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Research Article

The Effect of NaCl and CMA on the Growth and Morphology of *Arctostaphylos uva-ursi* (Kinnikinnick)

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Numerous studies have described the negative effects of the commonly used deicer, NaCl, on plants; this has led to research on less toxic alternatives, for example, calcium magnesium acetate (CMA). The present research investigated the native ground cover species, *Arctostaphylos uva-ursi* (kinnikinnick), as a possible candidate for landscaping in high salt conditions. The effect of NaCl and CMA on the growth, morphology, and survival of *A. uva-ursi* plants was examined to explore the use of CMA as a potential environmentally friendly alternative deicing agent to that of NaCl. The influence of these deicing agents on selected soil properties was also investigated. It was found that this ground cover species was able to tolerate moderate-to-high levels of NaCl and even greater concentrations of CMA. Therefore, *A. uva-ursi* proved to be a candidate for landscaping use in a north central city of Canada, where deicing agents are used in winter months.

1. Introduction

Chemical deicing agents are widely applied to roads in cold climates to keep pavement surfaces bare during winter months. Typical application rates of NaCl, the most common deicer in North America, are in the order of tens of $Mg\,yr^{-1}\,km^{-1}$ of road [1]. These salts may enter the surrounding environment in a variety of ways. For example, road deicers may be directly applied to nontarget areas, or, they may move into nontarget areas through the plowing or transport of salt-impacted snow and ice. Dissolved salts in road spray and in snow and ice melt waters may also move from applications into the environment. These salts commonly impact road-side soils, fauna, and vegetation; dissolved salts in snowmelt runoff may also enter and degrade surface water and ground water systems [1, 2].

The negative effects of NaCl on roadside and landscaping trees and shrubs are well documented [3–7]. Dissolved salt ions from chemical deicers (e.g., Na^+, Cl^-) can cause osmotic stress in plants [8, 9]. Soil salinity can interfere with root uptake of both water and nutrients [10], and accumulation of salt ions can cause toxicity in leaves [9], and reduce both frost hardiness [11] and drought tolerance [12]. Salts can also be deposited as spray on leaves, stems, and buds, resulting in external damage, including leaf browning, twig dieback, and slow or no-bud flushing [13], and killing of floral buds [14]. In addition, movement of deicing salts away from application areas can negatively impact aquatic ecosystems, causing degradation of habitat for aquatic organisms and impact drinking water supplies for humans [15]. Despite these problems, NaCl is still the most widely used deicing material due to its effective deicing characteristics, easy storage and application requirements, and low overall capital cost [2, 16].

Environmental concerns of widespread NaCl usage has led to the exploration of alternative chemicals as deicing agents, including calcium magnesium acetate (CMA), an organic salt compound. Unlike Cl^-, the acetate anion biodegrades over time, thereby, reducing the migration and accumulation of salts in the environment. Several studies show that CMA has low toxicity [17–19], and when properly used, has no significant negative effects on air, plants, soils, water quality, and public and occupational health, although it is more toxic to certain algae than NaCl at high concentrations [19] and when using certain bioassays [20]. Contact of CMA with plant tissue results in no topical damage to leaves and twigs [16]. In most cases, CMA should have little impact on the dissolved oxygen content of surface waters due to dilution and decomposition of acetate prior to reaching these waters [2]. This alternative deicer has also been found to be less corrosive on metals and building materials than NaCl [21, 22] and in some cases shows inhibition of corrosion [17]. It works at least as well as salt in achieving bare pavement and is relatively more effective in longer storms [21]. The primary reason that CMA is not more widely used is its high cost relative to NaCl [23], but the total estimated cost of using CMA as a highway deicer, taking into consideration the cost of all side effects, will be less than half that of using NaCl [17].

In addition to investigation of alternative deicers that are more environmentally friendly, it is of interest to explore plants used in roadside landscaping that are tolerant of salt. There has been movement away from using nonnative plant species toward using native plants by highways (e.g., [24]) and in urban areas (e.g., [25]). Trees and shrubs are often planted for landscaping metropolitan spaces without much thought of their adaptation to the local habitat. Contaminants, soil conditions, and maintenance factors are rarely considered; instead, plant form, texture, foliage, flower fruit, and fall colour are often held as priorities when choosing for landscaping [26].

