THE UNIVERSITY OF CALGARY

EVALUATION OF NINE SALTWATER SPILL RECLAMATION TREATMENTS FOR AGRICULTURAL LAND NEAR LLOYDMINSTER ALBERTA

by

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ABSTRACT

EVALUATION OF NINE SALTWATER SPILL RECLAMATION TREATMENTS FOR AGRICULTURAL LAND NEAR LLOYDMINSTER, ALBERTA

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Heavy oil projects operating in the Lloydminster area of Alberta extract oil and saltwater from subsurface geological formations. The saltwater or brine is separated from the oil, transported by pipelines and tank trucks to disposal facilities and disposed of by injection into saltwater bearing formations. Accidental spillage of this sodium chloride brine, due to pipeline breaks and road mishaps, occurs at a rate of over 900 spills annually in Alberta throughout the separation, transportation and injection phases. Most spills occur in agricultural areas and result in soil contamination which reduces crop production. This is an inconvenience for farmers and becomes an operating cost for oil companies. Even though clean up and restoration is monitored by the Energy Resources Conservation Board, Alberta Environment and Saskatchewan Energy and Mines, reclamation is often unsuccessful and can be improved through the refinement of treatment selection and application procedures.

In this study, nine treatment alternatives for brine contaminated soil on four sites in the Lloydminster area are described and evaluated in terms of their influence on soil chemistry in the 0-15 and 15-30 cm soil zones and above ground biomass production. Treatments range from the "do nothing" approach to compound treatments containing a combination of organic matter, ammonium nitrate and gypsum. Results indicate soil drainage has an overwhelming influence on treatment effectiveness, making no single treatment suitable for application under all soil conditions. The influence of the test treatments on the four brine spill sites are discussed separately for each site and a set of general recommendations are provided. Detailed, site specific recommendations can only be developed following identification of actual spill site conditions.

KEYWORDS: saltwater, brine, site, plot, treatment, sodium adsorption ratio, electrical conductivity, chloride, biomass, inflorescence, leaching, resalinization, ammonium nitrate, organic matter, calcium nitrate, gypsum, SSC-50, contaminated control, Lloydminster, Alberta.

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1.0 INTRODUCTION

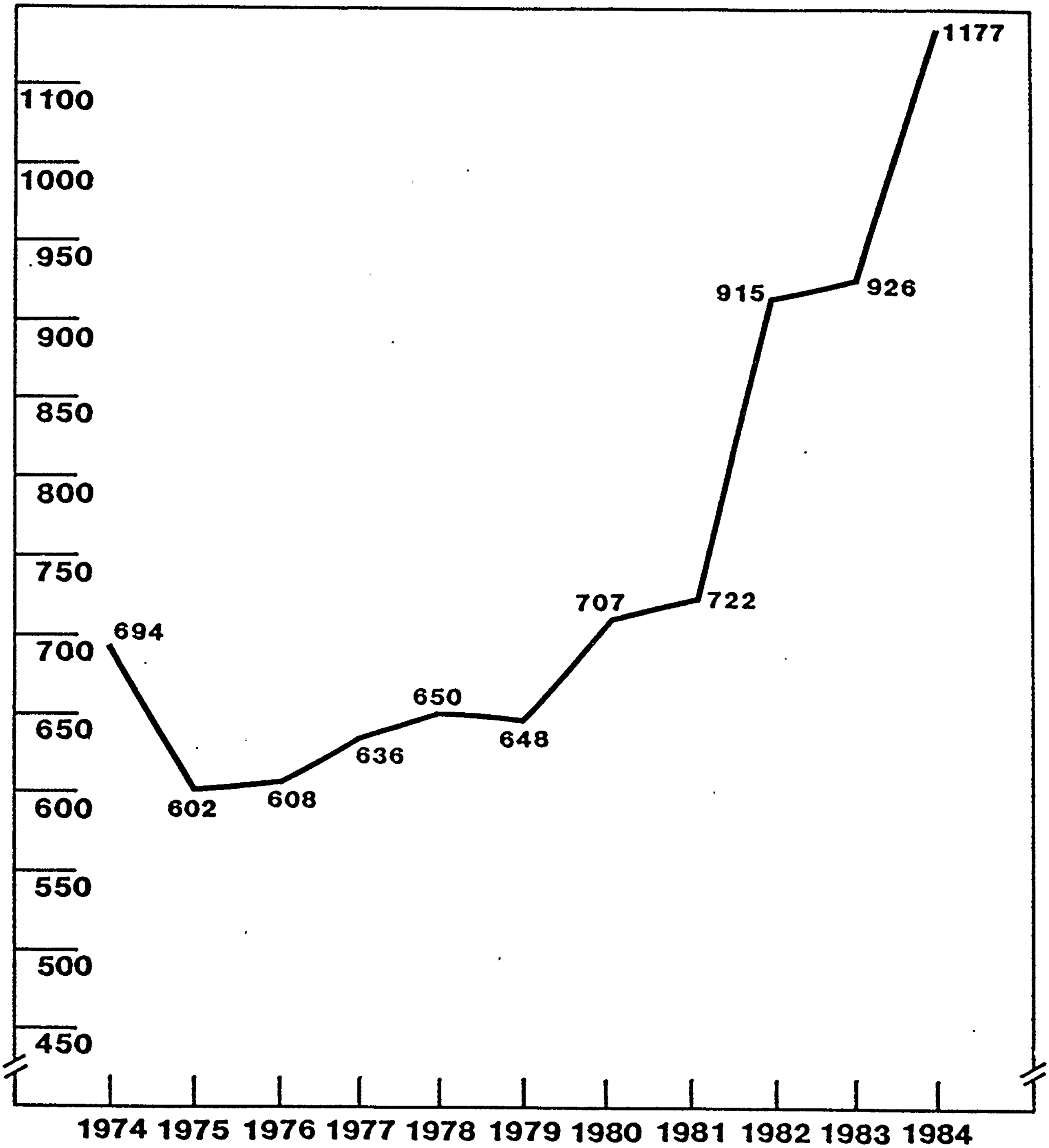
Over 900 spills occur annually in Alberta associated with oil production (ERCB, 1985) (Figure 1.1). Spill products include saltwater, oil and condensate. The volume of materials spilled during a single event varies from less than one cubic metre to thousands of cubic metres and may cover several hectares of land. The problems encountered as a result of hydrocarbon related spills are not unique to Alberta and Saskatchewan but rather are worldwide in oil producing areas.

In the Lloydminster area, heavy oil is produced from more than 80 different oil pools. When produced, this crude oil contains saltwater with concentrations up to 80 000 mg/L of sodium chloride (McRory, 1982). The saltwater is separated from the oil by gravimetric methods and frequently disposed of by injection into saltwater bearing formations. Inevitably some of the condensate, crude oil or saltwater are spilled in transit from production facilities to the injection wells or processing facilities. These spills result from a number of causes, however, pipeline breaks account for approximately 50 percent of all spills. The remaining spills are largely due to equipment failure, operator error or truck mishaps.

Procedures used to mitigate the effects which spills have on soil differ for each fluid. Saltwater creates the most widespread problems which may persist for many years. In contrast, some crude oil spills are cleaned up quickly and effectively with 100 percent site restoration within two years. In general, spills in poorly drained depressional areas require intensive well managed reclamation efforts to restore productivity.

FIGURE 1.1

TOTAL NUMBER OF HYDROCARBON AND SALTWATER SPILLS IN ALBERTA



If left unattended, saltwater spills can result in soil contamination and reduced vegetative growth which may persist for decades (Manitoba Agriculture, 1985). The reduced agricultural productivity is a liability until restoration is complete. Severely contaminated sites present potential hazards to livestock, wildlife and water supplies.

Even though reclamation procedures have significantly improved in recent years as field personnel become more familiar with the effects their activities have on future reclamation programs, methods are still needed which will minimize the damaged area, hasten reclamation and reduce the potential for the problem to migrate.

A brine spill reclamation study, sponsored by Husky Oil Operations Ltd. (Husky), was initiated in May, 1984 to improve response to spillage of saline produced water on agricultural land. Lack of consistent reclamation success in the Lloydminster area coupled with government concern prompted Husky's Production Department to fund a research project on brine spill reclamation. The study was designed to evaluate potential reclamation treatments in terms of their success under environmental conditions encountered in the Lloydminster area. The study began with a review of related literature (section 2.1), followed by field work, data collection and data analysis. Conclusions and recommendations were developed from results obtained during this field program.

1.1 Purpose

The purpose of the research was to identify and develop treatments which would minimize long-term soil contamination and return salinized farmland to crop production as quickly as possible. The methodology was designed to test practical solutions to salinity problems, therefore, commonly available materials were selected for testing.

1.2 Reclamation Objectives

Ideally, the objective of a reclamation program is to return the sites to conditions similar to those which existed before the spill. Saltwater spills alter the chemical and physical nature of the soil to such an extent, however, that a more realistic approach aimed at restoring productivity is required.

This usually involves one or more of the following approaches:

a) Reduction of soluble salts, hydrocarbons or heavy metals;
b) Aeration to improve permeability and soil structure;
c) Increase the Ca:Na ratio to restore soil chemical balance;
d) Fertilization to ensure an adequate supply of nutrients;
e) Application of organic matter to improve soil physical conditions; and
f) Adjustment of pH.

Specific objectives of the research program were to:

a) Reduce sodium (Na) and chloride (Cl) contaminants in the soil by displacement and natural leaching;
b) Improve soil permeability and leachability by applying organic matter to impove dispersed soil physical properties caused by the brine;
c) Displace sodium and chloride from soil colloids by applying gypsum and/or lime as calcium amendments which may allow calcium to replace sodium;
d) Improve fertility and plant productivity on brine contaminated soil by applying nitrogen fertilizer;
e) Assess the effectiveness of different combinations of organic matter, fertilizer, and calcium amendments for improving brine contaminated soil conditions and enhancing plant productivity;
f) Assess the effectiveness of SSC-50, a commercially available brine spill treatment, for improving brine contaminated soil conditions and enhancing plant productivity; and
g) Adjust pH to neutral where necessary.

2.0 PROBLEM DEFINITION

Exposure to the extreme salinity of oilfield brine has negative effects on physical and chemical soil properties (White and de Jong, 1975). These effects result from the direct action which sodium ions have on the clay colloids in soil. Although not fully understood, the interaction between sodium and clay colloids indicates that fundamental changes occur in the physical and chemical properties of soil contaminated with saltwater (Envirocon, 1975). The following changes have been observed:

a) Sodium disperses clay particles in the soil interfering with leaching and drainage through soil;
b) Available moisture and nutrients are reduced because the soil exchange complex is dominated by sodium;
c) The soil becomes sticky when wet and very hard when dry;
d) Soil microbial activity is limited under high sodium concentrations which decreases soil aeration and fertility; and
e) Electrical conductivity increases due to the high sodium ion concentration which also limits the osmotic uptake of water and essential plant nutrients.

The magnitude of the problem on a given site is influenced by the concentration and quantity of brine spilled, climate, topography, vegetation, groundwater regime and soil chemical and physical properties. The soil drainage and particle size distribution are the most important factors influencing the degree of soil contamination per unit of saltwater spilled (P.I.T.S., 1981).

Soil is made up of solid, liquid and gaseous components. The solid soil particles (sand, silt and clay) have the ability to chemically bond different elements. This bonding capability is, in part, determined by the surface area of the particles (Buckman and Brady 1969). The surface area is directly proportional to the particle size distribution of the soil unit involved. Sand particles have less surface area per unit volume and therefore fewer active bonding sites than silt or clay soils. Clays have the greatest surface area and thus the greatest bonding activity.

Mineral ions and plant nutrients dissolved in the water interact with oppositely charged sites on the sand, silt or clay portions of the soil. At a given concentration, the degree of potential contamination per unit of saltwater spilled is directly related to particle size (Edwards and Blauel, 1974). The fine grained clay soils are more susceptible to severe contamination than coarse grained sandy soils.

The area where the solid-water-gas interaction occurs in soils is known as the soil exchange complex. The degree of chemical activity and the structure of the soil are related to the number and availability of chemical bonding sites within the soil exchange complex. In a normal uncontaminated soil, clay colloids are chemically bonded together. This is due to the availability of chemical bonding sites within the soil exchange complex. Negatively charged sites on the surface of the colloids are frequently bonded to bivalent ions, such as calcium and magnesium. In this manner, two soil colloids can be bonded together with bivalent ions to form soil aggregates. This aggregation enhances soil structure, aeration, fertility and permeability.

When a soil is exposed to a saturated solution of monovalent sodium ions (saltwater), these ions will occupy available sites on the colloid surface by forcing other less concentrated ions off the exchange complex. When this occurs, the colloids are no longer strongly joined by the presence of bivalent ions and they disperse. This dispersal of clay colloids is called deflocculation and causes the soil to become structureless and less permeable to water. This phenomenon is more acute in clay soils and becomes less significant in sandy soils.

The nature of deflocculation relates directly to the concentration of the soluble cations in the soil solution. Under normal soil conditions calcium and magnesium are the principal cations found in the soil solution. When a saltwater spill occurs, the sodium ion frequently becomes the dominant cation in the soil solution. If sodium is not the dominant cation initially, it may become dominant when calcium and magnesium compounds are precipitated out of the soil solution (Richards, 1954). These precipitates can form as the soil solution becomes concentrated, due to evaporation and absorption of water by plants. Under these conditions part of the exchangeable calcium and magnesium is replaced by sodium.

Calcium and magnesium cations are more strongly adsorbed by the exchange complex than sodium at equivalent solution concentrations. In general, more than half of the soluble cations must be sodium before significant amounts are adsorbed by the exchange complex. When a saltwater spill occurs, a large number of sodium cations are introduced to the soil solution and thus sodium becomes the predominant adsorbed cation (Richards, 1954).

2.1 Review of Reclamation Procedures

Reclamation of saline, sodic and solonetzic soils is becoming increasingly important in the agricultural areas of the world. Most of the problems which result from these soil conditions occur due to salinity introduced by improper irrigation practises and natural salinity which increases in area as a result of poor farming techniques. Similar but more acute problems are encountered in the oil industry due to formation fluid brine spills.

Extensive research on soil salinity and sodicity resulting from natural processes has already been conducted in developed agricultural regions. Reclamation procedures developed as a result of this research are aimed at site specific conditions. Saline soils interfere with plant growth due to a high concentration of neutral soluble salts. Sodic soils affect plant growth as a result of toxicity and alkaline soil conditions (pH greater than 8.5) caused by high sodium and hydroxyl ion concentrations. Solonetizic soils developed on saline parent material and with an accumulation of clay in the B horizon, can also seriously affect yield and overall vigor of field crops (Buckman and Brady, 1974). Under these conditions reclamation procedures should be aimed at reducing soluble salts, reducing sodium concentrations, neutralizing soil pH and breaking up impermeable B horizons.

Less research has been conducted on oilfield brine spills, however, many of the same principles can be applied to accelerate the reclamation of brine affected soils. Spill characteristics, soil properties, climatic conditions and vegetation dictate the focus of the reclamation program. Soluble salts contained in brine are not biodegradable and must be removed from the soil profile by leaching. The main elements toxic to plants in oilfield brine are sodium and chloride. The chemical, physical and biological approaches to reclamation rely predominantly on leaching to rid the soil of any toxic elements which have been released as a result of the reclamation treatments.

The leaching of sodium involves replacing the monovalent sodium ion with divalent cations to encourage flocculation rather than dispersal. Once the sodium has been replaced on the soil colloids, it must be removed by leaching. In order to remove salts from the rooting zone and prevent resalinization the following general approaches are often used:

a) Increase permeability by improving soil structure;
b) Increase volume of water available for leaching if soil is permeable;
c) Improve drainage to lower water table and facilitate leaching; and
d) Vegetation management practises which reduce surface evaporation by depressing the water table.

The water for leaching must be provided by natural precipitation or by irrigation. In the Great Plains of western Canada, leaching by natural precipitation is often difficult, especially when natural drainage is poor. Thus, various hydro-technical approaches are used to improve natural drainage, including surface trenches, vertical wells and tile and mole drains.

The chemical treatment approach relies on calcium compounds and fertilizers to improve soil conditions. Calcium amendments are designed to replace the monovalent ions on the soil colloids to facilitate leaching and subsequent removal of the toxic elements from the soil. Fertilizer applications are designed to restore soil fertility on spill sites.

Soil physical characteristics determine the rate and efficiency of leaching, as well as the amount of exchangeable sodium held in the soil. Amendments which improve soil physical characteristics not only improve growing conditions for plants but improve the leaching efficiency of precipitation or irrigation water.

The biological approach enhances the effectiveness of other treatments. Vegetation uses soil moisture in the rooting zone, lowering the water table and allowing more efficient leaching of soluble salts throughout this zone. Salts subsequently accumulate at depth in the soil profile or are carried away laterally by groundwater movement.

Salt mining plants which physically remove salts from the rooting zone are of marginal benefit because the total weight of salts removed is very low requiring a lengthy reclamation program (White, 1975).

2.1.1 Chemical Approach

The primary objective in chemical amelioration of brine spills involves replacing exchangeable sodium with calcium. The availability of calcium (Ca^{++}) to replace sodium (Na^{+}) is determined by soil tests and depends on:

a) Concentration of soluble salts;
b) pH;
c) Lime and gypsum content of the soil; and
d) Exchangeable sodium percentage.

Amendments which are commercially available to facilitate the replacement include:

a) Soluble calcium salts;
b) Lime containing products;
c) Calcium mobilizing agents (e.g. sulphur);
d) Soil conditioners; and
e) Fertilizers.

The amendments chosen for site-specific application depend on the existing soil conditions and the size and degree of site contamination. To date no accurate methods exist to determine the quantity of amendments required at a specific level of contamination.

Calcium Chloride

Calcium chloride ($CaCl_2$) is very soluble and easy to apply but is expensive and requires sufficient moisture to promote leaching. Chloride can be toxic at high concentrations and is very mobile. It is seldom used because of the prohibitive cost.

Calcium Sulphate

Gypsum ($CaSo_4$) is the most widely used amendment for soil contaminated with excess sodium. It is relatively inexpensive and is widely available (White and de Jong, 1975). The calcium concentration in the soil solution and the total water percolating through the soil profile are the main factors which control replacement of sodium (Na^+) by calcium (Ca^{++}) (White, 1975). Water percolation is important because gypsum has a low solubility which is pH dependent. As the pH increases the solubility of gypsum decreases, especially above pH 9.

The amount of gypsum necessary for reclamation depends on the exchangeable sodium percentage of the soil and its exchange capacity. The amount of gypsum required to replace 1 meq. of exchangeable sodium per 100 gm. soil is given as 1.7 tonnes/ha. foot of soil (Richards, 1954).

Calcium amendments also have a beneficial effect on soil structure. When individual soil particles become coated with gypsum, plasticity is reduced and friabiliy is increased. This is achieved by adequate incorporation of the gypsum. The more thorough the incorporation the more soil particles are in contact with the gypsum which improves the benefit. Reducing plasticity and the effects of dispersion allows more effective water penetration and increases the rate at which soluble salts are leached.

Lime

Lime containing products include such compounds as ground limestone ($CaCO_3$), slaked lime ($Ca(OH)_2$), lime sludge and calcareous soil. These lime containing products have proven successful in reclamation of soils high in sodium but their effectiveness depends on soil acidity (pH). The solubility of $CaCO_3$ depends on CO_2 pressure, pH and the concentration of the soil solution. Lime is most soluble at low pH and is therefore most effective on acid soils (pH less than 6.5). On soils with a pH in excess of 7.5 lime is no longer effective and can be toxic at pH 13. At pH 7.5 or greater the solubility of lime is less than 2 meq/1. At the same time, liming a soil increases the pH, which is self-inhibiting to it's effectiveness. On degraded soils high in sodium such as sodic soils, solods and solodized solonetzic soils, lime is most effective because exchangeable sodium is partly replaced by H which increases the solubility of $CaCO_3$ (Richards, 1954). When lime and manure are used in combination, the effectiveness of lime is increased because the CO_2 released when organic matter decomposes increases the solubility of lime by lowering the pH (White and de Jong, 1975).

Calcium Mobilizing Amendments

The use of calcium mobilizing agents, including sulphuric acid (H_2SO_4), hydrochloric acid (HCL), sulpher (S) and iron or aluminum sulphates ($FeSO_4$, $AlSO_4$), is restricted to sodic soils containing calcium carbonates (White and de Jong, 1975). Acid reacts with lime in calcareous soils to produce gypsum which supplies calcium for sodium replacement.

Although hydrogen and calcium flocculate soils, hydrogen is less effective as a flocculant. It is important to note that acids can only be used in reclamation when they will not make the soil acidic and when sufficient lime is present in the soil to produce gypsum (Hoyt, Nyborg and Penney, 1974).

Sulphuric acid is created when sulphur and lime sulphur (CaS_5) are oxidized in the soil. This process is slower than direct application of acid because it is a biological process. The bacterial activity needed for efficient sulphur oxidation requires favorable soil conditions and can be inhibited under low temperatures, dry soil conditions or a high soil pH.

The efficiency of the calcium for sodium exchange is enhanced if the soluble salts are first leached from the rooting zone before adding the chemical amendment (White and de Jong, 1975). Leaching may cause dispersion of the soil which reduces permeability. Permeability tests will determine if leaching will reduce soluble salts or cause dispersion.

Soil Conditioners

Soil conditioners are effective at stabilizing the structure of heavy soils, however, improvement in sandy soils is insignificant. Stabilizing effects last for up to five years (White and de Jong, 1975). Careful application is required since activation in the soil is closely linked to available moisture. Beneficial effects focus on improved percolation and water holding capabilities of the soil. Improved soil structure, as a result of conditioner application, will also improve conditions for plant growth.

