zone using one-way ANOVA with species number as the independent variable. The influence of salt zone and topographic zone on the number of species at each site was examined as a linear model with one interaction effect using SAS. The linear model function is robust to unbalanced designs.

Results

A total of 80 graminoid and forb species were identified in the quadrants (table 2, at end of chapter). Thirty-five species were clearly native, 32 were introduced, and the remaining 13 were classified as cryptic. Cryptic species are those of indeterminate origin and included ones which may be native but may also have been deliberately planted, and ones which could only be identified to genus, with the genus containing both native and introduced species. Rhode Island bentgrass was classified as cryptic because the populations found on roadsides in Rhode Island appear to be genetically distinct from the cultivated colonial bentgrass (K. Amundson, USDA-ARS, personal communication). Species number per site ranged from 27 to 39. Topography had a significant effect on both the species richness of the site and the distribution of species within the site. The upper front slope had the fewest species, while the swale itself had the most (table 3). Both total species number and the percent native species were significantly correlated with the topographic diversity of the site; r values were 0.39 and 0.64 respectively. We also tested the relationship between species diversity and salt exposure. When the data was pooled across all sites the mean number of species per quadrant increased as salt levels decreased, from 6.9 in zone 1 to 9.1 in zone 3. However, when the full model including salt zone, topographic zone and the interaction was analyzed only the topographic zone effect was significant.

Topographic zone	Number of quadrants	Average number of species	Standard Deviation
Upper front slope	33	6.2	2.4
Lower front slope	18	6.7	2.8
Flat	22	8.4	2.1
Swale	28	9.4	3.4
Back Slope	13	9.1	3.6

Table 3 Variation in species number among topographic zones. The upper front slope is within 3 m of the pavement, while the lower front slope is >3 m from the pavement. Species numbers were averaged across all sites with a particular zone. Differences are significant at at P=0.01 according to a nonparametric one-way ANOVA.

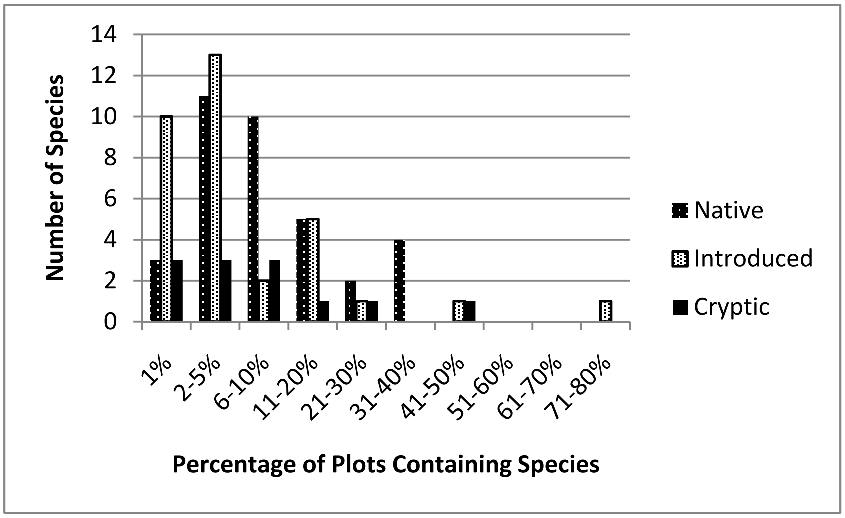

Figure 4 Frequency distribution for the abundance of native, introduced and cryptic species across all seven sites, measured as percent of total quadrant sections in which a species was found.

Most of the introduced species occurred in ≤ 5% of the total quadrant sections, while most of the native species occurred in 2-10% of the sections (fig. 4). Only 3 species occurred in more than 40% of the sections. The ten most frequently occurring species for each site are shown in table 4. Smooth crabgrass was the most common species overall as well as at five of the sites; coverage exceeded 90% in many quadrants on the upper front slope. Sheep sorrel and Rhode Island bentgrass ranked second and third overall. Both species are very tolerant of drought and infertile, acidic soil, which permits them to thrive on roadsides. Large crabgrass and Blue toadflax were found in most plots within zone 1, but were rare in the other zones. Like smooth crabgrass these plants are annuals, and can avoid stresses from salt and drought as dormant seeds. Oxalis occurred at all sites as scattered plants on slopes outside the high salt zone. Other species were common at one or two sites but rare or absent at other sites.

Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Smooth crabgrass^{i}	Smooth crabgrass^{i}	RI bentgrass^{c}	Smooth crabgrass^{i}	Smooth crabgrass^{i}	Red fescue^{c}	Smooth crabgrass^{i}
RI bentgrass^{c}	Toad flax	Smooth crabgrass^{i}	Toad flax	Toad flax	Sheep sorrel^{i}	Prairie 3-awn
Hairy paspalum	RI bentgrass^{c}	Sheep sorrel^{i}	Path rush	Tall fescue^{i}	Kentucky bluegrass^{c}	RI bentgrass^{c}
Red fescue	Quackgrass^{i}	Few-flowered panicgrass	RI bentgrass^{c}	Red fescue^{c}	Quackgrass^{i}	Sheep sorrel^{i}
Sheep sorrel^{i}	Pennsylvania sedge	Yarrow^{cc}	Red fescue^{c}	Path rush	Smooth crabgrass^{i}	Purple lovegrass

Table 4 Five most abundant species at each site based on the number of quadrant sections in which each species occurred. Introduced species are indicated with a superscript i, and cryptic species with a superscript c.

Only six introduced species exceeded 25% coverage of the quadrants in which they were found. Smooth crabgrass averaged 53.6% cover across 85 quadrants. Sheep sorrel was the most frequently encountered introduced perennial species, averaging 33% coverage across 56 quadrants. Cat's ear and narrow-leaf plantain were the second and third most frequently encountered, but both species had relatively low density. Quackgrass and tall fescue had greater coverage but occurred in fewer quadrants. Perennial ryegrass and birdsfoot trefoil were expected to be among the most common introduced perennials, as they are components of the RIDOT seed mixes (RIDOT 2004). However, perennial ryegrass was found at only one site, where it covered 3% of a single quadrant. Bridsfoot trefoil was present in eight quadrants scattered across five sites, and averaged only 13.1% coverage. The number of native species exceeded the number of introduced species at all sites except #6 (fig. 5).

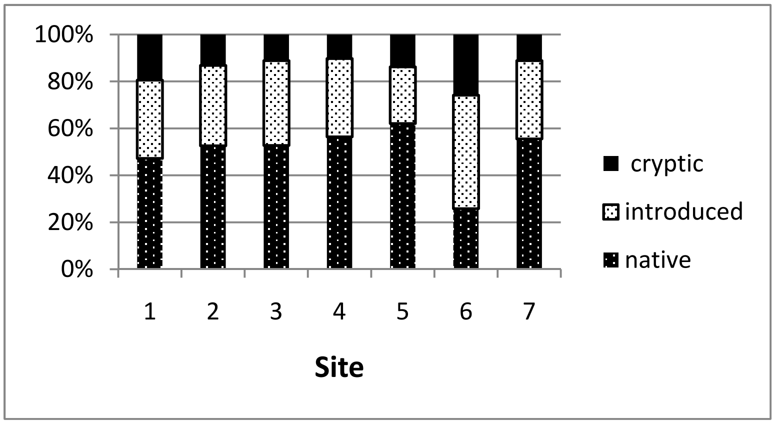

Figure 5 Relative abundance of native, introduced, and cryptic species at each site.

With the exception of site #6 the percentage of native species averaged 54% and ranged from 47-62%. The most common native perennials were white-haired panic grass, path rush, and hairy paspalum. Other perennial species present in more than 10% of the plots were little bluestem, purple lovegrass, switchgrass, oxalis, and roundseed panic grass. The most common native annuals were blue toadflax, large crabgrass, and prairie 3-awn. Six native species exceeded 25% coverage within the quadrants in which they occurred: prairie 3-awn, fescue sedge, Pennsylvania sedge, path rush, toad flax, and six-weeks fescue.

The most common cryptic species were Rhode Island bentgrass, red fescue, and Kentucky bluegrass, all of which have been deliberately planted on roadsides. Kentucky bluegrass was found in 14 quadrants, 10 of which were at site #6. Creeping red fescue was present at four sites, in a total of 35 quadrants. Rhode Island bentgrass, which has not been deliberately seeded in over 35 years, has shown the best persistence of any of the seeded grasses. It was found in 49 quadrants and at all sites except #6. None of the other cryptic species were present in more than 10% of the quadrants. Four species exceeded 25% coverage: Kentucky bluegrass, red fescue, Rhode Island bentgrass, and creeping bentgrass. Creeping bentgrass was found in only 4 quadrants, but it dominated those quadrants.

Discussion

We began the vegetation survey expecting to find primarily the species seeded by RIDOT (red fescue, Kentucky bluegrass, perennial ryegrass, and bird's foot trefoil) along with common weed species such as crabgrass, quackgrass, and sheeps sorrel. Instead we found a diverse collection of native and naturalized grassland plants and scant evidence of RIDOT's seeding efforts. Our results supported the hypothesis that roadside grasslands are serving as refugia for rare grassland plant species. Among the 35 native species were five grasses that are considered to be of special concern in Rhode Island or neighboring states. Philadelphia witchgrass and hairy paspalum (*P. setaceum* var. *psammophilum*) are listed in Rhode Island (Gould et al. 1998). Only one population of Philadelphia witchgrass and two of hairy paspalum are listed in the Rhode Island Natural Heritage Program database (Enser 2007). However, we found Philadelphia witchgrass at two of our sites and hairy paspalum at four sites. Round-seeded panic grass is listed in Connecticut and white-haired panic grass is listed in Massachusetts (USDA-NRCS 2009). We found these species at five and six sites, respectively. Old pasture bluegrass is listed in Rhode Island and Massachusetts (USDA-NRCS 2009, Gould et al. 1998). As of this writing, none of these species are commercially available in the seed trade. Seed is not available even for native species considered ubiquitous such as prairie three-awn, purple lovegrass, and poverty oatgrass. The native seed mix used on roadsides in Rhode Island contains little bluestem, switchgrass, and hard fescue, in addition to perennial ryegrass (RIDOT 2004). This mix had not been used on any of the sites surveyed. However, hard fescue was common at three sites, switchgrass was present at five sites, and little bluestem was present at five sites and common at one site. Clearly these grasses are capable of establishing and persisting on mowed roadsides.

Figure 6 Image of site 5 showing zoning of vegetation. The picture was taken in mid-July; the crabgrass closest to the pavement is still green while perennial grasses further down the slope are dormant.

We had expected that the distance from the pavement would have a significant effect on the species richness since salt levels have been shown to be highest within 3 m of the pavement and to decrease with increased distance from the pavement (Bryson and Barker 2002). However, our results suggest that differences in species numbers are primarily affected by site topography. At sites 3, 5, and 7 salt zones and topographic zones corresponded and clear zoning of vegetation was visible (figure 6). Salt zone 1 was upper front slope and was dominated by smooth crabgrass and blue toadflax at all three sites. Zone 2 was lower front slope and contained a mix of grasses and forbs. Zone 3 was the swale; path rush and various sedges were the dominant species. Significant differences between salt zones were not observed at the other four sites. Site 6 was essentially flat and had uniform vegetation across the entire site. Sites 1, 2, and 4 had more variable topography, with back slopes and swales which did not run parallel to the pavement. These results suggest that moisture and perhaps nutrient levels are at least as important as salt exposure in determining plant survival on the roadsides. Other research has found that increasing the organic matter and nutrient levels in roadside soils dramatically improves vegetation survival on the shoulder even in the high salt zone (Wakefield et al. 1974, chapter 2 this report)

Introduced and invasive species are perceived to be a significant problem on mowed roadsides (Forman et al. 2003, Harper-Lore 1999) because they may spread from roadsides to other sites, and because they decrease the regional uniqueness of roadsides. Approximately half the species present in our survey plots are non-natives, as is common for upland grasslands in New England (Neill 2007). However, the majority of introduced species were rare, occurring in fewer than 5% of the quadrants (Fig. 4). The flora of the northeastern United States has a higher proportion of non-native grass species than any other region, and non-natives are particularly common among the 'disturbance specialists' that colonize grasslands (Von Holle and Motzkin 2007, Angelo and Boufford 2010). The most abundant introduced species were smooth crabgrass, sheep sorrel, quackgrass, cat's ear, and tall fescue. All of these have been widely naturalized since before 1850 (Beck 1868) and may be as natural a part of the New England upland grassland community as the native species which adapted to take advantage of agricultural grasslands in historical times (Foster and Motzkin 2003).

