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SALT EFFECTS ON CRANBERRY SOILS, PLANT GROWTH, AND PRODUCTIVITY

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16. Abstract

The Massachusetts Highway Department (MassHighway) engages in Environmental Stewardship as part of its mission "To support the construction and maintenance activities that provide the Commonwealth with safe roads and bridges and to protect and where possible enhance the environment." The use of salt for highway deicing is a necessary activity with potential for environmental impact though migration of salt into water supplies and through salt contamination of soils. Since cranberry farming is a significant land use in Southeastern Massachusetts, the research project described herein was undertaken by the UMass Amherst Cranberry Station with funding provided by MassHighway and the Federal Highway Administration.

Salt applied to roads may migrate onto cranberry bogs and into their water supplies. Does salt adversely effect cranberry soils, growth, and/or productivity? If so, at what concentration are these effects apparent and what concentrations of salt would be present in affected cranberry soils or plants? The overall objective of this project was to define both chronic and acute salt concentrations in irrigation water that can adversely impact cranberry production systems by evaluating the effects of salt exposure on cranberry growth, yield, or soil chemistry.

Based on these research results, there is good indication that a cranberry water supply containing Cl at 250 ppm or greater would be cause for concern and indicate the potential need for remedial action. Symptoms, soil chemistry changes, and possible growth stimulation at 100-125 ppm Cl indicate that a cranberry water supply containing 100 ppm or greater Cl for extended periods might also be cause for concern. Taking all of these results into account, setting the level of concern for Cl in cranberry irrigation water at 100 ppm appears warranted. This is well below the 250 ppm that was definitively associated with negative effects in greenhouse experiments and the 500 ppm that negatively affected growth in soil-free culture. Therefore, 100 ppm Cl is proposed as the level at which closer scrutiny of a water supply over time would be warranted. If the 100 ppm level persisted for more than 2 months, particularly during the irrigation season, chronic effects might become a concern. This Cl level is equivalent to ~165 ppm NaCl.

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SALT EFFECTS ON CRANBERRY SOILS, PLANT GROWTH, AND PRODUCTIVITY

Final Report

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Executive Summary

This study of the Salt Effects on Cranberry Soils, Plant Growth, and Productivity was undertaken as part of the Executive Office of Transportation Research Program for the Massachusetts Highway Department (MassHighway). This program is funded with Federal Highway Administration (FHWA) Statewide Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to the Commonwealth of Massachusetts transportation agencies.

The use of salt for highway deicing is a necessary activity with potential for environmental impact through migration of salt into water supplies and through salt contamination of soils. MassHighway engages in Environmental Stewardship as part of its mission "To support the construction and maintenance activities that provide the Commonwealth with safe roads and bridges and to protect and where possible enhance the environment." Since cranberry farming is a significant land use in Southeastern Massachusetts, MassHighway approached the UMass Amherst Cranberry Station to address the question of potential impact of road salt on cranberry farms. As Southeastern Massachusetts becomes more urbanized, placement of roads and highways adjacent to cranberry bogs has increased. Routes I-495 and 25, in Wareham and Plymouth, pass near several cranberry bogs and the proposed extensions of Route 44 and Route 106, in Plymouth and Kingston, will result in more miles of highway adjacent to cranberry bogs. Since cranberry bogs are often the lowest elevation feature in the landscape, road runoff can migrate into the bogs.

The research project described herein was undertaken by the UMass Amherst Cranberry Station. The overall objective of this project was to define both chronic and acute salt concentrations in irrigation water that can adversely impact cranberry production systems by evaluating the effects of salt exposure on cranberry growth, yield, or soil chemistry. Those concentrations would then be used as a standard for comparison for cranberry water supplies. In addition, project results can be used to recommend mitigation treatments for cranberry soils that have become salt-laden.

In order to examine the effects of salts on cranberry production systems, a two phase approach, including laboratory and field studies, was undertaken:

Phase I – Effects on plant growth and yield

1. In three greenhouse experiments, pot-grown cranberry plants were exposed to salt. Salts studied were sodium chloride (NaCl), commonly used for deicing; calcium chloride ($CaCl_2$), also used for deicing; potassium chloride (KCl), chosen to isolate chloride effects; sodium sulfate (Na_2SO_4), chosen to isolate sodium effects; and magnesium sulfate ($MgSO_4$), chosen to isolate conductivity effects in the absence of sodium or chloride. Exposures were to varied concentrations and timings, including an experiment that simulated applying all irrigation with salt-contaminated water.
2. In soil-free culture, cranberries were exposed to NaCl or to Cl or Na separately in order to examine effects at 100 ppm chloride (or equivalent sodium). This system

was also used to examine the effects on cranberry plants of calcium-magnesium acetate (CMA), an alternative deicing material used in low-salt highway areas.

Phase II – Effects on soil chemistry

1. In the laboratory, absorption/desorption was studied using typical cranberry soils exposed to salt, including NaCl, $CaCl_2$, KCl, Na_2SO_4, $MgSO_4$, and CMA. Resultant changes in soil chemistry were documented.
2. Soil chemistry was evaluated at a cranberry field site that receives direct road runoff.
3. Using cranberry soil cores, the potential of fertilizer applications as mitigation treatments for salt-loaded soils was investigated. An effective treatment identified in the laboratory was field tested.

The greenhouse experiments were conducted at the UMass Amherst Cranberry Station located in East Wareham, Massachusetts. Field studies were conducted by UMass Cranberry Station personnel. Soil-free culture studies were conducted under subcontract with the Cranberry Institute and were carried out at the University of Wisconsin, Madison. Soil chemistry laboratory studies were conducted at Washington State University Irrigated Agriculture Research and Extension Center located in Prosser, Washington.

Minimum concentration of salt in cranberry irrigation to produce adverse effects.

In greenhouse studies, adverse effects to cranberries were seen after long-term exposure to 100 ppm Cl in irrigation water. Salts studied included NaCl, Na_2SO_4, and KCl. Adverse effects included elevated Na and Cl in the plants and soil, visible symptoms on the leaves, and possible vegetative growth stimulation. At 250 ppm, symptoms increased and flowering was suppressed.

In soil-free culture, cranberry growth was suppressed at 500 ppm Cl, at higher concentrations plants exhibited severe leaf drop and eventual death. At the 100 ppm concentration, growth effects were not significant but at the end of the study, plants exposed to 100 ppm Na has produced more vegetative growth than control plants and exposure to Na or Cl at 100 ppm resulted in elevated tissue Na and Cl respectively.

In soil sorption/desorption studies, treatment with salts at concentrations of Cl greater than 250 ppm resulted in significant, only partially reversible, changes to cranberry soil chemistry. At 250 ppm, recovery occurred after desorption.

Based on these research results, there is good indication that a cranberry water supply containing Cl at 250 ppm or greater would be cause for concern and indicate the potential need for remedial action. Symptoms, soil chemistry changes, and possible growth stimulation at 100-125 ppm Cl indicate that a cranberry water supply containing 100 ppm or greater Cl for extended periods might also be cause for concern.

Taking all of these results into account, setting the level of concern for Cl in cranberry irrigation water at 100 ppm appears warranted. This is well below the 250 ppm that was definitively associated with negative effects in greenhouse experiments and the 500 ppm that negatively affected growth in soil-free culture. Therefore, 100 ppm Cl is proposed as the level at which closer scrutiny of a water supply over time would be warranted. If the 100 ppm level persisted for more than 2 months, particularly during the irrigation season, chronic effects might become a concern. This Cl level is equivalent to ~165 ppm NaCl.

However, the possible growth stimulation effect at 100 to 125 ppm and the elevation in tissue Na and Cl at all concentrations warrant further investigation.

Based on an examination of data from control samples in the greenhouse and laboratory and field samples from uncontaminated sites, one should expect to find the levels for Na and Cl proposed in the table below in uncontaminated cranberry plants and soil. Levels consistently greater than these would be cause for concern. Damage to cranberry bogs associated with 15 ppm Cl in the soil has been previously reported (Chandler and Demoranville, 1959).

The soil Cl value is similar to that found in control samples in the laboratory sorption/desorption study and in the field collections and a bit lower than that found in the greenhouse irrigation study controls. However, the greenhouse irrigation study controls received tap water that contains some Cl, which may explain the higher Cl in these soils.

	Proposed background levels for Na	Proposed background levels for Cl
Cranberry soil	Up to 15 ppm	7 ppm
Cranberry shoot tissue	~ 0.06% dry weight	~ 0.05% dry weight
Cranberry root tissue	~0.03% dry weight	~0.05% dry weight

The lowest salt concentration at which a single overspray adversely affects cranberry plant growth (acute effect).

When soil flushing with uncontaminated irrigation water was included in greenhouse studies, cranberry plants appeared to tolerate single exposures to irrigation containing salt concentrations as high as 5000 ppm. Acute exposure of cranberry plants twice in 16 weeks in the greenhouse to concentrations of salt as high as 7500 ppm also had minimal effect on cranberry growth, but tissue Na was elevated.

More frequent exposures to irrigation with salt concentrations as high as 2500 ppm also appear to be tolerated by the cranberry plants in the presence of soil flushing. Compared to the $MgSO_4$ treatment, intermittent treatment with any salt containing Na or Cl was associated with increased shoot growth. This may indicate a tendency to increased vegetative growth when cranberries are exposed periodically to high concentrations of Na or Cl.

If exposure to high salt concentrations is only infrequent and natural leaching is present, cranberries should tolerate such exposures. In the field, this would be accomplished by rainfall or irrigation. However, if exposure continues intermittently, there is some indication that vegetative growth might be stimulated.

In soil-free culture, exposure to concentrations of as low as 100 ppm CMA killed cranberry plants within 5 days. However, in a field situation, CMA would react with the soil, potentially attenuating effects.

Impact on cranberry growth and yield of chronic exposure to low salt concentrations.

In two greenhouse studies of chronic salt exposure with periodic soil flushing, growth effects on cranberry were equivocal. In the first study, growth was unaffected but tissue Na and Cl was elevated at the 625 ppm concentration and leaf spotting was observed. In the second study, growth appeared to be slightly suppressed in cranberries receiving chronic exposure to 250 and 625 ppm concentrations of salt but possibly stimulated at 125 ppm.

In a third greenhouse study, chronic exposure with no soil flushing was studied. All irrigation contained the comtaminating salts. All salts and concentrations were associated with an increase in leaf symptoms compared to the controls and with elevated Na and/or Cl in the plant tissue and in the soil. Leaf symptoms generally consisted of spotting, reddening, and eventual leaf drop. After chronic exposure to 100 ppm Cl, symptoms were severe, soil chemistry was out of balance, tissue levels of Na and/or Cl were elevated, and vegetative growth may have been stimulated. At 250 ppm, symptoms were more apparent and flowering was suppressed.

The effect of salt loading on cranberry soil chemical characteristics.

Cranberry soil, a sandy soil with organic matter in the range of 1-3.5%, appears to have a limited capacity for sodium and chloride loading. Based on supernatant examination after sorption, for both Na and Cl, the 250 ppm concentration seemed to result in little change to the soil chemistry. However, as added salt concentrations increased above 250 ppm, the Na and Cl that loaded onto the soil was less readily released by leaching. In addition, as cations were added at higher concentrations, other cations were driven from the soil. This could be a problem if high Na levels depress the beneficial cations Ca, K, or Mg. However, the converse is also true. Mg or Ca loading drove Na from the soil, indicating that Mg and Ca salts could be used for mitigating Na-contaminated cranberry soil.

Of the mineral salts examined, NaCl appeared to be the Cl source associated with the greatest Cl loading in the soil. Na was elevated similarly regardless of Na source. Addition of any salt increased soil electrical conductivity (EC) as concentration increased but none of the mineral salts had detrimental effects on soil pH. It appears that exposure of cranberry soil to 250 ppm or less salt is unlikely to have long-term detrimental effects as long as leaching occurs, i.e. any absorbed salt will leach away readily during rain events.

Adding CMA to cranberry soil led to an increase in soil Ca and Mg as might be expected. However, CMA addition at high concentrations also appeared to increase plant availability of Na and to a lesser extent Cl. Of more concern was the apparent effect of CMA on soil pH, with all concentrations studied resulting in soil pH greater than 6.0, the highest pH recommended for cranberry soil.

Treatments to remediate salt exposed cranberry soils.

The addition of even moderate amounts of K, Mg, and Ca containing fertilizers helped to restore NaCl-loaded cranberry soil to pre-loading chemistry if the soil also received leaching (rainfall or flooding). In the laboratory, the best mitigation treatment was the equivalent of a high fertilizer rate (2 tons/acre) combined with the equivalent of a deep flood and seasonal rainfall. The equivalent of moderate fertilizer (500 lbs/acre) plus normal seasonal rainfall was also fairly successful at restoring NaCl-loaded soil and had the additional advantage of making little impact on the soil cation balance. Application of the common fertilizer materials, SulPoMag and gypsum (3:1 ratio) without any change in water management, appeared to assist in vine recovery at a salt-injured cranberry site. Fertilizer rates of 500 and 1000 lb/acre were equally effective.

Recommendations

Establish 100 ppm Cl as an interim level of concern for cranberry water supplies. Cl at that level or greater over a period of 2 months or longer is likely to be associated with adverse effects.

Levels approaching 250 ppm Cl in a cranberry water supply should be cause for concern and a trigger for corrective action.

At sites where salt contamination is suspected or where the 100 ppm Cl level of concern has been reached, the baseline levels for Na and Cl in cranberry soils and plants defined in this project should be used as a basis for comparison with samples collected from such sites.

Further research should be conducted, including field exposures, to confirm the 100 ppm Cl level of concern for cranberry water supplies.

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1.0 Introduction

This study of the Salt Effects On Cranberry Soils, Plant Growth and Productivity was undertaken as part of the Executive Office of Transportation (EOT) Research Program for the Massachusetts Highway Department (MassHighway). This program is funded with Federal Highway Administration (FHWA) Statewide Planning and Research (SPR) funds. Through this program, applied research is conducted on topics of importance to Commonwealth of Massachusetts transportation agencies.

The use of salt for highway deicing is an activity with potential for environmental impact through migration of salt into water supplies and through salt contamination of soils. MassHighway engages in Environmental Stewardship as part of its mission "To support the construction and maintenance activities that provide the Commonwealth with safe roads and bridges and to protect and where possible enhance the environment." Since cranberry farming is a significant land use in Southeastern Massachusetts, MassHighway approached the UMass Amherst Cranberry Station to address the question of potential impact of road salt on cranberry farms. As Southeastern Massachusetts becomes more urbanized, placement of roads and highways adjacent to cranberry bogs has increased. Routes I-495 and 25, in Wareham and Plymouth, pass near several cranberry bogs and the proposed extensions of Route 44 and Route 106, in Plymouth and Kingston, will result in more miles of highway adjacent to cranberry bogs. Since cranberry bogs are often the lowest elevation feature in the landscape, road runoff can migrate into the bogs.

Visible damage attributed to road salt deposition or runoff has been observed along the edges of cranberry bogs bordered by highways. Damage from salt water incursion during hurricanes has also been documented (Chandler and Demoranville, 1959). This damage was manifested as crop reduction, adverse impact on fruit quality, and actual plant death in areas where the saline water puddled on the bog. After Hurricane Bob in 1991, similar effects were observed by UMass Cranberry Station scientists. In addition, instances of damage from salt spray were reported (Hurricane Bob was associated with salt-laden winds and low rainfall).

In samples collected during the 1950s, chloride (Cl) in water supplies and in cranberry bog soil *water* varied from 6-20 ppm (Chandler and Demoranville, 1959). The exception was a bog and its adjacent pond, which had not recovered from sea water incursion during the 1938 Hurricane (217 ppm in the pond and 198 ppm in the bog soil *water*). The soil water in a bog with an area of dying vines had approximately 700 ppm Cl in the injured area, but the adjacent ditch water contained only 37 ppm Cl (Chandler and Demoranville, 1959).

Cranberries were injured in 1954 (visible browning) by a single exposure to water with 2000 ppm Cl during Hurricane Carol. Recently planted vines showed more damage than established vines (Chandler and Demoranville, 1959).

After direct salt water incursion into cranberry bogs during Hurricane Carol in 1954, Chandler and Demoranville (1959) found that cranberry plants were damaged when soil Cl was as low as 15 ppm if the soil was predominantly coarse sand (low in organic matter). Bogs with damaged vines showed soil Cl levels from 15-76 ppm Cl in the root zone. High organic cranberry soils (>3.5%) with good drainage could tolerate soil Cl as high as 300 ppm with no visible vine damage, however, the crop was not evaluated. It should be noted that the mean Massachusetts cranberry bog soil organic matter content was 3.4% in a survey conducted in 1993 (Davenport and DeMoranville). That survey was limited to established bogs (more than 10 years in production); most newer bogs have 2% or less organic matter.

In a sand culture study of lingonberry (*Vaccinium vitis-idaea* L.), a close relative of cranberry, Kruger and Naumann (1984) found that yield declined sharply when leaf Cl levels rose from 0.1 to 0.2% but vegetative growth showed no change. The change in tissue Cl was brought about by watering the lingonberry plants with solutions containing between 70 and 570 ppm Cl (2-16 meq/L).

Blueberries grown in sand culture with nutrient solution containing moderate (575 ppm) or high (2300 ppm) NaCl exhibited retarded root and shoot growth, leaf necrosis, and reduced leaf gas exchange (Wright, et al., 1992, 1993, 1994). Both Southern highbush and rabbiteye blueberries showed these effects. The negative impact was largely due to sodium - similar effects were seen when Na was supplied as Na_2SO_4. Low levels of added Ca provided only limited amelioration. This research indicates that cranberries, like the closely related blueberries, may have no mechanism to regulate Na uptake. As a calcifuge plant (Korcak, 1987; Wright, et al. 1993), cranberries, like blueberries, could be expected to be sensitive to excess Cl^-, Na^+, and Ca^{++} ions.

The research project described herein was undertaken by the UMass Amherst Cranberry Station with funding provided by the Executive Office of Transportation and the Federal Highway Administration. The overall objective of this project was to define both chronic and acute salt concentrations that can adversely impact cranberry production systems by evaluating the effects of salt exposure on cranberry growth, yield, or soil chemistry. Those concentrations would then be used as a standard for comparison for cranberry water supplies. In addition, project results can be used to recommend mitigation treatments for cranberry soils that have become salt-laden.

The following specific initial project objectives were developed:

1. Define the critical level for salt in cranberry irrigation water, i.e. the minimum concentration associated with adverse effects.
2. Determine the lowest salt concentration at which a single overspray adversely affects cranberry plant growth (acute effect).
3. Determine the impact on cranberry growth and yield of chronic exposure to low salt concentrations.
4. Determine the effect of salt loading on nutrient management in cranberry production with specific reference to cranberry soil chemical characteristics. Investigate the use of electrical conductivity measurement as a field-monitoring tool.
5. Investigate treatments to remediate salt exposed cranberry soils.
6. Produce a chart of sodium (Na) and chloride (Cl) levels versus cranberry yield potential.

The first three objectives were investigated using cranberry plants grown in sand culture in the greenhouse and in soil-free culture. Plans to examine yield effects with field-grown plants were unsuccessful. As a result, the project scope was modified to include additional sand and soil-free studies in lieu of the field applications. In the absence of field studies, a chart of salt level versus cranberry yield, objective 6, was removed from the scope of the agreement. Instead, a baseline level for Na and Cl in cranberry tissue and soil was defined, i.e. that level that exists in cranberry plants and soils that have not been exposed to salt. Salt loading effects on cranberry soil, objective 4, were investigated in the laboratory using absorption/desorption experiments and in the field at a cranberry site that received direct road runoff. Remedial treatments, objective 5, were developed in a laboratory experiment using columns packed with soil collected from cranberry bogs. The successful treatment was then investigated at the field site that received road runoff.

2.0 Research Methodology

2.1 Methods Overview

In order to examine the effects of salts on the cranberry system, a two-phase approach was undertaken:

Phase I – Effects on plant growth and yield (objectives 1-3)
January 1999 - September 2004

1. In three greenhouse experiments, pot-grown cranberry plants were exposed to salt. Salts studied were:
   - sodium chloride (NaCl), commonly used for deicing;
   - calcium chloride ($CaCl_2$), also used for deicing;
   - potassium chloride (KCl), chosen to isolate chloride effects;
   - sodium sulfate (Na_2SO_4), chosen to isolate sodium effects; and
   - magnesium sulfate ($MgSO_4$), chosen to isolate conductivity effects in the absence of sodium or chloride.

   Exposures were to varied concentrations and timings, including an experiment that simulated applying all irrigation with salt-contaminated water.
2. In soil-free culture, cranberries were exposed to NaCl or to Cl or Na separately in order to examine effects at 100 ppm chloride (or equivalent sodium). This system was also used to examine the effects on cranberry plants of calcium-magnesium acetate (CMA), an alternative deicing material used in low-salt highway areas.

Phase II – Effects on soil chemistry, laboratory and field studies (objectives 4 and 5)
October 1998 - October 2004

1. In the laboratory, absorption/desorption was studied using typical cranberry soils exposed to salt, including NaCl, $CaCl_2$, KCl, Na_2SO_4, $MgSO_4$, and CMA. Resultant changes in soil chemistry were documented.
2. Soil chemistry was evaluated at a cranberry field site that receives direct road runoff.
3. Using cranberry soil cores, the potential of fertilizer applications as mitigation treatments for salt-loaded soils was investigated. An effective treatment identified in the laboratory was field-tested.

2.2 Materials & Equipment

The greenhouse experiments were conducted at the UMass Amherst Cranberry Station located in East Wareham, MA. Field studies were conducted by UMass Cranberry Station personnel. Soil-free culture studies were conducted under subcontract with the Cranberry Institute and were carried out at the University of Wisconsin, Madison. Soil chemistry laboratory studies were conducted at Washington State University Irrigated Agriculture Research and Extension Center located in Prosser, WA.

2.3 Analytical procedures.

Analyses of plant tissue samples from greenhouse studies were conducted at Midwest Laboratories, Inc., Omaha, Nebraska. Plant tissue was dried at 60ºC, ground to pass 20 mesh, digested in nitric acid and analyzed by standard ICP-OES (inductively coupled plasma emission spectroscopy, Official Methods of Analysis, 15th ed., Association of Official Analytical Chemists, Method 985.01) for cations. Chloride in plant extracts was analyzed using titration with silver nitrate (Official Methods of Analysis, 15th ed., Association of Official Analytical Chemists, Method 915.01, volumetric method 1).

Analyses of soil samples from greenhouse studies, field collections, and laboratory experiments were conducted at Midwest Laboratories, Inc. Samples were extracted in neutral ammonium acetate or water (1:5 soil : water) (Handbook of Reference Methods for Soil Testing, 1974, Council on Soil Testing and Plant Analysis, p. 60-65, 87) and analyzed for cations using ICP (Recommended Chemical Soil Test Procedures for the North Central Region, No. 499. North Dakota State University p. 17-18). Soil pH was measured using a 1:1 soil : water mixture (Recommended Chemical Soil Test Procedures for the North Central Region, No. 499. North Dakota State University p. 5-8). Soluble salts were measured in a 1:1 soil: water mixture (USDA Agriculture Handbook 60, p. 89-90). Chloride was measured spectrophotometrically after extraction with 0.01 M calcium nitrate (Recommended Chemical Soil Test Procedures for the North Central Region, No. 499. North Dakota State University p. 26-27).

Analyses of water samples generated in the laboratory studies were conducted by J. Davenport at the Irrigated Agriculture Research and Education Center at Washington State University or at Midwest Laboratories, Inc. using the same methods as for soil extracts.

Analyses of plant tissue collected from the soil-free culture studies were conducted at the University of Wisconsin, Madison Soil and Plant Analysis Lab. Plant tissue was dried at 45ºC, ground to pass 40 mesh, digested in nitric-perchloric acid and analyzed by standard ICP-OES (inductively coupled plasma emission spectroscopy, EPA method 6010) for sodium. Chloride in nitric acid digested samples was determined by an automatic chloride titrator (Digital chloridometer) by coulometric-amperometric titration with silver ions. The chloride method was adapted from *Standard methods for the Examination of Water and Wastewater,* 15th Edition, 1980. (pgs. 273-275), Method 407C.

2.4 Scope of Research.

The objective of this project was to define both chronic and acute salt levels that could lead to adverse effects in cranberry production systems by evaluating the impact on cranberry growth, yield, or soil chemistry. Those concentrations would then be used as a standard for comparison for cranberry water supplies, defining the concentrations of Na and/or Cl in those supplies above which adverse impacts on growth or production could be expected. In addition, project results could be used to recommend mitigation treatments for cranberry soils that have become salt-laden. Specific tasks undertaken in pursuit of the project objectives are listed below.

2.4.1 Phase I - Effects on plant growth and yield (objectives 1-3):

1. At the UMass Amherst Cranberry Station, in two greenhouse experiments, pot-grown cranberry plants were challenged with chronic, intermittent, or acute exposures to NaCl, $CaCl_2$, KCl, $NaSO_4$ or $MgSO_4$ to simulate road salt, its components, or a non-road salt control at similar conductivity in order to determine threshold levels for salt impact on growth. In a third greenhouse experiment, salt-contaminated irrigation was simulated in order to determine impact on cranberry growth and flowering. The results were used to determine threshold concentration, below which no negative impact on cranberry growth would be expected.
2. At the University of Wisconsin Madison, in hydroponic and aeroponic soil-free culture, cranberry plants were exposed to sodium chloride or its components to determine the lowest concentration adverse to growth, specifically focusing on 500 ppm and 100 ppm concentrations of Na and Cl. Effect of CMA on cranberry plants was also studied in this system.

2.4.2 Phase II - Effects on soil chemistry (objectives 4 and 5):

1. At Washington State University, absorption/desorption studies were conducted using typical cranberry soils exposed to road salt or its components and the alternative, CMA Resultant changes in soil chemistry were documented.
2. In Massachusetts, soil from a field site receiving salt-laden road run-off was collected and analyzed. Impacts on soil chemistry were documented.
3. At Washington State University, using cranberry soil cores, the potential of five combinations of fertilizer applications and flushing as mitigation treatments for salt-loaded cranberry soils were investigated. A treatment that was effective in the laboratory was field tested in Massachusetts.

2.5 Phase I – Effects on Plant Growth & Yield

Greenhouse studies

2.5.1 Experiment 1 - Frequency, rate, and method of salt application effect on actively growing cranberries.

Upright cranberry stems were collected directly from a 'Stevens' planting, cut to a minimum length of 2.5 inches, and stripped of leaves from all but the top inch. The uprights were held in refrigerated storage until planting.

Four-inch square pots were lined with landscape cloth and filled with sand collected from a commercial cranberry farm. Table 1 shows the particle size characterization of the sand. The particle size distribution fits that recommended for sand used in cranberry production, i.e. approximately 70% coarse sand with particle size 0.5-2 mm.

Water and sand used in this and subsequent greenhouse studies was analyzed for conductivity to provide baseline data. The results are shown in Table 2. These results were typical - conductivity in these water sources was checked periodically and remained similar throughout the study.

Table 1. Characteristics of sand used for greenhouse plantings based on sieve test of oven dried sand

Particle size	Weight (g)	Percent
> 2.0 mm*	7.914	15.9
1.0-2.0 mm**	14.210	28.6
0.5-1.0 mm**	22.334	45.0
< 0.5 mm***	5.178	10.4

*gravel; **coarse sand; ***fine sand, silt, and clay

Table 2. Conductivity of water and sand used in greenhouse studies.

Material	Conductivity (μS)
Deionized water -- lab	1.340
Tap water -- lab	120.4
Greenhouse tap water	114.9
Sand (50g in 50 ml deionized water)	41.3

From June 23-25, 1999, uprights were taken from storage and recut on an angle to a length of exactly 2.5 inches and held with cut ends in containers of water. On July 25, the cuttings were planted, four per pot. Immediately prior to planting, cuttings were immersed for approximately 20 seconds in Dip 'n Grow™ liquid rooting concentrate diluted 1:10. Active ingredients in this material are 1% indole-3-butyric acid and 0.5% 1-naphthaleneacetic acid, plant growth regulators that promote rooting of woody cuttings. Cuttings were pushed into the sand to a depth of approximately 1.5 inches. The pots of sand had been placed under mist irrigation prior to planting so that the sand was moist.

After planting, the pots were placed in trays (15 pots/tray) and arranged on greenhouse benches under a mist irrigation system. The misting system was set to overspray the pots with water for three minutes, eight times each day, so that the sand surface remained uniformly moist.

As the temperatures declined and the days shortened in the fall, watering was cut back to one minute, six times each day. In the late fall, the pots were moved to a refrigerated storage unit for chilling. Chilling at temperatures below 45ºF was necessary to induce flowing in cranberries. The plants were returned to the greenhouse in February 2000 after their chilling requirements were satisfied, and resumed growth. Applications of ammonium sulfate fertilizer were made every two-three weeks to encourage vigorous growth. The fertilizer regimen was modified to include phosphorus and potassium in addition to nitrogen when the salt treatments began, and fertilizer applications were changed to a weekly schedule. Plants were hand-watered daily as the irrigation system in the greenhouse was upgraded. Once the new sprinklers were installed, automated watering resumed at 15 minutes per day. Shorter watering times were possible due to increased uniformity of the upgraded system.


Randomizing pots in greenhouse.

Salt treatments began the week of June 26, 2000 and continued through mid-October. Prior to salt treatments, the trays of pots were arranged in blocks on the greenhouse benches (see photo to the right). Each block of trays represented one replicate of one application timing and contained one pot for each rate of each salt and each application method. Each block also contained three pots for water controls. The treatment array is shown in Table 3. The spray application consisted of salt solution applied to the shoots only; the soil was covered with a plastic barrier. The drench application consisted of 80 ml of salt solution poured onto the soil surface. The combined treatment received a drench application and foliar spray without the plastic cover. Sprays were applied using a CO_2-pressurized sprayer and a 30 second spray to thoroughly wet the foliage.

Table 3. Treatment design for greenhouse experiment #1.

Treatment factor	**Levels**
Timing	Chronic, intermittent, acute
Application method	Spray, drench, both
Salt	NaCl, KCl, $CaCl_2$, Na_2SO_4, $MgSO_4$
Concentration	See table 4
Replicates (blocks)	4

Salt solutions (Table 4) were prepared from reagent grade salts in concentrations based on Cl. For example, a 100 ppm treatment of NaCl contained 165 mg/L NaCl to give 100 mg/L Cl and 65 mg/L Na; a 100 ppm treatment of KCl contained 210 ml/L KCl to give 100 mg/L Cl; and a 100 ppm Na_2SO_4 treatment contained 201 mg/L Na_2SO_4 to give 65 mg/L Na, the equivalent Na to that in the NaCl treatment.

Table 4. Concentrations in Cl equivalents for acute, intermittent, and chronic treatments.

Treatment (timing)	mg Cl/ L per application						
Acute -- single dose	250	500	1000	2500	5000		
Intermittent - every 2 weeks	50	100	250	500	750	1000	2500
Chronic - twice weekly	12.5	25	62.5	125	187.5	250	625

Concentrations for Na_2SO_4 resulted in equivalent Na to that in the NaCl treatments. $MgSO_4$ concentrations resulted in equivalent electrical conductivity to that in the NaCl treatments.

Salt treatments were applied over a 16 week period. Acute treatments were applied as a single application on July 3, 2000. Chronic treatments were applied twice per week on June 30, July 7, July 11, July 14, July 18, July 21, July 25, July 28, Aug. 1, Aug. 3, Aug. 8, Aug. 11, Aug. 14, Aug. 17, Aug. 22, Aug. 25, Aug. 28, Sept. 1, Sept. 5, Sept. 8, Sept. 11, Sept. 15, Sept. 19, Sept. 22, Sept. 26, Sept. 29, Oct. 3, Oct. 6, Oct. 11, and October 16, 2000. Intermittent treatments were applied every other week on July 12, July 26, Aug. 9, Aug. 23, Sept. 6, Sept. 20, Oct. 4, and Oct. 17, 2000. During the 16 weeks of treatment, the plants were held under the mist system and continued to receive 15 minutes of water per day in addition to the salt treatments.

During the 16 weeks of treatment, plant observations were recorded. At the end of the 16 treatment weeks, the plants were destructively harvested. For each pot, soil was washed from the roots of the four plants and the plants were separated into shoots and roots. These were dried in a 60 ºC oven for at least two days until a stable dry weight was achieved. Dry weight was recorded and the plant samples were then ground to 20 mesh and sent for mineral analysis at a commercial laboratory, Midwest Laboratories, Inc. Ground plant samples were digested in nitric acid and mineral elements in the digest were determined by ICP (inductively coupled plasma atomic emission spectroscopy), chloride by ion chromatography. See Section 2.3 for details.

2.5.2 Experiment 2 - Frequency, rate, and method of salt application effect on actively growing cranberries.

A second group of cuttings were planted in May 2000 and were maintained with 15 minutes mist per day and ammonium sulfate fertilization. Planting methods were the same as for Experiment #1. In October 2000, the pots were moved outdoors to begin chilling requirement, prior to moving them into a cold room late in November. They were returned to the greenhouse at the end of February 2001. Irrigation was set for 15 minutes at 6 a.m. each day and was adjusted in late June to 18 minutes to account for increased temperature in the greenhouse. Treatments began on 6 July 2001 and continued for 16 weeks. This experiment was a repeat of the previous one with adjustments as described below.

Prior to treatments, the trays of pots were arranged in blocks on the greenhouse benches. Each block of trays represented one replicate of one application timing and contained one pot for each rate of each salt and each application method. The treatment array is shown in Table 5. Salt solutions were prepared similarly to those used in Experiment #1. In this experiment, a zero-salt control was included for each timing and application method (Table 6).

Table 5. Treatment design for greenhouse experiment #2.

Treatment factor	Levels
Timing	Chronic, intermittent, acute
Application method	Spray or drench
Salt	NaCl, KCl, $CaCl_2$, Na_2SO_4, $MgSO_4$
Concentrations	See table 6
Replicates (blocks)	5

Table 6. Concentrations in Cl equivalents for acute, intermittent, and chronic treatments.

Treatment (timing)	mg Cl/ L per application						
Acute - every 8 weeks	0	250	500	1000	2500	5000	7500
Intermittent - every 2 weeks	0	50	100	250	500	1000	2500
Chronic - twice weekly	0	12.5	25	75	125	250	625

Concentrations for Na_2SO_4 resulted in equivalent Na to that in the NaCl treatments. $MgSO_4$ concentrations resulted in equivalent electrical conductivity to that in the NaCl treatments.

Salt treatments were applied over a 16 week period. Acute treatments were applied once at week 1 and once at week 8. For each salt, applications are made as a soil drench of 80 ml/pot to simulate soil flooding or as an overspray of the foliage to simulate sprinkler applications. The combined treatment of spray and drench was eliminated in Experiment #2 and a replicate was added. The spray treatments were applied using trigger-spray bottles with each pot receiving 7 sprays of solution - enough to wet the foliage thoroughly (see Table 7 for calibration results). The soil was left uncovered during spray treatments.

Table 7. Spray bottle calibration for experiment #2.

	Replicate runs					
Bottle	**1**	**2**	**3**	**4**	**5**	**avg.**
	ml per 7 sprays					
1	8.1	8.4	8.4	8.9	8.8	8.5
2	9.1	8.9	8.6	8.6	8	8.6
3	6.6	5.4	6.4	6.6	6.3	6.3
4	6	6.4	6.2	6.4	6.1	6.2
5	7	6.6	7.4	6.8	7	7
6	8.6	8.1	8.4	8.5	8.2	8.4
7	7.4	7.1	7	7.2	7.2	7.2
overall average						7.4
range						6.2-8.6

During the 16 weeks of treatment, plant observations were recorded. At the end of the 16 treatment weeks, the plants were destructively harvested. For each pot, soil was washed from the roots of the 4 plants and the plants were separated into shoots and roots. These were dried in a 60 ºC oven for at least 2 days until a stable dry weight was achieved. Dry weight was recorded and the plant samples were then ground and sent for mineral analysis at a commercial laboratory (Midwest Laboratories, Inc.). See experiment #1 methods and Section 2.3 for a description of the analyses. Data were analyzed using PROC GLM of PC SAS™ (SAS Institute, Cary, NC). When significant differences were determined, Tukey's means separation test was performed. This test indicates which treatment means are significantly different from the others. Data were then compiled in graphical or tabular format using letters to designate treatment means that were statistically different, i.e. data points associated with the same letter are not different, those with different letters are statistically different.

2.5.3 Experiment 3 - Simulation of contaminated irrigation application to actively growing cranberries.

A third greenhouse study in which all irrigation contained the test salt treatments was conducted. In April 2002, plants were established in 4" pots of sand in the greenhouse as described for experiment #1 and were fertilized periodically with fertilizers containing no Na or Cl. Plants were moved out from the automated watering system in the third week of July 2002 and assigned to randomized blocks. Each block consisted of one tray per treatment containing eight pots with four plants per pot. There were five replicate blocks and a total of 40 trays. Once treatment blocks were established, all irrigation was supplied using watering cans containing the appropriate salt solution or water (see photo to the right). Solutions were made using greenhouse tap water and this same water source was used for the control. The treatments are shown in Table 8. Trays were watered daily or every other day to maintain even moisture. For each watering event, the volume of solution applied to each tray was the same. However, the volume used for a given day was adjusted, as needed depending on environmental conditions and varied from 800 to 1600 ml per tray during the summer.


Applying contaminated irrigation treatments.

Table 8. Treatments for experiment #3. All watering was with the treatment solutions.

