

Characterization of rangeland and cropland Natrargids
by David James Sieler

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University
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Abstract:
Natrargid soils in eastern Montana represent approximately 121,000 to 162,000 hectares. Under the present Soil Conservation Service classification system, these soils are not suitable for crop production. However, observations of current cultivation efforts on these Natrargids provide contrary evidence. A field soil sampling study and greenhouse column study were conducted. The field sampling study characterized soil properties of two predominant soils in the area, Gerdrum (fine montmorillonitic, Borollic Natrargid) and Creed (fine montmorillonitic, Borollic Natrargid), and range and crop uses during three periods of cropping intensity. The greenhouse study utilized undisturbed soil columns excavated from field sites to evaluate spring wheat productivity and provide physical and chemical characterization of soils after multiple cropping and amendment application. Gerdrum and Creed soils, three management uses (native range, recently plowed, and long-term crop), and three amendments (check, gypsum, and phosphogypsum) were evaluated. Dry matter, growth components, and drainage water were collected after each of four cropping sequences for characterization. Destructive sampling of the columns was completed at termination of the experiment. Results indicate differences occurred among soils, uses, and amendments. Field and greenhouse studies indicated elevated salt and SARs for two common Natrargids. Characterization of field samples provided preliminary information on the extent and distribution of salts, pH, and SAR. More detailed analysis of many additional sites would be required to fully characterize Natrargids in southeastern Montana. Simulated cropping sequences in the greenhouse demonstrated an improvement in spring wheat growth in response to tillage and soil amendments, particularly with recently cultivated native range soils. Future crop and soil management of Natrargids should consider current salt and sodium levels, drainage characteristics, and tillage practices and their long-term impact on soil productivity.

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APPROVAL

of a thesis submitted by

David James Sieler

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.

April 21, 1994
Date

Jeffrey S. Jacobsen
Chairperson, Graduate Committee

Approved for the Major Department

4/21/94
Date

Head, Major Department

Approved for the College of Graduate Studies

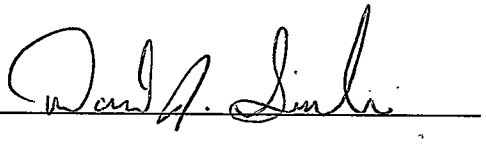
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ABSTRACT

Natrargid soils in eastern Montana represent approximately 121,000 to 162,000 hectares. Under the present Soil Conservation Service classification system, these soils are not suitable for crop production. However, observations of current cultivation efforts on these Natrargids provide contrary evidence. A field soil sampling study and greenhouse column study were conducted. The field sampling study characterized soil properties of two predominant soils in the area, Gerdrum (fine montmorillonitic, Borollic Natrargid) and Creed (fine montmorillonitic, Borollic Natrargid), and range and crop uses during three periods of cropping intensity. The greenhouse study utilized undisturbed soil columns excavated from field sites to evaluate spring wheat productivity and provide physical and chemical characterization of soils after multiple cropping and amendment application. Gerdrum and Creed soils, three management uses (native range, recently plowed, and long-term crop), and three amendments (check, gypsum, and phosphogypsum) were evaluated. Dry matter, growth components, and drainage water were collected after each of four cropping sequences for characterization. Destructive sampling of the columns was completed at termination of the experiment. Results indicate differences occurred among soils, uses, and amendments. Field and greenhouse studies indicated elevated salt and SARs for two common Natrargids. Characterization of field samples provided preliminary information on the extent and distribution of salts, pH, and SAR. More detailed analysis of many additional sites would be required to fully characterize Natrargids in southeastern Montana. Simulated cropping sequences in the greenhouse demonstrated an improvement in spring wheat growth in response to tillage and soil amendments, particularly with recently cultivated native range soils. Future crop and soil management of Natrargids should consider current salt and sodium levels, drainage characteristics, and tillage practices and their long-term impact on soil productivity.

INTRODUCTION

The presence of salts and sodium (Na) plays a major role in the productivity of agricultural and non-agricultural soils and in groundwater quality. Salted soils include saline and saline-sodic soils. Soluble salts, including Na salts, can accumulate in both irrigated and dryland soils, and in some cases decrease or prevent agricultural production. It has been estimated that nearly 81,000 dryland hectares in Montana have been put out of production by salinization of soils (Schafer, 1982). Naturally occurring Na affected (alkali) soils probably cover an equal or greater area of land.

Natrargids, previously classified as Solonetz soils, are soils affected by the presence of Na salts which frequently occur in unglaciated plains of eastern Montana. These light colored, cool, arid to semiarid soils are formed from soft sandstones, siltstones and claystones and occur often in the landscape as a complex pattern of nearly barren "slick spots." They are on gently rolling hills to badlands of glacial till plains and smooth parts of sedimentary plains and terraces. The geologic formations include: Fox Hill Sandstone, Hell Creek Formation and Fort Union Formation (Veseth and Montagne, 1980).

Sodium in combination with montmorillonite, the dominant clay in eastern Montana soils, make Natrargid soils difficult to manage for efficient agricultural production. Sodium affected soils typically have poorly structured, clayey, and Na dispersed shallow subsoil horizons of clay accumulation. As a result, surface crusts form, causing adverse conditions: emergence of seedlings is inhibited, tillage operations become difficult, and infiltration rate decreases, hence, these soils have low water storage and low permeability. Low permeability often results in waterlogging of surface horizons, restriction of root development and erosion.

Natrargid soils represent 121,500 to 162,000 hectares in southeastern Montana, predominately in Custer, Fallon, Garfield, Powder River, Prairie and Rosebud Counties and most of the soils in the Eastern Sedimentary Plains that are not affected by past glaciation. Previous field work by the Soil Conservation Service (SCS) suggests that Borollic Natrargids in southeastern Montana have high sodium adsorption ratio (SAR) values and low salinity, unlike the Borollic Natrargids on Glacial Till Plains. Currently, these soils are mapped as Natrargids based on low salinity, depth to salt, high SARs, and surface horizon thickness. Under this classification, these soils are not suitable for crop production. However, observations of current cultivation activities provide evidence to the contrary.

Normally these Natrargids should not produce yields in excess of 670 kg/ha of winter or spring wheat, but consistent yields of 1680 to 2350 kg/ha have been reported by producers, suggesting that productivity of these soils improves with cultivation (VanFossen, 1988).

The objectives of this study were to 1) characterize some chemical and physical properties of Natrargids, 2) determine changes that occur in Natrargids as influenced by successive cropping, and 3) provide guidelines for management of Natrargids.

LITERATURE REVIEW

The capability of an agricultural soil to produce a particular crop can be defined as soil productivity. Soil productivity is obtained only when the soil possesses favorable chemical and physical properties (Page and Willard, 1946). Certain factors can be manipulated to increase soil productivity; however, the cost of the improvement may not be reasonable. In such cases, attention should be given to careful selection of cropping systems and management practices that successfully maximize the soil's production potential.

Natrargid Soils

In subhumid and arid regions, soluble salts are not readily leached from the soil profile, but as water evaporates or is utilized by growing plants, soil salts move toward the surface and remain. After many years, soils with high salt concentrations in the rooting zone develop. Most salty soils occur in arid regions and in poorly drained soils of subhumid regions rather than in regions of high rainfall and permeable soils where soluble salts are leached (Donahue et al., 1983).

Soil Conservation Service classification identifies different types of Na affected soils (Soil Survey Staff, 1975). Natrargid soils are Argids with a natric horizon, but do not have a duripan or a petrocalcic horizon whose upper boundary is within one meter of the surface. Natric horizons commonly have columnar or prismatic structure and an upper boundary within a few centimeters of the soil surface. Natrargids commonly have carbonates throughout the profile and/or soluble salts which may accumulate below the natric horizon. Most Natrargids are nearly level, and the texture tends to be fine when associated with other Aridisols. On the margins of arid regions, Natrargids are associated with the driest of Mollisols. The presence of soluble salts and slow permeability of the natric horizon restricts the development of a mollic horizon.

The traditional theory on the genesis of Natrargids involves the upward movement of sodium from a water table (Gedroits, 1927; Kellogg, 1934; Kovda, 1939; MacGregor and Wyatt, 1945). Munn and Boehm (1983) examined Natrargid rangeland in northern Montana and suggested that Natrargids may develop in the total absence of a water table. The genesis of Na affected soils is based on the concept of "colloidal-chemical exchange", which suggests that sodic soil development involves Na eventually dominating the exchange complex (Gedroits, 1927). The high Na concentration causes soil colloids to disperse and become

mobile. These colloids are transported downward via percolating water (Munn and Boehm, 1983). Upon drying, they form a dense and compact illuvial horizon, in which, after many wetting and drying cycles, columnar structure develops (Gedroits, 1927; Arshad and Pawluk, 1966; Birkeland, 1974). Sodic soils limit plant growth by decreasing water infiltration rates and internal drainage, leading to water stagnation in the topsoil during wet periods and insufficient salt leaching (Sandoval et al., 1959; Van Schaik and Cairns, 1969).

Sodium Effects of Sodic Soils

Sodium influences soil productivity directly by chemical toxicity to plants due to nutrition and metabolism imbalances and indirectly by physical changes in the soil and restricted water movement caused by soil particle dispersion (Poonia and Bhumbla, 1973). High Na concentrations corresponding with high pH values cause/develop adverse soil physical characteristics leading to poor air-water-plant relationships. These undesirable physical changes make soil extremely impermeable to water and difficult for root penetration. Dispersion may also be influenced by the electrolyte concentration. The dispersion of soil particles destroys soil structure, resulting in a hard impermeable crust when the soil is dry and "puddling" or "slick spots" when wet. Near saturated conditions and

temporary flooding often occur in sodic soils for short periods of time during a substantial irrigation event (Sharma, 1986) or during heavy precipitation.

When water reaches the soil surface as rainfall, it evaporates, infiltrates, accumulates on the soil surface, or forms surface runoff. As a result, soil surfaces leached with rainwater will be especially susceptible to low levels of exchangeable Na and the formation of a crust at the soil surface is further accelerated by raindrop impact energy (Keren and Shainberg, 1981). Clay particle swelling reduces soil pore size and dispersion clogs soil pores (Frenkel et al., 1978). Swelling and/or dispersion of soil colloids alters the geometry of soil pores and thus affects the capacity for intake and movement of water throughout the soil which can result in anaerobic conditions. Consequently, if this condition persists for an extended period of time, root respiration and aerobic microbiological activities are decreased (Muhammed et al., 1969). Clay dispersion and swelling within the soil matrix are interrelated phenomena, and either one can reduce soil hydraulic conductivity, thereby reducing soil productivity. Swelling is not generally evident unless the ESP exceeds about 25 or 30%, but dispersion can be evident at ESP levels as low as 10 to 20%, if the electrolyte concentration level is low enough.

Quirk and Schofield (1955) demonstrated that clay does not disperse and reductions in the relative hydraulic conductivity of sodic soils do not occur even at high ESP levels, if the salt concentration or electrical conductivity (EC) of the permeating solution exceeds a certain "threshold" level (the concentration of salt which causes a 10 to 15% decrease in soil productivity) dependent on the SAR. Applications of high quality water such as rainwater may lower the electrolyte concentration below the critical level which may cause hydraulic conductivity to drop.

In the SAR range of 10 to 30 with a salt concentration of 0 to 10 mmol/L, Frenkel et al. (1978) concluded that pore plugging with dispersed clays was the main cause of decreases in hydraulic conductivities of typical irrigated montmorillonitic, vermicullitic and kaolinitic arid sodic soils. They further concluded that the exact levels of SAR and concentration of salts that result in reductions of hydraulic conductivity may depend on soil clay content, mineralogy and bulk density. Pupisky and Shainberg (1979) also concluded that at low SAR levels and low salt concentrations, dispersion and migration of clay into conducting pores was the major cause of hydraulic conductivity reductions of surface soils.

A study was conducted by Abu-Sharar et al. (1987) to test the hypothesis that slaking, not clay dispersion, is the major cause of hydraulic conductivity decreases in arid

and semiarid soils that are leached with successively more dilute electrolyte solutions of constant and relatively low SAR's. In this study, the dominance of macropores, instead of clay dispersion and plugging of conducting pores, lead to soil aggregate instability by providing larger spaces in their surroundings which was conducive to slaking and thus a subsequent collapse of soil structure. Abu-Sharar et al. (1987) suggests that slaking may very well play an important role in the reduction of hydraulic conductivity by reducing the amount of macropores.

The degree to which flocculation and dispersion is affected by water quality depends on the relative amount of exchangeable Na compared to neutral soluble salts. As a result, sodic or saline-sodic soils may or may not exhibit adverse physical properties although high osmotic potentials and the effects of high exchangeable Na concentration do sometimes present problems (Cates, 1979).

Saline Soil Remediation

Saline soil improvement is accomplished by decreasing the soluble salt concentration in soil solution by improving soil drainage and leaching salts through the soil profile with low SAR and salt content water, and/or by uptake through salt tolerant plants.

The ESP must be reduced below 6 to 12% (depending on soil texture and irrigation method) by increasing the

exchangeable Ca concentration or by increasing the EC to more than 4 dS/m (Robbins et al., 1988) to improve sodic soils. Physical conditions of sodic soils can be improved by tillage, incorporation of organic matter, or amendment application. This increases aeration and water penetration which in turn favors plant growth and soil productivity (Cates, 1979).

Improving soil drainage, increasing salt leaching, and reducing exchangeable Na by replacing with exchangeable Ca are required to improve saline-sodic soils. Leaching of soluble salts from a saline-sodic soil, creates a sodic soil and decreases the ESP in a soil of greater salt concentration.

Leaching of soluble salts from the soil profile requires application of water in excess of crop demand. The leaching fraction (LF) is the ratio between the amount of water drained below the root zone and the amount applied as irrigation. Leaching of salts depends on the amount and flow velocity of water, initial water content, distribution time of water, and soil texture.