The vegetation community at site #6 was distinct from the other six sites. Only 26% of the species at site #6 were native, while 48% were introduced (Fig. 5). The most common species at this site were red fescue, sheep sorrel, Kentucky bluegrass, and quackgrass (Table 4). Smooth crabgrass ranked 5th and was found in significantly fewer quadrant sections than at the other sites. A number of introduced species were significantly more common at site #6, or were found only at that site. These include fall dandelion, narrow-leaf plantain, birds-foot trefoil, ragweed, green foxtail, dandelion, smooth bedstraw, yellow foxtail, wild carrot, lambsquarter, and yellow nutsedge. Most of these are common weeds of disturbed sites. The most common native species at site #6, prairie 3-awn and large crabgrass, are also annuals common on disturbed sites. The prevalence of red fescue and Kentucky bluegrass and the absence of Rhode Island bentgrass and most perennial native grass species at site #6 may be a result of higher soil moisture and nutrient retention at this site than at the other sites surveyed. The slope-and-swale topography of the other sites was absent at site #6, which was essentially flat. However, the large number of annual weeds suggests that the site may have been significantly disturbed more recently than the other sites. This is further supported by the abundance of quackgrass along the pavement edge as quackgrass is a major component of the hay bales used for erosion control during construction and often sprouts from the bales (figure 7).

Figure 7 Quackgrass and other agricultural weeds sprouting from bales used to prevent sediment from entering a drain.

The Federal Highway Authority no longer considers soil to be a reliable source of native plant seeds for revegetation of roadsides, and recommends deliberate planting of native species (Harper-Lore 1999). However, our findings suggest that the soil seedbank is still a viable source for native species in Rhode Island, and that wind dispersal is sufficient to bring seed of many native species to the roadside (figure 8). This is significant as wide-spread use of native grass and forb seed on roadsides is cost-prohibitive, and seed is unavailable for many southern New England species and ecotypes. It appears that cool-season grasses, particularly perennial ryegrass, are effective as non-persistent nurse species on the roadside, preventing soil erosion while the native vegetation re-establishes. At present frequent mowing favors grasses over native forbs, but many native forb species are present in areas missed by mowers and would spread if mowing frequency were reduced.

Figure 8 Naturally-occuring purple lovegrass was abundant at site 7 in August.

Recommendations for Practice

Roadsides are an important habitat for native plants, especially low-growing grassland species which may be out-competed by species such as little bluestem and switchgrass on the better soils of the conservation grasslands. Habitat value could be improved through the following practices:

- Reduce mowing frequency to only 2x/year to increase the establishment of forbs while preventing the establishment of woody invasive species

- Discontinue the use of hay bales for erosion control as they spread a number of introduced species, including quackgrass which aggressively out-competes native species under roadside conditions.
- Re-formulate native seed mixes to include species such as hairy paspalum, poverty oatgrass, purple lovegrass, and the various species of panic grass.
- Develop seed sources for Rhode Island bentgrass and restore it to the standard seed mixes.
- Regard the standard seed mixes as only temporary vegetation (lasting less than 5 years) and plan for succession by slower-growing native species.

Literature Cited

Anderson, S. 2009. The roads of metro Boston. Available online at http://www.bostonroads.com. Accessed December 6, 2010.

Angelo, R. and D. Boufford. 2010. Atlas of the Flora of New England. Available online at http://neatlas.org. Accessed December 6, 2010.

Beck, L.C. 1868. Botany of the United States north of Virginia. Harper and Brothers, New York, NY. 480 pp.

Bryson, G.M., and A.V. Barker. 2002: Sodium accumulation in soils and plants along Massachusetts roadsides. Communications in Soil Science and Plant Analysis 33:67-78.

Enser, R.W. 2007. Rare native plants of Rhode Island.Available online at http://www.rinhs.org/wp-content/uploads/ri_rare_plants_2007.pdf. Accessed December 6, 2010.

Flora of North America Editorial Committee (FNA), eds. 1993+. Flora of North America North of Mexico. 12+ vols. New York, NY and Oxford, UK.

Forman, R.T.T., D. Sperling, J.A. Bissonette, A.P. Clevenger, C.D. Cutshall, V.H. Dale, L. Fahrig, R. France, C.R. Goldman, K. Heanue, J. A. Jones, F.J. Swanson, T. Turrentine and T.C. Winter. 2003. Road Ecology Science and Solutions. Island Press, Washington. 481 pp.

Foster D.R. and G. Motzkin. 2003 Interpreting and conserving the openland habitats of coastal New England: insights from landscape history. Forest Ecology and Management 185:127-150.

Gleason, H.A. and A. Cronquist. 1991. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. New York Botanical Garden, Bronx, NY. 993 pp.

Gould, L.L., R.W. Enser, R.E. Champlin, and I.H. Stuckey. 1998. Vascular Flora of Rhode Island. Rhode Island Natural History Survey, Kingston, RI. 265 pp.

Graves, C.B., E.H. Eames, C.H. Bissell, L. Andrews, E.B. Harger, and C.A. Weatherby. 1910. Catalogue of the Flowering Plants and Ferns of Connecticut Growing Without Cultivation. State Geological and Natural History Survey, Hartford, CT. 569 pp.

Harper-Lore, B. L.,ed.1999. Roadside Use of Native Plants. U. S. Department of Transportation Federal Highway Administration, Washington, DC. 665 pp.

Neill C. 2007. The challenge of managing disturbance regimes, terrestrial communities and rare species in a suburbanizing region: The northeastern US coastal sandplain. Biological Conservation 136:1-3.

Phillips, C.E. 1962. Some Grasses of the Northeast. University of Delaware AES Field Manual No. 2. Newark, DE. 77 pp.

Rhode Island Department of Transportation (RIDOT). 2004: Standard specifications for road and bridge construction. Rhode Island Department of Transportation, Providence, Rhode Island.

USDA-NRCS. 2009. The PLANTS Database. National Plant Data Center. Available online at http://www.plants.gov. Accessed November 13, 2009.

Vinlove F. and R. Torla. 1994. Comparative estimations of US home lawn area. Journal of Turfgrass Management 1:83-97.

Von Holle B., and G. Motzkin. 2007. Historical land use and environmental determinants of nonnative plant distribution in coastal southern New England. Biological Conservation 136:33-43.

Wakefield, R.C., R.S. Bell, J.A. Jagschitz, A.J. Clapham, A.T. Dore, A.P. Nielsen, and B.C. Laskey. 1974. Establishment of Roadside Vegetation in Rhode Island. RIAES Bulletin 416. Kingston, RI. 36 pp.

Table 2. Species identified in roadside grasslands with their status and occurrence data.

Species (scientific name)	Species (common name)	Status	# sites present	% total sections	Mean Coverage
Achillea millefolium L.	Yarrow	cryptic	4	6.1	23.4
Agrostis capillaris L.	Rhode Island bentgrass	cryptic	6	43.0	45.2
Agrostis perennans (Walter) Tuck.	Autumn bentgrass	native	3	6.1	13.7
Agrostis stolonifera L.	Creeping bentgrass	cryptic	2	3.5	35.8
Aira caryophyllea L.	Silver hairgrass	introduced	6	12.3	25.0
Ambrosia artemisifolia L.	Ragweed	cryptic	1	3.5	4.8
Andropogon virginicus L.	Broomsedge	native	4	8.8	14.7
Anthoxanthum odoratum L.	Sweet vernal grass	introduced	2	4.4	15.0
Aristida oligantha Michx.	Prairie 3-awn	native	3	21.1	36.0
Artemisia vulgaris L.	Mugwort	native	1	0.9	4.0
Carex festucacea Schkuhr ex Willd.	Fescue sedge	native	3	8.8	24.6
Carex pensylvanica Lam.	Pennsylvania sedge	native	3	5.3	35.7
Carex swanii (Fernald) Mack.	Swan's sedge	native	2	2.6	8.3
Carex vulpinoidea Michx.	Fox sedge	native	1	0.9	10.0
*Centaurea spp.*L.	Batchelor's buttons	cultivated	1	0.9	29.0
Centaurea stoebe L.	Spotted knapweed	introduced	1	2.6	24.0
Cerastium fontanum Baumg.	Mouse-ear chickweed	introduced	3	3.5	6.3
Chamaesyce maculate (L.) Small	Spotted spurge	introduced	2	1.8	1.0
Chenopodium album L.	Lambsquarters	cryptic	1	0.9	1.0
Conyza canadensis (L.) Cronquist	Horseweed	native	4	6.1	3.7
Cruciata laevipes	Smooth bedstraw	introduced	1	0.9	4.0
Cyperus esculentus L.	Yellow nutsedge	introduced	1	1.8	1.5
Cyperus lupulinus (Spreng.) Marcks	Hop sedge	native	1	0.9	2.0
Dactylis glomerata L.	Orchard grass	introduced	1	0.9	13.0
Danthonia spicata (L.) P. Beauv. ex Roem. & Schult.	Poverty oatgrass	native	4	8.8	16.1
Daucus carota L.	Wild carrot	introduced	1	0.9	2.0
Dichanthelium acuminatum (Sw.) Gould & C.A. Clark	White-haired panic grass	native	6	33.3	9.9
Dichanthelium oligosanthes (Schult.) Gould	Few-flowered panicgrass	native	4	7.9	18.0
Dichanthelium sphaerocarpon (Elliot) Gould	Roundseed panicgrass	native	5	15.8	20.7
Digitaria ischaemum (Schreb.) Schreb. ex Muhl.	Smooth crab	introduced	7	74.6	53.6
Digitaria sanguinalis (L.) Scop.	Large crab	native	7	36.0	8.9
Elymus repens (L.) Gould	Quackgrass	introduced	5	16.7	32.2
Eragrostis spectabilis (Pursh) Steud.	Purple lovegrass	native	4	19.3	14.7
Festuca arundinacea Schreb.	Tall fescue	introduced	4	8.8	40.0
Festuca rubra L.	Red fescue	cryptic	4	30.7	38.1
Festuca trachyphylla (Hack.) Krajina	Hard fescue	native	3	9.6	13.5
Hieraceum L. spp.	Hawkweed	cryptic	5	6.1	2.7
Holcus lanatus L.	Velvet grass	introduced	1	2.6	8.7