Treatment salt	Salt concentration
None - water control	0
NaCl	50 mg/L Cl; 32 mg/L Na
NaCl	100 mg/L Cl; 65 mg/L Na
NaCl	250 mg/L Cl; 162 mg/L Na
KCl	100 mg/L Cl
KCl	250 mg/L Cl
Na_2SO_4	65 mg/L Na
Na_2SO_4	162 mg/L Na

After three months, all runners were removed from each tray to form a composite runner sample for each replicate of each treatment. These samples were dried, weighed, ground, and sent for mineral analysis as previously described. After runner removal, the trays were moved outdoors for one month during which time, treatments continued. The trays were then moved into a cold-frame glasshouse to complete chilling. Watering was as needed, continuing to use the treatment solutions. In February 2003, after chilling was complete, the trays were returned to the greenhouse where they flowered and set some fruit. Flowering and fruiting were observed and recorded. Runners were removed and processed in June 2003 using the same method as in the previous October. Treatments continued until October 2003, at which time the plants were destructively harvested and analyzed as previously described. Prior to washing the soil from the plants, aliquots of soil from were collected from each pot sent to Midwest Laboratories to be analyzed for mineral content and conductivity using standard methods (see Section 2.3). Data were analyzed and reported as in Experiment #2.

Soil-free culture studies

In the field, the amount of salt ions that cranberry roots actually contact is attenuated by soil. Thus, it can be hard to differentiate between soil and plant effects. Soil-less culture techniques offer the ability to grow plants while minimizing soil effects. Two culture techniques were used in this project, hydroponics and aeroponics. In hydroponics, plants are grown in aerated water to which nutrient salts have been added to provide elements that are essential for growth. In this technique the solution interacts with the plant and the concentration of ions declines over time as they are assimilated by plant roots. Solution pH tends to drop over time. While this method offers imperfect control of concentration over time, it is inexpensive and rapid, allowing the screening of a range of salt concentrations. Hydroponic culture was used to determine that concentrations of >500 ppm Na or Cl negatively affected cranberries in hydroponics. This provided a starting point for the more definitive aeroponics studies.

In aeroponics a nutrient solution is intermittently sprayed on the roots. This approach almost completely eliminates soil chemistry factors. However, this method was limited to a smaller number of treatment/replicate combinations based on available equipment. Plants are suspended in buckets enclosed in wooded boxes. The boxes are climate controlled so that a differential is maintained between root and shoot temperature, simulating field conditions. Based on the results of hydroponic studies, aeroponic studies were designed to examine the 500 and 100 ppm concentrations of Na and Cl.

Cuttings of 'Stevens' cranberry vines were collected from the field for these experiments. Stevens is the most commonly grown hybrid cranberry cultivar in North America. Leaves were removed from the cuttings and the cuttings were incubated in aerated water to induce rooting. Once the cuttings produced roots they were transferred to the hydroponics or aeroponics system. Four plants were suspended in each bucket and the vines held in place with split sponge rubber stoppers for either system.

2.5.4 Experiment 4 - Hydroponics experiments

The purpose of the hydroponics studies was to establish sublethal ranges for both sodium and chloride. These concentrations could then be used in aeroponics to study exposure over time. In the hydroponics system the plant roots were dangled into pots of nutrient solution.

Sodium studies

Rooted cranberry plants were placed in a hydroponics system containing nutrient solution (see Appendix 1). After 6 weeks, Na was added at concentrations from 0 to 1500 ppm (0, 50, 100, and additional 100 ppm intervals to 1500 ppm). At the end of eight weeks of sodium exposure, the plants were harvested, separated into tops and roots, and dried in a forced air oven at 45°C. After drying, plants were ground to pass 40 mesh and analyzed for concentration of sodium by ICP spectrometry. Methods were standard for the University of Wisconsin analytical laboratory (see Section 2.3).

Chloride studies

After 6 weeks in hydroponics in nutrient solution (Appendix 1), rooted cranberry cuttings were exposed to nutrient solutions containing six different concentrations of Cl (250, 500, 750, 1000, 2000, 2500 ppm). Each pot contained four rooted cuttings, with two pots per Cl treatment. Two control pots continued to receive standard nutrient solution. Four compounds, KCl, NH_4Cl, $MgCl_2$, and $CaCl_2$, were used to elevate chloride to the appropriate levels, depending upon their relative percentage of Cl per molecule (Table 9). To avoid any interference, very little Na was used. NH_4 as an anion was carefully added as a Cl carrier to avoid any excess nitrogen that might skew normal growth. Plants were allowed to grow for six weeks in the Cl-containing solutions at which time they were harvested, dried, weighed, and ground for analysis of Cl using a chloridometer (see Section 2.3 for methods).

Table 9. Chloride salts used for hydroponic experiment.

Concentration	Solutions used
200 mg/L	6.4 ml $CaCl_2$ (140 mg/L), 9.6 ml KCl (106.5 mg/L)
500 mg/L	6.4 ml NH_4Cl (141.8 mg/L), 6.4 ml $CaCl_2$ (140 mg/L), 12.8 ml $MgCl_2$ (283.5 mg/L)
750 mg/L	6.4 ml NH_4Cl (141.8 mg/L), 6.4 ml $CaCl_2$ (140 mg/L), 12.8 ml $MgCl_2$ (283.5 mg/L), 23 ml KCl (256 v)
1000 mg/L	9.6 ml $CaCl_2$ (210 mg/L), 12.8 ml $MgCl_2$ (283.5 mg/L), 9.6 ml NH_4Cl (106.35 mg/L), 36 ml KCl (400 mg/L)
2000 mg/L	12.8 $CaCl_2$ (280 mg/L), 12.8 $MgCl_2$ (283.56 mg/L), 9.6 ml NH_4Cl (106.35 mg/L), 119.8 ml KCl (1330 mg/L)
2500 mg/L	16 ml $CaCl_2$ (350 mg/L), 16 ml $MgCl_2$ (354 mg/L), 9.6 ml NH_4Cl (106.35 mg/L), 152.3 ml KCl (1690 mg/L)

Calcium Magnesium Acetate study

A hydroponics experiment with Calcium Magnesium Acetate (CMA) at 100 ppm in standard nutrient solution (Appendix 1) was established. The commercial CMA product was not used because it contained clay and other binding material that prevented keeping it in solution. Based on information provided by the manufacturer, and using reagent grade materials, a solution was produced with the approximate formulation of $Ca_3Mg_7(C_2H_3O_2)_{20}$. This was added to the hydroponic nutrient solution to give a final concentrations from 100 to 1600 ppm CMA. This study was discontinued after five days due to extremely adverse reaction of the cranberry plants to direct CMA exposure.

2.5.5 Experiment 5 - Aeroponics experiments

In aeroponics, a nutrient solution is sprayed on the cranberry roots intermittently so the ionic concentration is constant and the solution pH is constant. After rooting in aerated water, cuttings were grown for about eight weeks in aeroponics with normal nutrient solution (Appendix 1) to provide sufficient tissue for analysis (see photos below). The roots are sprayed with nutrient solution for two seconds every 15 minutes resulting in the application of 3 ml solution per bucket each 15 minutes (Peterson and Krueger, 1988). Once the plants were well established, treatment salts were added to the nutrient solution in half of the buckets, the other half served as untreated controls. Na was examined separately from Cl and conversely using Na_2SO_4 or KCl. After the treatments were applied, three-two plant replicate samples were harvested periodically. The plants were separated into tops and roots, roots were quickly rinsed in deionized water, shoots and roots were dried, and dry weight measured. The tissue was then analyzed for Na or Cl content, by ICP and chloridometer, respectively.


Aeroponics setup.


Plants growing in aeroponics


Mister in bottom of aeroponics container.

Based on the results of hydroponic experiments, 500 ppm Na or Cl concentrations were studied in aeroponics. To follow-up on results from the greenhouse studies, aeroponics experiments at the 100 ppm concentration of Na or Cl were also conducted.

2.6 Phase II – Effects on Soil Chemistry

2.6.1 Experiment 6 - Absorption/desorption study - mineral salts.

Salt loading could shift the chemistry of the soil in such a way as to create an unfavorable environment for cranberry growth and development. Understanding the impact of loading of salt or salt components can establish benchmark levels to be used in monitoring soil quality.

Cranberries in Massachusetts are grown predominantly on soils where the top 8-12" is comprised of sand or layered sand and organic matter resulting from the cultural practice of sanding (Davenport and DeMoranville, 1993). Previous research has shown that soil organic matter content can influence the plant response to salt impact (Chandler and Demoranville, 1959). To encompass the array of soil organic matters expected in layered soils, both a medium and low organic layered soil was collected. Additionally, since planting into sand is the current trend in Massachusetts, a straight sand was also collected. All soils were collected in Massachusetts and shipped to Washington State University (WSU) for study.

To determine the loading levels of salt and salt components, soil studies were established to study both sorption and desorption of Na, Cl, NaCl, $CaCl_2$, and high electrical conductivity (EC). The three Massachusetts soils were analyzed for baseline soil pH (1:1 water:soil v:w basis), EC (Rhoades, 1996), cation exchange capacity (Sumner and Miller, 1996) and organic carbon content (Ben-Dor and Banin, 1989). Baseline soil pH and organic carbon are listed in Table 10.

Table 10. Baseline soil pH and organic carbon content for 3 soils, average of 4 values.

	Soil pH	% Organic Carbon
High Organic Matter Soil	5.73	3.735
Low Organic Matter Soil	6.43	0.908
Sand Soil	6.7	0.834

Bottles for sorption experiment

Filtering extract after sorption.

Field moist soils were weighed and 100 g aliquots were placed in 250 ml brown glass bottles. Solutions of known concentrations of salt (see Table 11) were added to each bottle (see photo to the right). The loading rates were based on 0, 250, 500, 1000, and 2500 mg Cl/L or the equivalent concentration of Na in the NaCl treatment. Soils were allowed to sorp the salt solutions for 1 week, 2 week, 1 month, or 2 month durations, after which the supernatant was extracted by filtration and replaced by deionized water. A one week period for desorption into the deionized water followed. All treatment combinations were replicated three times. The soil solution was extracted by filtration again after desorption (see photo to the left. Extracts were analyzed for Na and Cl. At experiment end, soils were analyzed for pH, EC, and the cation (potassium (K), calcium (Ca), magnesium (Mg), and sodium) and Cl content at WSU or by Midwest

Laboratories using standard methods (see Section 2.3). Statistical analysis was conducted using PROC GLM of PC SAS™ (SAS Institute, Cary, NC).

Table 11. Amount salt used (g) per 1 L to make sorption solutions.

Equivalent Cl (mg/L)	250	500	1000	2500
NaCl	0.4121	0.8243	1.6485	4.1213
Na_2SO_4	0.5008	1.0018	2.0034	5.0086
KCl	0.5258	1.0515	2.1031	5.2577
$CaCl_2$	0.3913	0.7826	1.5653	3.9133
$MgSO_4$ (conductivity equivalent)	0.617	1.287	2.628	6.651

2.6.2 Experiment 7 - Absorption/desorption study - CMA.

To examine the effects of the road salt alternate material CMA on cranberry soil chemistry, CMA was added to the same sand and a similar low organic matter cranberry soil as was used for the previous sorption/desorption studies. CMA was applied to reach rates equivalent to 0, 250, 500, 1000, or 2500 ppm Cl-equivalent rates of Ca and Mg used for $CaCl_2$ and $MgSO_4$ in the previous study. This resulted in adding 0, 0.037, 0.078, 0.153, or 0.0385 g of commercial CMA to 100 g of soil for each rate, respectively.

Field moist soils were weighed, 100 g aliquots were placed in 250 mL brown glass bottles, and CMA was added to each bottle as per treatment protocol. Soils were allowed to sorp the salt solution for one week, two weeks, or four weeks after which the supernatant was extracted by filtration and replaced by deionized water. A one week period for desorption into the deionized water followed. All treatment combinations were replicated three times. The soil solution was extracted by filtration again after desorption. Sorption and desorption extracts were analyzed for Na and Cl. Soils were then chemically extracted and analyzed for pH, EC, and the cation (K, Mg, Ca, Na) and Cl content. Statistical analysis was conducted using PROC GLM of PC SAS™ (SAS Institute, Cary, NC). Results from the main effect of salt rate were presented as few significant differences were related to soil type or sorption time.

2.6.3 Experiment 8 - Remediation study.

Soils, which have been characterized as having salt levels beyond those acceptable to cranberry production, are likely to require some type of remediation. In saline-sodic soils in arid regions of North America, either gypsum, calcium chloride or sulfur, plus leaching have been used in combination to remediate affected soils (Troeh et al., 1980). As cranberries grow in a higher precipitation areas, natural rainfall would help ameliorate a saline or sodic situation. However, in a severe situation, additional remediation may be needed.

The soil amendments used in saline-sodic soil remediation in western North America contain calcium chloride, sulfur, or calcium sulfate (gypsum) (Troeh et al., 1980). The purpose of the sulfur is to help shift the cation complex to hydrogen ions, driving away the sodium. The calcium based materials work in the same manner, but with calcium rather than hydrogen ion saturation of the soil cation exchange complex.

Use of sulfur as a soil amendment is not uncommon in cranberry production. However, research has shown that use of sulfur on wet soils will cause plant phytotoxicity (Sandler et al., 1996), which is not an issue in saline-sodic soil recovery as the remediation is conducted in the absence of living plants. Due to the acidic nature of cranberry soils, high doses of calcium sulfate are not recommended, however, beds are routinely fertilized with the fertilizer known as Sul-Po-Mag (DeMoranville, 1996), which can be described chemically as $KMgSO_4$. Additionally, work on blueberry, also in the genus Vaccinium, has shown that low Ca is more effective at ameliorating the effects of Na than is high Ca (Wright, et al., 1993). A soil amendment of 25% calcium sulfate (gypsum) and 75% potassium/magnesium sulfate (Sul-Po-Mag) would most closely estimate the needed replacement cations and anions (DeMoranville, 1996) for remediation from NaCl injury in a cranberry soil.

Three soils were collected in Massachusetts from cranberry bogs with high organic matter content, low organic matter content, and a sand soil (see sorption study above). The high and low organic matter soils were collected as intact blocks. Soils were chemically characterized for initial soil pH, % organic carbon, cation exchange capacity, concentration of the cations K, Mg, Ca, and Na, and soil EC using standard methods (see Research Plan section).

Leaching columns were made from 2- inch diameter 1/8 inch thick PVC cut to 10 inch lengths. Each column was cut in half lengthwise to allow insertion of intact soil cores. For the sand, a known mass of soil was packed to an 8 inch depth in each core. For the low and high organic matter soils, intact cores were punched from the soil blocks and slid into one half of the column. The columns were caulked with adhesive silicon, fitted with a one hole rubber stopper with a Whatman 42 filter paper between the stopper and the soil to prevent soil movement, and finally tightened using two hose clamps per column. Each column was placed in a known location in a rack designed specifically for this experiment. The three photos below show the experimental setup.


Setting up soil columns for mitigation study


Leaching from columns after treatment (mitigation)


Panoramic view of leaching - mitigation study

NaCl was surface applied to columns of each soil type to give six concentrations: 0, 250, 500, 1000, 2500, and 5000 mg Cl/L soil. Each salt treatment was replicated three times per soil. After the NaCl treatments, the soils were watered with 1/2 pore volume of deionized water and allowed to sit for one week to move the salt throughout the soil.

After NaCl contamination treatment, the soils were treated with one of five possible remediation treatments:

1) 2 pore volume leaching, simulating a single flood event;
2) 25% gypsum/75% Sul-Po-Mag blend at 2 ton/a plus a constant rate leaching with the seasonal equivalent of irrigation plus rainfall of 10 in per growing season (Davenport et al., 1994);
3) Gypsum/Sul-Po-Mag at 2 ton/a plus the two pore volume displacement simulated flood (combination of 1 and 2);
4) Gypsum/Sul-Po-Mag at 2 ton/a followed by the equivalent of twice seasonal water, 20 in;
5) Gypsum/Sul-Po-Mag at the lower rate of 500 lb/a followed by seasonal water, 10 in.

Total Na, Ca, Mg, K and Cl, were determined in the leachate water and after leaching, soils were analyzed for Na, K, Ca, Mg, Cl, EC and pH by Midwest Laboratories using standard methods as previously described. To best accommodate available space, each remediation treatment was conducted separately and sequentially.

2.6.4 Experiment 9 - Monitoring of a cranberry bog that receives direct road runoff.

Two areas that receive direct road runoff were monitored at a commercial bog owned by Lydia and Barry Mathias, along Route 106 in Kingston, Massachusetts. Two areas along Route 106 drain onto the Mathias property. The east area drains through a culvert directly into a perimeter bog ditch. The bog area adjacent to this outflow shows extensive die-back in the planting. In the west area, the road drains onto the land surrounding the bog and infiltrates into the ground. Drainage puddles in an area adjacent to the bog but does not appear to run directly into the perimeter ditch. Maps of the area, including sampling locations, are shown in Figures 44 through 46.

Soil samples were collected along transects beginning near the road, crossing through the drainage ditch along the bog edge, and out into the bog itself. Samples were also collected at the opposite end of the bog system to serve as controls. Samples collected from the East field direct discharge area were designated samples A through X, while those collected from the indirect discharge area at the West field were designated samples 1 through 15. Field sampling began in Spring of 2001. Additional samples were collected Fall 2002, Spring and Fall 2003, and Spring and Fall 2004. Samples were sent to Midwest Laboratories and analyzed for standard minerals plus Na, Cl and conductivity (see Section 2.3).

2.6.5 Experiment 10 - Field remediation experiment

A field experiment was established in the area of dying vines at the Mathias site East field. An area was marked out in 4 x 4 meter plots (Figure 58). Treatments were each applied to six replicate plots in a completely randomized design. There were four treatments: an untreated control, and rates of fertilizer of 250, 500, and 1000 lbs/acre. The fertilizer was a 3:1 mixture of SulPoMag and gypsum -- similar to that used in the laboratory remediation study. The rates were chosen to bracket at one-half times and two times the 500 lbs/acre low rate treatment from the laboratory study. Prior to treatment in June 2003, soil samples were collected from each plot. Soil was re-sampled after two months (August 2003), prior to the winter flood (November 2003) and in the spring of 2004, 11 months after treatment. Soil samples were analyzed for cations and Cl using standard methods as previously described. Recovery, based on percent vine cover, was assessed in September 2004.

3.0 Research Results

3.1 Phase I - Effects on Plant Growth & Yield

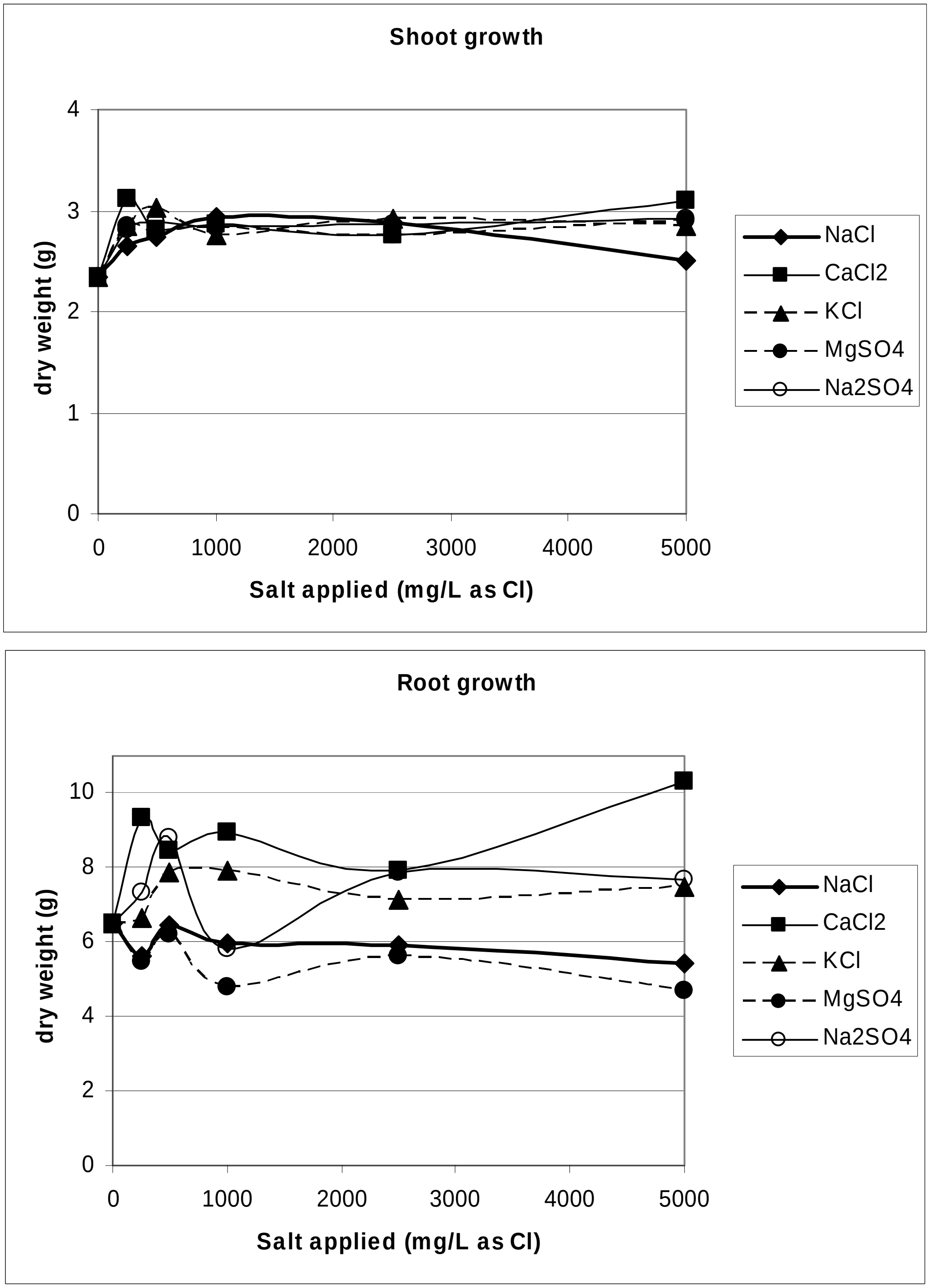
3.1.1 Experiment 1 - Frequency, rate, and method of salt application effect on actively growing cranberries.

The initial greenhouse experiment compared salts, rates, timing (intensity), and application methods. During the course of the treatments, various symptoms were noted on salt-treated cranberry plants. These included red spotting of leaves (see photo below), abnormal runner growth, 'brittleness' of shoots, and yellowing.

Foliar symptoms - 625 ppm NaCl

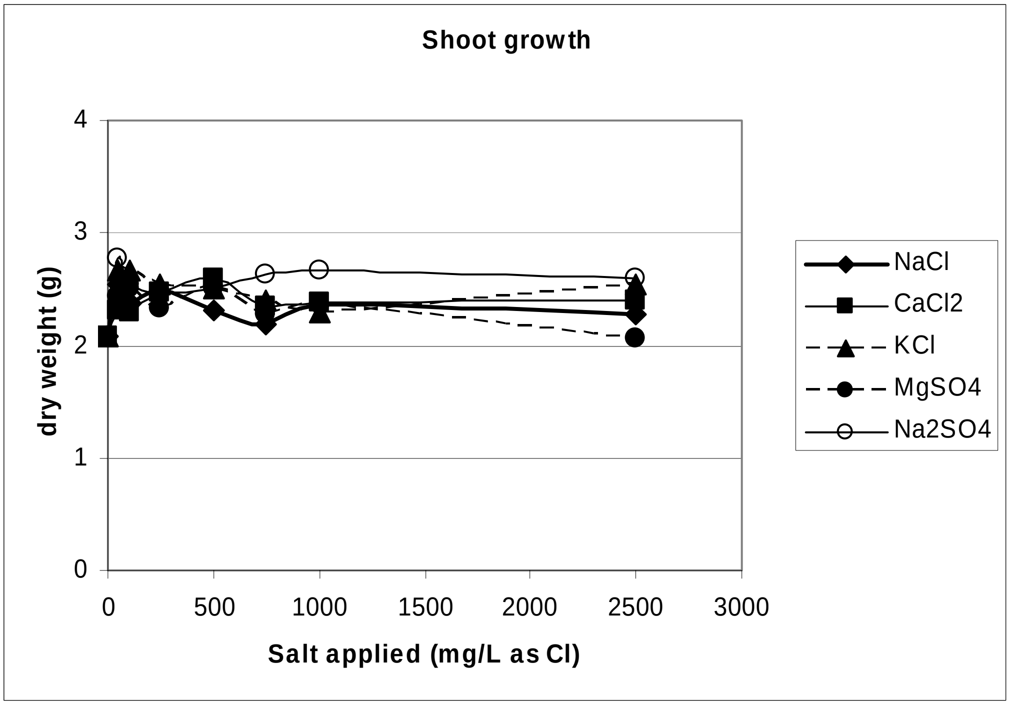
After 16 weeks, plants were removed from the soil, separated into shoots and roots, dried and weighed. The weight results for the three timings are shown in Figures 1-3. Statistical analysis showed no significant effect of application method (spray vs. drench) for any timing so those data were combined for each frequency group. A single acute high concentration application of salt at week 1, simulating a single overspray event, had little effect on plant growth after 16 weeks (Figure 1). The root data showed more variability with salt and concentration but differences were not statistically significant. It should be noted that since the plants were in a mist bed, the soil was flushed extensively and this may have mitigated any impact of the single high-concentration salt applications.

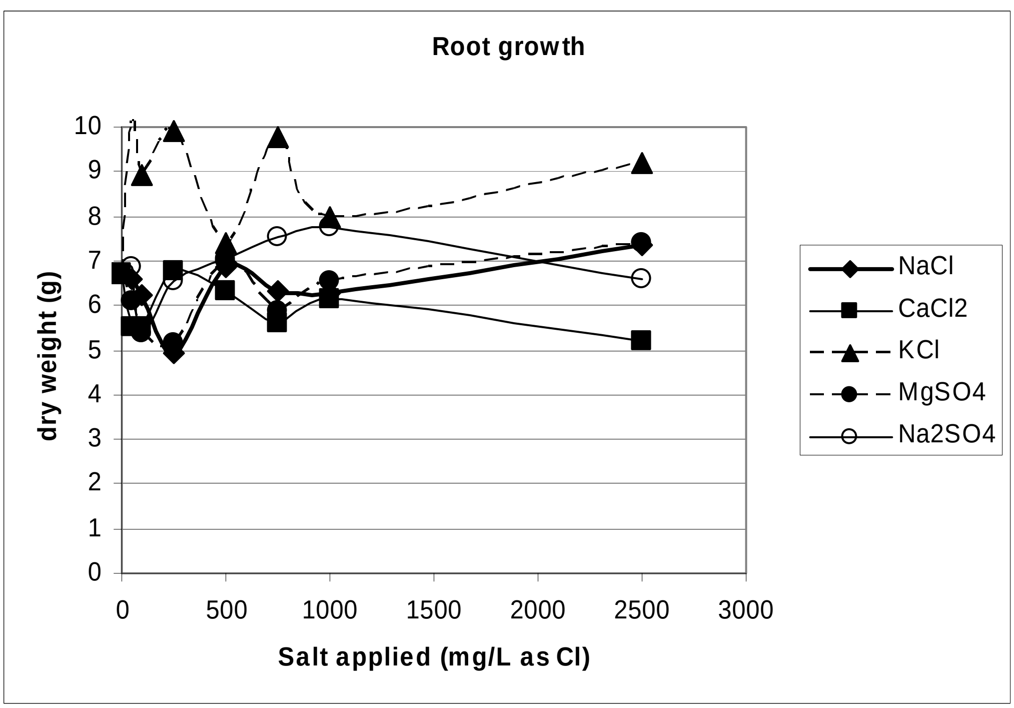
Figure 1. Effects of a single, acute salt exposure on cranberry shoot (top) and root (bottom) growth. Evaluation 16 weeks after treatment.



Similarly to the acute treatments, intermittent application of moderately high rates of salt did not impact cranberry shoot growth after 16 weeks (Figure 2). Plants receiving high concentrations of $CaCl_2$ had the poorest root growth. However, exposures to such high concentrations of salt would be expected to be rare in field situations.

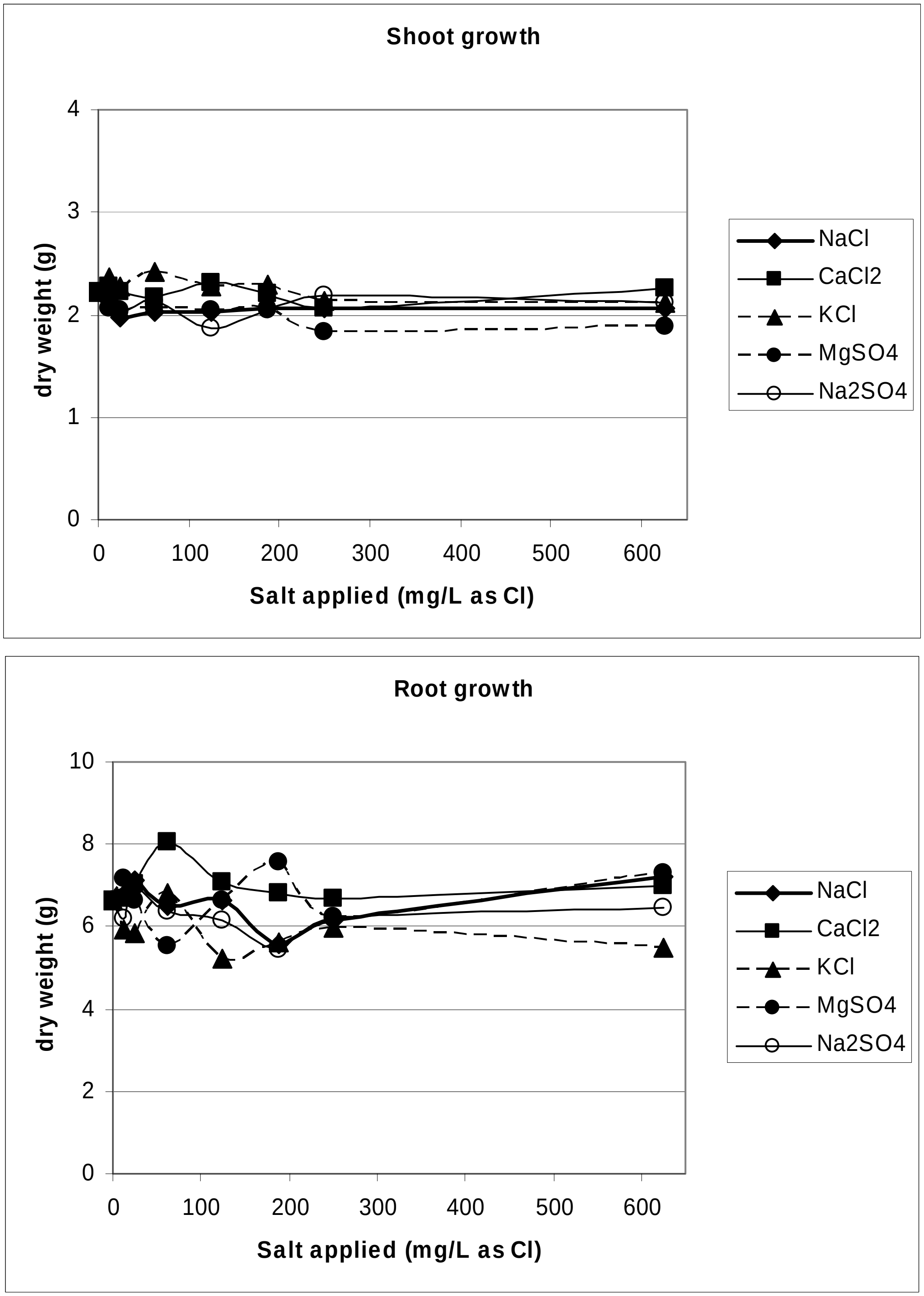
Figure 2. Effect of intermittent salt exposure on cranberry shoot (top) and root (bottom) growth. Salt was applied every other week and growth was evaluated after 16 weeks.





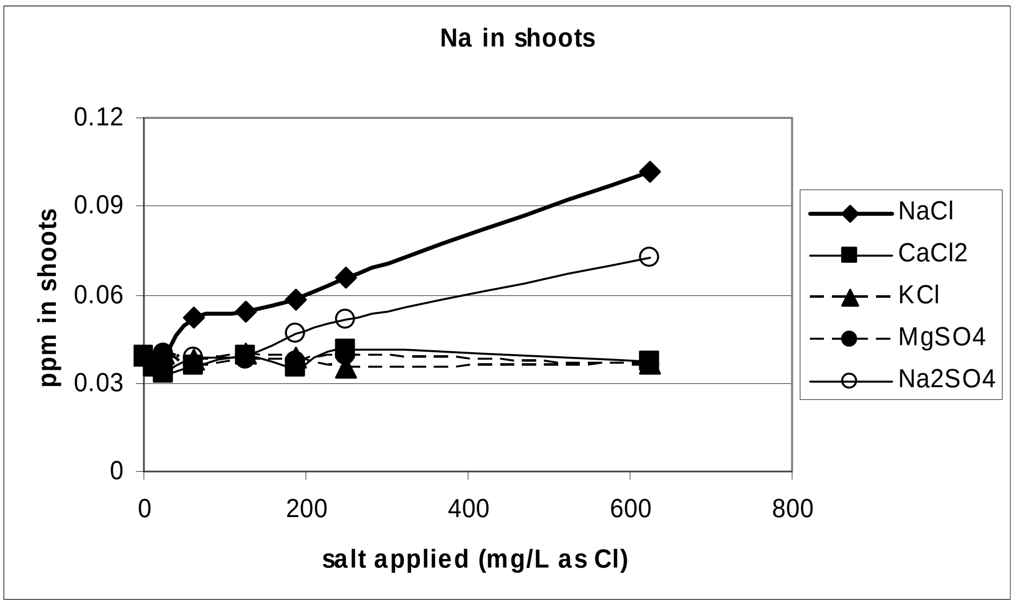
After 16 weeks of twice weekly salt applications at low rates, growth of roots and shoots was unaffected (Figure 3). However, since this is the most likely exposure modality in a field situation with a contaminated water supply, the mineral content of shoots and roots from two randomly selected replicates of the chronic treatments was examined.

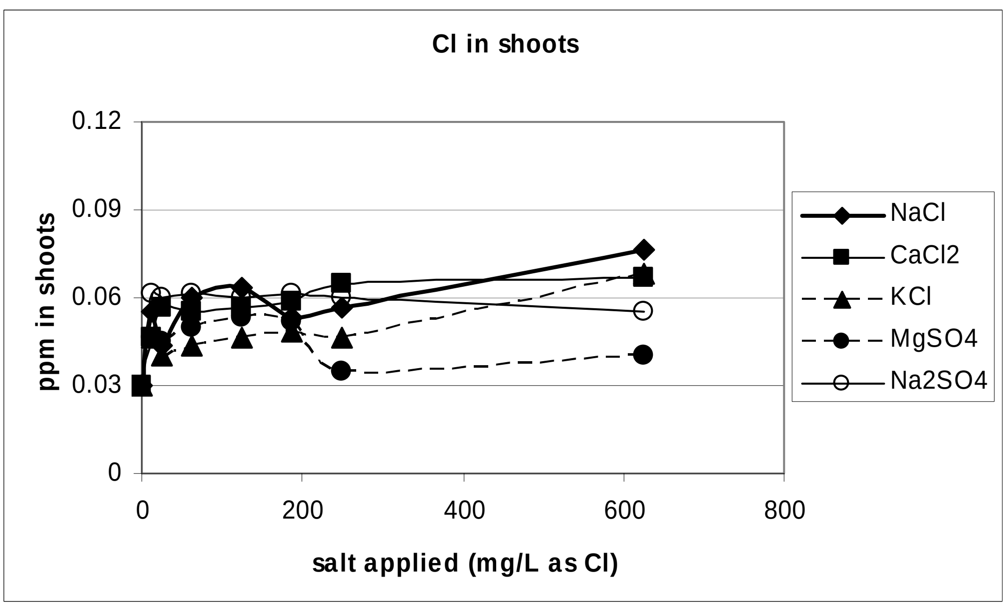
Figure 3. Effect of chronic exposure to salt on cranberry shoot (top) and root (bottom) growth. Salt was applied twice weekly and growth was evaluated after 16 weeks.



Figures 4 and 5 show the data for Na and Cl in shoots and roots of plants exposed to salt twice weekly for 16 weeks. In comparison to the zero-salt control plants, both sodium salts (NaCl and Na_2SO_4) were associated with elevated Na in shoots at the 625 ppm concentration, with moderate elevation at 250 ppm NaCl (Figure 4 top). To a lesser extent, root Na was also elevated in plants receiving 625 ppm NaCl or Na_2SO_4 compared to that in roots of plants receiving no salt.