Sodic Soil Remediation

Reclamation of sodic soils can occur with tillage and/or by application of amendments. Soil physical properties may deteriorate if a sodic soil is physically disturbed (Skidmore et al., 1975). Tillage is used to

improve surface soil aggregation and to bring subsoil horizons rich in gypsum and/or calcium carbonate ($CaCO_3$) to the soil surface. Tillage studies (Webster and Nyborg, 1986; Chang et al., 1986; Alzubaidi and Webster, 1982) concluded that deep plowing was the most effective practice in reducing ESP and SAR in most sodic soils and as a consequence, improves soil physical conditions and soil productivity. Deep plowing also changes the chemistry of the soil solution, thereby improving plant nutrition conditions in the rooting zone (Alzubaidi and Webster, 1982). Webster and Nyborg (1986) found that chemical amendments used in conjunction with tillage can often further improve surface layers of sodic soils. Loveday (1976) reported that deep tillage in a sodic clay soil enhanced leaching of Ca and Na salts. Cairns and Beaton (1976) studied the mixing of surface soil, hardpan layer (sodic horizon), and lime layer. The researchers suggest that deep plowing mixes the layers and the resulting exchange of Ca for Na greatly improves soil physical properties.

Tillage can play a significant role in the behavior of soil water. Differences in total porosity, pore size distribution, and pore geometry have considerable effects on measured and observed aspects of water movement and retention, not only in the topsoil, but at deeper rooting depths. Practical improvements resulting from tillage of

sodic soils include: reduced crust strength with greater seedling emergence, with reduced seeding rates and increased infiltration; drainage, leaching and water storage with an associated reduction in frequency of water needed; and an overall improvement in the efficiency of water use.

Amendments added to sodic soils initiate changes due to electrolyte concentration and cation exchange effects (Loveday, 1976). Chemical amendments are of three forms: 1) soluble Ca salts which directly supply soluble Ca, 2) Ca salts of low solubility which slowly supply Ca to soils with pH less than 7, and 3) acids or acid formers which free Ca already present in the soil (U. S. Salinity Laboratory Staff, 1954). The main Ca amendments include: gypsum ($CaSO_4 2H_2O$) and phosphogypsum, which is a source of gypsum.

Gypsum is the most common amendment used on sodic soils, primarily because of its low cost. The amount of gypsum required for a particular soil depends on the amount of exchangeable Na in the soil profile (U. S. Salinity Laboratory Staff, 1954). The addition of gypsum to a sodic soil causes exchangeable Na to be replaced with Ca. According to Keren and O'Conner (1982) the dissolution rate of gypsum depends on the activity of Ca in solution, the rate of Ca diffusion to exchange sites, and size of the gypsum particles. Gypsum dissolution increases with increased exchangeable Na concentrations and decreases in the presence of lime (Oster and Frenkel, 1980). In arid and

semiarid regions under dryland conditions, the penetration of gypsum into the soil may be impeded due to the lack of water available to dissolve the gypsum and facilitate the exchange of Ca for Na (Ryzhova and Gorbunov, 1975). In addition, high SAR levels in subsoil horizons may decrease rates of water movement under sodic conditions and thus, impede the movement of dissolved gypsum into sodic horizons (Graveland and Toogood, 1963; Carter et al., 1978).

Gypsum is available as industrial or mined gypsum which differ in physical properties. Industrial gypsum is a by-product of the phosphate fertilizer industry. The dissolution rate of industrial gypsum is much higher than mined gypsum, due to the increased surface area. The high rate of dissolution of industrial gypsum was responsible for maintaining high infiltration rates (Keren and Shainberg, 1981). Shainberg et al. (1982) observed that the long-term electrolyte concentration of gypsum was important for a chemically stable soil which did not release salt into the soil solution. As a result, the rate of dissolution of gypsum will change according to the electrolyte concentration.

Powdered phosphogypsum is a by-product from the phosphate fertilizer industry where phosphoric acid (H_3PO_4) is reacted with phosphate rock ore by a wet-process method using H_2SO_4 (Mays and Mortvedt, 1986). Phosphogypsum consists of gypsum (80-99% $CaSO_4 2H_2O$), less than 1%

phosphate (P_2O_5), and other mineral impurities, which is used for amelioration of sodic soils (Keren and Shainberg, 1981). Phosphogypsum has also been used as a source of sulfur for plant nutrition (Tsarevskii, 1984). Keren and Shainberg (1981) observed the dissolution rate of phosphogypsum to be much higher than gypsum, and consequently was very effective in maintaining a high infiltration rate in a sodic soil. Agassi et al. (1986) concluded that infiltration rates were higher when soil was treated with phosphogypsum than with gypsum. The researchers also suggested that powdered phosphogypsum particles applied to the surface may interfere with the continuity of the crust and may act as a mulch, thus increasing the infiltration rate of the soil. Kazman et al. (1983) concluded that when incorporating phosphogypsum, infiltration rate decreases did not occur at all ESP levels tested.

Phosphogypsum contains contaminants which may be hazardous to the environment, such as Radium 226 with concentration levels higher than the Environmental Protection Agency (EPA) suspect levels (Range Inventory and Analysis, 1986). Results from a study conducted by Mays and Mortvedt (1986) imply that phosphogypsum may be applied to agricultural soils at relatively high rates without increasing levels of radioactivity in corn, wheat, or soybean grain. However, the EPA recently banned shipment of phosphogypsum because reports suggest it contains unsafe levels of radioactive radon (U.S. Gypsum Company, 1990).

MATERIALS AND METHODS

Field and greenhouse studies were implemented to characterize Natrargids as influenced by management and amendment application. Similar soil properties were determined for each study in addition to drainage water properties for the greenhouse study.

Field Study

The field study characterized soil properties of two Natrargid soils as influenced by cultivation and native range management use conditions. Field study sites were identified by SCS soil scientists according to Natrargid classification specifications (VanFossen, 1988). All locations were in the southeast portion of Custer County, Montana (Figure 1).

The soil series at each of the locations consisted of Gerdrum and Creed; fine montmorillonitic, Borollic Natrargids. Each location represented a different length of time cultivated. The short-term location had been cultivated 2 years (short-term), the mid-term location 5 years (mid-term), and the long-term location 10 years (long-term). Each cultivated site for both soils, at all locations, was paired with a native range use site for both

soils. Thus, each location consisted of both soil series in cultivated and range conditions.

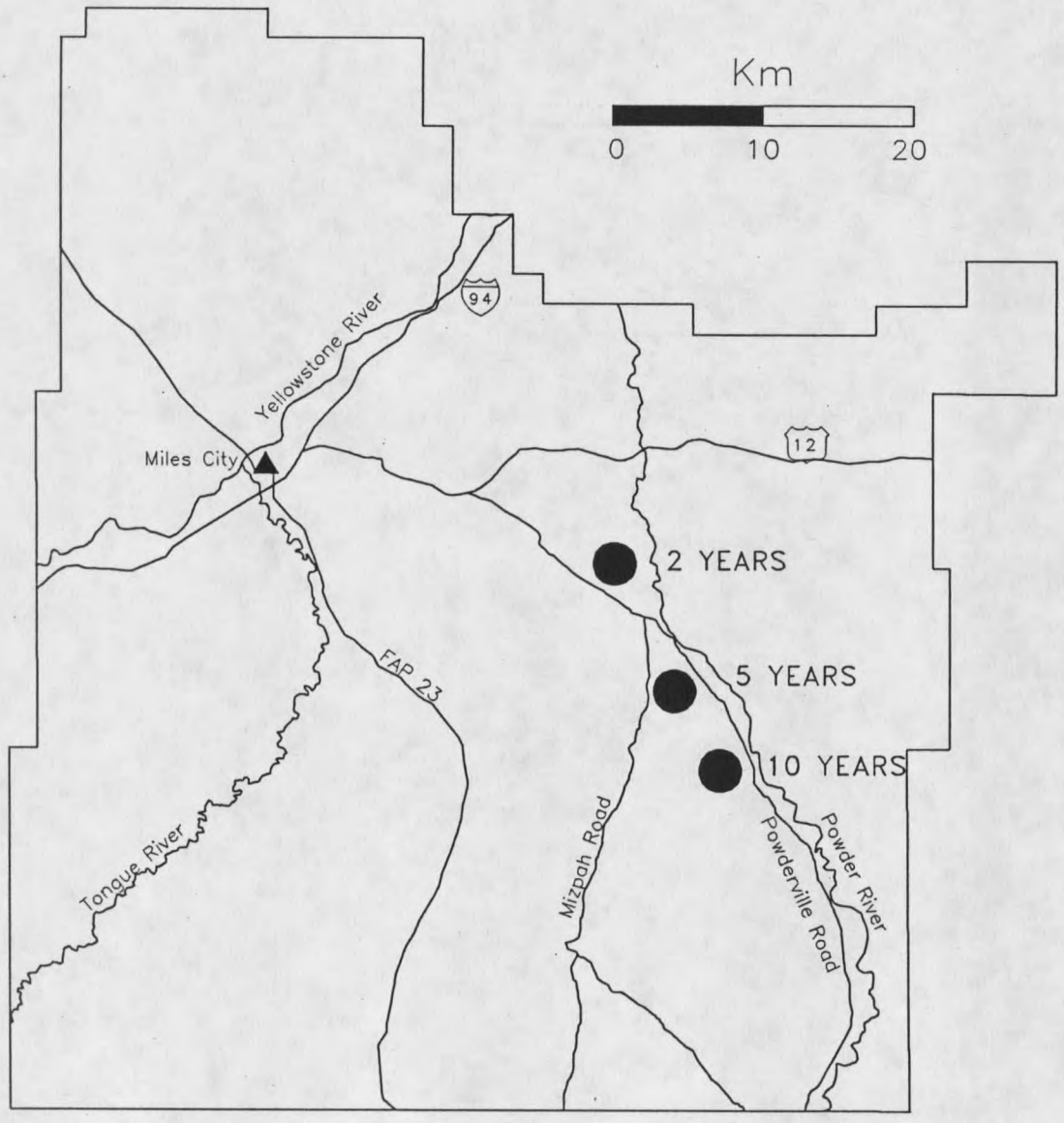


Figure 1. Map of sample sites in Custer County, Montana. Dotted areas designate approximate locations of field sample sites.

At each location, four soil core samples were collected from each soil series x land use combination to a depth of 150 cm, using a Giddings hydraulic soil sampler. Each core was divided by depth: 0 to 15, 15 to 30, 30 to 45, 45 to 60, 60 to 75, 75 to 90, 90 to 120, and 120 to 150 cm. Samples were placed into plastic lined paper bags and then oven dried at 105° C.

Soil pH of all soil samples was determined in a 1:1 0.01 M $CaCl_2$ solution: soil suspension ratio (Page et al. 1982). Electrical conductivity was measured in a 1:1 water:soil suspension. Organic matter (OM) was determined colorimetrically (Sims and Haby, 1971). Calcium carbonate ($CaCO_3$) was determined using a gravimetric method outlined by the United States Salinity Laboratory (1954). Water soluble Na, Ca, and Mg concentrations of soil samples were analyzed using a saturated paste extract method (United States Salinity Laboratory, 1954). The concentration of the soluble Na, Ca, and Mg cations in the extract were diluted and analyzed by atomic absorption spectrophotometry. Sodium adsorption ratios were calculated. Saturation moisture percentage (SAT) was determined as percent gravimetric water in a subsample of the saturated paste.

Greenhouse Study

A 12-month greenhouse study was conducted with 51 cm deep undisturbed soil columns excavated from paired mid-term

crop (cultivated) and native range use sites. Sites were approximately 50 meters apart and within the same Natrargid mapping unit. The soils in this study were the same as the mid-term soils in the field study.

Undisturbed soil columns were obtained using a sampling technique developed by South Dakota State University (Carlson, 1979, unpublished manuscript). Each soil column was excavated by attaching a steel cutting bit to a polyvinyl chloride (PVC) tube (20 cm diameter by 55 cm long) which was then driven into the soil using a tractor mounted hydraulic post driver (Figure 2). After excavation of the soil filled tubes, the cutting bit was removed and a PVC base plate (24 by 24 cm) with a drainage hole was permanently attached to the bottom of each tube. Twelve columns were excavated from each soil series in the mid-term crop use (previously cultivated 5-6 years) and 24 columns were excavated from each soil in native range use. Caution was taken throughout the excavation process to minimize soil compaction, structure disturbance and soil water loss. The columns were then transported to the Plant Growth Center.

Three uses (native range, recently plowed and long-term crop) and three amendment applications (check, gypsum and phosphogypsum) were superimposed on the soils in columns. The greenhouse study was arranged in a 2 (soils) x 3 (uses) x 3 (amendments) factorial replicated four times (Figure 3).



Figure 2. Field excavation of soil columns.



Figure 3. Column arrangement in greenhouse.

Tillage operations were performed to a depth of 25 cm on the long-term crop use columns. Twelve native range columns were cultivated to a depth of 25 cm, thereby creating a recently plowed treatment. Tillage operations were completed prior to each cropping period. Twelve native range columns received no tillage. Amendment treatments included a check (no amendment), gypsum ($CaSO_4 \cdot 2H_2O$), and phosphogypsum which consists of the gypsum waste material (85% $CaSO_4 \cdot 2H_2O$), mineral impurities and less than 1% phosphate (Keren and Shainberg, 1981). Amendment rates were determined based on soil profile descriptions and characterization completed by the SCS. Gypsum and phosphogypsum were applied directly to the Creed and Gerdrum soil columns at rates of 33.3 and 35.0 Mg ha^{-1}, respectively. The amendments were incorporated with the tillage operations in the appropriate columns.

'Cutlass' spring wheat (Triticum aestivum L.) treated with Vitavax (125 mg Vitavax 200 per 100 g of seed) was seeded 2 cm deep at a rate of 20 seeds per column for each of four cropping periods (October 2, December 13, February 16, and April 20). After 25 days, seedlings were thinned to five plants per column. Plant nutrients were applied twice during each cropping sequence at a rate of 100 kg N ha^{-1}, 25 kg P ha^{-1}, and 30 kg K ha^{-1}, in a 50 ml solution.