Hypericum gentianoides (L.) Britton, Sterns & Poggenb.	Orange grass	native	3	4.4	19.4
Hypericum L. spp.	St. Johnswort	cryptic	1	0.9	1.0
Hypochaeris radicata L.	Cat's ear	introduced	5	24.6	15.0
Juncus bufonius L.	Toad rush	native	3	4.4	29.2
Juncus tenuis Willd.	Path rush	native	5	31.6	22.9
Leontodon autumnalis L.	Fall dandelion	introduced	2	14.0	13.8
Lepidium densiflorum Schrad.	Peppergrass	native	2	3.5	5.0
Linaria vulgaris Mill.	Butter and eggs	introduced	2	1.8	4.0
Lolium perenne L.	Perennial ryegrass	introduced	1	0.9	3.0
Lotus corniculatus L.	Birds-foot trefoil	introduced	5	7.0	13.1
Lythrum salicaria L.	Purple loosestrife	introduced	1	1.8	11.0
Mollugo verticillata L.	Carpet weed	native	3	6.1	5.7
Nuttallanthus canadensis(L.) D.A. Sutton	Toad flax	native	7	36.8	39.8
Oxalis stricta L.	Oxalis	native	7	12.3	1.4
Panicum philadelphicum Bernh. ex Trin.	Philadelphia witchgrass	native	2	2.6	4.0
Panicum virgatum L.	Switchgrass	native	5	17.5	8.6
Paspalum setaceum Michx. *var. psammophilum* (Nash) D. Banks	Hairy paspalum	native	4	22.8	20.2
Plantago aristata Michx.	Hairy plantain	native	2	4.4	7.4
Plantago lanceolata L.	Narrow-leaf plantain	introduced	6	18.4	12.2
Poa pratensis L.	Kentucky bluegrass	cryptic	4	12.3	29.1
Poa saltuensis Fernald & Wiegand	Oldpasture bluegrass	native	1	2.6	4.7
Polygonum pensylvanicum L.	Prostrate knotweed	native	2	2.6	3.3
Polygonum persicaria L.	Lady's thumb	introduced	1	2.6	3.0
Potentilla canadensis L.	Dwarf cinquefoil	native	3	8.8	9.1
Rumex acetosella L.	Sheep sorrel	introduced	7	49.1	33.1
Schizachyrium scoparium (Michx.) Nash	Little bluestem	native	5	19.3	16.6
Scleranthus annuus L.	Annual knawel	introduced	1	0.9	20.0
Securigera varia (L.) Lassen	Crown vetch	introduced	1	0.9	2.0
Setaria pumila (Poir.) Roem. & Schult.	Yellow foxtail	introduced	1	0.9	4.0
Setaria viridis (L.) P. Beauv.	Green foxtail	introduced	1	3.5	3.5
Solidago L. spp.	Goldenrod	native	3	4.4	7.8
species not known	Mosses and lichens	cryptic	4	6.1	42.0
Spergularia rubra (L.) J. Presl & C. Presl	Sand spurry	introduced	5	16.7	18.9
Sporobolus vaginiflorus (Torr. ex A. Gray) Alph. Wood	Poverty dropseed	native	3	9.6	18.3
Taraxacum officinale F. H. Wigg	Dandelion	cryptic	2	2.6	1.7
Trifolium arvense L.	Rabbit's foot clover	introduced	1	0.9	14.0
Trifolium pretense L.	Red clover	introduced	2	1.8	3.5
Trifolium repens L.	White clover	introduced	2	1.8	2.0
Veronica L. spp.	Speedwell	cryptic	1	0.9	2.0
Vicia sativa L.	Common vetch	introduced	1	2.6	8.7
Vulpia myuros(L.) C.C. Gmel.	Rat-tail fescue	introduced	1	0.9	4.0
Vulpia octoflora (Walter) Rydb.	Six-weeks fescue	native	1	2.6	42.3

Chapter 2: Use of soil amendments to improve turfgrass survival

Introduction

Since the development of the first parkways in the early 20th century mowed turf grasses have been preferred vegetation for use on the shoulders and medians of limited access roadways in the United States (FHWA, 2003). In addition to their aesthetic qualities, these grasses prevent soil erosion, trap dust, and filter storm water while not posing a hazard to errant vehicles. However, the roadside is a hostile environment, and turfgrasses struggle to survive, particularly within 5 m of the pavement. Heat reflected from the pavement and the constant wind from passing vehicles creates a droughty microclimate (Forman, 2003). The pavement is sloped to drain water to the vegetated shoulder or median, which is itself engineered to rapidly drain water into the swale leading either to storm drains or to ponds (NHI, 2009). In regions with cold winters salt (sodium chloride) is used to keep the pavement free of snow and ice; the bulk of the salt accumulates within 7 m of the pavement (Bryson, 2002; Hutchinson, 1967; Prior, 1967). The soil remaining in the highway right-of-way after construction is generally of poor quality, and heavy leaching, salt, and other chemicals from the pavement further degrade the soil. As a result, the first 5 m of the vegetated shoulder and median are often bare of vegetation or dominated by annual weeds such as crabgrass which leave the soil vulnerable to erosion from heavy fall and spring rains.

To improve the survival of perennial vegetation on the roadside it is necessary to identify the specific stresses limiting vegetation growth, and then to either identify plants which can tolerate those stresses or identify ways to ameliorate the stresses while still maintaining safety. This study was designed to evaluate the effects of improved genetics, salt tolerance, and organic matter amendments on perennial grass survival along two highways in Rhode Island. It was initiated in response to widespread erosion and slope failure along limited access highways following two unusually snowy winters and extensive loss of perennial turf cover.

This study had two objectives. The first was to determine whether improved turfgrass varieties selected for tolerance to either low-input or saline conditions were superior to common creeping red fescue under roadside conditions. Newer improved varieties are generally not used on roadsides because seed is more expensive than for common types or old varieties. The second objective was to determine whether amendment of existing roadside soil with organic matter would improve long-term persistence of perennial grasses. Incorporation of organic matter at planting is more feasible than yearly fertilization for highway departments, but there was concern that the increased organic matter would result in soil salinization and turf damage.

Materials and Methods

Plant Materials: Twenty-two turfgrass entries were included in this study. Twenty improved varieties and one seed mixture were selected by industry breeders (Table 1); these varieties had been developed for salt tolerance, adaptation to low-input environments, or both. The varieties represented seven species: red fescue, alkaligrass, Kentucky bluegrass, tufted hairgrass, perennial ryegrass, Idaho bentgrass, and tall fescue. Common creeping red fescue was included as a standard variety because it is the primary component of the seed mixes currently used by RIDOT (RIDOT, 2004).

Table 1 Turfgrass varieties used in roadside trials.

Variety	Species	Scientific name
Diva	Kentucky bluegrass	*Poa pratensis* L.
Pure Gold	Tall Fescue	*Festuca arundinacea* Schreb.
Epic	Red Fescue	*Festuca rubra* L.
7.0929	Red Fescue	*Festuca rubra* L.
Tarheel II	Tall Fescue	*Festuca arundinacea* Schreb.
GolfStar	Bentgrass	*Agrostis idahoensis* Nash
Salinas	Perennial Ryegrass	*Lolium perenne* L.
Cindy Lou	Red Fescue	*Festuca rubra* L.
7.0858	Alkaligrass	*Puccinellia distans* (Jacq.) Parl.
IS-TF154	Tall Fescue	*Festuca arundinacea* Schreb.
SeaLink	Red Fescue	*Festuca rubra* L.
Fiesta 3	Perennial Ryegrass	*Lolium perenne* L.
Common Creeping	Red Fescue	*Festuca rubra* L.
Pro-OC-1	Tufted Hairgrass	*Deschampsia cespitosa* (L.) P. Beauv.
7.0013	Alkaligrass	*Puccinellia distans* (Jacq.) Parl.
7.0855	Alkaligrass	*Puccinellia distans* (Jacq.) Parl.
Blade Runner	Tall Fescue	*Festuca arundinacea* Schreb.
All*Star 2	Perennial ryegrass	*Lolium perenne* L.
Bingo	Tall Fescue	*Festuca arundinacea* Schreb.
Fults	Alkaligrass	*Puccinellia distans* (Jacq.) Parl.
7.0856	Alkaligrass	*Puccinellia distans* (Jacq.) Parl.
Experimental DOT mix	20% J-5 Chewings fescue	*Festuca rubra* L. ssp. *fallax* (Thuill.) Nyman
	20% Fults Alkali grass	*Puccinellia distans* (Jacq.) Parl.
	10% GolfStar Idaho bentgrass	*Agrostis idahoensis* Nash
	20% Top Gun II perennial ryegrass	*Lolium perenne* L.
	30% Bluechip Kentucky bluegrass	*Poa pratensis* L.

Soil Treatments: The three soil treatments were plain soil, soil amended with 50% biosolids, and soil amended with 50% yard waste compost. The yard waste compost was obtained from Rhode Island Resource Reclamation; it consisted primarily of ground wood and leaves and had not been screened. The biosolids were obtained from the West Warwick Sewage Treatment Plant. They had been processed but not composted and resembled very fine black sand.

Locations: The study was conducted in two locations. One site was on the shoulder of interstate 95 northbound between exits 2 and 3 in Hopkinton, RI (I-95). The highway at this site runs from southwest to northeast. The second site was in the divider strip between interstate 295 northbound and a state police weigh station just north of exit 9 in Lincoln, RI (I-295). The highway at this site actually runs from west to east. The two locations were chosen to represent the extremes in snow fall for mainland Rhode

Island. The I-95 site is in southwestern Rhode Island and is coastal, receiving more rain and less snow than the I-295 site which is inland in north central Rhode Island.

Field Plot Design and Establishment: We used a split-plot design with the soil treatments as the main plots and the turfgrass varieties as the subplots. Each individual subplot was 1.2 m x 1.8 m with the long dimension running perpendicular to the roadway. Each main plot was 80.5 m long x 1.8 m wide with the long dimension running parallel to the roadway. Main plots were separated by 4 m buffer zone to prevent mixing of amendments. The turfgrass varieties were replicated three times within each soil treatment at each location with each replication independently randomized. Main plots were not replicated within each location.

The trials were established in September 2007 with I-95 seeded on September 22 and I-295 on September 24. Existing vegetation consisted primarily of crabgrass. The entire trial area was rototilled to a depth of 5 cm with a tractor-mounted rototiller and all rocks larger than fist-size were removed. For the compost and biosolids treatments a 5 cm thick layer of compost or biosolids was spread over the tilled soil and then incorporated to a depth of 10 cm. The plain soil treatment was rototilled a second time to a depth of 10 cm but no amendments were incorporated. The beds were raked smooth and subplots marked with string. Turfgrass varieties were seeded by hand at one-half the recommended lawn seeding rate for each species. Each plot was lightly raked to incorporate the seed. The entire trial was then hydromulched following RIDOT guidelines (RIDOT, 2004) except that no seed was included in the mixture. Each location received a single application of 1.25 cm of water the second week of October to ensure that all entries established successfully. Following establishment the trial areas were maintained by RIDOT crews in a manner identical to the surrounding roadside. This maintenance consisted of occasional mowing with a tractor-mounted industrial flail mower.

Establishing the roadside trial plots in September 2007. Clockwise from top left: rototilling the plots, spreading soil amendments, seeding, and preparing to hydromulch.

Soil Testing: Soil samples were taken in September 2010 to evaluate the long-term effects of soil amendments. Soil cores were collected with a standard soil core sampler every 1.5 m down the length of each main plot and then thoroughly blended to create the test samples for each plot. Soil texture, organic matter content, and concentration of all nutrients other than nitrogen were determined by the University of Connecticut Soil Nutrient Analysis Laboratory using standard procedures. Plant available nitrogen was estimated from the CO_2 burst measured using the Solvita Haney-Brinton test system (Woods End Laboratories, Mount Vernon, Maine). Carbon dioxide release and soil nitrogen content are strongly correlated, with nitrogen in pounds per acre equal to 50% of the amount of CO_2 (in ppm) released in 24 hours (Haney et al. 2008).

Data Collection and Analysis: Percent living turf cover was estimated visually for each plot in spring, summer, and fall of each year beginning with Fall 2007 and ending with Summer 2009. Turf height was measured in April 2008, prior to the first mowing. Dormancy was rated on a 1-9 scale in late July 2008 after a 6-week drought. Data was analyzed using Repeated Measures ANOVA for the percent cover data and standard GLM ANOVA for other data. Fisher's LSD test was used for means separations as it is robust to unequal replication.

Results

There were significant differences between locations, between soil amendment treatments within location, between species within soil amendment treatment, and between turfgrass varieties.

Differences between Locations: Repeated measures ANOVA showed that the turf cover was significantly greater at I-95 than at I-295. The overall means for the two locations were 40% and 33% respectively. Turf cover was also greater at I-95 for all treatments on all dates with a few exceptions (Figure 1). In November 2008 cover was greater at I-295 for the biosolids and compost treatments because the I-295 site had not been mowed since July while the I-95 site had been mowed regularly. Cover of the planted turf grasses declined in the biosolids treatment at I-95 during the summer of 2009 due to invasion by quackgrass. As a result turfgrass cover was lower than at I-295, even though total vegetation cover was not. The differences between locations are likely due to differences in soil moisture, as the soil is sandier at I-295 (table 2) and the site is surrounded by pavement on all sides, whereas the I-95 site has a wooded back slope to the southeast. The area outside the plots at I-295 is dominated by annual grasses, chiefly crabgrass (*Digitaria ischaemum*) and prairie three-awn (*Aristida oligantha*), while the vegetation is more varied at I-95 and includes an abundance of perennial grasses and forbs.