Traditional methods to improve soil structure and improve permeability, such as gypsum and organic matter application have proven as effective as soil conditioners at a fraction of the cost (White and de Jong, 1975).

Fertilizers

Fertilizers promote spill site restoration by correcting an unbalanced nutrient status common in saline soils which have been leached. They enhance plant growth which reduces soil moisture and adds organic matter (White and de Jong, 1975). This indirectly decreases salinity.

Some fertilizers may be more beneficial than others. Ammonium nitrate lowers the pH and enhances the solubility of $CaCO_3$ (Carter, Cairns and Webster, 1977). Calcium nitrate supplies nitrogen and it supplies calcium to replace sodium on the exchange complex. Salinity should be monitored on soils with a high fertilizer requirement because fertilization adds salts to the soil and could increase salinity. If leaching is being promoted to reduce soluble salts, greater nutrient deficiencies will tend to occur and fertilization will become more important. This will depend on the soil permeability.

2.1.2 Physical Approach

The emphasis of the physical approach is on incresing the permeability of the soil to water. This increases the rate of leaching and thus the rate of soluble salt removal.

In some soils, calcium is found in the subsoil. When this occurs the calcareous subsoil can be brought up to mix with to the surface soil horizons by using specialized equipment. Here it replaces sodium on the soil exchange complex.

The following approaches have been used:

a) Deep ploughing;
b) Subsoiling;
c) Sanding;
d) Digosage;
e) Earth filling; and
f) Profile inversion.

Deep Ploughing

This method of physical soil improvement attempts to break up impermeable layers, bury undesirable layers and bring up calcium rich subsoil to mix with surface soil horizons that have a high exchangeable sodium percentage. Depth to gypsum containing subsoil and distribution of soluble salts within the soil profile are factors to be considered when determining ploughing depth. In most cases, plough depths are between 35 and 150 cm (White and de Jong, 1975). This method of reclamation has been used widely in Russia on Solonetzic soils. In arid regions, irrigation or other measures to enhance the leaching efficiency of natural precipitation may be necessary in addition to deep ploughing.

Success of this method on soils high in sodium depends on mixing subsurface lime or gypsum with the B horizon which has an accumulation of clay and is high in exchangeable sodium. The exchangeable sodium percentage (ESP) must be lowered sufficiently to prevent dispersion when the soil is leached.

In Vegreville, Alberta, experiments have shown that deep ploughing black solonetzic soils to 55 cm significantly reduced the ESP and the concentration of soluble salts, particularly NaSO4 , in the top 150 cm (Cairns and Bowser, 1977). Cereal crop yields remained the same but forage crop yields were doubled and root penetration was significantly increased.

Subsoiling

This method involves breaking up the impermeable subsurface layers without disturbing the order or number of soil horizons. Subsoiling improves permeability, aeration and allows better percolation to help remove soluble salts and breaks up impermeable layers. Maximum depth of cultivation should be one meter or maximum depth which equipment will penetrate. Irrigation and shelterbelts to improve leaching and reduce evaporation combined with subsoiling which increases water infiltration, make subsoiling much more effective.

Profile Inversion

This method of multi-stage ploughing has been used successfully in the U.S.S.R. on solonetzic soils (White and de Jong, 1975). In this three stage operation, the B and C soil horizons are inverted. This places the B horizon which has a high exchangeable sodium percentage under the C horizon which has a high gypsum content. The A horizon is then placed back on the surface. Subsequent leaching supplies calcium from the C horizon to exchange for sodium in the buried B horizon.

Sanding

Applying sand to a soil changes the texture of the soil and thus changes some of its physical properties. By making a fine textured soil coarser it helps promote aeration and permeability which facilitates increased leaching and soluble salt removal. The amount of salt to be added will depend on the initial soil texture. Generally 30 to 50 percent sand should be sufficient to maintain permeability, even in a soil with a high sodium content. Drawbacks to this procedure include drought during long dry periods and loss of nutrient holding capability as a result of rapid water movement through the soil and reduced organic matter content in the surface soil.

Digosage

Digosage involves bringing in a soil which is high in lime or gypsum and mixing it with the existing soil. It is only feasible when these soil types are available in the immediate area. Otherwise, trucking costs could exceed the cost of simply applying lime or gypsum. This is probably not a feasible alternative to gypsum application in Alberta.

Earth Filling

Removal of contaminated soil and bringing in fertile topsoil can be effective for small areas. It is most suitable in areas where soluble salts are concentrated near the surface. Raising the surface elevation by this method effectively lowers the water table which reduces surface evaporation and accumulation of soluble salts on the soil surface.

2.1.3 Biological Approach

Living plants, plant residues and animal wastes are all forms of organic matter. They improve soil physical properties when used to aid in reclamation.

Saline soils can be improved by generous (33 to 45 tonnes/ha/year) applications of organic matter (Alberta Agriculture, 1980). On saline mineral soils humus deficiencies are usually the result of inhibited plant growth. This deficiency causes undesirable soil physical characteristics such as crusting and puddling which decrease the infiltration rate of water. When organic matter such as manure is applied, immediate improvement in soil structure is evident in terms of improved water infiltration and leaching. Structural soil stability is also improved when manure is added because bacteria, algae, fungi and actinomycetes are encouraged. These organisms help stabilize soil aggregates.

Soil chemistry can also be altered by addition of organic matter. Decomposition of organic matter releases carbon dioxide. This increases the solubility of calcium carbonate supplying calcium ions to exchange for sodium in soils with a high exchangeable sodium percentage. The increase in calcium availability is somewhat counteracted by the increase in gas exchange potential of soils high in organic matter. This is due to increased soil aeration. Decomposing organic matter also supplies plant nutrients in an available form and is a source of energy for soil bacteria (Alberta Agriculture, 1980).

Manure is superior to peat in terms of increased yields and water retention (White and de Jong, 1975). Manure applied at 8 tonnes/ha, increased wheat yields significantly. Peat at the same rate under the same field conditions had no quantifiable beneficial results (White and de Jong, 1975). The fibrous nature of peat increases soil porosity. This induces moisture stress caused by increased evaporative losses from the topsoil. The ameliorative value of organic material for reclamation is due to:

a) Decreased salinity due to dilution of the saline soil with organic matter;
b) Reduced sodium ion concentration in the manure treated soil due to increased leaching; and
c) Improvement in plant nutrition.

Plant growth has physical effects on soil properties similar to those induced by the addition of organic matter as manure. This is especially true when plants are ploughed down as a green manure crop. Plant roots improve soil structure by growth and decomposition. Carbon dioxide released through decomposition promotes exchange of calcium for adsorbed sodium. Respiration is likely less important than the physical effect of the roots which improve permeability and leaching.

Reduction in capillary rise of water to the soil surface also limits surface evaporation which concentrates soluble salts at the soil surface. Plant growth fosters this reduction in capillary action because plants remove water throughout the soil profile. The subsequent reduction in the depth of the water table reduces surface evaporation and promotes leaching. Plants with deep root systems and high transpiration rates such as Alfalfa and Sweet Clover are most suitable, although both are only moderately tolerant of saline soils (Manitoba Agriculture, 1969).

Halophytic plants also help remove salts from the soil although they must be harvested and removed to have any beneficial effect. Removal of these plants constitutes a loss in organic matter which would otherwise be added to the soil. Halophytes which remove quantities of salt from the soil are Atriplex spp. and Kochia spp. of the Chenopodiaceae family. Dry matter yields from these plants are also much higher on saline soils than yields from common forage plants. Some halophytic plants can be used as fodder but the resulting manure cannot be used in reclamation due to its high salt content.

If vegetation can be established on saline soils beneficial effects can be expected. This may be difficult since most field and forage crops have a relatively low tolerance for salinity. Relative tolerances of some common field and forage crops are presented in Figure 3.3.

Two native species which are highly salt tolerant and have some value as fodder are Distichilis stricta (desert salt grass) and Pucinellia airoides (Nuttal alkali grass). Drawbacks to their use include the difficulty of obtaining seed and potential migration as weeds in adjacent cultivated fields. In most cases, it is preferable to reduce salinity by other means to facilitate the establishment of forage crops.

Mulches can be effective in encouraging water infiltration and reducing evaporation. Typical mulches include straw, manure, hay, wood chips and sand and gravel. Experiments have shown that electrical conductivities are significantly reduced in the surface soil when the leaching effectiveness of natural precipitation is enhanced by applying a surface mulch (White and de Jong, 1975).

2.1.4 Hydro-Technical Approach

Most succesful reclamation systems used on saline soils involve both drainage and leaching. To prevent resalinization net downward movement of water is necessary in the rooting zone. Once drainage continuity has been established, natural precipitation for leaching can be enhanced by moisture conservation practices such as the use of snow fences, shelterbelts, stubble crops and surface mulches. If not enough water is provided under this management plan, irrigation may be necessary to effect successful reclamation.

The amount of leaching water required for reclamation is governed by the following parameters (White and de Jong, 1975):

a) Amount of salt to be removed;
b) Salt content of the leaching water; and
c) Effectiveness of the leaching.

The approximate quantity of water required to leach different percentages of salt in a medium textured soil is as follows (White and de Jong, 1975):

a) 15 cm of water/.3 m of soil : 50% salt removal;
b) 30 cm of water/.3 m of soil : 80% salt removal; and
c) 60 cm of water/.3 m of soil : 90% salt removal.

In general, the leaching efficiency of precipitation or applied water decreases with increasing clay content of the soil. This is because of the large number of small pores in a clay soil in which the saltwater is not replaced efficiently by fresh water (White and de Jong, 1975). Leaching water to supplement rainfall can be applied by:

a) Continuous ponding;
b) Intermittent ponding; and
c) Trickle irrigation.

Continuous ponding is the fastest way to remove salts, however, trickle irrigation is the most efficient method. This is because continuous ponding causes most of the water to move rapidly through the large pores when the soil is in a state of saturation. Under trickle irrigation, sprinkling or natural precipitation, the soil is not saturated and the water moves through the smaller pores because the larger pores are air filled. These large pores contain air because surface tension is not adequate to suspend large droplets of water within the soil profile.

Some other factors that must be considered if leaching is to be undertaken include:

a) Land leveling requirement;
b) Time of year;
c) Quality of leaching water; and
d) Drainage facilities.

Land leveling may be required if the area is to be leached by continuous ponding. This will allow even distribution of water over the entire site.

Fall is best suited to leaching since the water table is low as a result of plant growth during the summer season. The fall season is also more suitable because surface evaporation is lowest.

Care must be taken with respect to quality of leaching water. Soil structure can be adversely affected if the salt content of the leaching water is high.

Adequate drainage must also be maintained otherwise the watertable will rise and resalinization may occur. If drainage is necessary it is important that the "critical depth" be established for the site. This is the depth where groundwater can rise to the surface via capillary action. If the water table is above the critical depth, drainage will be required to facilitate reclamation and prevent resalinization.

Critical depth is controlled by the physical and chemical properties of the soil as well as climatic influences, soil permeability, groundwater salinity and vegetation. Medium textured soils seem to be most susceptible to salt accumulation and need water table control to a greater depth than either light (sand) or heavy (clay) textured soils (White and de Jong, 1975).

Drainage requirements for reclamation are governed by the need to maintain the watertable below the critical depth. The maximum total drainage requirement can be determined by taking the sum of:

a) Leaching requirement;
b) Amount of water that must be removed to lower the watertable to the critical depth; and
c) Amount of water that must be removed to maintain the watertable at the critical depth.

Once reclamation has been achieved, the water table must be maintained below the critical depth. If necessary, surface and/or subsurface drainage systems can be installed to stabilize ground water levels.

Surface drains are shallow trenches (15 to 30 cm) which collect water and dissolved salts in excess of the infiltration capacity of the soil. In order for this method to be effective, salts must be concentrated at or near the suface so they can be dissolved. The soil permeability must also be low.

Subsurface drains can be horizontal or vertical. Depending on site conditions horizontal drains can be shallow or deep with open and closed configurations. Although shallow drains (1m) are frequently used, their effectiveness for reclamation may be limited because the watertable is not lowered enough to prevent resalinization.

Deep drains on the other hand, actually control groundwater depth and are most often found utilizing a closed tile system. These drains are most effective, use less land and require low maintenance.

Mole drains may be used where temporary drainage is required. These shallow, small diameter drains are formed by a moling plough and are usually 5 to 10 cm in diameter and 40 to 60 cm deep (White, 1975). Depending on site and soil conditions, the effective distance of these drains will vary.

Drainage is expensive and usually reserved for highly problematic spill sites. High watertables and the resalinization which is often encountered under these conditions can make reclamation by any other means impossible. Large area spills with high watertables are likely candidates for drainage systems. Application of drainage systems to spill sites is considered to be capital and labor intensive. Several types of systems are available depending on site specific requirements.

The study design and test treatments were selected to meet the reclamation objectives of trying to overcome the chemical and physical soil problems encountered when oilfield brine is spilled on agricultural land. Practical treatment solutions, designed to improve plant growth and productivity and which could be applied at the farm level without specialized equipment and materials, were stressed and were selected from among a large number of potential treatments. One specialized treatment (SSC-50), which is produced commercially, was included in the testing program due to it's widespread use in the oil industry as an initial treatment for salt water spills. Plant growth and productivity were stressed in the research because brine induced changes to soil chemistry were long term problems which can be more effectively remedied once normal plant growth is re-established. Treatments which improve plant growth also tend to improve soil chemical conditions and for this reason both factors were intensively monitored during the study.

3.0 METHODOLOGY

3.1 Site Selection

Thirty-eight brine spill sites were surveyed during the field reconnaisance program. These potential study sites were identified by using spill file records provided by the Husky Land Department located in Lloydminster, Saskatchewan. Soils, vegetation, extent of visual contamination and drainage were surveyed at each location. Each potential site was sampled in what appeared to be the most contaminated area. Control samples were taken adjacent to the spill to determine approximate soil chemistry prior to the spill. The soil samples were subjected to detailed salinity analyses as described in Section 3.4 below.

The results of these analyses formed the basis for selection of the actual test sites. Only contaminated sites which exceeded predetermined limits were selected for field trials. The limits were based on the range in contamination determined by the initial site selection soil analysis program.and only large area, moderately to highly contaminated sites with adequate drainage were selected, to ensure that results could be collected The limits used for site selection were:

a) Sodium adsorption ratio greater than 15;
b) Size of spill greater than 500 m;
c) Medium to fine soil texture (sandy silt to silty sand with a trace of clay);
d) Level topography;
e) Land availability and previous ability to sustain agricultural crops; and
f) Well to moderately drained soil conditions.

The four contaminated study sites selected for treatment were located on private agricultural land in the Lloydminster area (Figure 3.1) where Husky was currently paying for crop loss and inconvenience. These sites were typical of old saltwater spill sites which occur in the

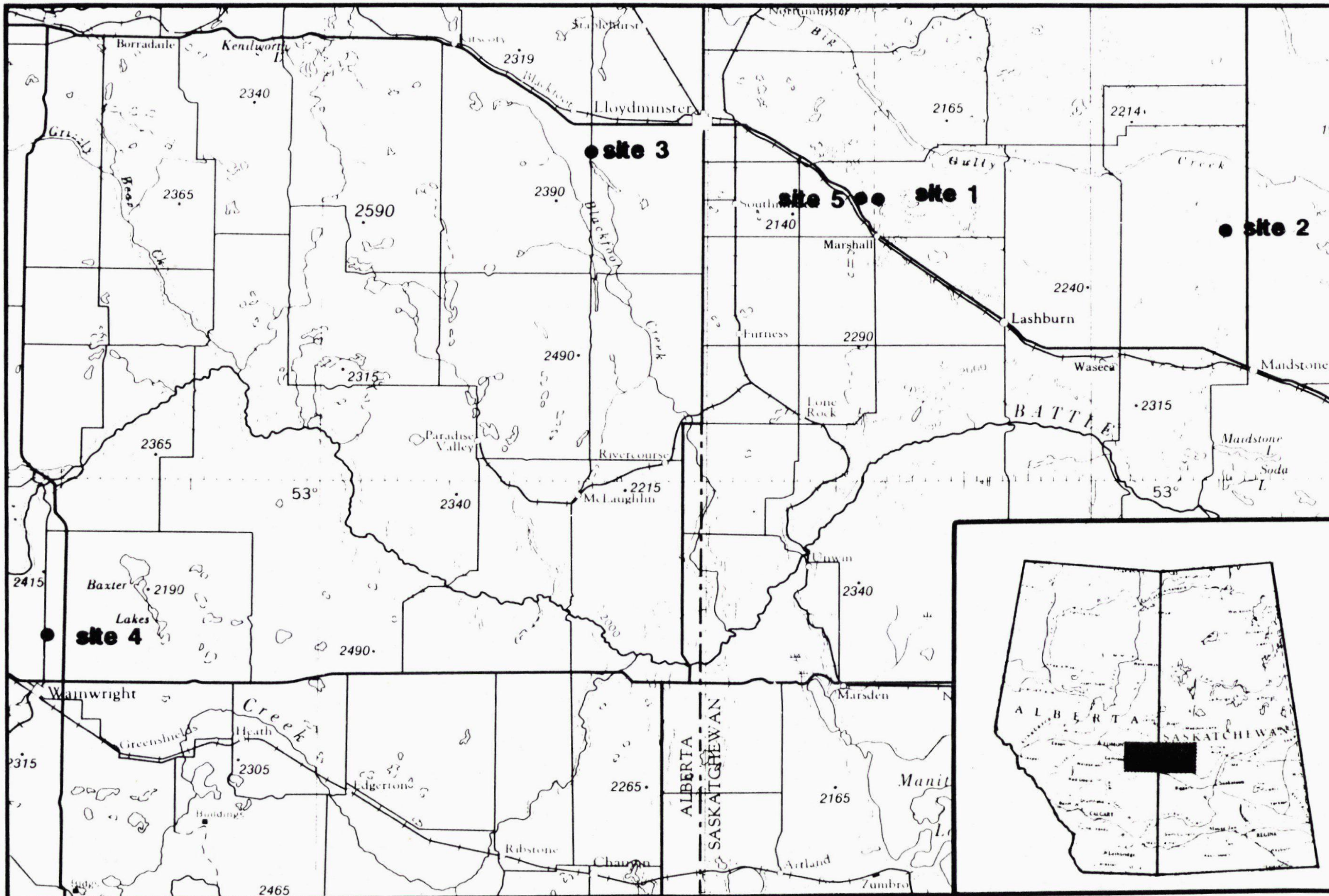


FIGURE 3.1 **Location of Study Sites Within the Study Area**

region. A single uncontaminated site was used as a control for evaluating the effect of reclamation treatments applied to contaminated plots.

Legal descriptions of the five site locations are listed below:

Contaminated:

SITE 1 LSD 8-18-49-26	W3M	(Aberfeldy)
SITE 2 LSD 6-28-48-23	W3M	(Golden Lake)
SITE 3 LSD 10-30-49-1	W4M	(Devonia Lake)
SITE 4 LSD 9-32-45-6	W4M	(Wainwright Unit 2)

Uncontaminated:

SITE 5 LSD 5-18-49-26	W3M	(Aberfeldy)

3.2 Selection of Reclamation Treatments

The test treatments were selected for application on contaminated sites from a number of potential treatments based on their suitability, availability and ease of application under the field conditions encountered in the Lloydminster area. Nine different treatments were tested, including a contaminated control (treatment 1) where no amendment was applied. Five single amendment treatments and three multi-amendment treatments were tersted in addition to the contaminated control.

The treatments selected for testing included:

1. Contaminated control (no amendment)
2. Organic matter
3. Gypsum or lime (depending on pH)
4. Calcium nitrate ($CaNO_3$)
5. Ammonium nitrate (NH_4 NO_3)
6. Organic matter + gypsum/lime
7. Organic matter + ammonium nitrate
8. Organic matter + ammonium nitrate +gypsum/lime
9. Saline soil saver (SSC-50)

3.3 Split Plot Experimental Design

A stratified random design utilizing repeated measures was used to evaluate the effect of the test treatments (Figure 3.2). Twenty-seven treatment plots were established at each site. Individual plots measured two meters square, with an area of four square meters. The twenty-seven treatment plots were split into three independant blocks. Each block contained nine treatments and each of the nine different treatments occured only once at some random location within each block. This design ensured adequate separation of the treatment replicates within the twenty-seven plots established at each site. A buffer strip, 50 cm wide, was established between all plots to minimize the chance of communication among treatments. A total of one hundred and thirty-five plots were established at the five study locations.

