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DE-ICING SALTS, SALT-TOLERANT VEGETATION AND CALCIUM SULFATE

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10. Abstract A study of de-icing salts, salt-tolerant vegetation, and calcium sulfate was undertaken as part of the Massachusetts Highway Department Research Program. The objectives of this research were (1) to conduct a literature search to characterize chemical processes and subsequent damage to vegetation from airborne and soil-borne de-icing salts, (2) to characterize roadside conditions in Massachusetts by assessment of damage to trees, shrubs, and grasses along highways, (3) to conduct a survey of cold-region highway departments for methods and specifications of mitigating salt damage along highways, (4) to prepare specifications and methodology for ameliorative practices and recommendations for evaluation of salt-tolerant plants. The research process began in January 2000 with research continuing in the spring, summer, and fall of 2000. The literature search and survey of highway departments showed that sodium chloride (NaCl) is the most common deicing agent used. In Massachusetts, an average of 240 lb of NaCl is used per lane mile in multiple applications per year, an amount that is common with other agencies (280 lb per lane mile). The total amount of NaCl used in Massachusetts is about 290,000 tons per year. Highway departments reported that salt damage occurred commonly to roadside vegetation within about 50 ft of the pavement. Dieback, defoliation, and abnormal branching were identified in the literature and in the survey as symptoms of salt injury to roadside plants. Aerial spray was a major means of transmission of salts to plants, as evergreen, coniferous trees were reported to suffer more damage than deciduous trees and damage was on the side of trees facing the road. Analysis for sodium (Na) indicated that the evergreen trees accumulated more foliar Na than deciduous trees and that the accumulation diminished with distance from the highway. Sodium concentration in soil also diminished with distance from the highway. It was not determined whether airborne delivery or soil-borne delivery of salt was the more ruinous process. The review of literature identified salt-tolerant grasses and woody ornamentals for roadside planting. Nurseries in New England were surveyed for the availability of the woody plant materials, and a list of available plants by nursery was prepared along with a list of vendors for grasses. Experiments were designed to test ameliorative practices and salt-tolerant plants along medians and at intersections of Massachusetts highways as considerations for future research. The survey suggested that ameliorative practices were not used commonly by other agencies in cold regions and hence were untested. Highway departments in cold-weather regions generally do not monitor salt damage to vegetation and have not evaluated practices to ameliorate damage. Vegetation differs considerably in tolerance to salt, but much of the plant materials have not been tested in roadside conditions. Future research could address landscape design in planting patterns and use of salt-tolerant plants and, in severely affected areas, the use of ameliorating agents to lessen salt damage to roadside plants.

11. Key Words Sodium chloride, sodium, road salts, salt-tolerant plants, invasive plants, woody ornamentals

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Final Report

by

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The contents of this report and statements of findings and conclusions are those of the authors, who are responsible for the accuracy of the report. The contents do not state official policy of the Massachusetts Highway Department. This report does not constitute a standard, specification, or regulation.

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Executive Summary

A study of de-icing salts, salt-tolerant vegetation, and calcium sulfate was undertaken as part of the Massachusetts Highway Department Research Program. The objectives of this research were (1) to conduct a literature search to characterize chemical processes and subsequent damage to vegetation from airborne and soil-borne de-icing salts, (2) to characterize roadside conditions in Massachusetts by assessment of damage to trees, shrubs, and grasses along highways, (3) to conduct a survey of cold-region highway departments for methods and specifications of mitigating salt damage along highways, (4) to prepare specifications and methodology for ameliorative practices and recommendations for evaluation of salt-tolerant plants. The research process began in January 2000 with research continuing in the spring, summer, and fall of 2000.

This research provided a search of the literature to characterize the processes and kinds of damage from airborne and soil-borne deicing materials. An outcome of the search was construction of lists of salt-sensitive and salt-tolerant plants to assist highway department landscapers in the identification of plants for roadside planting in Massachusetts. From the list of trees and shrubs that were identified in the literature as being salt tolerant, the availability of these plant materials was determined by contacting nurseries doing business in the New England. The results of these contacts are tabulated. A list of vendors for grasses is provided also.

Research was conducted to characterize conditions along some roadsides in Massachusetts to ascertain if salt (NaCl) deposition in soils and accumulation in plants is linked to damage to roadside vegetation. Leaves of trees, shrubs, and grasses apparently damaged or not damaged by road salts and soil samples were collected at various distances from the pavement and analyzed for sodium (Na) accumulation. The relationships of Na accumulation to plant injury are reported.

Other highway agencies in cold-weather regions outside of Massachusetts were surveyed for their practices and materials used for snow and ice removal. These agencies were asked for their observations concerning damage imparted to roadside vegetation by deicing materials.

In the research, two experiments were designed for future investigations of selected plant materials and ameliorating agents for soil amendments. These experiments are proposed to be conducted in medians or at interchanges of highways where salt deposition and runoff may be intensive.

A synopsis of the research for the literature review, on the characterization of roadside conditions, the survey of agencies, the identification of availability of salt-tolerant plants, and the experiments follows. The deliverables for this research project consist of a set of technical memoranda and a final report representing a consolidation of these memoranda.

Literature Search

Three reviews of literature were done for this task. One of the reviews deals with salt tolerance of various types of roadside vegetation; one addresses salt damage to roadside grasses and other turfgrasses; and one addresses deicing-agent damage to woody roadside vegetation. These three reviews are integrated into this report along with a comprehensive listing of the references cited.

Each of these reviews discusses the injuries that can occur from use of deicing agents on highways in cold climates. Emphasis is on sodium chloride (NaCl), the predominant deicing agent used in the Northeast. The reviews consider the forms of injury that occur on roadside vegetation, the plant physiology of roadside plants subjected to deicing agents, methods of amelioration of injury, and listings of salt-sensitive and salt-tolerant plants. A detailed listing of salt-tolerant plants and regional vendors are presented under Section 5.0 Investigation of Availability of Salt-tolerant Plant Materials. Appendix II has a list of invasive plants. Only three of the sixty-seven salt-tolerant plant species identified from this research have invasive tendencies (Table 2-4).

Sodium chloride is the most common deicing agent used on cold-region highways (See Section 4.0 Survey of Agencies). Salt damage to roadside trees and shrubs is manifested often as desiccation of needles of coniferous plants and defoliation of evergreen and deciduous plants and sometimes in death of the plants. It is difficult to ascertain whether salt damage to roadside vegetation is caused by salt runoff, by road spray, or by both actions. Although both means of salt deposition can negatively affect roadside vegetation, research efforts usually have focused on one or the other, but rarely on both means. It should not be inferred that because a plant is capable of withstanding saline conditions in the root zone that it is equally capable of tolerating salt spray on its leaves or vice versa.

Salt-tolerant deciduous trees and shrubs were more commonly reported in the scientific literature than evergreens. In general, salt spray onto the foliage of evergreen trees and shrubs was reported to be more ruinous to roadside vegetation than soil-borne salinity from runoff. Injury to foliage on the sides of evergreen trees suggests that salt spray is a principal factor in saline damage to roadside vegetation.

The lack of tolerance of evergreen trees and shrubs to salt spray limits their use for roadside planting. Many of the species of evergreen trees and shrubs that are reported to be salt-tolerant are prone to diseases. Perhaps, roadside conditions increase the susceptibility of these plants to diseases. Salt damage and disease damage often may be confused and misidentified.

Assessment of roadside injury during this project (See Section 3.0 Characterization of Roadside Conditions) suggests that grasses were not severely injured along Massachusetts roadsides; however, injury is reported in the literature, and potential is high for injury to grasses in highway medians, where deposition of salt may be higher than along the perimeter roadsides. Early visual symptoms associated with salt stress in grasses are similar to drought stress, specifically, narrow leaf width, stiffer blades, and darker blue-green color are observed. As salt stress progresses, shoots appear wilted (even though soil moisture is non-limiting) and become increasingly darker in color. High salinity levels cause leaf tip die back (leaf firing) and stunted shoot growth. Stunted shoot growth results in the loss of turfgrass density, eventually causing shallow rooting. Salinity problems can be identified by these visual symptoms, however, diagnosis is easily confused with drought stress symptoms. Selection of saline-tolerant grass species for roadside planting seems to be related to selection of grasses for drought tolerance.

The review of literature indicated that salt damage to vegetation was a well-researched topic. Salt-tolerant trees, shrubs, and grasses have been identified. For beauty in the landscape, evergreen species need to be placed some distance from the road (possibly exceeding 50 feet from the roadside) to avoid injury from saline sprays. Research on ground covers other than grasses seems limited in scope. A need exists to investigate the benefits of grass mixes, and possibly the use of legumes for roadsides where deicing salts are commonly used, as this information was lacking in the scientific literature.

Characterization of Roadside Conditions

The most common deicing material applied by the Massachusetts Highway Department is NaCl. In Massachusetts, the rate of application of deicing agents is about 240 lb per lane mile (1.6 km). The objective of this research was to examine injury to plants along roadsides and to assess relationships of damage to the amount of Na detected in plants and soils.

The damage on most plant species was manifested as burning or browning of the leaves or needles. Coniferous species, especially pines (*Pinus* spp.), were sensitive to NaCl injury. In coniferous species, the damage appeared as browning on the ends of the needles, but new growth was usually not affected. Most of the damage occurred on the needles on the tree side that faced the road and where salt spray from cars or plows could have been a factor in the degree of damage. Widespread damage was also seen on spruce (*Picea* spp.), sumac (*Rhus typhina*), and mountain laurel (*Kalmia latifolia*) along roadsides. With sumac, injured plants had only 10% of the foliage as uninjured plants.

Some salt-tolerant species, apparently undamaged by NaCl, in the same vicinity as the damaged plants, were various oaks (*Quercus* spp.), maples (*Acer* spp.), grasses (mixed species), ferns (mixed species), and yarrow (*Achillea millefolium*). The Na concentrations in the leaves of pines, sumacs, grasses, and oaks decreased as the distance from the pavement increased. The Na concentrations in pine needles were 3356 mg/kg at 10 feet, 1978 at 15 feet, and 1513 mg/kg at 20 feet. With distance from the pavement, Na concentrations in maple leaves decreased from 249 mg/kg at 10 feet to 150 mg/kg at 30 feet. The concentrations of Na in roadside soil ranged from 101 mg/kg at 5 feet to 16 mg/kg at 30 feet from the pavement, with a marked decrease in soil Na concentration occurring after 15 feet. The pH decreased as the distance from the pavement increased ranging from pH 7.60 at 5 feet to pH 5.78 at 30 feet. The electrical conductivity (EC) values (saturated-paste extracts) decreased as the distance from the pavement increased and ranged from 0.16 dS/m (decisiemens per meter, commonly millimhos per cm) at 5 feet to 0.12 dS/m at 30 feet.

In general, most of the severe cases of salt damage to plant species were within 15 feet of the pavement. Within 15 feet of the pavement, salt spray likely causes a majority of the damage. This injury is suggested by the fact that most of the foliar damage is on the side of the tree that faces the road. Coniferous species, especially pines, were highly susceptible to salt damage. Regardless of species, the concentrations of Na in leaves were higher in the plants exhibiting damage than the plants of the same species with healthy appearance. The Na levels in plant leaves decreased as the distance from the road increased regardless of species. About 90% of the salt that is sprayed from the road is found within 30 feet of the pavement; therefore, the farther plants are from the pavement, the less the chance of the spray to contact the plants. It seemed also that deciduous species were more tolerant of NaCl than coniferous species. Coniferous species have more surface area to intercept the salt from spray than the deciduous species, which do not have foliage in the winter.

Sodium concentrations in roadside soils and in foliage of roadside vegetation are an indication of the potential of plant injury from deicing salts. The concentrations of Na in the soil decreased as the distance from the pavement increased. The soil pH values were more alkaline at distances closer to the road. It appears that the Na on the soil complex results in a slightly alkaline soil. Electrical conductivity (EC) values, a measurement of the soluble salts, were highest at sites close to the road than at sites away from the road.

Review of literature for characterization of roadside conditions indicated that high concentrations of Na in the soil can also affect plant species in ways other than direct toxicity by Na. The Na in the soil can reduce soil structure and can have adverse effects on the microenvironment of the rhizosphere by reducing oxygen to the roots. The Na also can affect the fertility status of the soil by exchanging with the available nutrients on the soil complex and could eventually lead to nutrient deficiencies with subsequent leaching of cations. When plants are stressed by low fertility or reduced oxygen at the roots or by injured foliage, they become susceptible to diseases. Considerable infestation of diplodia disease (*Sphaeropsis sapinae*) was noted on black pine (*Pinus thunbergii*), which was not sampled in this study.

The concentrations of Na in the leaves of plants and in the soil can be influenced by many factors, such as, amount of NaCl applied to the roads, plant distance from the pavement, slope of the topography, wind, daily traffic, frequency of road plowing, soil permeability, and soil texture.

Survey of Agencies

Surveys were mailed in March 2000 to landscape architects and supervisors at twenty-five state or federal highway agencies in cold-weather regions of the United States and Ontario, Canada. Fourteen states across the northern half of the United States and one province of Canada participated in the survey. Most of the agencies addressed the queries in the survey sufficiently to convey information about practices of additions of deicing materials, injury to vegetation, and practices for alleviating salt damage.

The amount of roadway mileage requiring snow and ice control differed considerably among agencies, with Rhode Island having the least (4,000 lane miles) and Pennsylvania having the most mileage (over 96,000 lane miles). The most common deicing agent used was NaCl. Only New Hampshire and South Dakota stated that solid calcium chloride ($CaCl_2$) was used as a deicing agent, and similarly only Indiana and Massachusetts used calcium magnesium acetate. Calcium chloride was most often used as a liquid additive to solid materials such as NaCl or sand. The average amount of sand with deicing agents used per season was 17 tons per lane mile. Of the fifteen agencies that responded, only Montana, Wisconsin, and Minnesota used corn by-products, and only North Dakota used ashes or cinders in their winter maintenance programs.

Sodium chloride was most often used as a deicing agent on roadways when temperatures were between 20 and 32°F, whereas $CaCl_2$ was the salt of choice at temperatures lower than 20°F. The average rate of NaCl use was 280 lb per lane mile, and the average sand mix rate was 450 lb per lane mile. Brine and liquid mixtures were used primarily for pre-wetting roads and for bridges at an average rate of 35 gals. per lane mile. Of the deicing materials used, NaCl was considered the most damaging to roadside vegetation. Only eight states responded to the portion of the survey concerning the damage of deicing agents to vegetation. However, all eight observed damage to white pine (*Pinus strobus*) by road-applied salts. The most common damage to evergreens was a browning or necrosis of the needles facing the roadway, whereas deciduous trees and shrubs suffered from die-back and witches broom(abnormal brushlike growth of weak, closely clustered shoots at the ends of branches). Several agencies observed that evergreens were damaged most often from salt spray and that deciduous plants suffered principally from salt-containing runoff. Most damaged trees were at or within approximately 50 feet from the roadway (pavement), but some were up to 300 feet away. Only one-third of all agencies surveyed indicated that they monitored roadside vegetation for salt damage.

Most design criteria dictated that larger trees be located at least 30 feet from the roadway, mainly for automobile safety reasons. In general, the distance at which a particular plant type could be placed from the road was related to the caliper (the diameter of the trunk three feet from the ground) of the plant and degree to which the vegetation would impede visibility. Some states have designated, where possible, a five to thirty foot clear zone from the edge of the pavement in which no shrub or tree can be present. In the narrative report, tabulated data are provided to give details of the responses to the survey.

Availability of Salt-Tolerant Plant Materials

The research under this task determined the availability of salt-tolerant species at New England nurseries and at nurseries in other northern areas if these nurseries had sales representatives in the New England area. Limiting the assessment of availability to the New England area was a necessity to help to ensure winter hardiness in Massachusetts. The review of literature (Section 2.0, Table 2.2) established a list of salt-tolerant plants from which selections were made for determinations of availability in the New England market area. The determination of availability of plants was by written and telephone contacts of vendors followed by consultation of catalogs provided by the vendors. Trees, shrubs, and groundcovers, including turfgrasses, were listed (Table 5-1) only if they were identified to be salt tolerant. None of the plants listed in Table 5.1 have been suggested to be invasive (see Appendix IV).

Preparation of Specifications and Methodology

The negative impacts of salinity on plants can be partially alleviated by the application of certain soil amendments. The most commonly used are calcium-containing salts, such as calcium sulfate ($CaSO_4$) and calcium chloride ($CaCl_2$), and other agricultural amendments such as Mg- and P- containing fertilizers. Most soil amendments are designed to improve soil tilth (the physical condition of soil in relation to plant growth) and fertility by imparting physical changes in the soil. In some instances, amendments with Ca-containing salts may reduce the toxicity of Na and Cl by blocking absorption of these elements by plant roots. Applications of calcium-containing salts also can improve soil tilth since a consequence of using Na-containing (sodic) salts for deicing is the loss of favorable soil structure by dispersion of clays if Na enters the soils along roadsides. Calcium ions will displace Na ions from clays and bring about flocculation and aggregation of the clays. Organic amendments such as peat, compost, or leaf litter may improve soil tilth, thus enhancing the growth of plants subjected to Na-containing salts.

The extent to which soil amendments can ameliorate salt damage to existing vegetation needs investigating. If existing vegetation is injured by salt, lacks aesthetic value, or is otherwise unsuitable, salt-tolerant herbaceous and woody species need to be selected and investigated for planting along roadsides. It is not understood if soil amendments are needed when salt-tolerant plant species are used along roads, and the potential advantages of combining these plants and amendments in the same area needs to be investigated.

Designs for research are presented in the narrative section for testing of soil amendments and plant species in highway medians and at interchanges. Sites in western Massachusetts for conducting the research are suggested.

Because of their ease of access for experimental work and their exposure to deicing agents, highway medians are ideal places to conduct salt tolerance studies. They are some of the primary sites where salt damage occurs to herbaceous vegetation. Because of location, vegetation in medians could receive larger amounts, perhaps twice the amount, of deicing salt as vegetation along the outer perimeters of the roadway, thereby exposing experimental plots placed in the medians to heightened levels of salinity. The terrain of medians and the lack of appreciable obstructions also allow them to accommodate equipment for practices such as spraying chemicals, plowing or tilling, and seeding. This area also lends itself to ease of observation, as differences among treatments can be viewed and accessed easily along the roadway. An experiment was proposed to assess seven vegetation treatments combined with five soil amendments.

Areas near intersections or overpasses are also ideal for studying the effects of deicing salts on vegetation. Efforts to control ice formation during winter months will be intensive where major roads cross, with the potential for more salt usage in these areas than in lone stretches of highway. Depending on location, vegetation may receive road spray and saline runoff from upper and lower roads at an overpass. Similarly, areas located at the junction of ramps and the main highway will also be subjected to deicing salts from two different road surfaces. These angle-shaped plots are common to places where ramps and main highways meet and are prime locations for field plots for the evaluation of shrubs and ground cover salt tolerance. Use of trees and tall shrubs for research at interchanges might be avoided because of potential obstructions of views by the plants.

An experiment was designed for future research at interchanges and included four soil amendment and four vegetation treatments.

1.0 INTRODUCTION

A study of de-icing salts, salt-tolerant vegetation, and calcium sulfate was undertaken as part of the Massachusetts Highway Department Research Program. The objectives of this research were (1) to conduct a literature search to characterize chemical processes and subsequent damage to vegetation from airborne and soil-borne de-icing salts, (2) to characterize roadside conditions in Massachusetts by assessment of damage to trees, shrubs, and grasses along highways, (3) to conduct a survey of cold-region highway departments for methods and specifications of mitigating salt damage along highways, (4) to prepare specifications and methodology for ameliorative practices and recommendations for evaluation of salt-tolerant plants. The research process began in January 2000 with research continuing in the spring, summer, and fall of 2000.

2.0 LITERATURE SEARCH

2.1 Salt Tolerance of Various Types of Roadside Vegetation

Salts are used extensively in cold regions to suppress the formation and accumulation of ice on roadways during winter months. Despite their effectiveness for deicing, road applied salts can have negative effects on vegetation. For a highway planting to be sustainable, consideration should be given to the salt tolerance of plants, as they vary in ability to withstand saline runoff and road spray. In a survey conducted in this research project, several transportation agencies indicated that plants were considered to be either tolerant or sensitive to deicing salts (see Section 4.0 Survey of Agencies). A need exists to verify these observations with findings from formal research as presented in the scientific literature.

It can be difficult to ascertain whether salt damage to a particular plant is caused by saline runoff, road spray, or both deliveries. Although both means of salt deposition can negatively affect roadside vegetation (Townsend, 1980), research efforts usually focus on one or the other, but seldom on both means. This emphasis results in a shortcoming in some salt-tolerance studies. It should not be inferred that because a plant is capable of withstanding saline conditions in the root zone that it is equally capable of tolerating salt spray on its leaves or vice versa. For example, many researchers agree that white pine (*Pinus strobus)* is damaged by salt spray (Barrick et al., 1979; Hofstra and Hall, 1971; Simini and Leone, 1986), but Townsend (1980) suggests that this tree is unaffected by saline conditions in the root zone. Reports concerning the salt-tolerance of plants should be evaluated in view of the focus and type of the experiments that were conducted. Likely, plant damage reported in survey-type studies, such as those of Gibbs and Palmer (1994) and Shortle and Rich (1970), is related to root or foliage stress caused by salt delivery from saline runoff or sprays or by a combination of these means. However, these studies did not identify the source of the salt damage.