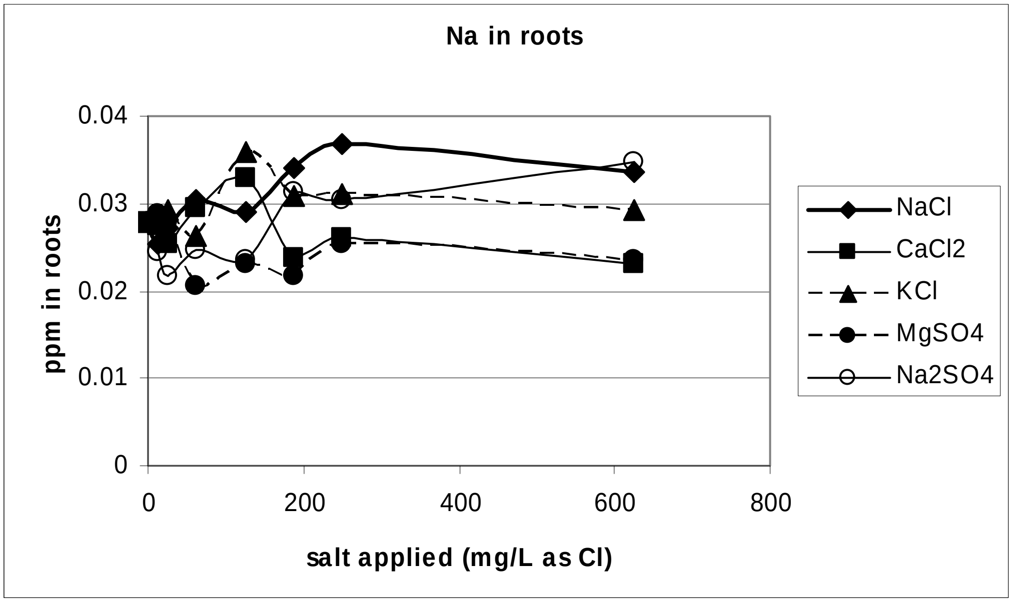
Figure 4. Na (top) and Cl (bottom) in shoots of cranberry plants after receiving chronic, twice weekly salt exposure for 16 weeks. See Figure 3 for growth data.

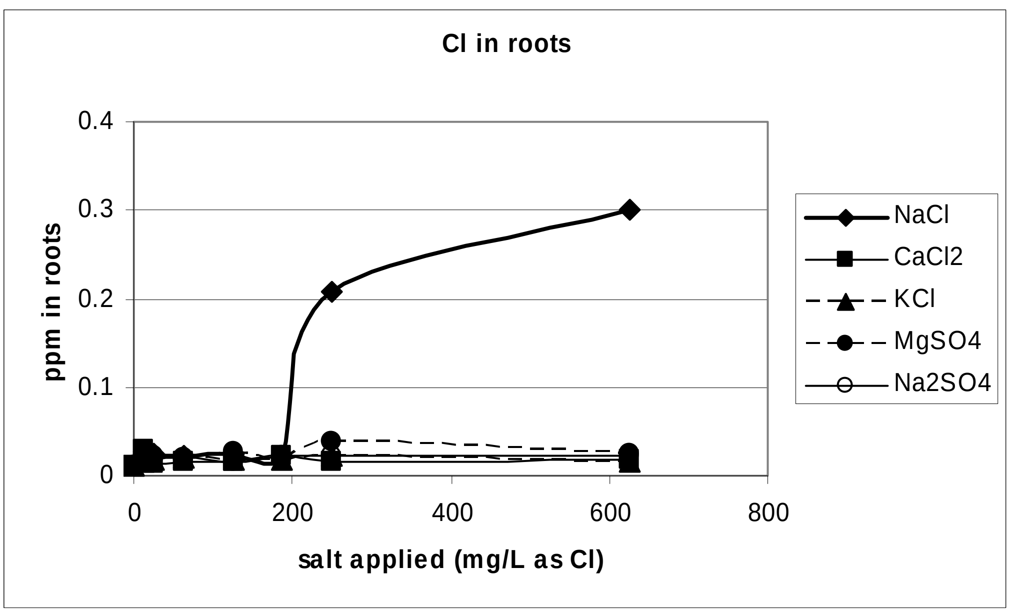




NaCl at 625 ppm increased shoot Cl compared to the untreated control as did the other Cl-containing salts to a lesser degree (Figure 4, bottom). NaCl was associated with extremely elevated Cl in roots at the 250 and 625 ppm concentrations (Figure 5, bottom). Since Cl elevation in the shoots of these plants was modest, it is possible that the cranberry plants sequestered Cl in their roots or on the root surface. It is not clear why root Cl was not elevated by treatment with $CaCl_2$ or KCl.

Figure 5. Na (top) and Cl (bottom) in roots of cranberry plants after receiving chronic, twice weekly salt exposure for 16 weeks. See Figure 3 for growth data.





To summarize, cranberries were quite tolerant of occasional acute salt exposures as long as soil flushing was present. In the field, this would be accomplished by rainfall or irrigation. During chronic exposures to low concentrations of salt, cranberry growth was unaffected when soil flushing was present. However, chronic exposures to NaCl at 625 ppm Cl were associated with elevated Na and Cl in the shoots and extremely elevated Cl in the roots. It would be expected that elevated Na and Cl would eventually lead to measurable adverse impacts on the cranberry plants.

Result summary - Experiment 1

When soil flushing is present, cranberry plants appear to tolerate single exposures to salt concentrations as high as 5000 ppm. More frequent exposures to concentrations as high as 2500 ppm also appear to be tolerated with soil flushing. With soil flushing present, chronic exposure to concentrations as high as 625 ppm did not affect cranberry plant growth. However, loading of Na and Cl into the plant tissue was apparent after 16 weeks of treatment as were visible symptoms on the plant foliage (see photo to the right).

Foliar symptoms - 625 ppm NaCl

3.1.2 Experiment 2 - Frequency, rate, and method of salt application effect on actively growing cranberries.

Based on the results of the first greenhouse experiment, the study was repeated with some modifications. The spray/drench combination was eliminated since the data from that treatment in the first experiment were no different than those from the drench-only treatment. Applying soil covers during spray treatments was discontinued in order to eliminate the confounding factor of plant injury during cover manipulations. Other changes included increasing the acute frequency to two applications, eight weeks apart, adding a zero-salt control to each salt/rate series, and using a slow-release fertilizer, containing no Cl, for plant maintenance.

Significant effects on shoot and root growth were found in the second greenhouse experiment. Method of salt application (spray or soil drench) was not significantly different, so method data were combined. There was no significant interaction of salt type and salt concentration, so these significant main effects were looked at separately.

High concentration applications of $CaCl_2$, $MgSO_4$, and Na_2SO_4 every two or eight weeks were associated with decreased root growth compared to that of plants receiving NaCl or KCl. These data are shown in Figures 6 and 7 with the concentration levels combined. Shoot growth did not differ among acute salt treatments. However, in the intermittent treatments, shoot growth was lowest in the plants receiving $MgSO_4$. Differences in growth response to salt concentration in the acute and intermittent treatments were not significant.

During chronic exposures to lower salt concentrations (12.5 - 625 ppm), plants receiving $MgSO_4$ had the greatest root growth compared to the other Na or Cl containing salts, significantly greater than that of plants receiving $CaCl_2$ or KCl (Figure 8). When data for all salts were combined, plants treated with the 250 ppm concentration twice per week showed depressed shoot growth (Figure 9). Interestingly, it appears that growth might be stimulated at lower concentrations, e.g. 125 ppm. It is possible that as salt concentration increases, there is a level at which vegetative growth is stimulated but that as the concentration increases further, toxicity effects lead to suppressed growth.

Figure 6. Effects of acute salt exposure on cranberry growth.
Salt application at weeks 1 and 9, evaluation after 16 weeks. Data for all concentrations combined. Root treatments (striped bars) that do <u>not</u> share a letter differ significantly from other treatments (*P*<0.05, Tukey test for means separation). Shoot differences were not significant.

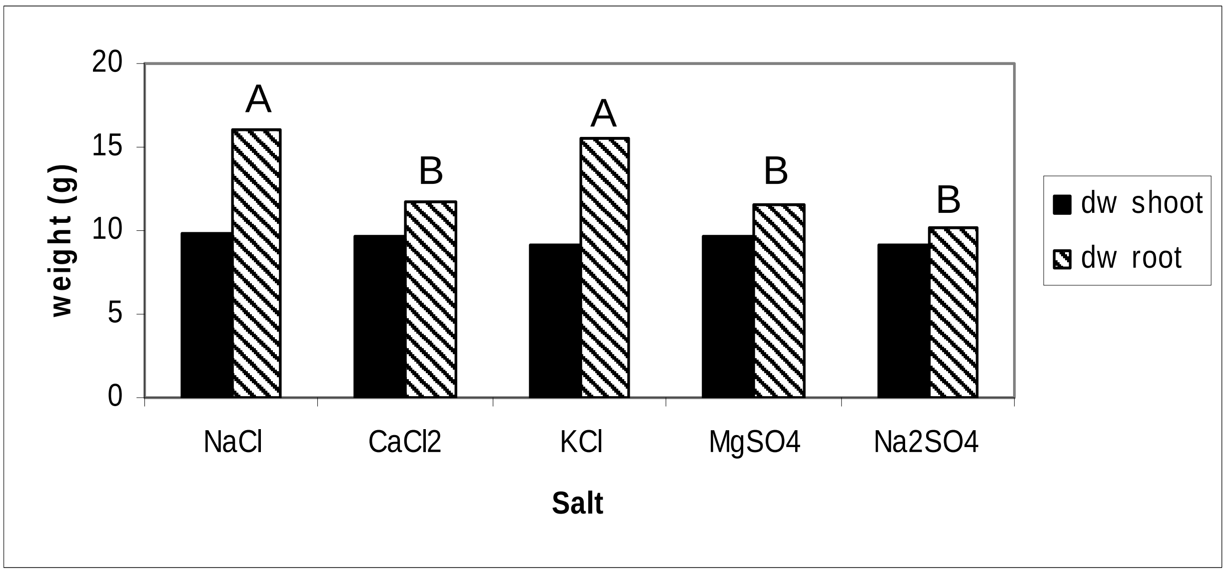


Figure 7. Effects of intermittent salt exposure on cranberry growth.
Salt applications every 2 weeks, evaluation after 16 weeks. Data for all concentrations combined. Data within shoot (solid bars) or root (striped bars) treatments that do <u>not</u> share a letter differ significantly from other treatments (*P*<0.05, Tukey test for means separation).

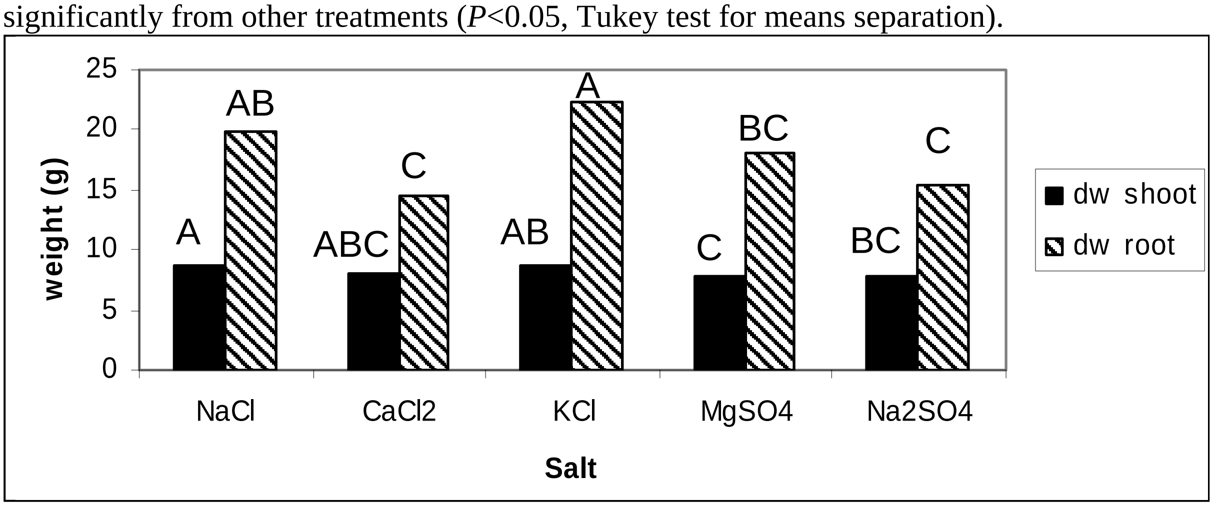


Figure 8. Effects of chronic salt exposure on cranberry growth.
Salt applications twice per week, evaluation after 16 weeks. Data for all concentrations combined. Root treatment data (striped bars) that do not share a letter differ significantly from other treatments (*P*<0.05, Tukey test for means separation). Shoot differences were not significant.

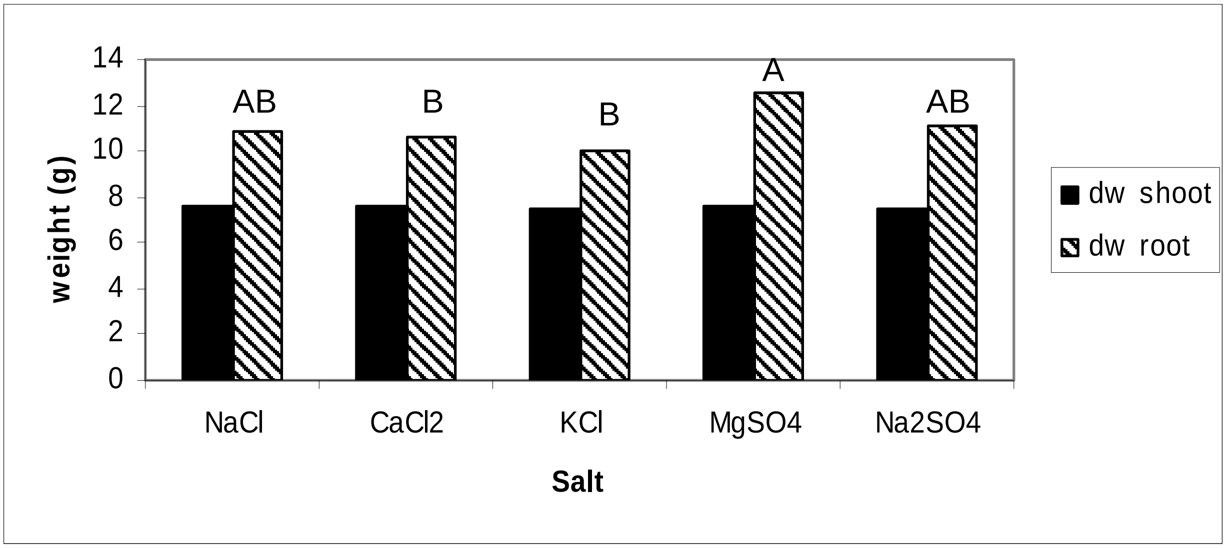
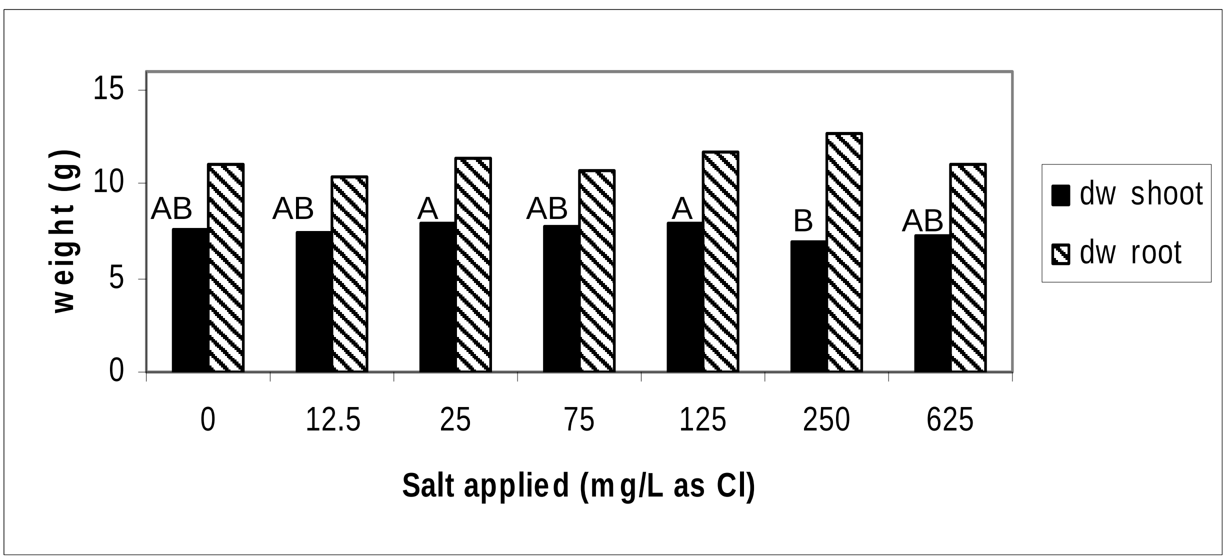
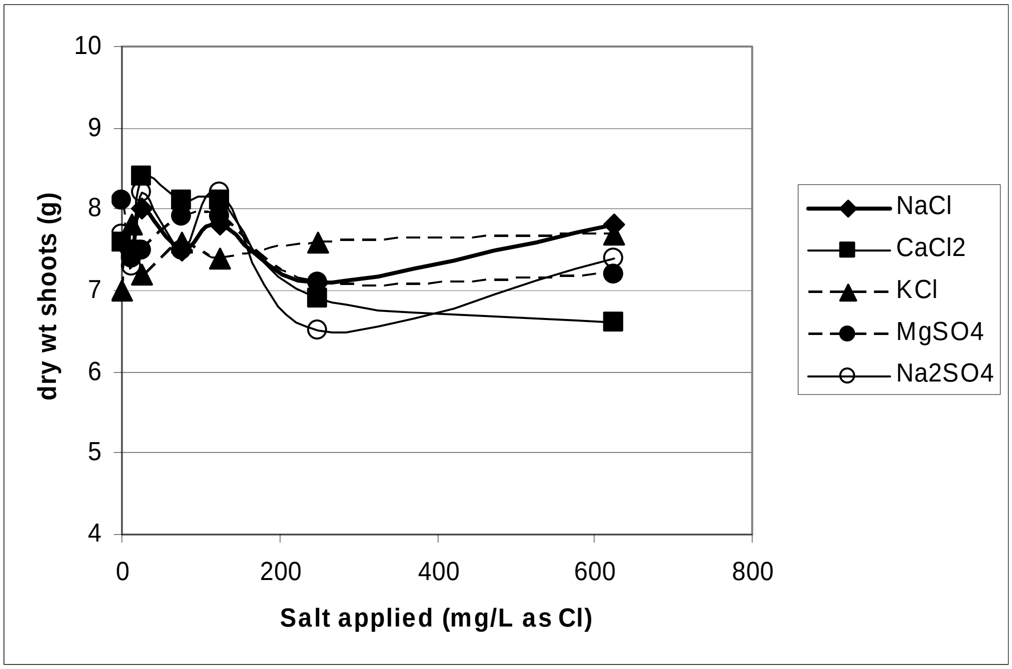


Figure 9. Concentration effects of chronic salt exposure on cranberry growth.
Salt applications twice per week, evaluation after 16 weeks. Data for all salts combined. Shoot treatment data (solid bars) that do not share a letter differ significantly from other treatments (*P*<0.05, Tukey test for means separation). Root data were not significantly different.



When the concentration data for the individual salts were examined, the most negative effects on growth were associated with increasing concentrations of $CaCl_2$, $MgSO_4$, and Na_2SO_4 -- in the chronic exposure treatments, all three showed reduced shoot growth at 250 and 625 ppm compared to the zero-salt rate (Figure 10). Chronic exposure to $CaCl_2$ had a significant negative linear effect on growth - growth decreased as concentration increased. This is particularly apparent at 250 and 625 ppm.

Figure 10. Shoot growth of cranberries exposed to twice weekly salt for 16 weeks. The effect of $CaCl_2$ was significant, with a negative linear relationship with concentration.



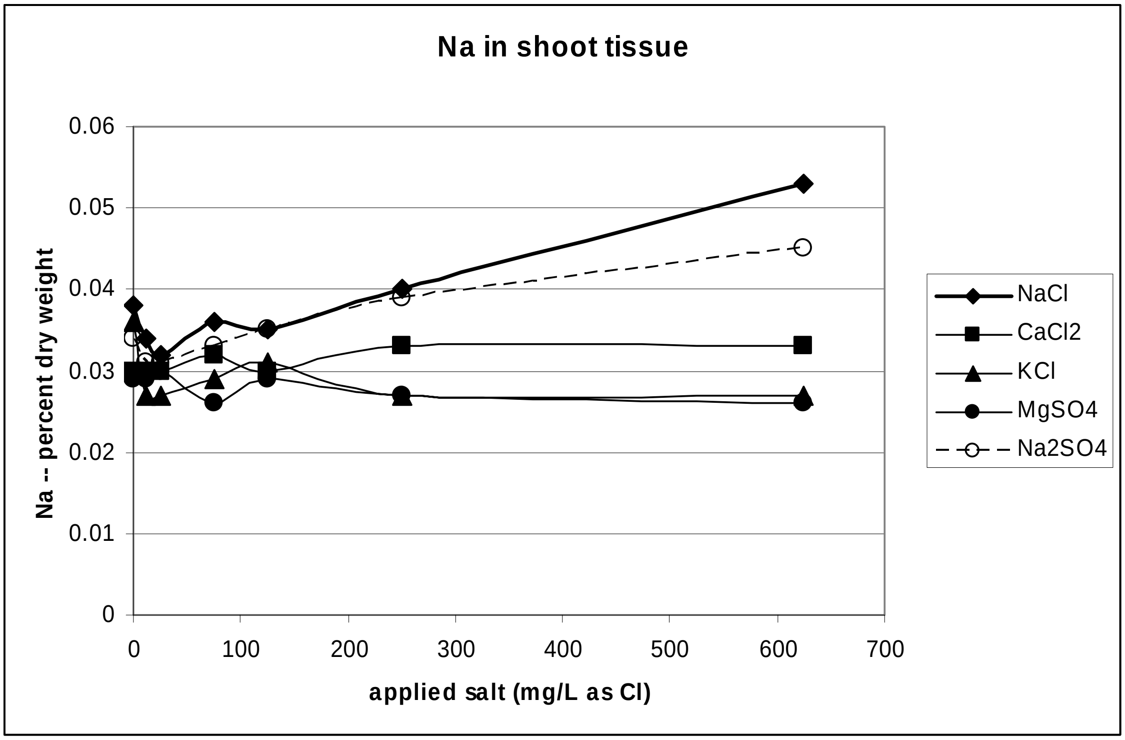
While some were significant, growth effects were minor for the most part. For this reason, only a subset of the plants (two replicates for acute and intermittent treatments, three replicates for chronic) were examined for effects of salt treatments on mineral content of the root and shoot tissue. In the acute treatments (applied weeks one and nine at high concentrations), the only significant effects after 16 weeks were those of increasing concentrations of NaCl, associated with increased shoot tissue Na content, and increasing concentrations of $CaCl_2$, associated with decreased shoot Mg. None of the acute treatments affected tissue Cl. However, as was the case in the first greenhouse experiment, significant flushing occurred due to overhead watering.

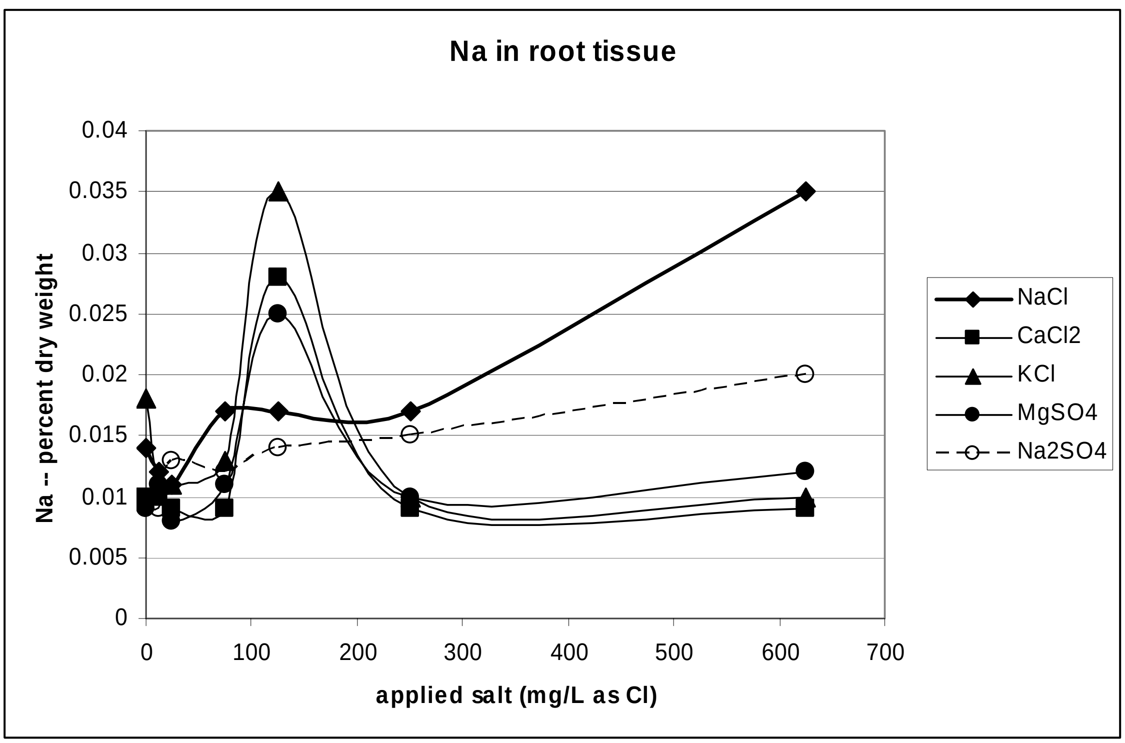
After 16 weeks of intermittent treatment with either sodium salt, Na increased significantly in the shoots with increasing concentration of applied salt. Intermittent NaCl applications also increased root Na and shoot Cl significantly with increasing applied salt concentration.

The twice weekly chronic salt treatments did not affect tissue Cl. However, application of increasing concentration of either Na salt increased shoot and root Na (Figure 11). Additional significant effects included decreased root K with increasing concentration of applied NaCl and decreased shoot Mg with increasing concentration of applied KCl. Increasing concentrations of applied $MgSO_4$ increased shoot Mg.

Figure 11. Na in shoots (top) and roots (bottom) of cranberries after 16 weeks of chronic salt exposure.

Regression analysis showed significant linear trends for NaCl and Na_2SO_4 data.





During this experiment, water that leached through the potted plants due to the overhead irrigation was collected and found to have elevated conductivity. It was apparent that much of the applied salt was being leached away at the next irrigation event. In a field situation with contaminated irrigation a similar situation would exist – periodic exposures to salt during irrigation followed by flushing during rain events. However, the extent of flushing in the greenhouse with daily irrigation is likely much greater than could be expected for normal seasonal rain in the field.

Result summary - Experiment 2

In summary, while there were some differences in cranberry growth response to infrequent (every 2 or 8 weeks) high concentration salt application depending on the type of salt, there was no significant relationship between concentration and response. That is, some salts affected growth but not in a way related to application concentration. In the acute and intermittent treatments, the application of sodium salts generally increased tissue Na content. In the chronic applications, growth was slightly suppressed at the 250 and 625 ppm Cl-equivalent salt rates. This suppression was significantly linear for $CaCl_2$. In chronic exposures, the breakpoint for negative effect on growth occurred between 125 and 250 ppm Cl-equivalent. At these concentrations, tissue Cl was not affected while tissue Na was increased by the Na salts.

Acute exposure twice in 16 weeks, at weeks 1 and 9, to concentrations of salt as high as 7500 ppm had minimal effect on cranberry growth compared to no effect with a single exposure in week 1. Compared to the $MgSO_4$ treatment, intermittent treatment with any salt containing Na or Cl was associated with increased shoot growth. This may indicate a tendency to increased vegetative growth when cranberries are exposed periodically to high concentrations of Na or Cl. Conversely, growth appeared to be slightly suppressed in cranberries receiving chronic exposure to 250 and 625 ppm concentrations of salt but possibly stimulated at 125 ppm. In all application timings, treatment with sodium salts was associated with elevated tissue Na.

3.1.3 Experiment 3 - Simulation of contaminated irrigation application to actively growing cranberries.

Due to continued concerns that flushing with overhead irrigation was obscuring effects in the greenhouse experiments, a third greenhouse experiment was conducted, eliminating overhead irrigation and using salt-containing solutions for all manual irrigation.

This experiment was designed to examine chronic exposure to low level salt contamination, from 0 to 250 mg/L Cl-equivalent. All irrigation was applied using watering cans containing the various treatment solutions beginning in July 2002. In October, all runners were harvested from the plants and the pots were moved to a cold greenhouse for chilling. Runners were weighed and measured. In general, salt exposed plants produced more runners, perhaps a stress response (Table 12). Plants in 3 of 5 replicates receiving 250 mg/L Cl as KCl were extremely affected, with poor growth and yellowing.

Table 12. Effect of chronic salt exposure on cranberry runner growth in pot culture.

Salt treatment	Avg. number of runners	Avg. weight of runners (g)
Control - no salt	18	4.22
50 mg/L Cl as NaCl	19	5.24
100 mg/L Cl as NaCl	16	3.94
250 mg/L Cl as NaCl	21	5.56
100 mg/L Cl as KCl	24	5.61
250 mg/L Cl as KCl	15	2.75
65 mg/L Na as Na_2SO_4	25	6.49
162 mg/L Na as Na_2SO_4	18	5.35

Both KCl treatments resulted in K levels well above the standard range for cranberry tissue (Table 13). However, other cations were not affected, leaving no simple explanation for the visual symptoms in these plants. As one would predict, increasing rates of Na by applying as the chloride or sulfate salt led to increased Na in the runners. Likewise, increased Cl applied as the sodium or potassium salt led to increased Cl in the runner tissue.

Table 13. Effect of chronic salt exposure on mineral content (dry weight basis) in cranberry runners in pot culture.

Salt treatment	% K	% Na	% Cl
Control - no salt	0.81 C*	0.03 E	0.06 CD
50 mg/L Cl as NaCl	0.79 C	0.14 D	0.10 CD
100 mg/L Cl as NaCl	0.72 C	0.23 C	0.13 BCD
250 mg/L Cl as NaCl	0.63 C	0.52 A	0.34 A
100 mg/L Cl as KCl	1.31 B	0.03 E	0.14 BC
250 mg/L Cl as KCl	1.88 A	0.03 E	0.22 B
65 mg/L Na as Na_2SO_4	0.74 C	0.16 D	0.05 D
162 mg/L Na as Na_2SO_4	0.68 C	0.33 B	0.06 D

* Data within columns that do not share a letter differ significantly ($P<0.0001$, Tukey test for means separation).

Following runner removal in the fall of 2002, the plants were subjected to chilling. Once chilling was complete, the plants were returned to the greenhouse and treatments resumed in early 2003. Flowering and fruiting were evaluated, as were leaf symptoms and plant health (Table 14).

Table 14. Effect of chronic salt exposure on cranberry flowering, fruiting, and overall appearance.

Salt treatment	% flowered	# flowers all reps combined	Flowers/ Upright	Mean Fruit Dry Wt Per rep (g)*
Control - no salt	32	325	6.4	1.34
50 mg/L Cl as NaCl	37	249	4.2	0.56
100 mg/L Cl as NaCl	54	460	5.3	1.29
250 mg/L Cl as NaCl	24	141	3.6	0.25
100 mg/L Cl as KCl	32	260	5.1	0.72
250 mg/L Cl as KCl	6	25	2.8	0
65 mg/L Na as Na_2SO_4	33	276	5.3	0.77
162 mg/L Na as Na_2SO_4	42	356	5.3	1.24

*Combined dry weight of fruit from 8 pots in a tray (rep)

Salt treatment	% uprights dead**	% pots with leaf symptoms
Control – no salt	11**	20
50 mg/L Cl as NaCl	8	40
100 mg/L Cl as NaCl	2	40
250 mg/L Cl as NaCl	3	80
100 mg/L Cl as KCl	4	60
250 mg/L Cl as KCl	54	20
65 mg/L Na as Na_2SO_4	16	100
162 mg/L Na as Na_2SO_4	8	40

**some death due to winter injury

Cl seemed to be associated with reduced flowering, at least at 250 ppm (Table 14). Na appeared to have less impact on flowering. Leaf symptoms (reddened leaf tips) were more apparent in all salt treatments compared to controls after this long exposure (see photo to the right). Note that the 250 ppm KCl treatment had few pots with leaf symptoms due to the fact that many uprights were already dead. In fact, the 250 ppm KCl was the only treatment consistently associated with plant death.

Typical leaf symptom in contaminated irrigation study.

In the summer of 2003, runners were once again removed, dried, and weighed. In the fall, the plants were destructively harvested and separated into shoots and roots for weighing and mineral analysis. Overall, due to variability, growth effects were not statistically significant with the exception of the 250 ppm KCl treatment. However, an examination of the data shows that increased above-ground growth, particularly of runners, occurred with salt contamination (Figures 12 and 13).

Figure 12. Final dry weights of shoots and roots from cranberry plants irrigated with salt solutions.

Each data point represents the average of 40 pots (8 pots per replicate, 5 replicates). Runner weights not included.

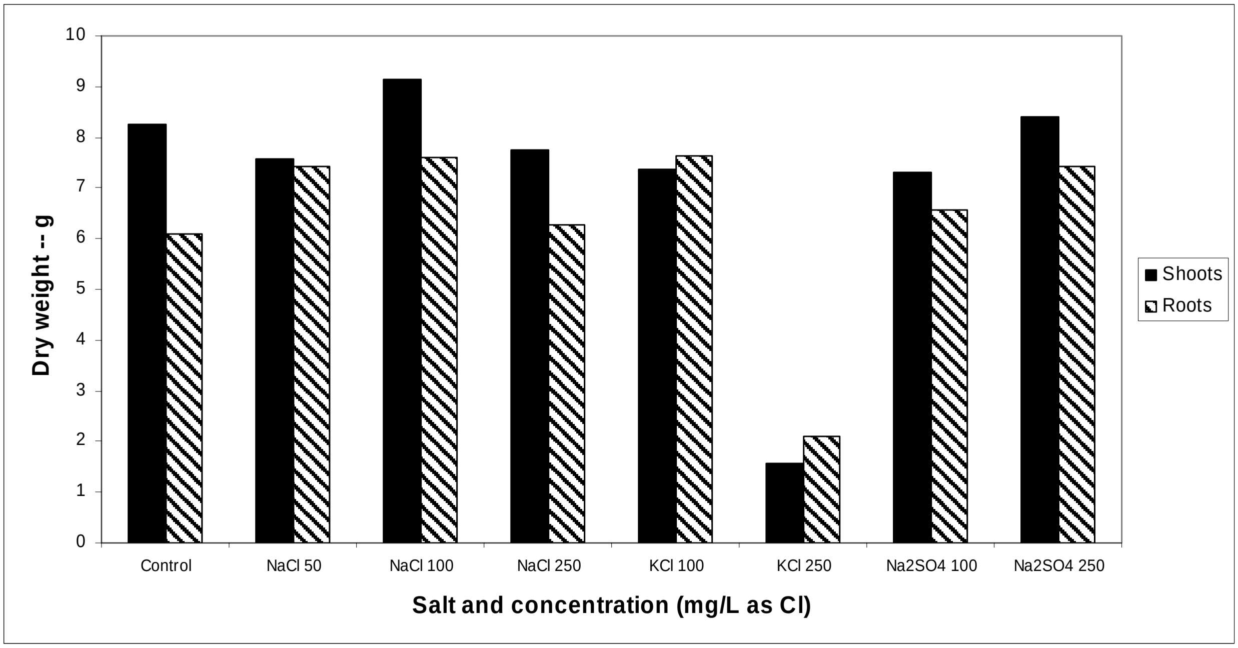
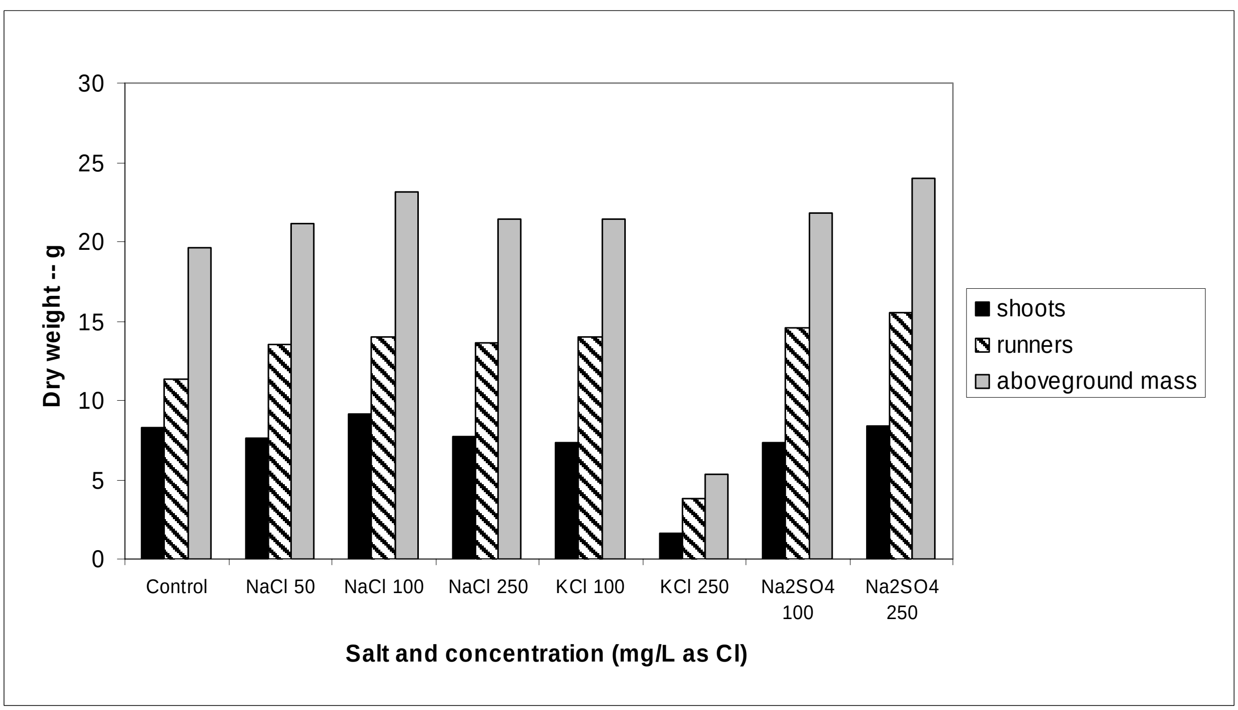


Figure 13. Final dry weights of shoots and runners from cranberry plants irrigated with salt solutions.