3.4 Soil Sampling

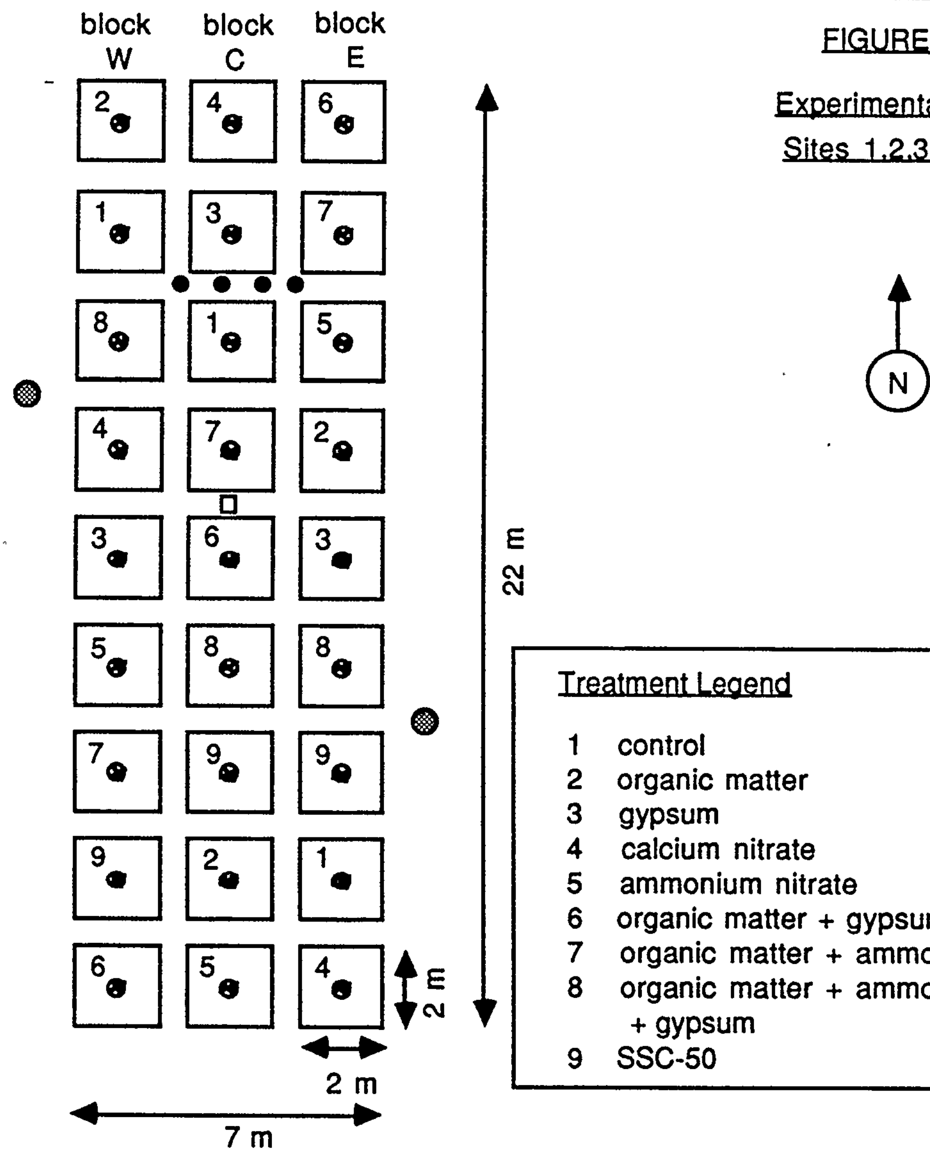
Induced soil salinity (brine spills) can vary extensively with horizontal and vertical distance from the origin of the spill and through time. Factors which influence salt migration at the spill site include soil texture, soil moisture, micro-relief, precipitation and vegetation. With these factors in mind, the objectives of the soil sampling program were to:

a) Determine the severity of the spill;
b) Make recommendations for the amount and type of ameliorating soil amendments to be applied to the saltwater damaged area based on the results of the detailed soil chemical analyses; and
c) Determine the variablity in soil chemistry within each site and among the five selected sites.

Soils in each of the one hundred and thirty-five (135) plots were sampled in the spring of 1985 prior to amendment application and in the fall immediately after biomass samples were harvested. Soil samples were collected from the center of each plot using a five cm diameter soil auger at depths of 0-15 cm, 15-30 cm, and 30-60 cm (Figure 3.2). Only samples from the 0-15 cm and 15-30 cm depths were analyzed. The 30-60 cm samples

FIGURE 3.2

Experimental Design
Sites 1,2,3,4 and 5



Treatment Legend

1 control
2 organic matter
3 gypsum
4 calcium nitrate
5 ammonium nitrate
6 organic matter + gypsum
7 organic matter + ammonium nitrate
8 organic matter + ammonium nitrate + gypsum
9 SSC-50

Environmental Monitoring Legend

- borehole with standpipe installed (Sites 1,2,3 and 4 only)
- soil moisture monitoring location (15,30,45,60 cm at Sites 3 and 5 only)
- rainguage (Site 1,2,3 and 4 only)
- soil sampling location (0 - 15 cm, 15 - 30 cm sample depths)

were placed in storage should further testing be required. Both pre-treatment and post-treatment soil samples were analyzed by the Saskatchewan Soil Testing Laboratory in Saskatoon. The analyses were conducted according to procedures outlined by the Canadian Society of Soil Science Manual on Soil Sampling and Methods of Analysis (McKeague, 1978).

Determinations were made for the following:

a) pH;
b) Electrical conductivity (EC);
c) Chloride concentration;
d) Sulphate concentration;
e) Calcium concentration;
f) Magnesium concentration;
g) Potassium concentration;
h) Sodium concentration; and
i) Sodium adsorption ratio (SAR).

Soil testing before and after application of soil amendments provided information to determine changes in soil chemistry resulting from soil treatment. Soil chemical data were used to derive inferences about biomass results. Correlations between soil chemistry and biomass are described in Section 5.0.

3.5 Selection of Indicator Crop

In the Lloydminster region, Bonanza barley is a commonly seeded field crop which is moderately to highly salt tolerant at both the germination and established stages (Table 3.3). Although barley is tolerant to periodic short term flooding and to salinity in 5-10 mS/cm range, in more highly contaminated areas even barley may be limited in its overall suitability as a reclamation species because of its failure to produce biomass.

The relative severity of the salt contamination at the selected sites required a moderately high degree of salt tolerance in the indicator crop if results were to be obtained. Cereal

TABLE 3.3

Tolerance of Crops to Salinity at Two Stages of Growth (Agriculture Canada, 1977)

	Growth Stage	
Crop	Germinated	Established
Barley	High	High
Rye	High	Moderate
Corn	Moderate	Low
Wheat	Moderate	Moderate
Alfalfa	Low	Moderate
Sugar Beets	Very low	Moderate
Beans	Very low	Very low

crops less tolerant than barley were considered unsuitable. Salt tolerant forage crops which exceed barley's salt tolerance were also available. These were considered undesirable because of a landownder preference for cereal or oilseed crop production on the prime agricultural land in the region. After considering the local cropping practices of the region and the fact that it is impractical for farmers to seed different plant species on a small area within a large field, Bonanza six-row barley was selected as the indicator species to reflect the range in results obtained when different treatments were applied to brine contaminated soil.

3.6 The Research Model

The soil treatments were selected for their ability to influence existing soil conditions, vegetative plant growth and productivity (yield). The ability of a particular treatment to improve existing soil conditions is the critical element in reclamation of saltwater contaminated soils. Certain amendments may also help improve growth and productivity of crops on contaminated soil without actually improving the soil's physical and chemical properties (some fertilizer applications may improve plant growth without increasing yield). For this reason, it was necessary to measure the success of the reclamation program in terms of both soil chemical parameters and plant growth and productivity. These factors were quantified using information from detailed soil salinitiy analyses and biomass weight and yield data. Analysis of variance was used to determine if the test treatments had similar effects on the four contaminated sites.

The independent and dependent variables introduced or inherent to the study are listed below: Biomass was affected by all of the independant variables.

Independent Variables:

a) Amount of organic matter applied in kilograms per hectare;
b) Amount of calcium nitrate fertilizer applied in kilograms per hectare;
c) Amount of ammonium nitrate applied in kilograms per hectare;
d) Amount of gypsum or lime applied in kilograms per hectare;
e) Seeding rate of Bonanza barley.

Dependent Variables:

a) Change in SAR, EC and chloride concentrations in the 0-15 cm soil zone;
b) Seed head weight (inflorescence) in grams per square meter developed on each treatment plot; and
c) Stem weight in grams per square meter developed on each treatment plot.

The ANOVA Model:

$Y_{ij} = u + a_i + e_{ij}$

where:

u = overall mean

a_i = effect of treatment i

e_{ij} = random error

i = 1,2,3........9 (treatments)

j = 1,2,3.......12 (number of replicates per treatment)

3.7 Treatment Application

Organic matter supplements were applied to the test plots in September, 1984. Gypsum, lime and fertilizer amendment combinations were applied in May, 1985, following site preparation, and incorporated into the soil surface. SSC-50 was applied as specified in the product application guideline (10:1 dilution with water).

Chemical amendments were weighed using a 10 kg pan balance and bagged individually prior to application. Gypsum was applied at 14 kg per plot, the equivalent of 35 tonnes per hectare at sites 1, 2, 3 and 5 because the pH at these sites was between 6.0 and 8.0 (treatments 3,6 and 8). The quantity of gypsum was calculated based on the contamination at site 1 and applied at the same rate to all sites to standardize the application rate. Lime was applied to site 4 at a rate of 5 kg per plot, the equivalent of 12.5 tonnes per hectare, because of the acid soil conditions ($pH<5.5$)encountered (treatments 3,6 and 8). This quantity of lime was calculated to increase the pH by 1.5 units to neutralize acidic soil conditions. Calcium nitrate was applied at 260 grams per plot to supply the equivalent of 100 kg elemental nitrogen per hectare (treatment 4). Ammonium nitrate was applied at 120 grams per plot to supply the equivalent of 100 kg elemental nitrogen per hectare (treatment 5). Manure was applied in bulk as a 7.5 to 10.0 cm top dressing (treatments 2,6,7 and 8). Saline Soil Saver (SSC-50) was applied to the selected plots as a 22 litre tank mix containing 2 litres product mixed with 20 litres of water (treatment 9). Additional leaching water was not applied to SSC-50 plots, or to any of the other treatment plots, to eliminate the influence of artificial leaching over and above natural precipitation. The details of quantities and combinations of amendments applied to each site are provided in Table 3.4. Barley was sown in May, 1985 on all test locations at a constant rate equivalent to 60 kg. per hectare (24 grams per plot) with a Tye rangeland seed drill.

Site preparation was accomplished by rototilling all plots thoroughly in two directions to a depth of 15 cm prior to test treatment application. Following test treatment application the plots were again rototilled to a depth of 7.5-10 cm to incorporate the amendments into the soil surface. SSC-50 (treatment 9) was simply sprayed on the soil surface, as specified in the product guide.

TABLE 3.4

QUANTITIES AND COMBINATIONS OF AMMENDMENTS APPLIED TO EACH SITE

Treatment Number	Amendment Combinations	Quantity Applied Site 1	Site 2	Site 3	Site 4	Site 5
1	contaminated control	no treatment	no treatment	no treatment	no treatment	no treatment
2	organic matter	7.5-10.0 cm top dressing	7.5-10.0 cm top dressing	7.5-10.0 cm top dressing	7.5-10.0 cm top dressing	7.5-10.0 cm top dressing
3	gypsum	14.0 kg	14.0 kg		14.0 kg	5.0 kg
	lime			5.0 kg		
4	calcium nitrate	260 gm	260 gm	260 gm	260 gm	260 gm
5	ammonium nitrate	120 gm	120 gm	120 gm	120 gm	120 gm
6	organic matter	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm
	gypsum	14.0 kg	14.0 kg		14.0 kg	5.0 kg
	lime			5.0 kg		
7	organic matter	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm
	ammonium nitrate	120 gm	120 gm	120 gm	120 gm	120 gm
8	organic matter	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm	7.5-10.0 cm
	ammonium nitrate	120 gm	120 gm	120 gm	120 gm	120 gm
	gypsum	14.0 kg	14.0 kg		14.0 kg	5.0 kg
	lime			5.0 kg		
9	Saline Soil Saver (SSC-50)	2 l product in 20 l water	2 l product in 20 l water	2 l product in 20 l water	2 l product in 20 l water	2 l product in 20 l water

3.8 Environmental Monitoring

The dominant environmental factors influencing the experimental sites were potential capillary rise of groundwater, root zone soil moisture and precipitation. The influence of exposure to the sun was minimized by standardizing the aspect presented by each site. This standardization was accomplished using compass measurments which placed the long axis of each of the five sites parallel to a north / south allignment.

3.8.1 Groundwater

The capillary potential of groundwater to rise toward the soil surface was monitored with two standpipes installed at each experimental site. Standpipes consisted of a 5 cm pvc pipe perforated at 0.3 m intervals through the lower 1.5 m to allow entrance of groundwater. The slotted section was backfilled with native soil after installation and capped to prevent entrance of surface water. A tape measure, accurate to one centimeter, was used to determine the distance to groundwater from the soil surface after the water levels were stabilized. These depths were recorded for each site throughout the growing season whenever site visits were conducted.

3.8.2 Root Zone Soil Moisture

Site 5 and Site 3 were selected for soil moisture profile monitoring. Site 5 contained a well drained soil and Site 3 contained an imperfectly drained soil with a high water table.

Root zone soil moisture was monitored at the Devonia Lake (site 3) and Aberfeldy (site 5) sites using wired gypsum blocks and an electrical potential gypsum block soil moisture meter to measure resistance (Delmhorst Moisture Tester Model KS-1). Gypsum moisture blocks were installed at depths of 15, 30, 60 and 90 cm. Installation consisted of augering a 5 cm hole to the appropriate depth, inserting the gypsum block, backfilling the zone around the block with a slurry of the native soil and water, and finally, backfilling and tamping the native soil in lifts to grade. Wires connected to the blocks were tied around surface stakes which identified the depth. The monitoring stations were allowed to stabilize for two weeks before initial readings were taken with the soil moisture meter.

Resistance measurements determined by the Delmhorst Soil Moisture Meter (Model KS-1) were converted to a soil moisture contents between field capacity and the wilting point using Table 3.5. Field capacity is the maximum amount of water a free draining soil can hold. The wilting point is the level of soil moisture content at which plants can no longer absorb moisture remaining in the soil.

3.8.3 Precipitation

Precipitation data were collected for Sites 1 through 4 by installing rain gauges at a central location within the site boundaries. The amount of rainfall collected was recorded approximately every two weeks throughout the active growing season from May to September.

The rain gauges consisted of 250 ml graduated cylinders fastened to stakes 0.6 m above the soil surface. Gauges were filled with 10 ml light mineral oil after installation to prevent water evaporation and thus increase measurement accuracy.

TABLE 3.5

CONVERSIONS FOR DELMHORST MOISTURE TESTER MODEL KS-1 AND CYLINDRICAL GYPSUM BLOCKS

MOISTURE TENSION (bars)	RESISTANCE (ohms)	METER READING	APPROX. WATER USED (%)
0.2	130	9.8	field capacity
0.3	260	9.0	
0.4	370	8.5	
0.6	750	7.0	25
0.8	1100	6.0	
1.0	1700	5.0	
1.5	3400	3.5	
1.8	4000	3.2	50
2.0	5000	2.8	
3.0	7200	2.2	
6.0	12500	1.5	
15.0	35000	0.6	wilting point

3.9 Mid Season Vegetation Evaluation

Detailed visual evaluations of standing vegetation on individual plots were conducted on June 22 and August 19 and 20, 1985. On these dates, all vegetation growing on the treatment plots was individually assessed for germination, height, overall appearance and variability.

Germination was evaluated by comparison to adjacent plots and to other sites via photographs. Height of barley was measured from the soil surface and recorded. Appearance and variability of the barley plants were also compared to adjacent plots and observations were recorded.

3.10 Vegetation Sampling

For sampling biomass, a quadrat was constructed specifically for the study from one centimeter wide angle iron which measured 50 cm by 110 cm (0.55 sq. meter). It was designed to enclose a constant number of seeded rows within the centre of each plot was painted red and white at alternating ten centimeter intervals so it could also be used to measure plant height.. The average height of barley within each plot was recorded before above ground biomass was harvested. Visual analyses of plant vigor, density and symptoms of stress were also recorded at harvest. After the quadrat was centered on each plot, the inflorescences of the enclosed vegetation were clipped at the base of the inflorescence and the stems were clipped 2-3 cm above the soil surface. Only above ground plant material was harvested because below ground or root biomass measurements were too difficult and time consuming to take. Inflorescence and stem biomass were placed in separate numbered paper bags, sealed, and sent immediately to Chemex Labs (Alta) in Calgary for oven-drying. Samples were dried in an oven at 105 degrees C until they reached a constant weight. An average tare weight was determined for the sample bags so oven-dry samples could be weighed "in the bag" to prevent errors in recording weights of loose vegetation. All samples were oven-dried within two days of sampling to prevent degradation of bagged plant material.

3.11 Methods for Analysis of Soil and Biomass Measurements

The nine soil treatments were analyzed for their ability to reduce electrical conductivity (EC), sodium adsorption ratios (SAR) and chloride (Cl) concentrations and increase plant productivity. The EC,SAR and Cl results from the 0-15 and 15-30 cm soil zones were statistically tested (pairwise t-tests) to determine if significant within-site changes in soil chemistry were measured during the study period (Zar, 1974). The inflorescence and total biomass weights were statistically tested (two sample t-test) to compare biomass developed on treated brine contaminated soil to biomass developed on an untreated, contaminated control within the same site (Huntsberger, 1974) (Cochran, 1964). Comparisons of treated contaminated plots to treated uncontaminated plots (two sample t-test) were also conducted to evaluate any statistical similariries in plant productivity One way Analyses of Variance (ANOVA) was used to determine if within site treatment effects were similar among sites (Afifi and Azen, 1979). Significant results are presented in section 4.0 and discussed in section 5.0.

4.0 DATA ANALYSIS AND RESULTS

Biomass production and changes in soil chemistry during the study period were used to compare treatment effectiveness on contaminated sites. Inflorescence weight, stem weight and total weight were used to measure biomass development. Electrical conductivity (EC), sodium adsorption ratio (SAR) and chloride values (Cl) were used to evaluate soil chemistry. Inflorescence and total weight production were considered the most important measures of reclamation success for the purpose of this study. Data from the study sites were analyzed independantly for each site to avoid confounding which could be introduced by grouping incompatible data (ie. grouping data from a highly contaminated site with data from a lightly contaminated site). The vegetation and soil chemical results were developed independantly for each site within the 0-15 cm and 15-30 cm soil zones. Only 0-15 cm results are addressed in the text but 15-30 cm results are provided in Appendix B for reference.

4.1 Analysis of Treatment and Site Effects

The Analysis of Variance (ANOVA) was used to determine if there were significant differences in among-site treatment effects (Afifi and Azen 1979). There were significant differences in within site treatment effects among sites 1, 2, 3 and 4 when data from the variables inflorescence weight and total weight were compared (Table 4.1). Thus, contaminated sites are addressed independantly, to eliminate the possibility of confounding the results.

4.2 Soil Chemistry

Pre-treatment and post-treatment values for electrical conductivity, sodium adsorption ratio and chloride from the 0-15 and 15-30 cm soil zones were compared for Sites 1 through 5 independantly using the pairwise t-test (Zar, 1974). Treatments which provided significant increases or decreases in these variables during the study period are presented for each site.

TABLE 4.1

ONE WAY ANOVA TESTING FOR
SIGNIFICANT TREATMENT EFFECT AMONG
SITES 1, 2, 3, & 4

TREATMENT EFFECT

Treatment	F Value	d.f.	P Value
inflorescence wt.	4.356	(8, 99)	0.0001*
stem wt.	6.402	(8, 99)	0.000*
total wt.	5.684	(8, 99)	0.000*

* Significant at the 0.001

Site 1

Electrical conductivity (EC) values were significantly reduced by organic matter, gypsum, calcium nitrate and organic matter and ammonium nitrate trreatments (Table 4.2). Calcium nitrate fertilizer (treatment 4) significantly reduced electrical conductivity by an average of 20.5 mS/cm from 42.1 mS/cm, just slightly more than gypsum (treatment 3) which significantly reduced conductivity by 18.4 mS/cm from 43.3 mS/cm. Organic matter and organic matter and ammonium nitrate (treatments 2 and 7) provided significant but smaller reductions in conductivity of 13.5 and 9.2 mS/cm.

Sodium adsorption ratio (SAR) values in the 0-15 cm soil zone at site 1 were reduced by three test treatments (Table 4.2). Calcium nitrate (treatment 4) significantly reduced SAR values an average of 17.7 units from 45.9. Organic matter and organic matter and ammonium nitrate (treatment 2 and 7) each significantly reduced SAR values 9.5 units from pre-treatment mean values of 32.0 and 34.8 respectively.

Chlorides in the 0-15 cm soil zone were reduced by two treatments (Table 4.2). Both calcium nitrate (treatment 4) and gypsum (treatment 3) significantly reduced chloride values in excess of 10 100 ppm from pre-treatment mean values of 17 666 ppm and 16 400 ppm respectively.

Calcium nitrate and gypsum were the two treatments which appeared to provide the most consistent and significant reductions in EC, SAR and chloride values at site 1 in the 0-15 cm soil zone.

The results of the statistical analysis performed on the 15-30 cm soil data are given in Table B1 in Appendix B. Gypsum and organic matter provide significant reductions in EC and chloride concentrations and calcium nitrate and ammonium nitrate provide significant

TABLE 4.2

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 1 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	39.4	24.8	14.5	20.15	0.338
2	34.9	21.4	13.5	4.51	0.035*
3	43.3	24.9	18.4	1.96	0.004**
4	42.1	21.6	20.5	1.95	0.003**
5	31.1	25.6	5.50	6.88	0.300
6	29.5	20.3	9.17	16.8	0.445
7	30.5	21.3	9.20	3.46	0.044*
8	24.8	18.8	6.00	21.7	0.679
9	34.9	24.3	10.6	9.10	0.181

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 1 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	32.8	23.5	9.27	10.07	0.252
2	32.0	22.5	9.47	2.23	0.018*
3	45.0	31.7	13.3	7.81	0.098
4	45.9	28.2	17.7	5.70	0.033*
5	10.0	9.27	0.73	0.51	0.132
6	30.5	23.0	7.47	12.9	0.423
7	34.8	25.3	9.47	2.88	0.029*
8	29.6	18.0	11.5	12.7	0.255
9	28.6	20.2	8.33	5.09	0.105

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 1 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	15 367	8 517	6 850	10 186	0.364
2	13 133	5 933	7 200	3 038	0.055
3	17 667	7 317	10 350	1 132	0.004**
4	16 400	6 283	10 117	1 115	0.004**
5	13 133	9 317	3 816	3 391	0.191
6	10 800	6 000	4 800	7 970	0.406
7	10 867	6 633	4 233	2 702	0.113
8	8 703	4 867	3 837	11 432	0.620
9	13 633	7 567	6 067	3 343	0.088

* Significant at the 0.05 level
** Significant at the 0.01 level

reductions in EC only. No significant reductions in SAR values were measured in the 15-30 cm soil zone at site 1.