Numerous traits influence the salt tolerance and suitability of plants for roadside designs. For instance, young trees are said to be more susceptible to salt injury from runoff than older or mature trees because the young trees have less extensive and more shallow root systems (Gibbs and Palmer, 1994). Rooting depth appears to be an important trait, as the deep-rooted oaks (*Quercus* spp.) suffer less damage from saline runoff than more shallow rooted maples (*Acer* spp.) (Westing, 1969). Evergreens are suggested to be less tolerant of saline road spray than deciduous species because evergreens retain foliage in winter and therefore intercept the saline spray directly on the leaves (Simini and Leone, 1986). In addition, cuticle characteristics (Hofstra and Hall, 1971; Lumis et al., 1973) have been also linked to salt tolerance. Also, although many salt-tolerant plant species are reported in the scientific literature, a significant portion of these have disease and insect problems or growth traits, making them unfavorable for landscape use.

Evergreens are valuable in cold regions because they are among the few plants that provide color in the winter landscape. However, few reported salt-tolerant evergreen plants lack serious insect or disease problems. For instance, Austrian pine (*Pinus nigra*) is tolerant of salt spray (Barrick et al., 1979; Lumis et al., 1973) but is susceptible to pine nematode and diplodia (Dirr, 1998). Similarly, Japanese euonymus (*Euonymus japonicus*) is not affected by salt runoff (Bernstein et al., 1972) but is plagued with numerous insect and disease problems (Dirr, 1998). Other evergreens, such as Mugo pine (*P. mugo*), are tolerant of road spray (Hofstra and Hall, 1971) but are not commonly used because of tremendous variability in their growth habit (Dirr, 1998). Although evidence indicates that white pine withstands saline conditions in the root zone, this tree may not be suitable for roadside planting because of its sensitivity to salt sprays (Barrick et al., 1979; Hofstra and Hall, 1971; Simini and Leone, 1986; Townsend, 1980).

Alternatively, Eastern red cedar (*Juniperus virginiana)* was unaffected by deicing practices along New Hampshire highways (Shortle and Rich, 1970). According to Dirr (1998), this plant can be used to create windbreaks and screens and can grow in a wide range of soil conditions. Because of the tendency of Eastern red cedar to be taller than wide (40 to 50 ft tall, 8 to 20 ft wide), this plant can be located close to power lines and other obstacles. Although many members of the juniper family are considered to be salt tolerant, a surprising lack of research has been made to establish this effect.

Sensitive evergreen trees indicated in the scientific literature (Table 2-1) include Colorado blue spruce (*Picea pungens*) (Monk and Peterson, 1962; Monk and Wiebe, 1961), Red pine (*Pinus resinosa*) (Shortle and Rich, 1970; Sucoff et al., 1975), White pine (Barrick et al., 1979; Hofstra and Hall, 1970; Simini and Leone, 1986), Douglas fir (*Pseudotsuga taxifola*) (Monk and Peterson, 1962; Monk and Wiebe, 1961), and Hemlock (*Thuga* spp.) (Monk and Peterson, 1962; Westing, 1969). In addition, several evergreen shrubs were indicated as being salt sensitive (Table 2-1) including glossy abelia (*Abelia grandiflora*) (Francois and Clark, 1978), Compact strawberry tree (*Arbutus unedo*) (Francois and Clark, 1978), Winged euonymous (*Euonymus alatus*) (Lacasse and Rich, 1964; Monk and Wiebe, 1961), Burford holly (*Ilex cornuta*) (Bernstein et al., 1972), and Oregon grape holly (*Mahonia aquifolium*) (Francois and Clark, 1978).

Salt-tolerant deciduous trees and shrubs were more commonly reported in the scientific literature than evergreens (Table 2-2). Several trees, such as Ash (*Fraxinus* spp.) (Gibbs and Palmer, 1994), Aspen (*Populus* spp.) (Shortle and Rich, 1970), Birch (*Betula* spp.) (Gibbs and Palmer, 1994; Lacasse and Rich, 1964; Shortle and Rich, 1970), Honeylocust (*Gleditsia triacanthos*) (Monk and Peterson, 1962; Monk and Wiebe, 1961; Townsend, 1980), and White oak (*Quercus alba*) (Holmes, 1961; Westing, 1969), have limited value in roadside designs because they are plagued by various insect and disease problems (Dirr, 1998). These trees may be useful in high priority areas if necessary management practices are employed. Birch trees, despite their problems, have bark that gives character to otherwise bland winter tree stands. Some trees, such as White oak and Black oak (*Quercus velutina*) (Holmes, 1961; Westing, 1969), may be difficult to transplant and establish because they have significant tap roots. In contrast, salt-tolerant Pin oak (*Quercus palustris*) (Townsend, 1980; Westing, 1969) and Red oak (*Quercus rubra*) (Shortle and Rich, 1970; Westing, 1969) have shallow, fibrous root systems, which facilitate transplanting and rapid establishment (Dirr, 1998).

Some salt-tolerant deciduous plants, such as Russian olive (*Elaeagnus angustifolia*) (Catling and McKay, 1980; Monk and Peterson, 1962), Silver buffaloberry (*Shepherdia argentea*) (Monk and Wiebe, 1961), and Black locust (*Robinia pseudoacacia*) (Shortle and Rich, 1970) can live in poor, unfertile soil conditions because they fix atmospheric nitrogen. Based on abilities to grow in poor soils and on drought- or salt-tolerance, good deciduous plants for roadside planting are Russian olive, Silver buffaloberry, Tamarix (*Tamarix* spp.) (Lacasse and Rich, 1964), Black locust, Pin oak, and Red oak.

Salt-sensitive deciduous species reported in the literature are Dogwood (*Cornus florida*) (Townsend, 1980), American elm (*Ulmus americana*) (Shortle and Rich, 1970), Hickory (*Carya* spp.) (Shortle and Rich, 1970), Ginkgo (*Ginkgo biloba*) (Gibbs and Palmer, 1994), Linden (*Tilia* spp.) and Squaw bush (*Rhus trilobata*) (Monk and Peterson, 1962; Monk and Wiebe, 1961), and various maples (Barrick and Davidson, 1980; Holmes and Baker, 1966; Lacasse and Rich, 1964). Future research needs to identify deciduous plants that have few disease and insect problems and that provide ornamental value, such as fall color, for which the northeastern United States is well known. Also, uncertainty exists as to whether some plants are salt-tolerant or salt-sensitive, as some researchers may have observed tolerance, whereas others observe sensitivity, for the same species, as is particularly the case with American elm.

Transportation agencies need to assess through research each species, and perhaps individual cultivars, for suitability as roadside planting in a given area. Agencies should be aware, also, of the invasive nature of some plants. Listings of invasive plants have been prepared (Massachusetts Highway Department; University of Connecticut; see Appendix IV). Appearance of a plant on these lists does not necessarily ban a plant from consideration in highway landscaping, as criteria are not firmly established. However, these listings should be consulted as guidelines for plants that might be avoided, particularly if alternatives are readily or equally available. Only three of the species listed in Table 2-2 may have invasive tendencies (Table 2-4).

Westing (1969) suggests that grassy vegetation is more resistant to salt injury than is woody vegetation, and seeding of salt-tolerant grasses along roads may be the least expensive way of maintaining roadside vegetation (Catling and McKay, 1980). Most grasses listed in Table 2-2 are halophytic grass species (Catling and McKay, 1980). Quackgrass (*Agropyron repens*), Plains bluegrass (*Poa arida*), Saltmeadow cordgrass (*Spartina patens*), and members of the genus *Puccinellia* are among a few reported. These grasses should be used in accordance with their ability to withstand highway mowing practices, or they should be used in areas where roadside maintenance is not a priority. Quackgrass is considered as a weed in agronomic practices. Sensitive grasses reported in the scientific literature (Table 2-1) are bentgrass (*Agrostis stolonifera*) (Ashraf et al., 1986), velvet grass (*Holcus lanatus*) (Ashraf et al., 1986), and Kentucky bluegrass (*Poa pratensis*) (Greub et al., 1985). A need exists to investigate the benefits of grass mixes and possibly the use of legumes for roadsides where deicing salts are commonly used, as this information is lacking in the scientific literature.

The following review gives details on the salt tolerance of grasses and an assessment of their suitability for roadside planting. Winter hardiness of grasses and their susceptibility to drought are important criteria to consider in selection of grasses for roadsides. The review suggests that grasses that are tolerant of drought are likely to be resistant to salt damage.

2.2 Salt Damage to Roadside Grasses

High soluble salt concentrations are major problems limiting turfgrass growth associated with the use of deicing salts along highways, sidewalks, and airport runways. Salinity damage may be directly the result of soluble salts in the soil or a combination of soil physical and chemical factors imparted by salts. For example, sodium-contaminated soils often drain poorly and are prone to compaction. Therefore, field studies are often required to establish plant response to the effects of salinity because of the complex interaction between soluble ions and edaphic (soil physical properties)-environmental factors.

In the humid Northeast, salts are leached continually from the root zone and are less likely to be a problem limiting turfgrass growth than in more arid regions. However, large quantities of salt (primarily NaCl) enter areas of roadside turf as the result of applications for snow and ice removal from pavements. The survey of use of deicing agents (see Section 4.0 in this report) indicates single application rates of 50 to 600 lb/lane mile and total applications of about 20 tons/lane mile annually (240 lb/lane mile and about 20.7 tons total/lane mile in Massachusetts), with multiple applications of these rates over the winter. Hutchinson (1970) estimated that typical total annual applications were 15 to 25 tons/lane mile, which are within the range of applications today. These deicing rates typically applied to highway areas are an important consideration when designing representative field experiments (See Section 6.0 in this report). The loss of grass cover along roadside areas results in soil erosion, weed encroachment, and costly re-establishment. Fertilizer is another potential source of salinity; however, roadside turf is rarely, if ever, fertilized.

Through osmotic desiccation, excess soluble salt restricts water intake (physiological drought). Grasses vary widely in their tolerance to salinity and in their associated mechanisms for withstanding or responding to salinity. Tolerance may be achieved by partitioning photosynthetic products from shoots to roots, through osmotic adjustments within tissues, and by accumulation of organic acids in tissues (Ackerson and Youngner, 1975).

Alternatively, a salt exclusion mechanism has been suggested to be operating for salt-tolerant Creeping bentgrass (*Agrostis palustris*), which took up less NaCl than non-tolerant genotypes of creeping bentgrass (Wu, 1981). Salt-tolerant species and cultivars were associated with less salt uptake and had higher leaf levels of K, Mg, and Ca than sensitive types (Torello, 1985).

Salt-tolerant types also accumulated 8 to 15 times more proline than sensitive cultivars. Proline accumulation has been associated with salt- and drought-tolerance in stabilizing osmotic imbalances (Levit, 1972). In general, increasing salt concentrations in soils increases osmotic stress (physiological drought or inability of plants to absorb water) as well as the potential for direct toxic and nutritional problems imparted by the salts.

Accumulation of one or more salts can alter the uptake of other nutrients, thereby causing mineral deficiencies. Increased concentrations of Na and Ca in tissues of Bermudagrass (*Cynodon* spp.) (Ackerson and Youngner, 1975) and Seashore paspalum (*Paspalum vaginatum*) (Dudeck and Peacock, 1985a) have been associated with decreased concentrations of K, Mg, and Ca with increasing soil salinity. The possibility of Ca deficiency has been suggested with increasing salinity (Rhoades, 1983). The partitioning of Na within the plant has been suggested as a salt tolerance mechanism in creeping bentgrass. Specifically, the highest concentrations were found in roots, and the lowest concentrations were observed in young leaves following treatment with NaCl (Chetelat and Wu, 1986). Chlorine concentrations were uniformly distributed throughout the plant. Several cool-season turfgrasses exhibited tolerance to Cl when Cl content in leaf tissues was less than 15,000 $mg \cdot kg^{-1}$, whereas Cl toxicity and limited growth was evident when tissues levels exceeded 30,000 $mg \cdot kg^{-1}$ (Cordukes, 1970).

The salt tolerance of turfgrass is based on plant growth responses to increasing salinity. Salinity affects shoot and root growth (Chetelat and Wu, 1986; Dudeck et al., 1983; Horst and Taylor, 1983; Torello and Symington, 1984; Youngner and Lunt, 1967). Root biomass increases with increasing salinity is a common plant response as a means to enlarge water and nutrient absorbing characteristics in response to water (osmotic) and nutrient stress (Dudeck et al., 1983; Parker, 1975; Torello and Symington, 1984; Youngner and Lunt, 1967). A concurrent decrease in shoot growth with increasing root growth is generally observed with increasing salinity (Dudeck et al., 1983). The suppression in shoot growth (leaf length) with increasing salinity is generally greater for salt-sensitive species and varieties than with tolerant turfgrass (Torello and Symington, 1984). Significant differences in salt tolerance have also been observed for germinating and establishing turfgrasses (Horst and Taylor, 1983). The drop in germination rate reported with increasing salinity has been attributed to increased osmotic stress (Dudeck and Peacock, 1985b).

Early visual symptoms associated with salt stress are similar to drought stress; specifically, narrow leaf width, stiffer blades, and darker blue-green color are observed. As salt stress progresses, shoots appear wilted (even though soil moisture is non-limiting) and become increasingly darker in color. High salinity levels cause leaf tip die back (leaf firing) and stunted shoot growth. Stunted shoot growth results in the loss of turfgrass density, eventually causing shallow rooting. Salinity problems can be identified by these visual symptoms; however, diagnosis is easily confused with drought stress symptoms. Accordingly, chemical analysis to identify the levels of soluble salts (soil electrical conductivity), pH, and the relationship between Na to Ca and Mg (*i.e.*, sodium adsorption ratio) are useful in diagnosis (Harivandi et al., 1992).

Low or high soil pH can play an indirect role in salinity damage because of nutrient toxicity and deficiency associated with soil acidity. Soil salinity at levels not ordinarily problematic can cause injury under extreme pH conditions (Harivandi et al., 1992). Optimum pH range for most turfgrass is 5.5 to 7.0 (Beard, 1973). However, altering soil pH of utilitarian turf such as roadside areas may not be a practical strategy for reducing salinity damage because of the cost of materials. Perhaps, selection of grasses that are salt-tolerant is a more practical strategy. Alternatively, severe salinity problems from deicing salts might be reduced by using road salts other than NaCl such as Calcium chloride (Harivandi et al., 1992).

Wide differences in salt tolerance exist among and within species of common turfgrasses (Dudeck and Peacock, 1985a, 1985b; Dudeck et al., 1983; Harivandi et al., 1982, 1983; Horst and Taylor, 1983; Wu, 1981; Youngner et al., 1967) (Tables 2-1 and 2-2). Intra-specific differences in salt-tolerance among cultivars have been reported (Dudeck and Peacock, 1985b; Harivandi et al., 1992; Horst and Taylor, 1983), allowing for the possibility of selecting more salt- tolerant genotypes. Further research is needed to evaluate cultivar differences in tolerance to salinity.

Since salt and drought tolerance are highly correlated (Levit, 1972), the potential exists to screen simultaneously for improved salt and drought tolerance. Therefore, selecting turfgrass varieties having superior drought tolerance may be an indirect but effect method for identifying genotypes with improved salinity tolerance. Extensive research targeting drought tolerance among turfgrass varieties for some of the major cool-season species have been conducted (Huang et al., 1998; Minner and Butler, 1985; White et al., 1993) and could be used to select cultivars for salinity tolerance evaluations.

However, it is important to recognize that salt-tolerant species can have their tolerance reduced under adverse stress conditions (poor drainage, drought, compaction, strongly acidic or alkaline soil pH).

Salinity can vary within a site resulting in patchy grass cover. To provide a permanent grassy cover, selecting grasses having superior tolerance to salt, drought, low fertility, low soil pH (a major limiting factor on unlimed soils in Massachusetts), and water submersion are important selection criteria to consider because these are major factors limiting turfgrass growth along highways. No single species alone can provide the wide adaptability and tolerance to all of these growth limiting factors. Consequently, mixtures of different species that provide a broad genetic base are required, including those species not necessarily tolerant of salinity.

2.3 Deicing Salt Effects on Woody Roadside Plants

Salting roads to melt ice and snow is a necessary practice to maintain safe driving conditions in the northern United States and in other places worldwide with similar winter climates. Sodium chloride is the most widely used chemical deicer because of its ready availability, low cost, and high degree of effectiveness. In Massachusetts, between 1975-1976 and 1989-1990, the Massachusetts Highway Department applied an average of 201,519 tons each winter or about 16.6 tons per lane mile to roads and highways under its jurisdiction (Pollock, 1992). The current application reported for Massachusetts highways is 290,000 tons of NaCl annually or about 20.7 tons/lane mile annually (see Section 4.0). Undoubtedly, if the amount of salt used by municipalities and on private property could be determined, the total amount of salt used for deicing in the state would be much higher than the value estimated.

The necessity of treating roadways to melt ice and snow is clear, but there are substantial hidden costs to salting. D'Itri (1992) cites a 1987 study by the New York State Energy Research and Development Authority, which estimates that for each dollar spent on road salt $57 of damage results to roads, bridges, vehicles, and contamination of water supplies. The contamination of ground and surface drinking water supplies by road salt and its potential effects on human health has received the greatest recent attention. Labadia and Buttle (1996) reported significant movement of NaCl through the unsaturated zone of roadside soils from highway surface runoff and from salt in melting snow banks to cause saline recharge of groundwater. The water contamination problem caused by road salt in Massachusetts and the response to it was reviewed by Pollock (1992).

The potential negative effects of chemical deicers on the roadside natural environment have been studied from a number of perspectives other than drinking water quality. Elevated salinity of lakes and streams may negatively affect many aquatic organisms, including fish, aquatic insects, and microorganisms (Jones et al., 1992). Wilcox (1986) studied a sphagnum peat bog and found that native plant species were replaced by non-bog species in response to contamination of the wetland by road salt. Presumably, the non-bog plants had an advantage over the native species due to their higher salt tolerance.

Soil structure, chemistry, and microbiology may be affected by road salt. High exchangeable Na resulting from NaCl applications may cause the dispersion of organic matter and other colloids (Amrhein and Strong, 1990) and a reduction in soil permeability (Amrhein et al., 1992). Sodium chloride-induced dispersion of organic matter and other soil colloids can result in increased mobilization of trace metals (Norrstrom and Jacks, 1998), including lead (Pb) in roadside soils (Howard and Sova, 1993), and may threaten groundwater. Gunter and Wilke (1983) measured soil enzyme activity in a forest soil treated with deicing salt and found significant but temporary reductions in the activity of several soil enzymes, such as urease, reflecting an inhibition of microbial activity in the salt-treated soil. Clearly, the results of soil research suggest that deicing salts could have a number of negative effects on roadside plants through salt effects on the soil.

Most research on deicing salt effects on roadside plants has focused on direct effects of salts on vegetation. The following review considers the effects of deicing salts on roadside perennial woody plants, such as trees, shrubs, and ground covers.

2.31 Symptoms of Deicing Salt Injury to Woody Plants

Researchers agree about the general characteristics of foliar and plant symptoms of deicing salt injury on deciduous woody plants and needle-leaved evergreens. The symptoms summarized here are based on the field observations of Hofstra et al. (1979), Lumis et al. (1973), and Lumis et al. (1975), and the reviews by Blaser (1976) and Dirr (1976).

With salt injury of deciduous species, vegetative and flower buds are often slow to develop or do not develop at all. This suppression in bud development may result in die back of branches less than two-years old.

Based on their observations of flowering trees and shrubs, Hofstra et al. (1979) concluded that flower buds are more sensitive to salt than vegetative buds as salt-affected plants often leaf out well but have no flowers. Inhibition of vegetative and flowering buds caused by deicing salt can reduce the productivity of economic tree species such as Apple (*Malus sylvestris*) (Hofstra and Lumis, 1975) and Lowbush blueberry (*Vaccinium angustifolium*) (Eaton et al., 1999). Some evidence suggests that NaCl-salt treatments can reduce the cold hardiness of deciduous species. Sucoff and Hong (1976) found that regular applications of 3% NaCl solutions during the period November to January reduced the hardiness of apple and lilac (*Syringa* spp.) twigs. In general, the symptoms of salt injury to the buds and twigs of deciduous species do not become apparent until the end of dormancy when active growth begins in the spring.

If deciduous species are actively growing and have leaves when salt treatments are made, as in Townsend's (1980) study of six urban tree species, then leaves show yellowing at the leaf tips first and then chlorosis and necrosis of the leaf margins. Similar foliar symptoms have been reported for trees growing along the roadside including Sugar maple (*Acer saccharum*) (Rubens, 1978).

Most of the work on the response of evergreens to deicing salt has focused on pine (*Pinus* spp.), hemlock (*Tsuga* spp.), and spruce (*Picea* spp.). The foliar symptoms of injury to these plants are very similar. In general the foliar symptoms of salt injury on evergreens starts as necrosis at the needle tips and then spreads to the base. Sometimes the appearance of chlorosis precedes the development of the necrosis (Townsend, 1984). Normally the symptoms of injury become apparent on evergreen species in late winter or early spring well before injury is noticeable on deciduous species. Under experimental conditions, symptoms can appear very rapidly. Townsend and Kwolek (1987) observed symptoms on containerized pines growing outdoors by two weeks after the pines were first sprayed with NaCl (2% w:v solution) in early March.

Anatomical as well as morphological effects on the leaves of White spruce (*Picea glauca*) and Northern red cedar (*Juniperus virginiana*) were studied by Kutscha et al. (1997). Profound abnormal effects on leaf anatomy resulted from soil or foliar applications of NaCl and included stomatal injury, fragmented cuticle, cell wall damage and abnormal chloroplasts. Injury increased with salt concentration and was worse with foliar than with soil application. Based on these results, it is not a surprise that Beaudoin (1992) found that injury to 32 coniferous tree species exposed to deicing salt spray was serious enough to result in a significant reduction in the foliar mass of the trees, a suppression in their photosynthetic capacity, and in most cases a significant suppression in total height at a given age, relative to unexposed trees.