In partnership with the City of Prince George, BC, the Prince George Northern Sustainable Landscape Initiative (NSLI) undertook a number of separate projects aimed at identifying alternative and sustainable landscaping strategies that would suit a northern "winter" city. Alternative ground-covers that would replace the more common grass species as roadside and median plantings were considered; a key concern was the species ability to tolerate the application of deicing materials. *Arctostaphylos uva-ursi* (L.) Spreng (alternative names: kinnikinnick, bearberry; family: Ericaceae) is native to the BC interior and is found around home sites, sand dunes, sandy banks, and commercial sites, as both a beautification plant and a critical area stabilizer and requires very little maintenance once it has been established [27]. It is long lived and cold tolerant [27], but we are not aware of any studies that have investigated its salt tolerance to deicing materials.

The present study investigated the influence of four concentrations each of NaCl and CMA (plus nonsalt control) on the morphological characteristics, growth, biomass, and survival of *A. uva-ursi*. The influence of these deicing agents on selected soil properties was also examined. This work allowed us to investigate further the potential use of this species as a native plant for urban landscaping in northern climates.

2. Materials and Methods

2.1. Plant Material. *Arctostaphylos uva-ursi* is a trailing, evergreen shrub forming mats [28], reaching heights of 7.5–10 cm [29]. Leaves of this species are alternate, leathery, and oval to spoon shaped and are about 2.5 cm long with shiny green upper surfaces [28]. The flowers are urn shaped and pinkish-white and form drooping terminal clusters, while the fruits are bright red berries resembling miniature apples. *A. uva-ursi* is common and widespread, from low elevations to alpine tundra. It grows on sandy and well-drained exposed sites, in dry forest and clearings, and on rocky slopes [28].

Table 1: NaCl and CMA treatments used in experiment.

Treatment (dissolved solute concentrations in treatment solutions)	NaCl (mM NaCl)*	CMA (mM CMA)*
Control	0	0
Low (20 mmol solute L^{-1})	10	6.7
Medium (60 mmol solute L^{-1})	30	20
High (140 mmol solute L^{-1})	70	46.7
Very High (280 mmol solute L^{-1})	140	93.3

* 1 mmol NaCl dissociates to form 2 mmol solute in solution; 1 mmol CMA dissociates to form 3 mmol solute in dilute solution.

2.2. Preparatory Work. On July 17, 2007, one-year-old *A. uva-ursi* plants (Linnaea Nursery, Vancouver, BC), growing individually in 20 cm diameter pots, were placed outdoors at the I. K. Barber Enhanced Forestry Lab at the University of Northern British Columbia (UNBC) in Prince George, BC. The potting soil mix was 2 : 1 : 1 peat moss : perlite : pumice (by volume) and occupied approximately 370 mL in each pot. Plants were watered and weeded as needed and were fertilized once a week with 40 mL of 100 mg L^{-1} N, 40 mg L^{-1} P_2O_5, and 100 mg L^{-1} K_2O from soluble 20 : 8 : 20 fertilizer. They were left outdoors until July 18, 2007 at which time they were transferred to a growth chamber to allow them to acclimatize to experimental conditions (see below) for one week.

2.3. Experimental Conditions and Treatments. The experiment was carried out between July 23 and September 23, 2007 under controlled environmental conditions (day/night 23°C/11°C) in a growth chamber (Environmental Growth Chambers, Chagrin Falls, OH) at UNBC. Conditions alternated between day/night temperature extremes by shifting at a rate of ±1°C/hour. The photoperiod was 17 h at a light intensity of 900–1200 μmol m^{-2} s^{-1}. Pots of replicate treatments (see below) were randomly arranged within the growth chamber; positions of pots were randomly moved within the chamber once a week to reduce the effects of possible temperature and/or light variation.

Nine treatments with 15 replicates each, for a total of 135 plants (i.e., pots), were used in the experiment. There were 4 concentration treatments for each of NaCl (Sigma Aldrich, Canada) and CMA: 20 (low), 60 (medium), 140 (high), or 280 (very high) mmol dissolved solute L^{-1} (Table 1). The ninth treatment was a deionized water control. These salt concentrations fell within the range reported for melt waters originating from snow and ice samples collected from northern roads or roadsides [7, 30].