Site 2

Electrical conductivity (EC) values at Site 2 were significantly reduced by the control, organic matter, gypsum and calcium nitrate (Table 4.3). The contaminated control (treatment 1) significantly reduced EC an average of 14.7 mS/cm from 25.4 mS/cm. Organic matter alone (treatment 2) significantly reduced conductivity 13.9 mS/cm from 25.6 mS/cm. Gypsum (treatment 3) significantly reduced conductivity 11.1 mS/cm from 23.5 mS/cm during the study period. Calcium nitrate (treatment 4) significantly reduced EC an average of 10.6 mS/cm at site 2, the smallest absolute reduction in EC which was significant.

Significant reductions in sodium adsorption ratio values were measured for organic matter, ammonium nitrate and gypsum and gypsum only treatments (Table 4.3). Organic matter, ammonium nitrate and gypsum (treatment 8) significantly reduced SAR values 22.9 from a pre-treatment average of 39.7. Gypsum (treatment 3) significantly reduced SAR values an average of 13.5 units from a pre-treatment mean value of 36.8.

Chloride values were significantly reduced by the control, organic matter, gypsum and calcium nitrate treatments (Table 4.3). The contaminated control (treatment 1) significantly reduced chloride concentrations an average of 6550 ppm from 9467 ppm during the study period. Organic matter (treatment 2) and gypsum (treatment 3) significantly reduced chloride concentrations by 6317 ppm and 5483 ppm respectively. Calcium nitrate (treatment 4) significantly reduced chloride concentrations an average of 4763 ppm from a pre-treatment value of 8933 ppm.

TABLE 4.3

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 2 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	25.4	10.7	14.7	4.28	0.027*
2	25.6	11.8	13.9	2.50	0.011*
3	23.5	12.5	11.1	0.49	0.001**
4	24.9	14.3	10.6	4.08	0.046*
5	24.8	8.50	16.3	8.84	0.086
6	28.2	12.4	15.8	9.75	0.107
7	19.4	8.40	11.0	6.70	0.105
8	22.8	10.1	12.7	13.8	0.251
9	31.9	13.6	18.4	13.1	0.136

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 2 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	35.7	29.5	6.13	6.21	0.229
2	30.3	19.5	10.9	6.84	0.111
3	36.8	23.3	13.5	4.76	0.039*
4	32.6	27.2	5.43	11.4	0.497
5	40.6	37.5	3.17	6.75	0.502
6	30.5	15.2	15.3	13.1	0.181
7	29.7	17.7	12.0	5.43	0.062
8	39.7	16.8	22.9	8.35	0.041*
9	32.7	21.6	11.1	9.73	0.187

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 2 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	9 467	2 917	6 550	1 929	0.028*
2	9 267	2 950	6 316	520.4	0.002**
3	8 033	2 550	5 483	251.7	0.001**
4	8 933	4 170	4 763	1 043	0.016*
5	8 900	2 300	6 600	3 300	0.074
6	10 467	3 067	7 400	3 742	0.076
7	6 167	1 833	4 333	3 134	0.139
8	8 167	1 500	6 667	5 326	0.161
9	11 667	3 050	8 617	5 008	0.097

* Significant at the 0.05 level
** Significant at the 0.01 level

The results of the statistical analysis performed on the soil chemical data from the 15-30 cm soil zone at are found in Table B2 in Appendix B. Treatments which provided significant results in the 0-15 cm soil zone did not provide any significant reductions in the 15-30 cm soil zone. Organic matter and ammonium nitrate (treatment 7) significantly reduced EC and chloride values. Organic matter and gypsum and organic matter, gypsum and ammonium nitrate (treatment 6 and 8) provided significant reductions in SAR values at site 2. The contaminated control (treatment 1), where no amendment was applied, and organic matter and ammonium nitrate (treatment 7) significantly reduced chloride concentrations.

There appears to be a relationship between the effect of the organic matter amendment and changes in soil chemistry in the 15-30 cm soil zone at site 2. Treatments containing organic matter were responsible for four out of five of the significant reductions in soil chemistry which were measured.

Site 3

Electrical conductivity was not significantly reduced by any of the test treatments during the study period (Table 4.4). Although not significant, some conductivity means were increased marginally, probably because poor drainage conditions were limiting treatment effectiveness.

Sodium adsorption ratios in the 0-15 cm soil zone were significantly reduced by ammonium nitrate (treatment 5) only (Table 4.4). Ammonium nitrate reduced SAR values an average of 2.9 from a pre-treatment mean of 18.1.

Chloride concentrations at site 3 were significantly reduced by organic matter, gypsum and ammonium nitrate (treatment 8) and SSC-50 (treatment 9) by an an average of 3800 ppm

TABLE 4.4

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 3 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	17.9	12.4	5.53	6.24	0.264
2	17.0	12.3	4.73	11.5	0.550
3	14.7	15.2	-0.57	3.47	0.804
4	15.1	15.5	-0.37	3.51	0.873
5	16.6	16.1	0.50	6.65	0.902
6	16.7	14.8	1.93	8.30	0.726
7	15.8	16.7	-0.90	9.66	0.887
8	23.3	14.6	8.70	4.93	0.093
9	22.8	20.6	2.20	2.85	0.313

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 3 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	16.9	14.7	2.23	1.12	0.075
2	15.0	10.6	4.40	2.86	0.117
3	16.5	14.7	1.77	3.50	0.474
4	14.4	13.2	1.23	2.40	0.467
5	18.1	15.2	2.93	1.12	0.045*
6	16.3	11.1	5.17	2.11	0.051
7	14.0	10.9	3.10	1.32	0.058
8	17.3	11.4	5.93	3.86	0.117
9	15.1	10.5	4.63	3.30	0.136

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 3 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	6 567	3 950	2 617	2 501	0.212
2	6 267	3 683	2 583	3 982	0.378
3	5 033	4 700	333.3	1 325	0.706
4	4 800	4 867	-66.67	1 498	0.946
5	5 467	5 150	316.7	1 722	0.780
6	5 700	4 483	1 216	3 696	0.626
7	5 133	4 983	150.0	4 239	0.957
8	8 467	4 667	3 800	1 472	0.047*
9	7 700	5 733	1 967	431	0.016*

* Significant at the 0.05 level
** Significant at the 0.01 level

and 1967 ppm respectively from pre-treatment values of 8467 ppm and 7700 ppm during the study period (Table 4.4).

The results of statistical comparisons performed on pre-treatment and post-treatment soil chemical data from the 15-30 cm soil zone are provided in Table B3 in Appendix B. Electrical conductivity and chloride concentrations were significantly reduced at the contaminated control plot, where no soil amendments were applied. Ammonium nitrate (treatment 5) and SSC-50 (treatment 9) also significantly reduced choride concentrations in the 15-30 cm soil zone. No significant reductions in SAR were measured in the 15-30 cm soil zone at site 3. There were more significant reductions in electrical conductivity and chloride values measured in the 15-30 cm soil zone than in the 0-15 cm soil zone. This phenomenon was likely caused by the upward capillary movement of groundwater moving the more mobile salts from the deeper soil zone toward the soil surface at this poorly drained site.

<u>Site 4</u>

No significant reductions in electrical conductivity (EC) were measured at site 4 (Table 4.5).

Sodium adsorption ratio (SAR) values were significantly reduced in the 0-15 cm soil zone by the contaminated control (treatment 1) where no amendment was applied, calcium nitrate, (treatment 4), organic matter and gypsum (treatment 6) and organic matter and ammonium nitrate (treatment 7) (Table 4.5). Calcium nitrate (treatment 4) significantly reduced SAR an average of 7.8 from a pre-treatment mean of 8.8. Organic matter and ammonium nitrate (treatment 7) reduced SAR an average of 7.0 units from 9.4 during the study period. SAR values were reduced an average of 6.7 units from a pre-treatment mean of 9.1 on the contaminated control plot (treatment 1). Organic matter and gypsum

TABLE 4.5

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 4 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	6.8	3.2	3.6	1.62	0.062
2	5.3	3.5	1.8	1.40	0.156
3	5.7	3.1	2.6	1.77	0.131
4	6.2	2.9	3.3	1.72	0.081
5	5.1	3.3	1.8	0.89	0.073
6	4.7	5.4	-0.7	1.00	0.368
7	6.4	4.0	2.4	0.99	0.052
8	4.7	5.3	-0.6	0.75	0.281
9	5.7	3.8	1.9	1.97	0.231

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 4 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	9.1	2.4	6.7	2.46	0.042*
2	7.8	1.3	6.5	3.15	0.070
3	8.1	2.0	6.1	4.09	0.120
4	8.8	1.0	7.8	2.85	0.042*
5	7.3	2.3	5.0	2.11	0.054
6	6.3	3.9	2.4	0.72	0.029*
7	9.4	2.4	7.0	1.93	0.024*
8	5.7	2.9	2.8	1.50	0.086
9	8.6	2.0	6.6	3.46	0.081

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 4 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	933.3	35.7	897.6	621.9	0.130
2	324.3	55.3	269.0	219.7	0.168
3	441.3	36.3	405.0	335.4	0.172
4	653.3	47.0	606.3	506.6	0.174
5	254.7	35.3	219.3	157.5	0.137
6	146.7	265.0	-118.3	252.5	0.502
7	630.0	63.0	567.0	195.5	0.037*
8	199.3	163.3	36.0	123.9	0.665
9	330.0	30.7	299.3	255.6	0.180

* Significant at the 0.05 level
** Significant at the 0.01 level

(treatment 6), which provided the smallest significant reduction in SAR, reduced SAR values only 2.4 units from a pre-treatment mean of 6.3.

Chloride values in the 0-15 cm soil zone were significantly reduced by only organic matter and ammonium nitrate (Table 4.5). Organic matter and ammonium nitrate (treatment 7) reduced chloride values an average of 567 ppm from a pre-treatment mean value of 630 ppm during the study period. The remainder of the test treatments provided no significant reductions in the moderately low pre-treatment chloride concentrations measured at this site.

The pre-treatment and post-treatment test means and the results of the statistical comparison conducted on the 15-30 cm soil chemical data are presented in Table B4 in Appendix B. No significant reductions were measured for electrical conductivity or sodium adsorption ratio during the study period. Chloride values were significantly reduced by organic matter (treatment 2), gypsum (treatment 3) and organic matter and ammonium nitrate (treatment 7) during the study period. Organic matter and gypsum provided the largest absolute reductions in chloride concentrations measured at site 4.

Site 5

Electrical conductivity values were significantly increased by gypsum (treatment 3), organic matter and gypsum (treatment 6), organic matter and ammonium nitrate (treatment 7), a combination of organic matter, gypsum and ammonium nitrate (treatment 8) and SSC - 50 (treatment 9) (Table 4.6). Electrical conductivity values were significantly increased by gypsum, organic matter and gypsum, organic matter and ammonium nitrate, a combination of organic matter, ammonium nitrate and gypsum and SSC - 50. The small but significant increases measured on this uncontaminated site indicate some of the amendments tested actually increase EC on uncontaminated soils where pre-treatment EC values are very low.

TABLE 4.6

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 5 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	0.87	0.37	0.50	0.265	0.082
2	0.70	2.27	-1.57	0.850	0.086
3	0.40	3.03	-2.63	0.208	0.002**
4	0.80	1.17	-0.37	1.007	0.593
5	0.43	1.07	-0.63	0.451	0.135
6	0.83	5.37	-4.53	1.650	0.041*
7	0.43	3.73	-3.30	0.700	0.015*
8	0.60	4.87	-4.27	1.222	0.026*
9	0.63	7.20	-6.57	1.617	0.020*

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 5 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	0.37	0.13	0.23	0.115	0.073
2	0.30	0.93	-0.63	0.802	0.305
3	0.30	0.93	-0.63	1.358	0.504
4	0.33	0.20	0.13	0.058	0.057
5	0.23	0.17	0.07	0.058	0.184
6	0.30	1.43	-1.13	0.551	0.070
7	0.33	2.00	-1.67	0.551	0.035*
8	0.27	1.60	-1.33	0.379	0.026*
9	0.47	0.17	0.30	0.173	0.095

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 5 0-15 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	6.00	23.0	- 17.0	8.71	0.078
2	8.33	154.7	-146.3	122.4	0.174
3	5.33	145.3	-140.0	226.9	0.397
4	8.67	30.3	- 21.7	17.0	0.158
5	6.67	18.0	- 11.3	4.93	0.058
6	8.00	331.7	-323.7	217.1	0.123
7	7.0	278.3	-271.3	88.3	0.034*
8	6.67	194.7	-188.0	148.2	0.159
9	8.33	29.7	- 21.3	12.5	0.098

* Significant at the 0.05 level

** Significant at the 0.01 level

The largest increases in EC were measured on plots where gypsum (treatments 3,6 and 8) was applied as part of the test treatment.

Sodium adsorption ratios (SAR) were significantly increased by organic matter and ammonium nitrate (treatment 7) and a combination of organic matter, ammonium nitrate and gypsum (treatment 8) (Table 4.6). Organic matter and ammonium nitrate (treatment 7) and organic matter, ammonium nitrate and gypsum (treatment 8) displayed average increases in SAR of 1.67 and 1.33 from pre-treatment mean values of 0.333 and 0.267 respectively. Sodium adsorption ratios were significantly increased on plots where organic matter and ammonium nitrate were applied as all or part of the test treatment.

Chloride values were significantly increased by organic matter and ammonium nitrate only (Table 4.6). Organic matter and ammonium nitrate (treatment 7) increased chlorides an average of 271 ppm from a pre-treatment mean of 7.0 ppm. No other significant increases were measured in the 0-15 cm soil zone at site 5.

Significant increases in chloride and SAR levels were unexpected results because sodium and chloride contaminants were not introduced at this site before or after the pre-treatment sampling and analysis programs were completed. Small increases in EC were expected from plots where gypsum (treatment 3, 6 and 8) was applied because of sulphates contained in the gypsum. Significant increases were not expected on plots where gypsum was not applied, but increases were measured on test plots where treatments 7 and 9 were applied.

Comparisons of the pre-treatment and post-treatment test means from the 15-30 cm soil zone are provided in Table B5 in Appendix B. SSC-50 (treatment 9) significantly reduced EC values in the 15-30 cm soil zone during the study period and was the only treatment where a significant reduction in EC was measured in both the 0-15 and 15-30 cm soil zones. Sodium adsorption ratios were significantly reduced only on the contaminated control, where no soil amendments were applied. No significant reductions in chloride concentrations in the 15-30 cm soil zone were measured during the study period.

4.3 Environmental Monitoring

Data from the groundwater, soil moisture and precipitation monitoring instruments were collected whenever site visits were conducted. The results obtained from these monitoring programs are provided below.

4.3.1 Ground Water

Groundwater measurements were obtained at Sites 1 through 4 for the duration of the study and compared with root zone soil moisture measurements at sites 3 and 5 to assess the potential for capillary rise of groundwater. Based on these measurements, Sites 1, 2 and 4 exhibited groundwater depths which were far enough below the soil surface to prevent the capillary rise of water to the surface and the subsequent evaporation of this potentially saline water. In all cases, groundwater depths at these sample sites were in excess of 1.19 m from the soil surface. Site 3 exhibited groundwater depths which were less than 1.0 m in depth during part of the study period. The potential for resalinization, at groundwater depths of less than 1.0 meter, was high in the loamy textured soils of the study region and this potential was evident at site 3. Statistical analysis of soil chemical data from site 3 indicatedthe least number of significant changes in soil chemistry (EC, SAR and chloride) occurred at this site (Table 4.7).

Soil suction and texture are important factors in determining the depth at which the water table will influence the soil surface by capillary rise. The loamy textured soils found in the Lloydminster study region have a greater potential for capillary rise than either finer or

TABLE 4.7

DEPTH TO GROUNDWATER (m)*

DATE (1985)	SITE 1 BH 1	SITE 1 BH 2	SITE 2 BH1	SITE 2 BH2	SITE 3 BH 1	SITE 3 BH 2	SITE 4 BH 1	SITE 4 BH 2
May 22	1.67	1.54					dry	dry
May 23			2.10	dry	1.24	0.96		
June 5	1.45	1.30	1.76	2.07	1.065	0.76	dry	dry
June 18							dry	dry
June 19	1.31	1.19	1.845	2.03				
June 20					0.77	0.24		
July 10			2.07	2.05				
July 11	1.52	1.44			1.09	0.89		
July 31							dry	dry
August 1	1.73	1.68	2.03	2.13	1.21	1.13		
August 20	1.78	1.80			1.21	1.23	dry	dry
August 26	1.51	1.66			1.04	0.68	1.82 m	dry
August 27			2.03	2.15				
Sept. 20	1.80	1.88	2.03	dry	destroyed	1.18	dry	dry

*depth measured from soil surface

TOTAL DEPTH OF BOREHOLES (m)

	SITE 1		SITE 2		SITE 3		SITE 4	
DEPTH	BH1	BH2	BH1	BH2	BH1	BH2	BH1	BH2
TOTAL DEPTH	2.07	2.07	2.13	2.16	2.12	2.10	2.2	2.18

coarser textured soils (Buckman and Brady 1969). The results of the groundwater monitoring program combined with results from the root zone moisture monitoring program indicate that at depths of less than 1.0 m at site 3, capillary rise of groundwater can cause the migration of salts to the soil surface.

4.3.2 Root Zone Soil Moisture

Soil moisture was monitored at Site 3 and Site 5 at 15 cm, 30 cm, 60 cm and 90 cm below the soil surface to determine if water was moving toward the soil surface above the phreatic zone. The readings obtained (Table 4.8) were calibrated to correlate with the approximate quantity of water in the soil (Table 4.9). Cross-referencing the depths and meter readings in Table 4.8 to the meter readings column in Table 4.9 provides seasonal results which indicate the approximate quantity of water used by vegetation at a given depth in the soil profile and the moisture tension holding the water remaining in the soil. Results of soil moisture tests were useful to determine critical water table depths and to assess the resalinization potential of the sites as discussed in section 4.3.1.

The Aberfeldy uncontaminated site (Site 5) showed a moisture regime typical of a well drained site. Surface soil moisture was near field capacity in the 15 and 30 cm zone after spring recharge. During the growing season, soil moisture in these zones decreased to near wilting point in response to plant water use and evaporation. Soil moisture in the 60 and 90 cm soil zones was initially at field capacity and remained at field capacity throughout the growing season. Barley, used as the indicator species, develops roots well below the 60 cm depth where it would obtain water during the latter part of the growing season. Soil moisture in this zone remained at field capacity throughout the latter part of the growing season, indicating capillary rise was limited to a level 60 cm below the soil surface. Soil moisture above the 60 cm soil zone, where vegetation obtained water for germination and

TABLE 4.8

ROOT ZONE SOIL MOISTURE READINGS

DATE	DEVONIA LAKE CONTAMINATED SITE 3 METER READINGS				ABERFELDY UNCONTAMINATED SITE 5 METER READINGS			
	15 cm	30 cm	60 cm	90 cm	15 cm	30 cm	60 cm	90 cm
June 5	10	10	10	10	9	9	10	10
June 19	10	10	10	10	9.5	9.75	10	10
July 3	10	10	10	10	2.5	3.5	10	10
Aug. 1	10	10	10	10	0.1	0.1	9.75	10
Aug. 20	10	10	10	10	0.1	0.1	10	10

TABLE 4.9

CONVERSIONS FOR DELMHORST MOISTURE TESTER

MODEL KS-1* AND CYLINDRICAL GYPSUM BLOCKS

MOISTURE TENSION (bars)	RESISTANCE (ohms)	METER READING	APPROX. WATER USED (%)
0.2	130	9.8	field capacity
0.3	260	9.0	
0.4	370	8.5	
0.6	750	7.0	25
0.8	1100	6.0	
1.0	1700	5.0	
1.5	3400	3.5	
1.8	4000	3.2	50
2.0	5000	2.8	
3.0	7200	2.2	
6.0	12500	1.5	
15.0	35000	0.6	wilting point

*provided by manufacturer

initial growth, was at the wilting point after August 1, 1985 which indicates moisture in this zone was not.replenished from below.

The contaminated site at Devonia Lake (Site 3) was selected for soil moisture monitoring because of the proximity of the water table to the soil surface and the resulting potential for resalinization. Data from the monitoring program indicate this site is poorly drained and the influence of capillary action on the soil moisture regime extends to the soil surface. The moisture content of the surface soil at Site 3 remained at field capacity throughout the growing season, indicating the resalinization potential is high, particularly following periods of high rainfall.

4.3.3 Precipitation

Precipitation information for Sites 1 through 4 was recorded throughout the study period (Table 4.10). Precipitation received during similar periods ranged from 174 mm at Site 2 to 286 mm at Site 4. All sites are in the same climatic zone within a 100 km linear distance. Extremes in precipitation are due mainly to thunder storms which move quickly through the area, depositing large volumes of rain on localized areas.

4.4 Mid-Season Vegetation Evaluation

On June 22, 1985, all sites were inspected for variablity in germination. At this time, not all plots had germinated but a definite pattern was evident. The best germination on the four contaminated sites occured where organic matter was applied as part of the treatment. On these plots, germination appeared normal, but weedy species were also present in greater abundance than on other plots. Plots which were fertilized or had calcium applied showed signs of germination or had just germinated. Control and SSC-50 plots showed no germination or very spotty germination.