2.32 Tolerance of Woody Plants to Deicing Salts

Large, comprehensive lists ranking the relative salt tolerance of woody roadside trees and shrubs based on the results of controlled research projects are not available. Most listings are based on reviews of a number of studies conducted in different ways and with different field observations. The most frequently cited list of woody plants and their sensitivity to road salt was compiled by Lumis et al. (1973) (Table 2-3). Plant sensitivity was determined by careful observations made in the spring along a highway in Ontario, Canada. Sensitivity ratings were based on plant injury due to aerial deposition of salt the preceding winter. Dirr (1976) compiled a list of the relative salt tolerances of trees citing the work of number of authors, but leaning heavily on the work of Lumis et al. (1973). Similar lists have been prepared by Carpenter (1970), Davidson (1998), and Kelsey and Hootman (1992). In general, agreement is good among the lists, which provide enough information for selecting salt-tolerant woody plants for roadside use anywhere in the northern United States.

2.33 Some Variables in Controlled Studies on Salt Tolerance of Roadside Plants

Many experimental approaches have been used to study the tolerance of roadside plants to deicing salt and are the greatest weakness of research in this area. Field observations of plants actually affected by routine road salt applications are one way that determinations of salt tolerance have been made (Lumis et al., 1973; Langille, 1976; Shortle and Rich, 1970). A major difference among these studies was the time of the year when observations were made and data were collected. Lumis et al. (1973) made their observations of plant injury in the "spring," Langille (1976) made his observations and collected leaf samples for Na and Cl analysis in mid-July, and Shortle and Rich (1970) did the same in late August and early September. Perhaps a study evaluating salt tolerance of plants should be designed to make observations and measurements at intervals starting as growth begins and ending just before leaf fall.

Although the results of field observations have helped develop an understanding of the response of roadside plants to deicing salt, many studies have been conducted on plants growing in containers under controlled conditions outdoors, in a greenhouse, or in a growth room. In these studies, salt is applied to actively growing or dormant plants by spraying on the aboveground plant parts or adding to the growth medium.

Townsend (1983) studied the salt tolerance of seven pine species by spraying dormant seedlings with NaCl solution (20 g NaCl/liter water) in a cold room (1-7°C) and then transferring the plants to a greenhouse (7-13°C) to allow symptom development. Eastern white pine (*Pinus stobus*) and two other species were the least tolerant of salt spray whereas Japanese black pine (*P. thunbergii*) and Swiss stone pine (*P. cembra*) exhibited the most tolerance.

In another study of 13 species of pine, Townsend and Kwolek (1987) grew plants outdoors in pots in a lath house for three years and sprayed them with NaCl solutions of varying strengths during March and April in each year. Based on symptoms, survival, and growth, plants were classified as "most tolerant," "most susceptible," and "intermediate in susceptibility" to salt spray. As in the earlier study (Townsend, 1983), Eastern white pine (*Pinus stobus*) was among the most susceptible, and Japanese black pine (*Pinus thunbergii*) was among the most tolerant; but contradicting the earlier results, Swiss stone pine (*Pinus cembra*)was among the most susceptible.

Salt tolerance of roadside woody plants has been studied by applying salt to a growth medium, often a substrate of very different consistency than roadside soil. Dirr (1978) determined salt tolerance of two-year-old seedlings of seven deciduous species growing in pots in a greenhouse. Plants were treated daily with NaCl solutions (14.5 g NaCl/liter water) applied to the growth medium of soil, perlite, and peat. Tolerance was determined by the appearance of symptoms of salt injury. Russian olive (*Elaeagnus angustifolia*) and Saltspray or Rugosa rose (*Rosa rugosa*) were not injured by treatment, whereas others showed moderate to severe injury.

In a greenhouse experiment, Headley et al. (1992) grew thirty-three cultivars of English ivy (*Hedera helix*) in a growth medium consisting of sphagnum peat moss and perlite; the growth medium was irrigated or the plants were sprayed daily with NaCl solution (14.5 g NaCl/liter water). Less visible salt damage, but greater reductions in dry weight, occurred when salt solution was applied to the growth medium instead of sprayed on the plants.

Some research suggests that the growth medium used in experiments with soil-applied salts may affect plant response. Fostad and Pedersen (2000) reported that Norway spruce (*Picea abies*) grown in sand were killed by salt application, but were much less affected by the same salt treatments when grown in peat, loam, or silt loam. In the same study, Norway maple (*Acer platanoides*) was injured more by salt when the plants were grown in peat than in silt loam; however, the opposite effect was true with silver birch (*Betula pendula*) and Scots pine (*Pinus sylvestris*).

Hydroponics systems with NaCl-saline nutrient solutions have been used to study the effects of salts on trees. In Townsend's (1980) solution culture study, salt treatments ranged between 0 and 7 g NaCl/liter, and the salt tolerance exhibited by some of the plants was similar to that generally accepted for the species.

Conclusions on salt tolerance of woody roadside plants have been drawn from experiments using either dormant or actively growing plants, but very little has been published on the effects of timing of salt application in relation to these growth phases of woody plants.

Probably the best demonstration of the effects of salt application timing on apparent salt tolerance was published by Headley and Bassuk (1991). The authors irrigated separate groups of container-grown Norway maple (*Acer platanoides*), Red maple, Pin oak, and Red oak with NaCl solutions once every month between October and April. Plant damage assessment and growth measurements were made in May. Plants treated between November and March, the dormant period, showed little damage and no reduction in growth relative to untreated plants. Plant damage, growth suppressions, and Na and Cl accumulation in the shoots were much greater with October and April treatments when the plants were not dormant.

Similar results--less damage and ion absorption with salt treatment during the dormant season--were obtained by Walton (1969) with Norway maple by Hofstra and Lumis (1975) with apple (*Malus* spp.), and by Lumis et al. (1976) with several evergreen and deciduous tree species. The results suggest that treating actively growing woody plants, particularly deciduous species, may not be the best indicator of deicing salt tolerance since most often road salt is applied during the dormant period.

2.34 Causes of Deicing Salt Injury to Roadside Woody Plants

Most of research on the effects of deicing salt on roadside woody plants has focused on the correlation between plant injury and the accumulation of Cl and Na in plant tissue following absorption through the foliage or from the soil through the roots. Elevated concentrations of Na and Cl in the stems or leaves generally correlate very well with the severity of symptoms that develop on the foliage of deciduous and evergreen woody plants following salt treatment (Fostad and Pedersen, 2000; Hofstra et al., 1971; Hofstra et al., 1976; Hofstra et al., 1979; Townsend and Kwolek, 1987).

Salt tolerance has been linked to the level of accumulation of Na or Cl or both elements in tissue of English ivy (*Hedera helix*) cultivars (Headley et al., 1992), *Pinus* species (Townsend and Kwolek, 1987), and plants from various other genera (Dirr, 1978; Lumis, et al., 1976; Townsend, 1984). In general, where the internal concentrations of both elements have been studied, results have shown that elevated tissue concentrations of Cl, rather than Na closely correlate with the occurrence and severity of foliar symptoms on a wide variety of woody, roadside plants (Dirr, 1974; Dirr, 1975; Dirr, 1978; Simini and Leone, 1986; Townsend, 1980; Walton, 1969).

However, in one study, elevated Na in leaf tissue of red oak and American beech (*Fagus grandiflora*) correlated better with poor growth and foliar injury than Cl (Thornton et al., 1988). Although not necessarily an explanation of the apparent greater sensitivity of woody plants to Cl versus Na, many researchers report finding higher tissue levels of Cl than Na (Dirr, 1978; Hofstra et al., 1979; Lumis et al., 1976; Townsend and Kwolek, 1987).

2.35 Environmental Effects on Sodium and Chloride Accumulation by Woody Plants

Since salt deposition by spray is an important way that Na and Cl reach the foliage, several researchers have studied some environmental factors affecting foliar absorption of Na and Cl. Foster and Maun (1980) studied the effects of relative humidity on foliar absorption of Na and Cl by White cedar (*Thuja occidentalis*). Sodium chloride sprays were much more damaging at high relative humidity (91-100%) than at low relative humidity (50-70%), presumably because high humidity delayed drying of the salt on the leaf surface thus prolonging Na and Cl absorption.

A similar effect of humidity on Cl uptake by leaves of several woody species was reported by Simini and Leone (1986), but Barrick and Davidson (1980) found no effects of relative humidity and temperature on Na and Cl absorption by the stems of Norway maple. Light and temperature also may affect salt accumulation by woody plants. Simini and Leone (1986) found that Cl absorption was favored by short photoperiods and low temperature. The authors believed that photoperiod and temperature might exert their effects on Cl absorption through an influence on cuticle formation.

2.36 Internal Effects of Sodium and Chloride on Woody Plants

Some researchers have tried to determine the nature of the negative effects of elevated tissue Cl and Na on the physiology and metabolism of roadside woody plants. Sucoff and Hong (1976) reported that reduced cold hardiness was related to winter application of NaCl to the twigs of woody plants. In their work with apple and lilac (*Syringa vulgaris*), cambial browning and the loss of cold hardiness were related to high levels of Cl in the twigs. Unfortunately, this study is the only report of a relationship between salt addition and cold hardiness.

Ion interactions involving Na, Cl, and other elements in woody plants have received attention. In two-year-old Norway spruce (*Picea abies*) grown in soil, increasing Ca supply depressed Na absorption and enhanced K absorption, resulting in a higher K/Na ratio, which was favorable to the plants (Bogemans et al., 1989). Also, there was some evidence of less Cl absorption with increased Ca.

Flukiger and Braun (1981) grew European cranberry bush (*Viburnum opulus*) in containers of soil and found that nutrient treatments resulting in increased K/Na or nitrate (NO_3)/Cl ratios promoted the recovery of plants treated repeatedly with NaCl during the winter. The results of these studies indicate that ion interactions involving Na and Cl might affect the nutritional status of the plants and suggest that fertilizing woody plants following winter salt application might be beneficial to salt-sensitive species. More work is needed in this area of investigation.

Some researchers have studied the effects of deicing salt on woody plants at the cellular and tissue level. Hautala et al. (1992) and Redmann et al. (1986) found evidence of cell membrane damage in the leaves of several species. Salt-induced membrane damage was proposed as the cause of abnormal K-ion leakage from cells in the needles of Scots pine (Hautala et al., 1992) and to the leakage of amino acids and other ultraviolet-absorbing substances in the leaves of Ash (*Fraxinus pennsylvanica*) and Quaking aspen (*Populus tremuloides*) (Redmann et al., 1986).

In a study of tissue sensitivity of woody plants to deicing salt, Barrick et al. (1979) considered the differences in pine needle surface characteristics (*i.e*., morphology, leaf area, surface wax, wettability and solution retention) as possible explanations for the difference in salt sensitivity between Austrian pine (*Pinus nigra*), a salt-resistant pine, and White pine, a salt-sensitive pine. However, needle surface characteristics could not explain the difference in species response to salt, and Barrick et al. (1979) concluded that differences in protoplasmic sensitivity of cells to salt was the basis for the difference in salt sensitivity between the two species. This conclusion was based on the fact that when tissue was analyzed, more Na and Cl were in the needles of Austrian pine than in white pine, whereas a test of tissue viability showed that white pine was more sensitive to increasing levels of NaCl than Austrian pine. The concept of protoplasmic sensitivity may help explain why Dirr (1978) found that some of the woody plants most severely affected by salt treatment in his study did not contain the most Cl.

Others have added to the understanding of deicing salt responses in woody plant cells and tissues. Kutscha et al. (1997) reported that salt treatments resulted in many abnormal changes in the leaf anatomy of white cedar and white spruce. Zobel and Nighswander (1990) reported finding significant deposition of phenolic compounds in the mesophyll of Austrian pine and red pine needles. The phenolic deposits appeared as necrotic spots on the leaf surface and were associated with the stomates. The authors suggest that in its early stages phenolic deposition is probably a defensive mechanism against salt stress caused by salt entry through the stomates even though the deposition ultimately leads to tissue death.

2.37 Soil Salinity Effects on Woody Plants

The main focus of research on the causes of deicing salt injury has been on the effects of Na and Cl ions; little attention has been paid to the potential for woody plant injury from the osmotic effects of elevated salinity caused by other soil-applied salts. In one study, soil in sidewalk planters and in median strips of streets and highways in Illinois was found to contain so much Na from deicing salt that the soils could be classified as “sodic” (Kelsey and Hootman, 1990; Hootman et al. 1994).

A sodic soil is a soil that has sufficient sodium to interfere with the growth of most crop plants. The electrical conductivity (EC) of these soils was also elevated, but the authors concluded that, by itself, EC was not a good predictor of plant injury and that Na effects on the soil were more important in explaining plant condition.

In controlled experiments, Dirr (1974) studied the effects of several salts on Honeylocust (*Gleditsia triacanthos*), and he measured very high EC values (12-26 dS/m) in 0.15M and 0.25M salt treatments. Serious injury occurred with Cl but not SO_4 salts. Dirr (1974) felt that the injury was caused by a specific Cl effect and not an osmotic effect caused by elevated salinity.

Bernstein et al. (1972) and Francois and Clark (1978) rated salt tolerance of over 25 different woody plants based on response to EC in outdoor plots salinized with Cl salts. Some species were capable of tolerating EC levels up to 13 dS/m with little or no injury or growth reduction. Unfortunately, almost all of the plants tested in the two studies are suitable for the climate of coastal southern California and are not adaptable to New England.

In general, researchers studying the effects of soil-applied salt on woody plants have not included measurement of soil EC in their experiments and have attributed injury to specific ion effects (Bogemans et al., 1989; Dirr, 1978; Fostad and Pedersen, 2000; Headley and Bassuk, 1991; Townsend, 1980; Walton, 1969). Future research on soil-applied salts should include studies on treatment effects on soil EC with experiments designed to examine the osmotic effects of salinity separately from specific ion effects.

2.4 Reducing Deicing Salt Injury to Roadside Woody Plants

2.41 Deicing Materials Other Than Sodium Chloride

Calcium magnesium acetate (CMA). Calcium magnesium acetate, trade name ICE-B-GON, is an effective deicer manufactured by reacting dolomitic limestone and acetic acid (Bryan, 1992). It is non-corrosive and supplies no Na or Cl. McFarland and O'Reilly (1992) reviewed the rather scant literature on CMA effects on vegetation and found no reports of phytotoxic effects of CMA unless CMA was applied in amounts well in excess of highway treatments. These studies included soil-applied and foliar spray CMA treatments to a number of herbaceous and woody plant species and were conducted in greenhouses and outdoors.

The effect of CMA versus NaCl on soil structure has received some attention. Results of several studies demonstrate that NaCl causes dispersion of organic matter and other colloids and reduces soil permeability(Amrhein and Strong, 1990; Amrhein et al., 1992, 1993). In these studies, CMA did not cause colloid dispersion but increased soil permeability due to the promotive effects of exchangeable Ca and Mg on flocculation and aggregate stability.

The dispersion of soil colloids by NaCl can result in increased mobilization of trace metals (Norrstrom and Jacks, 1998), which may threaten groundwater. In a study using soil columns, Elliot and Linn (1987) found that CMA initially increased copper (Cu) and zinc (Zn) mobility due to displacement by Ca and Mg, but ultimately Cu and Zn efflux was reduced by CMA because of an increase in pH due to the degradation of the acetate ion. Elliot and Linn (1987) concluded that CMA would probably inhibit the movement of heavy metals in most soils. In other studies, NaCl, but not CMA, increased the mobility of certain trace metals (Amrhein and Strong, 1990; Amrhein et al., 1992, 1993).

It appears that CMA is a good alternative to NaCl in many respects. Calcium magnesium acetate does not corrode vehicles and highway structures, and it appears to pose much less threat to the environment, especially to plants and soils, than conventional salt. Unfortunately, CMA costs about $650 per ton--more than twenty times the cost of NaCl (Gales and VanderMuelen, 1992). In short, some believe that CMA will not replace NaCl as a deicer until its cost can be reduced or the hidden costs of salt damage to vehicles, highways, and the environment are recognized by decision makers (D’Itri, 1982).

Urea. Urea, costing about $200 per ton, is sometimes applied as a solution to deice highways and airport runways (Gales and VanderMeulen, 1992). Urea is much less corrosive than NaCl but its long-term environmental effects as a deicer are unknown. Urea is rapidly converted to nitrate by the microbial processes of urea hydrolysis and nitrification under most soil conditions. Excess nitrate may stimulate undesirable levels terrestrial plant growth as well as algae in water and is itself a potential pollutant of drinking water.

Ice Ban® and Ice Ban Magic.® IceBan® is a liquid concentrate by-product of milling of grains for the production of alcohol. Ice Ban Magic® is a similar product, but magnesium chloride ($MgCl_2$) is added to it. Both products are very new to the deicer market and have generated a great deal of interest from highway departments and the press, but no research reports on its environmental effects including vegetation were found. Presumably, since these products consist of mainly carbohydrates, proteins, and other naturally occurring organic materials, they might pose no harm to trees and shrubs.

2.42 Gypsum for Ameliorating Salt Injury

It is well established that soils containing high exchangeable Na and low free calcium carbonate ($CaCO_3$) can be reclaimed for growing agronomic crops by the application of gypsum (calcium sulfate, $CaSO_4$) (Beaton et al., 1985). Gypsum is a very abundant and inexpensive source of Ca, which can be used to replace exchangeable Na on soil colloids; the displaced Na is then leached from the root zone. Several authors mention gypsum as a possible corrective treatment to roadside soils high in Na (Dirr, 1976; Moran et al., 1992; Westing, 1969) but provide no details on the use of gypsum.

Research and specific recommendations on the ameliorative properties of gypsum for roadside soils is very limited. Dirr and Biedermann (1974) reported that salt damage caused by repeated soil application of NaCl to containerized cotoneaster (*Cotoneaster dammeri*) was reduced by half, compared to untreated controls, by incorporation of gypsum into the growth medium or surface application. The most effective gypsum treatments were granular form instead of fine particles and incorporation instead of surface application. The authors recommended a gypsum application rate in the range of 20 to 40 lb per 100 sq ft. Recently, Barrott (1999) made a similar recommendation, but without a specific research basis, of 10 to 20 lb per 100 sq ft for new tree and shrub plantings in salt-exposed areas.

In a review of road salt (NaCl) effects on Sugar maple (*Acer saccharum*) and the role of road salt in the disorder called "maple decline," Rubens (1978) advocates the use of gypsum to reduce the Na content of the soil to protect the trees before the onset of irreversible decline. Based on his experience and the results of some preliminary trials conducted in Maine, he recommended gypsum applications at 12 tons per acre "on a regular basis" and stated that these treatments would be required over a period of 3 to 45 years for complete desalination. Clearly, more research is needed on the effectiveness and practicality of gypsum application before its use can be recommended as a routine practice along roadsides.

2.43 Other Methods of Reducing or Preventing Salt Injury

Planting salt-tolerant species, reducing the use of road salt, and using alternative chemicals for road treatment are obvious approaches to minimizing deicing effects on roadside plants. Each method has its own practical advantages and disadvantages. Some other methods of reducing or preventing salt injury have been suggested in the literature, but like the use of gypsum more research is needed to evaluate their efficacy.

Since it has been noted that NaCl leaches from the soil and washes from the foliage with rainfall, some workers have suggested deliberating washing and irrigating plants to reduce salt effects, if done in a timely fashion (Barrott, 1999; Carpenter, 1970; Dirr, 1976; Dragsted and Kubin, 1990). This approach has not been tested experimentally, and the practical limitations of washing and irrigating roadside plants are obvious. However, this method might be possible in intensively landscaped areas along highways, such as rest stops, interchanges, and toll plazas or where a roadway passes through a park or arboretum.

Dirr (1976) and Hofstra et al. (1979) proposed the use of fences or other barriers to reduce salt deposition on plants or on surrounding soil. Vertical polyethylene shelters facing a highway were effective in protecting lowbush blueberries from salt spray (Eaton et al., 1999). The numbers of live buds and blossoms and fresh fruits yields were increased from using the shelters. To be most effective, shelters and fences should be constructed to allow rain to reach the plants. Maples grown under overhead shelters and experimentally treated with salt were more severely affected by treatment than those grown in the open and exposed to rainfall (Simini and Leone, 1986). Snow fencing is used in many areas to keep snow off roads and perhaps could be placed to protect plants from salt injury from sprays or piled snow.

Matters pertaining to planting may affect the degree of salt injury to roadside plants. Late season planting has been suggested as a reason for poor salt tolerance of new plantings of pine (Davidson, 1970; Kelsey and Hootman, 1992). The major impediment to the establishment of new plantings late in the season is the development of a good root system before the onset of low soil temperatures. To prevent accumulations of excess salt in the root zone, Dirr (1976) suggested mounding planting areas. However, the aerial salt deposition data of Kelsey and Hootman (1992) suggest that the construction of berms for planting actually encourages the dispersal of airborne salt onto plantings by forcing the plume of salt mist upward. More work is needed to determine the advantages and disadvantages of building berms for planting to protect roadside plants from salt injury.