Distilled water was used for irrigation to simulate rain water quality. Soil columns were irrigated prior to

and during each cropping period (Figure 4). Table 1 provides the quantity of water applied and the irrigation schedule throughout the study period. Pore volumes were calculated to determine the volume of water needed to insure water drainage through the columns and to provide adequate water for crop growth during each cropping cycle. Each column received two liters of distilled water before cropping to establish similar water contents (field capacity) among all seeding columns. Soil columns were then irrigated adequately to facilitate drainage and to provide optimum moisture for crop production. All columns were irrigated uniformly, with the exception of the Gerdrum crop no amendment treatment; which frequently ponded, causing limited infiltration of irrigation water. Ponding of irrigation water was kept to a minimum to reduce surface sealing and water loss due to evaporation. Each column was irrigated with a drip irrigation system which maintained a constant rate of irrigation water on the soil columns, but did not allow ponding on the surface.

Table 1. Schedule of irrigation and fertilizer applications.

Crop sequence	Date	Fertilizer solution	Irrigation water
		----------liters column^{-1}----------	
1*	10/13	0.05	0.5
1	10/30		0.5
1	11/6		2.0
1	11/10	0.05	2.0
1	11/13		1.0
2*	12/22	0.05	0.5
2	1/6		0.5
2	1/22		2.0
2	1/24	0.05	2.0
2	1/26		1.0
3*	2/25	0.05	0.5
3	3/10		0.5
3	3/25		2.0
3	3/27	0.05	2.0
3	3/29		1.0
4*	4/27	0.05	0.5
4	5/12		0.5
4	5/28		2.0
4	5/30	0.05	2.0
4	6/2		1.0

* Indicates wetting period prior to corresponding cropping sequence with 2 liters water.



Figure 4. Greenhouse irrigation system. Each column was individually irrigated and fertilized using plastic bottles and drip emitters.

A water sample collection reservoir was placed below the drainage hole of each column (Figure 5). Collection reservoirs were fit tightly to the drain holes to eliminate evaporation and minimize $CaCO_3$ precipitation. Samples were collected from the columns eight times during the course of four cropping sequences: once at the end of each wetting period and once after each crop/irrigation cycle. The volume of leachate collected was recorded and used to calculate the leaching fraction (LF) for each column. A 50 ml water sample was collected from the bulk leachate solution. These samples were analyzed the same day for pH and EC, and then frozen until analyzed for water soluble Na, Ca, and Mg by atomic absorption spectrophotometry. Sodium adsorption ratios were then calculated.

Dry matter per column for each crop cycle was measured. Harvested plant material was placed in paper bags and oven dried four days and then weighed.

Following the fourth cropping period, columns were sampled by depth for selected soil properties (Figure 6). Sampling depths were 0 to 13, 13 to 25, 25 to 38, and 38 to 51 cm. Soil samples were placed into plastic lined paper bags and oven dried at 105° C. Soil pH, EC, $CaCO_3$, OM, Na, Ca, Mg, SAR, and SAT were analyzed from a saturated paste extract as previously described.



Figure 5. Drainage water collection of individual columns.



Figure 6. Destructive soil sampling of columns.

Statistical Analyses

Statistical analyses for each study and all variables were performed using SAS (SAS Institute, Inc., 1987). Analyses of variance for the greenhouse study were performed using leachate as repeated measures in time. The LSD test was used for comparisons between treatment means for each study.

RESULTS AND DISCUSSION

Field Study

The objective of this study was to characterize soil properties of two of the major Natrargid soils (Creed and Gerdrum) both under cultivation and native range site conditions at three SCS identified locations.

An attempt was made to determine whether soil properties were significantly different among main effects (soil, site, and location) and interactions. However, due to limited samples and inherent soil variability statistical analyses could not be completed. Therefore, the data collected from this study was used only to aid in characterizing and describing these Natrargids in relation to their EC, SAR, OM, and SAT characteristics.

Mean and standard deviation values for EC, SAR, OM, and SAT are presented in Table 2 for each soil, site, and location combination. Site condition influenced soil properties for each soil at nearly all locations. For example, EC ranged from 0.4 to 2.8 for range and crop, respectively. With the exception of location three, SAR trends were similar to EC, ranging from 1.2 to 16.5 for range and crop, respectively. These levels do not, however,

indicate salinity problems. Sodium adsorption ratio levels greater than 13 suggest sodicity at two of the sample locations which have been cropped and two range locations. Organic matter and SAT ranged from 1.0 and 42.3 to 2.9 and 58.7 for crop and range, respectively.

The wide range in EC, SAR, OM, and SAT properties are indicative of the difficulties encountered in chemically describing certain soils, and suggest the complexity in which these soils occur in the landscape. The variation in soil properties of these Natrargid classified soils make them difficult to manage.

Table 2. Summary of ANOVA of measurements from field study.

	EC		SAR		OM		SAT	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	dS/m		$(mmol\ L^{-1})^{-½}$		%		%	
Location								
Balsam	1.5	1.6	8.8	7.5	2.0	0.8	51.1	8.6
Hardy	1.7	1.6	10.6	8.3	2.3	0.9	50.7	11.3
Mizpah	1.8	1.3	13.8	6.9	1.5	0.7	45.9	8.0
Soil								
Gerdrum	1.8	1.4	11.3	7.3	1.8	0.9	52.2	9.3
Creed	1.5	1.6	10.8	8.4	2.0	0.8	46.3	9.2
Use								
Crop	1.8	1.5	12.1	6.9	1.9	0.8	49.5	10.9
Range	1.5	1.4	10.0	8.7	2.0	1.0	49.0	8.3

Greenhouse Study

A greenhouse study was conducted to determine the effects of management practices (native range, recently plowed, and on a relative basis, long-term crop) and addition of gypsum or phosphogypsum amendments on initial and post study properties of Creed and Gerdrum soils, leachate characteristics, and crop performance on these same soils.

The greenhouse study, conducted with undisturbed soil columns, simulated four seasons of continuous cropping. Comparison of pre-experiment with post-experiment soil properties indicated that the two soils were affected differently by the management practices and amendment additions. Crop performance was different between the soils and affected by management practices and amendments.

Pre-experiment Soil Characterization

Pre-experiment soil properties were measured to determine the effects of previous use on soil properties, and to characterize the soils prior to the greenhouse study.

Soil samples were collected at the time of column excavation and profile characterization. A single, composite bulk sample was collected from each individual sampling site. Bulk soil samples were collected for each horizon by SCS field staff. Results of soils analyses were depth-weighted to 13 cm increments to facilitate comparison

of results with test results from the post-study sampling. No statistical tests were conducted with the soil test results. Results of analyses of saturated paste extracts from the pre-experiment soils are presented in Table 3.

Table 3. Pre-experiment saturated soil paste extract values of selected soil properties[+].

Parameters	EC	pH	SAR
	$dS\ m^{-1}$		$(mmol\ L^{-1})^{-1/2}$
Soil series			
Creed	0.5	7.9	2.3
Gerdrum	1.3	8.0	6.3
Land use			
Native range	0.4	7.7	0.5
Long-term crop	1.3	8.2	8.0

[+]Values are averages for all uses and depths within each soil for both soils; and all depths for each land use.

Figure 7 illustrates the variation in EC, pH, and SAR as a function of depth for each soil series. The EC and SAR of the Gerdrum soil were substantially greater than the EC or SAR of the Creed soil, suggesting accumulation of salts in the Gerdrum soil. The substantially greater SAR throughout the profile of the Gerdrum soil suggest salts are predominantly sodium-based.

The EC, pH, and SAR were greater at all depths in long-term crop than at all depths in native range, with one exception (Figure 8). With the exception of EC and SAR of the long-term range site EC, pH, and SAR increased in value

with increasing depth of sampling. The differences in pre-experiment EC, pH, and SAR between the two land use conditions can be attributed to cultivation, based on the assumption that prior to plowout and cultivation, the soils were essentially identical between the long-term crop site and the native range site.

The soil at each study site was classified by the SCS as a Natrargid (Na affected). Laboratory analyses of the soil chemical properties indicated that neither soil is sodic, in as much as the average SAR of neither soil exceeds 13. However, remnant soil structural properties observed in the field suggest that these soils were previously dominated by Na salts to a greater degree than they are currently.

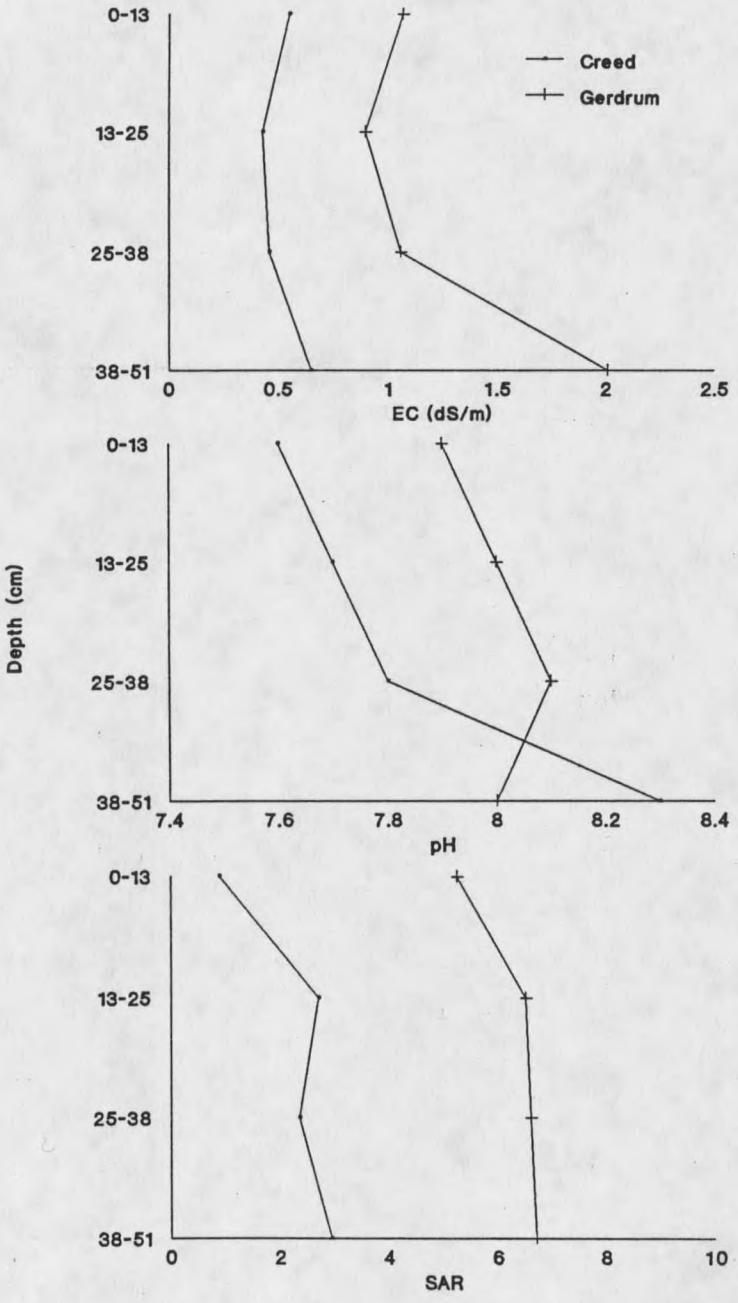


Figure 7. Pre-experiment EC, pH, and SAR of saturated paste extracts from Creed and Gerdrum soils.

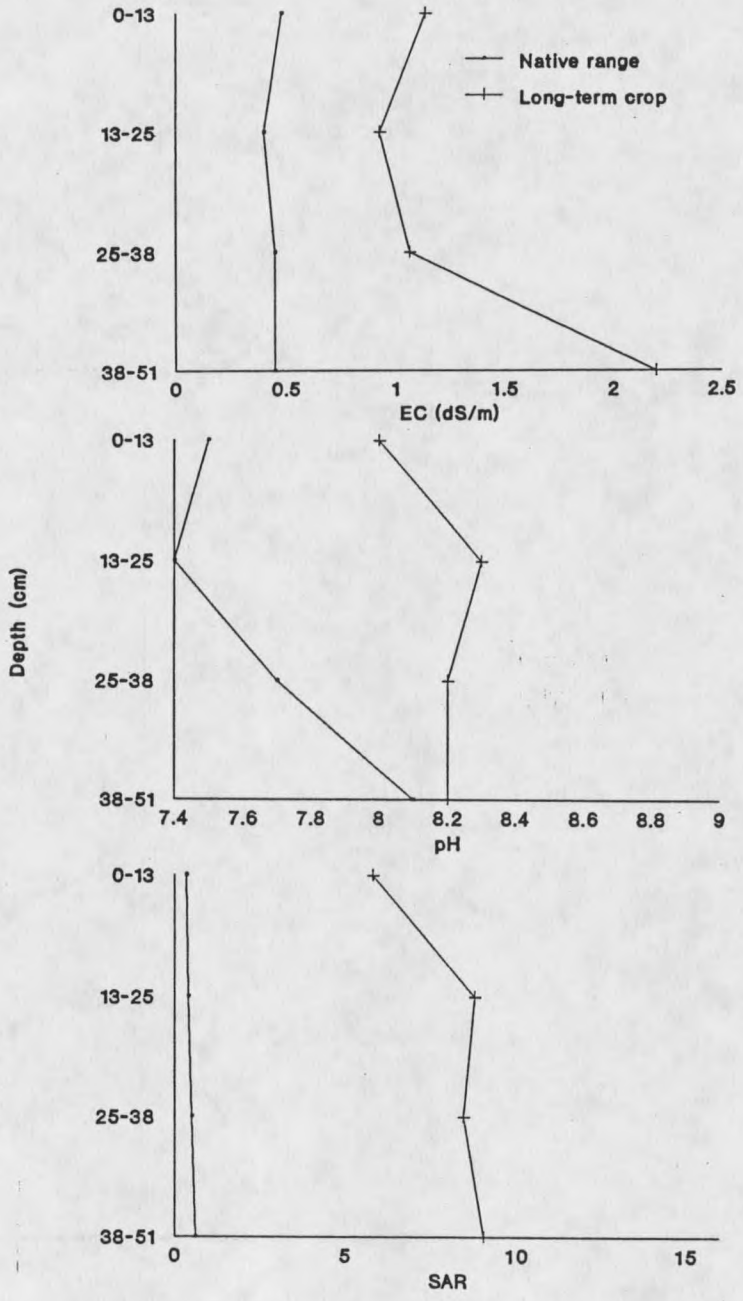


Figure 8. Pre-experiment EC, pH, and SAR of saturated paste extracts from native range and long-term crop study sites.

