Effect of irrigation water quality, amendment and crop on salt leaching and sodium displacement

by Teresa Ann Brock

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
A greenhouse experiment was conducted to study the interactive effects of irrigation water quality, surface-applied amendments, and crop species on sodium and salt leaching efficiency, soil chemical and physical properties, and crop yield.

Differences in measured parameters as a result of treatments probably resulted from a combination of soil physical and chemical properties and crop physiological factors. The most contributory factors appear to be: 1) variations in soil water contents and leaching fractions, 2) effects of plant roots and physiological characteristics of the various crops, 3) chemistry of the applied water and subsequent soil solution processes, and 4) differences in dissolution rates, solubilities and cation composition (Ca^{2+} or Mg^{2+}) of amendments.

The following conclusions resulted from this study: 1. Irrigation with water simulating future Powder River quality resulted in significant increases in salt concentration and SAR of soil and drainage water, relative to irrigation with past water quality. This increase resulted in a reclassification of the soil to a saline category.

2. Irrigation with water simulating past Powder River water quality resulted in lower soil SARs than pre-treatment soils. However, leaching fractions were not great enough to prevent salt accumulation.

3. Irrigation with water of future quality reduced surface soil macroporosity, relative to the effects of irrigation with past water quality.

5. Water quality had less impact on soil and drainage water chemistry in non-cropped columns than in columns with a crop.

6. Irrigation water quality did not significantly affect crop yield. Future water quality would most likely have reduced crop yields under conditions of greater water stress.

7. Effect of amendments on sodium leaching efficiency corresponded to amendment dissolution rate, that being: magnesium chloride > phosphogypsum > gypsum.

8. Beneficial effects of magnesium chloride appeared to be short term relative to the duration of effects of phosphogypsum or gypsum on soil properties. This is most likely due to the rapid leaching of magnesium chloride from the soil and easier replaceability of magnesium from the cation exchange complex than calcium.

9. Columns treated with phosphogypsum or gypsum had elevated soil ECs relative to ECs of soil from columns treated with magnesium chloride or the control by the end of the experiment. Addition of magnesium chloride elevated salt concentrations of drainage waters to a greater extent than other amendments.

10. Effects of amendments were negligible under irrigation with past quality water.

11. All amendments increased yields of alfalfa. Addition of phosphogypsum or magnesium chloride increased yields of barley.

12. Sodium and salt leaching efficiencies from columns planted to a crop appeared to improve with increasing evapotranspiration and smaller leaching fractions.

13. Barley had a more beneficial effect on soil chemical properties but a more adverse effect on soil structure than did alfalfa or sordan.

14. Sordan caused the greatest soil macroporosity of the crop treatments; however, salt leaching was inhibited by pore bypass.

15. Columns without a crop accumulated the least net salt and sodium.

16. Presence of a crop caused an increase in soil bulk density and a decrease in macroporosity.

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A thesis submitted in partial fulfillment
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Master of Science

in

Soils

MONTANA STATE UNIVERSITY
Bozeman, Montana

April 1991

APPROVAL

of a thesis submitted by

Teresa Ann Brock

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

23 May 1991 — Date | James W. Bauder — Chairperson, Graduate Committee

Approved for the Major Department

May 24, 1991 — Date | [signature] — Head, Major Department

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June 14, 1991 — Date | Henry L Parsons — Graduate Dean

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ACKNOWLEDGEMENTS

I would like to thank Dr. Bill Inskeep, Dr. Hayden Ferguson and Dr. Cliff Montagne for their contributions to this thesis and to my education at MSU. I am especially grateful to my advisor, Dr. Jim Bauder, whose unending support and guidance made this work possible. Thank you Jim for all your effort and encouragement.

Thanks to all my fellow graduate students for their support and for making my time at MSU enjoyable. And to Dave Sieler, Will Lanier and Chad Komloffski, whose help on this project was invaluable. Special thanks to Leo Jurica, and Bill and Glenn Gay who so generously donated their land and went out of their way to help with this project.

Most of all, I'd like to thank my sister Cathy and brother-in-law Paul Grossl for their technical advice and continual encouragement throughout the years.

And finally, to my parents, thank you for always supporting me in everything I've done.

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INTRODUCTION

The Powder River and its tributaries drain an area of approximately 34,700 square kilometers in northeastern Wyoming and southeastern Montana (Hembree et al., 1952). The headwaters of the Powder River drain a variety of igneous and metamorphic rocks but the vast majority of the basin is underlain by sediments of marine origin, including limestone, sandstone, gypsiferous shales, and siltstones (Figure 1). The combination of low precipitation (<35 cm annually) and exposure to marine sediments produces streamflow with high dissolved solids concentrations.