Calcium magnesium acetate was prepared by combining calcium acetate monohydrate [$Ca(C_2H_3O_2)_2 \cdot H_2O$] with magnesium acetate tetrahydrate [$Mg(C_2H_3O_2)_2 \cdot 4\ H_2O$] in the molar ratios of 1 : 2.33, respectively (both from Sigma

Aldrich, Canada). One mmol of NaCl produces 2 mmol of solute (1 mmol each of Na^+, Cl^-) in dilute solution. Upon dissolution, one mmol of CMA produces 3 mmol of solute in dilute solution: 1 mmol of Ca^{2+} and Mg^{2+} and 2 mmol of acetate ($C_2H_3O_2^-$) anion. Being a conjugate base, some acetate will associate with protons to form nonionic acetic acid. The colligative properties of solutions depend on the concentrations of dissolved solutes (either ionic or nonionic solutes) in solution.

NaCl and CMA solutions were prepared in deionized water and 40 mL were applied to the surface of the potting soils twice a week for 9 weeks. Chemical concentrations were increased incrementally to reduce shock to the plants. First, 20 mmol solute L^{-1} was applied to all treatments except for the control treatment on July 23, 2007. On July 27, the second treatment concentration was applied, wherein all plants, except for control and low treatment pots, received 60 mmol solute L^{-1} of salt solution. On July 31, a third treatment was applied in which all the treatments, except for control, low, and medium, received 140 mmol solute L^{-1} of salt solution. Finally, on August 3, 280 mmol solute L^{-1} of salt solution was applied to all very high pots and the treatments shown in Table 1 were given to all others. For the duration of the experiment, plants were fertilized once every 2 weeks with 40 mL of soluble 20 : 20 : 20 fertilizer that provided 50 mg L^{-1} each of N, P_2O_5, and K_2O. The fertilizer solution had a pH of 7.59 and an electrical conductivity (EC) of 0.552 mS cm^{-1}.

The plants received tap water daily or once every two days, as needed. Watering was conducted in such a manner as to maintain moderate soil moisture content (~60% water-holding capacity), but without allowing saturation and run through, which could have led to loss of NaCl or CMA through leaching. Such a practice allowed the salt contents in the soils to accumulate over the course of the study. This was our intent, as salts often accumulate along roadside soils over a period of time; depending on soil and climatic conditions, salts are not necessarily flushed from the root zone during the growing season. Accumulation of salts in soil was indirectly measured at the end of our study through soil EC (described below). Preliminary work showed that the pH and EC of the tapwater used in this study averaged ~7.40 and 0.230 mS cm^{-1}, respectively.

2.4. Morphological Measurements. Initial measurements of *A. uva-ursi* plants were made on July 24, 2007. One representative (sample) branch (the longest and most active) was chosen on each plant for more detailed investigation (Figure 1). The length of the primary (dominant) shoot and the number and length of secondary (nondominant) shoots were determined. For each shoot, both primary and secondary, the initial length was tagged with a small mark of nail polish 1 cm below the terminus. The total numbers of primary and secondary shoots were counted for the entire plant.

The following morphological measurements were done at the end of the experiment. The length from the initial mark of primary and secondary shoots, as well as the number of new secondary shoots, was found on the sample shoot. The number of new flushed buds and number of developing apical buds of all shoots on the whole plant were recorded. Qualitative observations, including overall health (e.g., colour, vigour) of the plants, were also noted.

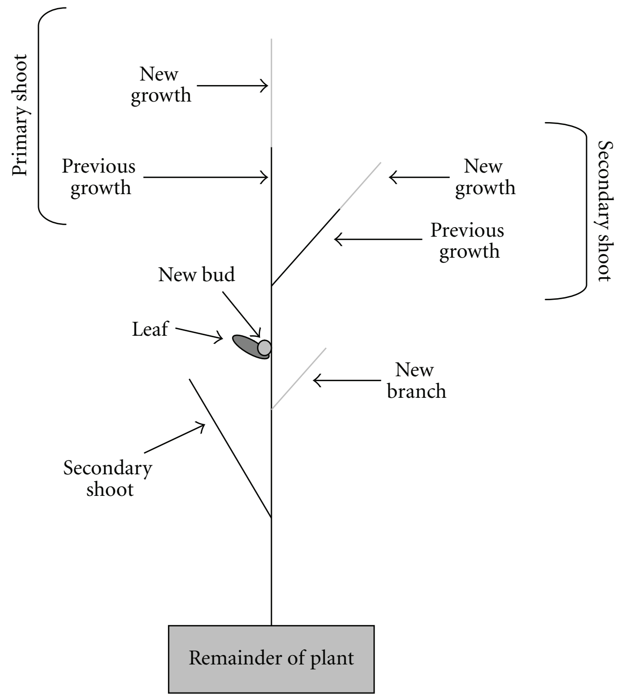

Figure 1: Schematic diagram of an *A. uva-ursi* plant showing various portions that were measured in the experiment. Details of the measurements of a sample branch are shown.