Post-experiment Soil Characterization

Chemistry of post-experiment saturated paste extracts differed between soils, among land use practices, and between amendment treatments (Table 4). Average EC, pH, and SAR of the Gerdrum soil were significantly greater than the average EC, pH, and SAR of the Creed soil following the greenhouse study. Electrical conductivity and SAR increased with depth for each soil in a pattern similar to that observed in the pre-experiment soils (Figure 7 versus Figure 9). However, the increase in EC with depth was greater in the Gerdrum soil than in the Creed soil. The change in pH with depth was similar for the two soils, increasing from 7.2 at the surface to approximately 7.8 at the bottom of the columns (Figure 9).

Generally, EC increased with depth and SAR decreased with depth as a result of the greenhouse cropping. Although the differences between pre-experiment and post-experiment EC and SAR levels cannot be statistically evaluated, the differences can be observed by comparing Figures 7 and 9. Comparison of the average EC, pH, and SAR of the pre-study soils with the average EC, pH, and SAR values of the post-experiment soils indicated that intensive cropping or application of surface-applied amendments caused the average EC to increase and the average pH and SAR to decrease (Table 3 versus Table 4). The increase in EC was probably caused by a lack of drainage and the addition of salts with

fertilizer and amendments during the greenhouse study, while cultivation of the surface soils most likely facilitated the release, displacement and leaching of Na salts during cropping. The EC of columns treated with amendments increased, reflecting the increase in solution concentration caused by the dissolution of the amendments.

Table 4. Selected soil properties of post-experiment saturated soil paste extracts[+].

Parameters	EC	pH	SAR
	dS m^{-1}		(mmol L^{-1})$^{-1/2}$
Soil series			
Creed	1.5 a[+]	7.2 a	1.0 a
Gerdrum	2.3 b	7.6 b	2.9 b
Land use			
Native range (check)	1.0 a	7.3 a	0.8 a
Recently plowed	1.9 b	7.3 a	1.0 a
Long-term crop	2.8 c	7.7 b	4.1 b
Amendment treatment			
No amendment (check)	1.1 a	7.5 b	2.7 b
Gypsum	2.2 b	7.5 b	1.5 a
Phosphogypsum	2.3 b	7.2 a	1.8 a

[+]Means within a column followed by different letters are significantly different at the 0.05 probability level, according to LSD test.

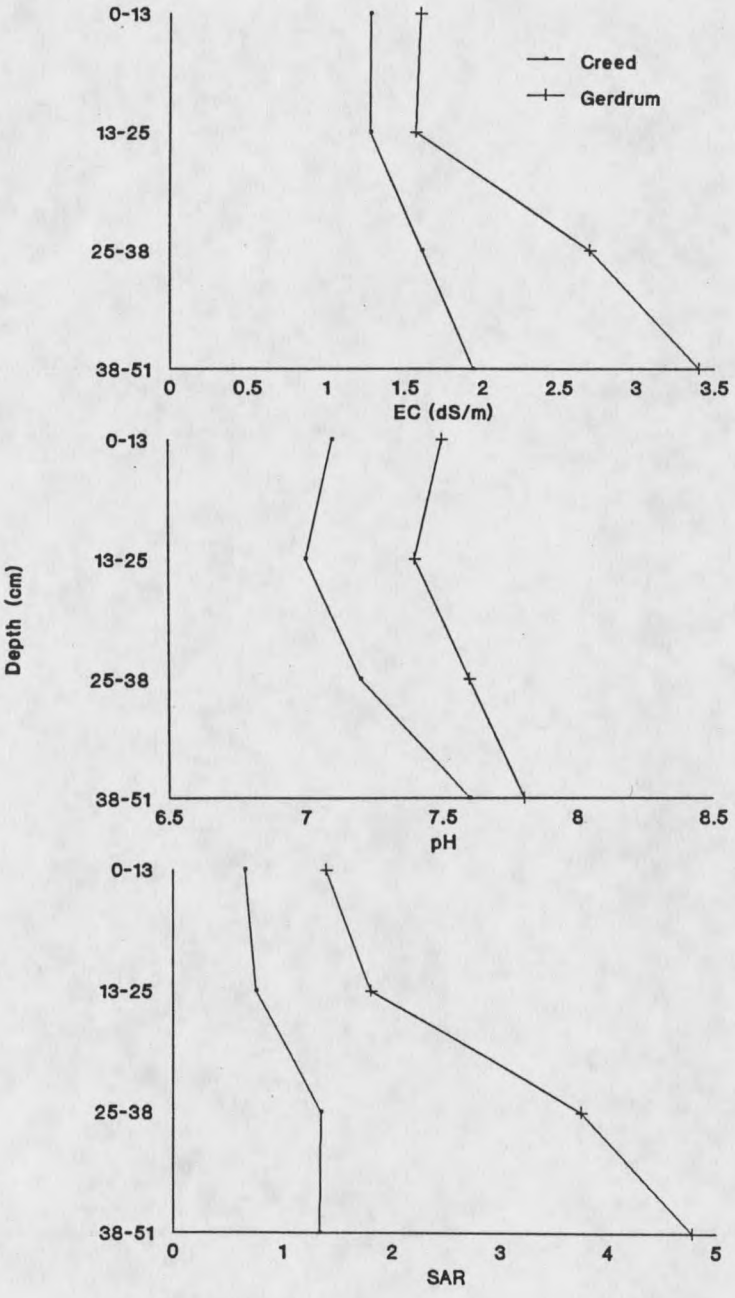


Figure 9. Post-experiment EC, pH, and SAR of saturated paste extracts from greenhouse column study using Creed and Gerdrum soils.

The decrease in SAR of the columns treated with amendments (relative to the SAR of all pre-treatment samples (SAR = 4.2)) and the lower SAR of columns treated with amendments, compared to the check columns (1.5 - 1.8 versus 2.7, Table 4) at the end of the study suggest that the amendments caused displacement of sodium from the soil exchange sites. The decrease in SAR may have also been the result of decreased Na concentration or increased Ca and Mg concentration from the addition of gypsum and phosphogypsum.

Although selection and sampling of soils for use in the greenhouse study and the subsequently used greenhouse design did not provide data which would allow for valid statistical comparisons of the pre- and post-experiment results, it is possible to speculate about observed differences in chemical properties. Assuming the pre-experiment soils were similar for the native range and recently plowed treatments, post-experiment differences between the native range columns and the recently plowed columns can be attributed to crop growth and leaching during the greenhouse study.

Average post-experiment EC, pH, and SAR were significantly greater for long-term crop treatment than for the native range and recently plowed treatments (Table 4). In general, EC and SAR increased with depth for native range and recently plowed treatments (Figure 10). The EC and SAR of the long-term crop treatments increased more noticeably with depth. Soil pH increased slightly with depth for all uses.

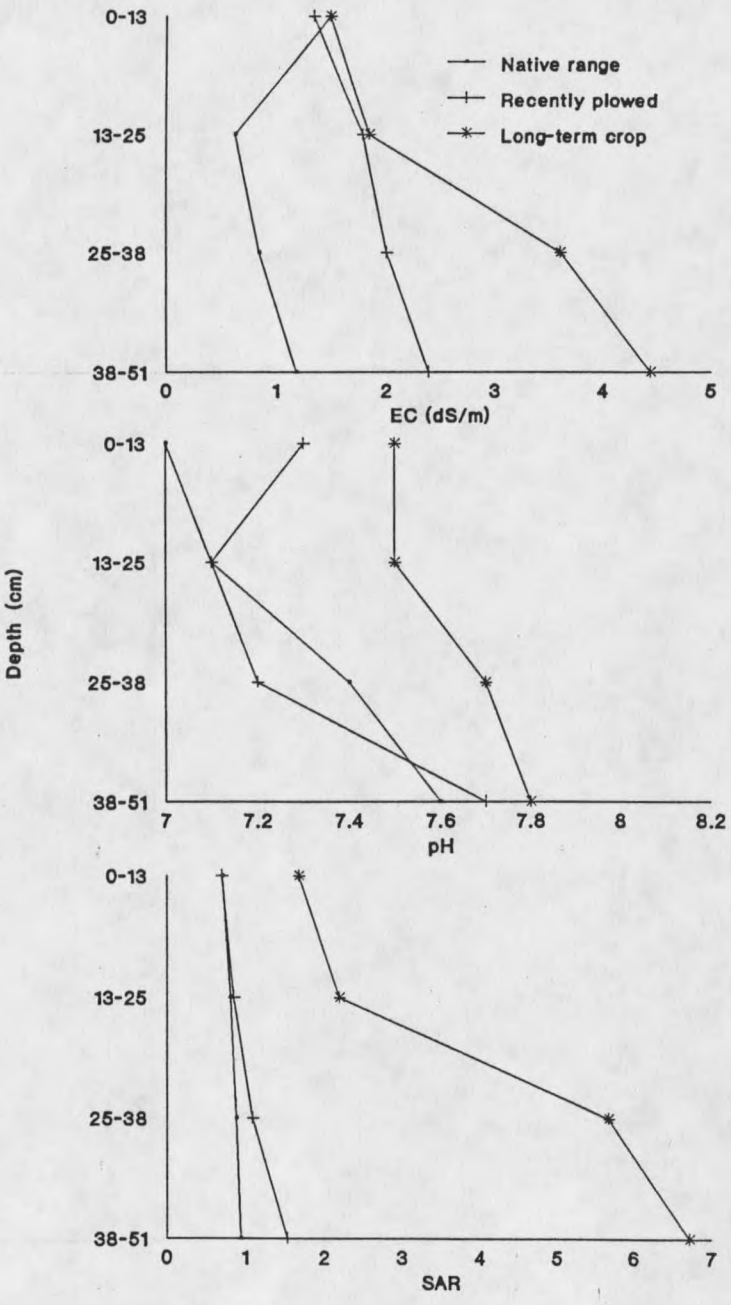


Figure 10. Post-experiment EC, pH, and SAR of saturated paste extracts from greenhouse column study using native range, recently plowed, and long-term crop soils.

No differences in pH or SAR were observed between native range and recently plowed treatments; EC differed significantly for the native range and recently plowed post-experiment soils at all depths below 13 cm. The data suggest that as the duration of cropping increased, the salt levels increased. This may be the result of little or no leaching because of inadequate irrigation and the physical nature of the column or by increased solubilization of salts in the root zone due to increased CO_2 concentrations from root activity.

Comparison of pre-experiment SAR with the post-experiment SAR of the long-term cropped soil suggests that cropping during the study has caused changes in the soil properties. Sodium adsorption ratio appears to have decreased, suggesting Na salts were removed during the experiment. Removal of Na salts could have occurred because of improved infiltration as a result of soil disturbance and structural alteration due to cultivation, addition of Ca and Mg in the amendments, or plant uptake of Na. Soil pH changed very little during the experiment.

Columns treated with either gypsum or phosphogypsum had greater post-experiment EC than the check treatments (Table 4). Average pH of soils treated with phosphogypsum was significantly lower compared to the pH of check treatments and soils treated with gypsum. Phosphogypsum resulted in significantly lower pH values than the no amendment (check)

and gypsum treatments (Table 4). The SARs of columns treated with gypsum or phosphogypsum were the same and significantly lower than the SAR of the non-treated columns (Table 4). In general, EC, pH, and SAR increased with depth (Figure 11). Post-experiment soil analyses indicate that addition of gypsum or phosphogypsum elevated the soil solution salt concentration and decreased the SAR. The relative effectiveness of the two amendments at influencing EC and SAR was similar.

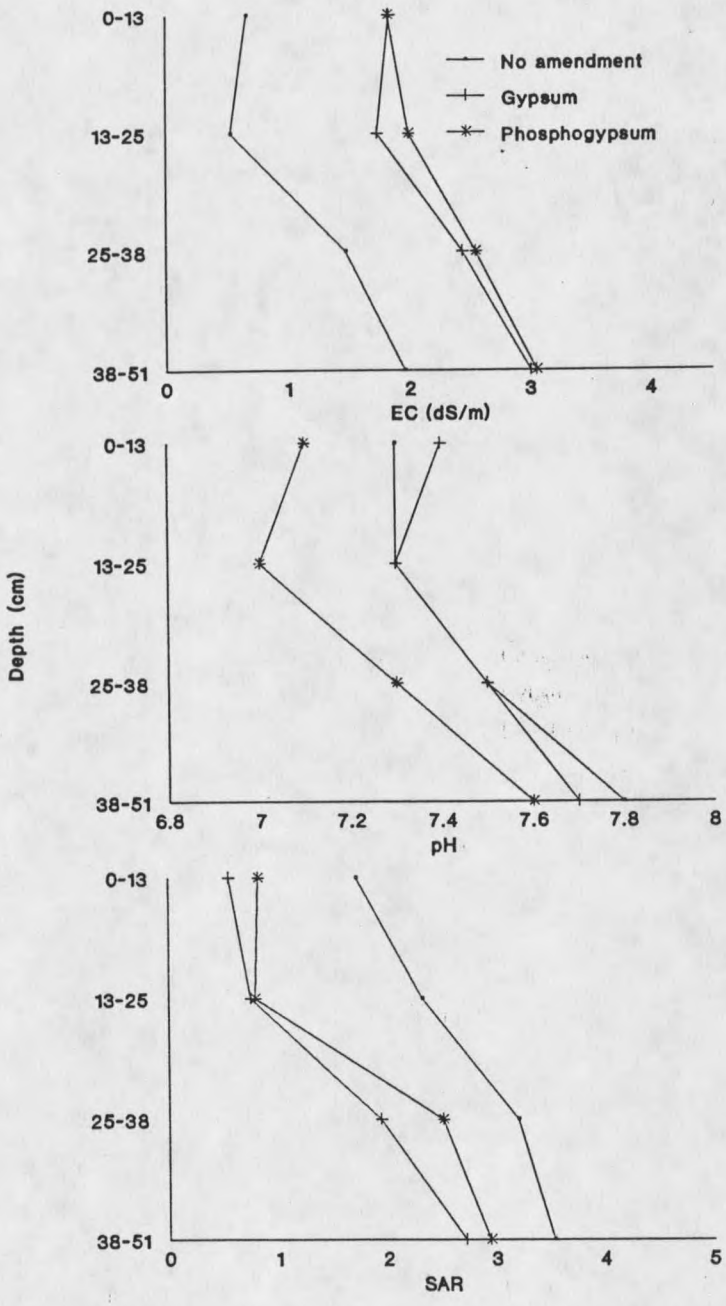


Figure 11. Post-experiment EC, pH, and SAR of saturated paste extracts from greenhouse column study using no amendment, gypsum, and phosphogypsum amended soils.