TABLE 4.10

PRECIPITATION MEASUREMENTS (mm)

May to September (1985)

DATE (1985)	SITE 1 Sample	SITE 1 Total	SITE 2 Sample	SITE 2 Total	SITE 3 Sample	SITE 3 Total	SITE 4 Sample	SITE 4 Total
May 23	10	10	10	10	14	14	20	20
June 5	6	16	36	46	12	26	38	58
June 19	52	68	18	64	88	114	54	112
July 11	14	82	14	78	23	137	-	-
August 1	27	109	14	92	15	152	48	160
August 20	39	148	-	-	41	193	39	199
August 26	42	190	62	154	55	248	71	270
September 20	5	195	20	174	Destroyed		16	286

On the uncontaminated site (Site 5) germination was substandard on plots where organic matter was applied and weedy species were also more common when germination and weediness was compared to other treated plots. All other plots except those treated with organic matter appeared to have germinated normally.

On August 19 and 20, all sites were assessed in detail. The average height of barley plants measured from ground surface to awn tips ranged from 10 cm to 110 cm. Correlation between treatments on different sites was observed with organic matter plots (treatments 2, 6, 7 and 8) appearing near normal and apparently healthy. Contaminated control and SSC-50 test plots (treatments 1 and 9) appeared unhealthy at this time and many plants were partially necrotic. Barley developed on fertilized and calcium treated plots (treatments 3, 4 and 5) was intermediate in height and vigor. Plots treated with organic matter contained more weedy species than other plots, but unlike the June 22 assessment, plots treated with organic matter on the uncontaminated site contained barley which appeared normal and similar in height to barley developed on other plots within the same site (site 5).

At the mature stage, barley growing on gypsum, calcium nitrate and ammonium nitrate plots (treatments 3, 4 and 5) was abnormal and displayed a number of general symptoms. Twisted leaves and awns were common mutations and marginal discoloration of foilage was widespread. A tendency for lower leaves to yellow completely and drop off was also observed. Poorly formed and filled seed heads and some aborted seed heads (no seed formation) were common on plots containing organic matter (treatments 6, 7 and 8). The poorest barley growth, developed on control and SSC-50 plots (treatments 1 and 9), was found to have shallow roots and up to 100% deformed or aborted seed heads. Plants still living on these plots appeared to be struggling to survive.

Overall, there was good visual correlation within similar treatments and a high degree of variability among treatments. Barley development on individual plots generally exhibited features which were consistent within plot boundaries. The most commonly observed differences were variations in crop ripeness and quantity of weeds. Ripeness varied within plots as well as between plots but showed no visual correlation to specific treatments. The presence of weedy species appeared to be linked to the organic matter amendment which may have been contaminated with weed seeds. Weeds were mostly absent on plots where barley did poorly, indicating weedy species were also negatively influenced by soil salinity. These very poor growth areas were immediately obvious due to patchy growth.

4.5 Vegetation Analysis

The influence of the test treatments on biomass was determined by comparing individual test treatment subsets (a group of the same treatments from one site) to the contaminated control subset within the same site and to the corresponding treatment subset developed on uncontaminated soil, using two sample t-tests.

Within Site 1

There were no significant differences in biomass weight development between treatments 2 through 9 and the contaminated control (treatment 1), even though large differences in mean weights among treatments were recorded (Table 4.11). The statistical similarities in the treatments, when differences in the data are apparent, are likely due to the small number of cases (n=3) used to calculate the result.

Site 1 versus Site 5

Site 1 produced similar inflorescence weights and significantly less stem and total weights than uncontaminated Site 5 for control (treatment 1), organic matter (treatment 2), gypsum (treatment 3), calcium nitrate (treatment 4), ammonium nitrate (treatment 5) and organic

TABLE 4.11

WITHIN SITE ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 1

TREATMENT (n = 3)	Mean Biomass gr./0.55 m^2 Inflorescence	Mean Biomass gr./0.55 m^2 Total	d.f.	Hypotheses Ho:	Hypotheses Ha:	2-Tail p-value Inflorescence	2-Tail p-value Total	Decision Inflorescence	Decision Total
1 control (no treatment)	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.952	0.797	Accept Ho:	Accept Ho:
2 organic matter (O.M.)	53.5	111.4							
1 control	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.369	0.321	Accept Ho:	Accept Ho:
3 gypsum (G)	19.9	36.0							
1 control	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.376	0.337	Accept Ho:	Accept Ho:
4 calcium nitrate (F_1)	19.0	35.5							
1 control	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.663	0.696	Accept Ho:	Accept Ho:
5 ammonium nitrate (F_2)	68.5	121.6							
1 control	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.347	0.391	Accept Ho:	Accept Ho:
6 O.M. + G	95.6	163.3							
1 control	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.690	0.559	Accept Ho:	Accept Ho:
7 O.M. + F_2	65.4	131.3							
1 control	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.380	0.364	Accept Ho:	Accept Ho:
8 O.M. + F_2 + G	129.2	231.1							
1 control	51.4	95.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.644	0.650	Accept Ho:	Accept Ho:
9 SSC-50	30.5	59.2							

* significant at the 0.05 level
** significant at the 0.01 level

matter and gypsum (treatment 6) treatments (Table 4.12). Organic matter and ammonium nitrate (treatment 7) and SSC-50 (treatment 9) treatments produced significantly lower inflorescence, stem and total weights than Site 5 when biomass from contaminated site 1 and uncontaminated Site 5 were compared.

Organic matter, ammonium nitrate and gypsum (treatment 8) was the only treatment which produced biomass weights similar to weights produced on site 5 for both inflorescence and total weight and produced a mean inflorescence weight of 129.17 grams and a mean total weight of 231.1 grams (Table 4.12). Treatments 6, 5 and 7 were the were the next most productive treatments tested at site 1 and produced mean inflorescence weights of 95.6, 68.5 and 65.4 grams and mean total weights of 163.3, 121.6 and 131.3 grams respectively. SSC-50 (treatment 9) produced the most significant differences from Site 5 and calcium nitrate (treatment 4) produced the lowest overall weights.

Within Site 2

There were no significant differences in mean biomass weight development when treatments 2 through 9 were compared with the contaminated control (treatment 1), even though substantial differences in the mean weights were observed (Table 4.13). The statistical similarity in the treatments, when there are large numerical differences in the calculated means, are likely due to the small number of cases (n=3) used to calculate the result

Site 2 versus Site 5

Treatments consisting of control (treatment 1), organic matter (treatment 2), gypsum (treatment 3), calcium nitrate (treatment 4), ammonium nitrate (treatment 5), organic matter and gypsum (treatment 6), organic matter and ammonium nitrate (treatment 7) and organic matter, ammonium nitrate and gypsum (treatment 8) developed inflorescence

TABLE 4.12

ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 1 VS. SITE 5 (control)

Treatments (n=3)	Mean Biomass Weight g/0.55 m²				Hypotheses		2 tail p-value			Decision		
	inflor.	stem	total	d.f.	Ho:	Ha:	inflor.	stem	total	inflor.	stem	total
1 control	51.40	43.97	95.37	4	$u_1=u_2$	$u_1 \neq u_2$	0.213	0.004**	0.030*	Accept Ho:	Reject Ho:	Reject Ho:
1 (uncontaminated)	144.67	181.53	326.20									
2 organic matter	53.53	57.87	111.40	4	$u_1=u_2$	$u_1 \neq u_2$	0.147	0.007**	0.015*	Accept Ho:	Reject Ho:	Reject Ho:
2 (uncontaminated)	190.47	304.87	495.33									
3 organic matter	19.90	16.10	36.00	4	$u_1=u_2$	$u_1 \neq u_2$	0.063	0.009**	0.008**	Accept Ho:	Reject Ho:	Reject Ho:
3 (uncontaminated)	128.80	243.33	372.13									
4 calcium nitrate	19.03	16.33	35.47	4	$u_1=u_2$	$u_1 \neq u_2$	0.129	0.004**	0.020*	Accept Ho:	Reject Ho:	Reject Ho:
4 (uncontaminated)	165.90	244.97	410.87									
5 ammonium nitrate	68.50	53.10	121.60	4	$u_1=u_2$	$u_1 \neq u_2$	0.325	0.027*	0.011*	Accept Ho:	Reject Ho:	Reject Ho:
5 (uncontaminated)	108.73	218.40	327.13									
6 O.M. + G.	95.57	67.73	163.30	4	$u_1=u_2$	$u_1 \neq u_2$	0.396	0.003**	0.006**	Accept Ho:	Reject Ho:	Reject Ho:
6 (uncontaminated)	141.10	423.33	564.43									
7 O.M. + Fl	65.40	65.90	131.30	4	$u_1=u_2$	$u_1 \neq u_2$	0.028*	0.011*	0.011*	Reject Ho:	Reject Ho:	Reject Ho:
7 (uncontaminated)	250.33	253.17	503.50									
8 O.M. + Fl + G	129.17	101.93	231.10	4	$u_1=u_2$	$u_1 \neq u_2$	0.517	0.056	0.196	Accept Ho:	Accept Ho:	Accept Ho:
8 (uncontaminated)	188.60	278.33	466.93									
9 SSC-50	30.53	27.30	59.23	4	$u_1=u_2$	$u_1 \neq u_2$	0.007**	0.006**	0.005**	Reject Ho:	Reject Ho:	Reject Ho:
9 (uncontaminated)	209.40	185.40	394.80									

* significant at the 0.05 level
** significant at the 0.01 level

TABLE 4.13

WITHIN SITE ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 2

TREATMENT (n = 3)	Mean Biomass gr./0.55 m^2 Inflorescence	Total	d.f.	Hypotheses Ho:	Ha:	2-Tail p-value Inflorescence	Total	Decision Inflorescence	Total
1 control (no treatment) 2 organic matter (O.M.)	63.2 57.6	127.9 163.7	4	$u_1 = u_2$	$u_1 \neq u_2$	0.888	0.411	Accept Ho:	Accept Ho:
1 control 3 gypsum	63.2 102.6	127.9 221.6	4	$u_1 = u_2$	$u_1 \neq u_2$	0.311	0.250	Accept Ho:	Accept Ho:
1 control 4 calcium nitrate (F_1)	63.2 60.9	127.9 131.3	4	$u_1 = u_2$	$u_1 \neq u_2$	0.962	0.958	Accept Ho:	Accept Ho:
1 control 5 ammonium nitrate (F_2)	63.2 95.9	127.9 183.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.212	0.076	Accept Ho:	Accept Ho:
1 control 6 O.M. + G	63.2 34.0	127.9 113.9	4	$u_1 = u_2$	$u_1 \neq u_2$	0.411	0.723	Accept Ho:	Accept Ho:
1 control 7 O.M. + F_2	63.2 88.5	127.9 198.6	4	$u_1 = u_2$	$u_1 \neq u_2$	0.606	0.291	Accept Ho:	Accept Ho:
1 control 8 O.M. + F_2 + G	63.2 135.1	127.9 269.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.098	0.073	Accept Ho:	Accept Ho:
1 control 9 SSC-50	63.2 44.2	127.9 98.1	4	$u_1 = u_2$	$u_1 \neq u_2$	0.496	0.383	Accept Ho:	Accept Ho:

* significant at the 0.05 level
** significant at the 0.01 level

weights which were similar to uncontaminated Site 5 (Table 4.14). Organic matter, ammonium nitrate and gypsum (treatment 8) produced the highest inflorescence and total weights (135.1 and 269.4 grams respectively) measured at site 2. SSC-50 (treatment 9) produced the most significant differences from Site 5 and the lowest biomass weights measured.

Within Site 3

Organic matter (treatment 2), organic matter and gypsum (treatment 6) and organic matter, gypsum and ammonium nitrate (treatment 8) treatments produced biomass weights which were significantly heavier than the contaminated control (treatment 1) for both inflorescence and total weights (Table 4.15). These treatments produced 290%, 329% and 432% more total biomass and 199%, 237% and 307% more inflorescence than the contaminated control respectively. Treatments which significantly improved biomass production contained organic matter as the common element. The improvements in biomass production measured on organic matter treated plots at site 3, which is poorly drained, likely resulted from physical improvements in the treated soil which prevented salts from rising to the soil surface by capillary action and causing restrictions in plant growth.

Site 3 versus Site 5

The control (treatment 1), organic matter (treatment 2), organic matter and gypsum (treatment 6) and organic matter ammonium nitrate and gypsum (treatment 8) treated plots produced inflorescence weights which were similar to uncontaminated Site 5 and total weights which were significantly different from uncontaminated Site 5 (Table 4.16). Organic matter, ammonium nitrate and gypsum (treatment 8) produced the highest mean inflorescence and total weights (163.1 and 284.3 grams respectively) but the total weight was significantly less than the weight produced by treatment 8 on uncontaminated Site 5.

TABLE 4.14

ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 2 VS. SITE 5 (control)

Treatment (n=3)	Mean Biomass Weight g/0.55 m²				Hypotheses		2 tail p-value			Decision		
	inflor.	stem	total	d.f.	Ho:	Ha:	inflor.	stem	total	inflor.	stem	total
1 control 1 (uncontaminated)	63.20 144.67	64.67 181.53	127.87 326.20	4	$u_1=u_2$	$u_1 \neq u_2$	0.243	0.011*	0.022*	Accept Ho:	Reject Ho:	Reject Ho:
2 organic matter 2 (uncontaminated)	57.57 190.47	106.13 304.87	163.70 495.33	4	$u_1=u_2$	$u_1 \neq u_2$	0.176	0.050*	0.025*	Accept Ho:	Reject Ho:	Reject Ho:
3 gypsum 3 (uncontaminated)	102.60 128.80	119.03 243.33	221.63 372.13	4	$u_1=u_2$	$u_1 \neq u_2$	0.623	0.116	0.181	Accept Ho:	Accept Ho:	Accept Ho:
4 calcium nitrate 4 (uncontaminated)	60.87 165.90	70.43 244.97	131.30 410.87	4	$u_1=u_2$	$u_1 \neq u_2$	0.289	0.013*	0.068	Accept Ho:	Reject Ho:	Accept Ho:
5 ammonium nitrate 5 (uncontaminated)	95.87 108.73	87.53 218.40	183.40 327.13	4	$u_1=u_2$	$u_1 \neq u_2$	0.686	0.102	0.006**	Accept Ho:	Accept Ho:	Reject Ho:
6 O.M. + G 6 (uncontaminated)	33.97 141.10	79.97 423.33	113.93 564.43	4	$u_1=u_2$	$u_1 \neq u_2$	0.076	0.003**	0.002**	Accept Ho:	Reject Ho:	Reject Ho:
7 O.M. + F 7 (uncontaminated)	88.53 250.33	110.07 253.17	198.60 503.50	4	$u_1=u_2$	$u_1 \neq u_2$	0.072	0.075	0.033*	Accept Ho:	Accept Ho:	Reject Ho:
8 O.M. + F + G 8 (uncontaminated)	135.13 188.60	134.23 278.33	269.37 466.93	4	$u_1=u_2$	$u_1 \neq u_2$	0.332	0.049*	0.019*	Accept Ho:	Reject Ho:	Reject Ho:
9 SSC-50 9 (uncontaminated)	44.16 209.40	53.97 185.40	98.13 394.80	4	$u_1=u_2$	$u_1 \neq u_2$	0.022*	0.001**	0.001**	Reject Ho:	Reject Ho:	Reject Ho:

* significant at the 0.05 level
** significant at the 0.01 level

TABLE 4.15

WITHIN SITE ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 3

TREATMENT (n = 3)	Mean Biomass gr./0.55 m^2 Inflorescence	Mean Biomass gr./0.55 m^2 Total	d.f.	Hypotheses Ho:	Hypotheses Ha:	2-Tail p-value Inflorescence	2-Tail p-value Total	Decision Inflorescence	Decision Total
1 control (no treatment)	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.045*	0.045*	Reject Ho:	Reject Ho:
2 organic matter (O.M.)	106.0	190.7							
1 control	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.374	0.409	Accept Ho:	Accept Ho:
3 gypsum	0.0	26.5							
1 control	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.541	0.314	Accept Ho:	Accept Ho:
4 calcium nitrate (F_1)	8.0	18.8							
1 control	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.804	0.599	Accept Ho:	Accept Ho:
5 ammonium nitrate (F_2)	18.7	40.3							
1 control	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.041*	0.031*	Reject Ho:	Reject Ho:
6 O.M. + G	126.4	216.7							
1 control	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.093	0.113	Accept Ho:	Accept Ho:
7 O.M. + F_2	116.4	193.9							
1 control	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.035*	0.039*	Reject Ho:	Reject Ho:
8 O.M. + F_2 + G	163.1	284.3							
1 control	26.6	65.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.575	0.380	Accept Ho:	Accept Ho:
9 SSC-50	9.9	25.7							

* significant at the 0.05 level
** significant at the 0.01 level

TABLE 4.16

ANALYSIS TREATMENT BIOMASS MEANS

SITE 3 VS. SITE 5 (control)

Treatment (n=3)	Mean Biomass Weight g/0.55 m² inflor.	stem	total	d.f.	Hypotheses Ho:	Ha:	2 tail p-value inflor.	stem	total	Decision inflor.	stem	total
1 control	26.57	21.53	65.83	4	$u_1=u_2$	$u_1 \neq u_2$	0.127	0.003**	0.015*	Accept Ho:	Reject Ho:	Reject Ho:
1 (uncontaminated)	144.67	181.53	326.20									
2 organic matter	106.03	84.67	190.70	4	$u_1=u_2$	$u_1 \neq u_2$	0.378	0.010**	0.029*	Accept Ho:	Reject Ho:	Reject Ho:
2 (uncontaminated)	190.47	304.87	495.33									
3 gypsum	0.00	0.00	26.47	4	$u_1=u_2$	$u_1 \neq u_2$	0.036*	0.007**	0.007**	Reject Ho:	Reject Ho:	Reject Ho:
3 (uncontaminated)	128.80	243.33	372.13									
4 calcium nitrate	8.03	5.43	18.83	4	$u_1=u_2$	$u_1 \neq u_2$	0.174	0.025*	0.057	Accept Ho:	Reject Ho:	Accept Ho:
4 (uncontaminated)	165.90	244.97	410.87									
5 ammonium nitrate	18.67	17.47	40.27	4	$u_1=u_2$	$u_1 \neq u_2$	0.048*	0.012*	0.001**	Reject Ho:	Reject Ho:	Reject Ho:
5 (uncontaminated)	108.73	218.40	327.13									
6 O.M. + G	126.43	90.27	216.70	4	$u_1=u_2$	$u_1 \neq u_2$	0.753	0.023*	0.005**	Accept Ho:	Reject Ho:	Reject Ho:
6 (uncontaminated)	141.10	423.33	564.43									
7 O.M. + F	116.40	77.50	193.90	4	$u_1=u_2$	$u_1 \neq u_2$	0.096	0.015*	0.029*	Accept Ho:	Reject Ho:	Reject Ho:
7 (uncontaminated)	250.33	253.17	503.50									
8 O.M. + F + G	163.06	121.20	284.27	4	$u_1=u_2$	$u_1 \neq u_2$	0.659	0.037*	0.031*	Accept Ho:	Reject Ho:	Reject Ho:
8 (uncontaminated)	188.60	278.33	466.93									
9 SSC-50	9.90	13.63	25.70	4	$u_1=u_2$	$u_1 \neq u_2$	0.001**	0.00**	0.00**	Reject Ho:	Reject Ho:	Reject Ho:
9 (uncontaminated)	209.40	185.40	394.80									

* significant at the 0.05 level
** significant at the 0.01 level

SSC-50 (treatment 9) treated plots produced significantly less biomass at Site 2 than at uncontaminated Site 5 and developed the lowest mean inflorescence and total weights (9.9 and 25.7 grams respectively) measured at Site 2.

Within Site 4

Calcium nitrate (treatment 4), ammonium nitrate (treatment 5), organic matter and gypsum (treatment 6), organic matter and ammonium nitrate (treatment7) and SSC-50 (treatment 9) produced biomass for both inflorescence and total weights which were significantly heavier than the contaminated control (treatment 1) (Table 4.17). These treatments produced 175%, 209%, 159%, 195% and 239% more inflorescence and 339%, 410%, 396%, 402% and 499% more total biomass than the control. SSC-50 (treatment 9) demonstrated the largest significant improvement in biomass production at site 4, but performed poorly by comparison at the other three contaminated sites. The fairly low level of contamination at site 4 compared to the other three sites and the action of the soil conditioners contained in SSC-50 may have caused this result.

Site 4 versus Site 5

All treatments tested at Site 4 developed inflorescence weights which were similar to inflorescence weights developed on uncontaminated Site 5 (Table 4.18). SSC-50 (treatment 9) produced the highest inflorescence weight followed by organic matter, ammonium nitrate and gypsum (treatment 8). Organic matter, ammonium nitrate and gypsum (treatment 8) produced the highest total weight at Site 4 but this weight was significantly less than the total weight produced by treatment 8 at uncontaminated Site 5.