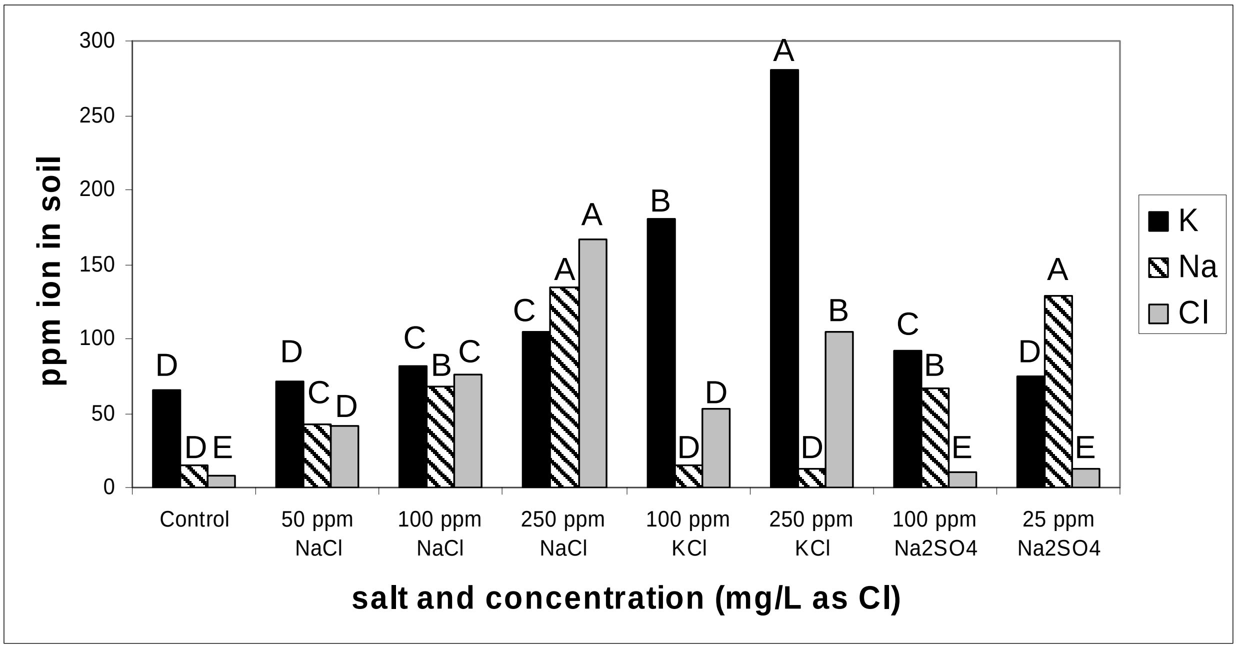
Each data point represents the average of 40 pots (8 pots per replicate, 5 replicates). Runners are combined mass of October and June collections.



The mineral content of the soil and plant shoots and roots were examined at the end of the experiment. The soil analyses show that the irrigation protocol did result in salt loading of the soil (Figure 14). In all cases, adding an ion led to its increasing in the soil with increasing concentration of the salt in the irrigation treatment.

Figure 14. Soil content of K, Na, and Cl (ppm) at the end of the greenhouse irrigation experiment.

Data are the average of 40 pots (8 pots in each of 5 replicates). Treatments that do not share a letter within each ion (e.g. compare all solid bars for K), differ significantly from other treatments (P<0.0001, Tukey test for means separation).

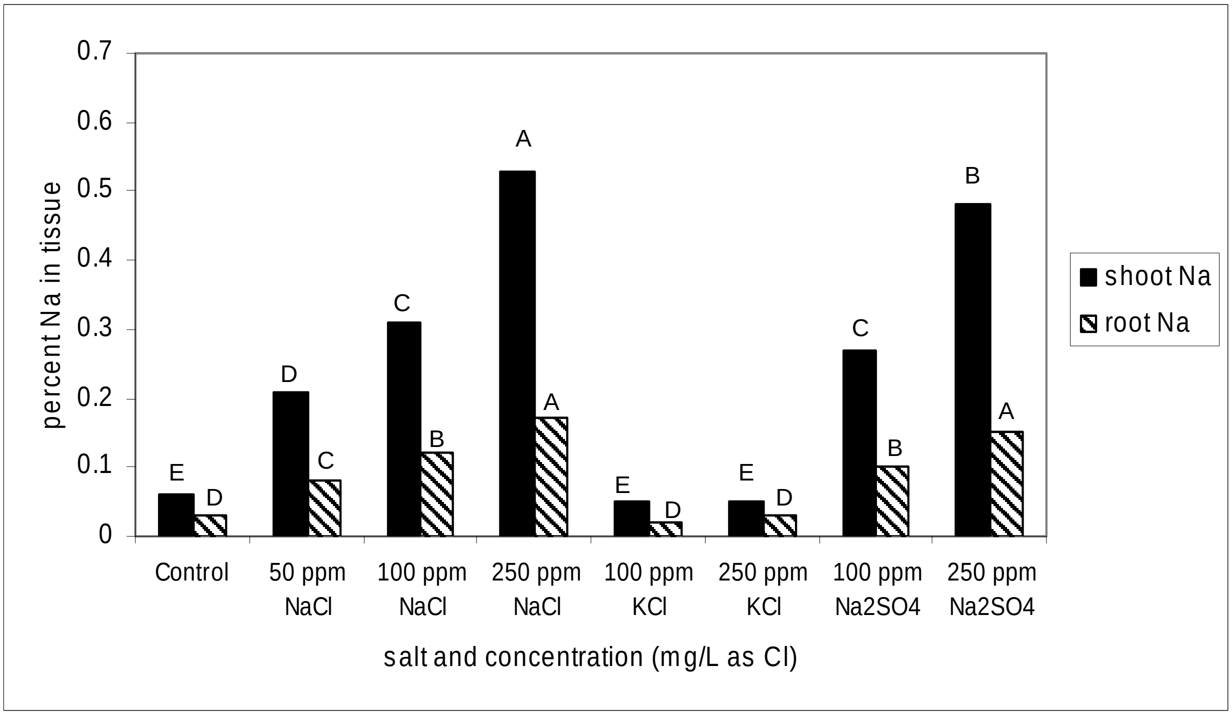


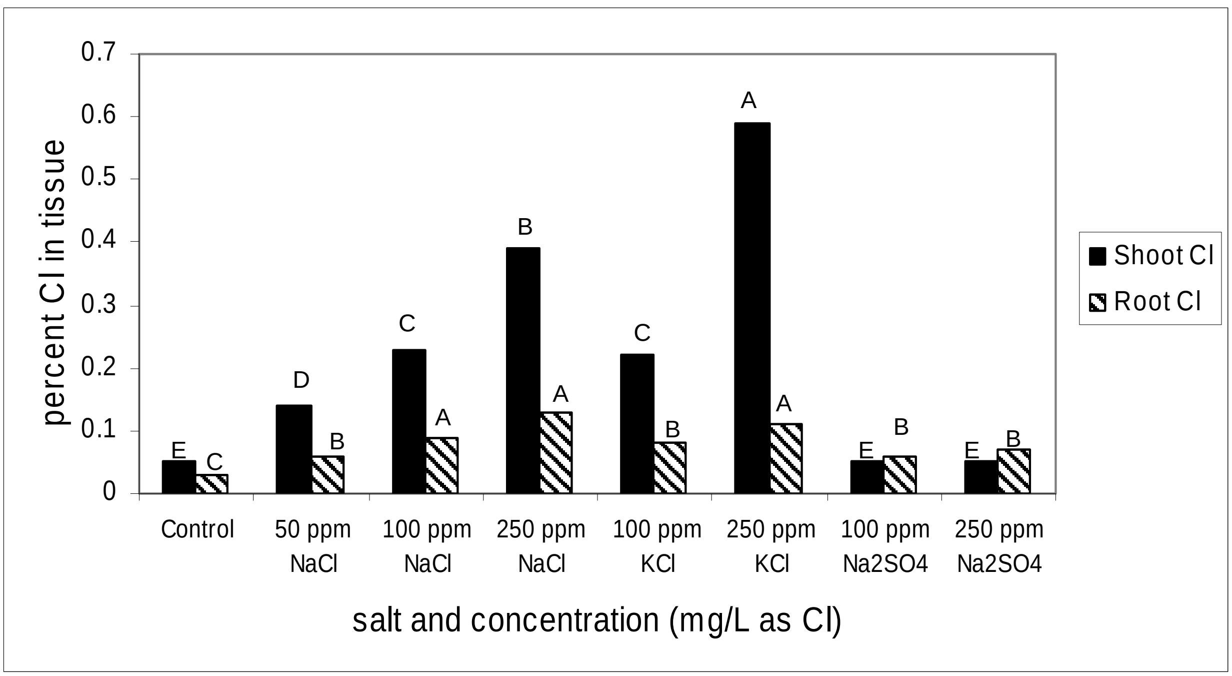
Similarly, the concentration of Na and Cl in shoots and roots increased with increasing rates of Na or Cl containing salts, respectively (Figure 15). The extremely high Cl in shoots of plants receiving 250 ppm KCl, may account for the severe impact of the treatment on these plants, many of which died. Both KCl treatments resulted in extremely high K in both shoots and roots (significant at *P*<0.0001, data not shown). This may also be a negative factor, although the other cations (Ca and Mg) were not suppressed.

In summary, all salts and concentrations were associated with an increase in leaf symptoms compared to the controls and with elevated Na and/or Cl in the plant tissue and in the soil. Flowering was decreased and leaf symptoms increased at 250 ppm Cl as NaCl. Vegetative growth appeared to be stimulated at 100 ppm Cl as NaCl but not strongly. Taking all of these results into account, setting the level of concern for Cl in cranberry irrigation water at 100 ppm appears warranted. This is well below the 250 ppm that was definitively associated with negative effects in this experiment and in the chronic portion of experiment 2. However, the possible growth stimulation effect at 100 ppm in this experiment and at 125 ppm in the previous experiment, and the elevation in tissue Na and Cl at all concentrations, warrant further investigation.

Figure 15. Content (percent dry weight) of Na (top) and Cl (bottom) in cranberry shoots and roots at the end of the greenhouse irrigation experiment.

Data represent the average of 40 measurements (8 pots in each of 5 replicates). Treatments that do not share a letter, within plant part (e.g. compare solid bars for shoots), differ significantly from other treatments (P<0.0001, Tukey test for means separation).





Results summary - Experiment 3

Chronic exposure to salt resulted in salt-laden soil and leaf symptoms on the cranberry plants. At the 100 ppm rate, leaf spotting was observed, soil chemistry was out of balance, tissue levels of Na and/or Cl were elevated, and vegetative growth may have been stimulated. Stimulation of vegetative growth in cranberry, particularly at the expense of flowering and fruiting is undesirable. At 250 ppm, visible symptoms worsened and flowering was suppressed. Based on these results, 100 ppm is recommended as the level of concern for Cl in cranberry irrigation water. However, the possible growth stimulation effect at 100 ppm and the elevation in tissue Na and Cl at all concentrations, warrant further investigation.

Based on the analysis of soil and plants from this study, one should expect to find the levels for Na and Cl proposed in Table 15 in uncontaminated cranberry plants and soil. Levels consistently greater than these would be cause for concern.

Table 15. Proposed background levels for Na and Cl in cranberry soil and plants based on results of irrigation study (greenhouse). Expected levels if no contamination present.

	Background Levels for Na	Background Levels for Cl
Cranberry soil	Up to 15 ppm	Up to 10 ppm
Cranberry shoot tissue	~ 0.06% dry weight	~ 0.05% dry weight
Cranberry root tissue	~0.03% dry weight	~0.05% dry weight

3.2 Phase II – Effects on Soil Chemistry

3.2.1 Experiment 4 - Hydroponics experiments

The purpose of the hydroponics studies was to establish sublethal ranges for both sodium and chloride. These concentrations could then be used in aeroponics to study exposure over time.

Sodium studies

In a hydroponics system, sodium rates from 0 to 1500 ppm were applied to cranberry plants. At rates as low as 50 ppm Na, shoot growth was reduced, with little effect on root growth (Figure 16). The greatest accumulation of Na occurred in or on the roots (Figure 17).

Figure 16. Effect of Na in solution on growth of cranberry in hydroponic culture.

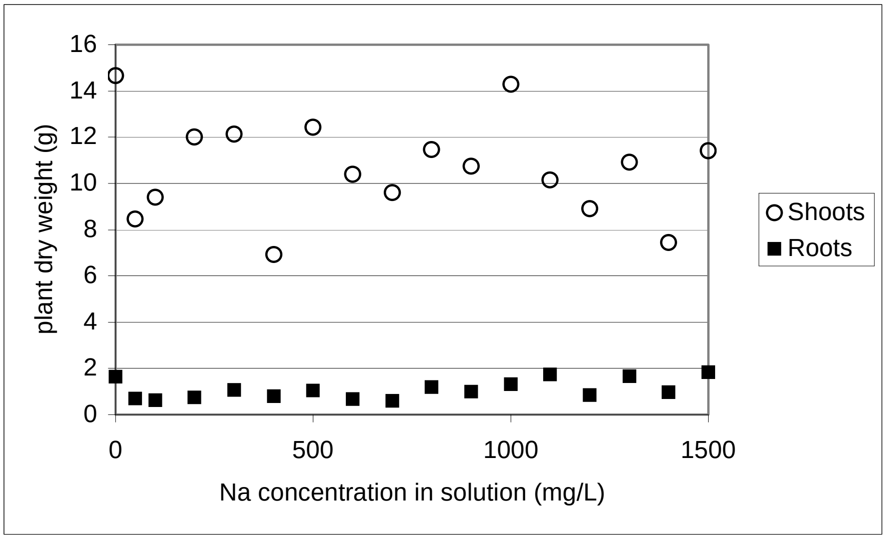
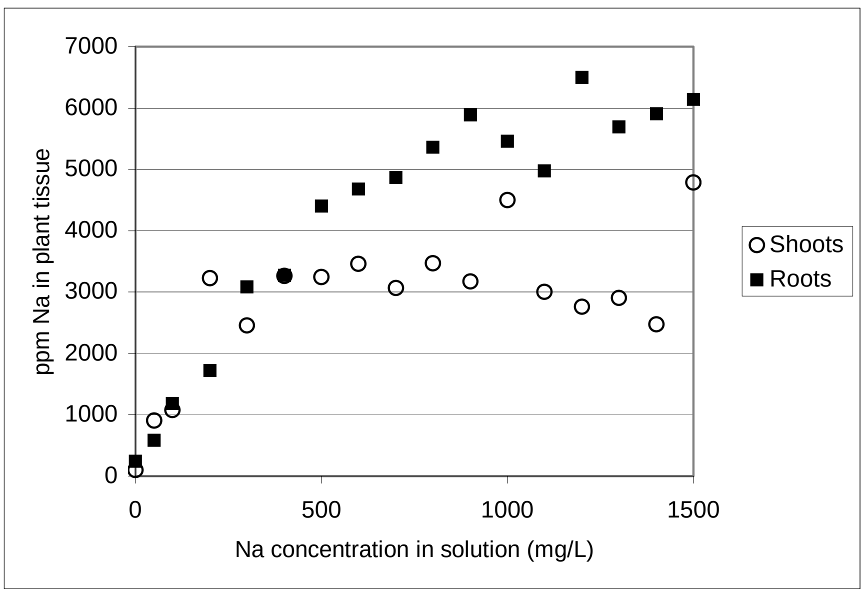


Figure 17. Effect of Na in solution on Na uptake by cranberry in hydroponic culture.



Chloride studies

In hydroponics rooted cranberry cuttings were exposed to six different levels of chloride (250, 500, 750, 1000, 2000, 2500 ppm). The results are shown in Table 16.

Table 16. Effect of exposure to different chloride solution concentrations on cranberry root and shoot dry weight and tissue chloride concentration.

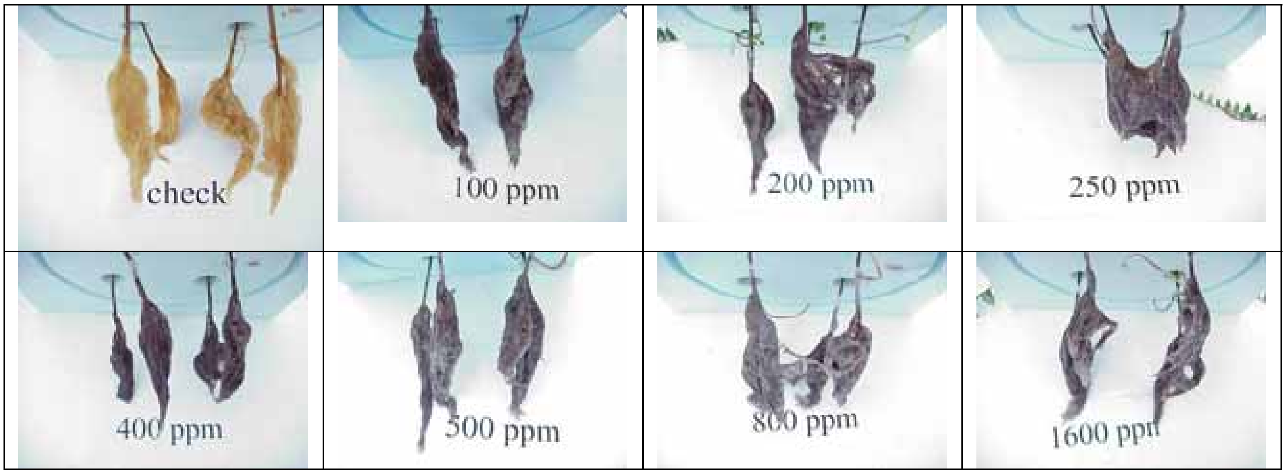
	Shoot dry weight	**Shoot Cl concentration**	**Root dry weight**	**Root Cl concentration**
Treatment (mg/L Cl)	*(g)*	*(ppm)*	*(g)*	*(ppm)*
0		2056		1906
250	5.8	1032	0.9	6409
500	6.4	9229	1.1	8063
750	7.2	8759	1.3	6494
1000	2.1	2597	0.8	5412

Elevation in shoot Cl was apparent at 500 ppm, while root Cl was elevated at the 250 ppm treatment level. Damage was observed at 500 ppm as browning of older leaves, with some leaf drop (photo at right). Very severe damage was observed on 4 of the eight plants in the 750 ppm treatment. All plants exposed to >750 ppm eventually died. Desiccation was evident in the higher-rate treatments, indicating possible osmotic imbalance and water potential issues. Data for 2000 and 2500 ppm are not included since the plants quickly died after exposure to these treatments.

The hydroponics data suggested that 500 ppm was a reasonable concentration to use in initial aeroponics studies of chronic exposure to sodium or chloride since higher rates, particularly of chloride, were confirmed to be damaging in the hydroponic studies.

Calcium Magnesium Acetate Study.

The effect of Calcium Magnesium Acetate (CMA) on cranberry growth was examined in a hydroponic system. The commercial product was not used because it contained clay and other binding material that prevented dissolution. Based on information provided by the manufacturer a solution was produced with the approximate formulation of $Ca_3Mg_7(C_2H_3O_2)_{20}$. After five days in the solution, roots of vines in all treatments except the control blackened and the plants died (see photos on next page).



Results summary - Experiment 4

At exposures of greater than 500 ppm Cl, cranberry plants showed visible damage (leaf browning and leaf drop). Response to Na in hydroponics was equivocal. Direct root exposure to 100 ppm CMA in solution killed cranberry plants.

3.2.2 Experiment 5 - Aeroponics

500 ppm Chloride

Symptoms, believed to be the result of Cl injury, were induced in aeroponic culture plants exposed to 500 ppm Cl. The symptoms were very unusual. Growth began to slow shortly after the introduction of Cl, then leaves midway down existing runners began to show necrotic spots. Eventually the runners began to grow again.

During this aeroponics study, cranberry plants exposed to 500 ppm Cl exhibited leaf drop and had lower shoot weight compared to untreated plants (Table 17). Extreme levels of Cl accumulated in the shoots, with the greatest Cl accumulation in the old leaves (data not shown).

Table 17. Effect of 500 mg/L Cl on dry weight and chloride content of cranberries grown in an aeroponic system.

	Harvest date			**Harvest date**		
	April 19	May 3	May 17	April 19	May 3	May 17
	Shoot dry wt (g)			*Shoot chloride content (ppm)*		
Untreated	3.12	8.32	9.07	2137	2568	3352
+ Cl (500 ppm)	3.03	8.45	7.75	11605	14398	14313
Significance	ns	ns	ns			
	Root dry wt (g)			*Root chloride content (ppm)*		
Untreated	0.29	0.74	1.14	4158	371	2620
+ Cl (500 ppm)	0.35	0.63	1.04	7855	4319	6403
Significance	ns	ns	ns			

500 ppm Sodium

No visual symptoms were observed on cranberries grown in aeroponics with exposure to 500 ppm sodium. By six weeks after treatments began, the fresh and dry weight of shoots exposed to 500 ppm Na were lower than the controls (Fig 18). The same was true of roots (Fig 19). The sodium concentration of shoots and roots in the control plants was significantly lower than in the treated plants (Fig 20). The concentration of sodium declined over time in both treatments and both tissues.

Figure 18. The effect of sodium at 500 ppm on shoot dry and fresh weight of cranberries grown in aeroponics.

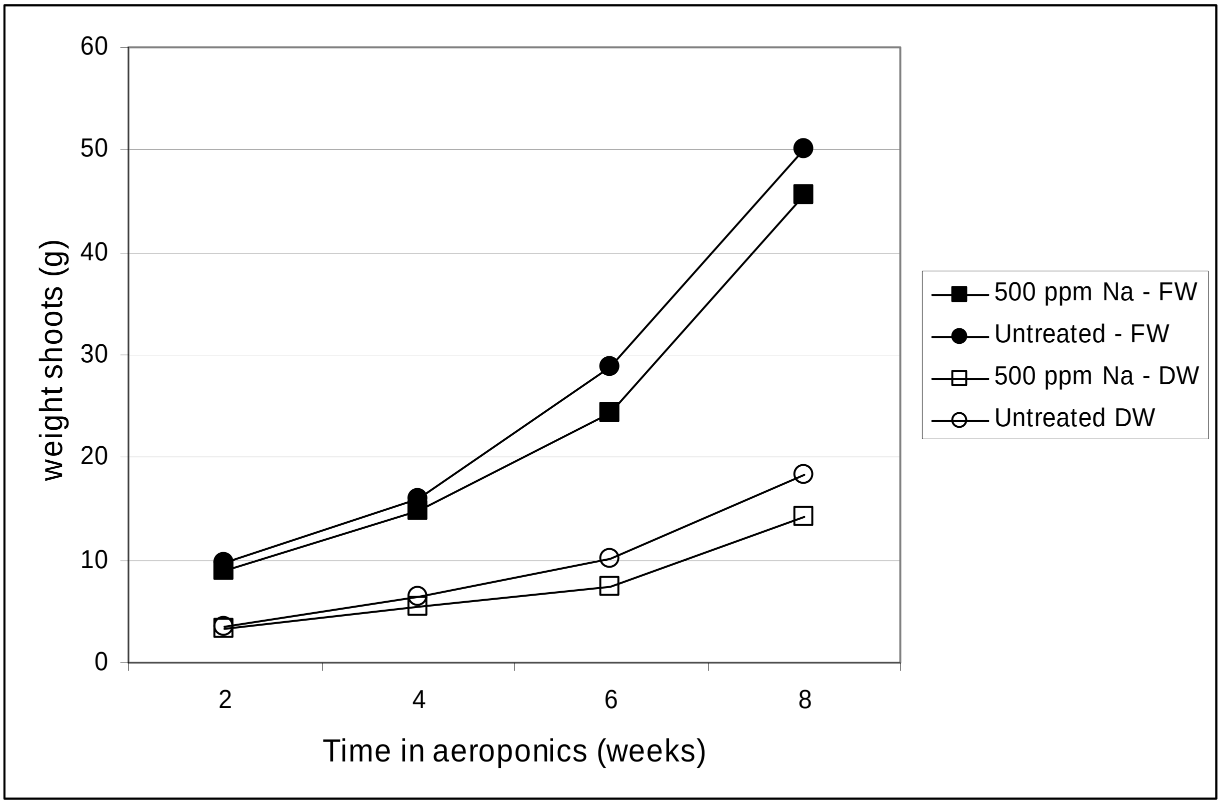


Figure 19. The effect of sodium at 500 ppm on root dry and fresh weight of cranberries grown in aeroponics.

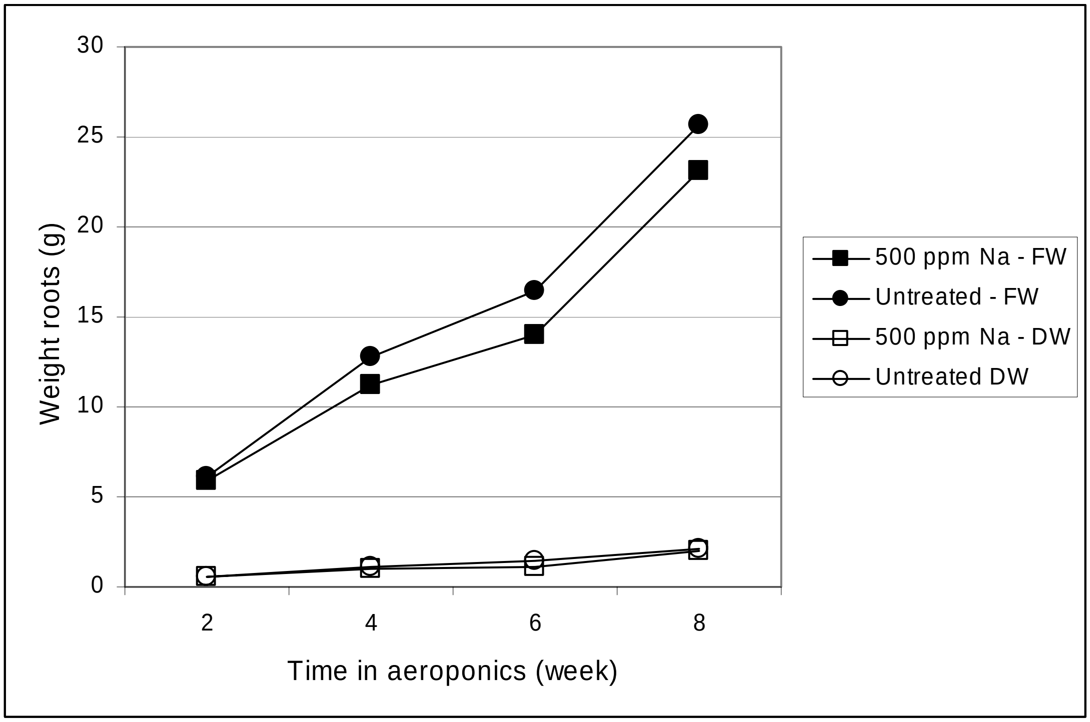
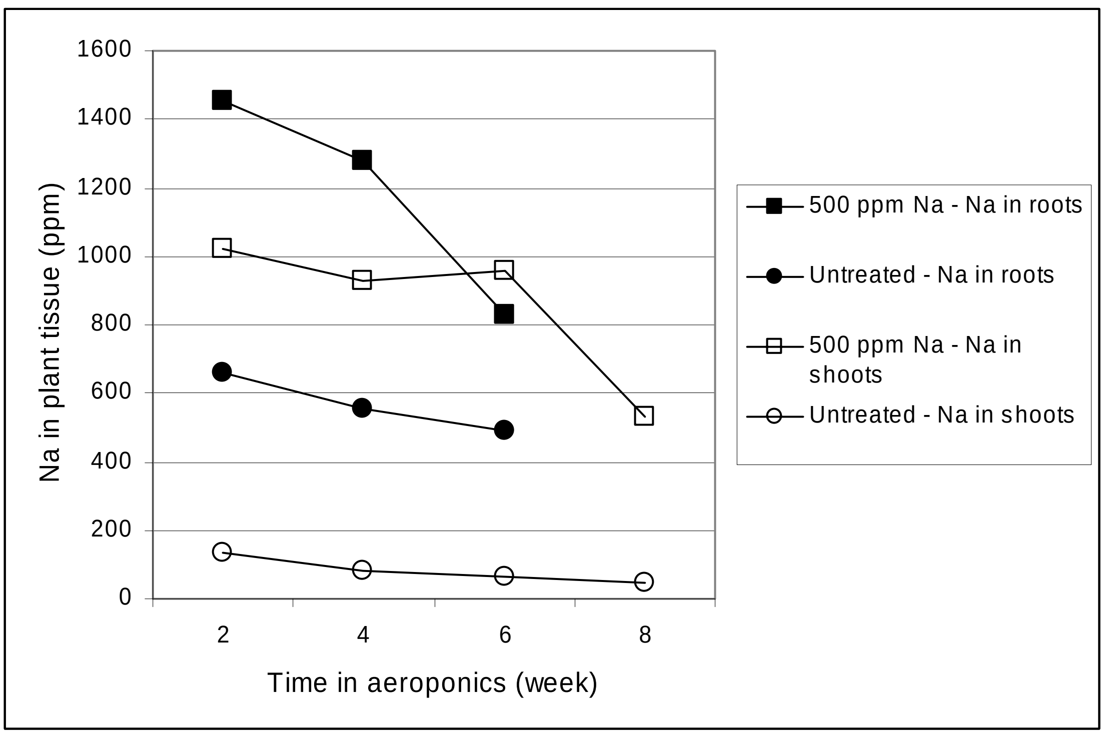


Figure 20. Changes in sodium concentration in roots and shoots of rooted cranberry cuttings exposed to 0 or 500 ppm Na in aeroponics.



Cranberry vines appeared quite tolerant of sodium. The control shoots had sodium in the range that would be normally expected, ~0.01%. The control roots had more sodium that would be expected (0.05-0.07%), however some sodium was likely adsorbed to the root surface rather than being inside the plant. No normal range for root nutrient concentrations has been determined. Despite quite high levels of Na in shoots and roots after exposure to 500 ppm Na, the impact on plant growth was fairly minimal (Figures 18 and 19).

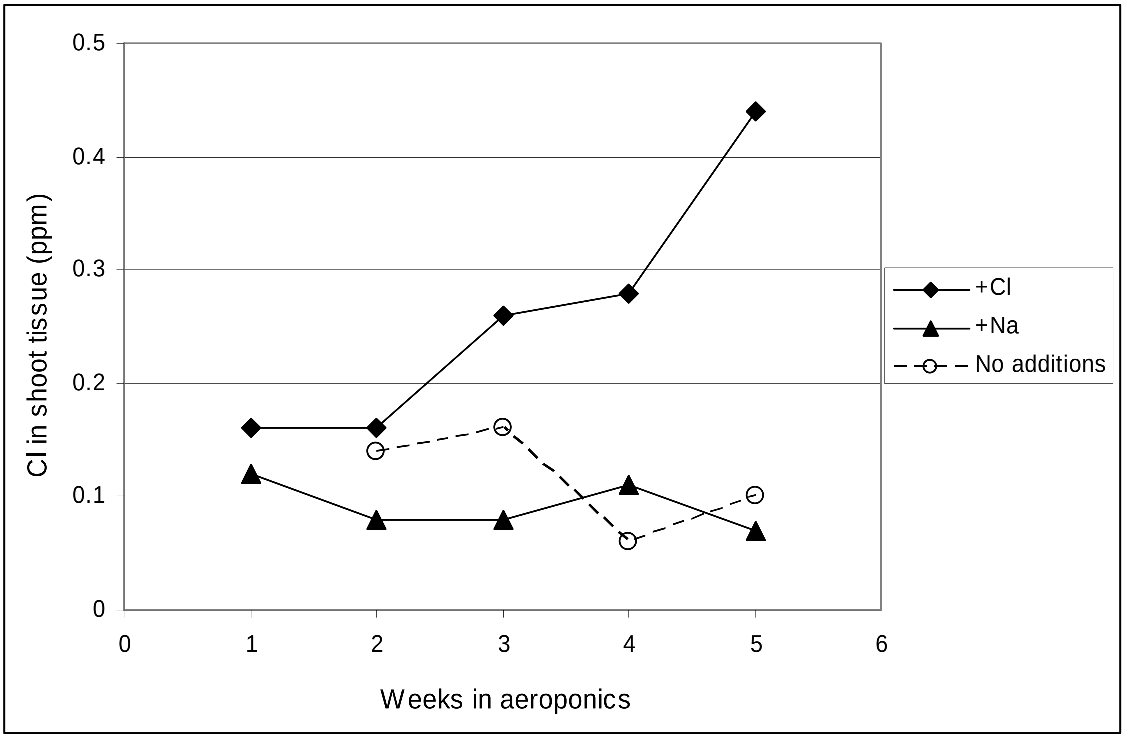
Further reflection suggested that exposure of cranberry vines to 500 ppm may have been overly aggressive and would greatly exceed soil concentrations of sodium or chloride that might result from the impingement of de-icing salts in cranberry water supplies. In addition, greenhouse studies showed effects at lower concentrations. Therefore the aeroponics experiments were repeated at 100 ppm.

100 ppm Chloride or Sodium

Exposing cranberries to 100 ppm Cl in aeroponics resulted in elevated Cl in the shoot tissue (Figure 21). While the dry weight of neither tops nor roots was significantly affected (Figure 23), by the final week, weights in the +Cl treatment appear to be declining. As was the case for Cl treatment, exposing cranberries to 100 ppm Na in aeroponics resulted in elevated tissue Na (Figure 21 and 22). However, growth was increasing by experiment end in the Na treated plants (Figure 23).

Figure 21. Chloride (top graph) and sodium (bottom graph) in cranberry shoots of plants exposed to 100 ppm Cl or Na in aeroponics.

Control (no addition) plants received neither Na or Cl.



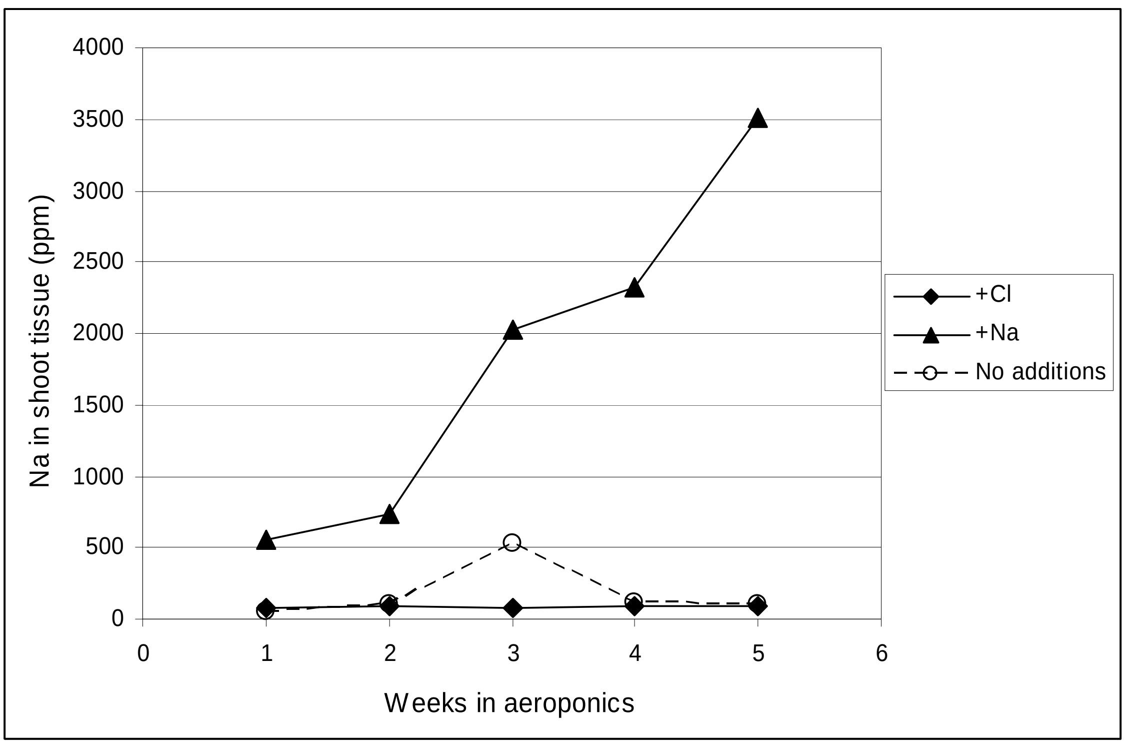


Figure 22. Sodium in cranberry roots of plants exposed to 100 ppm Cl or Na in aeroponics. Control (no addition) plants received neither Na or Cl.