2.5. Shoot Biomass Measurements. As there was a range of plant sizes in the original group of plants available for this experiment, we thought it appropriate to examine treatment effects on the ratio of fresh weight to dry weight of entire aboveground plants. This ratio is related to the amount of water in a plant; the greater the value is, the more water there is per unit dry biomass.

At the end of the experiment, all *A. uva-ursi* plants were cut at the base of the stem. The fresh weight of both the new aboveground growth and the previous growth (growth prior to the experiment), determined through the use of the initial markers, was found; the sum of the two weights was used to determine total aboveground fresh weight of each plant. The plant material was then dried in an oven (Despatch model LAD2-24-3, Minneapolis, MN) at 65°C for 48 h prior to weighing for dry weight determinations. From the above values, the ratios of fresh weight to dry weight and new growth to previous growth dry weight were determined for each plant.

2.6. Soil Properties. Soil pH and EC were determined prior to the growth chamber study. Ten representative soil samples (5.00 g each) were used to measure soil pH in a 1 : 4 soil : deionized water ratio (i.e., g soil : mL liquid ratio) according to the method of Hendershot et al. [31]. The average soil pH was 6.29 (Orion 5500 pH meter). Soil pH was also conducted at the end of the experiment (1 : 4 g soil : mL

Figure 2: The effect of NaCl and CMA on general health and appearance of *A. uva-ursi* plants. Photograph was taken at the end of the experiment. The plant in the top row is the control. The middle row of plants is from the NaCl treatment and the bottom row of plants is from the CMA treatment; both rows show plants from increasing treatment concentrations from left to right (20, 60, 140, and 280 mmol dissolved solute L^{-1}).

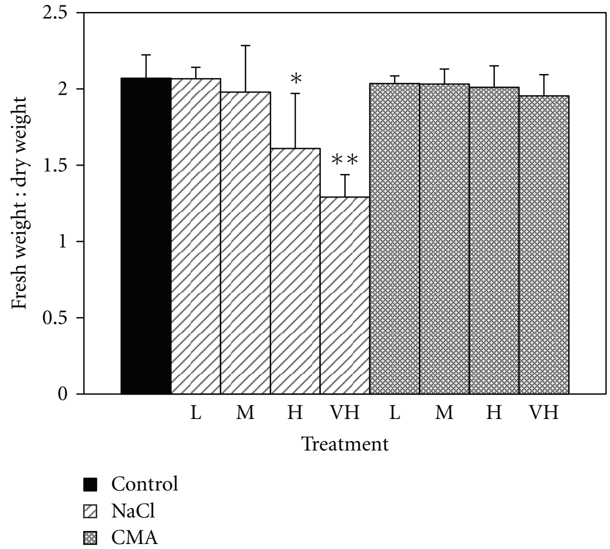

Figure 3: The effect of NaCl and CMA on the ratio of fresh weight to dry weight of entire plants of *A. uva-ursi*. Means ($n = 15$) and SD are shown. Treatment effects were analyzed using ANOVA coupled with the Bonferroni mean comparison test ($P < 0.05$). *Mean and **mean both show significant treatment effects ($P < 0.01$). All other means are not significantly different from each other. L: low treatment; M: medium treatment; H: high treatment; VH: very high treatment.

liquid ratio) using deionized water or 0.01 M $CaCl_2$ [32]. In addition, saturated soil extracts were obtained for each of these 4 soil replicates for the determination of EC using methods described by Miller and Curtin [33].

2.7. Statistical Analyses. For each measurement, one-way ANOVA models (SPSS Version 16) were used to test for significant treatment effects on plant and soil characteristics. The Bonferroni post hoc test was used to determine significant effects of individual treatments on means. Assumptions of normal distribution were tested by evaluating homogeneity within each treatment group and a few outliers were removed after examination. Transformations with natural logarithm were applied to the measurements such as the ratios of fresh weight to dry weight and new growth to previous growth dry weight to ensure that the assumption of normally distributed data was not violated.

3. Results

3.1. General Health and Appearance of Plants. Observations at the end of the experiment showed a visible increase in stress of *Arctostaphylos uva-ursi* plants treated with increasing treatment concentrations of NaCl or CMA, most notably with NaCl treatments (Figure 2). Leaves of plants from both NaCl and CMA treatments developed a reddish colour, however, this was more prevalent in CMA-treated plants. Plants from the NaCl treatment also became more brittle and dry with increasing concentration.