TABLE 4.17

WITHIN SITE ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 4

TREATMENT (n = 3)		Mean Biomass gr./0.55 m^2 Inflorescence	Total	d.f.	Hypotheses Ho:	Ha:	2-Tail p-value Inflorescence	Total	Decision Inflorescence	Total
1	control (no treatment)	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.093	0.141	Accept Ho:	Accept Ho:
2	organic matter (O.M.)	115.1	195.3							
1	control	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.214	0.317	Accept Ho:	Accept Ho:
3	gypsum (G)	43.3	68.6							
1	control	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.049*	0.026*	Reject Ho:	Reject Ho:
4	calcium nitrate (F_1)	109.9	192.6							
1	control	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.011*	0.000**	Reject Ho:	Reject Ho:
5	ammonium nitrate (F_2)	131.5	233.2							
1	control	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.033*	0.000**	Reject Ho:	Reject Ho:
6	O.M. + G	99.6	225.0							
1	control	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.025*	0.013*	Reject Ho:	Reject Ho:
7	O.M. + F_2	122.2	228.1							
1	control	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.158	0.052	Accept Ho:	Accept Ho:
8	O.M. + F_2 + G	146.7	307.3							
1	control	31.4	56.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.046*	0.007**	Reject Ho:	Reject Ho:
9	SSC-50	150.0	283.3							

* significant at the 0.05 level
** significant at the 0.01 level

TABLE 4.18

ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 4 VS. SITE 5 (control)

Treatment (n=3)	Mean Biomass Weight g/0.55 m²				Hypotheses		2 tail p-value			Decision		
	inflor.	stem	total	d.f.	Ho:	Ha:	inflor.	stem	total	inflor.	stem	total
1 control	31.43	25.37	56.80	4	$u_1=u_2$	$u_1\neq u_2$	0.180	0.006**	0.033*	Accept	Reject	Reject
1 (uncontaminated)	144.67	181.53	326.20							Ho:	Ho:	Ho:
2 organic matter	115.07	80.23	195.30	4	$u_1=u_2$	$u_1\neq u_2$	0.418	0.011*	0.048*	Accept	Reject	Reject
2 (uncontaminated)	190.47	304.87	495.33							Ho:	Ho:	Ho:
3 gypsum	43.30	25.33	68.63	4	$u_1=u_2$	$u_1\neq u_2$	0.177	0.045*	0.044*	Accept	Reject	Reject
3 (uncontaminated)	128.80	243.33	372.13							Ho:	Ho:	Ho:
4 calcium nitrate	109.87	82.77	192.63	4	$u_1=u_2$	$u_1\neq u_2$	0.524	0.016*	0.106	Accept	Reject	Accept
4 (uncontaminated)	165.90	244.97	410.87							Ho:	Ho:	Ho:
5 ammonium nitrate	131.47	101.77	233.23	4	$u_1=u_2$	$u_1\neq u_2$	0.561	0.064	0.029*	Accept	Accept	Reject
5 (uncontaminated)	108.73	218.40	327.13							Ho:	Ho:	Ho:
6 O.M. + G	99.63	125.33	224.97	4	$u_1=u_2$	$u_1\neq u_2$	0.391	0.005**	0.005**	Accept	Reject	Reject
6 (uncontaminated)	141.10	423.33	564.43							Ho:	Ho:	Ho:
7 O.M. + F	122.17	105.90	228.07	4	$u_1=u_2$	$u_1\neq u_2$	0.095	0.032*	0.035*	Accept	Reject	Reject
7 (uncontaminated)	250.33	253.17	503.50							Ho:	Ho:	Ho:
8 O.M. + F + G	146.73	160.60	307.33	4	$u_1=u_2$	$u_1\neq u_2$	0.560	0.054	0.042*	Accept	Accept	Reject
8 (uncontaminated)	188.60	278.33	466.93							Ho:	Ho:	Ho:
9 SSC-50	150.03	133.26	283.30	4	$u_1=u_2$	$u_1\neq u_2$	0.258	0.031*	0.088	Accept	Reject	Accept
9 (uncontaminated)	209.40	185.40	394.80							Ho:	Ho:	Ho:

* significant at the 0.05 level
** significant at the 0.01 level

Within Site 5

Organic matter and gypsum (treatment 6) was the only treatment which produced significantly more total biomass than the control (treatment 1) and produced 564 grams compared to 326 grams or 173% more total biomass (Table 4.19). There were no significant differences in inflorescence biomass production between any of the treatments tested (treatments 2 through 9 inclusive) and the control (treatment 1) at this uncontaminated site.

TABLE 4.19

WITHIN SITE ANALYSIS OF TREATMENT BIOMASS MEANS

SITE 5

TREATMENT (n = 3)		Mean Biomass gr./0.55 m^2 Inflorescence	Total	d.f.	Hypotheses Ho:	Ha:	2-Tail p-value Inflorescence	Total	Decision Inflorescence	Total
1 3	control gypsum	144.7 128.8	326.2 372.1	4	$u_1 = u_2$	$u_1 \neq u_2$	0.830	0.606	Accept Ho:	Accept Ho:
1 4	control calcium nitrate (F_1)	144.7 165.9	326.2 410.9	4	$u_1 = u_2$	$u_1 \neq u_2$	0.832	0.483	Accept Ho:	Accept Ho:
1 5	control ammonium nitrate (F_2)	144.7 108.7	326.2 327.1	4	$u_1 = u_2$	$u_1 \neq u_2$	0.597	0.988	Accept Ho:	Accept Ho:
1 6	control O.M. + G	144.7 141.1	326.2 564.4	4	$u_1 = u_2$	$u_1 \neq u_2$	0.960	0.035*	Accept Ho:	Reject Ho:
1 7	control O.M. + F_2	144.7 250.3	326.2 503.5	4	$u_1 = u_2$	$u_1 \neq u_2$	0.242	0.130	Accept Ho:	Accept Ho:
1 8	control O.M. + F_2 + G	144.7 188.6	326.2 466.9	4	$u_1 = u_2$	$u_1 \neq u_2$	0.559	0.107	Accept Ho:	Accept Ho:
1 9	control SSC-50	144.7 209.4	326.2 394.8	4	$u_1 = u_2$	$u_1 \neq u_2$	0.331	0.284	Accept Ho:	Accept Ho:

* significant at the 0.05 level
** significant at the 0.01 level

5.0 DISCUSSION AND CONCLUSIONS

5.1 SITE 1: Aberfeldy

Gypsum (treatment 3) and calcium nitrate (treatment 4) were responsible for the largest reductions in electrical conductivity (EC), sodium adsorption ratio (SAR) and chloride (Cl) concentrations. The plots where these treatments were applied were also the most contaminated initially and mean EC and SAR values were both greater than 42 and mean Cl concentrations were in excess of 16,400 ppm. These high levels of contamination and corresponing large reductions suggest large absolute reductions in EC, SAR and CL occurred in the first year because sodium and chloride in the soil exceeded the ionic bonding capacity of the soil. These excess ions were readily leached, increasing the chance of a significant result. Calcium nitrate (treatment 4) was the only treatment which significantly reduced EC, SAR and Cl concentrations in the 0-15 cm soil zone and EC values in the 15-30 cm soil zone and this is likely related to the solubility of calcium contained in this fertilizer product. From a soil chemistry standpoint treatment 4 was the most effective treatment. Organic matter and ammonium nitrate (treatment 7) also provided reductions in EC and SAR but the pre-treatment contamination levels on these plots was not as high.

A combination of organic matter, ammonium nitrate and gypsum (treatment 8) produced the highest mean inflorescence and total weights but these weghts were not significantly different from the within site control (Figure 5.1). Biomass weights from the contaminated site were also compared to the uncontaminated site and there were several treatments which produced statistically similar weights (Table 4.12). The limited number of cases used to develop this result was small (n=3) and this reduces the strength of the results.

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Post-treatment soil test results indicated contamination at site 1 was still severe enough to restrict overall plant growth at Site 1. The moderately drained nature of Site 1, determined by the groundwater monitoring program (Table 4.8), indicates there was potential for resalinization of the surface soil by capillary rise of phreatic water through the brine contaminated soil. This would occur during periods when groundwater levels were within one meter of the soil surface. Seasonal variation in these levels could influence the rate of recovery from contamination and cause continued restrictions in plant growth, if sustained periods of high groundwater levels were experienced. Pre-treatment and post-treatment soil chemical results indicate net downward movement of water was occurring during the year of the study because significant reductions in EC, SAR and Cl concentrations were measured for some of the test treatments in the 0-15 and 15-30 cm soil zones. Reductions in EC, SAR and chloride values, particularly in the 15-30 cm soil zone, were likely the result of leaching by the 195 mm of rainfall which fell during the study period.

Gypsum and calcium nitrate (treatments 3 and 4) both contained a calcium supplement, and were most effective at reducing brine induced soil contamination at Site 1. Treatments 3 and 4 also had the highest pre-treatment mean values for EC, SAR and chlorides and this high degree of contamination was probably responsible for the low overall biomass production in comparison to the other treatments tested at Site 1. Gypsum (treatment 3) reduced EC and chloride concentrations in the 0-15 and 15-30 cm soil zones. Calcium nitrate (treatment 4) reduced EC and SAR in the 0-15 and 15-30 cm soil zones and was the only treatment which reduced SAR in the 15-30 cm soil zone. Calcium, contained in treatments 3 and 4 is known to improve sodium based soil contamination but would have no direct effect on improving plant growth responses (Toogood and Cairns 1978). Calcium nitrate (treatment 4), in addition to providing a more soluble calcium source than gypsum (calcium sulphate), also provided the equivalent of 100 kg. nitrogen per hectare. The fact that calcium nitrate treatments showed no improvement in boimass production over gypsum treatments, which did not supply nitrogen, indicates brine induced soil contamination at Site 1 was probably the limiting factor to plant growth and not nitrogen. The solubility of calcium nitrate was apparent by the effect this treatment had on soil contamination in the 15-30 cm soil zone, where it reduced both EC and SAR, indicating calcium was leached to at least 30 cm depth in the soil profile. A combination of organic matter, ammonium nitrate and gypsum (treatment 8) was the only treatment where both inflorescence and total biomass were similar to the uncontaminated site (site 5). The high boimass production was probably the result of improvements in soil physical properties which allowed plants to take advantage of the nitrogen applied. Soil physical properties were improved by the organic matter and soil nitrogen was supplemented by ammonium nitrate (100 kg/ha actual N) which were both contained in treatment 8. The relationship of treatment 8 to the other treatments in terms of boimass is clearly in Figure 5.1, however, no significant reductions in soil chemistry were measured for treatment 8.

The lack of influence of treatment 8 on EC, SAR and chloride concentrations was probably related to the short time period between treatment application and post-treatment soil sampling. The effect of salts which are added in small quantities when animal manures or gypsum are applied to the soil could also be a factor (Alberta Agriculture, 1981).

5.2 <u>SITE 2: Golden Lake</u>

Electrical conductivity (EC) and sodium adsorption ratio (SAR) values were high enough at the end of the study period to restrict future plant growth. Post-treatment EC remains within a range of 8.5 to 14.3 mS/cm which restricts the germination and growth of all but salt tolerant plants (Buckman and Brady 1970). Sodium adsorption ratio values remain within a range of 15.2 to 37.5 which can result in dispersion of clay soil particles and cause reductions in soil permeability and aeration and adversely affect soil structure which may reduce seedling emergence (P.I.T.S. 1984). Post-treatment chloride concentrations were at a level which indicates future restrictions in plant growth would be moderate.

The contaminated control (treatment 1), where no amendment was applied, organic matter (treatment 2), gypsum (treatment 3) and calcium nitrate (treatment 4) reduced surface soil contamination at this highly contaminated site (Figure 5.2). This result was enhanced by the well drained nature and lack of dispersion in the medium textured soil at the site. Table 4.7 indicates groundwater depths in boreholes 1 and 2 at site 2 were never less than than 1.76 m below the soil surface and therefore resalinization was not a potential problem at this site. Total precipitation at the site during the study period was 174 mm, the least received by any of the four contaminated sites. This rainfall was distributed evenly over the study period and the large reduction in soil contamination compared to the other study sites indicates leaching efficiency was high. The reductions in EC, SAR and chloride concentrations measured in the 15-30 cm soil zone (Table B2) indicate internal soil drainage was enhanced by treatments which contained organic matter.

Organic matter (treatment 2), gypsum (treatment 3), calcium nitrate (treatment 4), organic matter and gypsum (treatment 6), organic matter and ammonium nitrate (treatment 7) and a combination of organic matter, gypsum and ammonium nitrate (treatment 8) provide reductions in EC, SAR and Cl concentrations in the 0-15 and 15-30 cm soil zones. Treatment plots where fertilizer was applied produced higher inflorescence and total biomass than the contaminated control, indicating barley was able to respond to the nitrogen at the levels of contamination measured. The barley may not have been able to take full advantage of the applied nitrogen because Site 2 received only 174 mm rainfall, the least measured at the four contaminated test sites, and this could have reduced the ability of the barley to take advantage of the available nitrogen applied to the selected plots. Gypsum (treatment 3), applied to reduce sodium contamination and improve soil structure, was the

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most effective treatment tested and reductions in EC, SAR and chloride were measured in the 0-15 cm soil zone. No significant reductions in EC, SAR and chloride were measured for gypsum in the 15-30 cm soil zone. Treatments which contained organic matter were the most effective at reducing soil contamination in the 15-30 cm soil zone. The ability of organic matter treatments to significantly reduce 15-30 cm soil contamination was probably related to improvements in water movement through the 0-15 cm soil zone, which would increase water movement through the 15-30 cm soil zone. Dispersed soil conditions may have limited water movement through plots where organic matter was not applied and consequently reductions in EC, SAR and chloride concentrations would have been minimal for these treatments.

5.3 SITE 3: Devonia Lake

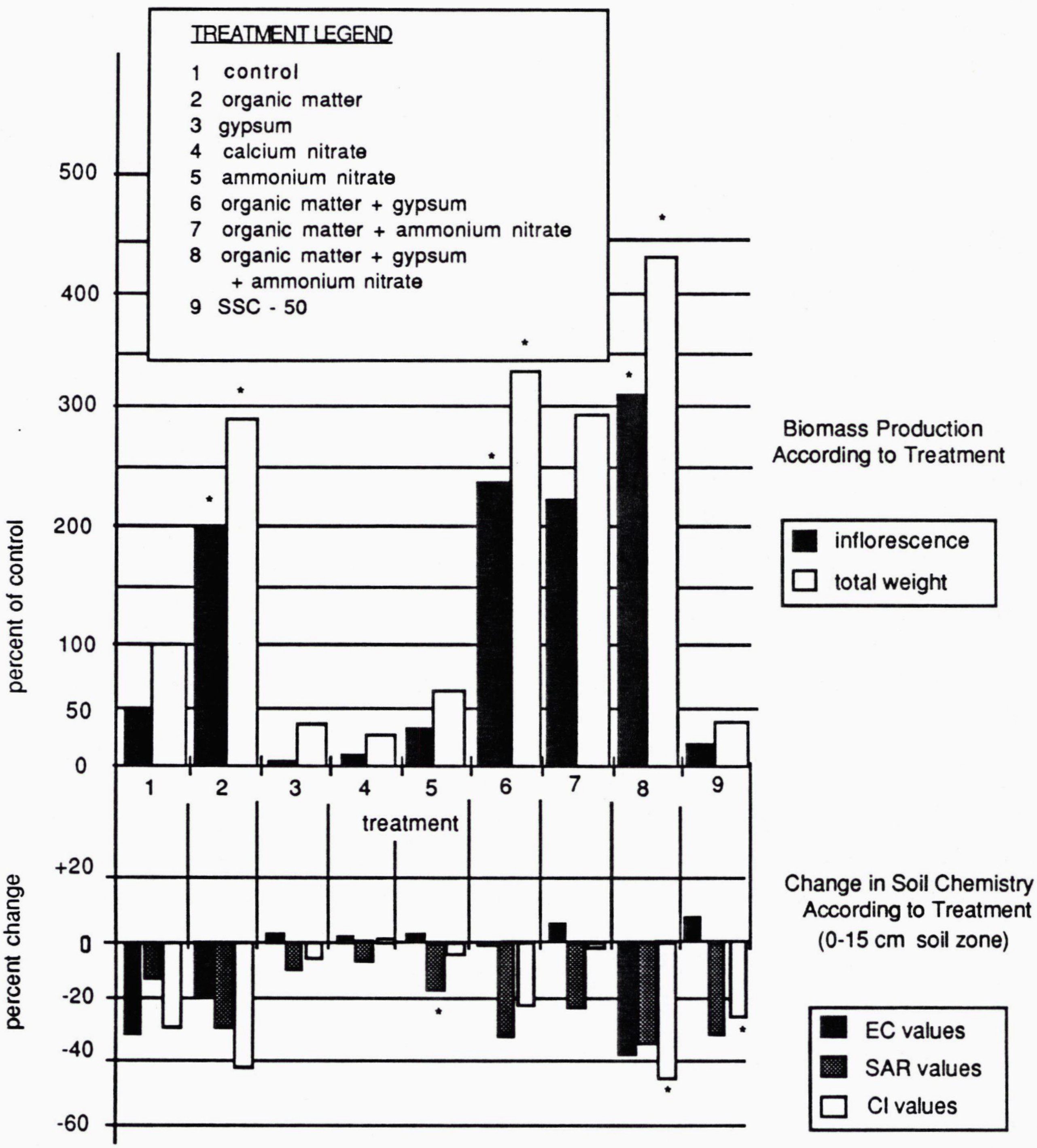
Within site comparisons of biomass data indicate organic matter (treatment 2), organic matter and gypsum (treatment 6) and a combination of organic matter, ammonium nitrate and gypsum (treatment 8) treated plots developed inflorescence and total weights which were higher than the mean weight developed on the control plots (Figure 5.3). These three treatments had an effect which enhanced biomass productivity at the site in spite of the poorly drained, saltwater contaminated soil conditions present at the Devonia Lake site. Organic matter was a component of the three treatments listed above and there were no other common elements among the treatments which showed improvement, therefore soil physical improvements or the dilution effect provided by the organic matter were likely responsible for the increases in vegetation production measured on plots containing organic matter.

There were very few reductions in soil chemistry measured during the study period due to poorly drained site conditions which prevent the leaching of soluble salts from the soil profile. Within site comparisons of soil chemical data indicate SSC-50 (treatment 9) was

FIGURE 5.3

Biomass Production Related to Percent Change in Soil Chemistry at Site 3

(Developed from Tables 4.4 and 4.15)



* significant at the 0.05 level

the only treatment which provided a reduction in soluble salts contained in the soil in both the 0-15 and 15-30 cm soil zones, where it significantly reduced chloride concentrations. This reduction is likely due to the effect of soil conditioners contained in SSC-50 which prevent surface evaporation and resalinization and allow some leaching and lateral redistribution of the salts when precipitation is adequate. Organic matter, gypsum and ammonium nitrate (treatment 8) reduced chloride concentrations in the 0-15 cm soil zone and ammonium nitrate (treatment 5) reduced SAR values in the 0-15 cm soil zone but these reductions were probably more closely linked to low standard deviation values within the sample populations than distinct treatment action. If this were not the case, treatment 8 would be expected to reduce SAR more than treatment 5, which consisted of only a fertilizer application, because treatment 8 contained an organic matter and gypsum supplement in addition to the same quantity and type of nitrogen fertilizer contained in treatment 5. Also, since chlorides are mobile and readily leached, other treatments containing organic matter would be expected to provide more reductions in chloride levels if there was a relationship between the organic matter contained in treatment 8 and reductions in soil chloride content. There were no other significant changes in the soil chemical parameters measured for Site 3 (Figure 5.3).

Electrical conductivities remained high enough after treatment to cause future restrictions in germination and overall plant growth (Table 4.4). Post-treatment SAR values remained high enough to cause dispersion of clay soil particles in the medium textured soil at the site and decrease permeability, aeration and surface soil structure which can reduce seedling emergence (Toogood and Cairns 1978). Treatments which contained organic matter appeared to reduce surface soil dispersion in visual observations made at the site which may have improved germination and seedling emergence and caused the overall improvement in vegetation productivity measured on plots treated with organic matter (Figure 5.3). Post-treatment chloride values (Table 4.4)were within a range which could cause foliar discoloration and injury to even salt tolerant plants (Edwards and Blauel 1973). The range in treatment effects at Site 3 appeared to be related to the poor drainage and saline conditions measured at this site and was an indication of the influence of the test treatments when applied under these soil conditions. Treatments which contained organic matter (treatment 2,6,7 and 8) appeared to produce well, while the remaining treatments performed similar to the control, however, this relationship between treatment and effect was not apparent for changes in soil contamination. Groundwater depths measured from the soil surface at Site 3 exhibit a range of 0.77 m to 1.21 m in borehole 1 and 0.24 m to 1.23 m in borehole 2 (Table 4.8). In each case, groundwater was close enough to the soil surface to influence the soil surface by capillary action and prevent permanent leaching of introduced soil contaminants.

The results of monitoring soil moisture at depths of 15 cm, 30 cm, 60 cm and 90 cm within the study site are shown in Tables 4.9 and 4.10. During the study period the soil remained at field capacity for all depths monitored and all readings of the instrumentation. This data indicates resalinization (upward capillary movement of water containing dissolved salts) was occurring during the study period and would account for the small insignificant increases in electrical conductivity and chloride concentrations which were measured in the 0-15 cm soil zone.

Results of precipitation monitoring indicated a total of 248 mm of rainfall fell during the study period, including a surge in precipitation during the early part of June (Table 4.11). The incidence of heavy, early season rainfall likely contributed to a rise in groundwater elevations measured at Site 3 on June 20, 1985 (Table 4.8). At these shallow groundwater depths, leaching soluble salts from the upper soil profile would be unlikely unless subsurface drainage was used to reduce groundwater elevations.

There were two interesting treatment effects indicated by the results at Site 3. Treatments containing organic matter improved biomass production without providing any significant reductions in soil contamination. This effect is probably due to the improvement in soil physical properties and/or the dilution of the surface soil contamination caused by the volume of organic matter additions. The remainder of the treatments, containing gypsum, calcium nitrate, ammonium nitrate or SSC-50 had very little effect on biomass development or soil chemistry. This indicates leaching is the most important process affecting site improvement under poorly drained soil conditions and when contaminants are held near the soil surface by high groundwater elevatiions, no widespread significant improvements can be expected.