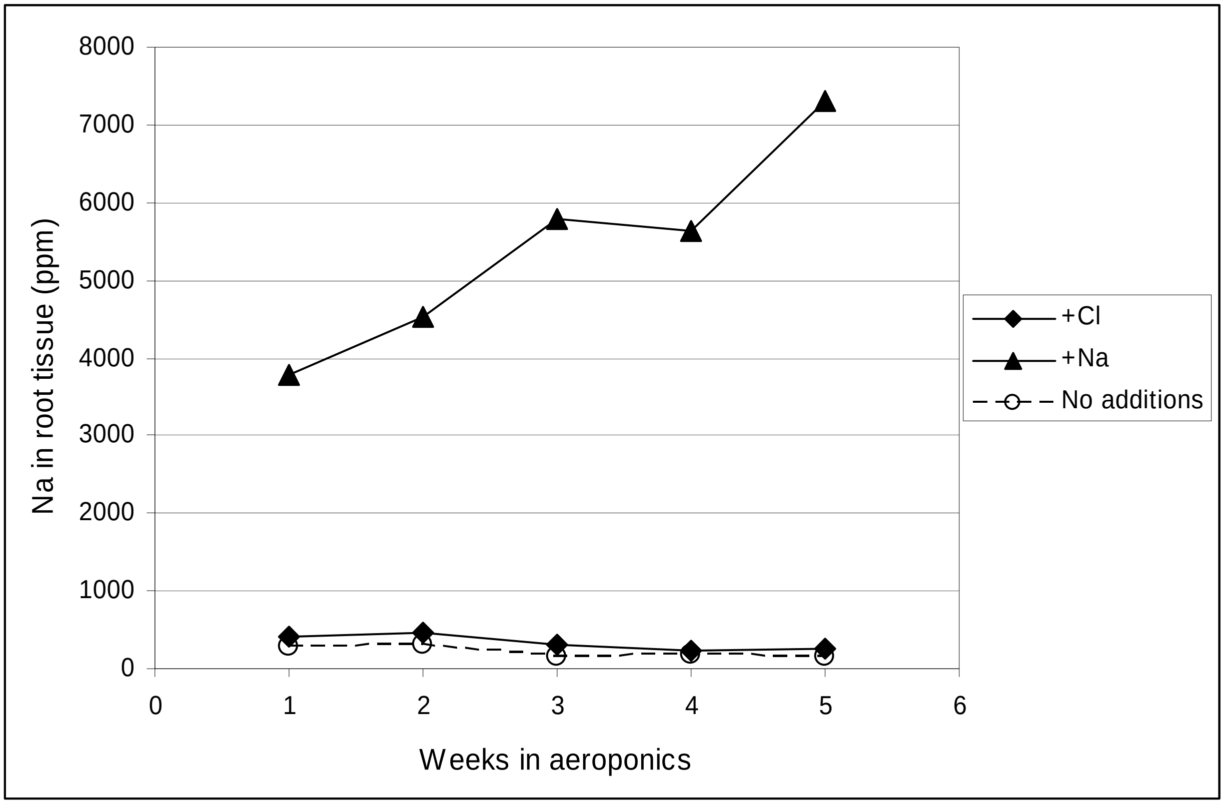
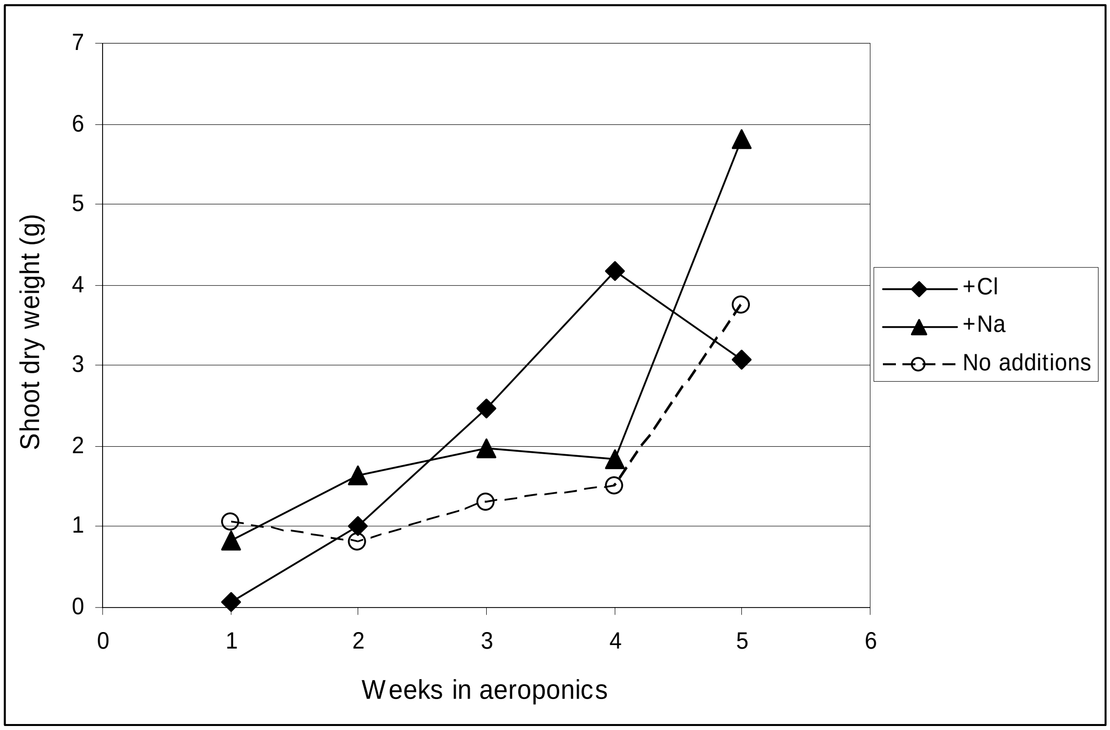
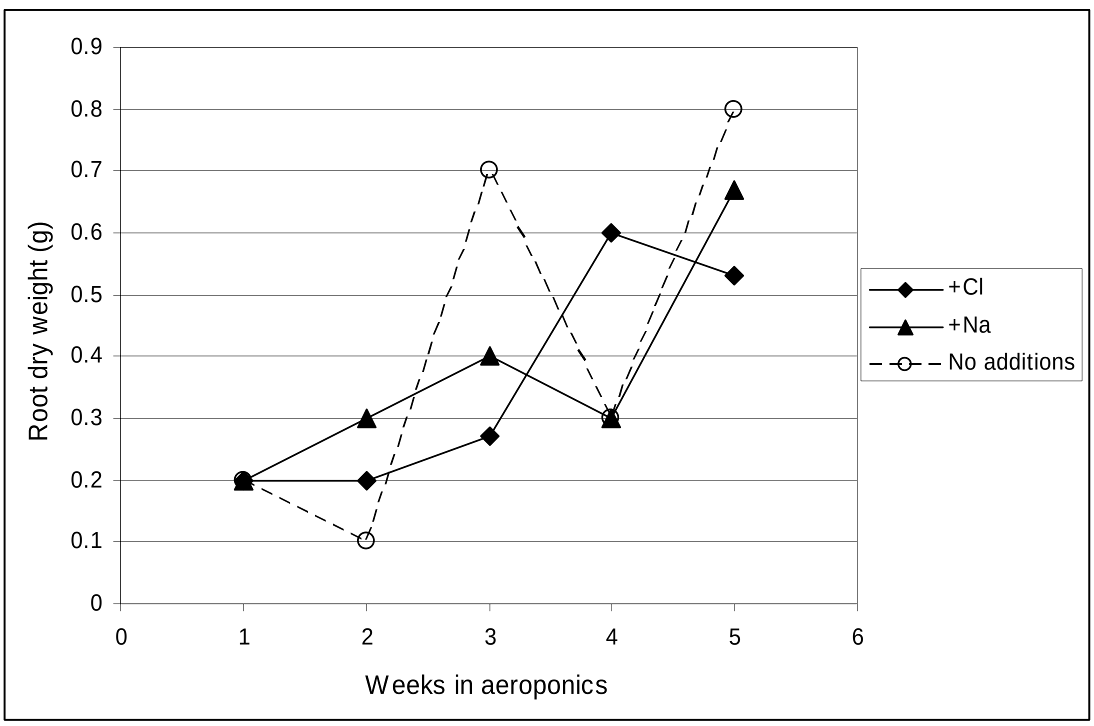


Figure 23. Dry weight of cranberry shoots (top) and roots from plants exposed to 100 ppm Na or Cl in aeroponics.

Control (no additions) plants received no Na or Cl.





Results summary - Experiment 5

Cranberries exposed to 500 ppm Cl accumulated extreme levels of Cl in shoots (particularly old leaves) and roots and exhibited leaf spotting, leaf drop, and irregular growth. Cranberries exposed to 500 ppm Na (no Cl) showed little impact on growth despite accumulating Na in shoots and roots. At 100 ppm exposures to Cl or Na, there was tissue accumulation of the respective salts but no consistent impact on plant growth. However, by the end of the study, growth was increasing with 100 ppm Na and decreasing with 100 ppm Cl. Both hydroponic and aeroponic studies indicate that 500 ppm salt concentrations, especially that of Cl, are detrimental to cranberries. At the 100 ppm concentration of either salt, impacts on growth were not apparent in the short term but tissue Na and Cl were elevated.

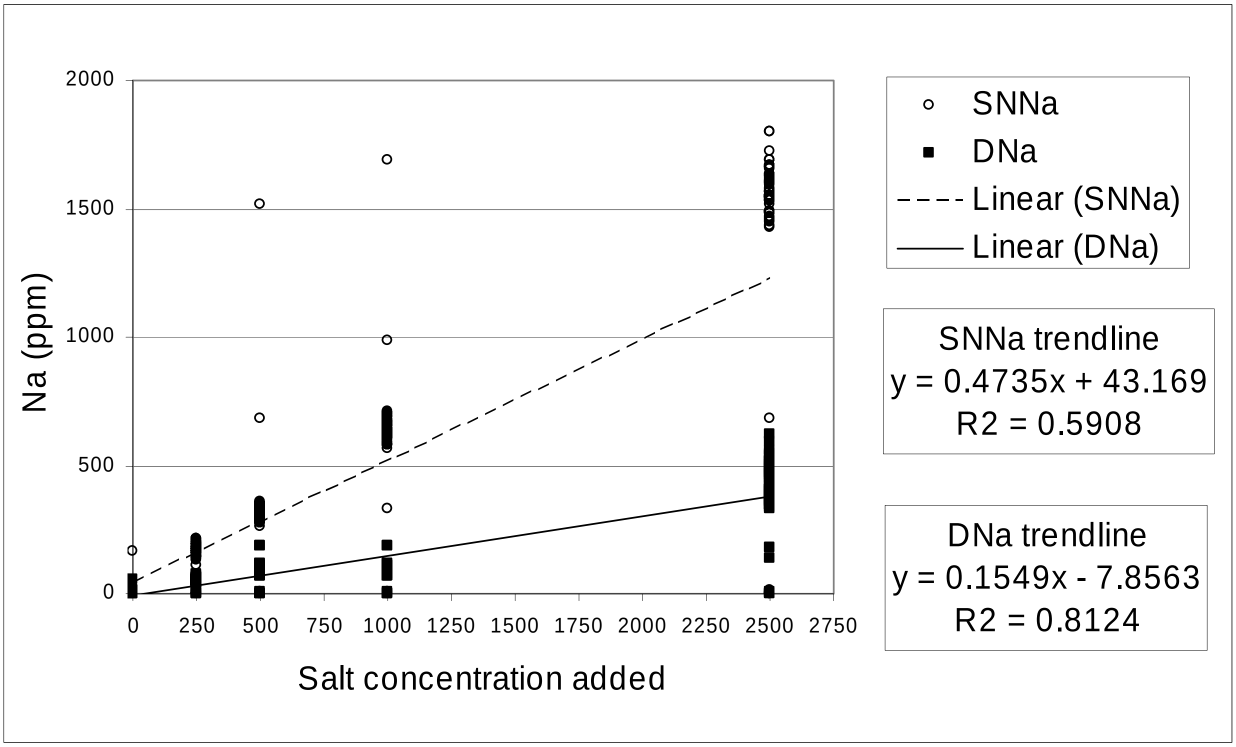
3.2.3 Experiment 6 - Absorption/desorption study - mineral salts.

Sand, high organic, and low organic soils, in general, were similar in their responses during sorption and desorption. Therefore, the data are shown with soil types combined. Sorption time data for 7 to 60 days, showed no consistent trends except for a tendency for decreased Cl sorption over time. It is possible that concurrent Cl desorption occurred. In terms of impact on cranberry soil chemistry, the significant factors appeared to be salt type and salt concentration.

Depending on the added salt concentration, concentrations of Na and Cl varied in the supernatant removed after sorption (all sorption durations combined) and after desorption. The data were separated into salt treatments with Na salts only (NaCl, Na_2SO_4 - Figure 24) or Cl salts only (NaCl, KCl, $CaCl_2$ - Figure 25) to examine the behavior of the two ions.

Figure 24. Sodium in supernatant after sorption (SNNa) and desorption (DNa) of sodium-containing salts (NaCl, Na_2SO_4).

Data points are actual data, lines are calculated regression.

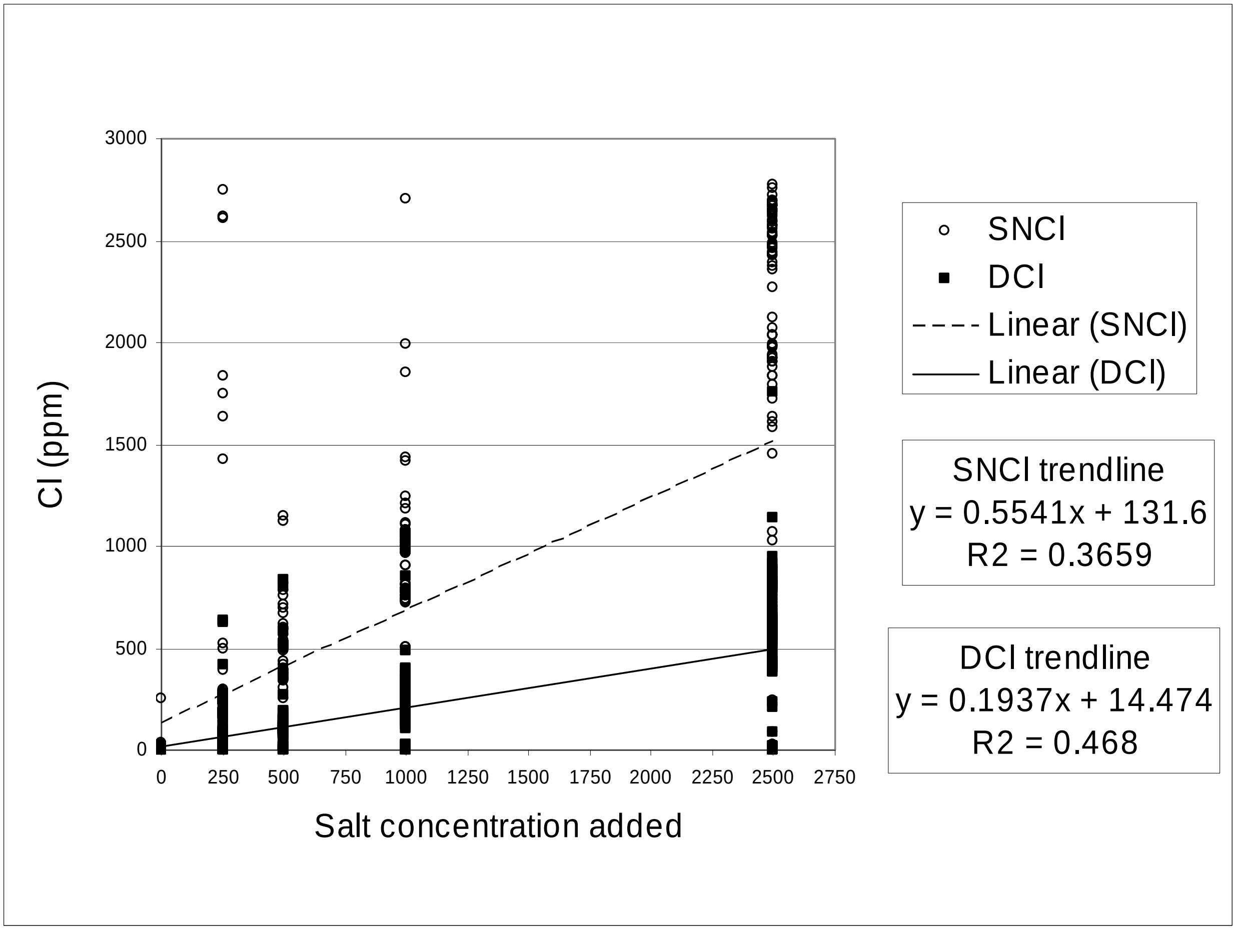


At the Na concentrations used in this study, a significant portion of the added Na remained in the supernatant, indicating a limited capacity for sodium loading in cranberry soil (Figure 24). Based on the amount found in the supernatants, from 10-40% of the added salt was sorped. In the desorption phase, virtually all of the sorped Na was released at the 250 ppm concentration, but at higher concentrations, only about 50% of the sorped Na was desorped.

The chloride data was similar to that for sodium. An examination of the concentration of Cl in the supernatant following the sorption phase shows little (10-25%) uptake into the soil at concentrations below 2500 ppm (Figure 25). An examination of the regression lines indicates that at all concentrations except 2500 ppm, all sorped Cl was desorped. In other words, Cl was somewhat more readily released from the soil compared to Na except at 2500 ppm, where ~50% was retained for both salts.

Figure 25. Chloride in supernatant after sorption (SNCl) and desorption (DCl) of chloride-containing salts (NaCl, KCl, $CaCl_2$).

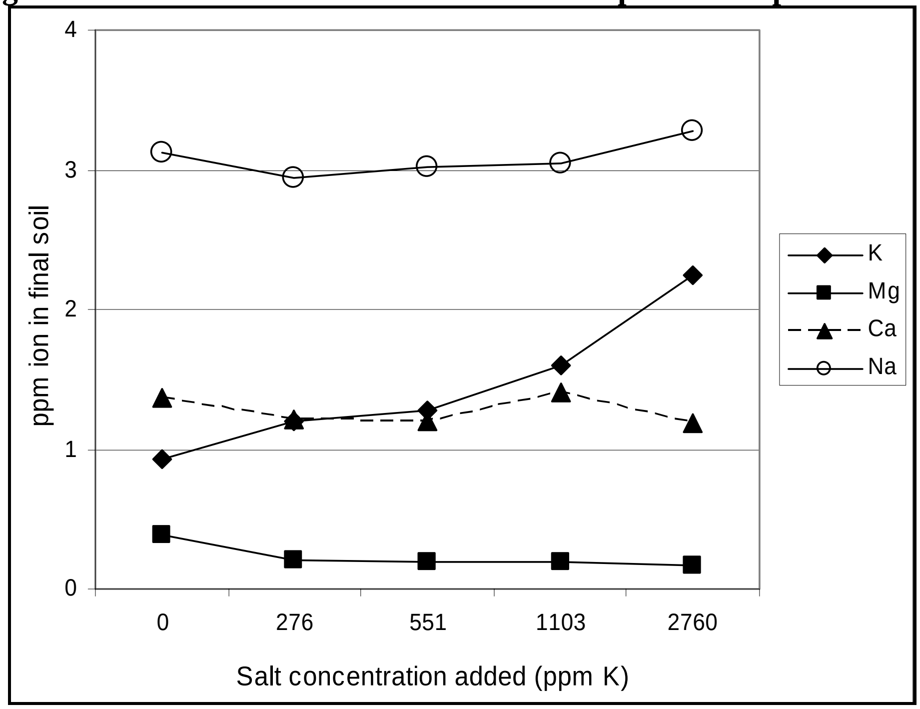
Data points are actual data, lines are calculated regression.



Based on supernatant examination, for both Na and Cl, the 250 ppm concentration seemed to result in little change to the soil chemistry. We then analyzed the chemical properties of the soil after desorption, looking at soil solution (extractable) ions, pH and EC.

Both salt concentration and salt type affected the mineral content of the soil after absorption/desorption. As would be expected, when a salt containing an analyte was applied, the concentration of that analyte in the soil was increased. For example, when soils were treated with KCl, the K concentration in the soil was higher than that in the control and increased with increasing KCl concentration (Figure 26). Similar results were obtained for salts containing Ca (Figure 27), Mg (Figure 28), Na (Figure 29), and Cl (Figure 30).

Figure 26. Final soil content of cations after sorption/desorption of KCl.



At the highest concentrations, addition of one cation led to depression of other cations. For example, addition of the highest concentration of KCl was associated with a decline in soil Ca (Figure 26) and addition of the highest concentration of $MgSO_4$ was associated with a decline in soil K (Figure 29). The addition of Ca or Mg salts decreased soil Na (Figures 27 and 28), indicating that these salts could have utility in mitigating sodium contamination.

Figure 27. Final soil content of cations after sorption/desorption of $CaCl_2$.

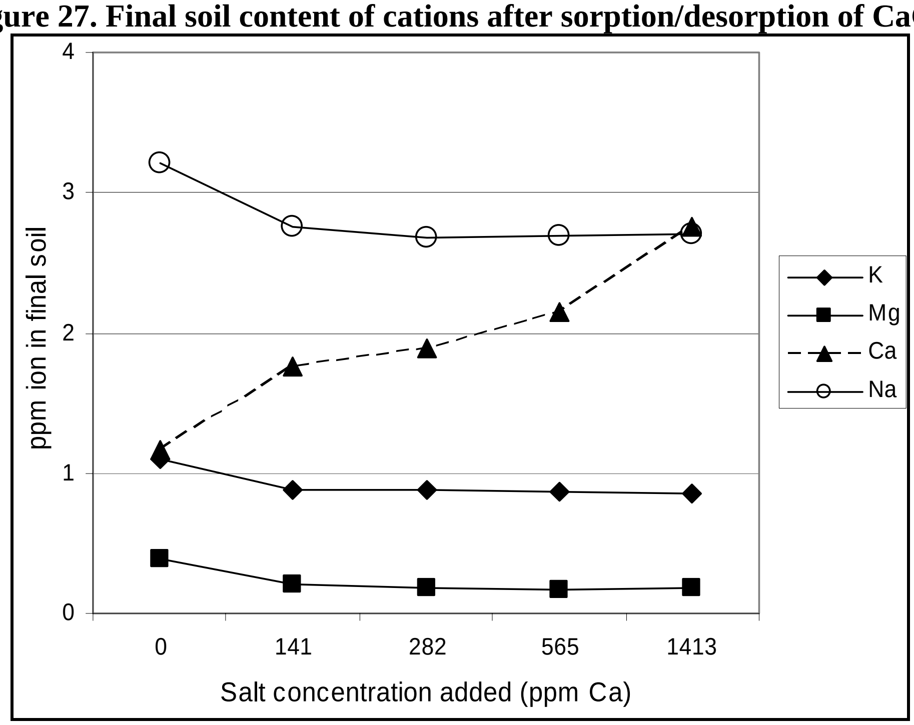


Figure 28. Final soil content of cations after sorption/desorption of $MgSO_4$.

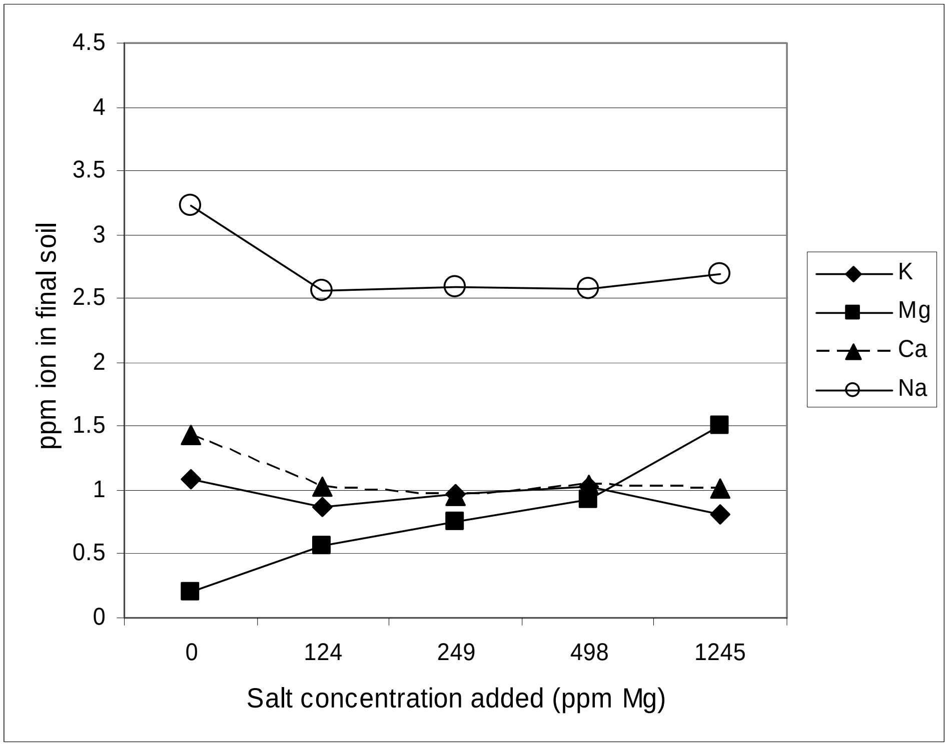
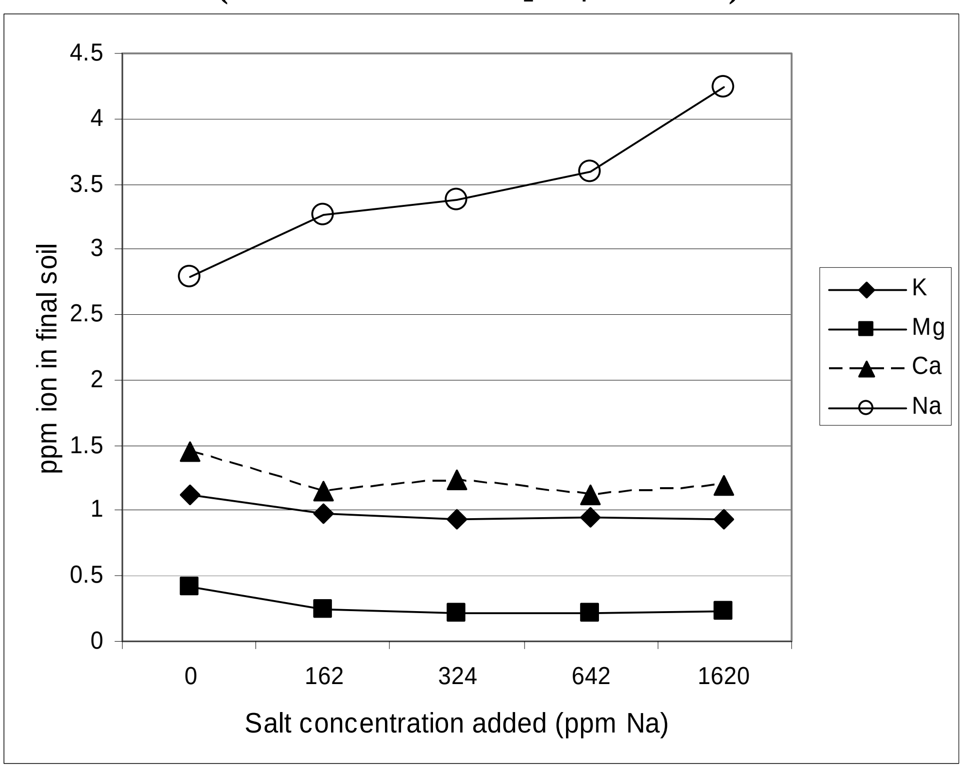
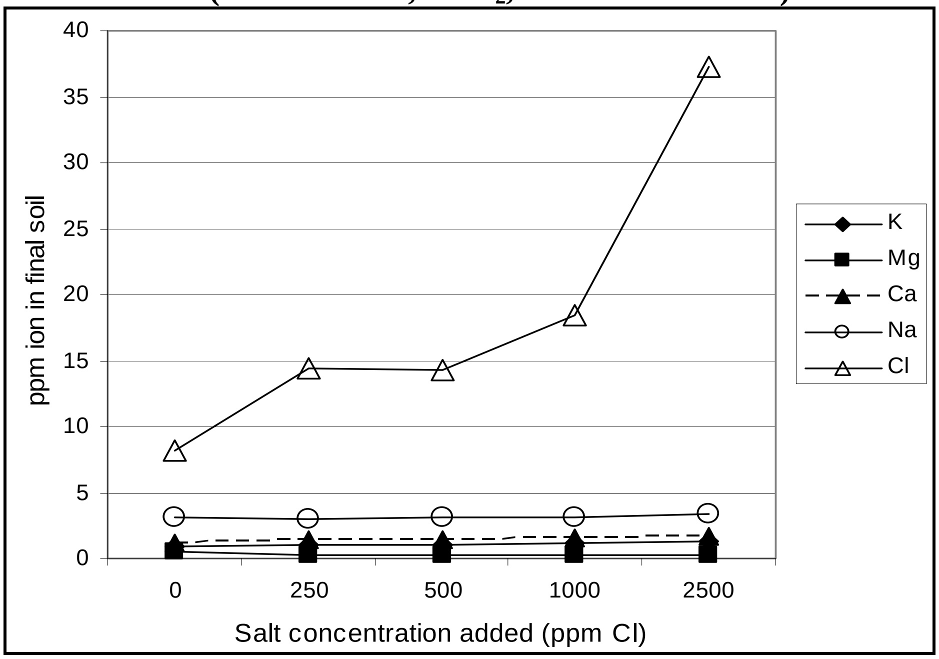


Figure 29. Final soil content of cations after sorption/desorption of Na containing salts (data for NaCl and Na_2SO_4 combined).



When sodium was added to the soil, levels of the other cations decreased slightly (Figure 29), but the effect did not increase with increasing Na concentration.

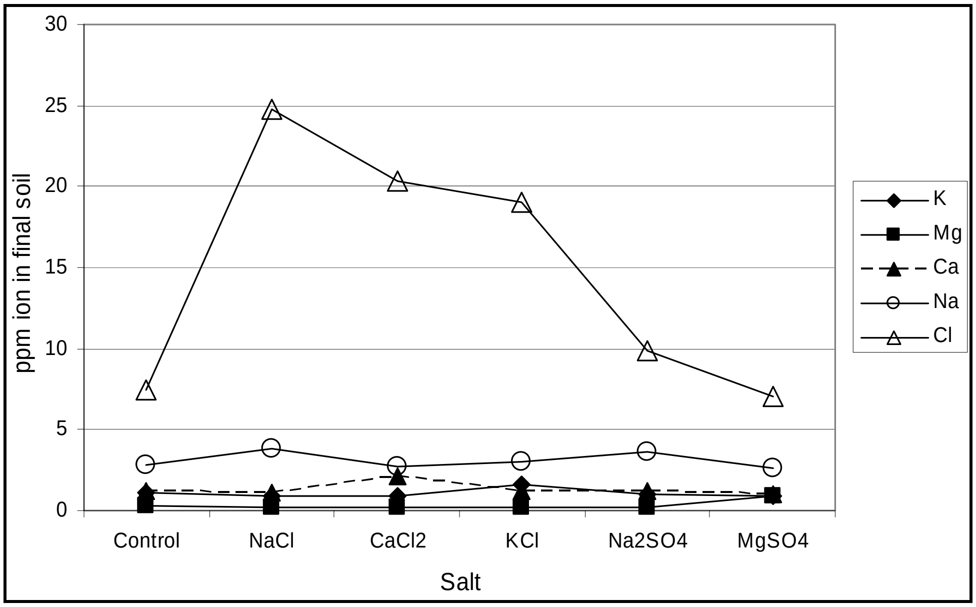
Figure 30. Final soil content of cations and Cl after sorption/desorption of Cl containing salts (data for NaCl, $CaCl_2$, and KCl combined).



The addition of salts containing Cl resulted in increased Cl in the soil. Despite the apparent desorption of Cl at low concentrations (Figure 25), Cl remained somewhat elevated in the soil even in the 250 ppm treatment (Figure 30). As expected, the addition of the Cl anion did not affect the levels of the cations, K, Mg, or Ca.

Figure 31. Final soil content of ions after sorption/desorption of various salts (all concentrations combined).

Values are averages of three replicates four concentrations for each salt, three replicates for the control.



Salt types were then compared to the control and each other with data from all four concentrations of each salt combined (Figure 31). As previously stated, adding a salt increased the soil level of the ions in that salt. Na was elevated similarly regardless of Na source (compare NaCl to Na_2SO_4). However, Cl was elevated to different extents depending on Cl source, with the greatest elevation associated with NaCl.

Salt type and concentration affected soil pH and EC (Figures 32 and 33). All salts increased soil EC compared to the control, with the greatest increase associated with the addition of $MgSO_4$ (Figure 32). This indicates that extreme loading of any salt may be problematic in terms of EC. The effect of salts on pH was variable (Figure 33) with some decreasing pH and others having little effect. Since low pH is desirable in cranberry production, the observed salt effects would not be detrimental in the field at least as regards pH.

As salt concentration increased, soil pH tended to decline (Figure 33). However, all soil pHs were in the standard range for cranberry. As expected, soil EC increased as concentration rate increased, with highest EC associated with the 2500 ppm concentration of any salt.

Figure 32. Final soil pH (left axis) and conductivity (right axis) after sorption/desorption with various salts (concentrations combined).

Values are averages of three replicates four concentrations for each salt, three replicates for the control

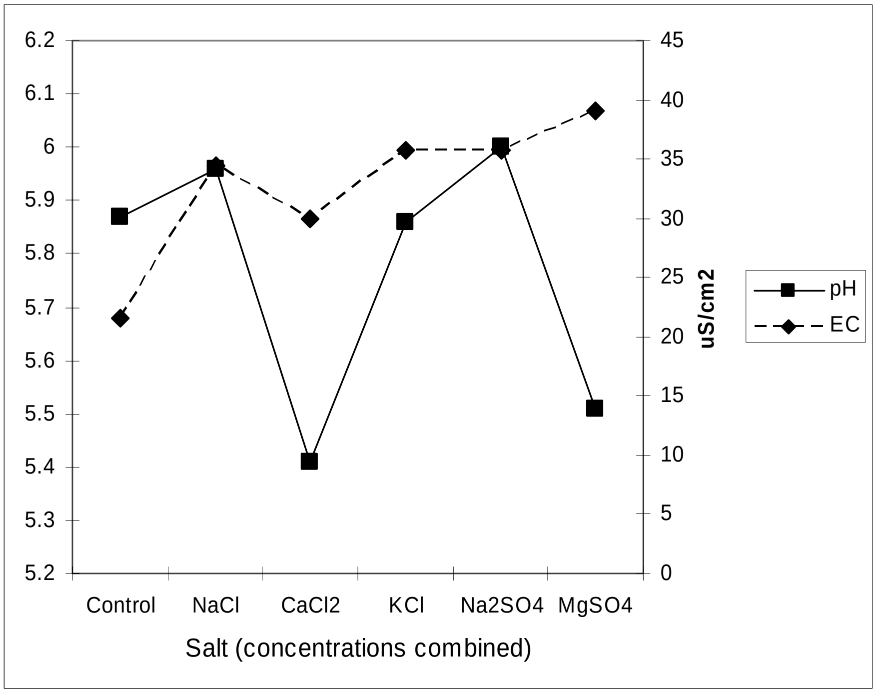
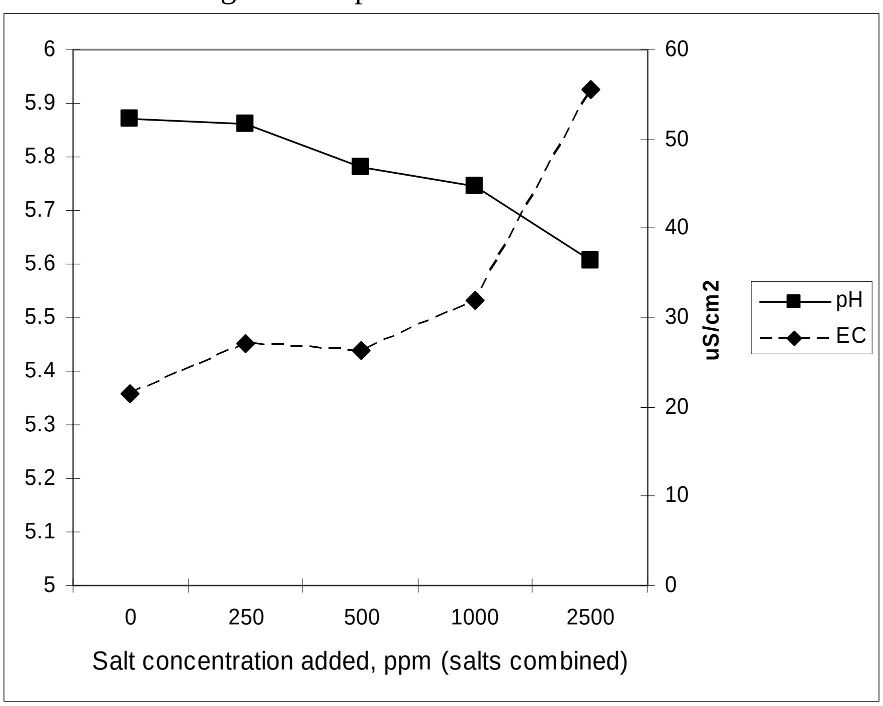


Figure 33. Final soil pH (left axis) and conductivity (right axis) after sorption/desorption with varied salt concentrations. Data for all salts combined.

Values are averages of 3 replicates of 5 salts for each concentration.



3.2.4 Experiment 7 - Absorption/desorption study - CMA.

To examine the effects of the road salt alternate Calcium Magnesium Acetate (CMA) on cranberry soil chemistry, CMA was added to the same sand and a similar low organic matter cranberry soil as was used for the previous sorption/desorption studies. Soils were allowed to sorp CMA of rates similar to those used for the mineral salts for 1, 2, or 4 weeks followed by a 1 week desorption. Results from the main effect of CMA concentration are presented here as statistical analysis showed few significant differences related to soil type or sorption time.