Differences between Soil Treatments: for the two locations were analyzed separately. However, the soil treatment effects followed the same pattern at each location (Figure 1). Turf cover was lower in the plain soil plots than in the amended plots throughout the study. The overall cover averages for I-95 were 54% for the biosolids treatment, 39% for the compost treatment, and 26% for the plain soil treatment. At I-295 the averages were 58%, 33%, and 9% for biosolids, compost, and soil, respectively. Differences were already apparent in November 2007 and increased during the spring of 2008. By May the turf in the biosolids plots was dark green and lush, while turf in the compost plots was noticeably nutrient deficient and turf in the plain soil plots was severely stunted and chlorotic. The grass was also significantly taller in the biosolids plots than in the compost or plain soil plots for all species except Idaho bentgrass and tufted hairgrass, for which there were no height differences (figure 2).

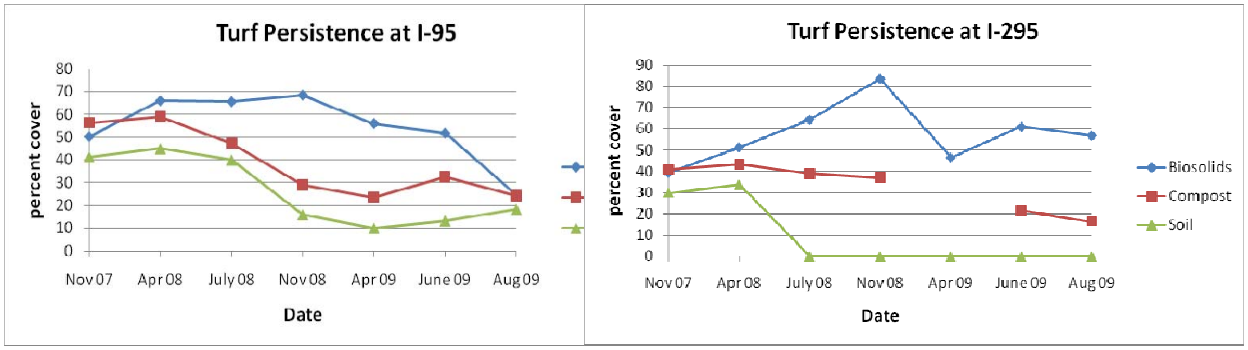

Figure 1 Turfgrass persistence at I-95 and I-295. Cover was estimated visually; values are the mean of three replications.

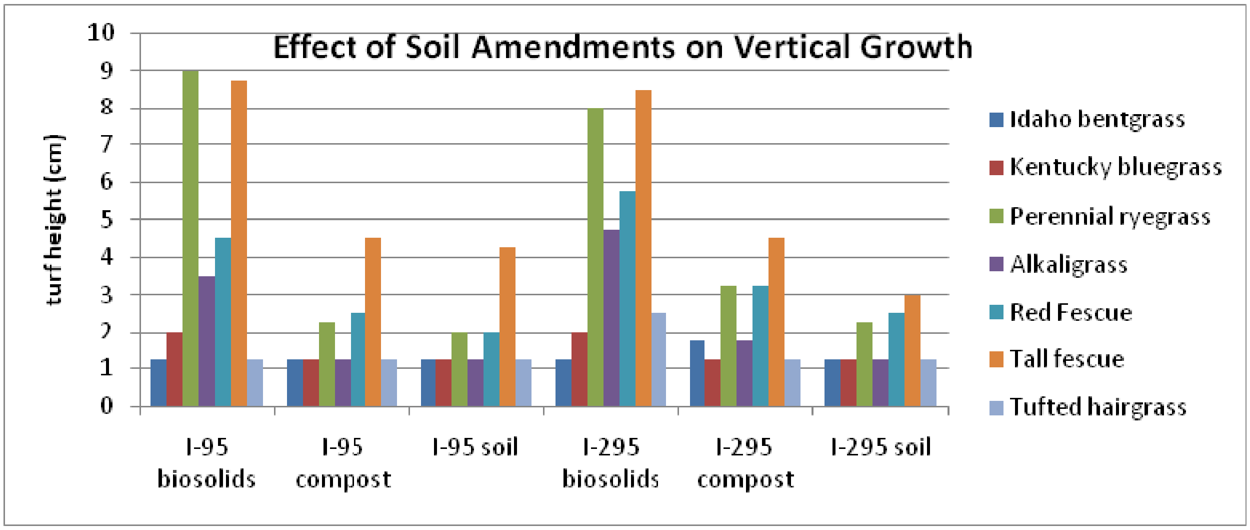

Figure 2 Effect of soil amendments on vertical growth. Turf height in the biosolids treatments were significantly greater than in the other treatments for all species except Idaho bentgrass and tufted hairgrass. Height was measured in May prior to the first mowing.

I-95 trial in May 2008, ten months after seeding. From left: biosolids, compost, and plain soil.

Six weeks without rain in June and July 2008 resulted in the turf at both locations becoming drought stressed and going dormant or dying. Dormancy was most extensive in the plain soil treatment at both locations. At I-295 all turfgrass plots in the treatment were completely killed, while at I-95 individual turgrass entry scores ranged from 1.3-3.7. At I-95 the biosolids treatment was significantly superior to either the compost treatment or the plain soil treatment, while at I-295 the compost treatment was slightly better than the biosolids treatment, although they did not differ statistically.

Much of the turf recovered from dormancy in the biosolids treatment at both locations, and turf cover increased over the fall of 2008. Recovery was not observed in the compost or plain soil treatments at either location; cover remained constant or declined between July and November (figure 1). Cover decreased over the winter of 2008-09, with the sharpest decrease in the biosolids treatment plots, which had the most cover going into the winter. Between April and August of 2009 the average turfgrass cover decreased sharply in the biosolids treatment at I-95 but increased slightly at I-295. Decrease in cover was primarily due to weed invasion, particularly of quackgrass. Cover increased in the compost and plain soil treatments, although it remained significantly lower than in the biosolids treatment. At I-295 cover in the plain soil treatment remained constant at 0%. Data were not available for the compost treatment at I-295 in April 2009, but levels in June and August were lower than for November 2008. The biosolids-amended soil plots supported significantly greater cover of perennial vegetation than either of the other treatments from May 2008 through August 2009 and beyond, although an increasing percentage of that vegetation was naturally occurring species rather than the grass species deliberately seeded into the plots. This was particularly true at I-95, where there was a greater amount of perennial vegetation in the area around the trial plots.

The soil in the trial areas was sampled in September 2010, just over one year past the conclusion of the study. Results are presented in table 2. The soil at I-295 is sandier than at I-95; otherwise the soils are similar. The plain soil plots at both locations contained below-optimum levels of macronutrients, including phosphorous, and had very low microbial activity. Addition of compost significantly raised the soil organic matter (SOM) levels in both locations, as would be expected. The compost also increased the macronutrient levels; in some cases this was sufficient to bring them into the optimal zone for plant growth. Microbial activity increased, but not significantly. Addition of biosolids increased the silt and clay fractions of the soil as well as the soil organic matter, although SOM levels were lower than in the compost plots. Addition of biosolids increased the soil pH and levels of all macronutrients, which in some cases exceeded the optimum levels. Microbial activity also increased significantly, although it was still below the level recommended for agricultural soils.

	texture (%)					Macronutrients (lb/acre)					metals (ppm)			
Plot	sand	silt	clay	% SOM	pH	N[a]	P	K	Ca	Mg	Pb	Cu	Zn	Fe
I-95 biosolids	74.2	21.8	4.0	3.2	7.2	21.8	>100	343	>4000	199	bg[b]	1.9	77.4	4.4
I-95 compost	78.8	20.4	1.4	5.0	6.6	16.7	10	262	2042	143	212	2.1	97.7	14.0
I-95 soil	79.2	17.4	3.4	2.1	6.5	13.9	8	132	763	83	295	7.9	130.8	12.5
I-295 biosolids	82.6	15.0	2.4	3.3	7.4	21.7	>100	317	>4000	200	bg	1.6	44.7	4.5
I-295 compost	86.6	12.0	1.4	5.0	6.9	14.7	20	278	1535	101	129	1.1	57.4	9.0
I-295 soil	84.6	14.0	1.4	3.0	6.5	13.9	14	157	684	79	178	3.3	53.3	38.0

Table 2. Soil test results. All samples were taken three years after amendments were applied.

a. Nitrogen was determined from CO_2 respiration using the Solvita Haney-Brinton test.
b. bg = typical background levels for agricultural soils

One concern with using biosolids as a soil amendment is that they have the potential to increase levels of heavy metals, particularly lead. Roadside soils frequently contain elevated levels of lead and other heavy metals; the plain soil treatments in this study had levels of 178 and 295 ppm at I-295 and I-95, respectively. Interestingly, the lead content of soil from the biosolids plots was below background for both locations.

Performance of Individual Turf Species: For roadside grasses the two most important components of performance are establishment and persistence. Thus we focused on the percent cover data from November 2007 (establishment) and June 2009 (persistence). We used the data from June rather than August for 2009 because the August data from the I-95 biosolids treatment was compromised by quackgrass intrusion into the plots. There were significant differences between species for both locations and all treatments in November 2007, and for all treatment x location combinations except the plain soil treatment at I-295 for June 2009. There were no differences in that plot as all the turfgrasses had died. Kentucky bluegrass, Idaho bentgrass, and tufted hairgrass were each represented by only one variety. For Idaho bentgrass and tufted hairgrass this is a reflection of the paucity of commercial varieties in these species. Only one variety of Kentucky bluegrass was included because this species generally shows poor performance under low fertility, drought, or salinity; only one seed company was interested in including material in the trial. Thus the performance of 'Diva' cannot be extrapolated to represent the performance of Kentucky bluegrass as a species.

Perennial ryegrass and the experimental DOT mix showed the best establishment in all treatments at both locations (Figure 4). Tufted hairgrass was similar to these species in the biosolids treatment at I-95, while 'Diva' Kentucky bluegrass, red fescue, and tall fescue were similar at I-295. Tall fescue was also similar in the compost treatment at I-295. Alkaligrass had very poor establishment in the compost treatment at both locations. In the plain soil treatment both alkaligrass and Idaho bentgrass had unacceptable establishment.

'Diva' Kentucky bluegrass showed the best persistence in the biosolids treatment at I-295, with 90% cover, in June 2009 (figure 5). Red fescue, Idaho bentgrass, and tall fescue were similar, with 72%, 67%, and 68% cover, respectively. Tall fescue showed the best persistence at I-95 with 75% cover. 'Diva' Kentucky bluegrass, red fescue, and the experimental DOT mix were similar, with 60%, 59%, and 55%

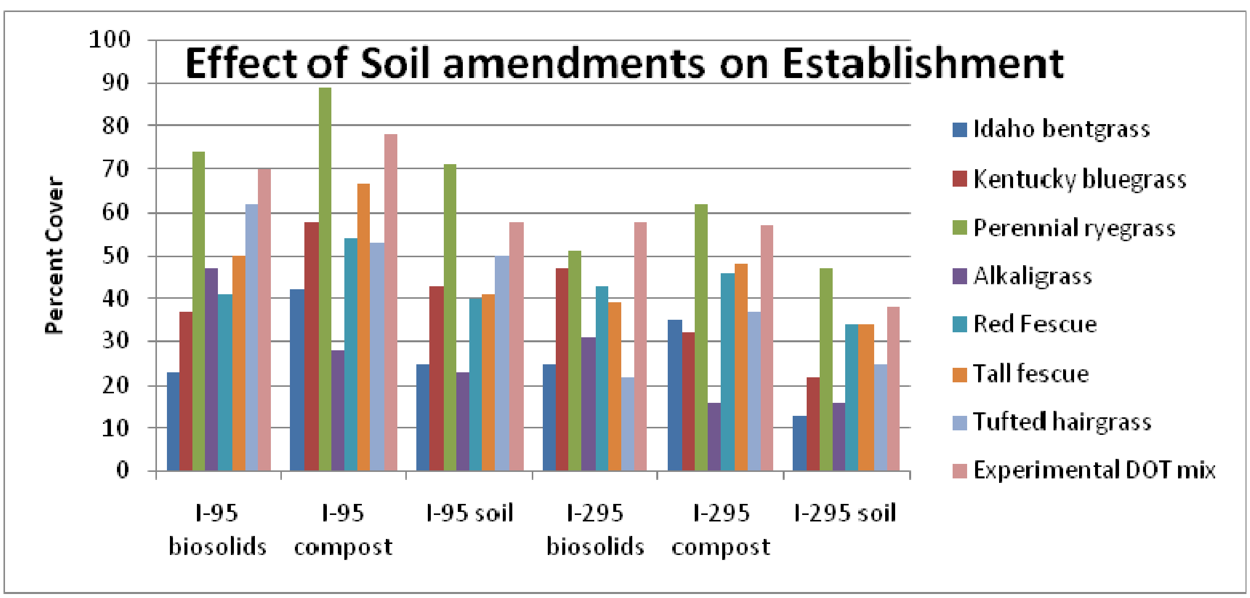

Figure 5 Establishment was evaluated as percent cover in November 2007, six weeks after seeding. Compost gave the best establishment, although the differences were significant only in comparison to the unamended soil.