Table 2-1. Salt-Sensitive Plant Species

Common Name	Scientific Name	References
Trees		
Norway maple	*Acer platanoides*	9, 47, 74
Red maple	*Acer rubrum*	74, 100
Sugar maple	*Acer saccharum*	62, 74, 100
Speckled alder	*Alnus rugosa*	100
American hornbeam	*Carpinus caroliniana*	47, 100
Shagbark hickory	*Carya ovata*	100
Flowering dogwood	*Cornus florida*	110
Kousa dogwood	*Cornus kousa*	110
Ginko	*Ginko biloba*	47
Black walnut	*Juglans nigra*	88, 89
Tuliptree	*Liriodendron tulipifera*	44
Colorado blue spruce	*Picea pungens*	88, 89
Red pine	*Pinus resinosa*	57, 100, 105
Eastern white pine	*Pinus strobus*	8, 25, 50, 100, 101
London planetree	*Platanus* x *acerifolia*	47, 110
Sycamore	*Platanus occidentalis*	45, 101
Douglas fir	*Pseudotsuga taxifolia*	88, 89
Arctic blue willow	*Salix purpurea nana*	88
Basswood	*Tilia americana*	100
Littleleaf linden	*Tilia cordata*	88, 89
Hemlock	*Tsuga* spp.	88, 115
American Elm	*Ulmus americana*	100
Shrubs		
Glossy abelia	*Abelia* x *gandiflora*	45
Compact strawberry tree	*Arbutus unedo*	45
Japanese barberry	*Berberis thunbergii*	88, 89
Pyrenees cotoneaster	*Cotoneaster congestus*	45
Winged euonymus	*Euonymus alatus*	74, 89
Hibiscus	*Hibiscus syriacus*	14

Table 2-1 (Shrubs Continued)

Common Name	**Scientific Name**	**References**
Burford holly	*Ilex cornuta*	14
Oregon grape holly	*Mahonia aquifolium*	45
Heavenly bamboo	*Nandina domestica*	14
Grasses		
Bentgrass	*Agrostis stolonifera*	5
Velvet grass	*Holcus lanatus*.	5
Bluegrass	*Poa* spp.	48

Table 2-2. Salt-Tolerant Plant Species

Common Name	Scientific Name	References
Trees		
Horse chestnut	*Aesculus chinensis*	47
Yellow birch	*Betula alleghaniensis*	100
Black birch	*Betula lenta*	100
Paper birch	*Betula papyrifera*	74, 100
Silver birch	*Betula pendula*	47
Gray birch	*Betula populifolia*	100
White ash	*Fraxinus americana*	47, 74, 100
Green ash	*Fraxinus pennsylvanica*	47, 88
Honey locust	*Gleditsia triacanthos*	88, 89, 110
Eastern redcedar	*Juniperus virginiana*	100
American sweetgum	*Liquidambar styraciflua*	44
Aleppo pine	*Pinus halepensis*	45
Mugo pine	*Pinus mugo*	58
Italian stone pine	*Pinus pinea*	44
Austrian pine	*Pinus nigra*	8, 58, 78
Eastern white pine**	*Pinus strobus*	110
Bigtooth aspen	*Populus grandidentata*	100
Quaking aspen	*Populus tremuloides*	100
Black cherry	*Prunus serotinia*	47, 100
White oak	*Quercus alba*	61, 100, 115
Pin oak	*Quercus palustris*	110, 115
Red oak	*Quercus rubra*	100, 115
Black oak	*Quercus velutina*	61, 115
Black locust	*Robinia pseudoacacia*	47, 88, 89, 100
Golden willow	*Salix alba vitellina*	89
Japanese pagodatree	*Sophora japonica*	110

Table 2-2 Salt-Tolerant Plant Species (Continued)

Common Name	Scientific Name	References
Shrubs		
Natal plum	*Carissa grandiflora*	14
Russian olive	*Elaeagnus angustifolia*	21, 88, 89
Japanese euonymus	*Euonymus japonicus*	14
Squaw bush	*Rhus trilobata*	88, 89
Silver buffaloberry	*Shepherdia argenta*	89
Tamarix	*Tamarix ramosissima*	74
Grasses		
Quackgrass	*Agropyron repens*	21
Diplachne	*Diplachne acuminata*	21
Heleochloa	*Heleochloa schoenoides*	21
Scratchgrass	*Muhlenbergia asperifolia*	21
Plains bluegrass	*Poa arida*	21
Nutall alkaligrass	*Puccinellia airoides*	48
Alkaligrass	*Puccinellia distans*	21, 48
Alkaligrass	*Puccinellia lemmonii*	48
Saltmeadow cordgrass	*Spartinia patens*	21
Alkali sacaton	*Sporobolus airoides*	48
Bromegrass	*Bromus inermis*	48
Hard fescue	*Festuca ovina duriuscula*	21

** White pine is tolerant to a saline root medium but is intolerant of salt spray.

Table 2-3. Sensitivity Ranking of Selected Trees and Shrubs to Aerial Drift of Deicing Salts. Source: Lumis, G.P., G. Hofstra, and R. Hall. 1973. Sensitivity of roadside trees and shrubs to aerial drift of deicing salts. HortScience 8:475-477.

Common Name	Scientific Name	[z]Injury Rating
Deciduous Trees		
Horse-chestnut	*Aesculus hippocastanum*	1
Tree of Heaven	*Ailanthus altissima*	1
Norway maple	*Acer platanoides*	1
Cottonwood	*Populus deltoides*	1
Black locust	*Robinia pseudoacacia*	1
Honey locust	*Gleditsia triacanthos*	1-2
Red oak	*Quercus rubra*	1-2
Sugar maple	*Acer saccharum*	1-2
English walnut	*Juglans regia*	1-2
Black walnut	*Juglans nigra*	1-2
Shagbark hickory	*Carya ovata*	1-2
Choke cherry	*Prunus virginiana*	1-2
White ash	*Fraxinus americana*	2
White elm	*Ulmus americana*	2
Black willow	*Salix nigra*	2
Mountain ash	*Sorbus* spp.	2
Poplar	*Populus* spp.	2
Silver maple	*Acer saccharinum*	2
Chinese elm	*Ulmus pumila*	2
Red maple	*Acer rubrum*	2-3
Lombardy poplar	*Populus nigra*	2-3
Basswood	*Tilia americana*	2-3
White birch	*Betula papyrifera*	2-3
Gray birch	*Betula populifolia*	2-3
Catalpa	*Catalpa speciosa*	2-3
Pear	*Pyrus* spp.	2-3

Table 2-3 (Deciduous Trees Continued)

Common Name	**Scientific Name**	**Rating**
Quince	*Cydonia oblonga*	2-3
Trembling aspen	*Populus tremuloides*	3
Largetooth aspen	*Populus grandidentata*	3
Crabapple	*Malus* spp.	3
Golden willow	*Salix alba tristis*	3
Bur oak	*Quercus macrocarpa*	3-4
Apple	*Malus* spp.	3-4
Hawthorn	*Crataegus* spp.	4
Manitoba maple	*Acer negundo*	4-5
Allegheny serviceberry	*Amelanchier laevis*	4-5
White mulberry	*Morus alba*	4-5
Beech	*Fagus grandifolia*	1
Deciduous shrubs		
Siberian pea-tree	*Caragana arborescens*	1
European buckthorn	*Rhamnus cathartica*	1
Staghorn sumac	*Rhus typhina*	1-2
Japanese lilac	*Syringa amurensis japonica*	1-2
Common lilac	*Syringa vulgaris*	1-2
Honeysuckle	*Lonicera* spp.	1-2
European cranberry-bush	*Viburnum opulus*	1-3
Russian olive	*Elaeagnus angustifolia*	1-3
Mock orange	*Philadelphus* spp.	1-3
Japanese barberry	*Berberis thunbergii*	2
Burningbush	*Euonymus alata*	2
Forsythia	*Forsythia x intermedia*	2-3
Privet	*Ligustrum* spp.	2-3
Alder buckthorn	*Rhamnus frangula*	2-3
Speckled alder	*Alnus rugosa*	3
Flowering quince	*Chaenomeles lagenaria*	3-4
Bumalda spirea	*Spirea x bumalda*	3-4

Table 2-3 (Deciduous Shrubs Continued)

Common Name	**Scientific Name**	**Rating**
Beauty bush	*Kolkwitzia amabilis*	3-4
Gray dogwood	*Cornus racemosa*	3-4
Red osier dogwood	*Cornus stolonifera*	4-5
Conifers		
Blue spruce	*Picea pungens*	1
Jack pine	*Pinus divaricata*	1-2
Mugo pine	*Pinus mugo*	1-2
Austrian pine	*Pinus nigra*	2
Tamarack	*Larix laricina*	2
Juniper	*Juniperus* spp.	2-3
Norway spruce	*Picea abies*	3
White cedar	*Thuja occidentalis*	3-4
Yew	*Taxus* spp.	4
Red pine	*Pinus resinosa*	4-5
Scots pine	*Pinus sylvestris*	4-5
White spruce	*Picea glauca*	4-5
Hemlock	*Tsuga canadensis*	4-5
White pine	*Pinus strobus*	5

Footnote to Table 2-3.

[z]A rating of 1 indicates no twig dieback or needle browning of conifers and no die back, tufting, or inhibition of flowering of deciduous trees and shrubs. Ratings of 5 represent complete branch die back and needle browning of conifers, and complete die back, evidence of previous tufting, and lack of flowering of deciduous trees and shrubs. Under severe conditions, plants rated 5 will eventually die. Ratings of 2, 3, and 4 encompass slight, moderate and extensive gradations of the above injury symptoms.

Table 2-4. Salt-Tolerant Plants That Are Listed in Table 2-2 and That May Have Invasive Tendencies[A].

Common Name	Scientific Name
Black locust	*Robinia pseudoacacia*
Saltspray rose	*Rosa rugosa*
Golden Willow	*Salix alba*

Footnote to Table 2-4

[A]Plants classified in this category possess traits which allow them to invade minimally-managed habitats, such as forests, woodlands, open spaces, and roadsides. In doing so, they may threaten naturally-occurring species and have the potential to cause ecological damage to plants, animals and human interests. A list of invasive species is provided in Appendix II. The listing in the appendix is for information only and does not carry any absolute classification of invasiveness and has no regulatory application.

3.0 CHARACTERIZATION OF ROADSIDE CONDITIONS

Sodium Accumulation in Soils and Plants along Massachusetts Roadsides

The most common deicing material applied by the Massachusetts Highway Department is sodium chloride NaCl. In Massachusetts, the rate of application of deicing agents is about 240 lb (110 kg) of NaCl per lane mile (1.6 km). The objective of this research was to examine injury to plants along roadsides and to assess relationships of damage to the amount of Na detected in plants and soils.

The most damage on plant species was manifested as burning or browning of the leaves or needles. Coniferous species, especially pines (*Pinus* spp.), were sensitive to NaCl injury. In coniferous species, the damage appeared as browning on the ends of the needles, but new growth was not affected. Most of the damage occurred on the needles on the tree side that faced the road and where salt spray from cars or plows could have been a factor in the degree of damage. Widespread damage was also seen on spruce (*Picea* spp.), sumac (*Rhus typhina*), and Mountain laurel (*Kalmia latifolia*) along roadsides. With sumac, injured plants had only 10% of the foliage as uninjured plants.

Some salt-tolerant species, apparently undamaged by NaCl, in the same vicinity as the damaged plants, were various oaks (*Quercus* spp.), maples (*Acer* spp.), grasses (mixed species), ferns (mixed species), and yarrow (*Achillea millefolium*). The Na concentrations in the leaves of pines, sumacs, grasses, and oaks decreased as the distance from the road increased. The Na concentrations in pine needles were 3356 mg/kg at 10 feet, 1978 at 15 feet, and 1513 mg/kg at 20 feet. The Na concentrations in maple leaves decreased with the Na concentrations being 249 mg/kg at 10 feet and falling to 150 mg/kg at 30 feet.

The concentrations of Na in roadside soil ranged from 101 mg/kg at 5 feet to 16 mg/kg at 30 feet from the roadside, with a marked decrease in the Na concentration in the soil after 15 feet. The pH decreased as the distance from the road increased ranging from 7.60 at 5 feet to 5.78 at 30 feet. The electrical conductivity values decreased as the distance from the road increased and ranged from 0.16 dS/m (decisiemens per meter) at 5 feet to 0.12 dS/m at 30 feet. This study suggests a relationship between Na accumulation, in leaves and in soil, and injury to roadside plants

Salts are applied to highways during winter months to help de-ice the roadways. Some of the salts used in the deicing procedures have been shown to have phytotoxic effects on plants (Barrick et al., 1979; Barrick and Davidson, 1980; Townsend, 1980). Research has shown that different plant species have varying susceptibility to damage from NaCl (Townsend, 1980). The method by which the NaCl comes into contact with the plant, either by salt spray or by soil-borne salt, is one of the most important factors in determining the severity of foliar damage (Sucoff et al., 1975).

Sodium damage to plants along roadsides is caused by salt sprays from plows and vehicles passing on the road or by the accumulation of Na in the soil (Barrick and Davidson, 1980; Sucoff et al., 1975). Research with pines (*Pinus* spp.) has shown that salt coating of the needles acts as a non-selective herbicide (Barrick et al., 1979; Barrick and Davidson, 1980). The salt on the needles creates an osmotic stress resulting in water loss and cell plasmolysis, ultimately ending in injury (Barrick et al., 1979; Barrick and Davidson, 1980). The severity of the damage to the plants from salt spray decreases the farther plants are from the road. Blomqvist (1999) reported that 90% of salt in roadside soils is detected within 40 feet of the road. Research showed that the most severe damage to foliage was on plants within 30 feet of the road (Lacasse and Rich, 1964; McBean and Al-Nassri, 1987). Salt spray injury was usually greater on the side of the plant that faced the road (Barrick and Davidson, 1980; Sucoff et al., 1975). McBean and Al-Nassri (1987) found that of the salt deposited on the road, 10 to 25% was spread through the air and found within 30 feet of the road. However, the distance of the trees from the side of the road is only one factor affecting severity of damage.

According to Sucoff et al. (1975), as the amount of daily traffic increased, the amount of salt required to maintain the road also increased in a linear relationship. Soil properties such as slope of terrain, drainage, texture, duration of freezing in the soil, and the degree of soil compaction affect the amount of Na that reaches the rhizospheres of plants (Holmes and Baker, 1966). High levels of Na in the soil also can alter the physical properties of the soil by dispersing soil aggregates, which would lead to puddling of finer textured soils (Holmes, 1961). Sodium replaces K and other cations on the soil exchange complex and can lead to nutrient deficiencies (Holmes, 1961).

In most cases, although salt is applied in the winter, the symptoms of salt damage do not appear in the leaves until the spring. The increase of injury in the spring is attributed to the increased intake of water. When the temperatures warm up in the spring, and new growth is forming, the rate of transpiration in the plants increases along with the translocation of water, nutrients, and Na (Barrick and Davidson, 1980; Holmes, 1961). However, plants that do not come into direct contact with Na from salt spray are not injured severely (Holmes, 1961).

Tolerances to salt damage vary widely among different plant species. Species of coniferous trees tend to have a more widespread amount of damage than other species. The symptoms of salt damage on pines were manifested as chlorosis or browning on the tips of the needles, whereas the new growth was not affected (Barrick et al., 1979; Townsend, 1980). In severe cases, the needles were completely brown and necrotic, and growth was suppressed. Salts applied to the roots resulted in a lesser degree of injury to the needles, and no growth suppression, than the salts that were applied directly to the needles (Townsend, 1980).

Deciduous species tend to be more tolerant to salt spray or to soil-borne salt than coniferous species. In deciduous trees, the symptoms of salt damage manifested as post-flushing dieback and foliage discoloration (Gibbs and Palmer, 1994). Deciduous species, which lose their leaves in the fall, are not as susceptible to salt spray as the coniferous species, which retain their foliage throughout the winter. In the spring, when new growth is forming, the concentrations of Na in the soil are lowered by leaching, resulting in much lower incidents of foliar damage than might occur from direct deposition of salt on the foliage.

Sodium chloride works effectively as a deicing agent with temperatures falling to – 8 C, and calcium chloride ($CaCl_2$) is effective to –20 C. Research has shown that by increasing Ca concentrations, the effects of stress from applications of NaCl can be reduced (Kawasaki and Moritsugu, 1978). Bogemans et al. (1989) demonstrated that substituting 20 to 30% of $CaCl_2$ for NaCl resulted in a 50% decrease of Na in the needles of spruce. Although $CaCl_2$ is less phytotoxic than NaCl, $CaCl_2$ is more expensive and difficult to handle and store (Rich, 1972). Therefore, since NaCl is the main deicing agent used in Massachusetts, this study focused on the toxic effects of Na to various plant species.

3.1 Materials and Methods

3.11 Sampling

Leaf and soil samples were taken from sites along Massachusetts roadsides that had apparent salt damage and from sites that showed no visible signs of salt damage to vegetation. The sampling sites included Massachusetts Routes 2, 8, 9, 63, 116, and 181, US Routes 2 and 202, Interstate 91, various sites on the University of Massachusetts at Amherst, campus, and from a forest area where no salt had been applied (Table 3-1). Soil samples and leaf samples were taken from each site. Soil samples were taken in 5- or 10-foot (1.5 to 3 m) increments, perpendicular to the road. The soil samples were taken with a soil corer to a depth of 12 inches (30 cm). For each sample, three sub-samples of single cores were obtained and thoroughly mixed to form one sample. Leaf samples were taken from vegetation that showed signs of Na damage on the foliage and also from healthy plant species on which no signs of injury were visible. The leaf samples taken from healthy plant species were collected from all sites sampled, including sites where no injury was visible on any species. Sampling sites were identified by distances from the road pavement at each site.

3.12 Soil Analysis

Soil samples were placed in an oven and dried at 70° C for 72 hours. After the soil was dry; pH, electrical conductivity (EC), and Na concentrations were determined.

Electrical Conductivity and pH. To determine EC and pH, the soil samples were extracted by a saturated paste method (Soil and Plant Analysis Council, 1992). The soils were saturated with distilled water and were allowed to sit for one hour with no shaking. The soils were then filtered by suction, and EC and pH were determined on the extract.

Soil Extraction. The soil samples were extracted with Morgan's universal solution to remove Na (Morgan, 1941). The Morgan's solution was prepared by dissolving 100 g of ammonium acetate in 1 liter of distilled water. The acetate solution was adjusted to pH 4.7 with glacial acetic acid. Ten grams of each soil sample were weighed into 100-mL beakers, and 40 mL of Morgan's solution were added. The samples were extracted for 30 minutes on a platform shaker at 120 rpm. The samples were leached by gravity filtration with the Morgan's solution until a 50-mL volume was collected for each sample.

3.13 Plant Analysis

Tissue Ashing. Leaves were dried in an oven at 70° C for 72 hours. The samples were ground through a 40-mesh screen. A mass of 0.200 g was weighed for each sample and placed in a porcelain crucible. The samples were ashed in a muffle furnace at 450° C for 8 hr. After the samples cooled, 5 mL of 0.075 molar nitric acid (HNO_3) were added to the ashed samples. After the ash dissolved, the samples were then transferred to a 50-mL volumetric flask. The crucibles were washed three times with 5-mL portions of the HNO_3 solution, and the solution was brought to volume. The HNO_3 solution was used in the samples and in the standards to keep the matrix of the two solutions the same (Miller, 1998).

Determination of Sodium. Portions of the soil extract or of the dissolved ash were placed in volumetric flasks and brought to volume after adding 2.5 mL of 20,000 mg KCl /L solution as an ionization suppressant. Each of these portions was then used to measure the concentrations of Na by atomic emission spectroscopy (Hanlon, 1998).

3.2 Results and Discussion

The plant species that had the most widespread and severe damage over all of the sampling sites were pines and sumacs. The damage to the needles appeared as browning or burning and was mainly on the side of the tree facing the road. The concentration of Na in the leaves of the damaged pines was about 75 times the average Na concentration in healthy pine needle samples (Table 3-2). Healthy samples of pines averaged 28 mg Na/kg in the needles, compared to an average of 2130 mg Na/kg in the samples of damaged needles (Table 3-2). Also, the Na concentration in the needles decreased as the distance from the road pavement increased ranging from 3356 mg/kg at 10 feet (3 m) to 1513 mg/kg at 20 feet (7 m) (Figure 3-1). The damage to the needles facing the roads is suggested to be primarily from salt spray. Evergreen trees retain their needles throughout the winter thus increasing the chance of damage to the needles by spray, relative to plant species that drop their leaves during the winter.

Sumac also had widespread damage along the roads sampled. Many sumacs were severely damaged, appearing to have less than 10% of the leaves remaining on the plant. The mean concentration of Na in healthy sumac samples, 177 mg/kg, did not differ greatly from the mean Na concentration in the leaves of damaged sumacs, 209 mg/kg (Table 3-2). It appeared that most of the damaged leaves had defoliated. The Na concentration in sumac leaves decreased as the distance from the road increased, ranging from 340 mg/kg at 10 feet (3 m) to 150 mg/kg at 25 feet (8 m) (Figure 3-1).

Samples of mixed grasses were taken, and the mean Na concentration in leaves was 928 mg/kg (Table 3-2). No damage was noted on any grasses even in areas where Na damage was evident on other plant species. The Na concentration in grass leaves decreased as the distance from the road increased, ranging from 1383 mg/kg at 10 feet (3 m) to 203 mg/kg at 30 feet (10 m) (Fig. 2-2).

Fern frond samples contained a mean Na concentration of 1280 mg/kg (Table 3-2). No visible Na damage was evident on the ferns that were taken from a site where sumacs had severe Na damage. Average Na levels in fern tissue samples taken from the forested area where no salt had been applied were 970 mg/kg.

Oak and maple species appeared to be salt tolerant. Both species were observed with no apparent damage in areas where damage was evident on other plant species. The average Na concentration was 197 mg/kg in oak leaves and 428 mg/kg in maple leaves (Table 3-2). The concentration of Na in maple leaves decreased as the distance from the road increased ranging from 249 mg/kg at 10 feet (3 m), increasing to 168 mg/kg at 15 feet (5 m), and decreasing to 150 mg/kg at 30 feet (10 m) (Figure 3-2). The concentration of Na in oak leaves decreased as the distance from the road increased ranging from 283 mg/kg at 10 feet to 120 mg/kg at 20 feet (7 m) (Figure 3-1).