Historically, Powder River water has been of marginal quality for irrigation. However, roughly 4500 hectares in the Montana portion of the Powder River drainage are irrigated with Powder River water.

Studies of irrigated soils along the Powder River in Montana indicate that salinization of some soils has occurred. The specific causes of salinization (i.e. irrigation water quality, cropping history, irrigation management, soil physical and chemical properties) are not always evident. However, it is known that irrigation with water containing high concentrations of salt can accelerate the salinization process, unless irrigation is accompanied by careful water and soil management.

Historic water quality trends for the Powder River indicate that total dissolved solids and sodium

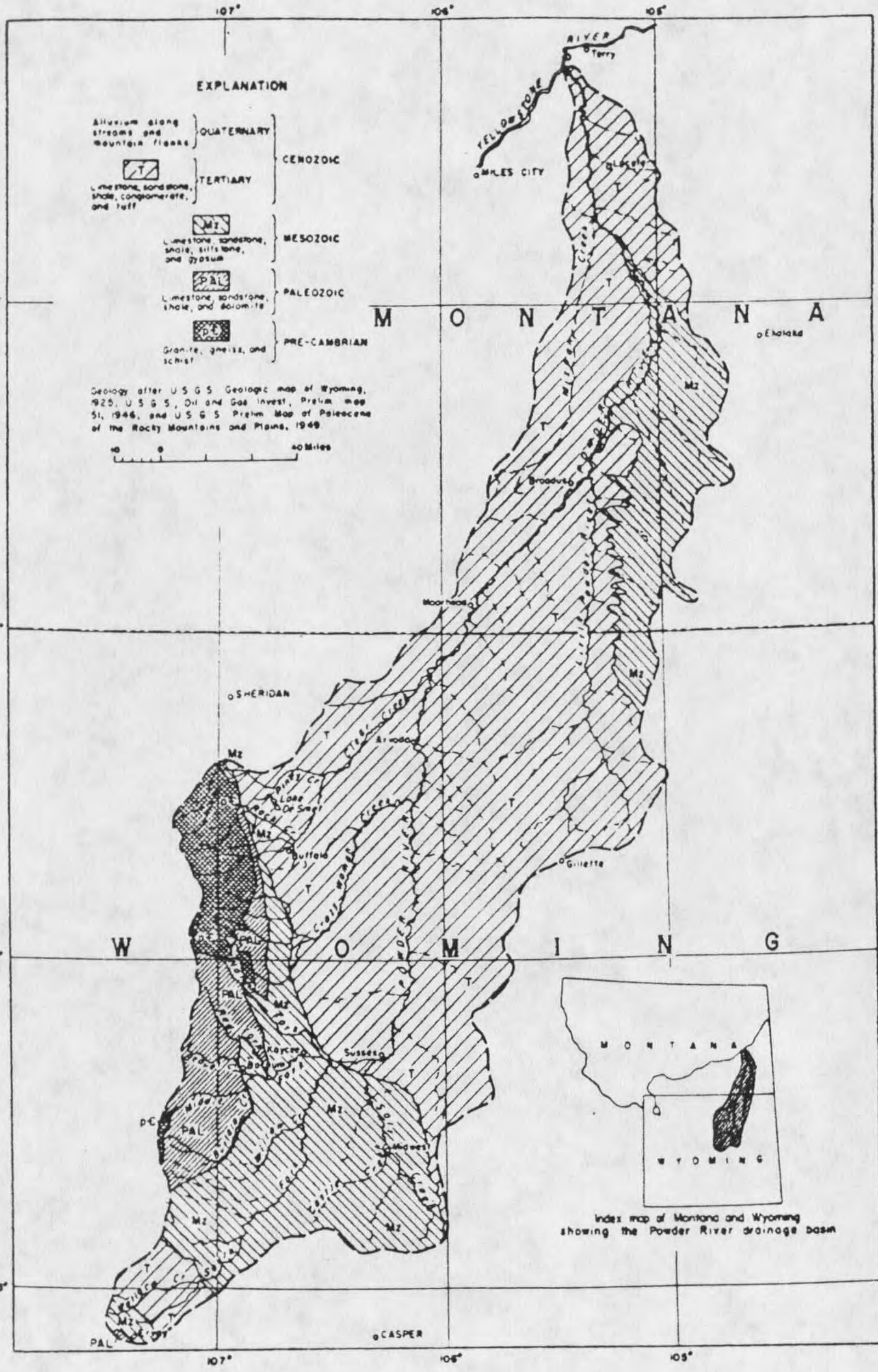

Figure 1. Geologic map of the Powder River drainage basin in Montana and Wyoming.

concentrations have been increasing over the past 20 years (Gallagher, 1986). It has been suggested that the reduction in crop yields reported by farmers irrigating with Powder River water has been a symptom of deteriorating soil conditions, caused by declining irrigation water quality.