An examination of the soil solution following sorption (Figures 34 and 35) and desorption (Figures 36 and 37) showed that as the CMA concentration increased, so did the supernatant concentrations of all examined elements except K. As might be expected, adding CMA increased Ca and Mg in the soil solution. However, CMA addition appeared to increase plant availability (solubility) of Na and to a lesser extent Cl (Figures 35 and 37) as well.

Figure 34. Concentration of ions in sorption supernatant (i.e., ion not sorped by soil) after sorption with CMA at five concentrations.

Values are averages of five replicates. Asterisks indicate statistically significant differences by concentration (*** P< 0.001). Figure 35 shows an expanded view of the Na and Cl data.

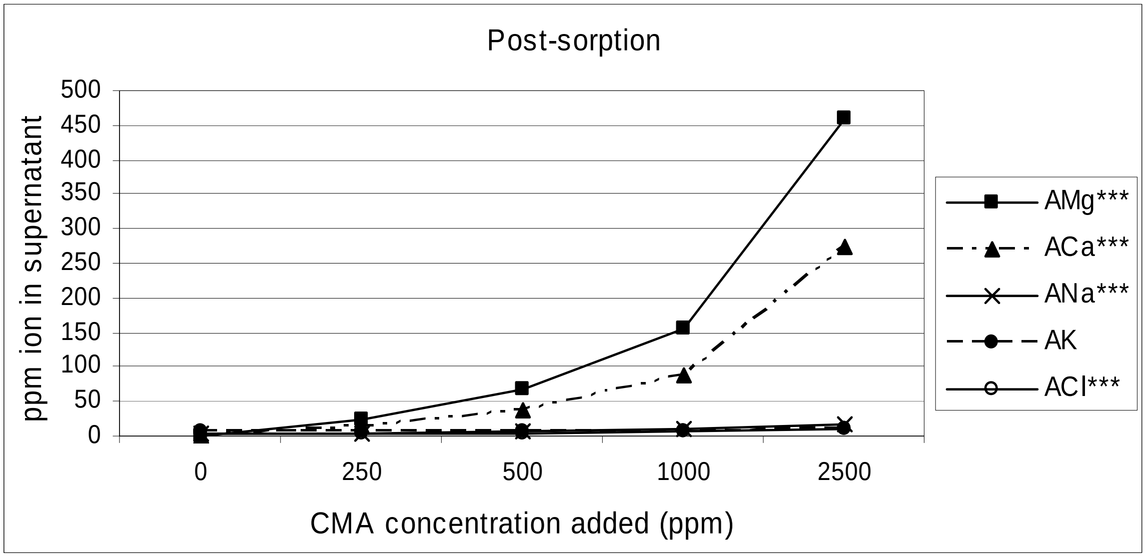


Figure 35. Concentration of Na and Cl in sorption supernatant (i.e., ion not sorbed by soil) after sorption with CMA at five concentrations.

Values are averages of five replicates. Asterisks indicate statistically significant differences by concentration (*** P< 0.001).

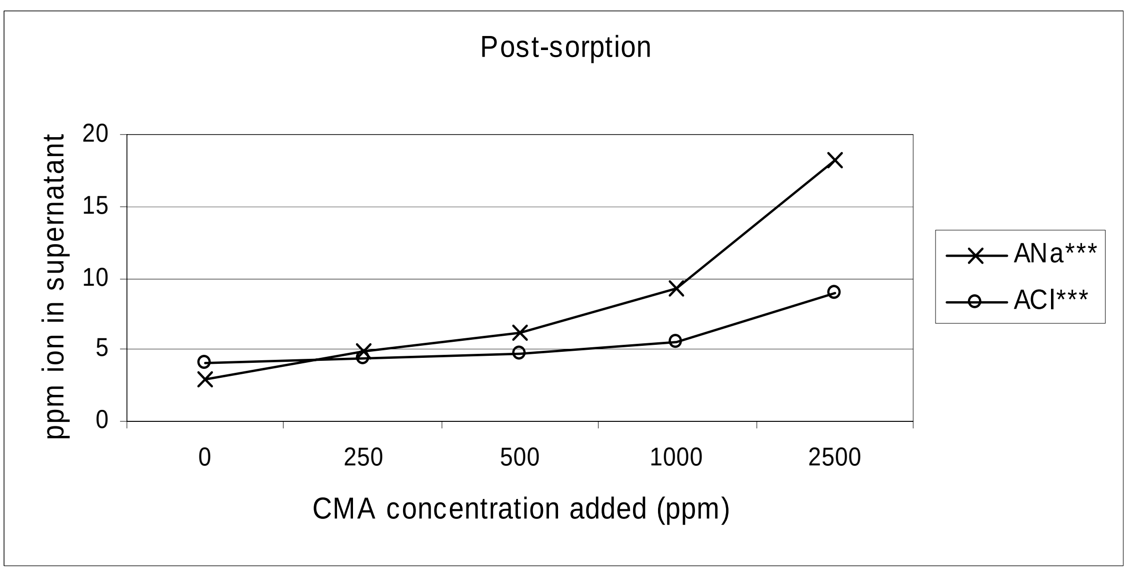


Figure 36. Concentration of ions in desorption supernatant (i.e., ions released from soil) after sorption with CMA at five concentrations and desorption with deionized water. Values are averages of five replicates. Asterisks indicate statistically significant differences by concentration (*** $P < 0.001$). Figure 37 shows an expanded view of the Na and Cl data.

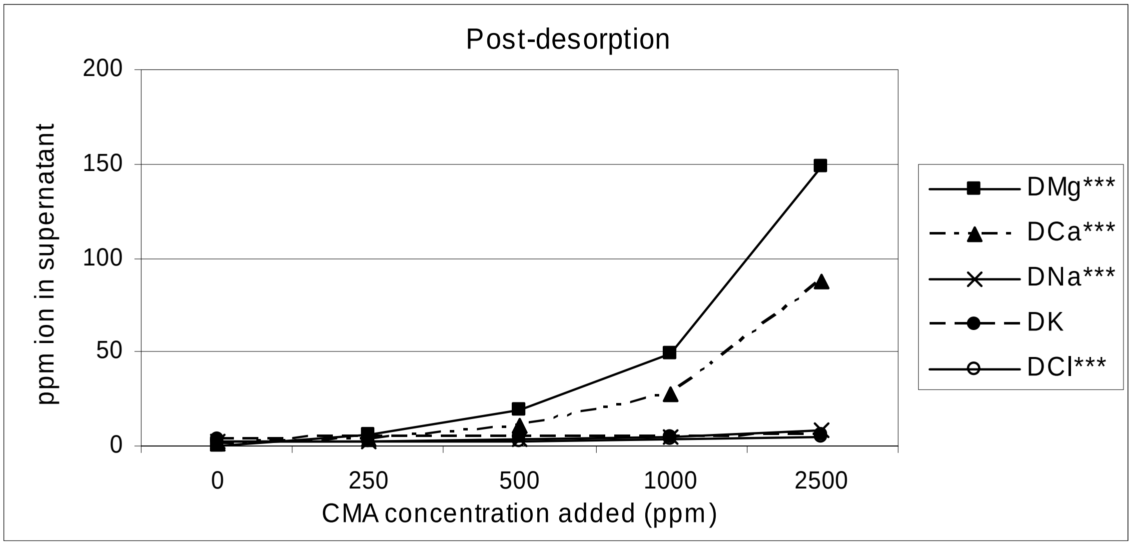
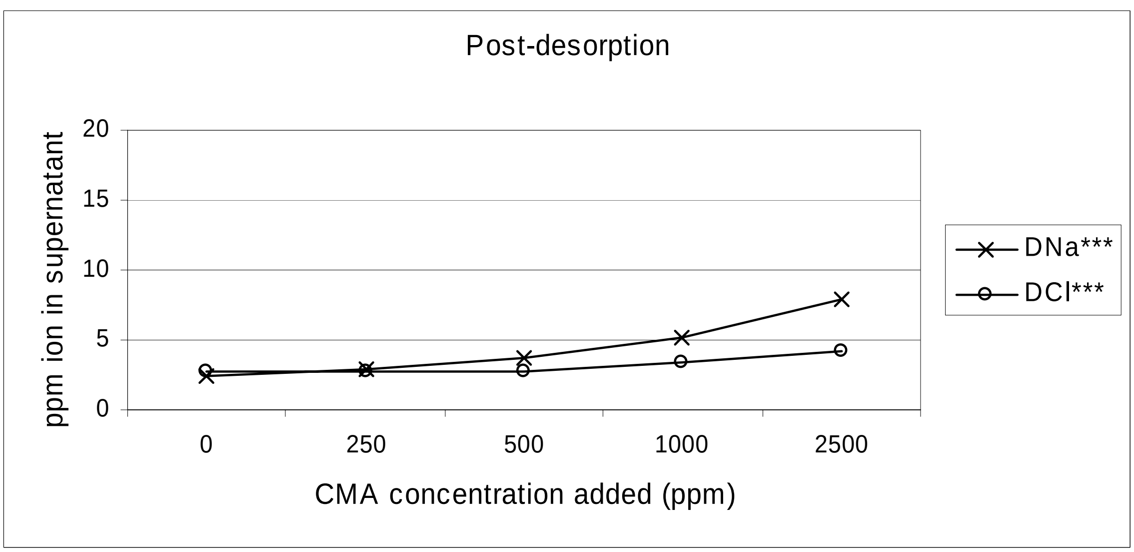


Figure 37. Concentration of Na and Cl in desorption supernatant (i.e., ions released from soil) after sorption with CMA at five concentrations and desorption with deionized water. Values are averages of five replicates. Asterisks indicate statistically significant differences by concentration (*** $P < 0.001$).



The soil was analyzed following the sorption/desorption cycle. Soil Mg increased significantly above that in the controls at all applied CMA concentrations. Ca in the soil was increased by CMA applications of 500 ppm or greater (Fig. 38). Neither Na nor K in the final soil were affected by CMA application (Fig. 38), however final soil Cl concentration was increased above that in the control at the 1000 and 2500 ppm CMA concentrations (Fig. 39). This may not be particularly meaningful, as all soils remained well below the baseline level of 7.5 ppm Cl found in the control treatments in the previous study of mineral salts.

Figure 38. Final soil concentration of ions after sorption and desorption with CMA at five concentrations.

Values are averages of five replicates. Asterisks indicate statistically significant differences by concentration (** *P*>0.001, <0.01, *** P< 0.001). See Figure 39 for an expanded view of the Na and Cl data.

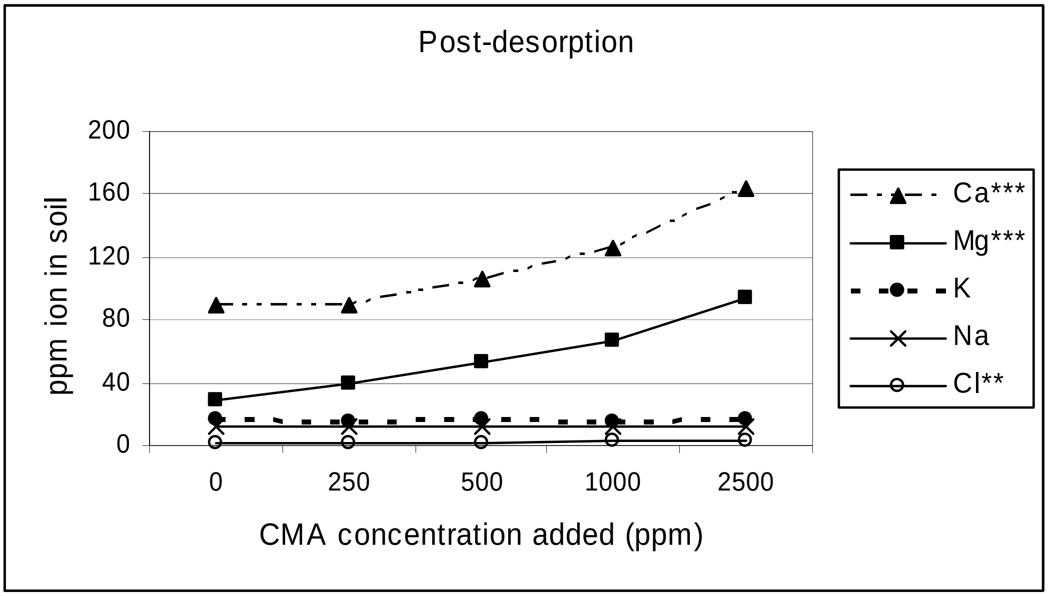
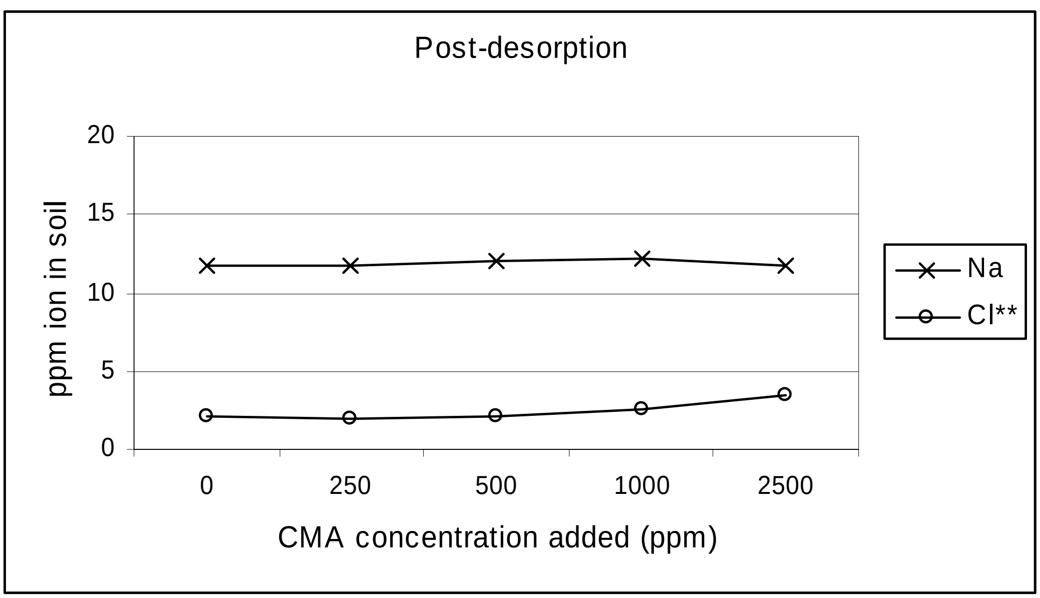


Figure 39. Final soil concentration of sodium (Na) or chloride (Cl) after sorption and desorption with CMA at five concentrations.

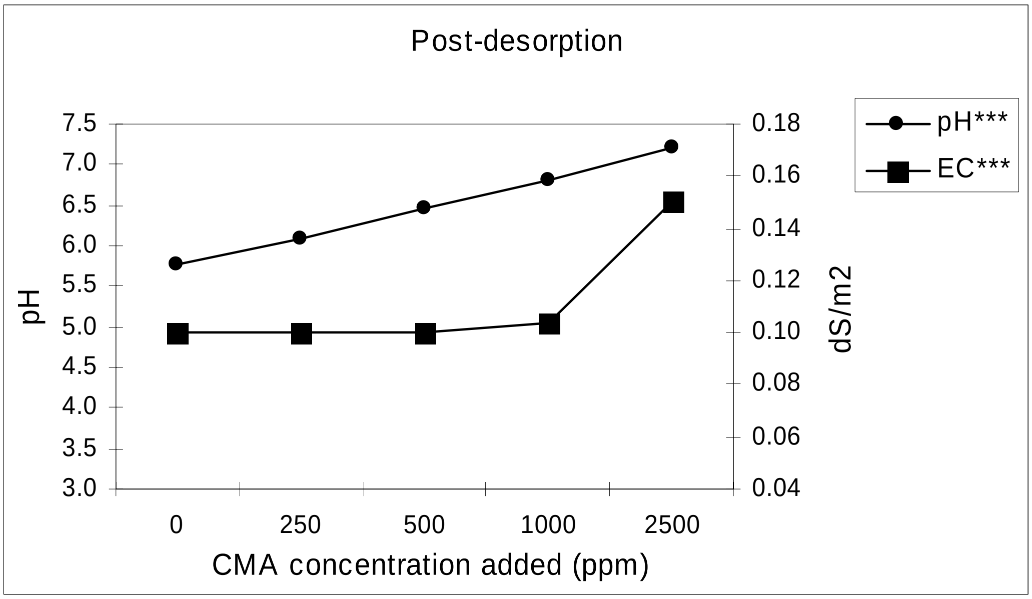
Values are averages of five replicates. Asterisks indicate statistically significant differences by concentration (** *P*>0.001, <0.01).



Soil pH increased linearly with CMA addition and all CMA treatments had pH values above 6.0, which is generally too high for cranberry production (Fig. 40). Soil conductivity was only increased in the 2500 ppm CMA treatment and in no sample did EC attain a level above 0.5 dSi/m^2.

Figure 40. Final soil pH and electrical conductivity (EC) after sorption and desorption with CMA at five concentrations.

Values are averages of five replicates. Asterisks indicate statistically significant differences by concentration (*** *P*< 0.001).



Results summary - Experiments 6 and 7

Cranberry soil appears to have a limited capacity for sodium and chloride loading. Based on supernatant examination, for both Na and Cl, the 250 ppm concentration seemed to result in little change to the soil chemistry. However, as added salt concentrations increased above 250 ppm, Na and Cl that loaded onto the soil was less readily released by leaching. In addition, as cations were added at higher concentrations, other cations are driven from the soil. This could be a problem if high Na levels depress the beneficial cations Ca, K, or Mg. However, the converse is also true, that is, Mg or Ca loading drove Na from the soil, indicating that Mg and Ca salts could be used for mitigating Na-contaminated cranberry soil.

Of the mineral salts examined, NaCl appeared to be the Cl source associated with the greatest Cl loading in the soil. Na was elevated similarly regardless of Na source. Addition of any salt increased soil EC as concentration increased but none of the mineral salts had detrimental effects on soil pH. It appears that exposure of cranberry soil to 250 ppm or less salt is unlikely to have long-term detrimental effects as long as leaching occurs, i.e. any absorped salt will leach away readily during rain events.

Adding CMA to cranberry soil led to an increase in soil Ca and Mg as might be expected. The apparent effect of CMA on soil pH was of some concern, with all concentrations studied resulting in soil pH greater than 6.0, the highest pH recommended for cranberry soil.

3.2.5 Experiment 8 - Remediation study.

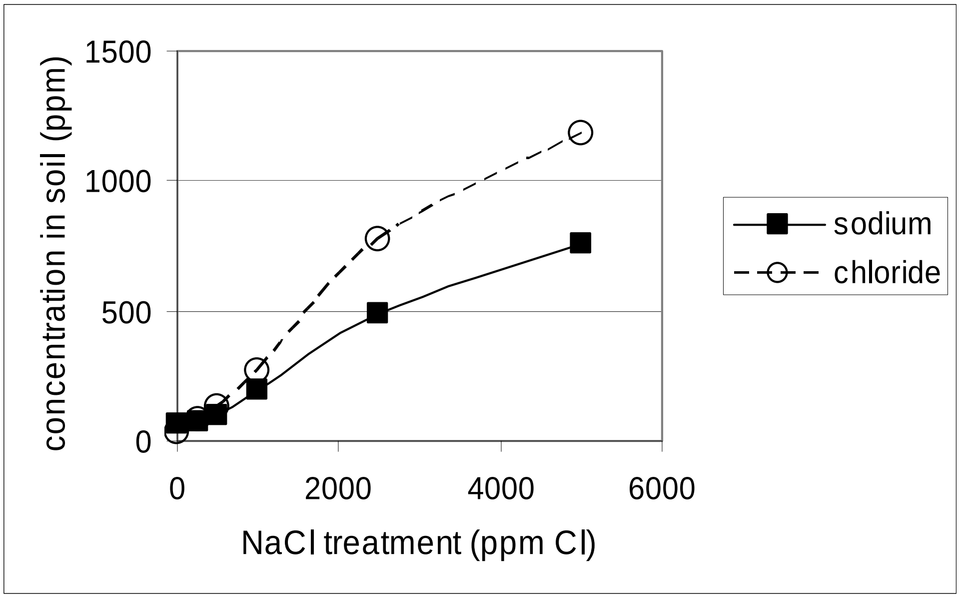
In order to study the effectiveness of Ca and K salts in remediating salt-laden cranberry soil, soil columns were established in the laboratory. Columns were loaded with concentrations of NaCl from 0 to 5000 mg/L Cl. One week after exposure, Na and Cl were elevated in both the bound and solution fractions of the soil (Figure 41). The solution fraction estimates plant-available Na and Cl in the contaminated soils. The remediation treatments were then applied.

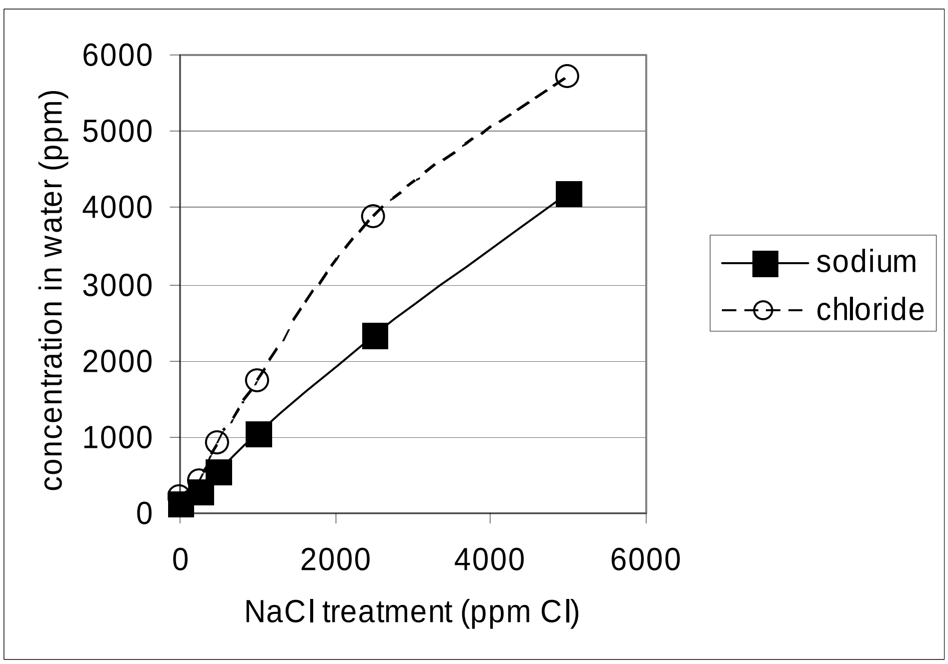
Remediation consisted of water alone (T1, equivalent of shallow flood) or fertilizer plus water (T2 = high fertilizer rate plus equivalent of seasonal rainfall, T3 = high fertilizer rate plus equivalent of shallow flood (T1 plus T2), T4 = high rate of fertilizer plus double seasonal water equivalent, T5 = lower fertilizer rate plus seasonal water equivalent (T2 with less fertilizer)). Shallow flooding was simulated using 2 pore-volume displacement, seasonal water equivalent was 10 inches, and double seasonal water equivalent was 20 inches. The fertilizer was a 25%/75% blend of gypsum (calcium sulfate) and SulPoMag (potassium magnesium sulfate) applied at a high rate (2 ton/acre) or low rate (500 lbs/acre).

Overall, the data support the conclusion that the addition of even moderate amounts of gypsum and SulPoMag can be expected to remediate salt contaminated soils, particularly if the annual rainfall is supplemented with additional flooding or irrigation (Figure 42). T4, where the fertilizer treatment was combined with twice the seasonal rainfall equivalent, resulted in soils with the lowest concentration of Na and Cl and came closest to returning the soil to the pre-contamination condition. An approximation of this treatment could be achieved in a field situation by applying the fertilizer in conjunction with a deep flood, followed by seasonal rainfall. However, T5 was also promising, being similar to T4 in comparison to initial soil values, and practical as it involves the addition of a more modest amount of fertilizer with no supplemental water beyond seasonal rainfall and irrigation. T5 also resulted in little change to the cation balance in the soil (Figure 43).

T1, flooding with no additional fertilizer, also was somewhat effective. This confirms the results of the sorption studies, showing that Na and Cl are readily flushed from cranberry soil depending on level of contamination.

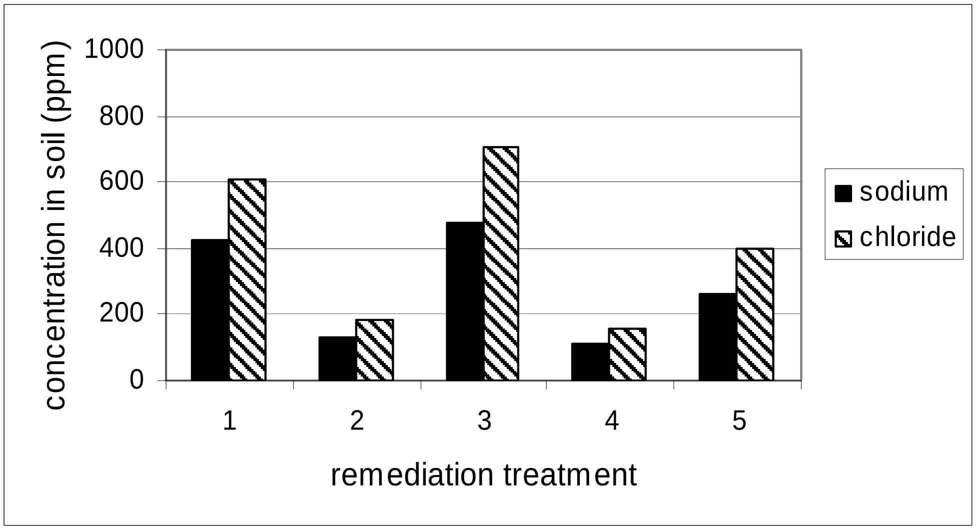
Figure 41. Soil (top) and leachate (bottom) Na and Cl content in salt-contaminated soils after salt application. Leachate concentration estimates amount available in soil solution.





T2 was somewhat effective but since the fertilizer rate was much higher than that of T5, for a roughly similar result, the additional cost for fertilizer would not be justified. Field trials of remediation treatments have been established at a contaminated site (see next section).

Figure 42. Soil Na and Cl content after contamination followed by remediation treatments (top) and comparison of Na and Cl soil concentrations prior to contamination with those following contamination and remediation (bottom).



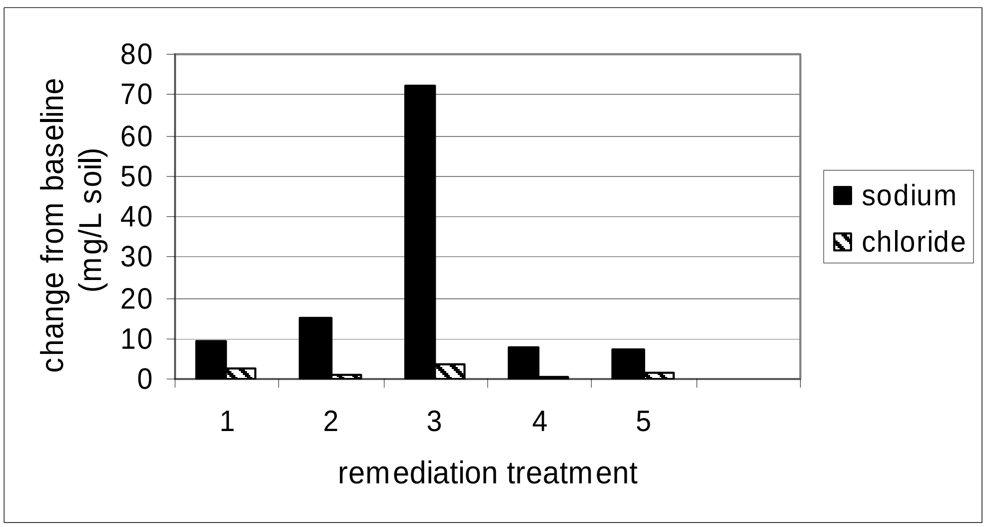
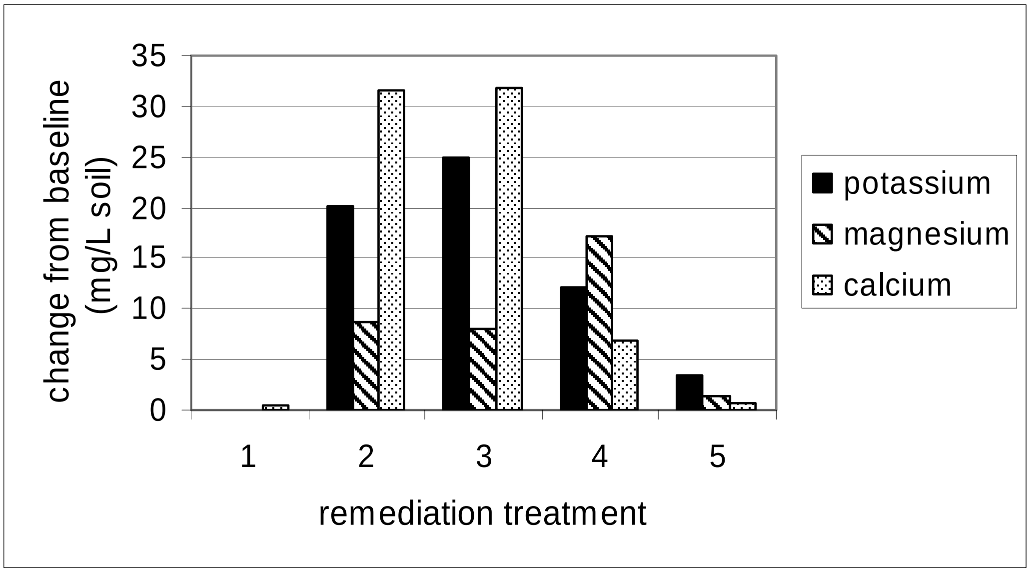


Figure 43. Comparison of soil K, Ca, and Mg content in soils prior to salt contamination to that following contamination and remediation treatments



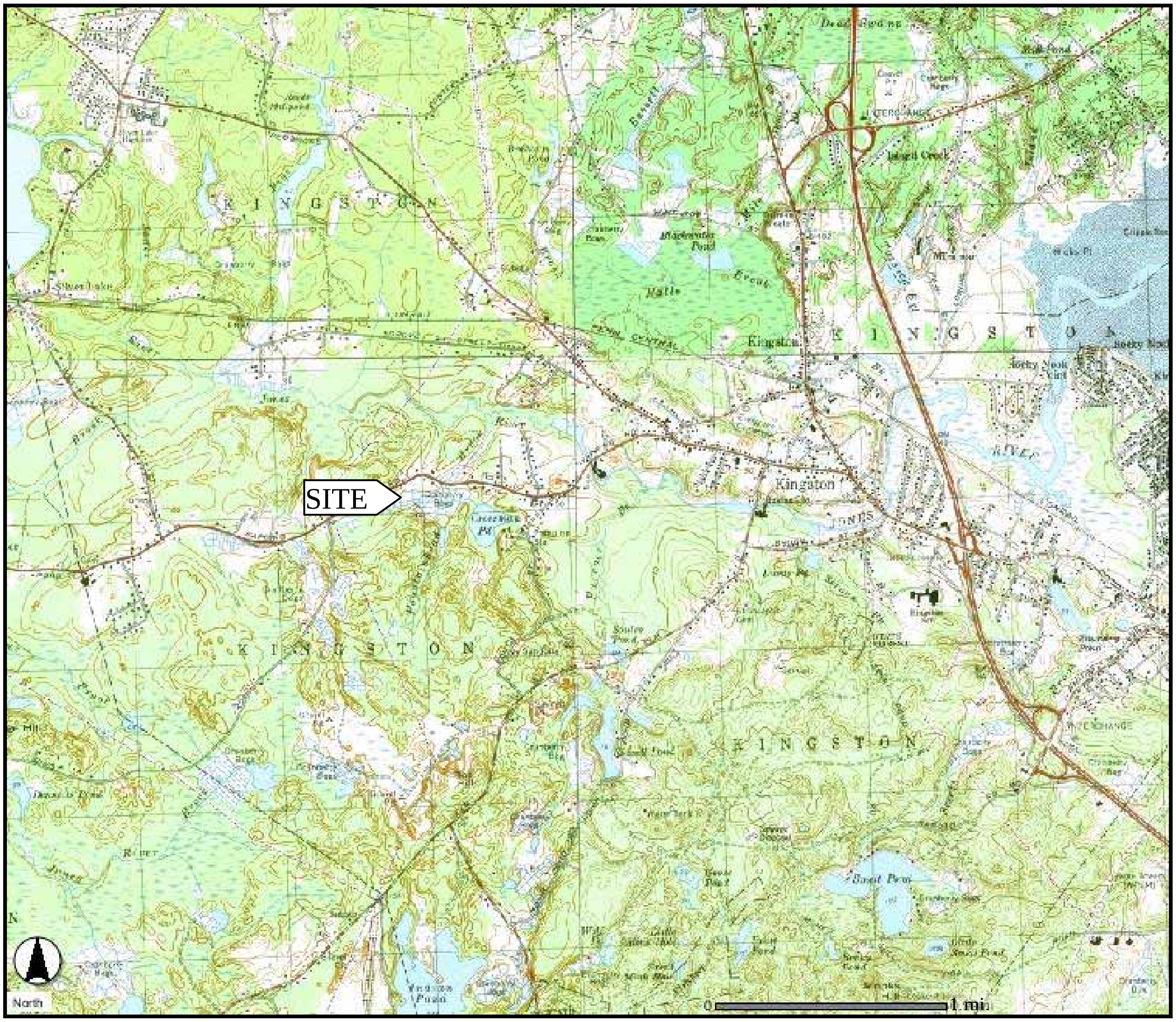
Results summary - Experiment 8

The addition of even moderate amounts of K, Mg, and Ca containing fertilizers helped to restore NaCl-loaded cranberry soil to pre-loading chemistry if the soil also received leaching (rainfall or flooding). In the laboratory, the best mitigation treatment was the equivalent of a high fertilizer rate (2 tons/acre) combined with the equivalent of a deep flood and seasonal rainfall. The equivalent of moderate fertilizer (500 lbs/acre) plus normal seasonal rainfall was also fairly successful at restoring salt-contaminated soil and had the additional advantage of little impact on the soil cation balance.

3.2.6 Experiment 9 - Monitoring of a cranberry bog receiving direct road runoff.

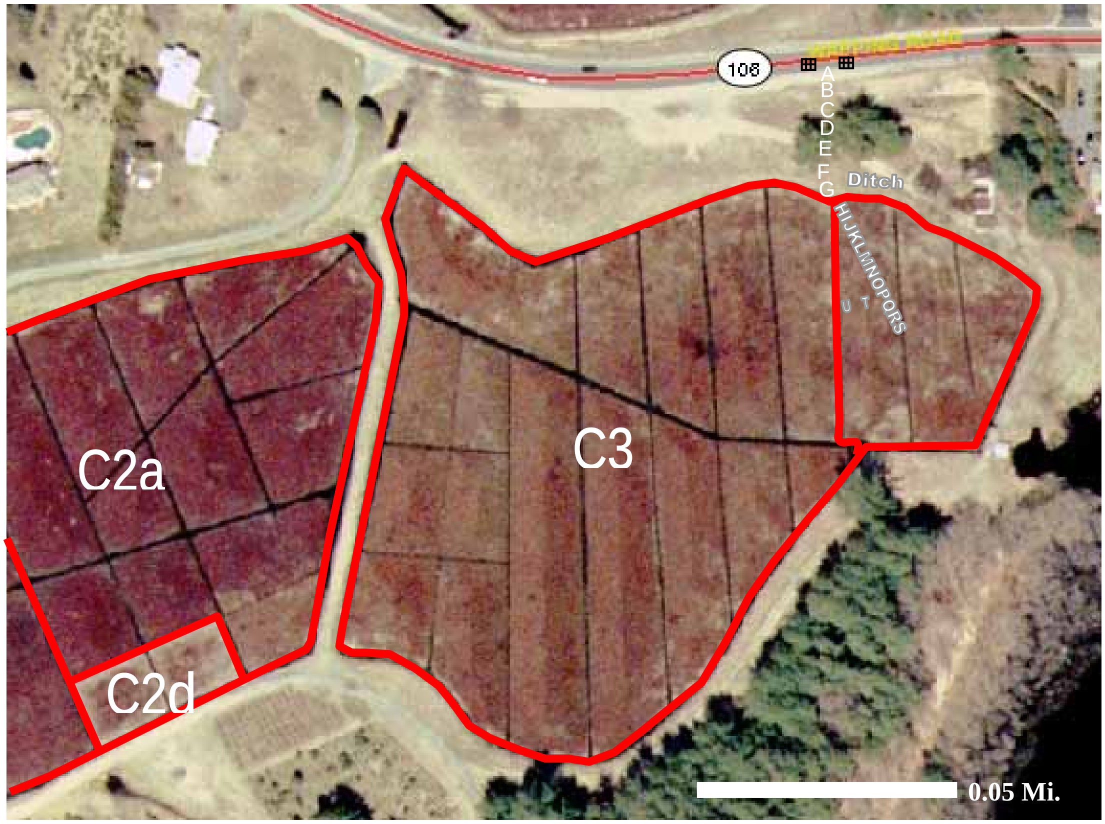
Two areas that receive direct road runoff were monitored at a commercial bog along Route 106 in Kingston, Massachusetts (figure 44). Two areas along Route 106 drain onto this property. One of these drains through a culvert directly into a perimeter bog ditch. The bog area (East Bog, Figure 45) adjacent to this outflow shows extensive die-back in the planting. In the other area (West Bog, Figure 46), the road drains onto the land surrounding the bog and infiltrates into the ground. Drainage puddles in an area adjacent to the bog but does not appear to run directly into the perimeter ditch.