3.2. Growth and Morphology. The stem length of both the primary and secondary shoots and the number of new secondary shoots on the sample branch (longest and most active) did not differ significantly across the treatments (Table 2). In addition, on the entire aboveground plant, the number of new flushed buds and number of new developing apical buds did not differ significantly with treatment. However, there were noticeable trends with the highest or two highest NaCl concentrations having a negative effect on the means (Table 2).

3.3. Shoot Biomass of Entire Plants. The ratio of fresh weight to dry weight of entire aboveground biomass was found to be significantly lower ($P < 0.05$) for plants within the high and very high NaCl treatments compared to all other treatments, which did not significantly differ from each other (Figure 3). The ratio was significantly lower ($P < 0.01$) for the very high NaCl treatment compared to the high NaCl treatment (Figure 3). There was no significant treatment effect on the ratio of new growth biomass to previous growth biomass (Figure 4).

3.4. Mortality. Only plants within the high NaCl and very high NaCl treatment groups showed mortality (20% and 54% mortality, resp.) (mortality measured as plant being completely dried out, brittle, and showing no signs of new growth) and were significantly greater than all other treatments. The mortality of the plants in the very high NaCl treatment group was significantly greater ($P < 0.01$) than the mortality in the high NaCl treatment group.

3.5. Soil pH and Electrical Conductivity. Soil pH was significantly higher at the end of the study in CMA treatments as compared to the control and NaCl treatments (Table 3). Treatment with NaCl created significantly higher soil EC than control or CMA treatments at the end of the study (Table 3). Treatments ranged from 0.8 to 1.9 mS cm^{-1}, but NaCl treatments ranged from 3.0 to 22.2 mS cm^{-1}.

Table 2: The effect of NaCl and CMA on growth and morphology of *A. uva-ursi* plants.

Treatment (mmol solute L^{-1})	Control	NaCl/CMA	20	60	140	280	P value
Stem length (ss/ps) (mm)	2.20 (3.212)*	NaCl	2.53 (4.998)	3.07 (4.621)	3.07 (5.738)	1.33 (1.839)	0.839
		CMA	2.60 (3.699)	1.27 (3.218)	1.20 (2.833)	2.13 (4.121)	
Stem length (ss/sds) (mm)	25.20 (31.743)	NaCl	17.47 (26.859)	19.60 (37.133)	5.13 (8.305)	3.73 (5.035)	0.284
		CMA	12.20 (12.013)	13.73 (20.869)	14.47 (22.119)	12.00 (25.355)	
Number of new secondary shoots (ss/sds)	0.80 (1.612)	NaCl	0.67 (1.496)	0.53 (2.066)	0.13 (0.352)	0.33 (0.617)	0.923
		CMA	0.53 (0.990)	0.87 (1.767)	0.40 (1.298)	0.80 (2.305)	
Number of new flushed buds (ep)	7.60 (7.818)	NaCl	5.47 (6.334)	6.67 (7.697)	2.00 (3.185)	4.13 (5.630)	0.248
		CMA	9.13 (8.254)	8.60 (12.322)	4.87 (5.383)	6.67 (8.877)	
Number of developing apical buds (ep)	2.20 (3.167)	NaCl	1.67 (3.222)	2.13 (2.997)	0.80 (1.568)	1.47 (1.767)	0.893
		CMA	1.87 (2.503)	1.67 (2.127)	1.53 (1.642)	1.33 (2.610)	

*Mean (n = 15) and SD (inside parentheses) are shown. Treatment effects were analyzed using ANOVA coupled with the Bonferroni mean comparison test ($P < 0.05$). ss: sample shoot; ps: primary shoot; sds: secondary shoot; ep: entire aboveground plant.