Implementation of efficient and economically feasible soil reclamation strategies may be necessary to maintain production in the face of deteriorating soil conditions associated with long-term irrigation with water having relatively high TDS concentrations and SARs. Drainage and leaching of accumulated salts from the soil profile are prerequisites of productive, long term irrigated crop management. Because sodium saturation and clay dispersion are frequently associated with salinization, most reclamation efforts focus on replacing soil-adsorbed sodium with calcium or magnesium, both of which contribute to aggregate stability and improved drainage. Many researchers have proposed the use of calcium or magnesium-rich chemical amendments for sodic soil reclamation (Dollhopf et al.,1988; Richards, 1954). Various crops have been reported to improve permeability and promote the removal of sodium and salt from the soil (Robbins, 1986a).

This project was undertaken to examine management alternatives (amendment additions and alternate crop species) and their potentials for improving soil conditions and crop yields from the predominant irrigated soil along the Powder River (Haverson soil series). Effects of irrigation water quality on crop yield and soil reclamation were also investigated.

LITERATURE REVIEW

Properties of Irrigation Water

Quality of irrigation water is of particular importance in arid climates. Salts formed in situ by weathering of soil minerals or by salt deposition from applied water tend to accumulate in the soil profile. Use of saline water may result in reductions of crop yields while use of sodic water may cause deterioration of physical properties of soils.

Salinity

Total salt concentration is of primary concern in evaluation of irrigation water suitability. The effect of salt on crop growth is believed to be largely of an osmotic nature, although some researchers have also reported specific ion toxicity effects (Shainberg and Oster, 1978). Osmotic potential is a colligative property, and is therefore related to the total salt concentration rather than the concentration of individual ionic species (Shainberg and Oster, 1978). Methods for determining salt concentrations include total dissolved solids (TDS), expressed in mg/L, and electrical conductivity (EC) in dS/m. For a mixture of salts in the range of electrical conductivity up to 10 dS/m, the relationship between EC and TDS is linear, approximated by:

$$TDS(mg/L) = 640 \times EC(dS/m)$$

(Richards, 1954).

In the range of EC that will permit plant growth, the osmotic potential of a solution can be estimated by the expression:

$$\psi(bars) = -.036 \times EC(dS/m)$$

(Richards, 1954).

Plant uptake of water occurs in response to total soil water potential. Under saline conditions, total soil water potential is a function of both the matric potential and osmotic potential. As a salt-affected soil dries, both the osmotic and matric potentials decrease (become more negative), resulting in increasing plant water stress.

The net result of soil salinization is reduction of crop yields. Rhoades (1972) indicated that the primary cause of soil salinization is evapotranspiration of applied irrigation water, leaving soluble salts concentrated in the root zone. Many researchers have found that saline irrigation water accelerates soil salinization, resulting in significant reductions in crop yield (Bernstein and Francois, 1973; Letey et al., 1985; Bajwa et al., 1986; Bresler and Hoffman, 1986; Dinar et al., 1986).

Water need not be excessively saline to cause a salinity problem, however. Richards (1954) found that application of less than 0.6 m of irrigation water with an EC of 1.0 dS/m changed 30 cm of a salt-free loam to a saline loam when leaching did not occur. Conversely, Engel et al. (1985) found that irrigation with extremely saline cooling tower water (EC=2.2 dS/m) did not reduce yields of corn and alfalfa or elevate salt concentrations in the upper root zone. This was attributed to the initially low soil salt content, coarse soil texture, and adequate leaching by rainfall. Thus, it is evident that soil salinity and the resulting effects thereof are determined not only by irrigation water quality, but also by such factors as soil characterisics and management practices.

Sodicity

An important consideration in estimating the potential hazard of irrigation water is the extent to which the exchangable sodium percentage (ESP) of the soil will increase as a result of adsorption of sodium from the water. ESP is defined as:

$$ESP = \frac{exchangeable\ Na\,(meq/L)}{CEC\,(meq/100\ gm\ soil)}\ x\ 100$$

This increase depends on the ratio of soluble sodium to the divalent cations in solution (sodium adsorption ratio), which is expressed as :

$$SAR = \frac{(Na)}{\sqrt{(Ca{+}Mg)/2}}\ ,$$

where concentrations are given in meq/L.