Figure 44 Kingston, MA Bogs Locus Map



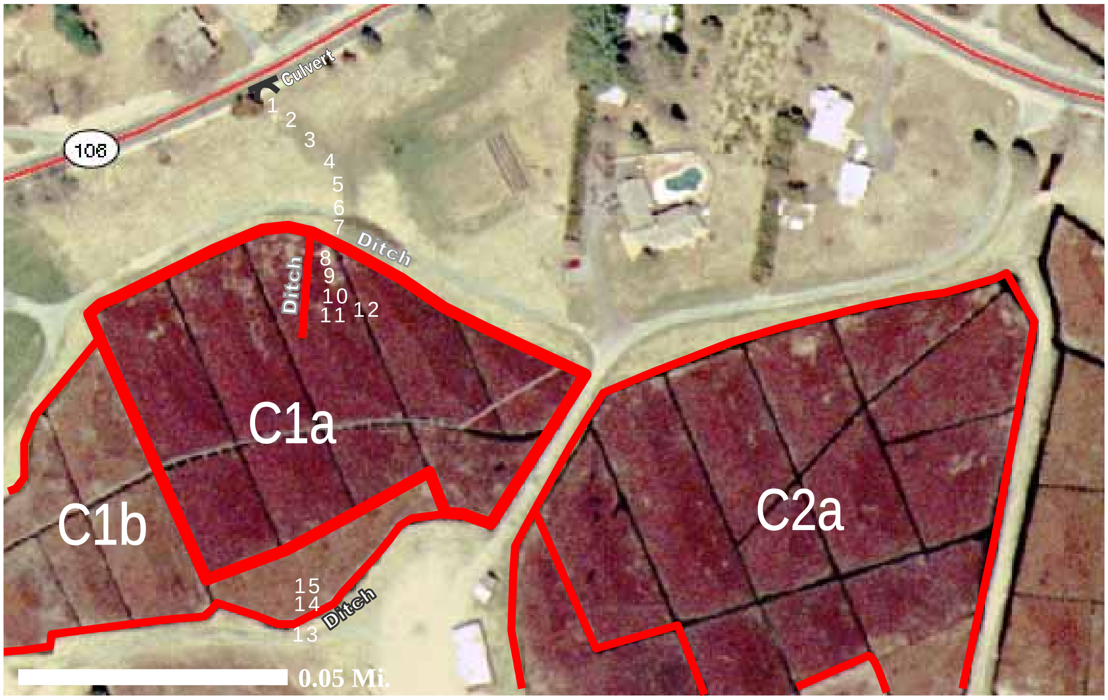
Source: MassGIS - USGS 25k Topographic Maps
Date accessed: June 27, 2005

Figure 45 East Field Sample Collection Points



Description: East field showing sample collection points. Samples A-F are off-bog soil. Sample G is the perimeter ditch at the point of discharge from the culvert. Samples H-U are on-bog soils extending through the area of dead plants. Samples W and X are on-bog soils distant from the highway and sample V is from the distant perimeter ditch. Mitigation plots are adjacent to the transect.

Figure 46 West Field Sample Collection Points



Description: West field showing sample collection points. Samples 1-6 are off-bog soil. Sample 7 is perimeter ditch. Samples 8-12 are on-bog. Samples 14 and 15 are on-bog at the point farthest from the road, sample 13 is the perimeter ditch distant from the highway.

Field sampling began in Spring of 2001 and continued through Fall 2004. Soil samples were collected along transects beginning near the road, crossing through the drainage ditch along the bog edge, and out into the bog itself. Samples were also collected at the opposite end of the bog system to serve as controls.

The soil test data for this project are shown in Figures 47 through 57. Control samples collected distant from the road edge, showed concentrations of up to 15 ppm Na and up to 7 ppm Cl in the cranberry soil. Since most control samples showed less than 6 ppm Cl, anything above 7 ppm would be cause for further investigation. This Cl action level is somewhat lower than that proposed based on greenhouse studies. Likely, the actual level of concern for cranberry soil Cl is somewhere between 7 and 10 ppm. Control soils in the sorption study contained ~7.5 ppm Cl.

Figure 47. Spring 2001, Na and Cl in soil (0-3 inch depth) from Mathias Bog, east site. Locations start at roadside (A) and move to bog edge (F); G is in bog ditch; H through M are in area of dead vines; N through U are moving away from the dead area out into the bog center; V is in ditch on opposite side of bog; W and X are on bog near distant ditch.

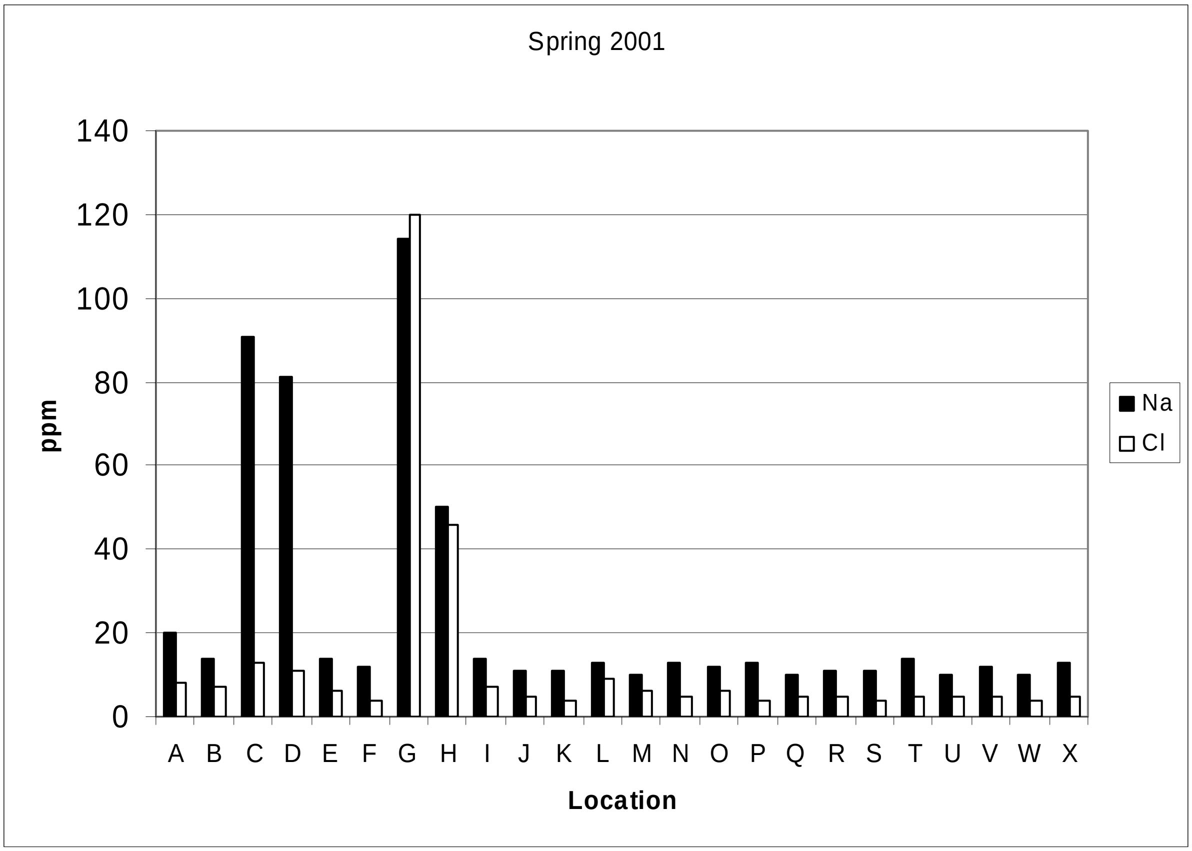


Figure 48. Spring 2001, Na and Cl in soil (0-3 inch depth) from Mathias Bog, west site. Locations start at roadside (1) and move to bog edge (6); 7 is in bog ditch; 8 through 12 are moving away from the ditch closest to road out into the bog center; 13 is in ditch on opposite side of bog; 14 and 15 are on bog near distant ditch.

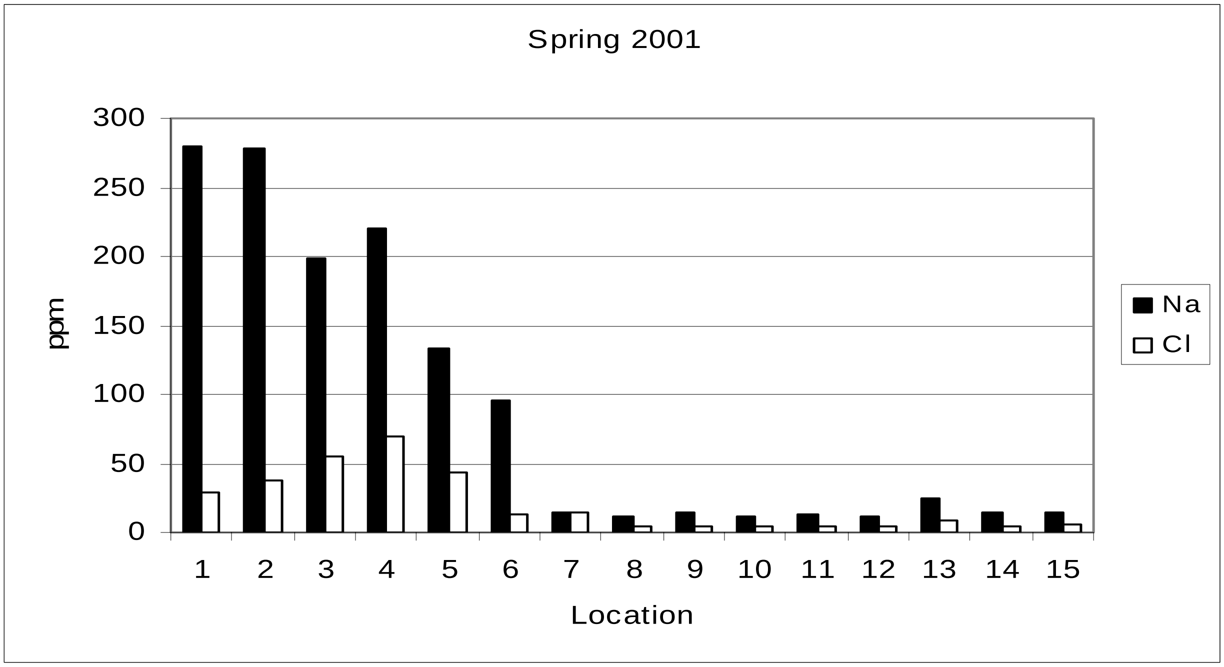


Figure 49. Fall 2002, Na and Cl in soil (top 4 inches) from Mathias Bog east site.

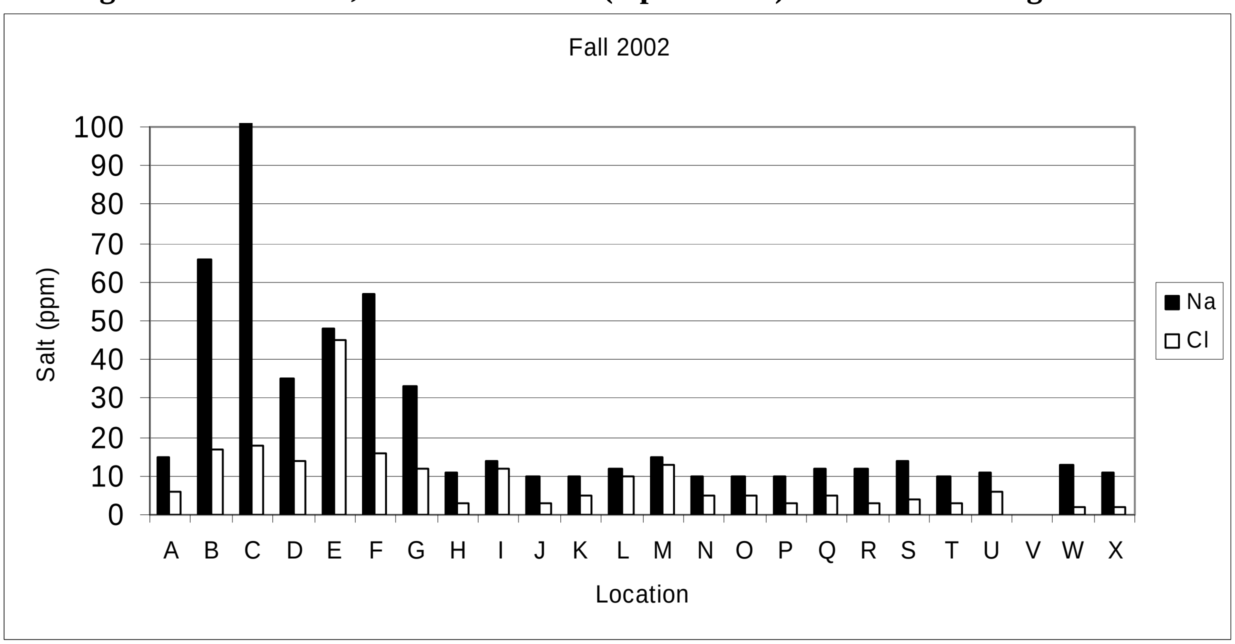


Figure 50. Fall 2002, Na and Cl in soil (0-3 inch depth) from Mathias Bog, west site.

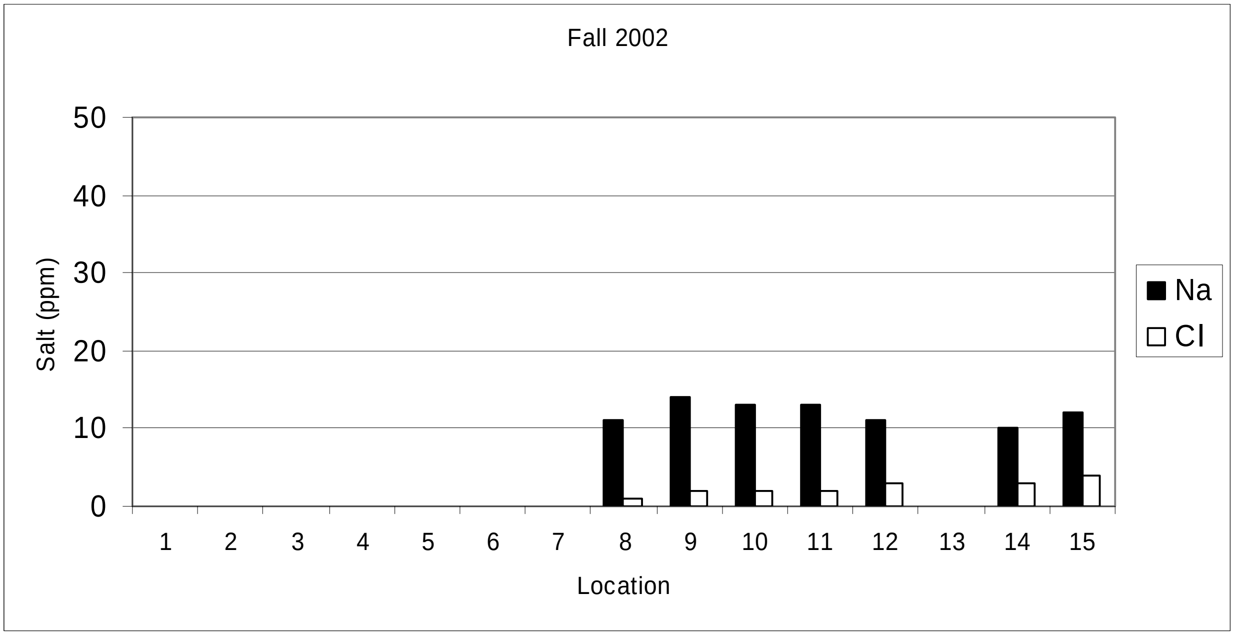


Figure 51. Spring 2003, Na and Cl in soil (top 4 inches) from Mathias Bog, east site.

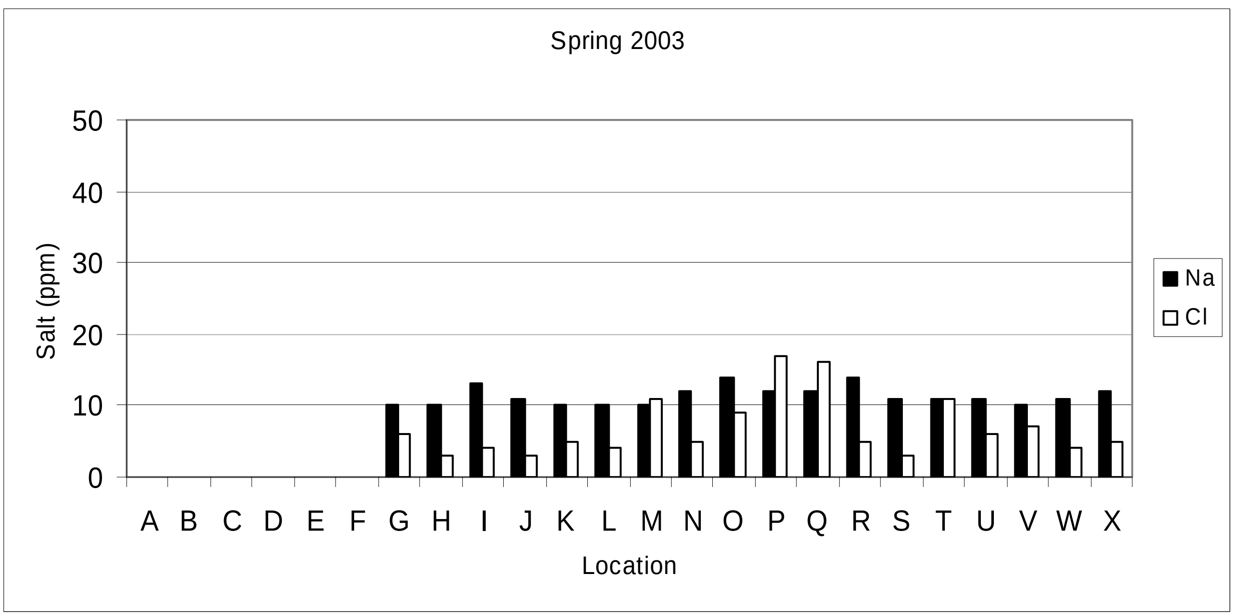


Figure 52. Spring 2003, Na and Cl in soil (0-3 inch depth) from Mathias Bog, west site.

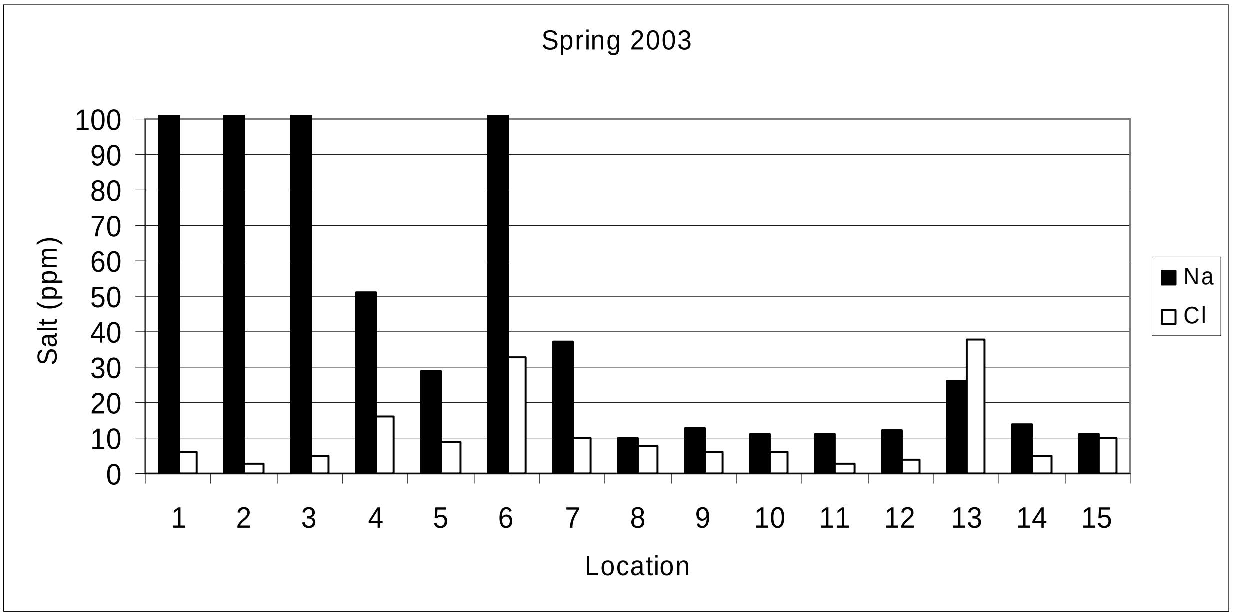


Figure 53. Fall 2003, Na and Cl in soil (0-3 inch depth) from Mathias Bog, west site.

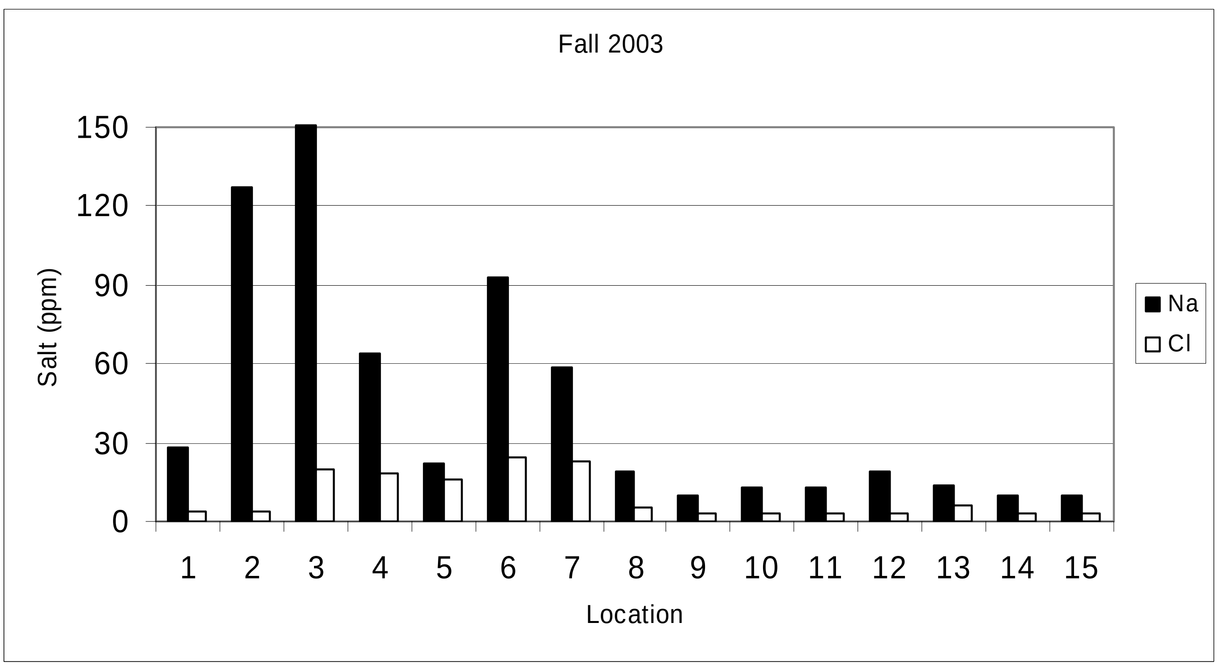


Figure 54. Spring 2004, Na and Cl in soil (top 4 inches) from Mathias Bog, east site.

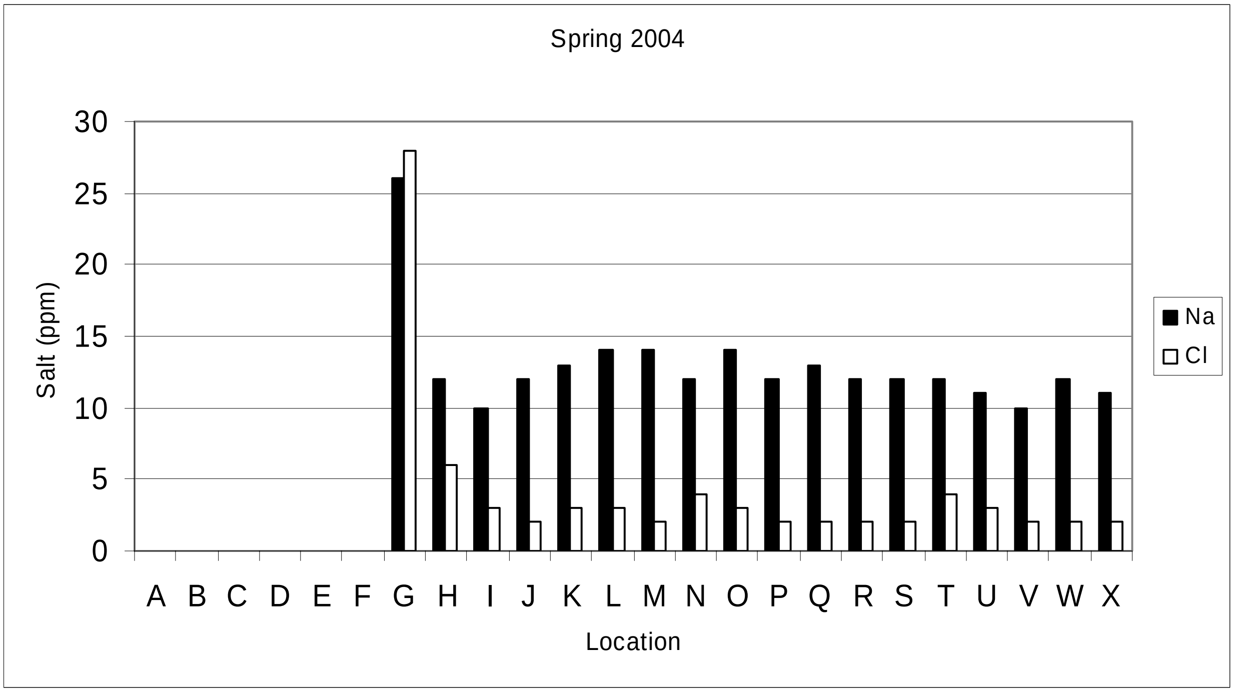


Figure 55. Spring 2004, Na and Cl in soil (0-3 inch depth) from Mathias Bog, west site.

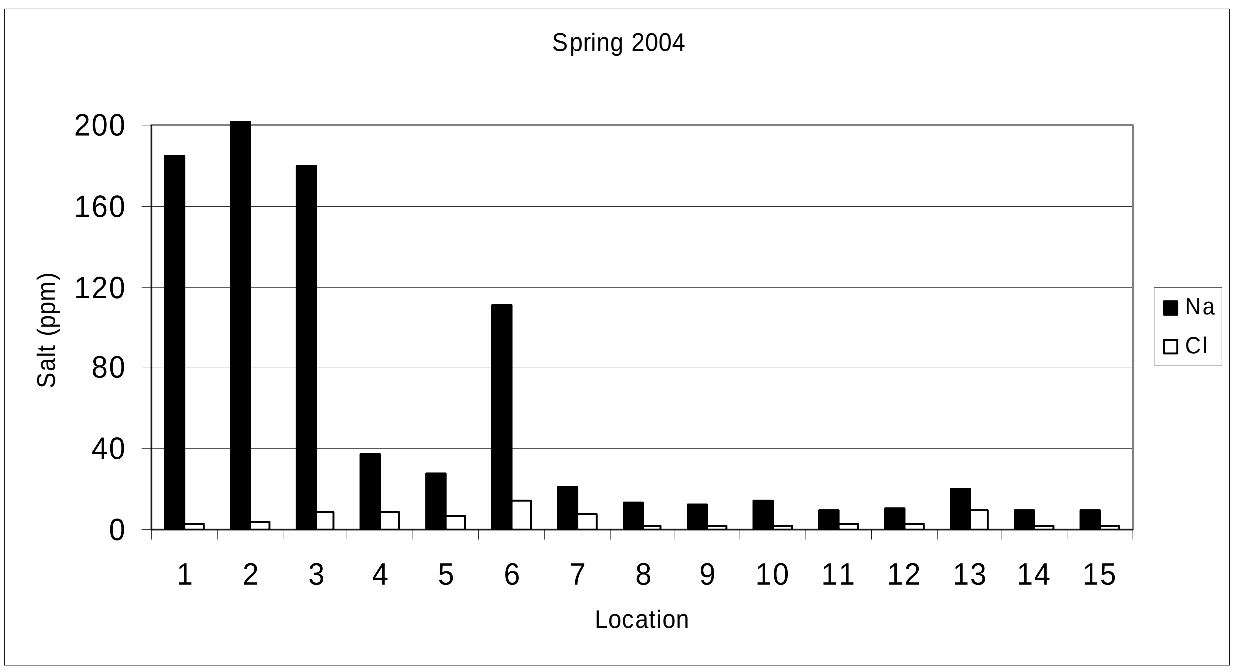


Figure 56. Fall 2004, Na and Cl in soil (top 4 inches) from Mathias Bog, east site.

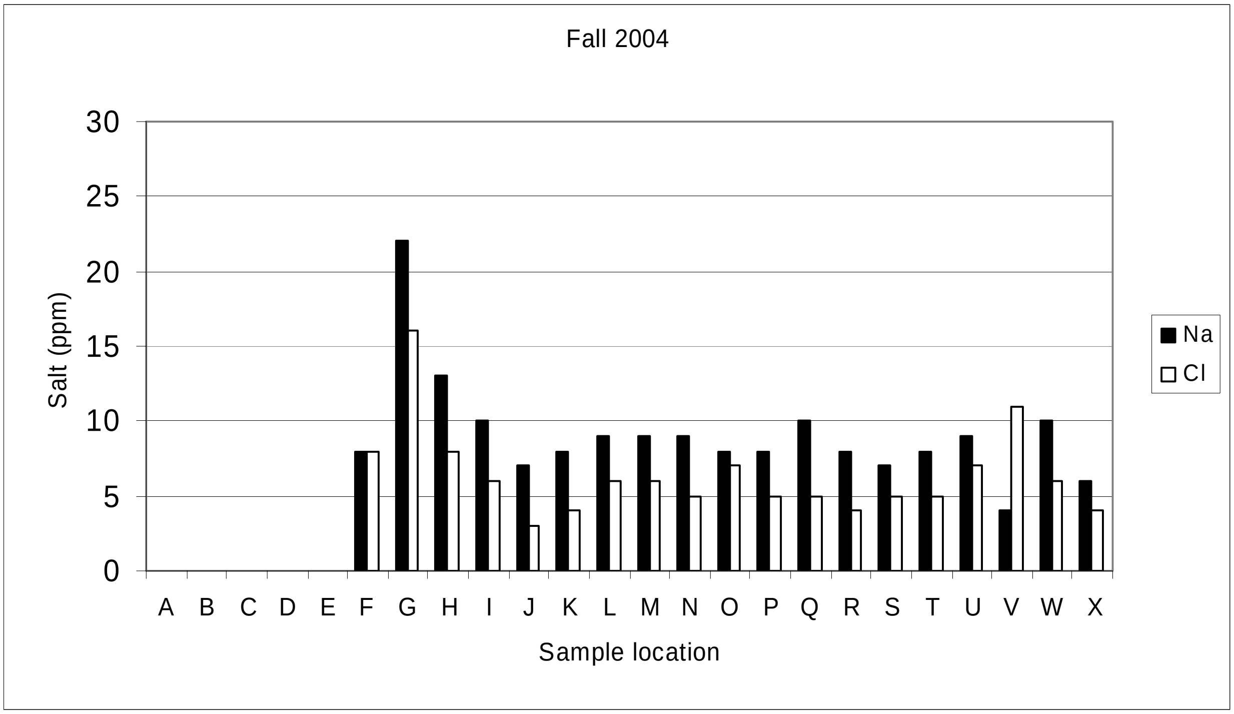
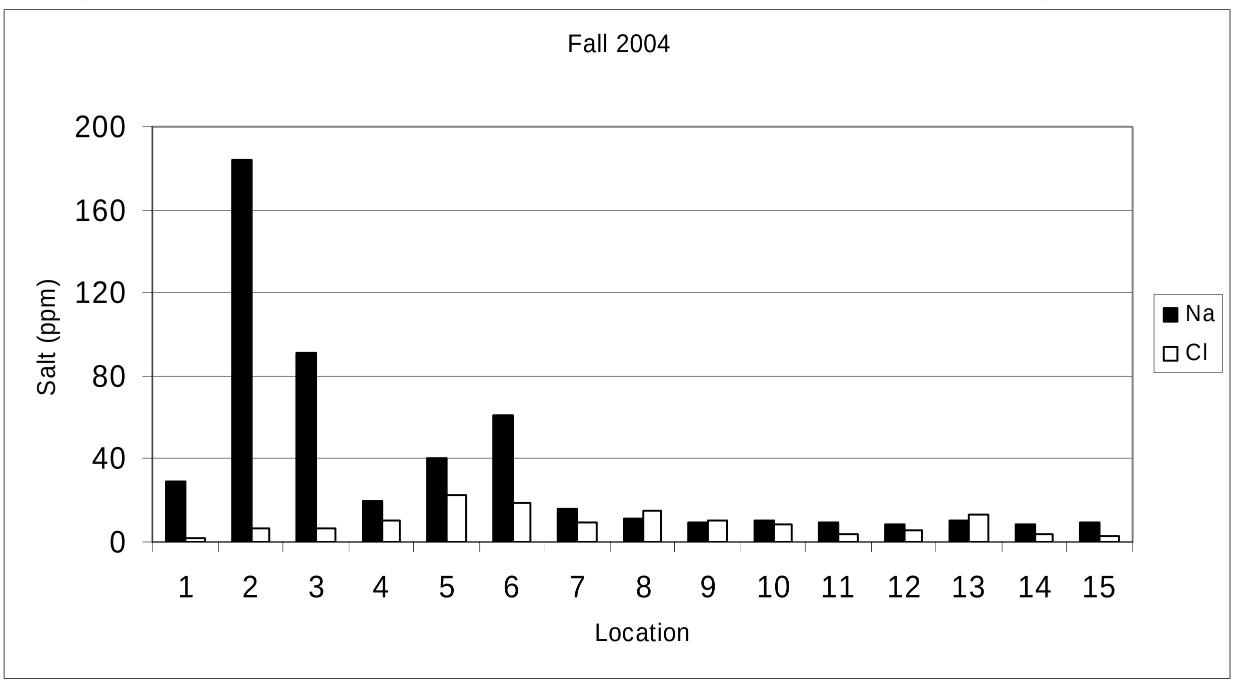


Figure 57. Fall 2004, Na and Cl in soil (0-3 inch depth) from Mathias Bog, west site.



After the winter of 2000, the water in the ditches along both transects (moving from the road onto the bog) was measured for Na, Cl, pH, and specific conductivity. The laboratory analytical results revealed high salt concentrations and conductivity compared to the control samples (locations V and 13) (Table 18). The elevated salt concentration from the ditch water along the numbered transect is of particular interest and concern, since to date, there is no visible damage on that bog. The lettered transect data is more predictable, since the drain pipe discharges directly into the perimeter ditch and since a large area of damage was already apparent.

Variation in conductivity of water samples was a good test for salt in water supplies or ditches, correlating with elevated salts. However, variability in soil conductivity measurements was negligible even when Na and Cl varied in the soil analysis, indicating that soil conductivity measurements are not a good field test for contamination, at least for low levels of contamination.

Table 18. Water analyses from Mathias bog. Spring 2001.

Location	Na mg/L	Cl mg/L	pH	Specific Conductivity μS/cm^2
At pipe dead end (location G)	17.4	33	6.15	155
43.5 ft from pipe, dead end (east of location G)	32.4	49	5.94	207
Far from road (location V)	6.0	8	5.83	60
Ditch near road, house location (location 7)	34.0	74	5.71	309
Ditch away from road, house location (location 13)	5.3	7	6.06	60

Along the lettered transect, an area of dead vines exists on the bog adjacent to the area receiving road runoff. Along that transect, most of the soil samples between the road and the ditch contained more than 2 times the normal Na and Cl (as high as 175 ppm Na and 45 ppm Cl). In the spring of 2001 (Figure 47) and the fall of 2002 (Figure 49), the mud in the ditch area for that transect was heavily loaded with both Na and Cl (sample G). In the spring of 2003 (very rainy spring), the ditch soil had returned to normal levels (Figure 51). In the initial samples (2001), on-bog Na and Cl were only elevated in the area immediately adjacent to the ditch (i.e., location H). The on-bog soil Na and Cl concentrations returned to normal levels at location I and remained low along the remainder of the transect. By Fall 2002, 3 of 6 samples collected in the area of dead vines showed elevated Cl and by the Spring of 2003, 3 samples further onto the bog (live vine area) had elevated Cl. Samples for this transect were not collected in Fall 2003. Spring and Fall 2004 samples show elevated Na and Cl in the ditch only (Fig. 54 and 56).