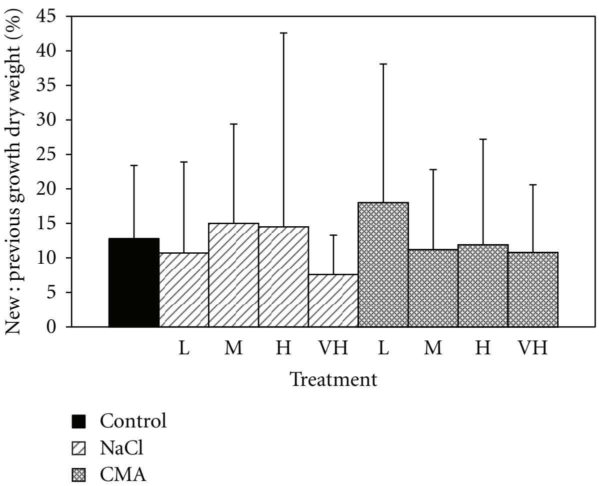

Figure 4: The effect of NaCl and CMA on the ratio of dry weight of new growth to previous growth of entire plants of *A. uva-ursi*. Means (n = 15) and SD are shown. Treatment effects were analyzed using ANOVA coupled with the Bonferroni mean comparison test ($P < 0.05$) and showed no significant differences between means ($P = 0.495$). L: low treatment; M: medium treatment; H: high treatment; VH: very high treatment.

Table 3: Influence of NaCl and CMA treatments on mean soil pH and soil electrical conductivity (EC) at the end of the experiment.

Treatment	pH (water)	pH ($CaCl_2$)	EC (mS cm^{-1})
Control	6.97 (0.23)[a]*	6.39 (0.25)[a]	0.630 (0.07)[a]
NaCl			
Low	6.34 (0.21)[a]	5.99 (0.20)[a]	2.96 (0.48)[a]
Medium	6.42 (0.36)[a]	6.21 (0.39)[a]	6.63 (0.87)[a]
High	6.63 (0.23)[a]	6.42 (0.38)[a]	13.64 (0.81)[a]
Very high	6.91 (0.30)[a]	6.54 (0.17)[a]	22.16 (1.23)[a]
CMA			
Low	8.29 (0.42)[a]	7.78 (0.38)[a]	0.83 (0.04)[a]
Medium	9.11 (0.07)[a]	8.72 (0.10)[a]	1.58 (0.33)[a]
High	9.50 (0.08)[a]	9.20 (0.12)[a]	1.75 (0.24)[a]
Very high	9.70 (0.10)[a]	9.49 (0.04)[a]	1.89 (0.18)[a]
P value	<0.001	<0.001	<0.001

*Mean (n = 4) and SD (shown in parentheses). Treatment effects were analyzed using ANOVA coupled with the Bonferroni mean comparison test ($P < 0.05$).
[a]Mean that share the same letter within a column are not significantly different.

4. Discussion

This research investigated the ability of the ground cover species, *Arctostaphylos uva-ursi*, to tolerate increasing concentrations levels (0, 20, 60, 140, and 280 mmol dissolved solute L^{-1}) of the deicing agents, NaCl and CMA, which were prepared in solution and periodically added to pots over the course of the 10-week study. The ionic strength of these solutions is within the range reported for melt waters from road ice and snow [7, 30]. Pots were watered in such a manner as to minimize the leaching loss of these salts from the potting soils, allowing salts to build up in concentration over time, as they might do in some soil environments. Soil electrical conductivity (EC) is an indirect measure of soluble soil salt content [33]. By the end of the study, the EC of soils from some NaCl treatments was very high, reflecting the accumulation of this inorganic salt in treated soils. In contrast, EC of CMA treatments was relatively low, most likely due to the biodegradation of acetate within the treated soils. This is discussed further below.

In general, *A. uva-ursi* was able to tolerate moderate-to-high concentrations of added NaCl and even greater concentrations of added CMA without experiencing mortality or signs of stress. However, plants did show signs of drying out in 70 and 140 mM NaCl treatments (i.e., 140 and 280 mmol dissolved solute L^{-1}). A reddish colour of leaves was observed in all treatments, but was more prevalent in the NaCl plants, especially at the higher concentrations. This reddish colour was possibly due to the presence of the pigment, anthocyanin, which accumulates in young, expanding foliage in response to various stresses including salt [32], nutrient deficiency damage or defense against browsing herbivores [34]. It has also been argued that anthocyanin confers cold and drought hardiness by adding to osmotic adjustment in leaf tissues [35]. Further, anthocyanin synthesis has been directly related to the presence of magnesium [36] and calcium [37].