A major factor affecting the final SAR value of soil water is the precipitation or dissolution of alkaline earth carbonates. In irrigation waters containing high concentrations of bicarbonate ions, there is a tendency for calcium, and to a lesser extent magnesium, to precipitate in the form of carbonate, thus increasing soil solution SAR and soil ESP (Shainberg and Oster, 1978).

Bower et al. (1968) proposed the following prediction equation to estimate carbonate precipitation effects on soil sodium status:

$$ESP = SAR_{adj} = SAR_{iw}[1.0+(8.4-pH_c^*)]$$

where $pH_c^* = (pk_2 - pk_{sp}) + p(Ca + Mg) + p(CO_3 + HCO_3)$, $p(Ca + Mg)$ and $p(CO_3 + HCO_3)$ are the negative logarithms of the molar and equivalent concentrations, respectively, and pK_2 and pk_{sp} are the negative logarithms of the second dissocation constant of H_2CO_3 and the solubility product of $CaCO_3$, respectively, both corrected for ionic strength.

The major problem associated with high soil ESP is the effect on physical properties of the soil. Divalent cations tend to flocculate clays and promote favorable soil structure, while sodium causes clay dispersion and swelling, resulting in reductions in hydraulic conductivity (HC).

Many studies have demonstrated the deleterious effect of sodium on soil structure. Soils leached with NaCl solutions of various concentrations had lower HC and were compressed to lower void ratios than those leached with $CaCl_2$ solutions (Waldron et al., 1970). The HC of a given soil has been shown to decrease with increasing ESP, provided the electrolyte concentration is below a critical threshold level that is dependent on soil characteristics (Quirk and Shofield, 1955). McNeal and Coleman (1966) concluded that the decrease in HC associated with high SAR-low electrolyte solutions was particularly pronounced for soils with high contents of montmorrillonitic clays, while soils high in non-swelling kaolinite and sesquioxides were insensitive to variations in solution composition.

Differences of opinion can be found in the literature as to whether swelling or dispersion is the major cause of reduced permeability of sodic soils. Shainberg and Oster (1978) assert that swelling results in reduced pore size and is a reversible process, while dispersion causes particle movement and pore blockage and is essentially irreversible. Shainberg and Caiserman (1971) found that swelling is not generally appreciable unless the ESP exceeds about 25 or 30. Conversely, Felhender et al. (1974) reported that dispersion can occur at ESP levels as low as 10 to 20 if the electrolyte level is less than 10 mg/L. Frenkel et al. (1978) concluded that plugging of pores by dispersed clay particles is the major cause of reduced HC in soils in the range of exchangeable sodium and electrolyte concentrations most commonly encountered in soils irrigated with sodic waters of questionable suitability. They also maintain that rainfall in soils irrigated with such water accentuates the problem.

Soil permeability decreases with the square of the pore radius. Therefore, regardless of the mechanism of the reduction in HC (dispersion or swelling), it is clear that a small reduction in the size of the larger pores has a large effect on permeability.

Reclamation of Saline-sodic and Sodic Soils

Reclamation procedures of saline-sodic and sodic soils should accomplish the following: 1) decrease soil ESP and pH to improve soil physical conditions, reduce problems associated with high Na concentrations, and improve soil nutrient status, and 2) remove soluble salts from the soil solution by leaching.

In the case of saline-sodic soils, removal of soluble salts without a corresponding decrease in ESP will result in a sodic soil, while only decreasing ESP will produce a soil solution of greater salt concentration (Cates, 1979).

Reclamation of sodic soils usually requires that water penetration into and through the soil be improved by either: 1) exchanging excess sodium with calcium so that leaching can procede, or 2) initially leaching with saline water and then progressivly decreasing the salinity of the applied water. Occasionally, calcium present in the subsoil as gypsum can be mixed with a shallow sodic layer by deep tillage, eliminating or reducing the need for amendments (Hoffman, 1986).

When both saline and non-saline waters are not available and deep tillage will not suffice, addition of an amendment is frequently mandatory. Amendments should be chosen considering such factors as:

1. physical and chemical properties of the soil
2. time available for reclamation
3. amount of water available for leaching and the drainage capacity of the soil
4. extent of reclamation needed
5. costs for amendments, water and application (Prather et al., 1978).

Amendments

Gypsum

Gypsum ($CaSO_4.2H_2O$) is the most commonly used amendment for sodic soil reclamation, primarily because of cost. Gypsum has effectively reduced ESP and increased permeability in numerous studies (Mustafa and Abdelmagid, 1981, 1982; Keren and Shainberg, 1981; Shainberg et al.,1982; Robbins, 1986a; Gupta and Singh, 1988).