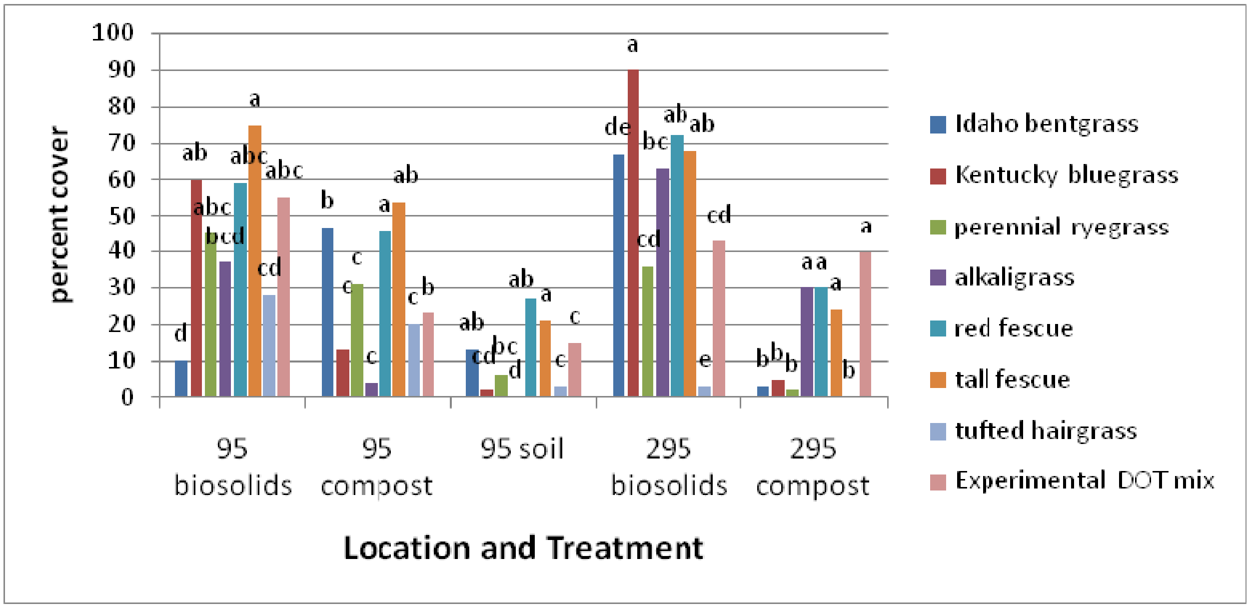

Figure 6 Effect of location, soil amendment, and species on turfgrass persistence measured as percent cover in June 2009, 21 months after seeding. Columns in the same location + treatment labeled with the same letter are not significantly different.

cover, respectively. Tufted hairgrass showed poor persistence at both locations, while Idaho bentgrass had very poor persistence (10% cover) at I-95. Alkaligrass had good persistence (63% cover) at I-295 but only moderate persistence at I-95, while perennial ryegrass had only moderate persistence at both locations.

Tall fescue, Idaho bentgrass, and red fescue showed the best persistence in the compost treatment at I-95, with 54, 47, and 46% cover, respectively, in June 2009 (figure 5). At I-295 the experimental DOT mix showed the best persistence, with 40% cover. Red fescue, alkaligrass, and tall fescue were statistically similar but had noticeably less cover, averaging 30% for red fescue and alkaligrass and 24% for tall fescue. Tufted hairgrass and 'Diva' Kentucky bluegrass had very poor cover at both locations. Alkaligrass failed at I-95 while perennial ryegrass and Idaho bentgrass failed at I-295. Perennial ryegrass had moderate cover at I-95.

Red fescue showed the best persistence in the plain soil treatment at I-95 with 27% cover (figure 5). Tall fescue, the experimental DOT mix and Idaho bentgrass formed a second group with very poor cover; the remaining species failed to persist. None of the entries persisted in the plain soil treatment at I-295.

Rate of vertical growth is also important for roadside grasses as budget constraints limit the frequency with which the grass is mowed. The ideal roadside grass would have minimal vertical growth but strong horizontal growth for damage repair and persistence. Height differences between species were most pronounced in the biosolids treatment, as growth was not limited by nutrient deficiency. Idaho bentgrass had the least vertical growth in both locations, reaching a height of only 1.3 cm (figure 2). 'Diva' Kentucky bluegrass and tufted hairgrass were similar in height at both locations, and alkaligrass was similar at I-95. Red fescue and alkaligrass were intermediate in height at both locations. Red fescue averaged 4.3 cm at I-95 and 5.8 cm at I-25; at both locations it was significantly taller than Idaho bentgrass but significantly shorter than either tall fescue or perennial ryegrass.

Performance of Individual Turfgrass Varieties: In the biosolids treatment at I-95 common creeping red fescue had the best cover in both June and August 2009 with values of 82% and 75% respectively. In June 2009 there were ten other varieties that were statistically similar; by August that number had decreased to six. Varieties that were similar on both dates were the red fescues 'Epic' and 'Cindy Lou', the tall fescues 'Blade Runner' and IS-TF154, 'Diva' Kentucky bluegrass, and the experimental DOT mixture. At I-295 'Diva' Kentucky bluegrass had the best cover in both June and August 2009 with values of 90% and 97% respectively. In June there were ten other varieties that were similar; in August there were twelve. However, there were only six varieties that were similar to 'Diva' on both dates: the red fescues 'Cindy Lou', 'Epic', and 7.0929; the tall fescues IS-TF154 and 'Tarheel', and the experimental alkaligrass 7.0855. When cover was compared over the entire study, the common creeping red fescue and the experimental DOT mixture were the best performers at I-95 while 'Diva' and 'Epic' were the best performers at I-295.

In the compost treatment at I-95 the top performer in June 2009 was the tall fescue 'Tarheel' with 65% cover. In August the top performer was another tall fescue, IS-TF154, with 72% cover. Five varieties were in the top group on both dates: 'Tarheel', IS-TF154, 'Bingo' and 'Bladerunner' tall fescues and 'Cindy Lou' red fescue. At I-295 the top performer in the compost treatment in both June and August was the experimental alkaligrass 7.0013 with 50% cover. Five varieties were similar in both months: the alkaligrass 'Fults', the red fescues 7.0929 and 'Sealink', the tall fescue 'Tarheel', and the experimental DOT mixture. When cover was compared over the entire study the tall fescue 'Bingo' was the top performer at I-95 and the experimental DOT mixture was the top performer at I-295.

There were no differences among varieties in the plain soil treatment at I-295. At I-95 common creeping red fescue had the best cover in June with 30% while tufted hairgrass had the best cover in August with 58% cover. However, the cover in the tufted hairgrass plot was all seedlings; common creeping red fescue had the best true persistence with 50% cover. The varieties similar to common red fescue were all red fescues or tall fescues; 'Sealink', 'Cindy Lou', 7.0929, 'Tarheel', and 'Bingo' were similar on both dates. For the study as a whole common creeping red fescue gave the best cover at I-95.

Variation within Species: This study included multiple varieties of red fescue, tall fescue, perennial ryegrass, and alkaligrass, enabling us to look at variation in performance between varieties of the same species. This is important because DOT guidelines rarely specify beyond the species level for planting stock, and contractors generally use old or unimproved varieties as seed is less expensive. There were no significant within-species differences in persistence, based on percent cover in June 2009. There were significant differences in establishment (based on percent cover in November 2007) among varieties for red fescue, tall fescue, and alkaligrass but not for perennial ryegrass. Among the red fescue entries the common type had the best establishment with 52% cover. The improved variety 'Cindy Lou' was similar. All of the tall fescue entries had similar establishment except for 'Pure Gold'; it was significantly slower than the others with only 28% cover. Among the alkaligrass entries the variety 'Fults' and the experimental entry 7.0013 had the best establishment with 35% cover.

Discussion

This study was conducted to evaluate three approaches to improving the persistence of perennial turfgrasses on roadsides in Rhode Island: soil amendment with organic matter, the use of improved turfgrass varieties, and the use of alternate turfgrass species tolerant of drought, low fertility, and/or salinity. We found that one-time amendment of soil with organic matter significantly improved turfgrass cover for the entire two-year study. Biosolids had a significantly greater effect than yardwaste compost; the effect of the single incorporation of biosolids continues to persist after three years (figure 6). Turfgrass persistence in the unammended soil was poor or non-existent for all varieties and species, indicating that there is little advantage to using improved varieties or alternate species. There were significant differences among species, particularly in the biosolids-amended soil, but the traditional species red fescue, Kentucky bluegrass, and tall fescue were superior to the alternate species. There were also significant differences among varieties but no clear superiority of the improved red fescue varieties over the common type in persistence. The improved varieties were significantly shorter than the common type, but all the red fescues were significantly shorter than tall fescue and perennial ryegrass.

This study was begun with the hypothesis that road salt exposure was the primary reason for the failure of perennial grasses to persist within 5m of the pavement. Salt has been shown to be a major limiting factor in other regions (Biesboer et al. 2008) and the Kentucky bluegrass and common red fescue that make up the bulk of the standard seed mix have only moderate salt tolerance (Marcum 2008). We expected that adding organic matter to the soil would increase sodium levels during the growing season,

Figure 7 I-95 trial in December 2010 three years after planting. From left the treatments are biosolids, compost, plain soil. The coarse grass in the front of the biosolids plot is quackgrass which has invaded. The dead grass is crabgrass and prairie 3-awn, both annual species.

reducing turfgrass survival. Addition of compost has been shown to increase salinity both directly and by increasing the cation exchange capacity of the soil (Hargreaves et al. 2008). We rejected our initial hypothesis as salt exposure did not appear to have significant effect on turfgrass survival, even though salt levels in runoff and snow regularly exceeded concentrations which caused significant loss of green tissue in greenhouse tests. The turfgrass species used in this study varied from moderately salt sensitive (Idaho bentgrass, Kentucky bluegrass, and tufted hairgrass) to extremely tolerant (alkaligrass) yet none of the species showed acceptable persistence in the plain soil treatments and Idaho bentgrass and Kentucky bluegrass out-performed alkaligrass in the biosolids treatment at I-295.

The soil test results for the unamended plots indicate that the roadside soil is deficient in all macronutrients, as well as being quite sandy. Organic matter levels were low, but not unusual for agricultural soils in Rhode Island, and pH was within the recommended range for turfgrass. This, combined with the poor persistence of even the alkaligrass in the unamended plots, led us to hypothesize that the inability of the perennial grasses to persist was due to lack of nutrients, such that turf growth was limited and the ability to recover from damage impaired. Our hypothesis was supported by the excellent persistence of most of the turfgrasses in the biosolids-amended soil and the significant improvement in the soil amended with yard waste compost. Cowley et al. (1999) found that 39-49% of the nitrogen available in biosolids was mineralized in the first year, compared to only 10% for yard waste compost. They also found that biosolids contain more total nitrogen than yard waste compost. The phosphorous content of biosolids ranges from 1-4% of total dry weight (Epstein et al. 1976) although much of the phosphorous may be bound to inorganic molecules and unavailable to plants (McCoy et al. 1986). The total phosphorous content of yard waste compost is much lower, less than 0.1% (Grebus et al. 1994). The addition of organic matter to the soil has been shown to improve cation exchange capacity, moisture retention, and plant growth (Grebus et al. 1994, Hargreaves et al. 2008). However, organic matter alone was not sufficient to permit satisfactory turf survival, and the increased levels of clay and silt in the biosolids-amended soil may have similarly improved cation exchange capacity and moisture retention. The results for the compost treatments further support this conclusion, in that the species with the best persistence were tall fescue, red fescue, Idaho bentgrass, and alkaligrass, all of which are tolerant of infertile soils. Further research is needed to determine whether a blend of biosolids and yard waste compost would be superior to either amendment alone, and to determine the best rate at which to amend the soil. The 50% biosolids rate used in this study resulted in excessive vertical growth, particularly for tall fescue, perennial ryegrass, and quackgrass.