A. uva-ursi growth and morphology, measured by stem length and number of new shoots and buds, were not affected by treatment, however, for the most part, there was a trend that showed a negative effect of NaCl on these plant characteristics. Shoot length of Japanese bitter orange was reduced by 30–80% in 30–120 mM NaCl treatments [38]. The toxicity of Cl^- and Na^+ has been shown in growth reduction in barley [39] and faba bean [40] in response to high concentrations of these ions. Fresh weight to dry weight ratios can be used as a measure of water content within a plant: the higher the ratio, the more water per dry biomass unit. This ratio was significantly lower for plants from the two highest NaCl concentrations, which could have been due to soil salt accumulation and the resultant reduction in osmotic potential of soil water, which would have reduced water availability to plants [41]. Calcium magnesium acetate treated plants showed no significant fresh weight to dry weight ratio difference among treatments, supporting past research of the nontoxic effect of CMA on plants [17–19]. Once plants are established in an area, it is important that they continue to grow and produce new vegetative and floral shoots. This study showed that the ratio of new growth to previous growth was not statistically significant across the treatments; perhaps a larger sample size may have separated out treatment effects.

In the current study, the medium NaCl treatment, 30 mM NaCl (equivalent to 60 mmol dissolved solute L^{-1}), resulted in a final soil EC of 6.6 mS cm^{-1}; levels exceeding 4 mS cm^{-1} are considered to be saline [33]. Exploratory analysis of roadside soils from Prince George (data not shown) showed some soils to exceed 4 mS cm^{-1} in the spring. In the present study, high and very high NaCl treatments resulted in final soil EC values of 13.6 and 22.2 mS cm^{-1}, respectively (Table 3). Plants subjected to 70 mM NaCl addition (equivalent to 140 dissolved mmol solute L^{-1}) resulted in 80% survival of plants, with the 140 mM NaCl (equivalent to 280 mmol dissolved solute L^{-1}) treatment resulting in 53% mortality. One-third of Japanese bitter orange plants treated with 120 mM NaCl had lost more than 50% of their leaves and had more than 20 cm shoot tip dieback [38]. A direct relationship has been documented between plant injury and Na^+ or Cl^- levels [14].

The greater tolerance of *A. uva-ursi* to CMA than NaCl could be in part due to the different behaviour these compounds have in soils. Calcium and magnesium in CMA are plant macronutrients which also promote the development of soil structure in mineral soils. In contrast, high concentrations of soluble Na^+ have been associated with plant toxicities, nutrient imbalances, and soil structural degradation [8, 9, 41]. Unlike Cl^- in NaCl, acetate in CMA biodegrades; Horner [18] reported that acetate from CMA completely degrades within 2 weeks. The half-life of acetate in soil is less than two days at 7°C producing carbon dioxide, water, and bicarbonate; carbonate precipitates may form in some soils [2]. The removal of acetate from solution increases osmotic potential and reduces the ionic strength of soil, as was reflected in the low EC of the CMA-treated soils at the end of the present study (Table 3). This should have reduced salt stress in *A. uva-ursi* plants subjected to CMA treatments, as compared to NaCl. Many plants exhibit salt stress when the soil EC exceeds 4 mS cm^{-1} [41, 42]. In the present study, all CMA treatments fell below 4 mS cm^{-1} by the end of the experiment, but NaCl treatments ranged from 3.0 to 22.2 mS cm^{-1}.

In the current study, CMA increased soil pH relative to the control and NaCl treatments (Table 3). This was likely due to a few factors. First, the acetate in CMA is a conjugate base; nonbiodegraded acetate in the soil would contribute to increased pH. Second, the degradation of CMA may have resulted in the formation of bicarbonate, contributing to increased soil pH. Third, Ca^{2+} and Mg^{2+} may have been more effective than Na^+ at displacing the exchangeable acidity of the soil used in this study. Others have found that CMA increases the pH of some soils [2, 18].

This research investigated the ability of the ground cover species, *A. uva-ursi*, to tolerate increasing levels of the deicing agents, NaCl and CMA. This plant was found to be capable of surviving under moderate-to-high levels of NaCl and under even greater concentrations of CMA. Therefore, *A. uva-ursi* could prove to be a candidate for landscaping in a northern city. Treatment with CMA demonstrated fewer negative effects on plant growth and morphology of *A. uva-ursi*, supporting its less toxic role as a deicing agent. On another positive note, CMA works best at about 25°F (−3.89°C), but has been shown to work in low temperatures below 15°F (−9.44°C), where NaCl loses its effectiveness [43]; this characteristic would work well in north central cities such as Prince George, BC, where temperatures can drop well below freezing from November through March. Calcium magnesium acetate is much more costly than NaCl, but if production of CMA and commercial availability increased, this cost difference may decrease [16]. Further, when one factors in external costs to municipalities, such as annual re-seeding of salt killed grasses over extensive areas, the overall cost of CMA may be competitive with that of NaC1. New methods for producing CMA have been developed that will improve its cost-effectiveness [44, 45].