When gypsum is mixed with soil, exchangable sodium is replaced with calcium by the reactions:

$$CaSO_4\ 2H_2O\ (solid) \rightarrow Ca^{2+} + SO_4^{2-} + 2H_2O$$

$$2Na(X) + Ca^{2+} \rightleftharpoons Ca(X) + 2Na^{+}$$

where (X) represents the soil exchange complex. The soil exchange complex acts as a sink for Ca^{2+} until both reactions reach equilibrium. Gypsum will continue to dissolve until the solution phase is saturated or the ion activity product of Ca^{2+} x SO_4^{2-} equals the solubility product of gypsum (Hira and Singh, 1980).

The effectiveness of gypsum is dependent on its dissolution properties. Gypsum's solubility in water is relatively low (2.4 kg m^{-3}), compared to calcium chloride ($CaCl_2$), which has a solubility of 977 kg m^{-3}. This low solubility may limit its effectiveness in arid environmnents or where insufficient water is applied. As the soil solution is concentrated by evapotranspiration, the solubility limits of gypsum are exceeded and gypsum is precipitated, resulting in a corresponding increase in the relative proportion of sodium in solution (Richards, 1954).

According to Keren and O'Conner (1982), the dissolution rate of gypsum depends on :

1) activity of Ca^{2+} in solution (which is governed by the exchangable Na^{+} fraction)
2) the rate of Ca^{2+} diffusion to exchange sites
3) size of the gypsum particles.

Gypsum dissolution increases with greater exchangable sodium concentrations and decreases in the presence of lime (Oster and Frenkel, 1980). The amount of water required for gypsum dissolution decreases with decreasing size of the gypsum particles (Hira and Singh, 1980).

Prather et al. (1978) found that more water and time were required for gypsum to be effective, relative to more soluble amendments such as $CaCl_2$ and H_2SO_4. He reports, however, that as soil ESP is reduced, gypsum becomes increasingly efficient in sodium leaching relative to the more soluble amendments because permeability is no longer limiting. Similarly, Shainberg et al. (1982) reported that gypsum had a long-term electrolyte effect on maintaining high HC, while $CaCl_2$ resulted in complete sealing of the soil after continuous irrigation with distilled water. Certain conditions, however, such as where insufficient water intake cannot be achieved, may preclude the use of gypsum singly. A combination of gypsum and a more soluble amendment may provide rapid improvements in infiltration and drainage as well as longer-term sodium displacement. (Prather et al., 1978).

Phosphogypsum

Phosphogypsum is a by-product of the manufacture of phosphoric acid (H_3PO_4) from phosphate rock ore processed with sulfuric acid (H_2SO_4) (Mays and Mortvedt, 1986). Gypsum is precipitated as a silt-sized (.002-.05 mm) waste product. Phosphogypsum consists of the gypsum waste material (80-99% $CaSO_4$ $2H_2O$), mineral impurities and less than 1% phosphate (Keren and Shainberg, 1981). Thousands of tons of phosphogypsum are produced annually in the U.S. with no apparent market (Smith, 1988). Thus, phosphogypsum is available at a relatively low cost.

Phosphogypsum has a much greater surface area than agricultural gypsum and is reported to have a 10 times greater dissolution rate (Keren and Shainberg, 1981). The high rate of dissolution of phosphogypsum accounted for its effectiveness in maintaining high infiltration rates on sodic and non-sodic soils subjected to simulated rainfall (Kazman et al., 1983; Gal et al., 1984; Agassi et al., 1986). Similarly, duPlessis and Shainberg (1985) reported that phosphogypsum, by dissolving readily and contributing Ca-electrolytes to the soil solution, prevented chemical dispersion of soil clays. Smith (1988) found that application of phosphogypsum improved physiochemical properties of a sodic bentonite minespoil.

Although phosphogypsum has shown promise as a sodic soil amendment, some of the contaminants in phosphogypsum may be environmentally hazardous. Phosphogypsum commonly contains Radium 226 (^{226}Ra) concentrations greater than the EPA suspect level of 5 picocuries gram^{-1} (Range Inventory and Anal.,1986). Mays and Mordvedt (1986) investigated the fate of ^{226}Ra after land application of 27 and 112 Mg ha^{-1} of phosphogypsum containing 25 pC gm^{-1} ^{226}Ra. They concluded that crop uptake of Ra was not affected while radioactivity in the surface 15 cm of soil was increased with both rates of phosphogypsum application. Conversely, a Wyoming study showed that a 30 cm incorporation of phosphogypsum at 35.5 Mg ha^{-1} resulted in no significant increase in ^{226}Ra levels (Range and Inventory Anal., 1986). Recently the EPA declared a ban on the transport of phosphogypsum from production sites (U.S. Gypsum Co., 1990). It is not clear whether this ban is temporary.