Salinity and nitrogen have a complex interaction in turfgrass, as explained by Bowman et al. (2006a, 2006b). When nitrogen levels are sufficient for maximum growth, even low salinity levels will reduce shoot growth. However, when nitrogen levels limit growth, increasing salinity levels has little effect on growth, although sodium and chloride levels in leaf tissue do increase and will eventually cause leaf death. In addition, salinity interferes with nitrogen absorption, so turf growing in salinity-affected soil is more likely to be nitrogen limited. Lack of nitrogen may also prevent recovery of the turf after the salinity stress is removed. We did not measure soil sodium levels directly, so cannot rule out salinity increase in the amended soils, but any increase was not sufficient to kill the grass and the high fertility in the biosolids-amended soil facilitated turfgrass recovery.

The use of biosolids as a nutrient source for roadside turfgrasses is not new; Wakefield et al. (1974) recommended annual fertilization with biosolids to the Rhode Island Department of Transportation in the 1970s. However, concerns about heavy metal contamination of soil and water have limited the use of biosolids as fertilizer. Biosolids can have high levels of heavy metals, and have been shown to increase metal concentrations in agricultural soils (Alloway and Jackson 1991, Walter and Cuevas 1999). However, these soils generally have very low initial levels of heavy metals. In contrast, many urban soils, particularly on roadsides, have dangerously high levels of lead and other heavy metals (Turer et al. 2001, Imperato et al. 2003). The addition of biosolids alone or in conjunction with vegetation has been shown to reduce the bioavailability of lead in these soils (Brown et al. 2003, Farfel et al. 2005). We found that addition of biosolids resulted in a decrease in soil lead levels to normal background, as well as decreasing levels of copper, zinc, iron, and aluminum. In addition, the increased turf cover in the biosolids-amended soil serves to trap and filter heavy metals deposited by vehicles.

Soil amendment had a far greater effect on turfgrass survival in this study than did either turfgrass species or variety. However, some differences are worth noting. Kentucky bluegrass and red fescue appear to offer the best combination of good persistence and slow vertical growth. Idaho bentgrass is a possibility for drier sites, and alkaligrass for sites where it can be allowed to reseed. Tall fescue maintains good cover but has excessive vertical growth, and it is beginning to appear on invasive species lists in some states. Perennial ryegrass showed relatively poor persistence even in the biosolids plots, and should not be considered a permanent turfgrass for roadsides in New England. Tufted hairgrass also does not appear to be adapted. Kentucky bluegrass, red fescue, and tall fescue are known to persist on roadsides in Rhode Island (Chapter 1) while perennial ryegrass, alkaligrass, and tufted hairgrass do not. Idaho bentgrass is not found outside of cultivation in New England but the related Rhode Island bentgrass (*Agrostis capillaris*) is widespread on roadsides. There were differences among varieties in establishment and vertical growth, but not in persistence, so specifying only to the species level should be acceptable. However, more research is needed on Kentucky bluegrass as there are known to be large differences between varieties of this apomictic grass and only the variety 'Diva' was included in this study.

Recommendations for Practice and Future Research

- Addition of biosolids or other nutrient-rich organic matter to plantable soil is the most effective way to improve vegetation establishment and persistence.
- Improved turfgrass varieties are not needed for red fescue.
- Red fescue, bentgrass, and low-input Kentucky bluegrass are best choices for roadside use.
- Even turf-type tall fescue is too tall, and perennial ryegrass does not persist – these grasses should not be used.
- High salt tolerance is not necessary, select for tolerance to low fertility instead.
- Quackgrass is well adapted and an aggressive invader. To improve aesthetics either control existing quackgrass stands and stop introducing it or deliberately seed the zone within 10 ft of the pavement to quackgrass.

References Cited

Alloway B.J., Jackson A.P. (1991) The behaviour of heavy metals in sewage sludge-amended soils. The Science of The Total Environment 100:151-176.

Bowman D., Cramer G., Devitt D. (2006a) Effect of Salinity and Nitrogen Status on Nitrogen Uptake by Tall Fescue Turf. Journal of Plant Nutrition 29:1481-1490.

Bowman D., Cramer G., Devitt D. (2006b) Effect of Nitrogen Status on Salinity Tolerance of Tall Fescue Turf. Journal of Plant Nutrition 29:1491-1497.

Brown S., Chaney R.L., Hallfrisch J.G., Xue Q. (2003) Effect of Biosolids Processing on Lead Bioavailability in an Urban Soil. J. Environ. Qual. 32:100-108. DOI: 10.2134/jeq2003.1000.

Bryson G.M., Barker A.V. (2002) Sodium accumulation in soils and plants along Massachusetts roadsides. Communications in Soil Science and Plant Analysis 33:67-78.

Cowley N., Thompson D., Henry C. (1999) Nitrogen mineralization study: Biosolids, manures, composts, in: W. S. D. o. E. a. N. B. M. Assoc (Ed.), Managing nitrogen from biosolids, Univ of Washington Press, Seattle. pp. 1–6.

Epstein E., Taylor J.M., Chancy R.L. (1976) Effects of Sewage Sludge and Sludge Compost Applied to Soil on some Soil Physical and Chemical Properties1. J. Environ. Qual. 5:422-426.

Farfel M.R., Orlova A.O., Chaney R.L., Lees P.S.J., Rohde C., Ashley P.J. (2005) Biosolids compost amendment for reducing soil lead hazards: a pilot study of Orgro® amendment and grass seeding in urban yards. Science of The Total Environment 340:81-95.

Forman R.T.T., Sperling D., Bissonette J.A., Clevenger A.P., Cutshall C.D., Dale V.H., Fahrig L., France R., Goldman C.R., Heanue K., Jones J.A., Swanson F.J., Turrentine T., Winter T.C. (2003) Road ecology: science and solutions Island Press, Washington, DC.

Grebus M., Watson M., Hoitink H. (1994) Biological, chemical and physical properties of composted yard trimmings as indicators of maturity and plant disease suppression. Compost Science & Utilization 2:57-71.

Haney R., Brinton W., Evans E. (2008) Estimating Soil Carbon, Nitrogen, and Phosphorus Mineralization from Short-Term Carbon Dioxide Respiration. Communications in Soil Science and Plant Analysis 39:2706-2720.

Hargreaves J.C., Adl M.S., Warman P.R. (2008) A review of the use of composted municipal solid waste in agriculture. Agriculture, Ecosystems & Environment 123:1-14.

Hutchinson F.E., Olson B.E. (1967) The relationship of road salt applications to sodium and chloride ion levels in the soil bordering major highways. Highway Research Record 193:1-7.

Imperato M., Adamo P., Naimo D., Arienzo M., Stanzione D., Violante P. (2003) Spatial distribution of heavy metals in urban soils of Naples city (Italy). Environmental Pollution 124:247-256.

McCoy J.L., Sikora L.J., Weil R.R. (1986) Plant Availability of Phosphorus in Sewage Sludge Compost1. J. Environ. Qual. 15:403-409.

NHI. (2009) Urban Drainage Design Manual, Hydraulic Engineering Circular, Federal Highway Administration, Washington, DC. pp. 477.

Prior G.A., Berthouex P.M. (1967) A study of salt pollution of soil by highway salting. Highway Research Record 193:8-21.

RIDOT. (2004) Standard specifications for road and bridge construction, Rhode Island Department of Transportation, Providence, Rhode Island.

Turer D., Maynard J., Sansalone J. (2001) Heavy Metal Contamination in Soils of Urban Highways Comparison Between Runoff and Soil Concentrations at Cincinnati, Ohio. Water, Air and Soil Pollution 132:293.

Wakefield R., Sawyer C., Lowe B. (1981) Management and renovation of roadside turfgrass, Dept. of Plant and Soil Science, Rhode Island Agricultural Experiment Station, University of Rhode Island.

Walter I., Cuevas G. (1999) Chemical fractionation of heavy metals in a soil amended with repeated sewage sludge application. The Science of The Total Environment 226:113-119

Chapter 3: Defining the salt stress – seasons and levels

Introduction

Since the 1950s, deicing salts have been in the arsenal of Departments of Transportation and are being applied to road surfaces in almost all states in the USA to improve winter traffic safety. (Godwin et al., 2003). These applications add up to 8 to 12 million tons of salt annually (NRC, 1991). Most of these applications are in the form of sodium chloride (NaCl) which is known to keep motorists save but also to incur environmental costs through water quality degradation and direct damage to road side plantings and adjacent ecosystems. Environmentally more friendly alternatives are expensive. While drivers benefit from the increased road safety associated with deicing, salts adversely impact surface and ground water quality (Howard et al., 1993; Heisig, 2000). Striking the balance between road safety and environmental impacts is a difficult undertaking.

The first contact of road salt with the adjacent ecosystems does not always occur at the immediate road side (Bryson and Barker, 2002). Road splash may be entrained into air currents and carried beyond the shoulder, ditch or other roadside landscape features. However, on the shoulder, plants are directly affected by salt in runoff or snow that has been plowed from the road (Bryson and Barker, 2002). Sodium interferes with the uptake of potassium and the proper functioning of cell enzymes. Furthermore, salts have indirect effects on soil fertility. They modify the concentration of cations in road side soils and thus the mineral nutrition and quality of road side plantings. Fertility may further be reduced by the effect of sodium on soil structure. When sodium concentrations are high enough, soil aggregates are dispersed reducing retention of both water and nutrients.

Roadside plantings provide several benefits. Beyond the esthetics of a green roadside, planting may reduce erosion and overland flow from road surfaces. Salt additions are only one of several challenges that the roadside communities face. Compaction and deposition of other motor vehicle related pollutants add to the woes of roadside ecology. In combination these factors may cause severe degradations of road side plant communities and subsequently reduce the benefits that they offer.

We were interested in researching whether salt persisted in the root zone into the growing season. It is likely that much of the salt will be lost due to overland flow and leaching because halide anions like Cl^- are highly mobile and the engineered road side soil next to major highways has low cation exchange capacity leaving even Na^+ ions susceptible to leaching. For this reason the question of whether salt persists in roadside ecosystems into the growing season is not trivial.

Materials and Methods

Study Sites

We selected 6 study sites initially. These were along major Rhode Island highways in Richmond (I95 N at the Welcome Center), Wakefield (Route 1 N at the Steadman Government Center), North Kingstown (Route 1 N, Exit 4), Smithfield (I295S, Exit), Lincoln (Route 146 S at the Lincoln Woods Exit) and Cumberland (I95 N at the rest stop before the Welcome Center). Sampling equipment failed in Richmond and Cumberland. The two sites were excluded from the salt survey. Aerial imagery of the six sites is shown in Figure 1.