Interactions for Post-experiment Soil Characterization

The effects of land use on soil properties were most evident in columns containing Gerdrum soil (Figure 12). Electrical conductivity was significantly different among all Gerdrum land uses and between Creed cultivated land use and Creed native range. Electrical conductivity of Creed soils plowed or long-term cropped was the same. Sodium adsorption ratio was similar for the Gerdrum soil in native range and the Gerdrum soil recently plowed. The SAR of both of these treatments was significantly lower than the SAR of the long-term cropped treatment.

Soils treated with amendments had greater EC and lower SAR than the control treatment with no amendment for each soil with the exception of the SAR for the Creed soil (Figure 13). Sodium salts were displaced and/or Ca and Mg salts were increased, particularly in the Gerdrum soil, causing the SAR to decrease. Improved drainage of the Gerdrum soil may have contributed to the decreased SAR of the Gerdrum soil, relative to the SAR of the Creed soil.

Addition of amendments to the columns in each land use treatment increased the EC and reduced the SAR of the long-term cropped treatment (Figure 14). This suggests that the addition of amendments can reduce the SAR of these soils over time when cultivated. The corresponding increase in EC suggests that salts were supplied to the soil columns by the amendments.

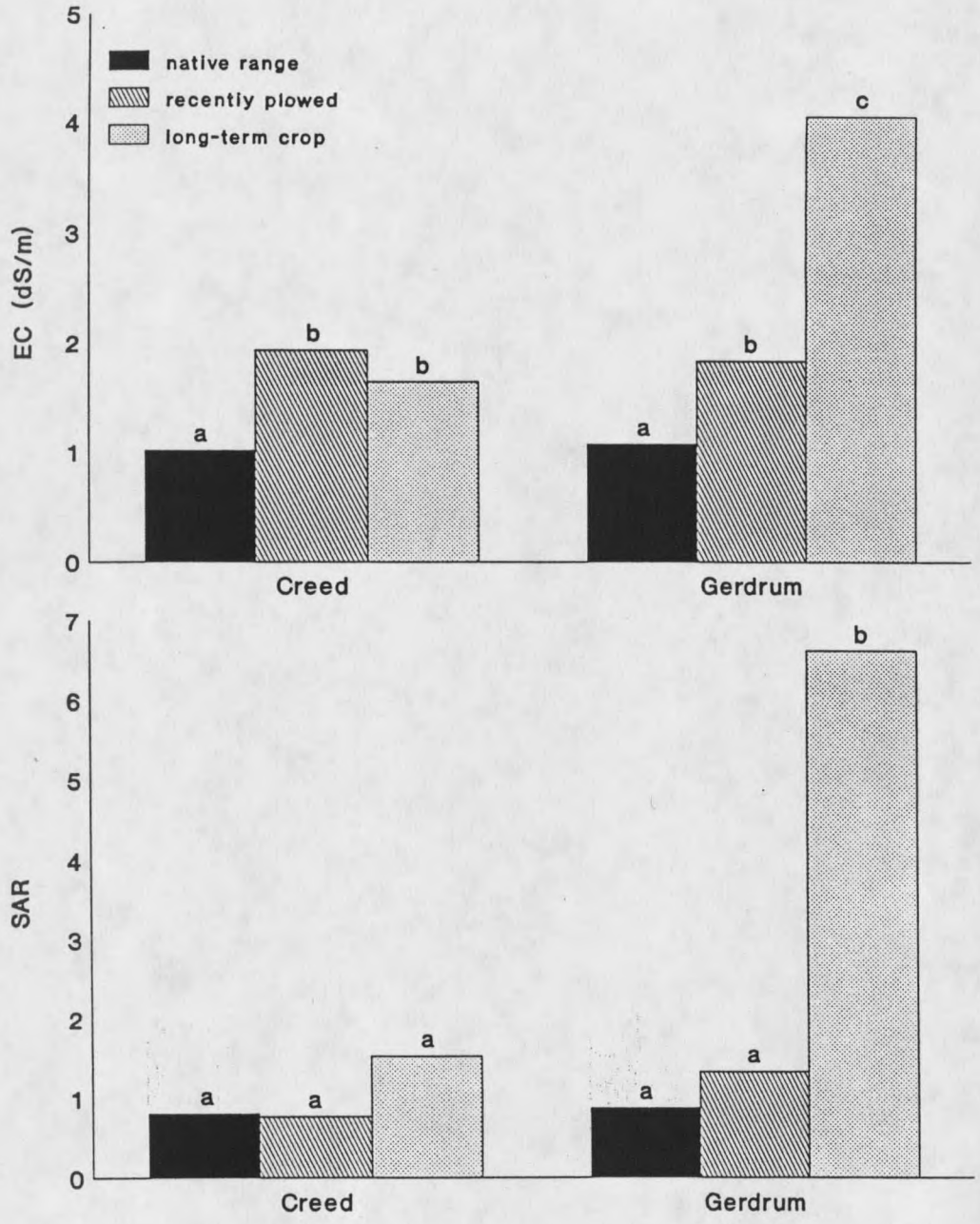


Figure 12. Use by soil effects on post-experiment EC and SAR in the greenhouse column study. Values averaged across amendment and depth. Significant differences shown by letters corresponding to LSD; alpha < 0.05.

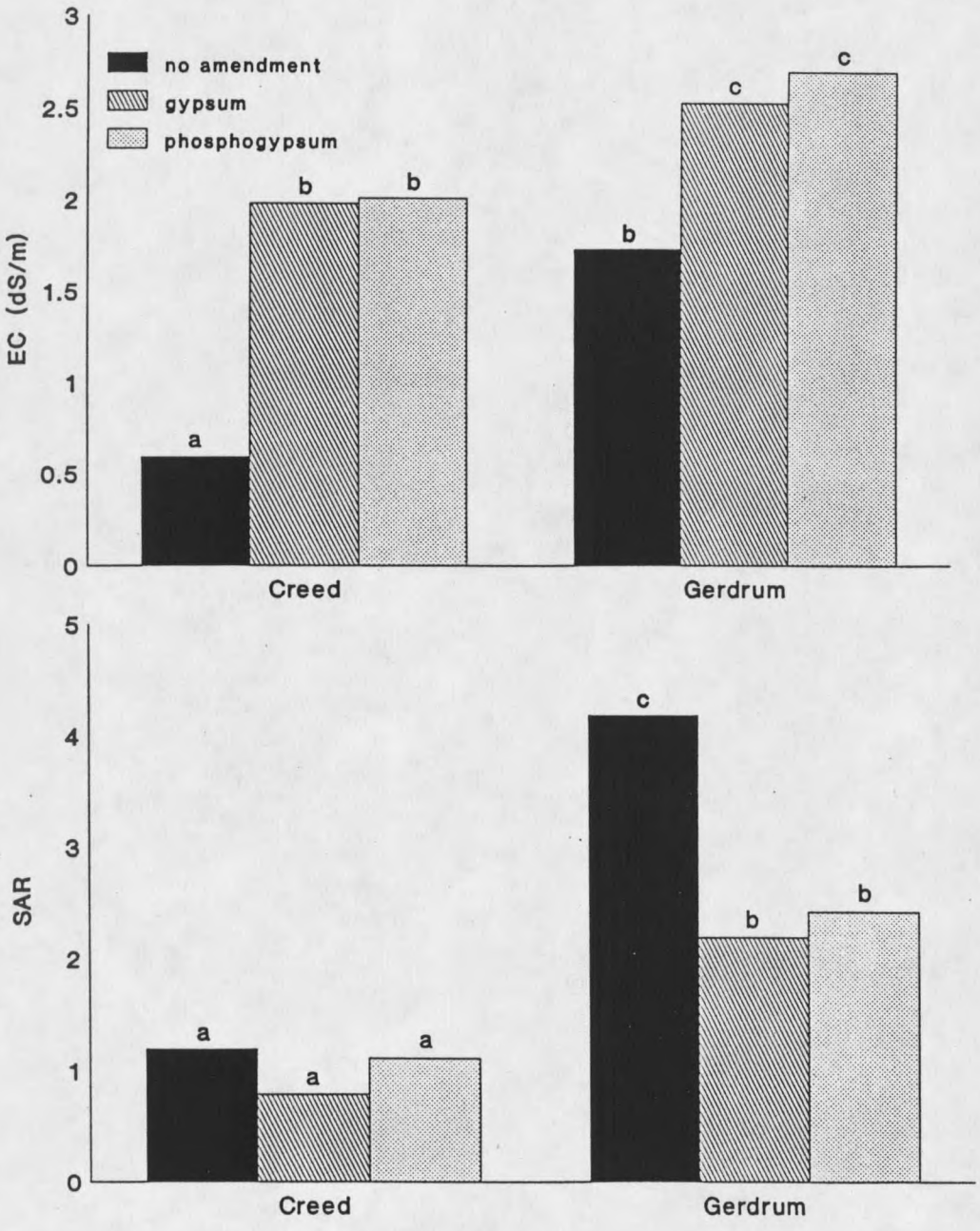


Figure 13. Amendment by soil effects on post-experiment EC and SAR in the greenhouse column study. Values averaged across land use and depth. Significant differences shown by letters corresponding to LSD; alpha < 0.05.

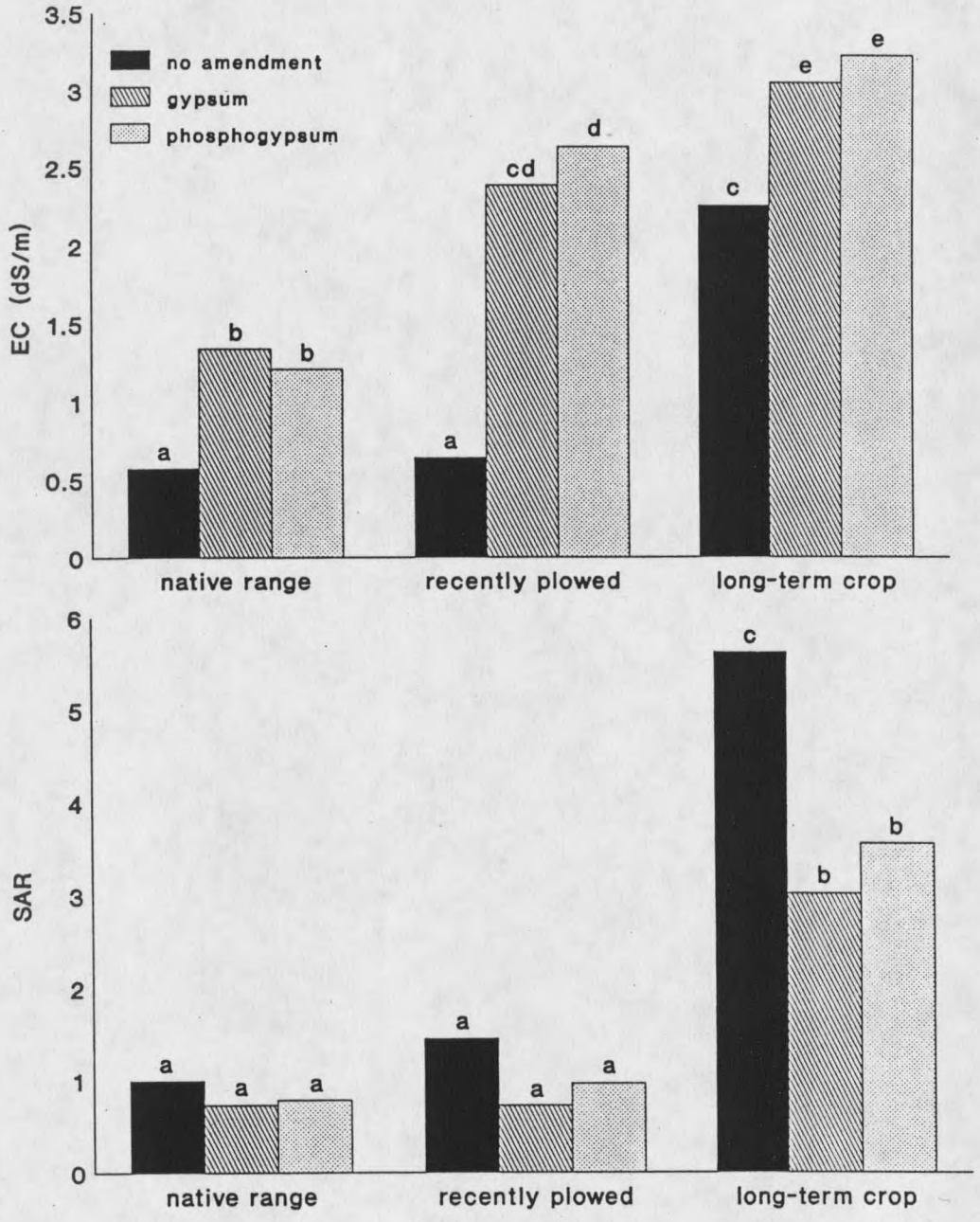


Figure 14. Amendment by land use effects on post-experiment EC and SAR in the greenhouse column study. Values averaged across soil and depth. Significant differences shown by letters corresponding to LSD; alpha < 0.05.