Magnesium Chloride

Magnesium chloride ($MgCl_2.6H_2O$) is a by-product of table salt evaporite production. Magnesium chloride, in brine form, is relatively inexpensive since it is considered a waste product at production sites (Smith, 1988).

Magnesium is the second most abundant exchangable cation in soils but has been studied relatively little, compared to other cations (Bohn et al., 1985). As divalent alkaline earth metals, Mg and Ca possess similar properties and have both been classified as important in the development of soil structure (Richards, 1954).

Magnesium chloride is very soluble (542 kg m^{-3}) compared to agricultural gypsum (2.4 kg m^{-3}). Highly soluble amendments such as $CaCl_2$ can rapidly increase HC and decrease ESP, largely due to their high electrolyte concentrations (Arora and Coleman, 1979; Prather et al.,1978).

Although magnesium chloride has been relatively untested as a chemical amendment, it has been reported to effectively displace sodium from the cation exchange complex (Peterson and Oad, 1974). Smith (1988) found that application of magnesium chloride brine to sodic bentonite minespoils reduced the soil SAR and saturation percentage and improved infiltration.

Some characteristics of magnesium chloride may make it undesirable as an amendment under some conditions. Some investigators have concluded that Mg and Ca are adsorbed equally and that the cation-exchange behavior of Ca and Mg is sufficiently similar that they can be considered as one species for irrigation water quality considerations (Richards, 1954). Others have reported that soils exhibit a preference for adsorption of Ca over Mg and the preference depends on the nature of the cation exchange complex (Sposito and Fletcher, 1985; Levy et al.,1972).

The preference for adsorption of Ca over Mg has been found to account for the increase in exchangable Na or K as the ratio of Mg/Ca increased (Haghnia and Pratt, 1988). Similarly, Rahman and Rowell (1979) reported that montmorillonitic soils containing Mg as the dominant exchangable cation adsorbed more Na and produced lower hydraulic conductivities than when Ca was the dominant cation. Quirk and Shofield (1955) showed that a Mg-saturated soil produced larger decreases in HC than a Ca-saturated soil when the predominant clay was illite. Hunsaker and Pratt (1971) concluded that ion exchange sites in allophane and in clay minerals coated with hydroxy-Al have a strong preference for Ca over Mg. Robbins and Carter (1983) calculated selectivity coefficients for simultaneous Ca-Mg-Na-K exchange for salt-affected soils. The lyotropic series (ease of ion replaceability) for these soils was Na $\geq$ Mg > Ca > K whereas the generally accepted series is Na > K > Mg > Ca.

Use of concentrated solutions may not be the most efficient amendment strategy under some conditions. Gupta and Singh (1988) found that more reclamation was achieved with gypsum than $CaCl_2$ after continuous irrigation with distilled water. This was attributed to gypsum being continuously solvated and exchanged over more parcels of water flux, leading to more efficient displacement than the highly soluble $CaCl_2$ which is essentially swept forward with the wetting front. This effect may also contribute to the salt load of drainage waters and degradation of groundwater and irrigation return flow. Moreover, high electrolyte concentrations in the root zone can adversely affect plant growth, especially where salinity is already a problem.

Sulfur Amendments

Other amendments have potential for improving sodic soil conditions. Sulfuric acid (H_2SO_4) can be used to rapidly reclaim sodic, calcareous soils (Cates, 1979). It reacts with soil calcium carbonates to produce a soluble source of calcium and promotes increased water intake rates in the soil. Elemental sulfur also promotes release of calcium in calcareous soils but requires more time for reclamation than sulfuric acid.

Crops in Reclamation

There is ample evidence that cropping plays a vital role in reclamation of saline and alkali soils. Besides crop varieties, a proper selection of crop rotations (depending on specific salt tolerances and ameliorative roles) is essential for achieving continued improvement of saline alkali soils (Yadav, 1975). Saraswat et al. (1972) suggest that alternating crops such as barley and rice will intensify the reclamation process. Zende (1972) reported that sugarcane, onion, paddy, sunflower, barley and wheat brought about appreciable reduction in the salt content of the soil. Ayers et al. (1951) suggest that barley, because of its high salt tolerance, be one of the first crops planted on land that is being reclaimed from excess salts or alkali.

The beneficial effects of plants in reclamation are not well understood but appear to be related to: 1) physical action of plant roots, 2) the addition of organic matter, 3) the increase in dissolution of $CaCO_3$, and 4) crop uptake of salts (Hoffman, 1986).