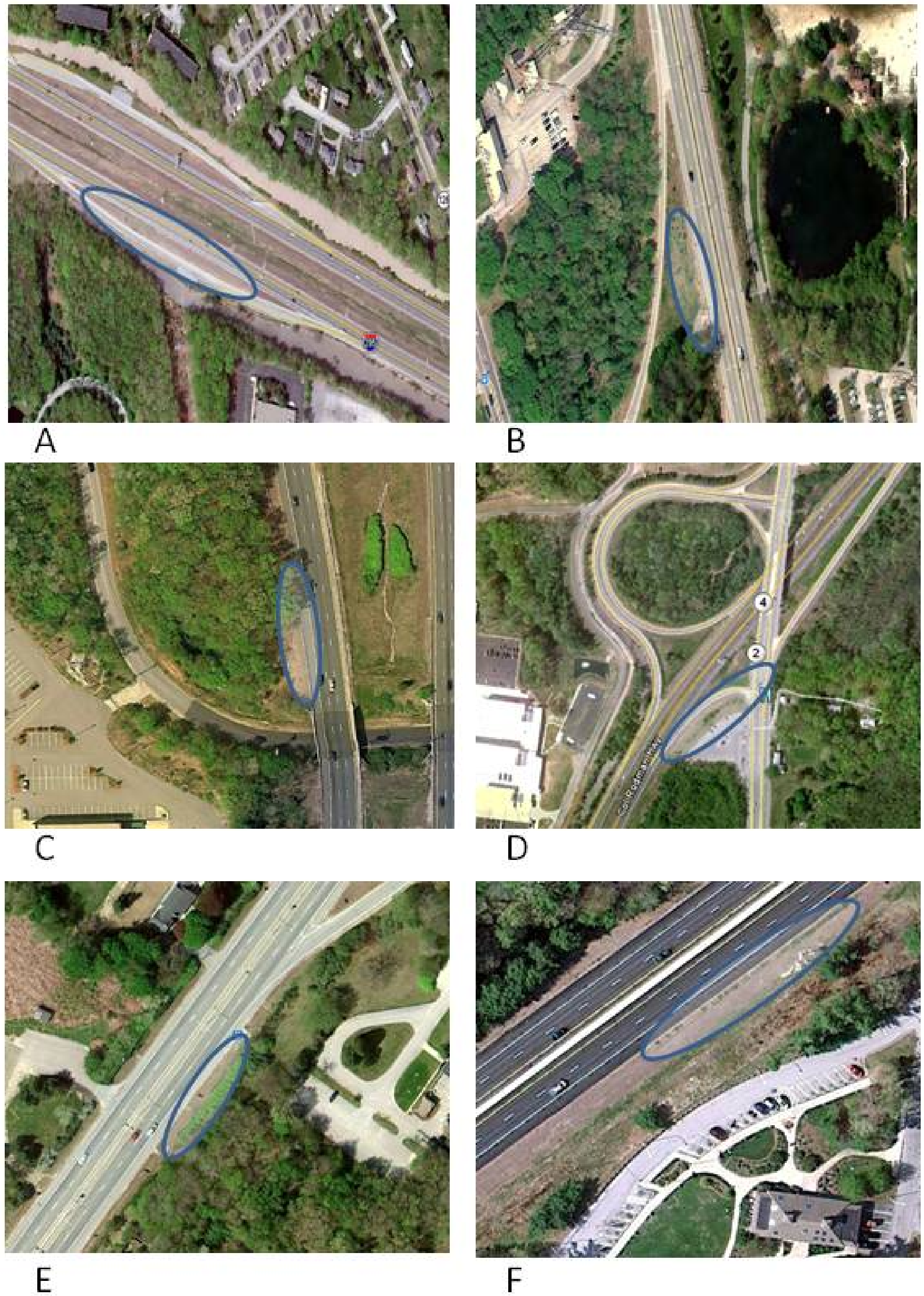

Figure 1: Sampling sites (A) I295 N at rest stop in Cumberland; (B) RTE 146 S in Lincoln near State Police Barracks; (C) I295 S in Smithfield near Smithfield crossings; (D) Rte 4 N near Park and Ride in East Greenwich; (E) Rte 1 N near Stedman Government Center, Wakefield; (F) I95 N near Welcome Center, Richmond. Research plantings are clearly visible in (F). Images from Google Earth, © 2010.

Weather Data

Weather data recorded at Woonsocket and T.F. Greene were purchased for the study period from the National Weather Service (Tables 1 to 4). Temperature, precipitation and event information are tabulated for the sampled storm events in Tables 1 to 4. Woonsocket data represent weather at the northern sampling sites (Lincoln, Cumberland and Smithfield), while the station at T.F. Greene represents weather at the southern sites (East Greenwich, Wakefield and Richmond).

Sample Collection

Samples were collected on storm events from December 2007 to May 2008 and from December 2008 to April 2009. During the 2007/2008 sampling season, runoff was present on most storm sampling dates even when the precipitation was falling as snow. Grab samples of overland flow were taken. In the winter of 2008/2009, snow events were not accompanied by runoff at the time of sampling. Thus, snow samples were collected.

In addition to surface water (runoff or snow) samples, soil water samples were collected using suction cup lysimeters. The lysimeters were installed at 30 cm depth in December 2007 and remained in the soil until June 2008. They were reinstalled in December 2008. Lysimeters consist of a porous ceramic cup and a hollow, clear plastic shaft. When suction is applied, soil water can permeate through the porous cup and is subsequently stored in the shaft. Water was taken from the shaft using a siphon arrangement consisting of thin tubing, that is inserted into the lumen of the lysimeter shaft, an Erlenmeyer flask with a side arm and a hand pump. Water siphoned from the lysimeter was stored in scintillation vials until measurement. On the each sampling date the lysimeters were evacuated and 50 kPa suction applied. 50kPa corresponds to a matric potential approximately 3 times greater than field capacity. Lysimeters responded within 45 minutes and sufficient water could be siphoned for Electrical Conductivity (EC) determinations.

Samples were taken back to the lab, acclimatized to lab temperature (65 – 70^{o} F) prior to the measurement of EC with a Pasco electrical conductivity probe (Pasco Scientific, Roseville, Ca).

Results

The two winter sampling seasons turned had very different temperature regimes. In Woonsocket the average daily minimum temperature was 22.2 and 20.3^{o}F for the period from 1/12/2007 – 3/31/2008 and for 12/1/2008 – 3/31/2009 respectively. The average daily mean temperature in 2007/2008 was 0.9^{o}F greater than in 2008/2009 (31.6 and 30.7^{o} F respectively). The inter-annual winter temperatures at T.F. Green Airport diverged more than in Woonsocket. The average daily minimum temperature was 26.4 ^{o}F and 24.1^{o}F for 2007/2008 and 2008/2009 respectively. The average daily mean temperature was 34.9 ^{o}F in 2007/2008 and 32.8 ^{o}F for 2008/2009.The temperatures on sampling events differed even more between the two years. In Woonsocket the average daily mean temperature for the sampling dates was 2 ^{o}F greater in 2007/2008 than in 2008/2009. At T.F. Green the difference was 4.3 ^{o}F.

In the winter of 2007/2008, soils did not freeze in December and January so that lysimeters yielded soil water (Tables 5 – 8). This was not the case in February and in some places March. Interestingly, lysimeters in the southern, warmer part of the State yielded soil water on fewer sampling events. The EC of Soil water ranged between 200 and 24000 µS/cm. As a reference, sea water has an EC of 48,000 µS/cm. Runoff water had ECs between 85 and 32,000 µS/cm. For runoff and soil water, northern sites had greater EC values than sites in Southern Rhode Island. During the early spring of 2008, EC values in lysimeters diminished quickly after a peak in mid-February. However, by end of May the EC values in soil water had doubled from their minimum in early May at all sites except at Route 1 N in Wakefield where the values only increased by a factor of 1.5.

In the winter of 2008/2009, lysimeters did not yield water until March and April. Soil water then had EC values of 60 to 20,000 µS/cm (Tables 9 – 12). Snow EC values at all sites approached or exceeded that of seawater with values at sites in northern Rhode Island exceeding those in the South. Soil water in April may have reflected some of these high snow EC values.

Discussion

EC in Runoff in 2007/2008 and snow in 2008/2009 were of the same order of magnitude (in the 10,000s µS/cm) as seawater. The snow in 2008/2009 had the greatest EC values, sometimes exceeding seawater EC. This may in part be due to greater applications of deicing salts during this colder year. However, salt may have concentrated in the snow. Most water is lost from the road side likely occurred as snowmelt runoff. However, snowpack sublimation is also an important part of the hydrologic balance during the winter and has been estimated to be as high as 20% for the deep snowpacks in the Canadian Rockies (MacDonald et al., 2010). It is likely that with less snow accumulations the fraction of snowpack lost to sublimation is greater. Sublimation likely is an additional factor that in combination with salt additions creates the high salt concentrations observed in the snowpack during the winter of 2009.

In the winter 2008, a distinct pattern of electrical conductivity in soil water emerged. This pattern showed a steady increase in EC until March 2008. This trend is similar to that reported for soils in Sweden by Olofsson and Lundmark (2009). Thereafter, EC decreased until end of April when a EC began to rise until at least the end of the sampling season in May 2008. An increase in EC would undoubtedly mean an increase in NaCl concentration in soil solution. This is most likely a result of evaporation causing either greater concentrations of salt or bulk upward movement of water returning water with greater salt concentrations that had leached earlier that year. In either case by the end of May, the increased EC value reached about 5% of the EC of ocean water, which is not damaging to typical roadside grasses and should not interfere with N uptake at the low N levels likely to exist along the road side (Bowman et al., 2006).

The temperature differences during the two field seasons caused different patterns of melt water and salinity loss from the sites during winter and spring. The average mean daily temperature during the winter of 2008 was 4.3^{o} F warmer than in 2009 at T.F. Greene Airport in Warwick, RI. At the Woonsocket, RI, NOAA weather station, the average mean daily temperature was 2^{o} F warmer in the winter 2008 than in the winter of 2009. Our data suggests that the temperature distribution through the winter months can have a great effect on the fate of deicing salt. During cold winters, such as the winter of 2009, with long periods of permafrost the fate of most road side salt is ruled by accumulation of salt in snow and eventually surface runoff and some infiltration during snow melt (Labadia and Buttle, 1996). There was no visible runoff during winter storm events in 2009 and snow melt was undoubtedly decoupled from the storm events. At the same time, lysimeters did not yield any percolate until March 2009 when the soil thawed. Then the EC in soil water was high probably reflecting the salt that had built in snowpack. In years of moderate winter temperatures, such as 2008, the soil may stay frost free or thaw earlier allowing melt water to infiltrate and percolate as well as runoff during or shortly after storm events (2008).

One of the interesting observations during 2008 was that lysimeters in Southern Rhode Island yielded water on fewer occasions than those in the North, particularly lysimeters on Route 146 in Lincoln. It is possible that high salt concentrations in Lincoln allowed soils to thaw quicker than at other sites in mid – February when temperatures achieved maximum temperatures exceeding 50^{o} F state-wide.

Table 1: Woonsocket weather data for sampling dates in 2008. Snow and precipitation data give the sum of precipitation and snow during the four days prior to sampling.

Date	T_{max} ^{o}F	T_{min} ^{o}F	T_{mean} ^{o}F	**Precipitation 4 day** inches	**Snow 4 day** Inches	**Snow pack depth** Inches	**Event**
12/23/2007	26	24	25	0.55	2	12	Snow
1/13/2008	49	22	36	1.89	0	0	Rain
1/18/2008	35	16	26	0.41	0.5	4	wet snow
1/30/2008	49	25	37	0.06	0.5	2	snow
2/5/2008	47	24	36	1.79	0	0	rain
2/13/2008	30	16	23	0.79	3	3	snow
2/15/2008	39	25	32	2.93	3	0	rain
3/1/2008	32	9	21	0.75	3	3	snow
3/5/2008	58	37	48	0.82	0	0	rain
3/8/2008	48	36	42	2.41	0	0	rain
3/15/2008	57	32	45	0.33	0	0	rain
4/4/2008	53	34	44	0.86	0	0	rain
4/16/2008	60	28	44	0	0	0	
4/30/2008	60	34	47	2.19	0	0	rain
5/4/2008	46	42	44	0.42	0	0	rain
5/10/2008	55	45	50	0.42	0	0	rain
5/18/2008	74	49	62	1.03	0	0	rain
5/20/2008	59	38	49	1.1	0	0	rain
5/26/2008	77	50	59	0	0	0	

Table 2: Woonsocket weather data for sampling dates in 2009. Snow and precipitation data give the sum of precipitation and snow during the four days prior to sampling.

Date	T_{max} ^{o}F	T_{min} ^{o}F	T_{mean} ^{o}F	**Precipitation 4 day** Inches	**Snow 4 day** inches	**Snowpack depth** Inches	**Event**
12/18/08	34	26	30	0.44	0	0	
1/13/09	30	11	21	0.46	3.3	4	Snow
1/15/09	20	8	14	0.5	3.5	4	Snow
1/30/09	35	10	23	1.14	1	9	Snow
3/20/09	46	31	34	0.06	0	0	Rain
4/8/09	46	33	40	1.79	0	0	Rain
4/21/09	57	47	52	2.05	0	0	Rain

Table 3: T.F. Greene weather data for sampling dates in 2008. Snow and precipitation data give the sum of precipitation and snow during the four days prior to sampling.

