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

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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Bozeman, Montana

April 1994

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

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4/21/94 — Date

Head, Major Department

Approved for the College of Graduate Studies

5/12/94 — Date

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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 ($CaSO_4 \cdot 2H_2O$) 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% $CaSO_4 \cdot 2H_2O$), 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.

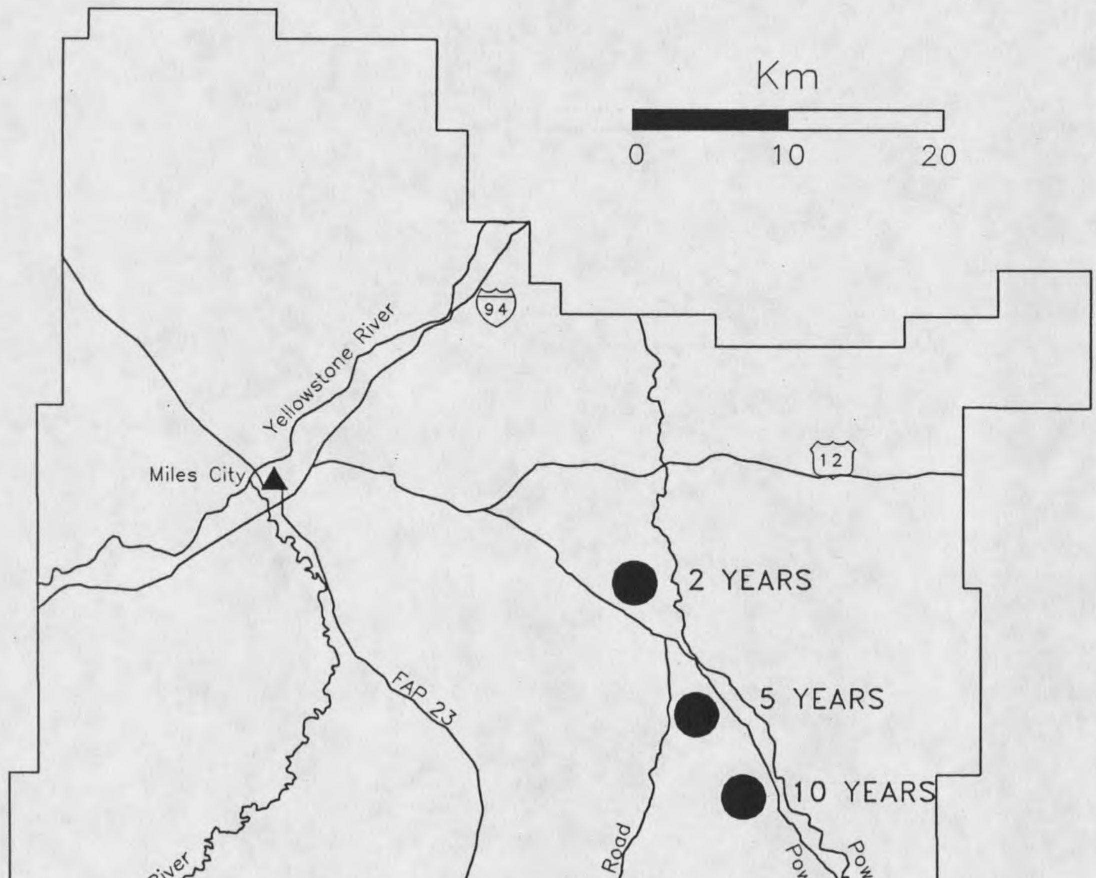

Figure 1. Map of sample sites in Custer County, Montana. Dotted areas designate approximate locations of field sample sites.

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).