Root Effects on Soil Structure

Little work has been conducted on the influence of root activities on the physical structure of soil or on the subsequent effect on water movement. However, crop species has been reported to result in significant alterations to soil structure (Gibbs and Reid, 1988). Several researchers have found improvements in structure under ley and pasture grasses (Wilson and Browning, 1945; Page and Willard, 1946; Skidmore et al., 1975). Deterioration of structure has been reported to occur under arable crops such as wheat, barley

(Low, 1972) soybeans and corn (Wilson and Browning, 1945).

Ojeniyi (1978) found that the presence of a barley crop resulted in lower macroporosity, smaller aggregates and lower mean void size relative to non-cropped areas. Skidmore et al. (1986) found that the pore size under sorghum was more conducive to water infiltration and had greater saturated HC than that from wheat plots. Organic matter concentrations did not account for these differences; therefore they were attributed to differences in root or microbial activities. Reid and Goss (1981) postulated that differences in aggregate stability between crop species result from contrasting root patterns, especially the proportion of lateral roots, since release of organic materials occurs mainly near the root tip. The sturdy, extensive root system of paddy was reported to contribute to loosening the soil and rendering it more permeable to leaching of salts (Yadav, 1975).

Plant roots, enlarging pores or creating new pores, compact the soil immediately around the root, thus decreasing the size and percentage of large pores. Also, the decrease in macroporosity by living roots blocking macropores decreased premeability and saturated hydraulic conductivity in soils under sod and maize (Barley, 1953; 1954). However, root decompostion frees channels for water movement, thereby increasing HC of the soil (Barley and Sedgley, 1959). Gish and Jury (1982) compared the effects of wheat roots and non-cropped soils on water movement. They found that living wheat roots produced the smallest dispersion coefficient while the greatest dispersion was exhibitied after the wheat roots decayed.

Plant Root Respiration and Organic Matter

Respiring plant roots and decomposing organic matter produce carbon dioxide (CO_2), which dissolves in water to produce carbonic acid (H_2CO_3). This acid increases the solubility of $CaCO_3$ minerals by lowering the pH, thus increasing soil solution Ca concentrations and facilitating Na exchange (Robbins, 1986b). The following reactions describe this process:

$$CO_2\ (g) + H_2O \rightarrow HCO_3^- + H^+$$

$$CaCO_3\ (s) + H^+ \rightleftharpoons Ca^{2+} + HCO_3^-$$

Robbins (1986a) reported that a sorghum-sudangrass hybrid crop produced high soil atmospheric CO_2 concentrations and greater sodium leaching efficiencies than several other crop and amendment treatments. He also concluded that CO_2 production by roots appeared to be associated with the rate of top growth and that irrigations should be timed for times of vigorous plant growth to take advantage of increased $CaCO_3$ solubility. In the same context, Rhoades et al. (1973) found that drainage water salt concentrations and lime solubility were greatest when alfalfa was rapidly growing.

Addition of organic matter (through incorporation or root exudates) tends to stabilize soil structure, improve permability and aeration, supply plant nutrients, and increase CEC (Cates, 1979). Additionally, decomposition of organic matter by microrganisms produces CO_2, resulting in increased lime solubilization.

Uptake of Salts by Crops

Salt removal by crops alone is generally insufficient to maintain a salt balance. Only 2% of the salt present in a rootzone with an EC of 4 dS m^{-1} would be removed by a barley, corn, sudangrass or alfalfa crop (Hoffman, 1986). Shainberg and Oster (1978) estimated that about 20% of the salt applied in irrigation water with EC of 1 dS m^{-1} could be taken up by alfalfa. Even plants that are very efficient in removing salt from saline soils, such as sea-blithe, remove less than 3 Mg ha^{-1} each harvest (Chaudhari et al., 1964).

Irrigation Managment for Salinity Control

Leaching of soluble salts from soils requires application of water in excess of what is required for crop growth. The leaching fraction (LF) is the ratio between the amount of water drained below the root zone and the amount applied in irrigation ($LF = D_d/D_i$). Under conditions of insignificant rainfall and negligable chemical reaction, EC of the drainage water (EC_d) is controlled by the leaching fraction. LF is related to the salt concentration in irrigation water (C_i) and drainage water (C_d) by:

$$LF = D_d/D_i = C_i/C_d = EC_i/EC_d$$

By varying the leaching fraction, it is possible to achieve some degree of control over EC of the drainage water and EC distribution in the rootzone (Shainberg and Oster, 1978). Numerous studies have demonstrated that salt concentrations of drainage waters and accumulation of salts in the soil decrease as leaching fractions increase (Bower et al., 1968; Rhoades et al., 1973, 1974; Oster and Rhoades, 1974; Jury and Pratt, 1980). Similarly, Bower and others (1968) proposed that as the leaching fraction increases, precipitation of $CaCO_3$ decreases, resulting in lower soil ESP as described by the equation:

$$ESP = \frac{1}{\sqrt{LF}} [SAR_{iw}(1+8.4-pH_c^*)$$

Rhoades et al. (1974) suggest achieving the lowest possible leaching fraction commensurate with satisfactory crop growth in order to minimize the salt burden on drainage waters. Although salt concentrations are higher with low leaching fractions, the total salt load is diminished due to: 1) the maximizing of precipitation of salts, 2) maximizing the amount of soluble salt diverted in water stored in the soil, and 3) minimizing of soil mineral weathering.