The poorly drained nature of the site prevents leaching of soil contaminants and promotes resalinization of the surface soil. If saline contaminants cannot be leached they remain in the soil where they restrict germination and growth as indicated in the biomass results. Subsurface drainage control would be necessary to provide permanent improvement at poorly drained sites such as Site 3.

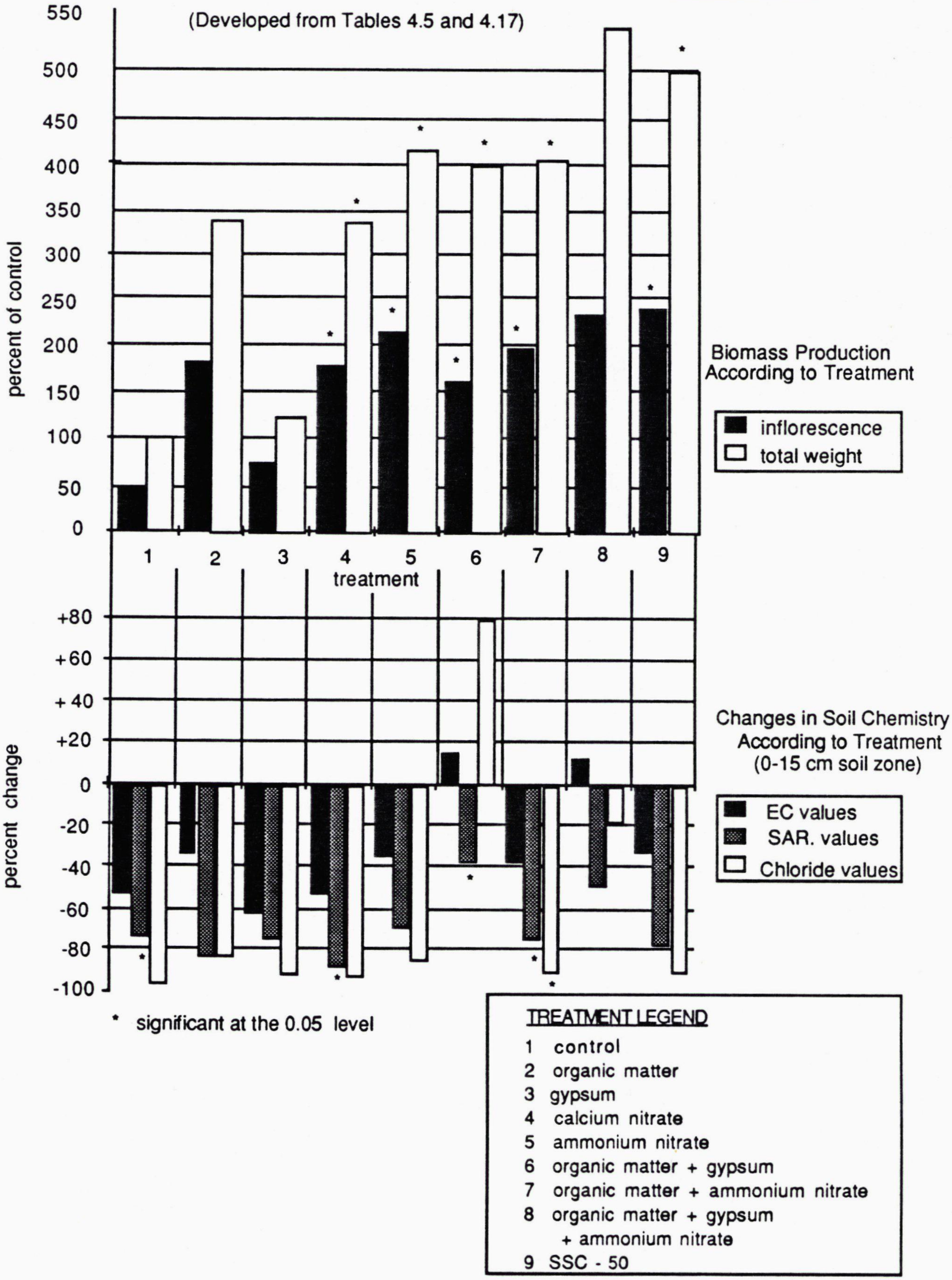
5.4 SITE 4: Wainwright

Site 4 is typical of old spill sites in the study area which were characterized by reduced levels of EC and chlorides but which continue to be restricted by moderately high SAR values (Figure 5.4).

Treatments which improved soil fertility ($CaNO_3$ and NH_4NO_3 fertilizers) and soil physical properties (organic matter) were the most effective treatments in terms of biomass production (Figure 5.4). These treatments included calcium nitrate (treatment 4), ammonium nitrate (treatment 5), organic matter and gypsum (treatment 6), organic matter and ammonium nitrate (treatment 7) and SSC-50 (treatment 9). Ammonium nitrate

FIGURE 5.4

Biomass Production Related to Percent Change in Soil Chemistry at Site 4



(treatment 5) and SSC-50 (treatment 9) produced the greatest amount of biomass (Table 4.17). Comparing Site 4 results with uncontaminated Site 5 results indicates Site 4 treatment plots produced similar inflorescence weights . Total weights produced at Site 4 were significantly less than at Site 5 (Table 4.18).

Organic matter and ammonium nitrate (treatment 7) provided the greatest reduction in soil contamination, significantly reducing both SAR and chloride values in the 0-15 cm soil zone and chlorides in the 15-30 cm soil zone.

The range in EC levels at site 4 were high enough to restrict germination and growth of plant species sensitive to salinity. Post-treatment soil chemistry indicated SAR values at Site 4 were high enough to reduce overall productivity but not high enough to suppress germination. The large reductions in SAR values which occured during the study period indicate well drained soil conditions prevail at this site.

The increase in chlorides measured for treatment 6 were probably the result of sampling or analytical error. Sampling error occurs when soil from the sampling auger is placed into the wrong bag or if contaminated soil from a different sampling interval is mixed with a less contaminated sample. Analytical error usually occurs when lab equipment is contaminated by a previous sample. Post-treatment Chloride values at Site 4 were low enough to have little or no influence on germination and growth of most plants.

Brine contamination of the soils at Site 4 was less than the other three contaminated sites as indicated by the soil analyses and the higher biomass production measured at this location. The reductions in pre-treatment soil contamination were due to treatment effect and a combination of well drained soil conditions and the large amount of precipitation which fell during the study period. Standpipes which were installed at Site 4 indicate groundwater levels were more than 1.82 m below the soil surface throughout the study period (Table 4.8) and at this depth, capillary rise of groundwater to the soil surface is unlikely. Site 4 received 286 mm of precipitation (Table 4.10) during the study period. Increased leaching, as a result of the high rainfall, would account for the greater reductions in contamination which were measured at this site.

Site 4 was the least contaminated of the four contaminated sites as indicated by the soils results provided in table 4.6. The relatively moderate degree of contamination was the result of natural leaching which occurred in the time elapsed after the original spill and the well drained soil conditions at this site. An indication of the age of the spill was the low degree of pre-treatment soil contamination and the low EC and chloride concentrations in relation to the SAR, which tends to cause the most persistent problems. SAR values in the 15-30 cm soil zone (table B4) were higher than in the 0-15 cm soil zone and this indicates sodium was gradually leaching out of the surface soil and accumulating deeper in the soil profile, or being leached more slowly at the 15-30 cm depth.

Significant reductions in SAR in the 0-15 cm soil zone were not duplicated in the 15-30 cm soil zone where no significant reductions in SAR were measured. Organic matter and ammonium nitrate (treatment 7) appeared to be the most effective treatment tested at Site 4 where it helped to significantly reduce SAR and chlorides in the 0-15 cm soil zone and chlorides only in the 15-30 cm soil zone. There were very few significant reductions in EC, SAR and chlorides at site 4 considering the fact that this site received 286 mm rainfall, the largest amount of all the contaminated sites, and the well drained soil conditions. As a result of the suspected long term soil contamination at this site, contaminants in the soil may be more firmly bonded to the soil colloids and this would make the site more difficult to reclaim. Clay content, which could account for this stronger bonding under certain conditions, appeared to be lower than the other contaminated sites and in fact sand content, which can improve leaching, appeared to be higher than average. No solid explanation can be found for this anomaly, which suggests there should be more significant reductions in soil contamination than were measured, unless some currently undetected contaminant is responsible.

5.5 SITE 5: Aberfeldy (uncontaminated)

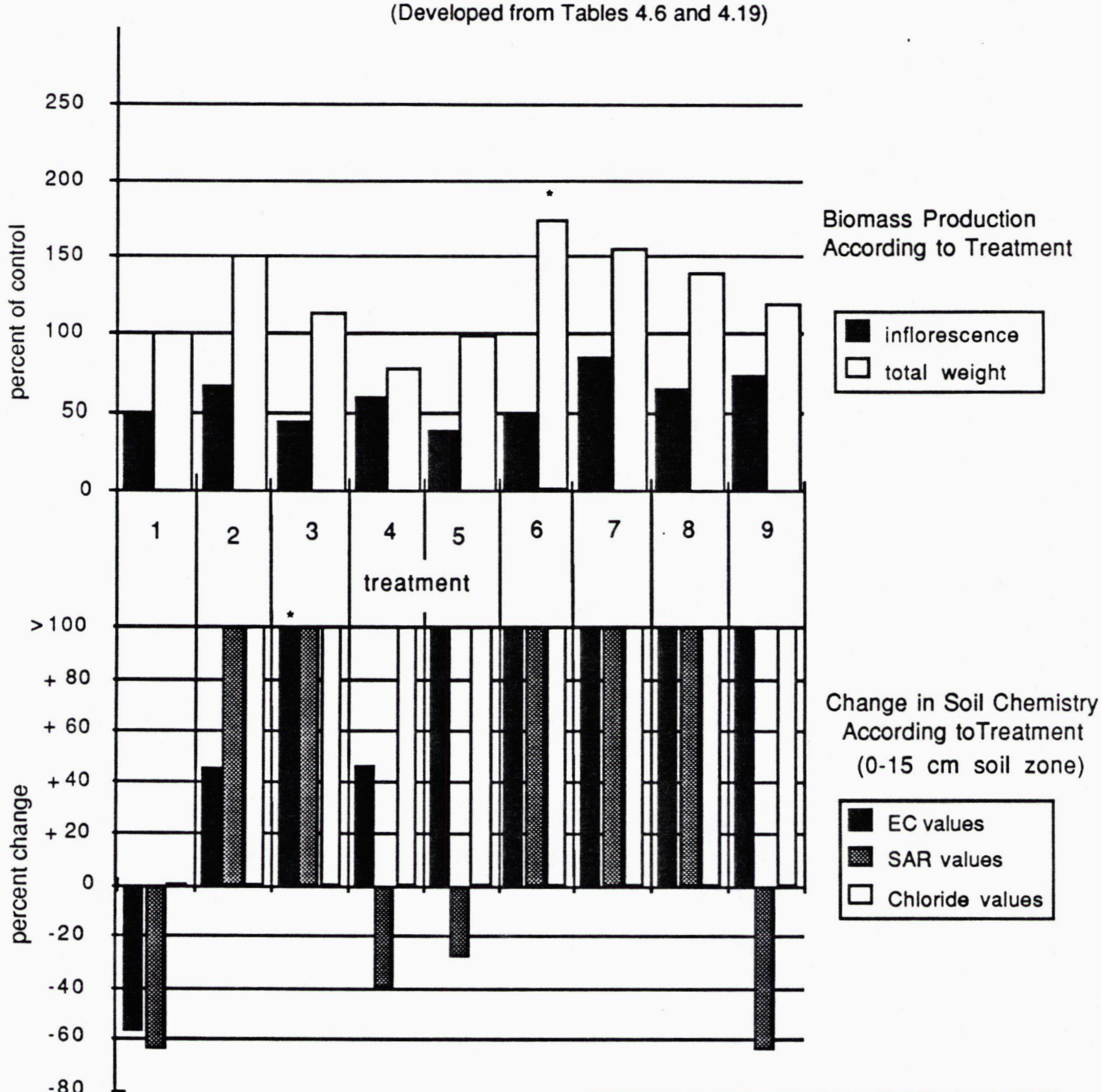
Site 5 was established to evaluate treatment effectiveness at the four contaminated locations. Total weight production was maximized by organic matter and gypsum (treatment 6) and organic matter, ammonium nitrate and gypsum (treatment 8) which produced 564 and 503 grams of biomass respectively. Organic matter and ammonium nitrate (treatment 7) developed the highest mean inflorescence weight of 250 grams. SSC-50 (treatment 9), organic matter (treatment 2), a combination of organic matter, ammonium nitrate and gypsum (treatment 8) and calcium nitrate (treatment 4) developed inflorescence weights of 209, 190, 188 and 165 grams respectively (Figure 5.5).

All treatments produced in excess of 320 grams total weight of vegetation on uncontaminated Site 5. Only ammonium nitrate (treatment 5) did not produce more biomass than the control treatment and this was likely due to weed competition. Organic matter appeared to show the greatest increase in productivity as a single amendment and when combined with nitrogen fertilizer and/or gypsum, appears to improve overall barley growth even under uncontaminated soil conditions. Improvements in stem biomass are particularly obvious and in all cases, stem weight is greater than inflorescence weight (Table 4.19). Some of this improvement in stem productivity is due to increased water availability as a result of an absence of a salt induced osmotic gradient and this also allows plants to take advantage of the nitrogen applied in treatments 4,5,7,8 and 9.

FIGURE 5.5

Biomass Production Related to Percent Change in Soil Chemistry at Site 5

(Developed from Tables 4.6 and 4.19)



* significant at the 0.05 level

TREATMENT LEGEND

1 control
2 organic matter
3 gypsum
4 calcium nitrate
5 ammonium nitrate
6 organic matter + gypsum
7 organic matter + ammonium nitrate
8 organic matter + gypsum + ammonium nitrate
9 SSC - 50

Absolute measurements of soil salinity at uncontaminated Site 5 indicate salinity levels were well below the range required to cause a reduction in plant growth (Table 4.6). The large increases or reductions displayed in Figure 5.5 for percent change in EC, SAR or chloride levels were caused when low initial values were doubled or halved during subsequent testing. Organic matter (treatment 2), gypsum (treatment 3), organic matter and gypsum (treatment 6), organic matter and ammonium nitrate (treatment 7) and organic matter, ammonium nitrate and gypsum (treatment 8) treatments caused a slight increase in EC, SAR and chloride values during the study period. These small but sometimes significant increases could have been caused by natural fluctuations in these variables during the growing season or slight variations in testing procedure (ie. the saturation percentage at which the samples were tested). All treatments which contained organic matter or gypsum caused increases in EC, SAR and Cl concentrations. Organic matter was a potential source of increased salinity because of salts contained in animal urine and feces (Buckman and Brady 1969). however, no salinity measurements were conducted on the organic matter applied in the study. Gypsum contains sulphates and this could increase conductivity values on plots where gypsum was applied. Capillary action could not have moved saline groundwater to the soil surface at Site 5 because root zone soil moisture monitoring indicated the site was well drained. Monitoring stations at 30 and 60 cm depths were dry compared to the 90 cm and 120 cm soil zones which remained at field capacity throughout the growing season (Tables 4.8 and 4.9). Pre-treatment and post-treatment EC,SAR and Cl concentrations seem to vary within a range which is well below the level considered to reduce growth of barley. The exact reason for the variation is not known but is probably related to soil testing accuracy, organic matter and gypsum applications or natural fluctuations in soil moisture content related to seasonal variation.

5.6 Discussion Summary

The study results indicated biomass production on treated contaminated soil was a function of the influence of the following factors which varied considerably among the sites:

a) Degree of contamination,
b) Test treatment applied,
c) Soil internal drainage and surface permeability and
d) Precipitation received during the growing season.

There were no significant differences in inflorescence and total weights between any of the treatments tested and the corresponding within site control at Sites 1 and 2 (Tables 4.11 and 4.13).

Organic matter (treatment 2), organic matter and gypsum (treatment 6) and organic matter, ammonium nitrate and gypsum (treatment 8) produced inflorescence and total weights which were higher than the within site control at Site 3 (Table 4.15). At this poorly drained site the organic matter contained in the effective treatments probably reduced surface contamination by dilution initially and allowed more plants to germinate and become established, producing a higher final biomass weight. Secondary effects likely included the prevention or reduction of capillary rise of groundwater to the soil surface through contaminated soil media caused by the larger soil pore spaces which organic matter provided.

Calcium nitrate (treatment 4), ammonium nitrate (treatment 5), organic matter and gypsum (treatment 6), organic matter and ammonium nitrate (treatment 7) and SSC-50 (treatment 9) produced higher inflorescence and total weights than the within site control at site 4 (Table 4.17). This site was the least contaminated of the sites and could be categorized as only moderately contaminated. The response measured at this site was probably due to the influence of nutrients on biomass production because four of the most effective treatments contained calcium or ammonium nitrate nitrogen fertilizer. Treatment 6, containing organic matter, also contains substantial nitrogen in addition to other nutrients. The lower degree of contamination at this site would have allowed barley to make use of the essential plant nutrients available. The effect of nutrients was not as evident on sites 1,2 and 3 where severe contamination had a more dramatic effect.

The mean total weights developed on uncontaminated site 5 were consistently higher than total weights developed on the four contaminated sites, indicating brine contaminated soil suffers reductions in vegetative productivity. The three replicates of each treatment tested at the five independant sites limited the ability to prove this conclusively.

During this study, inflorescence weights on contaminated soil were similar to inflorescence weights on uncontaminated soil but total biomass development under contaminated soil conditions was significantly reduced. These findings demonstrate that by maximizing inflorescence production the indicator crop (barley) was attempting to maximize seed production under adverse conditions, ie. when soil nutrient status and available soil moisture were low and when brine contamination of the soil was high.

Biomass results indicate seed weight was not influenced to the same degree as stem weight when barley was grown on salt affected soil. While seed weight may appear normal statistically, mean values shown in the data were always less than the control. Stem weight developed on contaminated soil was lower and in some cases significantly less than stem weight developed on the uncontaminated control site. This reduction in biomass production was evident by the shorter stems and sparse, widely spaced leaves found on plants in the field. Inflorescence weight was not impaired to the same degree as stem weight. This hypothesis was supported by the t-test results and observed during the field trials.

When water, nutrient supply and growing conditions were marginal, as found at the four contaminated study locations, the barley plant channels available resources into reproduction rather than vegetative growth. The resulting higher overall inflorescence weight to stem weight ratio produced on contaminated sites was evidence that barley was striving to optimize available resources.

The following discussion summarizes the important conclusions regarding individual treatment performance in terms of biomass production and changes in soil chemistry.

<u>Treatment 1</u> (contaminated control), Plots where no amendment was applied provided the poorest overall result in terms of biomass development. Some significant reductions in EC and chloride levels were measured on well drained sites 2, 3 and 4 as a result of the natural leaching process.

<u>Treatment 2</u> Organic matter produced high inflorescence and total weights on average and produced significant reductions in SAR at sites 2 and 4 and significant reductions in EC and chlorides at site 2. The influence of organic matter on improving physical soil properties was particularly evident on poorly drained site 3. The failure of this treatment to produce consistent reductions in soil contamination was probably due to the salts contained in the organic matter

<u>Treatment 3</u> Gypsum reduced biomass productivity at Sites 1 and 3 and slightly increased at Sites 2, and 4 when compared to the within site controls (treatment 1). Significant reductions in brine contamination were measured at Sites 1 and 2 in the 0-15 cm soil zone where there was adequate internal soil drainage. Gypsum appeared to be effective for reducing sodium concentrations under well drained soil conditions but did not enhance biomass production.

Treatment 4 Calcium nitrate applied 100 kg/ha of elemental nitrogen and produced biomass results similar to the within site controls except at moderately contaminated Site 4, where it produced more than the control. Calcium nitrate reduced SAR on sites 1 and 4, chloride concentrations on site 2 and EC on site 4 and was an effective treatment for reducing sodium based soil contamination under well drained soil conditions.

Treatment 5 Ammonium nitrate applied 100 kg/ha elemental nitrogen and produced biomass weights similar to the within site controls except at moderately contaminated Site 4 where it produced more than the within site control. At site 3 poor drainage influenced overall reductions in soil salinity to a minimum but significant reductions in EC and chlorides were measured for this treatment at site 2. Under heavily contaminated soil conditions (Sites 1,2 and 3) barley was not able to take advantage of the nitrogen supplied by this treatment because brine contamination and not nitrogen deficiency was the limiting factor to plant growth. Overall, ammonium nitrate was an ineffective treatment when applied without organic matter to improve soil physical properties.

Treatment 6 Organic matter and gypsum provided improvement in biomass production over the within site contaminated controls. The treatment provided significant reductions in SAR on sites 2 and 4 and significant reductions in EC and chlorides on site 2. Reductions in soil salinity were less than expected for this treatment possibly because of sulphates added in the form of gypsum and other salts contained in the organic matter amendment.

Treatment 7 Organic matter and ammonium nitrate produced similar biomass weights to the within site controls except at moderately contaminated Site 4 where it produced more biomass than the within site control. Electrical conductivities were significantly reduced on Sites 1 and 2 and SAR was significantly reduced on Sites 2 and 4. Chlorides were reduced on Sites 2 and 4 in the 15-30 cm soil zone. The organic matter provided improvements in soil physical properties which may have allowed barley to use the nitrogen supplied by the ammonium nitrate improving biomass production. The physical improvement provided by the organic matter would also accelerate the loss of contaminants by leaching.