Sodium damage was evident on mountain laurel and spruce. The mean concentration of Na in mountain laurel leaves was 423 mg/kg, and the mean concentration of Na in spruce leaves was 616 mg/kg (Table 3-2).

The concentration of Na in the soil decreased as the distance from the road pavement increased ranging from 101 mg/kg at 5 feet (1.5 m) to 16 mg/kg at 30 feet (10 m) (Table 3-3). A marked decrease in the concentration of Na in the soil occurred after a distance of 15 feet (5 m) from the road. The decrease in the Na concentration suggests that most of the Na in the soil comes from salt spray and hence falls near the road.

The pH of the soil decreased as the distance from the road pavement increased ranging from 7.6 at 5 feet (1.5 m) to 5.78 at 30 feet (10 m) (Table 3-3). The EC of the soil decreased as the distance from the road increased ranging from 0.16 dS/m at 5 feet (1.5 m), increasing to 0.23

at 15 feet (5 m), and then decreasing to 0.12 at 30 feet (10 m) (Table 3-3). The high pH and EC values suggest that the soils close to the road are not highly leached of Na and that they have a higher base saturation than the soils with the greater distances from the roadside.

3.3 Summary of Roadside Damage Survey

In general, most of the severe cases of salt damage to plant species were within 15 feet (5 m) of the road, apparently in a zone where salt spray causes a majority of the damage. Injury from spray is suggested by the fact that most of the foliar damage is on the side of the tree that faces the road. Coniferous species, especially pines, were highly susceptible to salt damage.

Regardless of species, the concentrations of Na in leaves were higher in the plants exhibiting damage than in the plants of the same species appearing healthy. The Na levels in plant leaves decreased as the distance from the road increased regardless of species. Based on the literature, about 90% of the salt that is sprayed from the road is found within 30 feet (10 m) of the road. Therefore, the farther that plants are from the road the less the chance of the spray to contact the plants. It seemed that deciduous species were more tolerant than coniferous species to Na. Coniferous species have more surface area to intercept the Na from the salt spray than the deciduous species that do not have foliage in the winter.

The concentrations of Na in the soil decreased as the distance from the road increased. The soil pH values were more alkaline at distances closer to the road. It appears that the effect of Na on the soil complex results in a slightly alkaline soil (Kawasaki and Moritsugu, 1978). The electrical conductivity (EC) values, a measurement of the soluble salts, were highest at sites close to the road than at sites away from the road.

High concentrations of Na in the soil also can affect plant species in ways other than by direct toxicity of Na. The Na in soil can reduce soil structure, causing puddling of fine-textured soil, and can have adverse effects on the microenvironment of the rhizosphere by restricting oxygen flow to the roots. The Na can also affect the fertility status of the soil by replacing nutrients (K, Ca, Mg) in the soil complex, eventually leading to nutrient deficiencies with subsequent leaching of cations. When plants are stressed by low fertility or reduced oxygen at the roots or by injured foliage, they become susceptible to diseases.

Considerable infestation of diplodia disease (*Sphaeropsis sapinae*) was noted on black pine (*Pinus thunbergii*), which was not sampled in this study. The concentrations of Na in the leaves of plants and in the soil can be influenced by many factors, such as, amount of NaCl applied to the roads, plant distance from the road, slope of the topography, wind, amount of daily traffic, how often the road is plowed, permeability, and soil texture.

Table 3-1. Plant Species Sampled from Each Roadside Site

Highway	Species Sampled	
	Damaged	Healthy
Mass. Route 2	White pine (*Pinus strobus*), Blue spruce (*Picea pungens*)	Red maple (*Acer rubrum*), mixed fescue (*Festuca* spp.), staghorn sumac (*Rhus typhina*), oak (*Quercus* spp.)
Mass. Route 8	White pine	Red maple, mixed fescue (*Festuca spp.)*
Mass. Route 9	White pine, red pine (*Pinus resinosa*), staghorn sumac (*Rhus typhina),* poplar *(Populus spp.)*	Red maple, mixed fescue, ferns, oak , poplar *(Populus spp.),* white ash *(Fraxinus* americana.), common yarrow *(Achillea millefolium*)
Mass. Route 63	White pine, red pine	Red maple, mixed fescue
Mass. Route 116	White pine, blue spruce	Red maple, mixed fescue, sumac, oak
Mass. Route 181	White pine, red pine	Oak
US Route 20	No damaged species	Red maple, mixed fescue
US Route 202	White pine, red pine	Red maple, mixed fescue
Interstate 91	White pine, red pine, blue spruce, staghorn sumac	Red maple, mixed fescue, sumac, oak
UMASS Campus (no salt area)	No damaged species	Red maple, white pine, mixed fescue
Forest (no salt area)	No damaged species	Red maple, mixed fescue, ferns *(Osmunda claytoniana, Polystrichum acrostichoides, Dennstaedtia punctilobula)*

Table 3-2. Mean Sodium Concentrations in Leaves of Various Plant Species.

Species	Na Concentration in Leaves, mg/kg			
	Healthy		Damaged	
	Mean	Range	Mean	Range
Ash	193	193	n/a	n/a
Ferns	1280	283-4131	n/a	n/a
Grass	928	203-2300	n/a	n/a
Maple	428	0-1693	n/a	n/a
Mountain Laurel	n/a	n/a	423	423
Oak	197	120-283	n/a	n/a
Pine	28	28	2139	250-3431
Poplar	338	338	310	310
Sumac	177	110-268	209	133-340
Spruce	n/a	n/a	616	208-1575
Yarrow	123	123	n/a	n/a

n/a, no observations were made.

Table 3-3. Mean Sodium Concentration, pH, and Electrical Conductivity (EC) in Soil as a Function of Distance from the Road Pavement.

Distance from Road (feet)	Soil Measurements			
	pH	EC, dS/m	Mean Na, mg/kg	Na Range, mg/kg
5	7.60	0.16	101	21 - 295
10	7.13	0.22	145	145
15	6.70	0.23	154	19 - 270
20	6.48	0.21	89	10 - 309
30	5.78	0.12	16	2 - 22

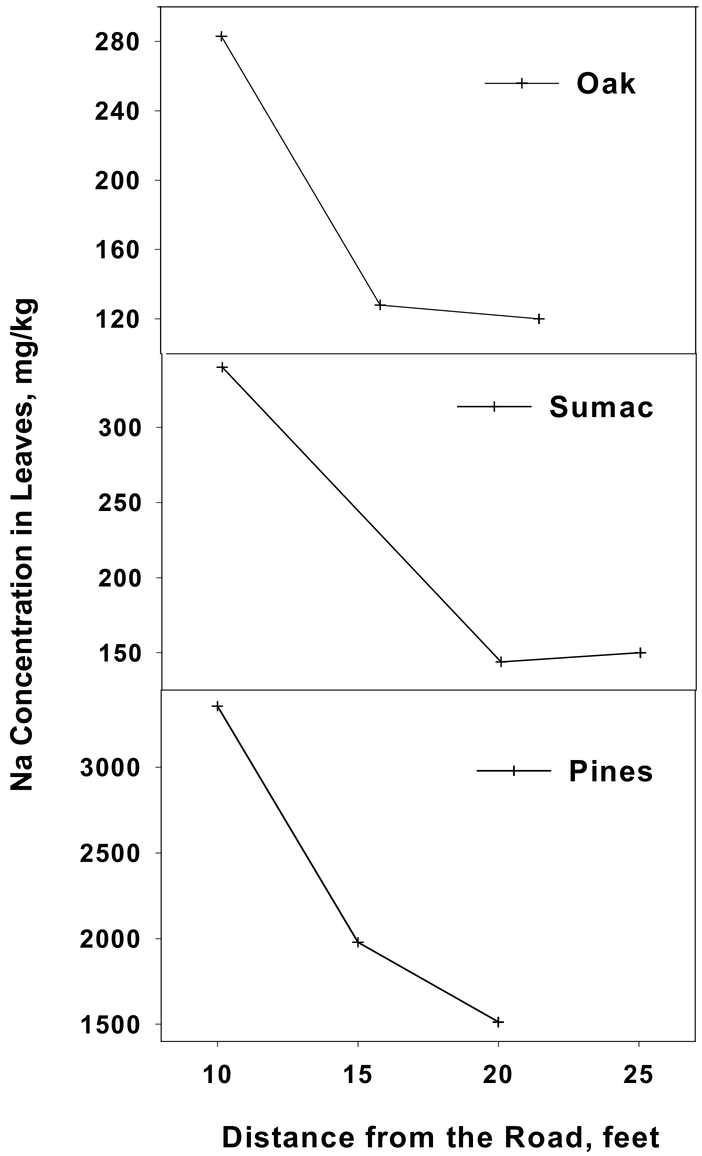


Figure 3-1.**Mean Sodium Concentration in Leaves of Oaks, Sumac, and Pines as a Function of Distance from the Road Pavement**

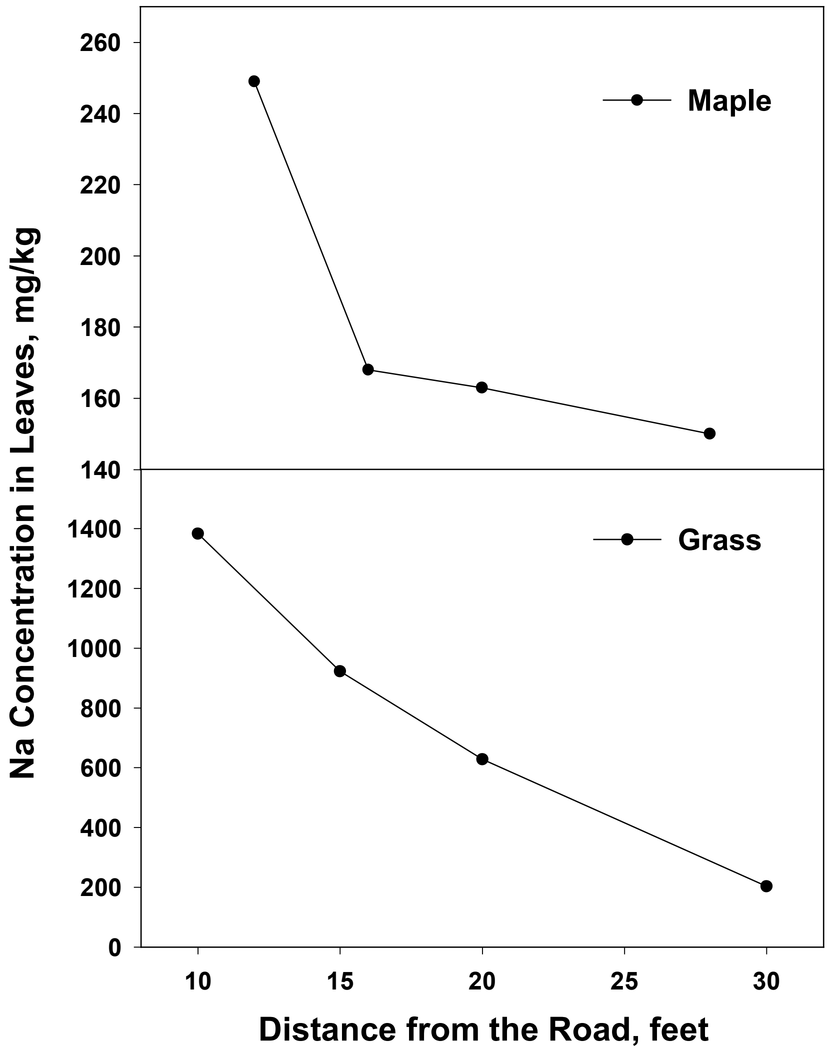


Figure 3-2. Mean Sodium Concentration in Leaves of Maples and Grasses as a Function of Distance from the Road Pavement.

4.0 SURVEY OF HIGHWAY DEPARTMENTS

The objective of this task was to develop and utilize a written survey of other cold-region highway departments, inquiring about their practices for deicing highways, for their assessments of damage to roadside vegetation and for their methods and specifications for mitigating salt damage to vegetation along highways. Surveys (Appendix II) were mailed in March 2000 to landscape architects and supervisors at twenty-five state or federal highway transportation agencies in cold-weather regions of the United States and Ontario, Canada. Fourteen responses were received. A list of responding agencies is shown in Table 4-1:

Table 4-1. List of Agencies That Responded to the Survey for Information on Application of Deicing Materials

Highway Departments	
Connecticut	Illinois
Massachusetts	Minnesota
Montana	Nebraska
New Hampshire	North Dakota
Pennsylvania	Ontario
Rhode Island	South Dakota
Vermont	Wisconsin

4.1 Summary of Survey of Responses

As shown in Table 4-1, 13 states across the northern United States and one province of Canada participated in the survey. Most of the agencies addressed the queries in the survey sufficiently to convey information about practices of additions of deicing materials, injury to vegetation, and practices for alleviating salt damage. The Survey results are presented in Tables 4-2 through 4-7.

The amount of roadway mileage requiring snow and ice control differed among agencies, with Rhode Island having the least (4,000 lane miles) and Pennsylvania having the most mileage (over 96,000 lane miles). The most common deicing agent used was sodium chloride (NaCl). Only New Hampshire and South Dakota stated that solid calcium chloride ($CaCl_2$) was used as a deicing agent, and only Indiana and Massachusetts used calcium magnesium acetate (CMA). Calcium chloride was most often used as a liquid additive to solid materials such as NaCl or sand. The average amount of sand used with deicing agents per season was 17 tons per lane mile. Of the fourteen agencies that responded, only Montana, Wisconsin, and Minnesota used corn by-products, and only North Dakota used ashes or cinders in their winter maintenance programs.

Sodium chloride was most often used as a deicing agent on roadways when temperatures were between 20 and 32°F, whereas $CaCl_2$ was the salt of choice at temperatures lower than 20°F. The average application of NaCl use was 280 lb per lane mile, and the average sand mix rate was 450 lb per lane mile. Brine and liquid mixtures were used primarily for pre-wetting roads and for bridges at an average rate of 35 gallons per lane mile. Of the deicing materials used, NaCl was considered the most damaging to roadside vegetation.

Only eight states responded to the portion of the survey concerning the damage of deicing agents to vegetation. However, responding agencies observed damage to White pine (*Pinus strobus*) by road-applied salts. The most common damage to evergreens was a browning or necrosis of the needles facing the roadway, whereas deciduous trees and shrubs suffered from die-back and witches broom (abnormal brush-like growth of weak, closely clustered shoots from the terminal end of a branch). Several agencies observed that evergreens were damaged most often from salt spray but that deciduous plants suffered from salt-containing runoff. Most damaged trees were within approximately 50 feet from the roadway, but some were up to 300 feet away. Only five agencies indicated that they monitored roadside vegetation for salt damage.

Design criteria frequently dictated that trees be located at least 30 feet from the road, mainly for automobile safety. In general, the distance at which a particular plant type could be placed from the road was related to the caliper (the diameter of the trunk three feet from the ground) of the plant and degree to which the vegetation would impede visibility. Some states designated a 5-to-30-foot zone from the edge of the road in which no shrub or tree can be present, if possible.

4.2 Summary of Surveys from Highway Agencies in Cold-Weather Regions (tables)

Table 4-2 through Table 4-7 summarize information from surveys returned from agencies that responded to requests for information. Information provided in Table 4-2 includes total lane miles requiring ice control, frequency of deicing material application under various environmental conditions, and total amount of various deicing agents used per season. Table 4-3 shows rates and conditions governing the application of NaCl, $CaCl_2$, and calcium magnesium acetate. Table 4-4 shows rates and conditions governing the use of sand with de-icing agents and use of brine or liquid mixtures by agency. Table 4-5 lists plants that have been observed to be damaged by the deicing operations, a description of the damage, and factors that appear to cause the damage. Table 4-6 lists plants observed by the reporting agencies to be tolerant to deicing agents. Table 4-7 presents design criteria or other practices that might ameliorate damage to roadside vegetation.

Table 4-2. Seasonal Snow and Ice Removal Information by State or Province.

State or Province	Total Roads Requiring Ice Control (Lane Miles)	Frequency of Deicing Material Application (times / season)				Amount of De-icing or Anti-skid Agent Used per Season					
		Fresh Snow	Packed Snow / Ice	Freezing Water / Melt	Freezing Rain	NaCl (Tons)	$CaCl_2$ (Tons)	Ca-Mg Acetate (Tons)	Sand + De-icing Agents (Tons)	Brine or Liquid Mixtures (Gallons	Other De-icing Agents (Tons)
Connecticut	6,000	□	□	□	□	97,690	no data	no data	346,128*	testing	no data
Illinois	42,300	□	□	□	□	420,000	no data	no data	no data	no data	no data
Indiana	11,390	30	5	5	10	301,000	no data	1,000	11,200	5,000	□
Massachusetts	14,033	22	no data	20	7	290,000	no data	100	82,000	200,000	33,000
Minnesota	29,500	28	28	9	5	203,138	minimal	minimal	212,000	no data	minimal
Montana	20,000	□	□	□	□	no data	no data	no data	no data	no data	no data
Nebraska	10,000	□	□	□	□	□	□	0	□	□	0
New Hampshire	4,200	20	10	15	no data	171,450	300	no data	144,241*	3,000	no data
North Dakota	16,500	many	many	many	many	20,000	0	0	□	□	no data
Ontario	11,540	many	6	6	6	223,000	testing	testing	312,200	no data	no data
Pennsylvania	96,986	□	□	□	□	no data	no data	no data	no data	no data	no data
Rhode Island	4,000	□	□	□	□	60,000	no data	no data	□	5,000	4,000
South Dakota	83,375	no data	no data	no data	no data	26,250	65 tons*	no data	105,350	no data	with sand
Vermont	6,312	no data	no data	no data	no data	68,413	no data	no data	141,960	no data	no data
Wisconsin	30,340	40	8	no data	8	375,000*	with sand	0	52,500*	29,000*	no data

* Estimated by the University of Massachusetts

✓ Applicable, but in unreported amounts

Table 4-3. Rates and Conditions of Use of Sodium Chloride, Calcium Chloride, and Calcium Magnesium Acetate by State or Province.

State or Province	Sodium Chloride		Calcium Chloride		Calcium Magnesium Acetate	
	Conditions	Lbs. / Lane Mile	Conditions	Lbs. / Lane Mile	Conditions	Lbs. / Lane Mile
Connecticut	no data	216	no data	no data	no data	no data
Illinois	20 - 32°F	100 - 500	5 - 20°F	150 - 500	not used	0
Indiana	snow + Ice	250	snow + Ice	✓	snow + Ice	✓
Massachusetts	most conditions	240	no data	no data	most conditions	240
Minnesota	10 - 30°F	200 - 600	<10°F	✓	warmer conditions	✓
Montana	not used	0	no data	no data	not used	0
Nebraska	no data	✓	no data	✓	no data	0
New Hampshire	>15°F	200 - 400	no data	✓	no data	no data
North Dakota	all conditions	50 - 300	not used	not used	not used	not used
Ontario	all conditions	235*	no data	currently testing	no data	currently testing
Pennsylvania	>20°F	150 - 250	<20°F	✓	no data	no data
Rhode Island	all conditions	✓	first treatment	✓	no data	no data
South Dakota	< 32°F	125 - 500	< 32°F	with sand only	no data	no data
Vermont	15 - 32°F	300 - 600	no data	no data	no data	no data
Wisconsin	all conditions	225*	no data	no data	not used	not used

*Estimated by the University of Massachusetts
✓Applicable, but no amounts given

Table 4-4. Rates and Conditions of Use of Sand with Deicing Agents and Use of Brine or Liquid Mixtures by State or Province.