Date	T_{max} °F	T_{min} °F	T_{mean} °F	Precipitation 4 day Inches	Snow 4 day Inches	Snowpack depth Inches	Event
12/23/2007	38	28	33	0.28	3	6	Snow
1/13/2008	48	29	39	1.28	0	0	Rain
1/18/2008	49	33	41	0.57	0	T	Rain
1/30/2008	49	30	40	0.17	0	0	Rain
2/5/2008	52	37	45	0.2	T	0	snow/rain
2/13/2008	54	26	40	3.04	2.2	1	Rain
2/15/2008	41	28	35	2.95	Trace	Trace	Snow
3/1/2008	42	27	35	0.45	1.2	1	Snow
3/5/2008	61	38	50	0.74	0	0	Rain
3/8/2008	62	40	51	3.6	0	0	Rain
3/15/2008	42	36	39	0.44	T	0	rain/snow
4/4/2008	49	37	43	1.54	0	0	Rain
4/16/2008	64	32	48	0	0	0	
4/30/2008	56	38	47	2.27	0	0	Rain
5/4/2008	59	45	52	0.54	0	0	Rain
5/10/2008	67	45	56	0.56	0	0	Rain
5/18/2008	71	54	63	0.31	0	0	Rain
5/20/2008	63	45	54	0.55	0	0	Rain
5/26/2008	77	52	65	T	0	0	

Table 4: T.F. Greene weather data for sampling dates in 2009. Snow and precipitation data give the sum of precipitation and snow during the four days prior to sampling.

Date	T_{max}	T_{min}	T_{mean}	Precipitation 4 day	Snow 4 day	Snowpack depth	Event
	°F	°F	°F	Inches	inches	Inches	
12/18/08	41	28	35	0.34	0.3	0	
1/13/09	37	14	26	0.49	3.8	2	Snow
1/15/09	17	10	14	Trace	0.2	1	Snow
1/30/09	40	17	29	1.3	2.4	3	Snow
3/20/09	42	28	35	0.12	0	0	Rain
4/8/09	46	33	40	1.79	0	0	Rain
4/21/09	57	47	52	2.05	0	0	Rain

Table 5: Electrical Conductivity (EC) of water samples at Route 146 in Lincoln, RI, in the winter of 2007/2008

	Soil Water			Runoff		
Date	Average	Minimum	Maximum	Average	Minimum	Maximum
		µS/cm			µS/cm	
12/22/2007	1072	581	2893			
1/13/2008	894.6	517	1734			
1/18/2008	1701.75	703	3050			
2/5/2008				877.5	385	1310
2/13/2008				6562.333	1416	10812
2/15/2008	9069.8	4480	14014			
3/1/2008				7871.5	5529	12272
3/8/2008	5727.6	3670	7812	247.5	95	420
4/4/2008	2293	771	6079	414.75	219	595
4/16/2008	838.5	612	1685			
4/30/2008	1068.4	789	1372			
5/4/2008	984.2	815	1333			
5/10/2008	1190	1008	1335			
5/18/2008	1369	783	1919			
5/20/2008	1905.4	1274	2363			
5/25/2008	2392.2	1635	3150			
5/27/2008	2141.825	1635	2925			

Table 6: EC of water samples at I295S in Smithfield, RI, in the winter of 2007/2008

Date	Soil Water			Runoff		
	Average	Minimum	Maximum	Average	Minimum	Maximum
		µS/cm			µS/cm	
12/23/2007	832	495	1130			
1/18/2008	2443	967	4838			
2/5/2008				2886	2775	3064
2/13/2008				6023	5591	6375
3/1/2008				29880	26711	32160
3/5/2008				2525	1967	2900
3/8/2008	9776	3566	24670	247	148	315
3/13/2008				2525	1967	2900
4/4/2008				596	546	672
4/16/2008	1228	650	1874			
4/30/2008	840	522	1294			
5/4/2008	887	576	1592			
5/10/2008	825	454	1717			
5/18/2008	933	423	2192			
5/20/2008	1279	596	2654			
5/26/2008	1540	665	3066			

Table 7: EC of water samples at RTE 4 in East Greenwich, RI, in the winter of 2007/2008

	Soil Water			Runoff		
Date	Average	Minimum	Maximum	Average	Minimum	Maximum
		µS/cm			µS/cm	
1/13/2008	2502	1150	5091			
1/18/2008	4120	4120	4120			
3/8/2008	2480	2056	2918	208	85	414
1/30/2008				4254	1407	5552
2/5/2008				1091	1050	1128
2/13/2008				877	789	997
3/1/2008				1842	543	3971
3/5/2008				208	85	414
4/30/2008						
5/4/2008	395	305	493	722	412	1273
5/10/2008	449	371	537			
5/26/2008	605	479	771			

Table 8: EC of water samples at Rte1 N in Wakefield, RI, in the winter of 2007/2008

	Soil Water			Runoff		
Date	Average	Minimum	Maximum	Average	Minimum	Maximum
		µS/cm			µS/cm	
12/23/2007	868.8	450	1192			
1/13/2008	1548.75	1162	2001			
1/18/2008	2986.5	2730	3243			
1/30/2008				3695	3363	4048
2/5/2008				1126	855	1880
3/1/2008				1673.5	1369	1931
3/5/2008				1830.5	1609	2218
3/8/2008	1380.714	365	2510	161.8	95	265
3/15/2008				1830.5	1609	2218
4/4/2008	506.1429	338	640	317.6667	221	382
4/16/2008	579.1667	387	789			
4/30/2008	521	225	684			
5/4/2008	445.8571	299	664	346.75	288	409
5/10/2008	482.6	355	609			
5/18/2008	441.1429	219	609			
5/20/2008	664.4286	364	864			
5/26/2008	621.8571	347	820			

Table 9: EC for soil water and snow at Rte 146 in Lincoln, RI, in 2008/2009.

Date	Soil Water			Snow		
	Average	Minimum	Maximum	Average	Minimum	Maximum
		µS/cm			µS/cm	
12/18/08				12598	10512	14746
1/13/09				46064	37241	64544
1/15/09				53959	45441	64544
3/20/09	No Yield					
4/8/09	2158	1235	3081			
4/21/09	1157	420	3018			

Table 10: EC of soil water and snow at I295S in Smithfield, RI, during the winter of 2008/2009.

Date	Soil Water			Snow		
	Average	Minimum	Maximum	Average	Minimum	Maximum
		µS/cm			µS/cm	
12/18/08				20895	19772	23926
1/13/09				20034	15383	69452
1/15/09				64808	60640	69452
1/30/09	No Yield					
3/20/09	10237	256	20217			
4/8/09	2278	67	3716			
4/21/09	No Yield					

Table 11: EC of soil water and snow at RTE 4 in East Greenwich, RI, in the winter of 2008/2009.

Date	Soil Water			Snow		
	Average	Minimum	Maximum	Average	Minimum	Maximum
		µS/cm			µS/cm	
12/18/08				26443	19364	30228
1/13/09				38587	24003	49782
1/15/09				41302	32423	49977
1/30/09	No yield					
3/20/09	11236	11236	11236			
4/8/09	No yield					
4/21/09	2602	1260	4135			

Table 12: EC of soil water and snow at Rte 1 in Wakefield, RI, in the winter of 2008/2009.

Date	Soil Water µS/cm			Snow µS/cm		
	Average	Minimum	Maximum	Average	Minimum	Maximum
12/18/08				7476	1932	22775
1/13/09				15766	11429	27490
1/15/09				34910	25073	40675
1/30/09						
3/20/09	No yield					
4/8/09	no yield					
4/21/09	1462	579	1978			

Literature Cited

Bryson, G. M. and Barker, A. V. 2002. Sodium accumulation in soils and plants along Massachusetts Roadsides., Communications in Soil Science and Plant Analysis 33:67-78

Godwin, K.S., S.D. Hafner, and M.F. Buff. 2003. Long-term trends in sodium and chloride in Mohawk River, New York: the effect of fifty years of road salt application. Environmental Pollution 124:273-281.

Heisig, P.M. *Effects of Residential and Agricultural Land Uses on the Chemical Quality of Baseflow of Small Streams in the Croton Watershed, Southeastern New York.* US Geological Survey Water-Resources Investigations Report 99-4173. *http://ny.usgs.gov/projects/misc/WRIR99-4173.pdf.* March 2000.

Howard, K.W.F., J.I. Boyce, S.J. Livingston, S. Salvatori. 1993. "Road Salt Impacts on Ground-water Quality." *GSA Today*. Volume 3, Number 12. *www.history.rochester.edu/class/roadsalt/home.html*. December.

Labadia, C.F. and J.M. Buttle. 1996. Road salt accumulation in highway snow banks and transport through the unsaturated zone of the Oak Ridges Moraine, Southern Ontario. Hydrological Processes 10: 1575- 1589.

MacDonald, M. K., Pomeroy, J. W., and Pietroniro, A.: On the importance of sublimation to an alpine snow mass balance in the Canadian Rocky Mountains, Hydrol. Earth Syst. Sci., 14, 1401-1415

National Research Council. 1991. Transportation Research Board. *Highway Deicing: Comparing Salt and Calcium Magnesium Acetate.* Special Report 235. .

Olofsson, B and A. Lundmark. 2009. Monitoring the impact of de-icing salt on roadside soils with time-lapse resistivity measurements. Environmental Geology 57:217-229.

Conclusions and Recommendations for Practice

In this two year study of vegetation survival along limited access roadways in Rhode Island we discovered that the major limiting factor for turfgrass survival is not salt but the extremely low fertility of the roadside soils. This lack of fertility is particularly acute on the front slope between the pavement and the swale, probably due to the leaching effects of the large amounts of water draining from the pavement. Survival of perennial vegetation is further compromised by the hot, dry environment created by the pavement and the wind from passing vehicles, by disturbance from vehicles, and by salt and other chemicals splashed or washed from the roadway. The incorporation of organic fertility sources such as biosolids into soils on the front slope dramatically improves vegetation survival by providing the plants with the nutrients needed to recover from the environmental stresses.

Despite the low fertility of roadside soils the mowed roadside contains a variety of grasses and forbs, including a number of native grassland species which have become rare as agricultural grasslands are replaced by forest or urban development. The grass seed mix used by RIDOT does not persist on the roadside to any great extent, but it serves to stabilize the soil until naturally occurring, adapted vegetation becomes established. The diversity of the roadside grasslands is limited by frequent mowing, and the number of species would likely increase if mowing were reduced to only once or twice a year. The other major threat to these grasslands is aggressive introduced species such as quackgrass, which are frequently introduced in hay bales used to control erosion during construction and pavement repairs.

We recommend the following changes to current RIDOT practice. These changes are mostly cost neutral; some may even save money.

- When establishing vegetation on the front slope (within 10-15 feet of the pavement) use a "plantable soil" which includes biosolids or other nutrient rich organic matter. A 50:50 mix will work; further research is needed to identify the ideal rates. Soil amendment is not needed in the swale or on the back slope.
- Use a seed mix containing common-type red fescue and low-input Kentucky bluegrass. Choose species for tolerance to low fertility, not for salt resistance. Perennial ryegrass should be used only for temporary seeding as it does not persist and may interfere with germination of more desirable species.
- Reduce mowing frequency to the minimum necessary to prevent establishment of woody species. This will encourage the native grasses and forbs already established on the roadside to spread.
- Develop a native grass seed mix that reflects the diversity of species that occur in New England grasslands, rather than relying on a few Midwestern prairie grasses. This mix could be used to augment the naturally-occurring seed and speed colonization of damaged areas.
- Discontinue the use of hay bales for erosion control. The bales often contain high levels of weeds, including quackgrass, which can invade the roadside grassland. Weed-free hay is generally reserved for livestock use. Mesh bags filled with compost would be a possible substitute. They are effective at controlling erosion, benefit the roadside by adding organic matter, and do not need to be removed, saving labor. If biodegradable plastic or mesh were used to make the bags, it would not even be necessary to remove the mesh.