Leachate Characterization

Leachate from four pre-cropped wetting periods (referred to as pre-leachate periods 1, 3, 5, 7) and four crop periods (referred to as crop-leachate periods 2, 4, 6, 8) was analyzed. Electrical conductivity, pH, and SAR of the leachate from the crop periods were nearly the same as the EC, pH, and SAR of the leachate from the pre-crop periods for each treatment. Therefore, the leachate data from the pre-crop and crop periods were combined into one discussion. Analysis of variance of the data from the pre-leachate and crop-leachate collection periods indicated significant differences in EC, pH, and SAR due to all main treatments (Figures 15, 16, 17, 18, 19, and 20). Electrical conductivity increased and SAR decreased due to all main treatments with each subsequent leaching. The pH initially increased and then decreased during pre-crop leaching, and then decreased with each subsequent leaching during the cropping period.

Drainage water from the Gerdrum soil had greater ECs than drainage water from Creed soil (Figures 15 and 16). Differences in leachate EC as a result of land use practice were significant. Leachate EC increased from native range to recently plowed to long-term crop (Figures 15 and 16). Leachate collected prior to cropping and during cropping of columns treated with gypsum or phosphogypsum had similar ECs, which were significantly greater than the EC of

leachate collected from the control treatments (Figures 15 and 16). The effects of the amendments on leachate salinity are a function of salts present in gypsum or phosphogypsum and the subsequent effect of the amendment on soil chemistry. Calcium, supplied by the amendments, replaced Na on the soil exchange sites, causing an increase in the salt concentration of leachate.

Leachate from Gerdrum soil columns had significantly greater pH than leachate from Creed soil columns (Figures 17 and 18). In addition, pH of the leachate from the columns with long-term cropping was significantly greater than the pH of leachate from the native range or recently plowed columns for pre-leachates 3, 5, and 7, and the fourth leachate sample during cropping. There was no difference in pH of leachate from the native range or recently plowed treatments (Figures 17 and 18). Leachate pH was generally similar for gypsum and phosphogypsum amended columns with the exception of pre-leachate 3 and 5. Amendment application consistently decreased pH of pre-cropped leachate and leachate collected during cropping (Figures 17 and 18). Sodium adsorption ratio of the leachate from the Gerdrum soil was significantly greater than the SAR of the leachate from the Creed soil. This difference in SAR was consistent with findings of the field study and was most likely a reflection of the pre-experiment levels (Figures 19 and 20). Sodium adsorption ratio of the leachate from the

long-term crop columns was greater than the SAR of leachate from the native range or recently plowed treatments. Native range and recently plowed treatments were similar, although the recently plowed treatments were numerically greater (Figures 19 and 20). Long-term cropping/cultivation of these soils may have promoted more efficient preferential movement of Na, evidenced by increased SARs. This is also supported by leaching fraction data (Appendix A).

Differences in SAR as a result of amendment application were not present in the pre-crop leachate. Sodium adsorption ratios of leachate from the control columns and columns treated with phosphogypsum were similar to each other and were both greater than the SAR of leachate of columns treated with gypsum (Figures 19 and 20).

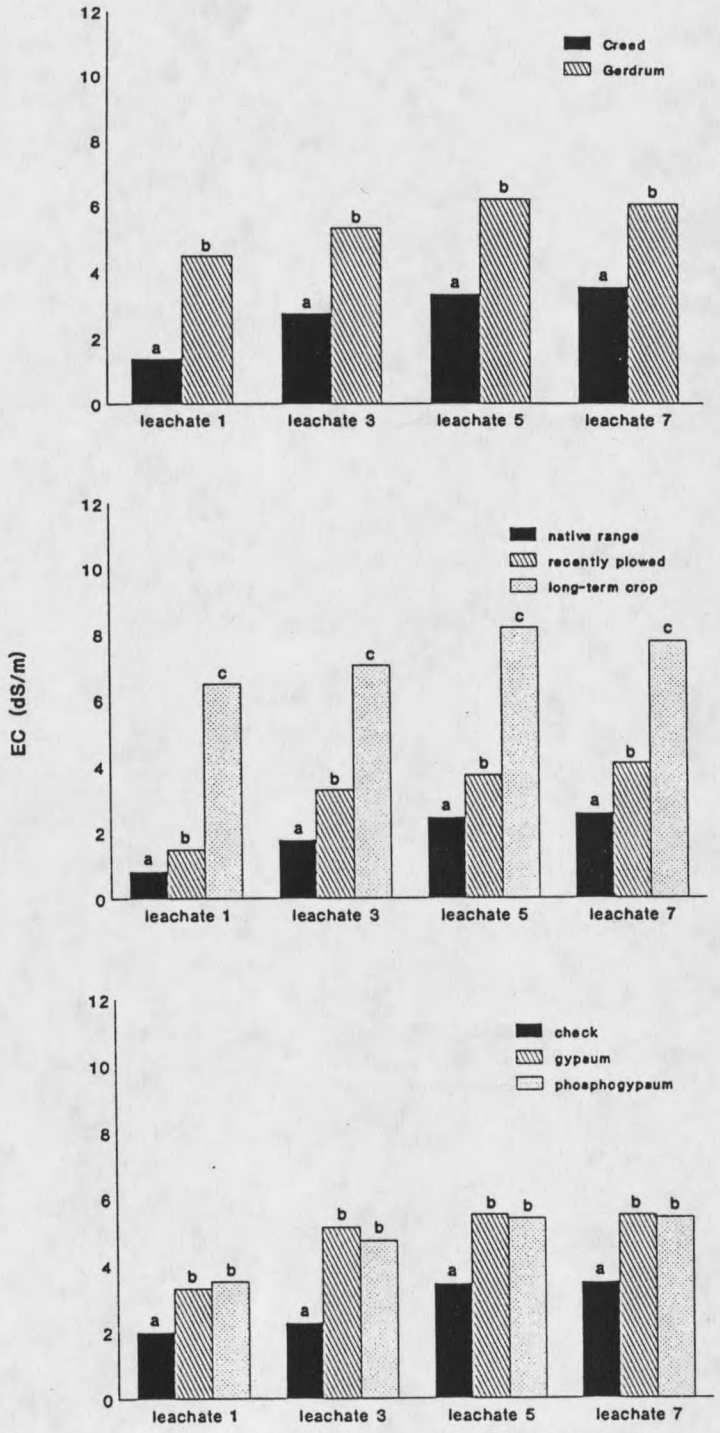


Figure 15. Effect of soil series, land use, and amendment on pre-leachate EC; values averaged over interactions. Significant differences for each leachate shown by letters corresponding to LSD; alpha < 0.05.

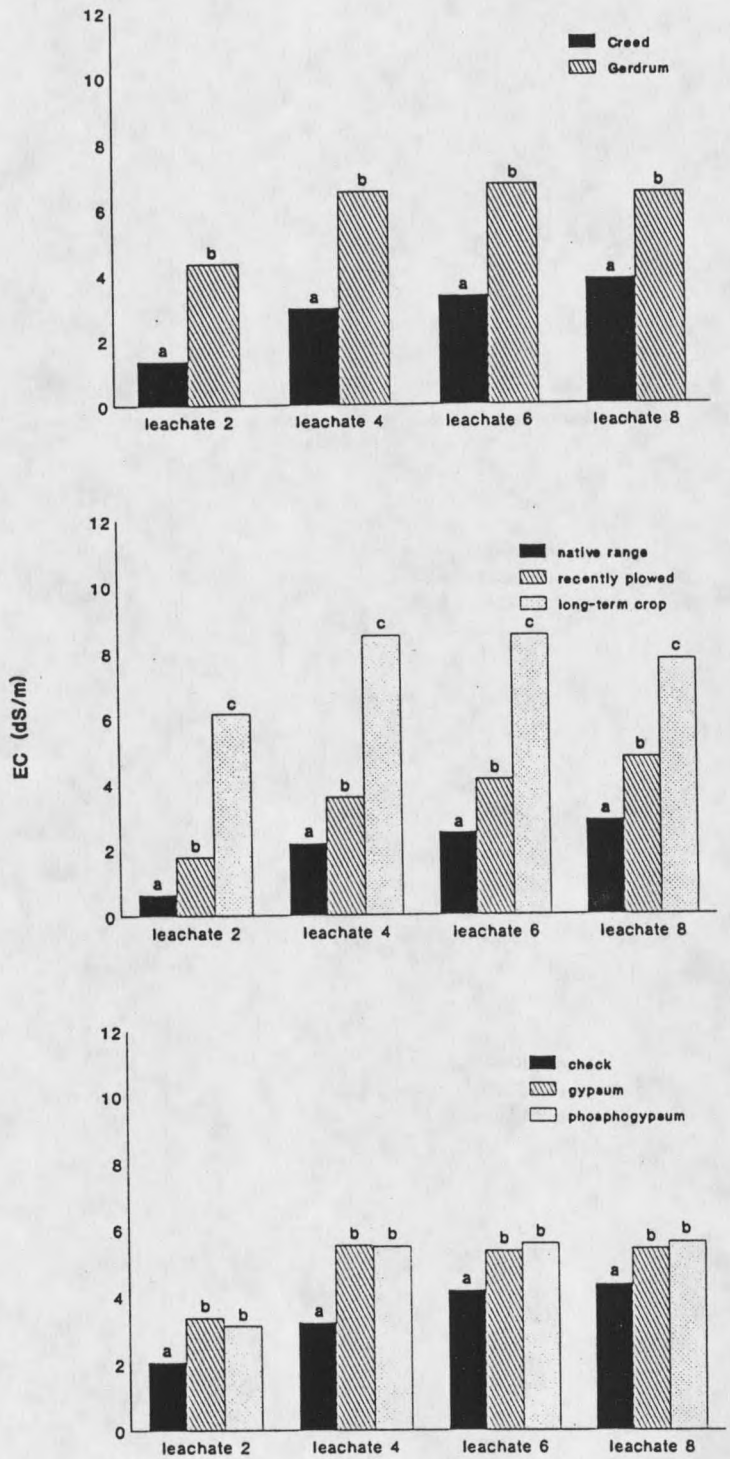


Figure 16. Effect of soil series, land use, and amendment on crop-leachate EC; values averaged over interactions. Significant differences for each leachate shown by letters corresponding to LSD; alpha < 0.05.

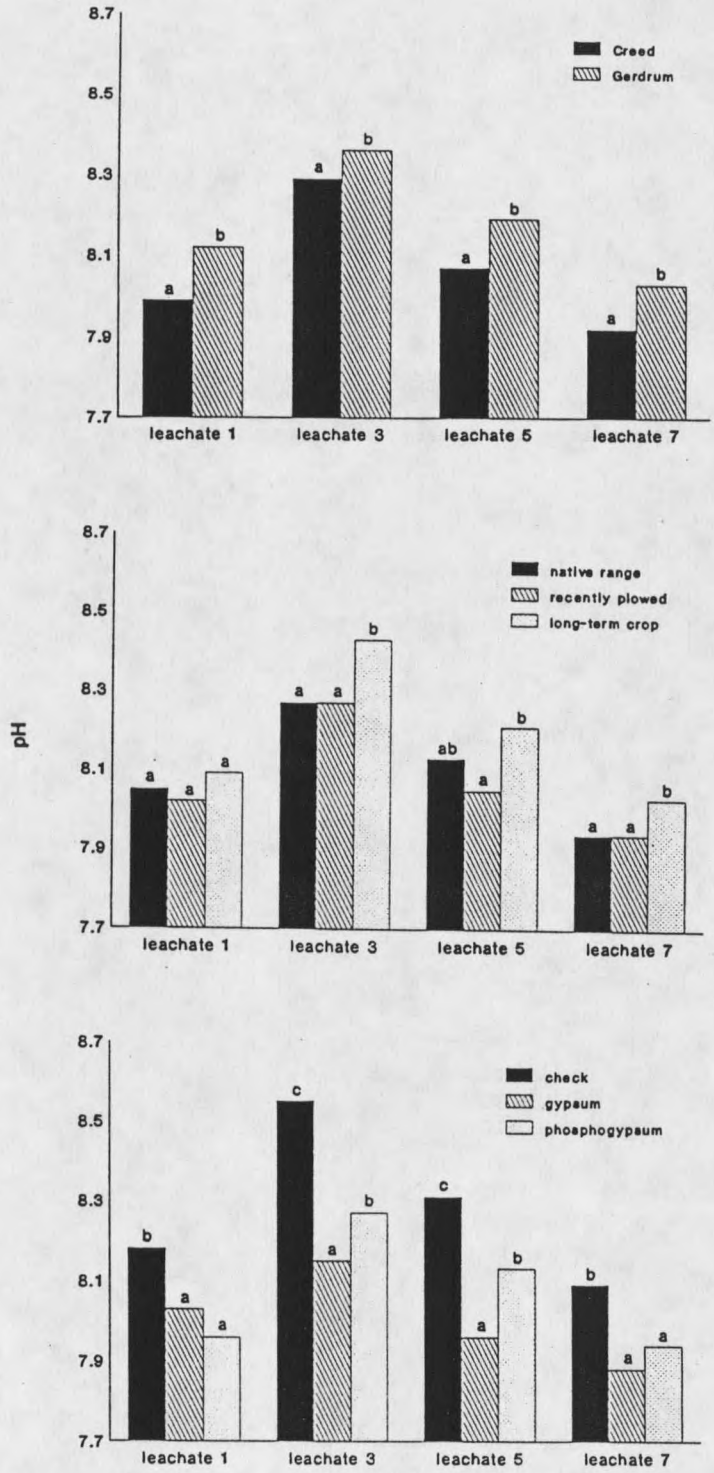


Figure 17. Effect of soil series, land use, and amendment on pre-leachate pH; values averaged over interactions. Significant differences for each leachate shown by letters corresponding to LSD; alpha < 0.05.