State or Province	Sand with De-icing Agent				Brine or Liquid Mixtures	
	Conditions	Sand Mix Rate (Lbs. / Lane mile)	De-icing Agent Added	Rate of Agent (per Ton of Sand)	Conditions	Gals. / Lane Mile
Connecticut	no data	715 (sand alone)	no data	no data	currently testing	currently testing
Illinois	not used	0	no data	no data	pre-treat bridges	20 - 60 (brine)
Indiana	snow + ice	250 (sand alone)	no data	no data	not used	0
Massachusetts	no data	240	NaCl	100 lbs.	most conditions	2 - 40 ($CaCl_2$)
Minnesota	no data	200 - 1,000	NaCl	200 lbs.	no data	2.5* (brine) (added to solids)
Montana	snow pack and ice	✓	$MgCl_2$ (liquid)	7 gals.	>10°F	20 - 70 ($CaCl_2$)
Nebraska	no data	✓	NaCl, $CaCl_2$	no data	no data	✓
New Hampshire	<15°F	✓	NaCl	200 lbs.	" cold "	✓
North Dakota	no data	200 - 500	NaCl	no data	pre-wetting only	✓
Ontario	" cold "	1000* (sand alone)	not used	0	no data	no data
Pennsylvania	<20°F	250 - 400	NaCl	no data	no data	no data
Rhode Island	all conditions	✓ (sand alone)	not used	not used	no data	no data
South Dakota	<32°F	300 - 500	$MgCl_2$ (liquid)	8 gals.	no data	no data
Vermont	<15°F	✓	NaCl	40 - 100 lbs.	no data	no data
Wisconsin	<10°F (pavement temp)	100 - 250	NaCl	100 lbs.	<15°F (pavement temp)	1.0* ($MgCl_2$) (added to solid NaCl)

*Estimated by the University of Massachusetts from data provided by agencies ✓Applicable, but no amounts given

Table 4-5. Plants Observed to be Damaged by Deicing Agents and Descriptions of Occurrence of Damage and Causal Factors

Type of Vegetation	Common Name	Scientific Name	States Reporting Damage (%)*	Distance of Damage from Roadway (feet from road)	Description of Damage and Causal Factors
Evergreen Trees and Shrubs	Arborvitae	*Thuja* spp.	25	**Trees damaged:** most within 50 ft some up to 200 ft **Shrubs damaged:** most within 50 to 100 ft	**Description:** Burning or browning of needles, sometimes only occurring on the side of the tree or shrub facing the roadway. **Causal Factors**: Roadway spray is thought to cause the majority of damage to evergreen plants, presumably because the spray affects the leaves which are retained during the winter.
	Canadian Hemlock	*Tsuga canadensis* .	13		
	Cedar	*Cedrus* spp.	25		
	Eastern White Pine	*Pinus strobus*.	100		
	Juniper	*Juniperus* spp.	38		
	Yew	*Taxus* spp.	13		
	Mugo Pine	*Pinus mugo*	25		
	Red Pine	*Pinus resinosa*	25		
Deciduous Trees and Shrubs	American Beech	Fagus grandifolia	13	**Trees damaged:** most within 50 ft or less some up to 300 ft **Shrubs damaged:** most within less than 20 ft some up to 100 ft	**Description:** Dieback and witches broom. Total tree death was reported in areas where runoff accumulates. **Causal Factors:** Damage to deciduous plants is caused more by runoff than road spray. Damage is particularly severe in areas where runoff accumulates. Roadway spray is reported to cause minimal damage to deciduous plants, evidently because the leaves are absent during the winter.
	American Cranberry	*Vaccinium macrocarpon*	13		
	Basswood	*Tilia americana*	13		
	Bur Oak	*Quercus macrocarpa*	13		
	Green Ash	*Fraxinus pennsylvanica*	13		
	River Birch	*Betula nigra*	13		
	Soft Maple	*Acer saccharinum*	13		
	Sugar Maple	*Acer saccharum* l	25		
	Washington	*Crataegus nitida*	13		
	Winterberry	*Ilex verticillata*	13		
Grasses and Lawns	Annual Rye	*Lolium* spp.	13	**Grass and Lawn damage:** most within less than 10 ft some up to 20 ft	**Description:** Death or dieback. Inability to control the invasion of weeds. **Causal Factors:** Salt spray and runoff accumulation
	Bluegrass	*Poa* spp.	25		
	Bromegrass	*Bromus* spp.	13		
	Fescue grasses	*Festuca spp.*	13		
	Perennial Rye	*Lolium perenne*	13		

* Represents the percent of eight states that responded to this section of the survey.

Table 4-6. Plants Observed to be Resistant to Deicing Materials.

Common Name	Scientific Name	Common Name	Scientific Name
Buckeye	*Aesculus parviflora*	Bar Harbor juniper	*Juniperus horizontalis*
Red chokeberry	*Aronia arbutifolia*	Crabapple	*Malus* spp.
Buffalo grass	*Buchloe dactyloides*	White spruce	*Picea glauca*
Siberian peashrub	*Caragana arborescens*	Colorado blue spruce	*Picea pungens*
Catalpa	*Catalpa speciosa*	Austrian pine	*Pinus nigra*
Summersweet clethera	*Clethera alnifolia* spp.	Ponderosa pine	*Pinus ponderosa*
Fescues	*Festuca* spp.	Japanese black pine	*Pinus thunbergii*
White ash	*Fraxinus americana*	Bluegrass	*Poa* spp.
Green ash	*Fraxinus pennsylvanica*	Saltspray rose	*Rosa rugosa*
Honey locust	*Gleditsia triacanthos*	Fragrant sumac	*Rhus aromatica*
Kentucky coffeetree	*Gymnocladus dioicus*	Silver buffaloberry	*Shepherdia argentea*
Climbing hydrangea	*Hydrangea anomala*	Common lilac	*Syringa vulgaris*
Inkberry	*Ilex glabera*	American arborvitae	*Thuja occidentalis*
American holly	*Ilex opaca*	Wheat	*Triticum aestivum*
Shore juniper	*Juniperus conferta*	Arrowwood viburnum	*Viburnum dentatum*

Table 4-7. Design Criteria for Vegetation or Planting Zone Setbacks by State or Province

State or Province	Design criteria for vegetation/planting zone setbacks	Other practices
Connecticut	No Report	No Report
Illinois	Most shrubs and trees are planted approximately 30 ft from the roadway, behind the ditch line. The following are specific distances that pertain to the planting of shrubs and trees near the edge of the shoulder, face of curbing or ditch line, or whichever is farthest from the pavement. 1. No plants less than 4-ft tall. 2. Plants that are branched to the ground and exceed 3 ft in height can not be placed closer than 10 ft from the roadway. 3. Coniferous evergreens cannot be closer than 20 ft from the roadway, and if branched lower than 10 ft from the ground, should be set back farther. 4. No dense or continuous hedge can be within 40 ft of the pavement on the north or west sides of the roadway in situations where they may cause snow to be drifted onto the pavement. 5. No trees can be located within 50 ft on the near side or 20 ft on the far side of an intersection. 6. Trees in the median should be located no closer than 50 ft from an intersection. 7. No tree can be located within a median which is less than 10-ft wide. 8. Landscape designs must provide a 6-ft, safe pedestrian walkway whether or not a sidewalk is present.	Plant material is selected based on its ability to thrive under conditions experienced in the part of the state in question.
Indiana	No Report	No Report
Massachusetts	Dictated by American Association of State Highway & Transportation Officials design standards. Design standards are based on speed, roadside protection (such as a guardrail), existing conditions, and the observations from Morton Arboretum. In general, planting setbacks are beyond 30 ft from the pavement on interstate or high-speed roadways.	No Report
Minnesota	Only very salt tolerant material should be planted within 30 ft of the pavement.	No Report
Montana	No Report	No Report
Nebraska	On interstates there is a 50' setback for trees and shrubs and a 30' setback on other primary highways.	No Report

Table 4-7. Design Criteria for Vegetation or Planting Zone Setbacks by State or Province-Continued

State or Province	Design criteria for vegetation/planting zone setbacks	Other practices
New Hampshire	Usual set back for any plant material that reaches a caliper of >3" is 30' or more. The exception is when a guard rail is present. Sight distances at intersections and driveways are an important criteria for roadside planning. In general, roadside design criteria reflect engineering standards.	Native plant species are preferred. Several species are used specifically for headlight glare, natural snow fence, crash attenuation and visual screening.
North Dakota	No Report	No Report
Ontario	see TAC guide (survey folder contains an address for obtaining the guide)	see TAC guide
Pennsylvania	Salt sensitive plants are typically not used for roadside landscaping, or they are placed at least 40' from the pavement. Trees that can obtain a trunk diameter of more than 4" are not to be located within the median area or on the outside of curves unless more than 9.0 meters from the pavement.	No Report
Rhode Island	Interstate and limited access highways have a 30' setback for trees and shrubs, and on secondary roadways there is a 10' minimum setback for mowing and site distance allowances.	No Report
South Dakota	Rural roads and interstates have a 30-ft clear zone, with urban roads having a minimum 2' and optimal 6' clear zone.	No Report
Vermont	There is an effort to redesign highway drainage to avoid vegetation areas which are salt-sensitive.	Salt-resistant grasses, shrubs and trees are used in plantings.
Wisconsin	Setbacks are 80 to 100' on the south and east side of roadways. To reduce salt spray damage, Plantings are on the upwind, instead of the downwind side, of the roadway.	No Report

Notes for tables:

Seven (47%) of responding agencies indicated that at times and in some locations, no deicing agents are applied and that plowing is the only means of removing snow. Depending on the state, plowing-only was conducted under the following conditions, <5°F, in times of high winds, in straight areas of the roadway, with fresh or dry snow, and with particularly large accumulations. Five (33%) responding states used deicing agents including pre-mixed sodium and calcium chloride, M-50 (liquids created from byproducts of agricultural, beer, and distilled alcohols processing, combined with magnesium chloride) , Iceban (liquid concentrate residue from the wet milling of corn and the production of alcohol), and potassium acetate. Only 13% (two states) of states surveyed used corn by-products, and only 7% (one state) used ashes.

5.0 INVESTIGATION OF AVAILABILITY OF SALT-TOLERANT PLANT MATERIALS

The research under this task determined the availability of salt-tolerant plant species at New England nurseries and at nurseries in other northern areas if these nurseries had sales representatives in the New England area. Limiting the assessment of availability of woody plant materials to the New England area was done to help to ensure winter hardiness in Massachusetts. Sources of grass seeds are listed from the region of the United States where seed production occurs.

The review of literature (Section 2.0, Table 2-2) established a list of salt-tolerant plants from which selections were made for determinations of availability in the New England market area. The determination of availability of plants was by written and/or telephone contacts of vendors followed by consultation of catalogs provided by the vendors. Trees, shrubs, and groundcovers, including turfgrasses, were listed in Table 5-1 only if they were identified to be salt tolerant and were supplied by nurseries in New England. None of the plants listed in Table 5-1 have been suggested to be invasive (see Appendix IV).

Table 5-1. Salt-Tolerant Trees, Shrubs, Groundcovers, Vines, and Grasses, and Their Availability from New England Nurseries.

Plant		Vendor																	
Common name	**Scientific name**	A. Bailey Nurseries	B. Bigelow Nurseries	C. Cobble Creek Nursery	D. Imperial Nurseries, Inc.	E. Klyn Nurseries, Inc.	F. Lake County Nurseries, Inc.	G. MacLoed Nursery	H. Millane Nurseries, Inc.	I. Norway Farms	J. Planters Choice Nurserymen	K. Prides Corner Farms	L. Shemin Nurseries, Inc.	M. Stewart's Nursery, Inc.	N. Summer Hill Nursery, Inc.	O. Sylvan Nursery, Inc.	P. Tarnow	Q. Western Maine Nurseries	R. Weston Nurseries, Inc.
Trees																			
Horse chestnut	*Aesculus chinensis*																		X
Buckeye	*Aesculus parviflora*		X	X		X	X					X				X	X		X
Red chokeberry	*Aronia arbutifolia*	X	X			X	X				X	X	X	X	X	X		X	X
Yellow birch	*Betula alleghaniensis*		X			X										X			
Black birch	*Betula lenta*		X													X		X	
Paper birch	*Betula papyrifera*	X	X	X				X			X			X		X			X
Silver birch	*Betula pendula*	X							X	X		X	X			X			X
Gray birch	*Betula populifolia*	X						X			X			X		X			
Catalpa	*Catalpa speciosa*	X	X			X		X								X			
White ash	*Fraxinus americana*	X	X			X	X	X					X	X		X			
Green ash	*Fraxinus pennsylvanica*	X	X		X	X	X		X	X	X		X	X		X	X		X
Common honeylocust	*Gleditsia triacanthos*	X	X			X	X	X	X	X	X		X	X		X	X		X
Kentucky coffeetree	*Gymnocladus dioicus*	X	X			X	X	X								X			X

Table 5.1 (Continued)

Plant		Vendor																	
Common Name	**Scientific Name**	A. Bailey Nurseries	B. Bigelow Nurseries	C. Cobble Creek Nursery	D. Imperial Nurseries, Inc.	E. Klyn Nurseries, Inc.	F. Lake County Nurseries, Inc.	G. MacLoed Nursery	H. Millane Nurseries, Inc.	I. Norway Farms	J. Planters' Choice Nurserymen	K. Prides Corner Farms	L. Shemin Nurseries, Inc.	M. Stewart's Nursery, Inc.	N. Summer Hill Nursery, Inc.	O. Sylvan Nursery, Inc.	P. Tarnow	Q. Western Maine Nurseries	R. Weston Nurseries, Inc.
Trees (Continued)																			
Inkberry	*Ilex glabera*	X	X		X	X	X	X			X	X	X		X	X	X	X	X
American holly	*Ilex opaca*		X		X	X			X				X			X			X
Eastern red cedar	*Juniperus virginiana*		X			X	X	X				X	X						X
American sweetgum	*Liquidambar styraciflua*		X			X	X	X	X	X			X	X					
Crabapple	*Malus* spp.	X			X	X	X	X	X	X		X	X	X	X	X	X	X	X
White spruce	*Picea glauca*		X	X	X	X	X	X	X	X		X	X	X	X	X	X		X
Colorado spruce	*Picea pungens*			X		X	X	X	X	X		X	X	X	X	X	X		X
Mugo pine	*Pinus mugo*		X	X	X	X	X	X	X	X	X	X	X	X		X	X		X
Austrian Pine	*Pinus nigra*		X			X	X	X	X	X			X	X	X	X			X
Eastern white pine**	*Pinus strobus*																		X
Japanese black pine	*Pinus thunbergii*							X	X				X			X			
Quaking aspen	*Populus tremuloides*	X														X			
Black cherry	*Prunus serotinia*	X	X																
White oak	*Quercus alba*	X	X			X										X		X	

Table 5.1 (Continued)

Plant		Vendor																	
Common Name	**Scientific Name**	A. Bailey Nurseries	B. Bigelow Nurseries	C. Cobble Creek Nursery	D. Imperial Nurseries, Inc.	E. Klyn Nurseries, Inc.	F. Lake County Nurseries, Inc.	G. MacLoed Nursery	H. Millane Nurseries, Inc.	I. Norway Farms	J. Planters' Choice Nurserymen	K. Prides Corner Farms	L. Shemin Nurseries, Inc.	M. Stewart's Nursery, Inc.	N. Summer Hill Nursery, Inc.	O. Sylvan Nursery, Inc.	P. Tarnow	Q. Western Maine Nurseries	R. Weston Nurseries, Inc.
Trees (Continued)																			
Pin oak	*Quercus palustris*	X			X	X	X	X	X		X		X	X		X			X
Red oak	*Quercus rubra*	X	X	X		X	X	X	X		X		X			X		X	
Black locust	*Robinia pseudoacacia*	X	X					X								X			
Golden willow	*Salix alba*	X	X	X			X	X	X		X							X	X
Japanese pagodatree	*Sophora japonica*		X										X			X			
Common lilac	*Syringia vulgaris*			X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
American arborvitae	*Thuja occidentalis*		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 5-1 (Continued)

Plant		Vendor																	
Common Name	**Scientific Name**	A. Bailey Nurseries	B. Bigelow Nurseries	C. Cobble Creek Nursery	D. Imperial Nurseries, Inc.	E. Klyn Nurseries, Inc.	F. Lake County Nurseries, Inc.	G. MacLoed Nursery	H. Millane Nurseries, Inc.	I. Norway Farms	J. Planters' Choice Nurserymen	K. Prides Corner Farms	L. Shemin Nurseries, Inc.	M. Stewart's Nursery, Inc.	N. Summer Hill Nursery, Inc.	O. Sylvan Nursery, Inc.	P. Tarnow	Q. Western Maine Nurseries	R. Weston Nurseries, Inc.
Shrubs, Groundcovers, Vines																			
Siberian peashrub	*Caragana arborescens*	X	X			X		X				X				X			
Summersweet Clethera	*Clethera alnifolia*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Russian Olive	*Elaeagnus angustifolia*	X				X		X											
Japanese euonymus	*Euonymus japonicus*																		X
Climbing hydrangea	*Hydrangea anomala*	X			X			X	X		X	X			X		X		X
Shore juniper	*Juniperus conferta*		X		X	X	X		X		X	X	X		X	X	X		
Bar Harbor juniper	*Juniperus horizontalis*				X						X	X	X	X	X	X			X
Fragrant sumac	*Rhus aromatica*	X	X	X		X	X				X	X				X			X
Squaw bush	*Rhus trilobata*	X				X													
Saltspray rose	*Rosa rugosa*	X	X	X	X	X		X			X		X	X	X	X			X
Silver buffaloberry	*Shepherdia argenta*	X		X															X
Tamarix	*Tamarix ramosissima*	X				X		X								X			X
Arrowwood viburnum	*Viburnum dentatum*	X	X		X	X	X		X		X	X		X	X	X		X	X

Table 5 -1 (Continued, listing of grasses)

Scientific Name	**Common Name**	**Sources**
Grasses		
Quackgrass .	*Agropyron repens*	Sources of grass seeds are listed under the note "S" at the end of the listing of trees and shrubs. Inventories of seed stocks by vendors were not determined.
Bromegrass	*Bromus inermis*	
Buffalo grass	*Buchloe dactyloides*	
Leptochloa	*Diplachne accuminata*	
Fescue	*Festuca* spp.	
Marshgrass	*Heleochloa schoenoides*	
Scratch grass	*Muhlenbergia asperifolia*	
Plains bluegrass	*Poa arida*	
Nuttall alkaligrass	*Puccinellia airoides*	
Alkaligrass	*Puccinellia distans*	
Alkaligrass	*Puccinellia lemmonii*	
Saltmeadow cordgrass	*Spartinia patens*	
Alkali sacaton	*Sporobolus airoides*	
Wheat	*Triticum aestivum*	

Key to listing of nurseries in Table 5-1.

A. Bailey Nurseries
1325 Bailey Road
St. Paul, MN 55119
Phone 800-829-8898
Fax 800-829-8894
Local Contact in NH - Carol Lorenz - Phone 888-539-3204

B. Bigelow Nurseries
P.O. Box 718
Northboro, MA 01532
Phone 508-845-2143
Fax 508-842-9245

C. Cobble Creek Nursery
991 Tyler Bridge Road
Bristol, VT 05443
Phone/Fax 802-453-3889

D. Imperial Nurseries, Inc.
P.O. Box 120
Granby, CT 06035
Phone 800-950-6051
Fax 860-844-6063
www.imperialnurseries.com

E. Klyn Nurseries, Inc.
3322 South Ridge Road
Route 84
Perry, OH 44081
Phone 440-259-3811

Note: Plant material available from:
New England Nursery Sales
P.O. Box 64
McIndoe Falls, VT 05050
Phone 802-633-2232

F. Lake County Nurseries, Inc.
Box 122 (Route 84)
Perry, OH 44081-0122
Phone 800-522-5253
Fax 800-699-3114

Note: Plant material available from:
New England Nursery Sales
P.O. Box 64
McIndoe Falls, VT 05050
Phone 802-633-2232
Fax 802-633-2349

Key to listing of nurseries in Table 5-1.(Continued)

G. MacLeod Nursery
16 Old Goshen Road
P.O. Box 628
Williamsburg, MA 01096
Phone 413-268-7211

H. Millane Nurseries, Inc.
604 Main Street
Cromwell, CT 06416-1443
Phone 860-635-5500
Fax 860-635-3685

I. Norway Farms
Norfolk, MA 02056
Phone 508-528-0107
Fax 508-528-0544
www.norwayfarms.com

J. Planters' Choice Nurserymen
140 Huntingtown Road
Newtown, CT 06470
Fax 203-426-8057

K. Prides Corner Farms
122 Waterman Road
Lebanon, CT 06249
Phone 800-437-5168
Fax 860-642-4155

L. Shemin Nurseries, Inc.
570 Main Street
Hudson, MA 01749
Phone 978-562-6988
Fax 978-568-1652

Key to listing of nurseries in Table 5-1.(Continued)

M. Stewart's Nursery, Inc.
135 Millers Falls Road
Turners Falls, MA 01376-2299
Phone 413-863-2510

N. Summer Hill Nursery, Inc.
888 Summer Hill Road
Madison, CT 06443
Phone 203-421-3055
Fax 203-421-5189

O. Sylvan Nursery, Inc.
1028 Horseneck Rd.
Westport, MA 02790
Phone 508-636-4573
Fax 508-636-3397

P. Tarnow
788 Sheridan Street
Chicopee, MA 01020
Phone 800-344-7791
Fax 413-592-0610

Q. Western Maine Nurseries
P.O. Box 250
One Evergreen Drive
Fryeburg, ME 04037
Phone 800-447-4745
Fax 207-935-2043

R. Weston Nurseries, Inc.
East Main Street
Route 135
P.O. Box 186
Hopkinton, MA 01748
Phone 508-435-3414
Fax 508-435-3274

S. **Vendors for Grasses**

Jacklin Seed
5300 Riverbend Avenue
Post Falls ID 83854
209-773-7581
800-688-7333
www.jacklin.com

Seed Research of Oregon
27630 Llewellyn Road
Corvallis, OR 97333
541-758-9115
srofarm@ibm.net

Cebco International Seeds, Inc.
P.O. Box 168
820 West First Street
Halsey, OR 97348
800-445-2251
541-369-2251
intlseed@intlseed.com

Pickseed West, Inc.
P.O. Box 888
Tangent, OR 97389
541-967-0123
Dfloydpswres@proaxis.com

Advanta Seeds Pacific, Inc.
P.O. Box 1044. S.E.
Albany OR 97321
800-288-7333
541-967-8923
festuca@proaxis.com

The Scotts Company
7644 Keene Road, NE
Gervais, OR 97026
503-792-3633
eric.nelson@scottsco.com

Pure Seed Testing, Inc.
P.O. Box 449
Hubbard, OR 97032
503-651-2297
crystal@turf-seed.com

6.0 PREPARATION OF SPECIFICATIONS AND METHODOLOGY

The objective of this phase of the research was to present a description of potential investigations on developing of specifications for use with ameliorating practices, such as use of calcium sulfate, and land-preparation and recommendations for evaluation of salt-tolerant plants. Section 6.2 addresses methodology and experimental designs that incorporate testing of soil amendments in highway medians, and Section 6.3 incorporates evaluation of salt-tolerant plants and amendments in land around highway interchanges.