Treatment 8 Organic matter, gypsum and ammonium nitrate provided the greatest absolute inflorescence and total weight production of all treatments tested except at uncontaminated Site 5. Treatment 8 provided significant reductions in SAR at site 2 but provided no other significant reductions in soil chemistry. The gypsum contained in this treatment appeared to do little to reduce SAR and may have actually contributed to existing soil salinity. Although treatment 8 was most effective for biomass production it provided little in the way of significant reductions in soil chemistry during one year of study.

Treatment 9 SSC-50 was a commercially available product containing calcium nitrate fertilizer and soil conditioners in solution. This treatment produced less biomass than the within site controls at Sites 1, 2 and 3 and considerably more at the moderately contaminated Site 4. This result may be a function of the lower contamination levels encountered at site 4. The treatment did not appear to be effective for sites were normal drainage regimes were encountered, however, it did produce significant reductions in chlorides in both the 0-15 and 15-30 cm soil zones at poorly drained site 3. No other significant reductions in soil chemistry were measured for this treatment.

Physical soil amendments appeared to enhance biomass production regardless of soil drainage but seemed to produce the most biomass on well drained sites. Chemical amendments tended to show no improvement in biomass production over the within site controls under severely contaminated soil conditions but they seemed to show an improvement in biomass production under moderately contaminated soil conditions.

Reductions in soil salinity appeared to be directly related to soil drainage conditions. Results from poorly drained Site 3 indicate amendments have little or no effect on reducing soil salinity where salts cannot be leached. Subsurface drainage may be the only method which will enhance removal of soil contaminants from a poorly drained spill site. Results indicated there were more statistically significant reductions in soil salinity from well drained Sites 2 and 4. Results from moderately drained Site 1 indicated some significant reductions in salinity were measured but these were less than reductions measured on the well drained sites.

The total amount of precipitation and when it is received, in conjunction with soil permeability, determine the effect rainfall will have on leaching soluble salts from the soil profile. The effect of precipitation on reducing salt spill contamination will depend on:

a) Soil texture,
b) Soil drainage,
c) Time of year,
d) Topographic location and
e) Degree of contamination.

Soil texture influences the leaching potential of precipitation by affecting the infiltration rate of water into the soil. Fine grained soils absorb water more slowly than coarse textured soils, therefore, during high volume, short duration storms, more water will be lost by run-off where fine grained soils are encountered and more water will infiltrate where coarse grained soils occur. The five test sites in the study region contained permeable, medium grained, loamy surface soils and impermeable, clay till subsoils, therefore, resistance to water infiltration was not considered limiting to leaching potential except where high water tables were encountered. Leaching trials were not conducted on soils of the study region, but visual observations following large storms indicated resistance to infiltration was not a problem where amendments were applied. Plots to which organic matter (manure) was applied as an amendment appeared to absorb precipitation more quickly than treatments which did not contain organic matter.

The leaching potential of precipitation is greater during the latter part of the growing season when soil moisture is low as a result of water use by vegetation. During this time of year the water table at poorly and imperfectly drained sites is lower, increasing the thickness of the soil zone where leaching of salts can occur. Reductions in salinity under these circunstances may be temporary because resalinization can be a problem on these types of sites when the water table rises again as a result of precipitation or during spring recharge from melted snow.

Revegetation of salt water spill sites can also increase the rate of reclamation of salt water spill sites. Vegetation adds organic matter, uses soil water and increases the permeability of the soil. Forage crops are often tolerant of salinity in the 5-10 mS/cm range, however, they are not commonly seeded in the Lloydminster region where cereal crops and oilseeds are of primary importance. Although salt tolerance is low to moderate, forage crops are most suitable for reclamation because they tend to be long lived, use a lot of water and are able to withstand wetness for short periods of time. Ideally, slow growing plants are more salt tolerant than fast growing plants. Deep-rooted plants with a low shoot-to-root ratio are more salt tolerant than shallow rooted plants with a higher shoot-to-root ratio (Agriculture Canada, 1977). Realistically, land owners will most often sow field crops according to their own crop rotation program and are unlikely to alter this procedure for small salt spill sites.

5.7 Conclusions Regarding Treatment Effects

The following conclusions were developed from results obtained during the research phase of the project:

a) A combination of organic mater, gypsum and ammonium nitrate (Treatment 8) was the most effective treatment for producing near normal inflorescence weights. In general, treatments containing organic matter (Treatments 2,6,7 and 8) appeared to produce the highest total weights but in many cases these results were not significantly different from the within site control.

b) Post treatment soil test results indicate pH changes were not significant under the short term treatment application program.

c) Chloride concentrations were subject to greater reductions than either EC or SAR concentrations during the study period. Results indicate chlorides were reduced the most on plots where organic matter was applied. Ammonium nitrate contained in treament 7 and treatment 5 appeared to cause chlorides to remain in the 0-15 cm soil zone. The reason for this is unknown.

d) Electrical conductivity (EC) was substantially reduced on all treatment plots but no treatment exhibits a distinct pattern of reduction. The relatively even reduction in contamination among treatments indicates natural leaching rather than treatment effect was responsible for the changes in EC.

e) Organic matter and gypsum were responsible for significant increases in EC on treated plots at uncontaminated Site 5. This likely occurred when sulphates and other unknown salts were introduced by the gypsum and organic matter amendments.

f) Sodium Adsorption Ratios were reduced less than either EC or Chlorides during the study. This indicates long term soil problems associated with brine spills will probably be caused by the sodium introduced into the soil.

g) Subsurface drainage is probably the only effective method of reducing soil contamination under poorly drained soil conditions. The nine treatments tested during the study had virtually no influence on EC, SAR and chlorides under the poor soil drainage conditions measured at Site 3.

h) Theoretically, calcium nitrate is the most soluble and mobile form of applying calcium and nitrogen to a spill site. However,under the soil conditions tested this treatment performed only marginally better than gypsum and not as well as gypsum, ammonium nitrate and organic matter applied together.

i) SSC-50 appeared to have some influence on soil chemistry under poorly drained soil conditions where it significantly reduced chloride concentrations. In terms of biomass production SSC-50 produced well only where low levels of soil salinity were encountered.

6.0 RECOMMENDATIONS

Recommendations were developed from methods applied during the field program and from results obtained by testing and monitoring site conditions during the study. To reduce or correct some site specific, brine induced salinity problems on old spill sites, the following management practices developed during the study could be applied:

a) Assess the physical characteristics of the site; drainage, topography, land use and soil texture for use in developing a reclamation program.

b) Improve surface drainage if water is ponding due to impermeable soil conditions.

c) Cultivate only the surface 10-15 cm zone when preparing soil for amendment and seed application to prevent mixing of subsurface contaminants with the leached surface horizons. Minimize subsequent tillage operations.

d) Apply 2.5-7.5 cm of organic matter (manure) and incorporate to a depth of 10-15 cm using a rototiller or several multi-directional passes of a double disc for larger areas.

e) Apply nitrogen fertilizer at a rate of 100 kg/ha elemental nitrogen and incorporate to a depth of 5-10 cm. Ammonium nitrate (NH_4NO_3) is preferred because it enhances the solubility of gypsum when the two amendments are applied together.

f) Apply gypsum at a rate equivalent to 1.25 times the amount of exchangeable sodium calculated in milli equivalents per 100 gr soil and multiply by 1.0 tonne/ha. Gypsum should be thoroughly mixed into the surface soil to increase the contact area.

g) Apply lime if acid soil conditions (below pH 6.0) are encountered to neutralize soil conditions. Lime should be thoroughly mixed into the surface 15 cm of soil.

h) Apply physical and chemical amendments as soon as possible after a spill. Where possible, fall applications prior to freeze up avoid interference with spring farming operations. Access is also better during the fall season as a result of drier soil conditons.

i) Avoid summerfallowing the spill site. Fallow encourages the buildup of the water table and increases surface evaporation which may cause salts to accumulate at the soil surface. Provide a surface mulch if no vegetation can be established to help reduce surface evaporation.

j) Seed when moisture conditons are most suitable. Fall or early spring seeding is recommended to take advantage of early spring moisture conditons. Avoid seeding too deep where salts leached from the surface soil may have accumulated. Use salt tolerant plant species if possible.

k) Monitor site improvement after each growing season to determine the stage of reclamation progress. Depending on the size of the spill site, the following information could be useful for developing additional reclamation requirements:
   i) Spill site yield and adjacent "normal" yield
   ii) Precipitation received at the site
   iii) Depth to groundwater and extent of seasonal fluctuations
   iv) Change in soil chemistry.

l) Re-treat annually or bi-annually as required, depending on site response to previous treatment.

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APPENDIX A

GLOSSARY

acid soil A soil material having a pH of less than 7.0
alkaline soil Any soil that has a pH greater than 7.0
amendment Material added to contaminated soil to improve soil conditions or plant productivity.
available water The portion of water in a soil that can be readily absorbed by plant roots. Most workers consider it to be the water held in a soil against a pressure of up to approximately 15 bars. (see also field capacity)
bar A unit of pressure equal to one million dynes per square centimeter.
borehole An augered hole in the soil where groundwater monitoring equipment was installed.
capillary fringe A zone of essentially saturated soil just above the water table. The size distribution of the pores determines the extent and degree of the capillary fringe.
clay As a particle size term: a size fraction less than 0.002 mm in equivalent diameter, or some other limit (geologists and engineers).
colloid A substance in a state of fine subdivision, whose particles are 10^{-4} to 10^{-7} cm in diameter.
field capacity The percentage of water remaining in the soil 2 or 3 days after the soil has been saturated and free drainage has practically ceased. The percentage may be expressed in terms of weight or volume.
groundwater Water that is passing through or standing in the soil and the underlying strata. It is free to move by gravity.
halomorphic soil A general term for saline and alkaline soil.
horizon, soil A layer of soil or soil material approximately parrallel to the land surface; it differs from adjacent genetically related layers in properties such as color, structure, texture, consistence, and chemical, biological, and mineralogical composition.
indicator plants Plants that are characteristic of specific soil or site conditions .
infiltration The downward entry of water into the soil.
inflorescence The flowering parts of a plant including the seed.
lime A soil amendment consisting principally of calcium carbonate, and including magnesium carbonate.It is used to supply calcium and magnesium as essential elements for growth of plants and to neutralize soil acidity.
manure The excreta of animals, with or without the admixture of bedding or litter, in varying stages of decomposition.
moisture, soil Water contained in the soil.
oven-dry Soil or plant material dried at 105 degrees C until it has reached a constant weight.
organic matter, soil The organic fraction of the soil; includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms and substances synthesized by the soil population.
permeability, soil The ease with which gases or liquids penetrate or pass through a bulk mass of soil or a layer of soil. Because different soil horizons vary in permeability, the specific horizon should be designated.
pore space The total space not occupied by soil particles in a bulk volume of soil.
productivity, soil The capacity of a soil, in its normal environment, to produce a specified plant or sequence of plants under a specified system of management. Productivity means the capacity of a soil to produce crops and is expressed in terms of yields.

produced water The saline water extracted with hydrocarbon materials and contained in the same formation. Salinity can vary depending on age and location of the formation.The **brine** is separated from the hydrocarbon material and disposed of by reinjection.

saline soil A non alkali soil that contains enough soluble salts to interfere with the growth of mostcrop plants. The conductivity of the saturation extract is greater than 4 mS/cm, the exchangeable sodium percentage is less than 15, and the pH is less than 8.5.

salinity, soil The amount of soluble salts in a soil, expressed in terms of percentage,parts per million, or other convenient ratios.

salinization The process of accumulation of salts in soil.

salt-affected soil Soil that has been adversely modified for the growth of most crop plants by the presence of certain types of exchangeable ions or of soluble salts. It includes soils having an excess of salts, or an excess of exchangeable sodium, or both.

sand A soil particle between 0.05 and 2.0 mm in diameter.

silt A soil separate consisting of particles between 0.05 and 0.002 mm in equivalent diameter.

sodium adsorption ratio (SAR) The ratio of (sodium) divided by (square root of calcium plus magnesium divided by 2) where cation concentrations are expressed in milliequivalents perliter.

sodic soil (i) A soil containing sufficient sodium to interfere with the growth of msot plants. (ii) A soil having an exchangeable sodium percentage of 15 or more.

standpipe Groundwater monitoring equipment which consisted of 2 inch pvc pipe slashed at 0.3 m intervals throughout the lower 1.5 m section to allow the entry of groundwater. Standpipes were installed in two borehole locations at each contaminated site

surface soil The uppermost part of the soil that is normally moved during tillage, or its equivalent in uncultivated soils. The normal range in depth is 7.5 to 25 cm.

synergism The ability of two or more organisms to bring about changes (usually chemical) that neither can accomplish alone.

tilth The physical condition of a soil as related to its ease of tillage, fitness as a seed bed, and impedance to seedling emergence and root penetration.

void Space in a soil mass not occupied by solid mineral matter. This space may be occupied by air, water, or other gaseous or liquid material.

water table (groundwater elevation) Elevation at which the pressure in the water is zero with respect to the atmospheric pressure.

wilting point (permanent wilting point) The moisture content of a soil at which plants wilt and fail to recover their turgidity when placed in a dark, humid atmosphere. The wilting point is commonly estimated by measuring the 15-bar moisture percentage of a soil.

APPENDIX B

TABLE B1

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 1 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	38.0	32.2	5.77	9.527	0.404
2	37.9	24.4	13.50	2.883	0.015*
3	40.4	29.2	11.27	2.139	0.012*
4	43.9	27.7	16.27	4.606	0.026*
5	30.9	29.6	1.27	0.404	0.032*
6	30.3	22.9	7.40	13.571	0.445
7	31.6	26.7	4.90	3.812	0.156
8	20.6	19.9	0.67	11.558	0.930
9	35.6	28.0	7.60	5.647	0.145

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 1 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	30.1	31.2	- 1.03	5.802	0.787
2	39.2	29.1	10.17	10.884	0.247
3	44.0	37.5	6.50	10.050	0.379
4	50.7	37.2	13.47	4.126	0.030
5	15.8	15.4	0.40	2.00	0.762
6	33.0	31.8	1.27	9.550	0.840
7	37.8	32.1	5.70	3.686	0.116
8	24.0	21.7	2.27	2.250	0.223
9	39.3	29.7	9.60	5.892	0.106

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 1 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	15 466	11 733	3 733	4 936	0.320
2	14 567	7 100	7 467	1 747	0.018*
3	16 667	9 683	6 983	1 375	0.013*
4	17 067	9 250	7 816	3 536	0.062
5	12 033	11 700	333	1 290	0.698
6	11 267	7 183	4 083	7 211	0.430
7	11 233	8 117	3 117	1 775	0.093
8	6 607	5 867	740	6 046	0.852
9	14 333	9 983	4 350	3 274	0.148

* Significant at the 0.05 level

** Significant at the 0.01 level

TABLE B2

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 2 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	23.0	14.4	8.6	4.716	0.088
2	18.73	17.90	0.83	2.743	0.651
3	19.9	18.6	1.3	2.757	0.510
4	18.2	15.6	2.6	4.869	0.453
5	14.6	10.6	4.0	2.574	0.116
6	22.8	13.8	9.0	5.229	0.098
7	18.6	10.8	7.8	2.183	0.025*
8	11.8	13.7	- 1.9	3.225	0.408
9	24.2	17.3	6.9	3.398	0.073

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 2 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	32.2	30.0	2.2	10.18	0.751
2	35.2	30.5	4.7	5.859	0.302
3	49.5	36.0	13.5	6.286	0.065
4	35.1	30.8	4.3	15.130	0.676
5	47.4	42.6	4.8	11.495	0.545
6	33.3	26.9	6.4	1.790	0.025*
7	36.0	30.7	5.3	9.241	0.428
8	42.7	27.0	15.7	3.758	0.019*
9	30.8	23.9	6.9	6.473	0.208

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 2 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	8 066	4 066	4 000	1 293	0.033*
2	6 500	5 417	1 083	1 675	0.379
3	7 067	4 817	2 250	1 506	0.122
4	6 000	4 517	1 483	1 643	0.258
5	4 733	3 100	1 633	721.7	0.059
6	8 233	2 900	5 333	2 571	0.070
7	6 167	2 550	3 617	1 206	0.035*
8	3 567	2 683	883	857.8	0.216
9	8 467	4 683	3 783	2 677	0.134

* Significant at the 0.05 level

** Significant at the 0.01 level

TABLE B3

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 3 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	13.9	11.2	2.73	1.002	0.042*
2	11.5	12.6	- 1.16	2.421	0.492
3	12.3	10.3	2.03	1.589	0.157
4	9.7	11.9	- 2.20	2.553	0.274
5	13.1	11.0	2.07	1.762	0.179
6	13.0	13.3	- 0.37	5.361	0.917
7	13.0	14.5	- 1.50	1.389	0.202
8	10.5	13.1	- 2.53	2.438	0.214
9	8.8	8.7	0.17	0.513	0.630

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 3 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	19.6	20.8	- 1.20	1.609	0.326
2	19.9	18.4	1.43	2.454	0.418
3	18.7	17.3	1.33	0.808	0.104
4	19.1	18.3	0.80	1.054	0.319
5	18.4	19.7	- 1.30	2.524	0.466
6	20.1	19.8	0.27	2.409	0.866
7	17.2	17.9	- 0.77	1.518	0.474
8	13.8	13.6	0.20	1.997	0.878
9	12.1	10.1	2.03	1.305	0.114

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 3 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	5 133	3 783	1 350	477	0.039*
2	4 100	4 283	- 183	1 111	0.802
3	4 500	3 417	1 083	596	0.088
4	3 100	4 083	- 983	896	0.198
5	4 567	3 617	950	304	0.033*
6	4 600	4 567	33.3	2 458	0.983
7	4 500	5 083	- 583	583	0.226
8	3 767	4 567	- 800	1 238	0.379
9	3 100	2 533	567	115	0.014*

* Significant at the 0.05 level
** Significant at the 0.01 level

TABLE B4

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 4 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	3.57	3.23	0.33	1.159	0.668
2	3.27	2.90	0.37	1.701	0.745
3	3.70	3.80	- 0.10	0.458	0.742
4	2.90	2.40	0.50	1.277	0.568
5	3.47	2.97	0.50	1.000	0.478
6	2.87	4.33	- 1.47	1.501	0.233
7	3.13	3.27	- 0.13	1.115	0.855
8	3.07	4.53	- 1.47	0.902	0.106
9	3.70	3.63	0.07	0.569	0.858

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 4 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	12.47	5.87	6.60	2.944	0.060
2	12.83	6.37	6.47	5.631	0.185
3	11.80	6.63	5.17	7.27	0.343
4	11.40	4.17	7.23	7.76	0.248
5	12.3	8.07	4.23	2.72	0.114
6	9.27	7.83	1.43	2.194	0.375
7	13.50	9.17	4.33	2.663	0.106
8	9.17	7.20	1.97	3.700	0.454
9	10.2	9.60	0.67	2.043	0.629

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 4 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	410.7	79.7	331.0	254.1	0.153
2	320.0	31.3	288.7	94.21	0.034*
3	440.0	43.3	396.7	86.68	0.016*
4	376.7	20.3	356.4	220.4	0.107
5	344.7	22.0	322.7	230.3	0.136
6	94.7	65.7	29.0	93.41	0.645
7	356.7	247.3	109.3	35.23	0.033*
8	130.0	88.3	41.67	147.6	0.673
9	371.7	54.0	317.7	321.3	0.229

* Significant at the 0.05 level

** Significant at the 0.01 level

TABLE B5

ANALYSIS OF CHANGE IN ELECTRICAL CONDUCTIVITY VALUES (mS/cm)

SITE 5 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	0.567	0.333	0.233	0.231	0.222
2	0.533	1.800	- 1.267	0.971	0.152
3	0.467	1.267	- 0.800	0.854	0.246
4	0.433	0.367	0.067	0.208	0.635
5	0.567	1.300	- 0.733	1.274	0.424
6	0.667	2.133	- 1.467	1.155	0.159
7	0.433	1.100	- 0.667	0.289	0.057
8	1.033	2.667	- 1.633	1.550	0.210
9	0.467	1.233	- 0.767	0.058	0.002**

ANALYSIS OF CHANGE IN SODIUM ADSORPTION RATIO VALUES

SITE 5 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	0.433	0.200	0.233	0.058	0.020*
2	0.400	0.733	- 0.333	0.666	0.477
3	0.733	0.400	0.333	0.321	0.214
4	0.400	0.167	0.233	0.115	0.073
5	0.433	0.433	0.000	0.265	1.000
6	0.333	0.333	0.000	0.200	1.000
7	0.533	0.667	- 0.133	0.058	0.057
8	0.467	0.500	- 0.033	0.252	0.840
9	0.400	0.267	0.133	0.115	0.184

ANALYSIS OF CHANGE IN CHLORIDE VALUES (ppm)

SITE 5 15-30 cm Soil Zone

Treatment	Pre-Treatment (x_1) mean (n=3)	Post-Treatment (x_2) mean (n=3)	Difference (x_1-x_2)	s.d.	2-tail p-value
1	12.33	17.33	- 5.00	4.359	0.185
2	16.67	142.67	126.0	158.71	0.303
3	8.33	27.33	- 19.0	17.776	0.205
4	14.00	24.67	- 10.67	16.44	0.378
5	12.00	11.33	0.667	4.041	0.802
6	9.00	14.33	- 5.333	14.048	0.578
7	10.33	64.67	- 54.33	31.770	0.098
8	12.67	114.67	-102.00	121.50	0.283
9	17.00	14.33	2.667	11.676	0.731

* Significant at the 0.05 level

** Significant at the 0.01 level