Along the second transect (numbered), there are no symptoms on the bog. Along that transect, the soils collected between the road and the bog edge were heavily loaded with Na and Cl (as high as 364 ppm Na and 70 ppm Cl). In spring 2001 and 2003 ditch samples (Figures 48 and 52) for this transect, Cl was elevated as was Na in 2003. By the spring of 2003, elevated Na and Cl were detected in ditch mud from the far side of this bog, indicating that salt had migrated throughout the drainage system. This may be attributed to large rain events in the spring of 2003 – samples were collected in May. In the fall of 2003 (Figure 53), Na and Cl in the ditch closest to the road remained elevated -- even though no salt had been applied since the end of the previous winter. In the spring of 2004, Na and Cl were elevated in all off-bog samples and in the ditch nearest to the road as well as that at the far side of the bog (Fig. 55). In the fall of 2004, Cl remained elevated in off bog and ditch samples (Figure 57) and for the first time, elevated Cl was found in on-bog samples nearest to the road, indicating that salt from the perimeter is moving into the bog.

Results summary - Experiment 9

Based on samples collected far from the influence of the road, it appears that uncontaminated cranberry soil should have no more than 15 ppm Na and 7 ppm Cl. The Cl value is similar to that found in control samples in the laboratory sorption/desorption study and a bit lower than that found in the greenhouse irrigation study. However, the greenhouse irrigation study controls received tap water that contains some Cl.

Soil values of Na and Cl are variable (5-50 ppm) even in areas showing damage. Most likely this is due to variation in seasonal rainfall. This is encouraging for sites where the runoff can be diverted -- recovery should occur due to natural leaching if the salt influx is removed. This is also predicted by the partial success of the water-only mitigation treatment in the laboratory.

3.2.7 Experiment 10 - Field remediation

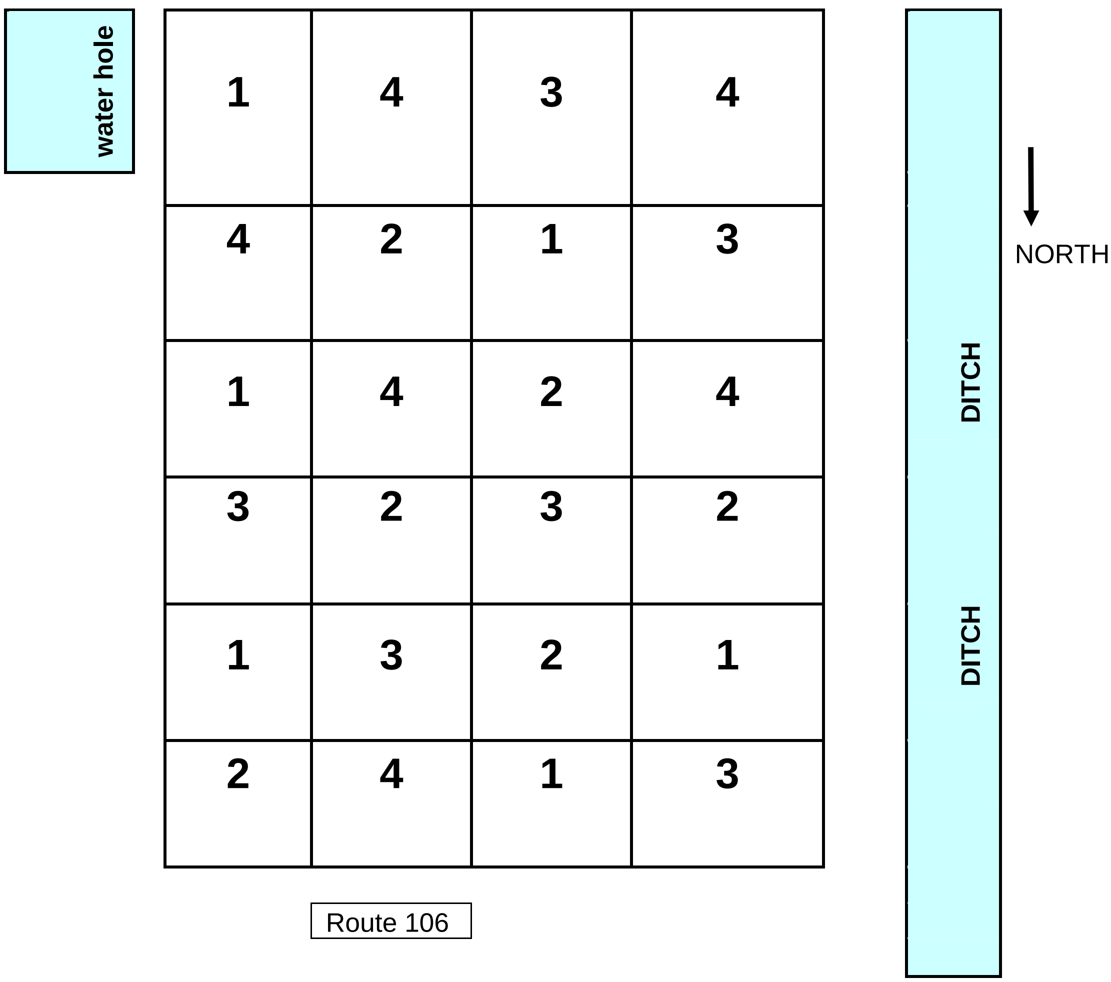
An area of the east field at the Kingston monitoring site has been used as the location for the mitigation field experiment. Treatments consisted of a mixture (1:3 ratio) of gypsum (calcium sulfate) and SulPoMag (potassium magnesium sulfate) applied at various rates (0, 250, 500 and 1000 lbs/acre of mixture) on 9 June 2003. A grid of 4 x 4 m plots was established with 6 replicate plots per treatment in a completely randomized design. The plot layout is shown in Figure 58.

Pre-treatment soil chemistry was compared to that 2, 5, and 11 months after treatment. The results for Na and Cl are shown in Figure 59. None of the treatments appeared to have any effect on soil Na levels (Figure 59, top). Soil Cl declined with time in all treatments when compared to pre-treatment levels. This indicates that the effects of precipitation, flooding and irrigation may have overshadowed the effect of the fertilizer application. However, even pre-treatment, soil Na and Cl levels were not elevated above the level expected in uncontaminated soil.

The soil was also analyzed for content of K, Ca, and Mg. Since all are contained in the fertilizer treatment, it was not surprising that all three increased in the plots receiving fertilizer, but not in the control plots (data not shown). After 11 months, all soil cations in all treatments had returned to pre-treatment levels, indicating that the fertilizer had been taken up by the plants and/or been leached from the soil.

Figure 58. Plot layout for field mitigation study

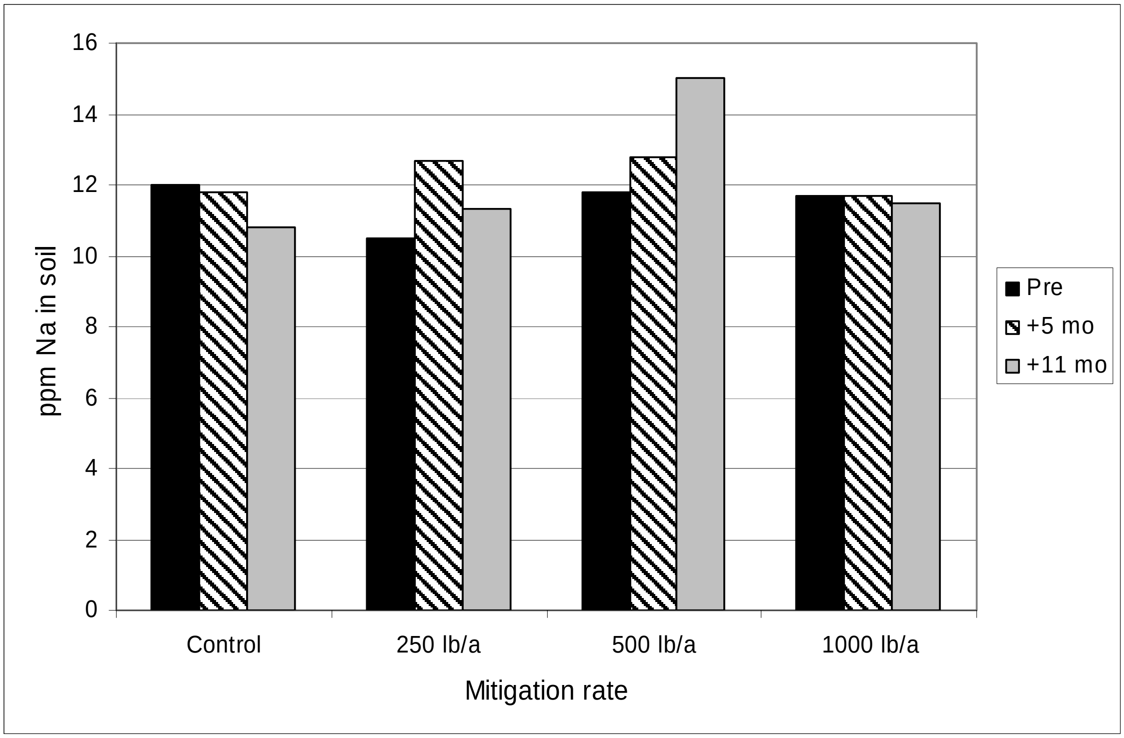
Mitigation Study   Mathias Bog - Kingston

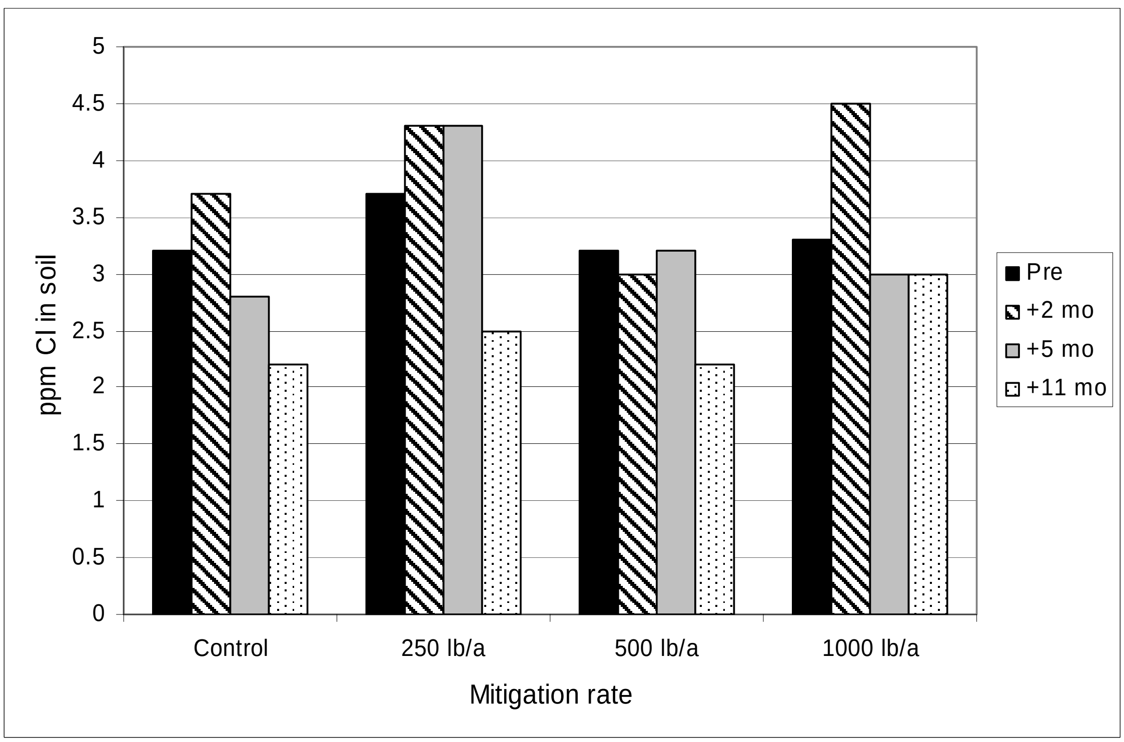


Plots are 4m per side   6 replicatess

Treatments	CaSO4/SulPoMag
1 - Control	none
2 - 250 lbs/acre	112 g / 336 g
3 - 500 lbs/acre	224 g / 672 g
4 - 1000 lbs/acre	448 g / 1344 g

Figure 59. Soil Na (top) and Cl (bottom) before and after field mitigation treatments.





Fourteen months after the application of the mitigation treatments, the plots were visually surveyed and percent ground cover was estimated. Pre-treatment, the plots were only sparsely vined. The vine cover percents, 14 months after treatment are shown in Table 19. While the soil analyses showed no treatment variation, there was a difference in visual appearance of the plots depending on treatment. Fertilizer application at 500 or 1000 lbs/acre was associated with increased vine cover compared to that in plots receiving 0 or 250 lbs/acre.

Table 19. Percent vine cover in mitigation study plots, 14 months after fertilizer application. Data are the means of 6 replicates.

Treatment	Percent vine cover
Control (no fertilizer)	60
250 lbs/acre fertilizer	44
500 lbs/acre fertilizer	72
1000 lbs/acre fertilizer	78

Results summary - Experiment 10

Application of common fertilizer materials, without any change in water management, appears to assist in vine recovery in salt-injured cranberry bogs. This is in agreement with the results of laboratory mitigation studies in which application of 500 lbs/acre fertilizer with watering equivalent to normal seasonal rainfall restored soil chemistry in salt-contaminated cranberry soil.

4.0 Conclusions

Based on greenhouse, laboratory, and field research results, conclusions were drawn regarding the initial questions posed in the problem statement and project objectives.

Monitoring of soil and water at the Mathias bog confirmed that salt runoff from roads can migrate into cranberry bogs. Sand culture and soil-free culture studies of cranberry plants exposed to salt showed that depending on salt and concentration, adverse effects on cranberry growth, flowering, and soil composition could be induced. Soil chemistry studies determined that recovery from extensive salt loading was poor but that at more moderate loads, cranberry soils could be restored to original chemistry through leaching with or without the addition of fertilizers. Concentrations of Na and Cl to be expected in uncontaminated cranberry soil were defined as were concentrations of Na and Cl in cranberry plant tissue above which concern should be raised. Finally a recommended level for concern regarding Cl in cranberry water supplies was proposed.

Project objectives:

1. *Define the critical level for salt in cranberry irrigation water, i.e. the minimum concentration associated with adverse effects.*

In greenhouse studies, adverse effects to cranberries were seen after long-term exposure to 100 ppm Cl in irrigation water. These effects included elevated Na and Cl in the plants and soil, visible symptoms on the leaves, and possible vegetative growth stimulation. At 250 ppm, symptoms increased and flowering was suppressed.

In soil-free culture, growth was suppressed at 500 ppm Cl, at higher concentrations plants exhibited severe leaf drop and eventual death. At the 100 ppm concentration, growth effects were not significant but at the end of the study, plants exposed to 100 ppm Na has produced more vegetative growth than control plants and exposure to Na or Cl at 100 ppm resulted in elevated tissue Na and Cl, respectively.

In soil chemistry studies, treatment with concentrations of Cl greater than 250 ppm resulted in significant, only partially reversible, changes to cranberry soil chemistry. At 250 ppm, recovery occurred with leaching.

Based on the research results, there is good indication that a cranberry water supply containing Cl at 250 ppm or greater would be cause for great concern and indicate the potential need for remedial action. Symptoms, soil chemistry changes, and possible growth stimulation at 100-125 ppm Cl indicate that a cranberry water supply containing 100 ppm or greater Cl for extended periods might also be cause for concern.

Taking all of these results into account, setting the level of concern for Cl in cranberry irrigation water at 100 ppm appears warranted. This is well below the 250 ppm that was definitively associated with negative effects in greenhouse experiments and the 500 ppm that negatively affected growth in soil-free culture. Therefore, 100 ppm Cl is proposed as the level at which closer scrutiny of a water supply over time would be warranted. If the 100 ppm level persisted for more than 2 months, particularly during the irrigation season, chronic effects might become a concern. This Cl level is equivalent to the Cl in ~165 ppm NaCl.

However, the possible growth stimulation effect at 100-125 ppm and the elevation in tissue Na and Cl at all concentrations, warrants consideration for further investigation.

Based on an examination of data from control samples in the greenhouse and laboratory and field samples from uncontaminated sites, one should expect to find the levels for Na and Cl proposed in the table below in uncontaminated cranberry plants and soil. Levels consistently greater than these could be cause for concern. Damage to cranberry bogs associated with 15 ppm Cl in the soil has been previously reported (Chandler and Demoranville, 1959).

The soil Cl value is similar to that found in control samples in the laboratory sorption/desorption study and in the field collections and a bit lower than that found in the greenhouse irrigation study controls. However, the greenhouse irrigation study controls received tap water that contains some Cl, that may explain the higher soil Cl.

	Proposed background levels for Na	Proposed background levels for Cl
Cranberry soil	Up to 15 ppm	7 ppm
Cranberry shoot tissue	~ 0.06% dry weight	~ 0.05% dry weight
Cranberry root tissue	~0.03% dry weight	~0.05% dry weight

2. *Determine the lowest salt concentration at which a single overspray adversely affects cranberry plant growth (acute effect).*

When soil flushing was present, cranberry plants appeared to tolerate single exposures to irrigation containing salt concentrations as high as 5000 ppm. Acute exposure twice in 16 weeks to concentrations of salt as high as 7500 ppm also had minimal effect on cranberry growth but tissue Na was elevated.

More frequent exposures to concentrations as high as 2500 ppm also appear to be tolerated in the presence of soil flushing. Compared to the $MgSO_4$ treatment, intermittent treatment with any salt containing Na or Cl was associated with increased shoot growth. This may indicate a tendency to increased vegetative growth when cranberries are exposed periodically to high concentrations of Na or Cl.

If exposure to high salt concentrations is only infrequent, and natural leaching is present, cranberries should tolerate such exposures. In the field, this would be accomplished by rainfall or irrigation. However, if exposure continues intermittently, there is some indication that vegetative growth might be stimulated.

In soil-free culture, exposure to concentrations of as low as 100 ppm CMA killed cranberry plants within 5 days. However, in a field situation, CMA would be expected to react with the soil, attenuating potential effects.

3. *Determine the impact on cranberry growth and yield of chronic exposure to low salt concentrations.*

In two greenhouse studies of chronic salt exposure with periodic soil flushing, growth effects on cranberry were equivocal. In the first study, growth was unaffected but tissue Na and Cl was elevated at the 625 ppm concentration and leaf spotting was observed. In the second study, growth appeared to be slightly suppressed in cranberries receiving chronic exposure to 250 and 625 ppm concentrations of salt but possibly stimulated at 125 ppm.

In a third greenhouse study, chronic exposure with no soil flushing was studied. All salts and concentrations were associated with an increase in leaf symptoms compared to the controls and with elevated Na and/or Cl in the plant tissue and in the soil. Leaf symptoms generally consisted of reddening and eventual leaf drop. After chronic exposure to 100 ppm Cl, symptoms were severe, soil chemistry was out of balance, tissue levels of Na and/or Cl were elevated, and vegetative growth may have been stimulated. At 250 ppm, symptoms worsened and flowering was suppressed.

Consideration for further investigation of potential growth and yield effects in a field setting is indicated may be warranted.

4. *Determine the effect of salt loading on nutrient management in cranberry production with specific reference to cranberry soil chemical characteristics. Investigate the use of electrical conductivity measurement as a field monitoring tool.*

Cranberry soil appears to have a limited capacity for sodium and chloride loading. Based on supernatant examination after sorption, for both Na and Cl, the 250 ppm concentration seemed to result in little change to the soil chemistry. However, as added salt concentrations increased above 250 ppm, Na and Cl that loaded onto the soil was less readily released by leaching. In addition, as cations were added at higher concentrations, other cations are driven from the soil. This could be a problem if high Na levels depress the beneficial cations Ca, K, or Mg. However, the converse is also true, that is, Mg or Ca loading drove Na from the soil, indicating that Mg and Ca salts could be used for mitigating Na-contaminated cranberry soil.

Of the mineral salts examined, NaCl appeared to be the Cl source associated with the greatest Cl loading in the soil. Na was elevated similarly regardless of Na source. Addition of any salt increased soil EC as concentration increased but none of the mineral salts had detrimental effects on soil pH. It appears that exposure of cranberry soil to 250 ppm or less salt is unlikely to have long-term detrimental effects as long as leaching occurs, i.e. any absorbed salt will leach away readily during rain events.

Adding CMA to cranberry soil led to an increase in soil Ca and Mg as might be expected. However, CMA addition at high concentrations also appeared to increase plant availability of Na and to a lesser extent Cl. Of more concern was the apparent effect of CMA on soil pH, with all concentrations studied resulting in soil pH greater than 6.0, the highest pH recommended for cranberry soil.

Variation in conductivity of water samples was a good test for salt in water supplies or ditches, correlating with elevated salts at the Mathias site. However, variability in soil conductivity measurements was negligible even when Na and Cl varied in the soil analysis, indicating that soil conductivity measurements are not a good field test for contamination, at least for low levels of contamination.

5. *Investigate treatments to remediate salt exposed cranberry soils.*

The addition of even moderate amounts of K, Mg, and Ca containing fertilizers helped to restore NaCl-loaded cranberry soil to pre-loading chemistry if the soil also received leaching (rainfall or flooding). In the laboratory, the best mitigation treatment was the equivalent of a high fertilizer rate (2 t/a) combined with the equivalent of a deep flood and seasonal rainfall. The equivalent of moderate fertilizer (500 lb/a) plus normal seasonal rainfall was also fairly successful at restoring salt-contaminated soil and had the additional advantage of little impact on the soil cation balance.

Application of the common fertilizer materials, SulPoMag and gypsum (3:1 ratio) without any change in water management, appeared to assist in vine recovery at a salt-injured cranberry site. Fertilizer rates of 500 and 1000 lb/a were equally effective.

6. *Produce a chart of sodium (Na) and chloride (Cl) levels versus cranberry yield potential.*

Completion of this objective was removed from the scope of the agreement. However, 100 ppm Cl is proposed as the level of concern for cranberry water supplies. Cl at that level or greater over a period of 2 months or more is likely to be associated with adverse effects. Levels approaching 250 ppm Cl should be cause for concern. Levels expected for Na and Cl in uncontaminated cranberry soil and tissue samples (table above) should be used as a standard for comparison for samples collected from sites where salt contamination is suspected or where Cl in the water supply is at or above 100 ppm Cl.

5.0 Recommendations

Establish 100 ppm Cl as an interim level of concern for cranberry water supplies. Cl at that level or greater over a period of two months or more is likely to be associated with adverse effects.

Further research should be conducted, including field exposures, to confirm the 100 ppm Cl level of concern for cranberry water supplies.

Levels equal to or greater than 250 ppm Cl in a cranberry water supply should be cause for more immediate concern and a trigger for corrective action.

At sites where salt contamination is suspected or where the 100 ppm Cl level of concern is reached, the following baseline levels as standards of comparison can be used in a monitoring program in which cranberry soil and plants are sampled:

	Proposed baseline levels for Na	Proposed baseline levels for Cl
Cranberry soil	Up to 15 ppm	7 ppm
Cranberry shoot tissue	~ 0.06% dry weight	~ 0.05% dry weight
Cranberry root tissue	~0.03% dry weight	~0.05% dry weight

6.0 Appendices

APPENDIX 1

Nutrient solutions for soil-free culture

Hydroponics:

$MgSO_4$	0.120 g/L
KH_2PO_4	0.136 g/L
$CaCl_2 \cdot H_2O$	0.147 g/L
K_2SO_4	0.89 g/L
NH_4SO_4	0.264 g/L
Fe Sequestrene 30	0.050 g/L
H_3BO_3	1.430 mg/L
$MnCl_2 \cdot 4H_2O$	0.905 mg/L
$ZnSO_4 \cdot 7H_2O$	0.444 mg/L
$CuSO_4$ anhydrous	0.063 mg/L
Mo_3 (85%)	0.018 mg/L

Aeroponics:

$MgSO_4$	0.120 g/L
KH_2PO_4	0.0.68 g/L
$CaCl_2 \cdot H_2O$	0.147 g/L
K_2SO_4	0.89 g/L
NH_4SO_4	0.132 g/L
Fe Sequestrene 30	0.017 g/L
H_3BO_3	0.715 mg/L
$MnCl_2 \cdot 4H_2O$	0.453 mg/L
$ZnSO_4 \cdot 7H_2O$	0.222 mg/L
$CuSO_4$ anhydrous	0.032 mg/L
Mo_3 (85%)	0.009 mg/L

APPENDIX 2

Abstracts from papers presented at ASHS-01. HortScience 36: 571.

Water and fertilizers for remediation of salt affected cranberry soils.
J. R. Davenport*, Washington State University Irrigated Ag Research and Extension Center, Prosser, WA; C. J. DeMoranville, UMASS Cranberry Experiment Station, E. Wareham, MA; T. R. Roper, University of Wisconsin, Madison, WI;
In southeastern Massachusetts, cranberry bogs adjacent to roads can show damage due to contamination from salt (NaCl) applied to the roads for deicing. Soils, which have been characterized as having salt levels beyond those acceptable to cranberry production are likely to require some type of remediation. In saline-sodic soils in arid regions of North America, either gypsum, calcium chloride or sulfur, plus leaching are used in combination to remediate affected soils. Cranberries grow in a higher precipitation area so that natural rainfall will help ameliorate a saline or sodic situation. However, in a severe situation, additional remediation may be needed. To evaluate potential remediation treatments, three characteristic cranberry soils were collected and placed into columns as intact cores. The soils were treated with NaCl at different levels to develop a salt affected chemistry. The salt treated soils were then subjected to remediation treatments with low to high levels of a calcium-potassium-magnesium sulfate fertilizer blend and leached with water ranging from ranges commonly applied during the season for production to rates equivalent to a winter flood. After remediation both the soils and any leachate from the columns were analyzed for pH, cation (Na, Ca, K, Mg) and Cl content. Overall, adding the calcium-potassium-magnesium sulfate fertilizer blend decreased Na in the soils and leachates when compared to using water alone. These results suggest that use of the fertilizer blend would be more favorable than using water alone to remediate salt affected cranberry soils.

Sodium and chloride effects on cranberry growth in aeroponics.
T. R. Roper*, A. R. Krueger, Dept. of Horticulture, University of Wisconsin, Madison, WI 53706; C. J. DeMoranville, UMASS Cranberry Experiment Station, E. Wareham, MA; J. R. Davenport, Washington State University Irrigated Ag Research and Extension Center, Prosser, WA.
Cranberry (*Vaccinium macrocarpon* Ait.) plantings adjacent to roads can show damage due to contamination from salt (NaCl) applied to the roads for deicing. Knowing tissue Na and Cl concentrations where a reduction in growth begins would allow tissue testing to be used as a diagnostic and predictive tool. Rooted cranberry cuttings were grown in solution culture with increasing concentrations of either Na (0 to 1500 ppm) or Cl (0 to 2500 ppm). Higher concentrations of both Na and Cl were found in the shoots than the roots. Chloride caused browning of older leaves when tissue levels reached 500 ppm. Sodium caused reduced growth when tissue levels were as low as 50 ppm. Exposure to 500 ppm Cl in aeroponics slowed cranberry growth shortly after the Cl was introduced, but then resumed. Chloride had no apparent effect on root growth. Growth of cranberry vines slowed when exposed to 500 ppm Na in aeroponics. Cranberry vines appeared to tolerate elevated Na or Cl tissue levels in soil-less culture.

APPENDIX 3

Abstract from NACREW presentation October 2003.

SALT EFFECTS ON CRANBERRY SOILS, PLANT GROWTH, AND PRODUCTIVITY
Carolyn DeMoranville*[1] , Joan Davenport*[2] , and Teryl Roper*[3] , [1]UMass Cranberry Station, E. Wareham, MA; [2]Washington State University Irrigated Ag Research and Extension Center, Prosser, WA; [3]University of Wisconsin, Madison, WI.

The objective of this project was to define both chronic and acute salt levels that can lead to adverse effects in cranberry production systems by evaluating the impact on cranberry growth, yield, or soil chemistry. Investigation of soil remediation methods was also a project objective but will not be included in this report. Three project tasks have addressed the major objectives. Task 1 – in a greenhouse, challenge pot-grown cranberry plants with chronic, intermittent, or acute exposures to NaCl, $CaCl_2$, KCl, Na_2SO_4 or $MgSO_4$ to stimulate road salt, its components, or a non-road salt control (similar conductivity) to determine critical levels for impact on growth. Task 2 – in culture (soil-free), expose cranberry plants to road salt or components to determine lowest concentrations adverse to growth. Task 3 – develop sorption/desorption curves for typical cranberry soils exposed to road salt or its components, document resultant changes in soil chemistry. Study soil from a field site receiving salt-laden road run-off. The accomplishment of these tasks should allow us to determine the critical concentration for salt impacts on cranberry. In turn, this benchmark number can be used, with a margin for safety, to develop criteria for monitoring cranberry water supplies potentially impacted by road salt run-off.

Task 1 – Greenhouse studies

Two greenhouse experiments in which cranberry plants were challenged with salt have been completed. In each, 5 salts (and a water control) were compared – NaCl, $CaCl_2$, KCl, Na_2SO_4 and $MgSO_4$ (high EC). Rates were based on Cl rate to be delivered or compared to. Both experiments ran for 16 weeks. In the first experiment (4 replicates), salts were compared in three treatment patters (single application [250-5000 ppm], every two weeks [50-2500 ppm], twice per week [12.5-625 ppm]) and three application methods (foliar spray, soil drench, both). In the second experiment (5 replicates), three treatment patterns (every 8 weeks [0-7500 ppm], every 2 weeks [0-2500 ppm], twice per week [0-625 ppm]) and two application methods (foliar spray, soil drench).

During the first greenhouse experiment, we observed red spotting of leaves, abnormal runner growth, 'brittleness' of shoots, and yellowing among plants in all salt treatments. After 16 weeks, we found no consistent effects on root or shoot dry weight. Mineral analysis of plants from the chronic (twice weekly) treatment was conducted -- plants treated with NaCl consistently showed the greatest accumulation of Na and Cl in shoots and roots compared to those treated with other salts.

Plants from the second study are being prepared for chemical analysis at this time. Examination of plant weights at the end of the experiment indicated that chronic (twice weekly) exposure to NaCl, $CaCl_2$, KCl, or Na_2SO_4 resulted in decreased root growth compared to plants receiving $MgSO_4$. Exposure to higher salt rates ever 2 or 8 weeks resulted in decreased root growth with $CaCl_2$, $MgSO_4$, or Na_2SO_4 compared to that of plants treated with NaCl or KCl. During chronic exposures, shoot growth declined with high salt rates (250-625 ppm of any salt).

A third greenhouse study in which all irrigation contains the test salt treatments has been in progress since the summer of 2002. Well established plants in sand culture were moved out from the automated watering system at that time. From that date, all irrigation has been supplied using watering cans containing the treatments. Treatments (5 replicates each with 8 pots of 4 uprights) are: water (control), 50 ppm NaCl, 100 ppm NaCl, 250 ppm NaCl, 100 ppm KCl, 250 ppm KCl, 100 ppm Na_2SO_4, 250 ppm Na_2SO_4. The plants were moved to a cold house in the fall of 2002. After 2500 hours, the plants were returned to the greenhouse. Flowering and fruiting was evaluated. A second removal of runners was conducted as before. The plants will be destructively evaluated in the fall of 2003.

In October 2002, all runners were harvested from the plants prior to moving to the cold house. Runners were weighed and measured. On the whole, salt exposed plants produced more runners, perhaps a stress response. Plants in a3 of 5 replicates receiving 250 ppm KCl were extremely affected, with poor growth and yellowing. Both KCl treatments resulted in K levels in the runners will above the standard range for cranberry tissue. However, other cations were not affected, leaving no simple explanation for the visual symptoms in these plants. AS one would predict, increasing rates of Na as chloride or sulfate led to increased Na in the runners. Likewise, increased Cl as the sodium or potassium salt led to increased Cl in the runner tissue.

Plants were overwintered in a cold frame and returned to the greenhouse in March 2003. In April, flowering commenced and plants were evaluated. Cl seemed to be associated with reduced flowering, at least at 250 ppm. Na seemed to have less impact on flowering but leaf symptoms (reddened leaf tips) were more apparent in all salt treatments compared to the controls. The 250 ppm KCl was the only treatment consistently associated with plant death. The 250 ppm Cl treatments (both NaCl and KCl) were associated with the poorest fruit production, while the control plants had the greatest production of fruit (dry mass basis). Flowering and fruit production was depressed (compared to the control) at Cl levels as low as 50 ppm.

Based on greenhouse data collected to date, we can state the following regarding cranberry plants growing in sand and exposed to road salts (including NaCl): a) Cranberry plants are quite tolerant of single or occasional exposures to salt, even at quite high rates(>1000 ppm); b) When watered with NaCl at 50 ppm or greater (chronic exposures), Na and Cl accumulated in cranberry shoots and Na accumulated in roots. Cl accumulated in roots at exposures of 200 ppm or greater; c) Exposure to salts containing Na or Cl over a long period was associated with decreased cranberry root growth. Shoot growth was suppressed at rates greater than 125 ppm (break point occurred between the 125 and 250 ppm treatments). However, runner growth may be stimulated. This is not desirable; and d) At levels as low as 50 ppm, Cl appeared to be associated with reduced flowering.

Task 2 – Soil-free culture studies

Cranberry plants were established in hydroponic culture to establish a rate range for Na and Cl toxicity. Once a range was defined, plants were established in aeroponic culture (plants were suspended in containers with nutrient solutions sprayed on the roots every 15 seconds). Test salts were also delivered to the plant roots with the misters.

Based on hydroponic and aeroponic studies, cranberry plants were shown to exhibit leaf spotting and leaf drop at 500 ppm Cl. At rates as low as 50 ppm Na in hydroponics, cranberry shoot growth was reduced. Shoot and root growth were reduced at 500 ppm Na in aeroponics after only 4 weeks. At present we continue to study Na and Cl as well ass CaMgAcetate (road salt alternative) at 100 ppm in aeroponic culture.

Based on aeroponic and hydroponic studies, we can state the following: a) At 500 ppm Na or Cl cranberry plants exhibit toxicity symptoms and reduced growth: b) At rates as low as 50 ppm Na some growth reduction occurred in hydroponic systems; c) In a preliminary hydroponics experiment, all cranberry plants were killed at 50 ppm CaMgAcetate. Presumably, in field use, acetate degrades rapidly. Otherwise, if this material reaches cranberry plants, it has great potential to be damaging.

Task 3 – Soil chemistry studies

To determine the loading levels of salt and salt components in salt-challenged soils, soil studies were established to study both sorption and desorption of Na, Cl, NaCl, and high EC. Three soils were collected in Massachusetts cranberry bogs – high organic matter content, low organic matter content, and sand soil. Solutions of known concentrations of salt (no salt [H_20], KCl, $CaCl_2$ NaCl Na_2SO_4 or $MgSO_4$) were added to a bottle containing 100 g of soil. The loading rates were based on 0, 250, 500, 1000, and 2500 mg Cl/L. Soils were allowed to sorp the salt solution for 1 week, 2 week, 1 month, or 2 month durations, followed by a 1 week period for desorption. All treatment combinations were replicated 3 times. The soil solution was extracted and replaced with DI water after the sorption period and extracted after desorption. Sorption and desorption extracts were analyzed for Na and Cl. Soils (desorped) were then extracted and analyzed for pH, EC, and the cation (K, Mg, Ca, Na) and Cl concentration.

Salt source influenced the final soil concentration of all analytes measured, whereas salt rate only affected K, Mg, Na, Cl, pH and EC, length of sorption affected Mg, Na, Cl and pH, and soil type affected Mg, Ca, pH, and EC. In all cases, EC values were too low to be of concern in cranberry production. However, soil pH was elevated to 6 or above under certain conditions.

To evaluate the effect of salt rate on the amount of Na and Cl remaining in the supernatant after sorption and that being released after desorption, data for Na-only and Cl-only salt sources were analyzed separately. Although solution concentrations of both analytes increased linearly with salt rate for both Na-only and Cl in the Cl-only treatments.

Supernatant and desorption Na and Cl concentrations differed with salt source when the treatments consisted of Cl-only sources. Solutions from soils treated with $CaCl_2$ had the least Na and Cl compared to those from water-, KCl- and NaCl-treated soils (Na and Cl increased in solution for those treatments in the order listed). The final soil concentration data for the $CaCl_2$ treatment supports the solution data tin that the highest concentration of Na and Cl in analyzed soil were in soil receiving this salt. That is, $CaCl_2$ exposure was associated with an increase in plant available Na and Cl in cranberry soil. This is particularly noteworthy with Na since $CaCl_2$ is not a Na source, indicating that this chemical may result in a release of reserve (bound) soil Na.

Overall the data suggested that: a) low organic matter soil chemistry was most affected by salt; b) increasing the rate of any salt increased the effect on soil chemistry; and 3) $CaCl_2$ had the most adverse affect on soil chemistry, leading to substantial binding of Na and Cl in the soil. This suggests that $CaCl_2$ is a salt source that should be avoided as a road-salt alternate and that changes in soil chemistry with other salts, including NaCl, may be benign in comparison since its effects appear more transitory.

APPENDIX 4

Project photographs

1. Aeroponics setup.

2. Plants growing in aeroponics

3. Mister in bottom of aeroponics container.

4. Bottles for sorption experiment

5. Filtering extract after sorption.

6. Setting up soil columns for mitigation study.

7. Leaching from columns after treatment (mitigation).

8. Panoramic view of leaching - mitigation study.

9. Randomizing pots in greenhouse.

10. Foliar symptoms - 625 ppm NaCl

11. Applying contaminated irrigation treatments.

12. Typical leaf symptom in contaminated irrigation study.

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