However, when amendments that decrease soil ESP are used, there is an increase in the TDS of the soil solution

(Miyamoto et al., 1975). Therefore the amount of water that must pass through the zone to be reclaimed increases.

Displacement of salts depends on the amount and flow velocity of percolating water, initial soil water content and redistribution time (Biggar and Nielson, 1967). Salts generally are leached more efficiently from coarse textured soils than from fine textured soils. Coarse texured soils have a lower volumetric water content and thus less water is needed to flush salts from the soil (Hoffman, 1986). Furthermore, in soils with large cracks and other bypass channels, salt leaching efficiency is low.

In the same context, leaching by intermittent ponding or sprinkling requires less water than continuous ponding (Beyce, 1972; Shainberg and Oster, 1978). The drier the soil, the larger the percentage of water flowing through the fine pores and the more efficiently the leaching water displaces the saline solution.

Abed (1975) reported that leaching efficiency is increased with intermittent ponding, but continuous ponding produced lower ESP values. Similarly, Singh (1968) reported that exchangable sodium decreased to a greater extent where soil was kept saturated. Sahota and Bumbla (1970) found intermittent ponding to be more effective at increasing leaching efficiency in the 0-30 cm depth but that continuous ponding was more effective below 30 cm.

FIELD STUDY

Objectives

The overall objective of this study was to determine the effect of surface-applied soil amendments on soil chemical properties and alfalfa yield on selected salt affected soils in Powder River Conservation District.

Specific objectives of the study were:

1. to determine the effect of soil type on soil and crop responses to soil amendment;
2. to characterize composition and changes in soil solution chemistry as a function of amendments, time and depth in the soil profile;
3. to provide educational opportunities for Powder River irrigators by demonstrating the impacts of various management alternatives on crop performance and soil properties.

Materials and Methods

Site Descriptions

Field plots were established at two sites in Powder River Conservation District in July, 1988.

Leo Jurica farm, Powderville: The study was located in an irrigated alfalfa field, approximately 8 km south of Powderville on the west bench of the Powder River. The field consisted of parallel, graded panels, separated by border dikes. The panels are irrigated by surface flooding, with water provided via a delivery canal and turn-out culverts. The field had a history of approximately 40 years of irrigation management. The alfalfa stand was three years old when the study was initiated; the previous crop was irrigated wheat.

The study location was in a soil mapping unit representative of the predominant irrigated acreage in the Powder River valley. The soil was a Haverson silty clay (fine-loamy mixed calcareous, Mesic Ustic Torrifluvent), consistent with the published soil survey for this location (U.S. Dept. of Agric., 1971). The soil is moderately well drained, with moderately slow permeability. Specific site location is illustrated in Figure 2.

Bill and Glenn Gay ranch, Bloom Creek: The study location was an irrigated alfalfa field, approximately 40 km south of Broadus on the west side of the Powder River. The field was a graded basin, with surrounding border dikes and upslope terrain. The basin is surface irrigated by flooding in the same manner as the Jurica site. The field had been irrigated for 18 years, with barley preceding the alfalfa. The alfalfa crop was three years old when the study was initiated.

The soil was Haverson silty clay (fine-loamy, mixed calcareous, Mesic ustic Torrifluvent) but differed in some soil properties from the Jurica site. The soil is classified as well drained with moderately slow permeability, although subsequent evaluation suggests that the soil has relatively low hydraulic conductivity. The specific location is illustrated in Figure 3.

Field Plot Set-Up

Sixteen plots were established in a randomized block design at each site, with four replications of each of four amendment treatments. Each experimental unit (plot) measured 4.6 x 3.0 meters. Metal borders (corrugated sheet metal approximately 20 cm high) were installed between each plot, to confine amendments to the plots and to insure uniform water distribution during irrigation. Rain gages were installed to monitor precipitation and each study site was fenced to prevent livestock from grazing in the study area (Figure 4).

Pre-Experiment Soil Sampling and Analyses

Pre-experiment soil samples were collected in July, 1988, using a Giddings hydraulic probe. Hole borings were