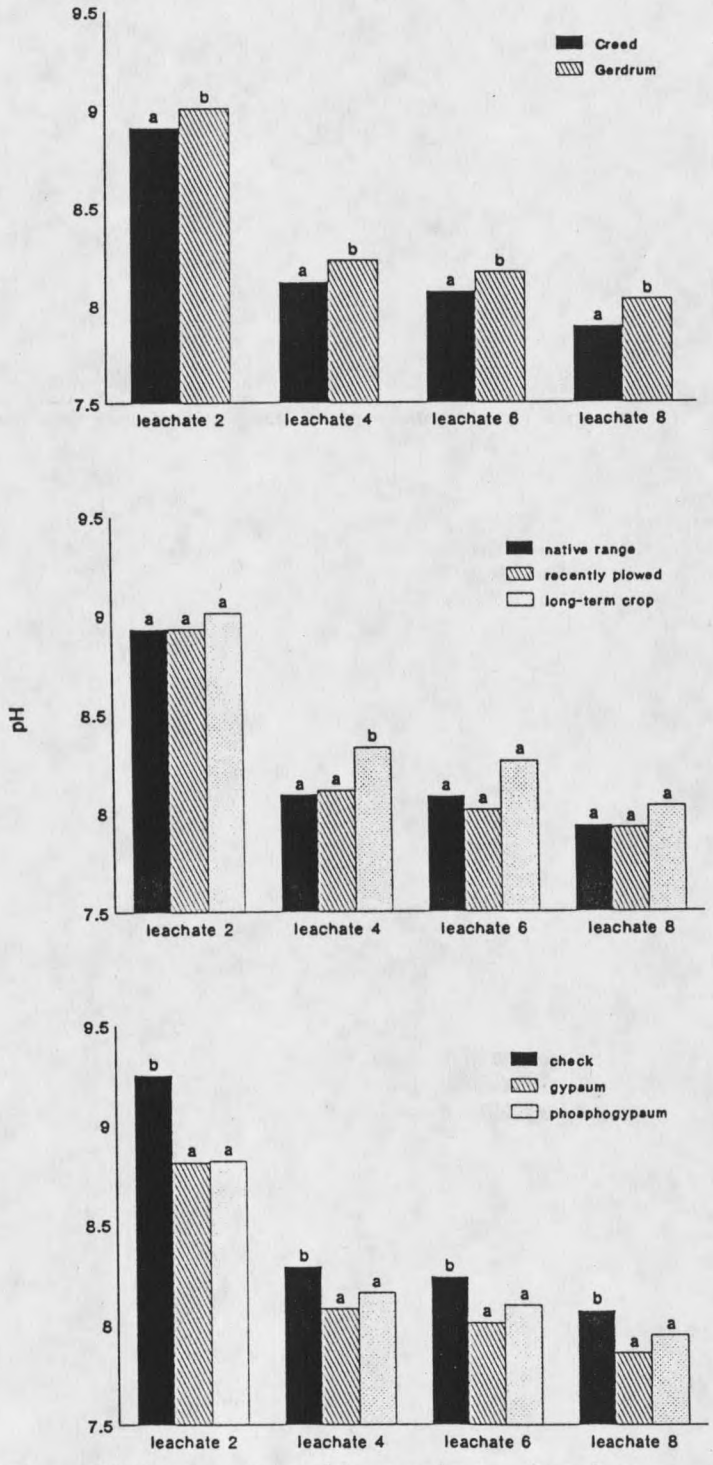


Figure 18. Effect of soil series, land use, and amendment on crop-leachate pH; values averaged over interactions. Significant differences for each leachate shown by letters corresponding to LSD; alpha < 0.05.

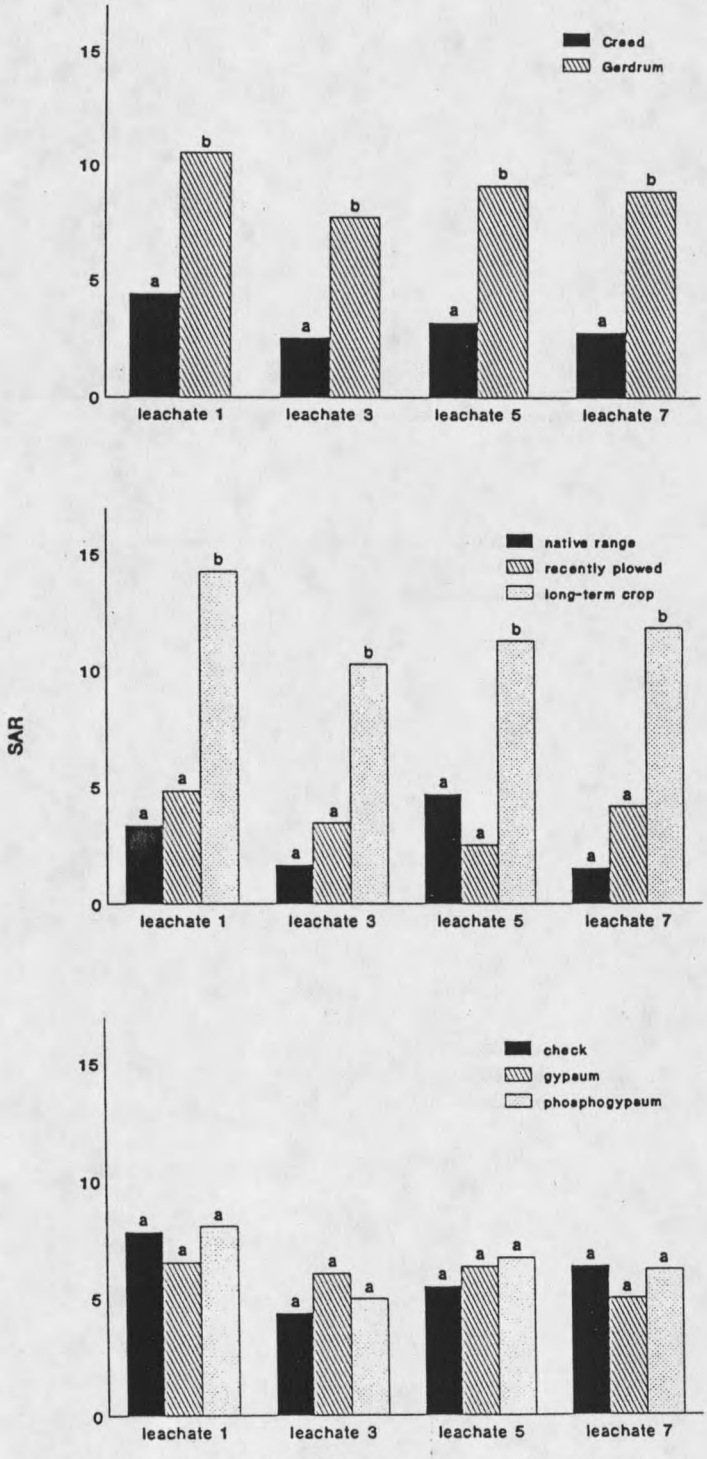


Figure 19. Effect of soil series, land use, and amendment on pre-leachate SAR; values averaged over interactions. Significant differences for each leachate shown by letters corresponding to LSD; alpha < 0.05.

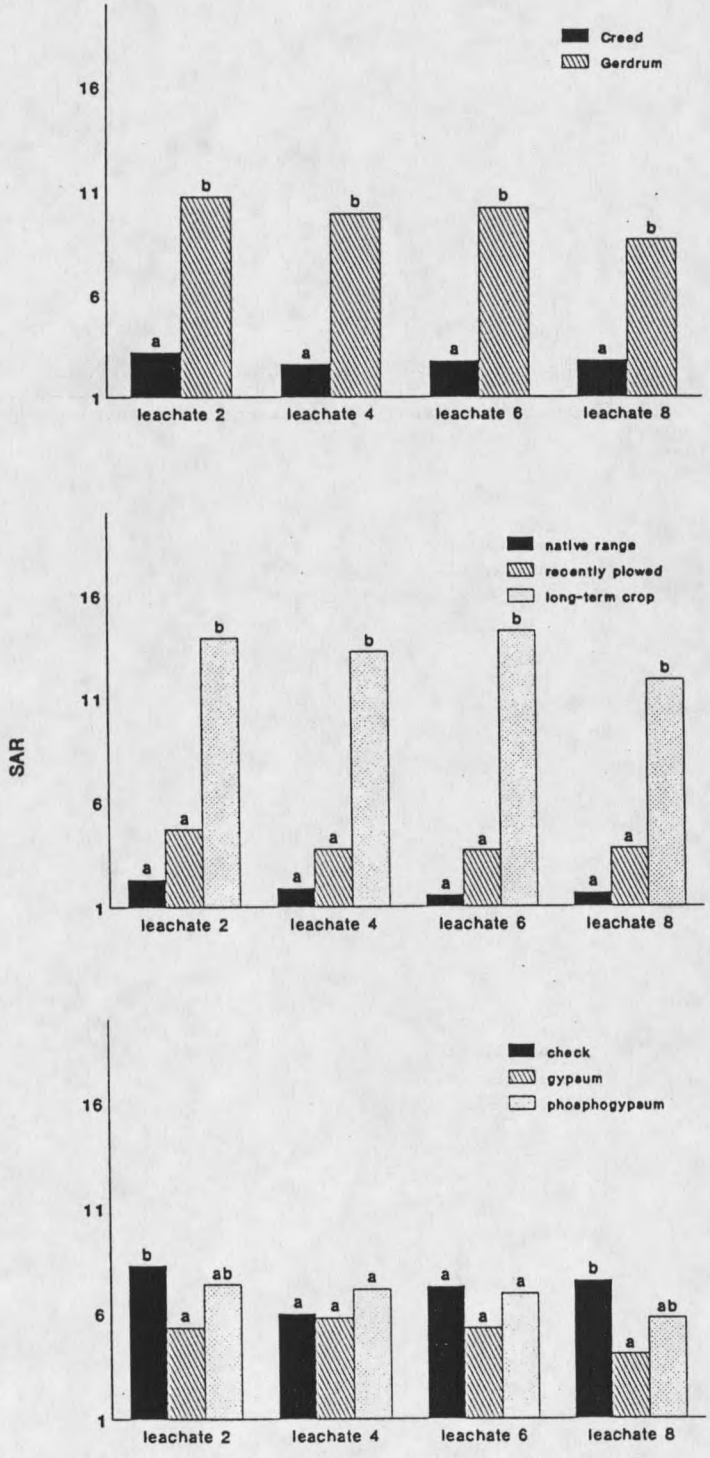


Figure 20. Effect of soil series, land use, and amendment on crop-leachate SAR; values averaged over interactions. Significant differences for each leachate shown by letters corresponding to LSD; alpha < 0.05.

Interactions for Leachate Characterization

Electrical conductivity and SAR of leachate from all collection periods differed significantly among land use practices, suggesting that land use practices can have an effect on the chemical and hydraulic properties of soils and their subsequent characteristics. Effect of land use on leachate EC and SAR was evident for both soils, although differences in EC and SAR among land use treatments were greater for the Gerdrum soils than for the Creed soils (Table 5 and 6). The EC and SAR of drainage water increased significantly as cultivation intensity increased.

Cropping practice and cultivation influenced the chemistry of each soil, but the effect was more evident for the Gerdrum soil. Leachate pH levels did not differ significantly among land uses (data not shown).

Table 5. Leachate EC for all soil by land use combinations.

Collection period	Native range	Recently plowed	Long-term crop
		EC (dS m^{-1})	
		Creed	
1	0.81 a[+]	1.33 abc	2.00 c
2	0.56 a	1.53 ab	1.96 b
3	1.61 a	3.12 b	3.51 b
4	2.04 a	3.45 b	3.39 b
5	2.31 a	3.47 b	4.24 b
6	2.49 a	3.86 b	3.64 b
7	2.56 a	3.79 b	4.28 b
8	2.69 a	4.66 b	4.12 b
		Gerdrum	
1	0.85 ab	1.62 bc	10.96 d
2	0.69 a	2.00 b	10.32 c
3	1.94 a	3.43 b	10.59 c
4	2.30 a	3.70 b	13.61 c
5	2.57 a	3.97 b	12.10 c
6	2.47 a	4.36 b	13.39 c
7	2.55 a	4.36 b	11.21 c
8	3.04 a	4.92 b	11.44 c

[+]Letters indicate mean comparison for land use at the 0.05 level according to LSD test.

Table 6. Leachate SAR for all soil by land use combinations.

Collection period	Native range	Recently plowed	Long-term crop
		SAR (mmol $L^{-1})^{-1/2}$	
		Creed	
1	2.1 a[+]	1.7 a	9.4 c
2	0.8 a	0.6 a	8.1 b
3	0.7 a	0.8 a	6.1 b
4	0.7 a	0.8 a	6.3 c
5	1.2 a	2.8 ab	5.7 bc
6	0.9 a	0.8 a	6.6 b
7	0.7 a	0.9 a	6.7 b
8	1.1 a	0.8 a	6.4 b
		Gerdrum	
1	4.7 ab	7.9 bc	19.1 d
2	3.8 a	8.7 b	19.7 c
3	2.6 a	6.1 b	14.4 c
4	3.1 b	6.6 c	20.1 d
5	8.2 c	2.3 ab	16.9 d
6	2.2 a	6.5 b	21.9 c
7	2.3 a	7.4 b	16.9 c
8	2.2 a	6.7 b	17.3 c

[+]Letters indicate mean comparison for land use at the 0.05 level according to LSD test.

The soil by amendment interaction caused significant differences in EC of the leachate obtained during the last three collection periods (Table 7). However, leachate pH and SAR levels were not significantly different due to the soil by amendment interaction (data not shown). Effect of amendment on leachate EC was evident for both soils. The EC

of leachate from gypsum and phosphogypsum-amended columns of Creed soil was greater than the EC of leachate from columns which were not amended for collection periods 6, 7, and, 8 and Gerdrum collection period 7. There appeared to be little difference in leachate characteristics between gypsum and phosphogypsum treatments. Amendments began to elevate the salt concentration of the leachate during the later part of the experiment, especially for the Creed soil.

The land use by amendment interaction had a significant effect on EC of leachate during all but the first two collection periods (Table 8). Leachate pH and SAR were not affected by the land use by amendment interaction (data not shown). Electrical conductivity of leachate from gypsum and phosphogypsum-amended columns was greater than from the control columns. Differences in quality of leachate from the gypsum and phosphogypsum treatments were generally nonsignificant.