6.1 Alleviating Salt Stress in Roadside Vegetation by Proper Plant Selection and Use of Soil Amendments

Liberal use of deicing salts may have negative impacts on soils and vegetation in the immediate vicinity of roadways. Massachusetts applies approximately 290,000 tons of sodium chloride (NaCl) per winter season along state-maintained roadways. The literature review (Section 2.0) notes that the vigor of roadside plants may be suppressed due to saline soils, foliar desiccation or other damage, poor plant nutrition, or poor soil tilth (physical condition) induced by road-applied salts. The research in this section addresses experiments that may be conducted to assess soil amendments that may improve nutrition of plants and soil properties under roadside conditions subjected to deicing agents.

Chemical elements, such as Na and Cl, in deicing salts may be antagonistic with essential elements in the soil, competing with the nutrients for plant absorption (Lacasse and Rich, 1964) and suppressing plant vigor. Salt-stressed trees and shrubs may be prone to nutritional disorders, such as Ca-deficiency, which in turn make them more susceptible to fungal and bacterial pathogens (Marshner, 1995). Sodium-containing salts, such as NaCl, may suppress plant growth by promoting the dispersal of soil particles rather than their aggregation, thereby imparting poor structure to the soil (Mengel and Kirkby, 1987). This lack of soil aggregation can lead to poor soil aeration, poor water infiltration, and consequently poor growing conditions.

Grass stands that lack vigor or are generally unhealthy from salt suppression can be overgrown by more aggressive weed species, which are not aesthetically pleasing and which may be less effective in controlling erosion than grasses. In more severe cases, deicing salts may lead to the death of large patches of grass in areas immediately adjacent to the roadway, leaving the bare soil exposed. Bare areas appear sporadically in the median of some four-lane highways in Massachusetts. These dead patches are not only unsightly but may enhance soil erosion and could lead to an increase in roadway maintenance costs. It was not determined that these bare spots were due to damage from deicing salts.

Leaves of woody plants are often damaged by saline road spray and by the accumulation of Na or Cl in their tissues (Townsend, 1980). The death of woody vegetation due to excessive salt use can be more destructive than that of loss of roadside grasses because of the cost of replacing woody plants and because lost aesthetic value takes many years to restore.

The negative impacts of salinity on plants can be alleviated partially by the application of soil amendments. Most amendments are designed to improve soil tilth and fertility and in some instances may act to reduce the toxicity of Na and Cl by blocking their absorption by plant roots. The most commonly used amendments are calcium-containing salts, such as calcium sulfate ($CaSO_4$) and calcium chloride ($CaCl_2$), and other agricultural amendments such as Mg- and P-containing fertilizers. As previously stated, a consequence of using Na-containing (sodic) salts for deicing is the loss of favorable soil structure if the Na enters roadside soils. Organic amendments, such as peat, compost, or leaf litter, may improve soil tilth, thus enhancing the growth of plants in the presence of sodic salts. Soil-applied amendments will have limited potential in reducing salt burn, which is related to osmotic desiccation of foliage by salt sprays.

Soil amendments, however, need further assessment for their capacities to ameliorate salt damage to existing vegetation. Evaluation is needed of salt-tolerant herbaceous and woody species that may be more adaptable to saline soils than existing species on site. It is not understood whether soil amendments are needed when salt-tolerant plant species are used along roads, hence, an investigation is needed of the potential advantages of combining these plants and amendments in the same area.

6.2 Roadway Median Salt Study: Experimental Design

Highway medians are probable places to conduct salt-tolerance studies. These areas are some of the primary sites where salt damage occurs to herbaceous vegetation. Because of its location, vegetation in the median can receive larger amounts, perhaps twice or more of the amount, of deicing salt as vegetation located along the outer perimeter of the roadway, thereby exposing experimental plots to heightened levels of salinity. The length of medians and the lack of appreciable obstructions also allow them to accommodate agricultural equipment for preparation and maintenance of research plots. Medians are also convenient areas for observations, as differences among treatments can viewed easily along the roadway.

Care must be taken when choosing particular stretches of medians for conducting field experiments. Undoubtedly, medians differ from one place to another with regards to width, slope, soil properties, and other features. However, because the length of roadways in Massachusetts with medians is expansive, it is possible to find stretches of a median that are uniform. These uniform areas would be suitable for experimental plots.

For an experiment, the median must be symmetrical with the left side of the median being of similar shape and elevation, with respect to the roadway, as the right side. Non-symmetrical medians in cross dimensions might not be acceptable for experimental plots. The physical differences from one side of a non-symmetrical median to the other could cause differences among experimental units that are not due to the treatments. For example, the uphill side of a median may differ from the downhill side with respect to water drainage, soil organic matter content, soil type and texture, exposure to light (in extreme cases), and other factors that influence plant growth.

In addition, if roadway runoff is the primary means by which salt is deposited in the median, the low-lying areas of the median will be exposed to higher concentrations of salt than other areas. At a given site, efforts must be made to choose a length of median with uniform soil characteristics, automobile traffic frequency, salt application rates, and similar overall growing conditions. However, it is not required that each separate median site be uniform with respect to all other sites. In fact, it may be advisable to choose different lengths of median, each having a different amount of traffic volume or salt application rate. Differences among sites would then suggest that these factors are contributors to the salt tolerance of the vegetation plots.

The proposed experiment site consists of seven vegetation treatments combined with five soil amendments in a split-plot design. Vegetation types will serve as whole plots and amendments as subplots. This arrangement is advantageous in that it puts all treatment combinations of a single vegetation type next to each other, thereby making evaluations of treatments simple.

Each site will have thirty-five treatment combinations, with each treatment (plot) encompassing the width of the median and being located one next to the other down the length of the roadway (Figure 6-1). Each individual treatment can be divided into two separate, equal experimental units with the ditch (center of the median) as the division between units. These separate units can provide an extra observation ("within term") for statistical analysis.

Each treatment combination should be allocated 25 yards of median length to obtain a representative response to treatments. Each site can act as a single block being 875 yards in length (approx. 0.5 miles) and have the thirty-five treatment combinations. Some sites identified as suitable for median experiments include:

1. Median north of exit 15 on Interstate 91.
2. Median between exits 18 and 19 on Interstate 91.
3. Median on Highway 116, west of the University of Massachusetts at Amherst.

It is advisable to choose sites that differ from each other if possible. Differences among sites would indicate that variables other than the treatments contributed to the outcome of the experiment. This discovery could lead to further research and a greater understanding of the factors that influence the salt tolerance of road-side vegetation. Two possible differences among sites could be different traffic volumes or the differences in proximity to urban areas where ice control may be more aggressive. Data to be collected from median plots include obtaining soil samples for the determination of Na or other relevant elements and visual indexing (ranking) of plant appearance to assess the performance of each treatment.

Vegetation suggested for median plots include existing plants, such salt-tolerant grasses, legumes, and wildflowers. Plant materials that might be introduced in an experiment include alkaligrass (*Puccinellia* spp.), bluegrass (*Poa* spp.), fescue (*Festuca* spp.), buffalograss (*Buchloe* spp.), crimson clover (*Trifolium incarnatum*), and a wildflower mix suitable for medians. Alkaligrass and bluegrass were indicated in the scientific literature as being salt tolerant (Catling and McKay, 1980; Greub et al., 1985), whereas fescue and buffalo grass were said to be resistant to deicing salt in the recent deicing salt survey.

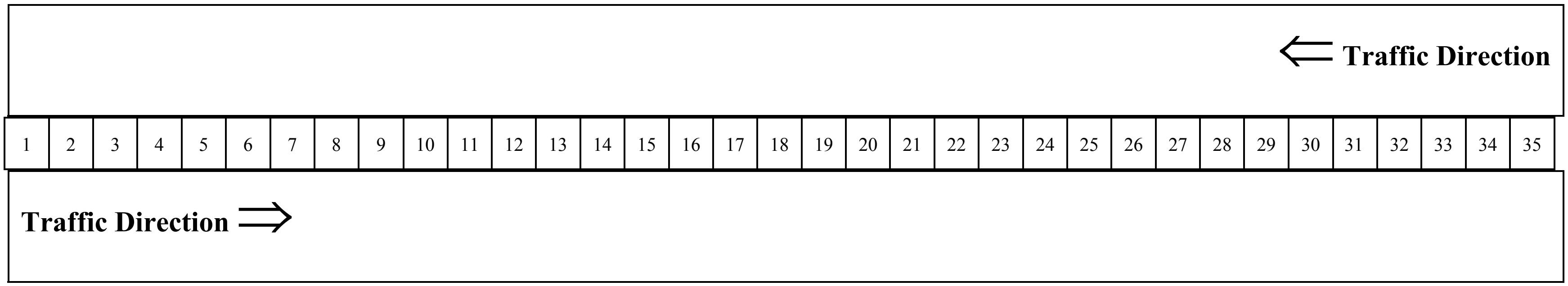
Some effort should be made to determine the suitability of aesthetically pleasing types of vegetation for saline road conditions. Crimson clover is not only visually striking, but fixes atmospheric nitrogen and requires little maintenance once established. Many states are now using expanses of wildflowers in road medians instead of grass. These plots, when properly managed, eliminate the need for mowing and provide a pleasing visual display. Although no evidence indicates that wildflowers and crimson clover are tolerant of deicing salts, the use of certain soil amendments may enable these plants to be used in saline environments and presents a researchable problem for this study.

Soil amendment treatments might consist of commonly used agricultural fertilizers and amendments including $CaCl_2$, CaSO4), magnesium sulfate ($MgSO_4$), and triple super phosphate [$Ca(H_2PO_4)_2$, 0 N-46 P_2O_5-0 K_2O]. Use of calcium-containing salts is beneficial because they promote aggregation of soil particles (Mengel and Kirkby, 1987), thereby increasing aeration and water infiltration.

Divalent cations such as Ca and Mg can remove Na from soil cation exchange sites and reduce the amount of plant exposure to this potentially harmful element (Westing, 1969). LaHaye and Epstein (1971) showed that bean (*Phaseolus vulgaris*), which was exposed to NaCl in the growth medium, increased in dry weight when given increasing amounts of $CaSO_4$. Research indicates that $CaCl_2$ and $CaSO_4$ ameliorate Na-induced plant stress (Awada et al., 1995), but the effects of chloride and sulfate on salt tolerance might need evaluating. Chloride, a component of common deicing salts such as NaCl and $CaCl_2$, at elevated concentrations is toxic to plants (Chavan and Karadge, 1980; Parker et al., 1983).

Use of $CaCl_2$ and NaCl for winter deicing can reduce the amount of Mg in soils adjacent to the roadway, primarily because Ca and Na compete with Mg for soil cation exchange sites and can increase leaching of Mg (McBride, 1994). Vegetation in these areas may be prone to Mg deficiency and reduced plant vigor. The application of triple super phosphate may reduce salt toxicity of roadside vegetation due to Cl by suppressing absorption of this ion by plant roots (Westing, 1969).

Figure 6-1. Diagram of Treatments for Experiments in Highway Medians



Note: The diagram above represents a portion of highway median divided into plots with lanes of traffic on each side. Numbers in plots designate treatments along the length of the median (see treatment descriptions on next page). This plot plan can be duplicated at each site as necessary to provide replication of treatments. The suggested dimensions of each plot are 25 ft by 25 ft. See Table 6.1 for identification of treatments.

Table 6-1. Descriptions of Numbered Treatment in Figure 6-1.

#	Treatment Description	#	Treatment Description
1	Existing vegetation + no amendment	19	Fescue + $MgSO_4$
2	Existing vegetation + $CaCl_2$	20	Fescue + triple super phosphate
3	Existing vegetation + $CaSO_4$	21	Buffalograss + no amendment
4	Existing vegetation + $MgSO_4$	22	Buffalograss + $CaCl_2$
5	Existing vegetation + triple super phosphate	23	Buffalograss + $CaSO_4$
6	Alkaligrass + no amendment	24	Buffalograss + $MgSO_4$
7	Alkaligrass + $CaCl_2$	25	Buffalograss + triple super phosphate
8	Alkaligrass + $CaSO_4$	26	Crimson clover + no amendment
9	Alkaligrass + $MgSO_4$	27	Crimson clover + $CaCl_2$
10	Alkaligrass + triple super phosphate	28	Crimson clover + $CaSO_4$
11	Bluegrass + no amendment	29	Crimson clover + $MgSO_4$
12	Bluegrass + $CaCl_2$	30	Crimson clover + triple super phosphate
13	Bluegrass + $CaSO_4$	31	Wildflower mix + no amendment
14	Bluegrass + $MgSO_4$	32	Wildflower mix + $CaCl_2$
15	Bluegrass + triple super phosphate	33	Wildflower mix + $CaSO_4$
16	Fescue + no amendment	34	Wildflower mix + $MgSO_4$
17	Fescue + $CaCl_2$	35	Wildflower mix + triple super phosphate
18	Fescue + $CaSO_4$		

6.3 Highway Interchange Salt Study: Experimental Design

Areas near intersections or overpasses are prime areas for studying the effects of deicing salts on vegetation. Efforts to control ice formation during winter months is intensive where major roads cross, with the potential for more salt usage in these areas than in lone stretches of highway. Depending on location, vegetation may receive road spray and saline runoff from the upper and lower roads at an overpass.

Similarly, areas located at the junction of ramps and the main highway will be subjected to deicing salts from two different road surfaces. These angle-shaped areas are common to places where ramps and main highways meet and are ideal locations for field plots for the evaluation of salt tolerance of shrubs and groundcovers under intensive exposure to deicing agents. Trees could obstruct the views of motorists and should not be considered for these plots. Using groundcovers and shrubs in these areas is beneficial in that the need for mowing might be eliminated on precarious slopes and around road signs that are usually inherent of these areas.

The selection of field plots near interchanges should take into account the number of similar plots that can be constructed at any one site, physical characteristics such as slope and area, the potential need for removal of existing vegetation, and differences in growing conditions that may exist. Some sites identified as being suitable for intersection experiments include:

1. Greenfield, exit 27 on Interstate 91 (the intersection of Interstate 91 and Gill Road).
2. Exit 28 on Interstate 91 (the intersection of Interstate 91 and Highway 10).
3. The intersection of State Route 116 and North Hadley Road.
4. Intersection of State Route 2 and Baldwinville Road.
5. Intersection of State Route 2 and South Main Street (south of Orange, Mass.).

Each site was selected based on the presence of similar junctions of a highway ramp with a main road. However, each site may need further evaluation to determine the uniformity of soil characteristics within each site.

The proposed experiment would include four soil amendments and four vegetation treatments arranged in a randomized block design with each treatment combination being present in five separate blocks or sites. Each of the four plots within a particular site will receive, at random, a separate soil amendment All types of vegetation will be present in all plots. The layout of vegetation with respect to the roadway should be similar among plots (Figure 6-2), but it is not necessary that each have the same amount of plant material. However, it is important that each plot have a sufficient amount of each vegetation type so that an accurate assessment can be made of its salt tolerance. Observations from these plots include obtaining soil samples for the determination of Na or other relevant elements and visual indexing to assess the performance of each treatment.

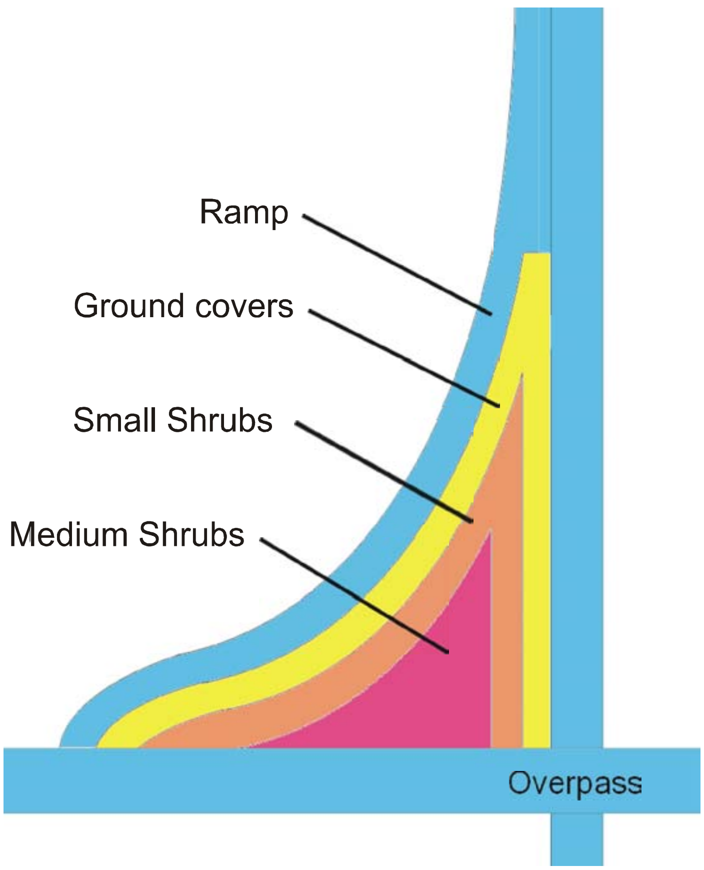


Figure 6-2. Example of Vegetation Arrangement for Experiment at Interchanges or Intersections

Note: The shape of vegetative areas near interchange areas may differ. The above is a generic diagram intended to show the layering effect created by using plant materials of different heights.

Potential groundcovers and shrubs for this experiment include Squaw bush (*Rhus trilobata*.), Fragrant sumac (*Rhus aromatica*), Summersweet clethera (*Clethera alnifolia*), Shore juniper (Juniperus conferta), Bar Harbor juniper (*Juniperus horizontalis*), and Saltspray rose (*Rosa rugosa*). Of the mentioned plants, only Squaw bush was indicated in the scientific literature as being salt tolerant; the others were said to be resistant to deicing salts by various transportation agencies in the recent deicing salt survey. Russian olive fixes atmospheric nitrogen and tolerates poor soils and was frequently used along roadsides in the eastern United States, but exhibits invasive qualities.

Members of the genus *Rhus* are also tolerant of poor soils and can be cut back with a large mower, if their height becomes unacceptable. Both junipers mentioned are known to be tolerant of various pollutants and saline environments and are used effectively along roadsides for borders and mass planting. In addition to being resistant to deicing salts, Saltspray rose also forms flowers and fruit that may improve the aesthetics of interchange areas.

Soil amendment treatments proposed for overpass experimental plots include: no treatment; $CaSO_4$ alone; $CaSO_4$ with organic matter; and $CaSO_4$ with organic matter and 10-10-10 fertilizer (N-P_2O_5-K_2O fertilizer). As stated previously, calcium-containing amendments have some ability to ameliorate salt damage to vegetation, and $CaSO_4$ is perhaps the most common amendment used for supplying Ca.

Some evidence indicates that incorporation of organic matter into soil could reduce the negative effects of deicing salts on vegetation. Organic matter not only improves soil tilth, but the increased aeration of the rooting medium may reduce the toxicity of Na and Cl to plants. In poorly aerated soils, the uptake and translocation of Na (Drew and Dikumwin, 1985) and Cl (Barrett-Lennard, 1986) in plants are enhanced, sometimes leading to accumulations of these elements in tissues and subsequent salt toxicity. The addition of organic matter may improve soil drainage, thereby expediting the movement of saline runoff from the root zone of plants.

Combining a fertilizer containing nitrogen, phosphorus and potassium may also increase the health of groundcovers and shrubs in test plots. These elements are essential for plant growth and may help alleviate salt stress by promoting plant health. Research is needed to determine which soil amendments may be used for vegetative stands near interchange areas to control salt related stresses in ground covers and shrubs.

7.0 CONCLUSIONS

Deicing agents, which are primarily chemical salts, are used extensively in cold regions to suppress the formation and accumulation of ice on roadways during the winter months. Despite their effectiveness for deicing, road-applied salts can have negative effects on roadside vegetation. This report presents results of research conducted on a search of literature and investigations to assess salt damage to plants along highways in Massachusetts.

A review of literature and a survey of state and provincial highway departments in cold climates showed that sodium chloride (salt or NaCl) is the most commonly used deicing agent. The average amount of NaCl used was 280 lb per lane mile in multiple applications per year. In Massachusetts, the usage of NaCl was about 240 lb per lane mile and about 290,000 total tons per year.

About a third of the highway departments responding to the survey reported that they monitored roadside vegetation for salt damage. Highway departments reported that salt damage occurred to roadside vegetation, with most of the damage to trees and shrubs occurring within 50 feet of the pavement but with some damage occurring as far as 100 to 300 feet from the roadway. Damage to grasses was usually close to the highway, being within 10 to 20 feet of the pavement.

The principal damage to trees and shrubs was identified as burning or browning of leaves or needles and defoliation. Dieback of branches and abnormal branching (witches' broom) were reported also in the surveys. The survey and review of literature showed that salt damage to grasses resembles symptoms of drought stress, such as narrow width, wilting, dark-green color, and die back of leaves and stunting. Invasions of weeds into grassy areas were associated with salt damage. According to the literature, new growth of surviving trees and shrubs usually does not show symptoms of salt injury. Often damage to trees and shrubs is most prevalent on the leaves of branches facing the roads, indicating that spray is a means of deposition of salt on the plants. Reception of salt sprays by evergreen (coniferous) trees appears to make them more sensitive to salt injury than deciduous trees.

In the study of roadside conditions in Massachusetts, mean sodium (Na) concentrations in pine needles were much higher in injured plants (2,138 mg Na/kg dry wt) than in uninjured plants (28 mg Na/kg dry wt). The assessment of roadside conditions in Massachusetts revealed that few broadleaf trees were injured by salt. Injury to roadside grasses and ferns was not evident in the areas studied.