Nonnative plants have been traditionally used for landscaping because they are relatively inexpensive, readily available, and easy to establish on disturbed sites [24]. However, using native plants for beautifying urban environments makes sense ecologically, as they are better for the environment, especially to maintain biodiversity [46] and they are already adapted to their native habitat. With the current movement toward sustainable landscaping and maintaining areas in their natural setting, the use of native plants in urban planning should become more widespread. As models for native plant application are developed, such as the one by Smith and Whalley [47] for expanded use of native grasses, revegetation and landscaping should become economically feasible as well as more environmentally friendly.

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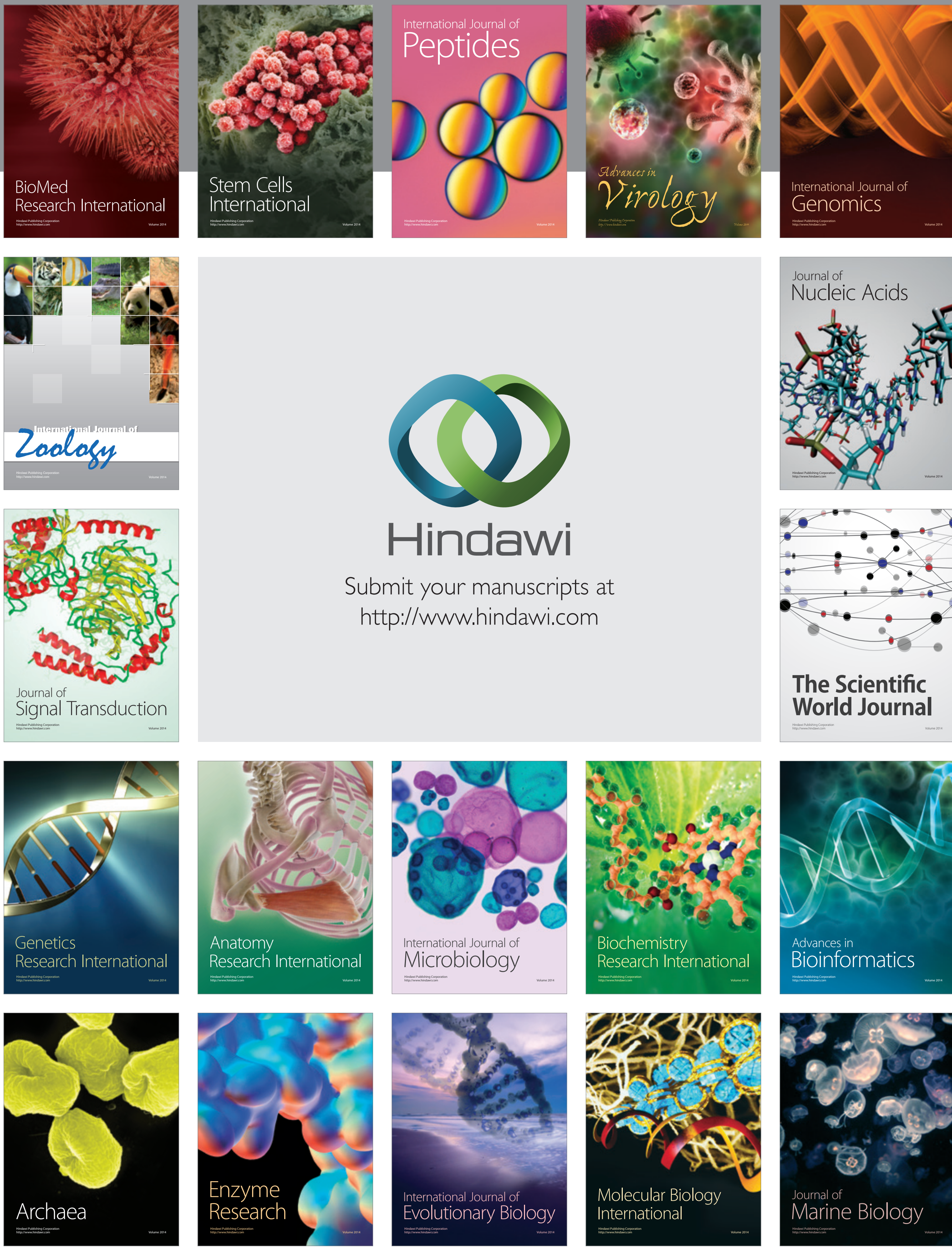
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