Addition of amendments elevated the salt concentration of the leachate. Electrical conductivity of the leachate increased with each successive irrigation. The semi-arid field conditions of these soils most likely resulted in net upward water movement and salt accumulation in the profile. The irrigation events of the greenhouse study reversed this process forcing water movement downward, thus increasing leachate EC.

Table 7. Leachate EC for all soil by amendment combinations.

Collection period	Check	Gypsum	Phosphogypsum
		EC (dS m^{-1})	
		Creed	
1	0.46	1.69	1.99
2	0.44	1.53	2.08
3	0.93	3.63	3.68
4	1.21	3.75	3.93
5	1.63	4.21	4.18
6	1.61 a[+]	4.19 b	4.20 b
7	1.84 a	4.47 cb	4.31 b
8	2.46 a	4.60 b	4.40 b
		Gerdrum	
1	3.52	4.88	5.02
2	3.67	5.18	4.16
3	3.60	6.61	5.75
4	5.21	7.31	7.07
5	5.23	6.80	6.61
6	6.73 c	6.52 c	6.98 c
7	5.08 c	6.52 d	6.51 d
8	6.28 c	6.26 c	6.86 c

[+]Letters indicate mean comparison for amendment at the 0.05 level according to LSD test.

Table 8. Leachate EC for all land use by amendment combinations.

Collection period	Check	Gypsum	Phosphogypsum
		EC (dS m^{-1})	
		Native range	
1	0.33	1.10	1.05
2	0.33	0.77	0.78
3	0.73 a[+]	2.42 b	2.17 b
4	1.16 a	2.73 b	2.63 b
5	1.53 a	3.01 b	2.79 b
6	1.63 a	2.97 b	2.85 b
7	1.56 a	3.16 b	2.93 b
8	1.99 a	3.62 b	2.99 ab
		Recently plowed	
1	0.47	1.77	2.19
2	0.92	1.99	2.37
3	1.07 a	4.21 c	4.54 c
4	1.33 a	4.47 c	4.93 c
5	1.48 a	4.57 c	5.11 c
6	2.01 ab	5.02 c	5.31 c
7	2.05 a	4.92 c	5.25 c
8	3.30 b	5.41 c	5.67 c
		Long-term crop	
1	5.17	6.99	7.29
2	4.92	7.30	6.21
3	4.99 c	8.73 e	7.44 d
4	7.15 d	9.41 e	8.95 e
5	7.28 d	8.95 e	8.28 ed
6	8.88 d	8.07 d	8.60 d
7	6.77 d	8.42 e	8.05 e
8	7.84 d	7.27 d	8.23 d

[+]Letters indicate mean comparison for amendment at the 0.05 level according to LSD test.

Crop Performance

Four spring wheat crops were grown during the study to simulate four periods of cropping and tillage operations, in addition to pre-study column conditions. Cropping duration ranged from 1 to 4 successive crops for recently plowed and 5 to 9 successive crops for long-term crop land use. Spring wheat yield during the study validated previously reported field observations that different soils responded differently to disturbance and tillage.

Crop yield data for each period, analyzed as a split-plot in time ANOVA, indicated no difference in yield over time; analysis of cumulative yield values provided similar results. Therefore, cumulative yield data were used to complete statistical analysis (Table 9).

Dry matter yield on the Creed soil columns was significantly greater than dry matter yield on the Gerdrum soil (Table 9). These data suggest that the Creed soil tends to be more suitable for sustained plant growth than the Gerdrum soil. Electrical conductivity and SAR of soil saturated paste extracts indicate much greater osmotic stress in the Gerdrum soil than the Creed soil; this difference may account for the observed productivity differences. However, soil conditions improved as the cumulative cropping frequency increased. The initial chemical and physical properties of the Creed soil suggested a better environment for crop growth.

Dry matter yield differed significantly among land use practices (Table 9). Long-term cultivation of these soils improved their productive capability, as evidenced by greater dry matter production for the long-term crop land use than either for the native range or the recently plowed land uses. There were no significant differences in yield between native range and recently-plowed treatments.

Apparently, cultivation improves soil structure, enhancing infiltration and therefore, increasing leaching of salts. Dry matter yield did not differ significantly between the check (no amendment) columns and columns amended with gypsum.

The columns amended with phosphogypsum produced significantly greater spring wheat dry matter yields than columns amended with gypsum or the control columns (Table 9).

Although phosphogypsum has a higher dissolution rate than gypsum, it is unlikely that increased phosphorus availability in the columns amended with phosphogypsum contributed to the observed yield difference. Furthermore, the lack of significant differences in leachate quality implies little difference in the degree to which phosphogypsum dissolved compared to gypsum dissolution.

Table 9. Effect of soil type, land use, and amendment on dry matter yield.

Parameters	Dry matter g column^{-1}
Soil	
Creed	33.7 b[+]
Gerdrum	30.1 a
Land use	
Native range (check)	29.7 a
Recently plowed	31.6 a
Long-term crop	34.3 b
Amendment	
No amendment (check)	31.6 a
Gypsum	30.3 a
Phosphogypsum	33.8 b

[+]Letters indicate means comparisons at the 0.05 level according to LSD test. Values averaged across land use and amendment for soil; soil and amendment for land use; soil and land use for amendment.

Interactions for Crop Performance

The effect of land use on crop performance was most evident in columns containing Gerdrum soil. These columns responded positively to increased intensity of land use, compared to the Creed soil (Figure 21). The increased plant growth response was associated with a decrease in EC and SAR for the Gerdrum soil after cultivation. Dry matter yield did not differ significantly among the various land use treatments of the Creed soil.

Native range columns amended with gypsum or phosphogypsum had significantly higher yields than the check (no amendment) columns. Dry matter yields from gypsum-amended columns were significantly lower than dry matter yields from the non-amendment and/or phosphogypsum-amended columns for the recently plowed and long-term crop uses. The reason for this decline is not clear.

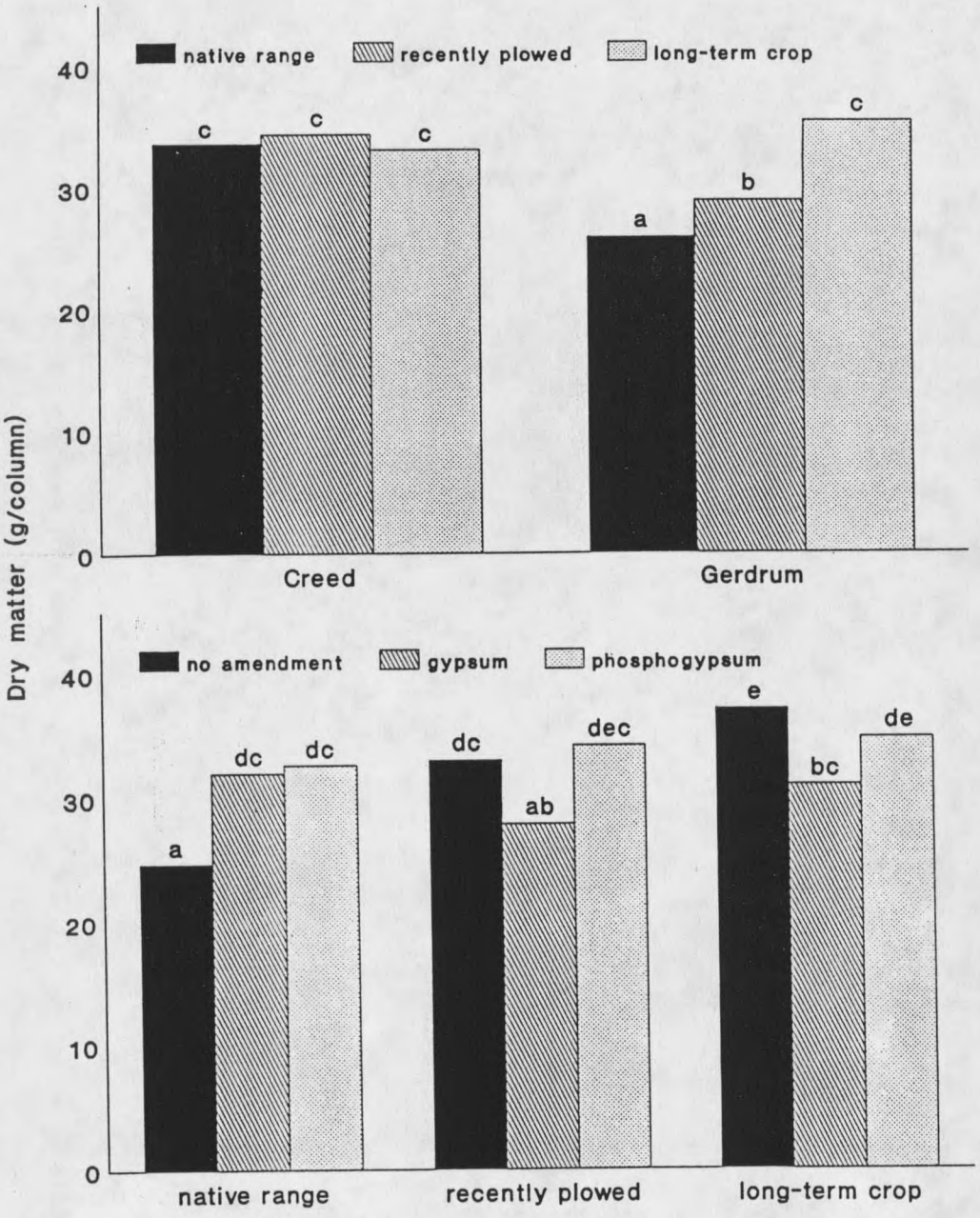


Figure 21. Land use by soil effects on dry matter yield; values averaged across amendment (top). Amendment by land use effects on dry matter yield; values averaged across soil (bottom). Significant differences shown by letters corresponding to LSD; alpha < 0.05.

SUMMARY AND CONCLUSIONS

Field and greenhouse studies were conducted to study the effect of cropping/cultivation and soil amendment application to two Natrargids on soil properties and spring wheat performance. Differences in chemical (pH, EC, SAR) and physical (SAT) properties and crop yield were observed between soils, and as a result of land use treatment and amendment additions. Comparisons of pre-experiment and post-experiment characteristics of Natrargids and leachate data suggest four periods of simulated cropping during the greenhouse study were not sufficient to create conditions similar to the field characterization study.

Although current SCS soil survey information indicates similarity in the two soils studied, our characterization from a limited number of sites provides evidence in a range of characteristics that influence spring wheat performance. Both studies indicate that under native range conditions the Creed soil is relatively better drained than the Gerdrum soil and has not accumulated appreciable amounts of salts. Consequently, the chemistry of the Creed soil is not detrimental enough to restrict yield even though soil and leachate data indicate EC and SAR of the Creed soil tend to increase following plowout of native range. The Creed soil initially has greater crop production potential.

Conversely, the Gerdrum soil under field conditions has accumulated more Na salts than the Creed soil, as evidenced by greater EC and SAR levels. These accumulations are most likely due to poor drainage or upward migration of sodium salts. This latter process of Natrargid formation was previously reported by Munn et al., 1983. The EC and SAR levels of the Gerdrum soil under native range conditions are sufficiently high enough to limit crop productivity based on our crop performance data. The limitations in yield are probably the cumulative result of osmotic stress, poor infiltration, salinity, and potential Na toxicity. When the Gerdrum soil is cropped/cultivated, soluble salts are leached from the profile and productivity improves. Cultivation can influence the physical and chemical characteristics and consequently soil productivity.

Amendments can also play a role in improving productivity on these Natrargids. When amendments were added to these soils, SARs decreased and drainage improved. An increase in ECs occurred as a result of amendment application, but based on crop performance data, the increase in EC was not detrimental to yield. It appeared that phosphogypsum had an overall positive effect on crop performance, in contrast to the gypsum application. Amendment application improved soil productivity when the soil was utilized as native range. The same effect was not observed on recently plowed or long-term land use. Presently, under field conditions of the study, the Creed

and Gerdrum soil SAR levels are not sufficiently high enough to warrant amendment application.

Productivity of each of the soils should improve with cultivation, provided no other factors necessary for plant growth are limiting. However, in the event that EC and SAR levels reach critical levels, productivity may eventually be impaired. Leaching of salts probably occurred at an accelerated rate during the greenhouse study, due to the addition of irrigation water in amounts exceeding soil water storage capacity. A similar effect may be present in the field under the crop fallow system where leaching occurs during the fallow period.

Maintaining adequate drainage through leaching of salts and amendment application improved soil productivity. Efforts should be aimed at improving drainage with the least leaching and amendment application while maintaining satisfactory plant growth. This would minimize degradation of the groundwater resource as a result of elevated EC and SAR levels of drainage water.

More field and greenhouse studies from numerous sites would be required to fully characterize the impact of cultivation on these Natrargids in southeastern Montana.

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APPENDIX

LEACHING FRACTION FOR MAIN EFFECTS

Table 10. Leaching fraction (LF) comparisons for main effects at all leachates.

Parameters	LF (%)							
Leachate	1	2	3	4	5	6	7	8
Soil								
Creed	.37 a+	.07 a	.49 a	.13 a	.10 a	.16 a	.25 a	.20 b
Gerdrum	.38 a	.07 a	.47 a	.12 a	.16 b	.16 a	.30 b	.14 a
Land Use								
Native range	.41 b	.09 c	.49 b	.18 b	.17 b	.25 b	.33 b	.20 b
Recently plowed	.37 ab	.07 b	.61 c	.11 a	.40 a	.11 a	.17 a	.14 a
Long-term crop	.35 a	.04 a	.33 a	.09 a	.18 b	.11 a	.33 b	.17 ab
Amendment								
Check	.36 a	.05 a	.36 a	.11 a	.11 a	.14 a	.29 ab	.14 a
Gypsum	.37 a	.08 b	.55 b	.15 b	.14 a	.18 b	.29 b	.20 b
Phosphogypsum	.40 a	.06 a	.52 b	.12 a	.13 a	.15 a	.24 a	.17 ab

+Letters indicate mean comparisons at the 0.05 level according to LSD test for pre-leachate and crop-leachate values.

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