The review of literature no only identified salt-tolerant species of grasses and woody ornamentals, but also included information on the types of injuries that occur from use of deicing agents on highways in cold climates and methods of ameliorating the injury. Salt spray onto foliage of evergreen trees and shrubs was reported as more ruinous to roadside vegetation than soil-borne salinity from direct deposition or runoff, but salt-tolerance of plants was often assessed as the ability of plants to withstand saline conditions in the root zone. Plants that tolerate soil salinity are not necessarily tolerant of salt transmitted by sprays. Most research focused on one or the other means of salt tolerance but seldom on both means. The plants identified as having salt tolerance were used as a base for a search of the availability of salt-tolerant plant materials for roadside planting. Listings of these plants and vendors are provided. Only three of the salt-tolerant plants were noted as possibly having invasive tendencies.

This research obtained information relative to deicing practices used by highway departments in cold regions of the Country. Sodium chloride is the principal deicing agent used and is the suspected factor in causing damage to roadside vegetation. Most of the damage to roadside vegetation occurs within 50 feet of the pavement, and spray seems to be the principal means of transmitting salt to plants. Evergreen coniferous plants receive more damage than deciduous plants. Highway departments reported that placement of plants at some distance from the highways was a major design criterion for highway safety and that setback might also give some protection against salt damage. Use of ameliorating treatments of the soil was not reported as a common practice to protect roadside vegetation against salt damage.

Experiments for future research were designed for testing of some salt-tolerant plants and agents that may ameliorate salt damage to vegetation. Schematic plans of test sections for research in highway medians and in areas at road intersections or interchanges were developed.

Suggested soil amendments included fertilizers, calcium-containing compounds, and organic matter to be used in combination with salt-tolerant grasses and shrubs.

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APPENDIX II: SURVEY SUBMITTED TO AGENCIES

Survey of Highway Departments

Practices of Deicing Streets and Highways

Mitigation of Salt Injury to Vegetation

1. How frequently (number of events per winter season) do the following conditions require application of deicing materials in your jurisdiction?

	Check all conditions that apply	Frequency	Comments
_	Fresh snow	______________	________________________________
_	Packed snow and ice	______________	________________________________
_	Freezing water or snow melt		
_	Freezing rain	______________	________________________________
	Bridge conditions		

2. Mileage of DOT/Agency roads requiring snow or ice control.

Arterial	___________________
Collector	___________________
Local	___________________
Total miles:	___________________

3. Materials used in snow and ice removal from your streets and highways

Materials Used	Under what conditions?	Application Rates	Estimated amount used per season	Effects on vegetation (Rank 1-least to 5-most damage)
Sodium chloride	_____________	_____________	_____________	_____________
Calcium chloride	_____________	_____________	_____________	_____________
Calcium magnesium acetate	_____________	_____________	_____________	_____________
Sand with deicing agent List agent(s)	_____________	_____________	_____________	_____________
Sand without chemicals	_____________	_____________	_____________	_____________
Corn by-products	_____________	_____________	_____________	_____________

Brine or liquid mixtures	______	______	______	______
Ashes or cinders	______	______	______	______
Other deicing materials (including combinations)	______	______	______	______
None (Plowing only)	______	______	______	______

4. Does your department monitor the roadsides for salt impacts?

Yes/No	**Type**	**Comments**
______	Site inspection	______
______	Site analysis(soil, water, plant tissues samples	______

5. If any "yes" answer in question 4, list species of vegetation affected by deicing materials by the following categories. Include approximate distances from edge of pavement where damage begins and ends.

	Category	
Type of Vegetation	**Damaged Species and Distance of Damage**	**Tolerant Species**
Evergreen Trees	______	______
Deciduous Trees	______	______
Evergreen Shrubs	______	______
Deciduous Shrubs	______	______
Ground Covers	______	______
Grasses	______	______

Lawns ______________ ______________

Crops ______________ ______________

6. Comment on your use of the following practices in roadside planting design to prevent or to mitigate damage from deicing materials. (If available, please attach specifications, lists, or other details as applicable).

Soil amendments or soil mixes ______________

Salt-tolerant plants ______________

Alternative deicing materials______________

Design criteria______________

Other ______________

7. List any research on salt-tolerant plants, mitigation, etc. that your state or agency has conducted.

Is the information, including any surveys, published or available?

8. Would you like to have the results of this survey? If yes, list to whom the results should be sent.

____

____

____

9. Additional contacts: (please include name, title, address, phone and e-mail (if applicable).

Snow Removal Operations

____

____

Landscape Design/Roadside Development

____

____

Research

____

____

____

APPENDIX III: Photographs of Salt-Damaged Plants along Massachusetts Roadsides

Index of Pictures

1. Massachusetts Route 116 North, Plumtree Road intersection, damaged white pine

2. Massachusetts Route 2 East, Exit 31b, damaged white pine

3. Massachusetts Route 2 West, Exit 30, damaged sumac

4. U. S. Route 202 North, mile marker 46.2, damaged white pine

5. Massachusetts Route 9 East, mile marker 16, damaged poplar

6. Massachusetts Route 9 West, mile marker 16, damaged sumac

7. Interstate 91 North, mile marker 115, damaged sumac

8. Interstate 91 North, mile marker 70, damaged sumac

9. Interstate 91 South, mile marker 18, damaged pine

10. Interstate 91 South, mile marker 21, damaged black pine (Diplodia disease)

11. Interstate 91 South, mile marker 21, damaged black pine and damaged sumac

12. Interstate 91 South, mile marker 29, damaged spruce and grass.

1. Massachusetts Route 116 North, Plumtree Road intersection, damaged white pine

2. Massachusetts Route 2 East, Exit 31b, damaged white pine

3. Massachusetts Route 2 West, Exit 30, damaged sumac

4. U. S. Route 202 North, mile marker 46.2, damaged white pine

5. Massachusetts Route 9 East, mile marker 16, damaged poplar

6. Massachusetts Route 9 West, mile marker 16, damaged sumac

7. Interstate 91 North, mile marker 115, damaged sumac

8.

Interstate 91 North, mile marker 70, damaged sumac

9. Interstate 91 South, mile marker 18, damaged pine

10. Interstate 91 South, mile marker 21, damaged black pine (with Diplodia)

11. Interstate 91 South, mile marker 21, damaged black pine and damaged sumac

12. Interstate 91 South, mile marker 29, damaged spruce and grass

APPENDIX IV

Eastern Region Invasive Plants, Ranked by Degree of Invasiveness as Based on Information from States

http://www.fs.fed.us/r9/weed/Sec3B.htm

This document, prepared by USDA-Forest Service, is an attempt to categorize and list the ecologically invasive plant species in the Forest Service Eastern Region. Included states are Connecticut, Delaware, Illinois, Indiana, Iowa, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, Vermont, West Virginia, and Wisconsin. This document is a compilation of the invasive species lists and information provided by botanists and ecologists from the above states. Information was received on invasive plants from fifteen of the twenty states in the region. Missing states are New Hampshire, New Jersey, Rhode Island, Michigan, and West Virginia. Rhode Island was not contacted; New Hampshire and New Jersey currently have no lists, and Michigan and West Virginia have lists in progress.

Disclaimer: Listed below are the species commonly known as invasive. This list does not include all suggested invasive species, nor does it have any regulatory implications. This list is an educational informational tool.

Category 1 Plants - highly invasive

These plants are all non-native, highly invasive, woody or herbaceous plants which invade natural habitats and replace native species.

Scientific Name	Common Name
Acer platanoides	Norway maple
Ailanthus altissima	Tree-of-heaven
Alliaria petiolata	Garlic Mustard
Ampelopsis brevipedunculata	Porcelain-berry
Berberis thunbergii	Japanese barberry
Butomus umbellatus	Flowering rush

Scientific Name	Common Name
Celastrus orbiculatus	Asiatic bittersweet, Oriental bittersweet
Centaurea maculosa	Spotted knapweed, Bachelors buttons
Coronilla varia	Crown vetch
Elaeagnus angustifolia	Russian olive
Elaeagnus umbellate	Autumn olive
Euphorbia esula	Leafy Spurge, Wolf's milk
Lonicera japonica	Japanese honeysuckle
Lonicera maackii	Amur honeysuckle
Lonicera morrowii	Fly honeysuckle, Morrow honeysuckle
Lonicera tatarica	Tartarian honeysuckle
Lonicera x *bella*	Bell's honeysuckle
Lythrum salicaria	Purple loosestrife
Microstegium vimineum	Japanese stilt grass
Myriophyllum spicatum	Eurasian water-milfoil
Polygonum cuspidatum	Japanese knotweed
Polygonum perfoliatum	Mile-a-minute vine
Potamogeton crispus	Curly pondweed
Rhamnus cathartica	Common buckthorn
Rhamnus frangula	Smooth buckthorn
Trapa natans	Water chestnut

Category 2 Plants - moderately invasive

These plants are less invasive than those in Category 1. If these species are significantly replacing native species, then they are doing so only in local areas.

Scientific Name	**Common Name**
Aegopodium podagraria	Goutweed
Berberis vulgaris	Common barberry
Bromus inermis	Smooth brome
Cirsium arvense	Canada thistle
Cirsium palustre	Marsh thistle, European swamp thistle
Egeria densa	Brazilian water-weed, Brazilian elodea
Epilobium hirsutum	Hairy Willow-herb
Euonymus alatus	Winged Euonymus, Winged burning bush
Euonymus fortunei	Wintercreeper, climbing euonymus
Festuca elatior	Tall-fescue, alta-fescue
Festuca pratensis	Meadow-fescue
Hesperis matronalis	Dame's rocket
Hydrilla verticillata	Hydrilla
Iris pseudacorus	Yellow Iris
Ligustrum vulgare	European privet
Lysimachia nummularia	Moneywort
Melilotus alba	White sweet clover
Melilotus officinalis	Yellow sweet clover
Najas minor	Naiad
Nasturtium officinale	Watercress
Nymphoides peltata	Yellow floating-heart
Paulownia tomentosa	Empress-tree

Category 2 Plants-Continued

Scientific Name	Common Name
Poa compressa	Wiregrass, Canada bluegrass
Poa pratensis	Kentucky bluegrass
Rosa multiflora	Multiflora rose
Sorghum halepense	Johnsongrass
Ulmus pumila	Siberian elm
Valeriana officinalis	Garden-heliotrope
Vinca minor	Greater periwinkle
Vincetoxicum nigrum	Black Swallow-wort
Vincetoxicum rossicum	Dog-strangling vine, Swallow-wort

Category 3 Plants - widespread non-native species

These plants are often restricted to disturbed ground and are not especially invasive in undisturbed natural habitats. Most of these species are found throughout much of our range.

Scientific Name	Common Name
Abutilon theophrasti	Velvet-leaf
Aira caryophyllea	Silver Hairgrass
Ajuga reptans	Carpet-bugle
Allium vineale	Wild Garlic
Amaranthus hybridus	Green amaranthus
Amaranthus retroflexus	Pigweed
Anthoxanthum odoratum	Sweet vernal grass
Arctium minus	Common burdock
Arenaria serpyllifolia	Thyme-leaf sandwort
Arrhenatherum elatius	Tall oatgrass
Asparagus officinalis	Asparagus

Category 3 Plants-Continued

Scientific Name	**Common Name**
Bromus squarrosus	Bromus tectorum, Downy chess, Drooping brome-grass
Campanula rapunculoides	Creeping bellflower
Capsella bursa-pastoris	Shepard's purse
Cardamine pratensis	Cookoo-flower
Carduus acanthoides	Plumeless thistle
Carduus nutans	Musk thistle
Centaurea spp.	Star-thistle, knapweed
Cerastium fontanum	Common mouse-ear
Chelidonium majus	Greater celandine
Chloris verticillata	Windmill grass
Chrysanthemum leucanthemum	Ox-eye daisy
Cichorium intybus	Chicory
Cirsium vulgare	Bull thistle
Commelina communis	Dayflower
Conium maculatum	Poison hemlock
Convolvulus arvensis	Field-bindweed
Corynephorus canescens	Silvergrass
Cycloloma atriplicifolium	Winged pigweed
Cytisus scoparius	Scotch broom
Dactylis glomerata	Orchard-grass
Datura stramonium	Jimsonweed
Daucus carota	Queen Anne's Lace
Dianthus armeria	Deptford pink
Dipsacus fullonum	Fullers teasel
Dipsacus laciniatus	Cut-leaved teasel

Dipsacus sylvestris	Common teasel

Category 3 Plants-Continued

Scientific Name	**Common Name**
Echinochloa crusgalli	Barnyard-grass
Echium vulgare	Viper's bugloss
Elytrigia (Agropyron) repens	Quackgrass
Epipactis helleborine	Helleborine
Euphorbia cyparissias	Cypress spurge
Fumaria officinalis	Fumitory
Galeopsis tetrahit	Hemp-nettle
Galinsoga quadriradiata	Quickweed
Galium mollugo	Wild Madder, White bedstraw
Galium verum	Yellow bedstraw
Glaucium flavum	Horned poppy
Glechoma hederacea	Gill-over-the-ground
Hemerocallis fulva	Orange day-lily
Hieracium aurantiacum	Orange hawkweed
Hieracium lachenalii	Hawkweed
Humulus lupulus	Hops
Hypericum perforatum	St. Johnswort
Lactuca serriola	Prickly lettuce
Lamium maculatum	Red dead nettle
Lapsana communis	Nipplewort
Leonurus cardiaca	Motherwort
Lespedeza cuneata	Chinese Lespedeza
Lespedeza stipulacea	Korean clover
Lespedeza striata	Bush-clover
Linaria vulgaris	Butter-and-eggs
Lolium perenne	Ryegrass

Lotus corniculata	Birds-foot trefoil

Category 3 Plants-Continued

Scientific Name	**Common Name**
Malva moschata	Musk-mallow
Malva neglecta	Common mallow
Matricaria discoidea	Pineapple-weed
Medicago sativa	Black medic
Morus alba	White mulberry
Myosotis scorpioides	Forget-me-not
Nepeta cataria	Catnip
Pastinaca sativa	Wild Parsnip
Penstemon digitalis	False foxglove
Phleum pratense	Timothy
Picris hieracioides	Ox-tongue
Plantago lanceolata	Buckhorn plantain
Plantago major	Broadleaf plantain
Poa annua	Annual bluegrass
Poa bulbosa	Bulbous bluegrass
Polygonum cespitosum	Knotweed
Potentilla argentea	Silvery cinquefoil
Potentilla recta	Sulphur cinquefoil
Prunella vulgaris	Heal-all
Ranunculus acris	Tall buttercup
Ranunculus repens	Creeping buttercup
Robinia hispida	Rose-acacia
Rudbeckia hirta	Black-eyed Susan
Rumex acetosella	Sheep sorrell
Rumex crispus	Curly dock
Saponaria officinalis	Soapwort

Sedum acre	Yellow sedum

Category 3 Plants-Continued

<u>Scientific Name</u>	**<u>Common Name</u>**
Sedum telephium	Live forever
Senecio vulgaris	Common groundsel
Setaria pumila	Yellow foxtail
Silene latifolia	White campion
Silene vulgaris	Bladder campion
Solanum dulcamara	Climbing nightshade
Sonchus arvensis	Field sow-thistle, perennial sow-thistle
Sonchus asper	Prickly sow-thistle
Sonchus oleraceus	Common sow-thistle
Stellaria graminea	Common stitchwort
Tanacetum vulgare	Tansy
Taraxacum officinale	Common dandelion
Thlaspi arvense	Field pennycress
Tragopogon pratensis	Yellow goat's-beard
Trifolium repens	White clover
Verbascum blatteria	Moth-mullein
Verbascum thapsus	Giant mullein
Veronica officinalis	Speedwell
Vicia cracca	Cow vetch
Xanthium strumarium, *X. pennsylvanicum*	Common cocklebur

Category 4 Plants - local concern and monitoring

These plants are non-native species that occur only locally in our region. They are not currently known to be especially invasive but should be monitored in the future. Many of these plants are cultivated species which occasionally escape.

Acer ginnala	Amur maple
Acer palmatum	Japanese maple
Acer pseudo-platanus	Sycamore maple
Actinidia arguta	Bower Actinidia, Tara-vine
Akebia quinata	Akebia, Five-leaf akebia
Alnus glutinosa	Black alder
Anthriscus sylvestris	Wild chervil
Aralia elata	Japanese angelica-tree
Arthraxon hispidus	Aruncus dioicus, Goat's beard
Bothriochloa spp.	Caucasian bluestem, Eurasian bluestem
Callitriche stagnalis	Callitriche
Caragana arborescens	Pea-tree, pea-shrub
Cardamine impatiens	Bushy rock cress
Carex kobomugi	Asiatic sedge
Centaurea repens	Russian knapweed
Clematis terniflora	Yam-leaved clematis
Convallaria majalis	Lily-of-the-valley
Dioscorea batatas	Cinnamon vine
Elsholtzia ciliata	Elsholtzia
Eragrostis curvula	African weeping lovegrass
Filipendula ulmaria	Queen of the meadow
Geranium nepalense	Sweet Nepalese crane's-bill
Glyceria maxima	Tall mannagrass, English water grass
Gypsophila paniculata	Baby's breath

Category 4 Plants-Continued

Scientific Name	Common Name
Hedera helix	English ivy
Heracleum mantegazzianum	Giant hogweed
Humulus japonicus	Japanese hops
Hydrocharis morsus-ranae	European frogbit
Ilex crenata	Japanese holly
Impatiens glandulifera	Purple jewelweed
Kochia scoparia	Summer Cypress
Lathyrus latifolius	Everlasting pea
Lathyrus sylestris	Everlasting pea
Leontodon autumnalis	Fall dandelion
Lepidium latifolium	Tall Pepperwort
Leucojum aestivum	Summer snowflake
Ligustrum obtusifolium	Amur river privet
Lonicera xylosteum	European fly-honeysuckle
Lunaria annua	Money-plant, honesty
Lunaria rediviva	Money-plant, perennial honesty
Lychnis flos-cuculi	Ragged-robin
Lysimachia vulgaris	Garden-loosestrife
Marsilea quadifolia	Water clover, water shamrock
Miscanthus sinensis	Eulalia
Myriophyllum aquaticum	Parrotfeather
Onopordum acanthium	Scotch thistle
Ornithogalum umbellatum	Star of Bethlehem
Pachysandra terminalis	Pachysandra
Perilla frutescens	Perilla
Phellodendron japonicum	Japanese cork tree

Category 4 Plants-Continued

Scientific Name	**Common Name**
Phyllostachys spp.	Oriental bamboo
Pinus thunbergiana	Japanese black pine
Polygonum aubertii	Silver lace vine
Polygonum sachalinense	Giant knotweed
Populus alba	White poplar
Prunus avium	Sweet cherry
Prunus mahaleb	Perfumed cherry
Pueraria lobata	Kudzu
Quercus robur	English oak
Ranunculus ficaria	Lesser celandine
Rhamnus davurica	Dahurian buckthorn
Ribes sativum	Garden red currant
Rorippa amphibia	Great watercress
Rosa eglanteria	Eglantine, sweetbrier
Rosa rugosa	Beach rose
Rubus phoenocolasius	Wineberry
Salix alba	White willow
Salix babylonica	Weeping willow
Salix fragilis	Crack willow
Senecio jacobaea	Tansy-ragwort
Sorbaria sorbifolia	False Spiraea
Sorbus aucuparia	Eurasian mountain-ash
Taxus cuspidate	Japanese yew
Thymus pulegioides	Wild thyme
Thymus serpyllum	Thyme
Tussilago farfara	Colt's-foot
Ulmus parviflora	Chinese elm

Category 4 Plants-Continued

Scientific Name	**Common Name**
Viburnum dilatatum	Linden viburnum
Viburnum lantana	Wayfaring tree
Viburnum opulus	European cranberry bush
Viburnum plicatum	Japanese Snowball
Viburnum sieboldii	Siebold viburnum
Wisteria floribunda	Japanese wisteria

Category 5 Plants - native invasives

These plants are native to North America and have been reported as being invasive in our region, or parts thereof. Some of these plants are regionally exotic, having moved in from another part of North America.

Scientific Name	**Common Name**
Amorpha fruticosa	False indigo
Ampelamus albidus	Sandvine
Aralia spinosa	Hercules' club
Cabomba caroliniana	Fanwort, Carolina water-shield
Cornus drummondii	Roughleaf dogwood
Cornus olbigua	Silky dogwood
Cornus racemosa	Gray dogwood
Cornus sericea	Red osier dogwood
Deschampsia cespitosa var. *parviflora*	Small-flowered tickle grass
Froelichia gracilis	Cottonweed
Helianthus tuberosus	Jerusalem artichoke
Hieracium kalmii	Canada hawkweed
Juniperus virginiana	Red-cedar
Maclura pomifera	Osage orange
Magnolia tripetala	Umbrella tree

Category 5 Plants-Continued

Scientific Name	Common Name
Mirabilis nyctaginea	Heart-leaved umbrella-wort
Myriophyllum exalbescens	Water-milfoil
Myriophyllum heterophyllum	Water milfoil
Panicum amarum	Beach-grass
Phalaris arundinacea	Reed canarygrass
Phragmites australis	Common reed grass
Physocarpus opulifolius	Ninebark
Pinus virginiana	Virginia pine
Podophyllum peltatum	May-apple
Populus grandientata	Large-toothed aspen
Populus tremuloides	Quaking aspen
Rhus glabra	Smooth sumac
Robinia pseudo-acacia	Black locust
Saururus cernuus	Lizard's tail
Solanum nigrum	Black nightshade
Typha angustifolia	Narrow-leaved cat-tail
Typha latifolia	Broad-leaved cat-tail
Viburnum opulus var. *americanum*	European cranberry bush

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Appendix is adapted from compilations by the USDA-Forest Service at **http://www.fs.fed.us/r9/weed/Sec3B.htm**