SSSAJ Soil Science Society of America Journal

QUICK SEARCH: [advanced]
Author: Keyword(s):
Go
Year: Vol: Page:

HOME HELP FEEDBACK SUBSCRIPTIONS ARCHIVE SEARCH TABLE OF CONTENTS

Institution: MSU Bozeman Sign In as Member/Individual (Non-Member)

Soil Science Society of America Journal 65:199-204 (2001)
© 2001 Soil Science Society of America

This Article

- **Abstract FREE**
- **Figures Only**
- **Full Text (PDF)**
- **Alert me when this article is cited**
- **Alert me if a correction is posted**

Services

- **Similar articles in this journal**
- **Similar articles in ISI Web of Science**
- **Alert me to new issues of the journal**
- **Download to citation manager**
- **Cited by other online articles**
- **Search for citing articles in:** **ISI Web of Science (4)**

PubMed

- **Articles by Mace, J.E.**
- **Articles by Amrhein, C.**

Agricola

- **Articles by Mace, J.E.**
- **Articles by Amrhein, C.**

DIVISION S-6-SOIL & WATER MANAGEMENT & CONSERVATION

Leaching and Reclamation of a Soil Irrigated with Moderate SAR Waters

J.E. Mace and C. Amrhein

Dep. of Environmental Sciences, Graduate Program in Soil and Water Sciences, Univ. of California, Riverside, CA

Corresponding author (chrisa@mail.ucr.edu)

ABSTRACT

Irrigation with blended drainage water can damage soil structure, impair infiltration, and increase runoff and erosion. This loss of permeability is often attributed to the slaking of aggregates and clay dispersion, which leads to pore plugging. Soil swelling is usually considered an important factor only when exchangeable sodium percentages (ESP) exceed 15%. We hypothesized that swelling is more important than generally recognized in reducing soil hydraulic conductivity (HC), and swelling can occur at low ESP. In this study we attempted to identify the mechanisms reducing HC and the reversibility of the processes during gypsum and sulfuric acid application. Synthetic drainage waters with sodium adsorption ratios (SAR) of 1, 3, 5, and 8 and electrolyte concentrations (C) of 0, 2.5, 5, 10, 25, 50, and 100 $\mathrm{mmol_c\ L^{-1}}$, were leached through machine-packed soil columns to evaluate the effects of clay dispersion and swelling on HC. Following the initial leachings, the soils were amended with surface applied gypsum and H_2SO_4, and leached with deionized water. Clay concentration in the leachate was used as a measure of clay dispersion, and internal soil swelling was assumed to be proportional to changes in the water holding capacity at -22 kPa tension. Internal soil swelling at low electrolyte concentrations (<12 $\mathrm{mmol_c\ L^{-1}}$) reduced the number of large, free-draining pores and increased the water holding capacity of the soil at low tension. This loss in HC, which occurred at all SAR, was largely reversible with surface-applied gypsum. At SAR 5 and 8, there was irreversible plugging of soil pores by dispersed clay, as well as internal swelling. These findings suggest that even diluted drainage waters used for irrigation will have an adverse effect on soil structure, especially during rainfall.

Abbreviations: C, electrolyte concentration • CEC, cation exchange capacity • EC, electrical conductivity • ESP, changeable sodium percentages • hydraulic conductivity, HC • hydraulic conductivity • SAR, sodium adsorption ratios

INTRODUCTION

IN MANY IRRIGATED AREAS of the world there may not be an adequate supply of good quality irrigation water, or the cost of water is high enough that growers look for alternatives such as shallow groundwater or agricultural drainage water. Often, this drainage water is of poor quality and may be blended with good quality water before irrigating to decrease the amount of crop and soil damage.

Many studies have evaluated the effects of irrigation water composition and C on clay dispersion and the subsequent HC of soils (e.g., Quirk and Schofield, 1955; McNeal et al., 1968; Frenkel et al., 1978; Shainberg et al., 1981; Abu-Sharar et al., 1987; Yousaf et al., 1987; Curtin et al., 1994). Typically, the greater the SAR, the greater the potential for aggregate slaking, soil swelling, and clay dispersion, and thus a reduction in HC. The primary loss of HC in soils is generally attributed to aggregate slaking and clay dispersion, which lead to pore plugging (Sumner, 1993). Swelling is thought to be a concern only if the ESP is >15% (Shainberg, 1990; Sumner, 1993). The problem with this generalization is that large improvements to HC can be achieved in plugged soils by gypsum application or by increasing the electrolyte concentration of the applied water. This suggests that the process by which HC was originally lost is reversible and that swelling is more important than generally thought.

It has been well established that extensive degradation to soil structure can occur when irrigation waters have SAR values >13 (Shainberg and Letey, 1984). Not as much work has been done evaluating the effect of moderate SAR (< 8), particularly when combined with low C; however, many of the blended drainage waters that growers are using, or would like to use, have moderate SAR. A few years ago in the San Joaquin Valley of California, a shortage of high quality water from the reservoirs forced farmers to use blended water to finish off the irrigation season. This was followed by a short rainy season where low C water (rain) did not infiltrate and runoff occurred. The beneficial effects of leaching were lost and the soil water was not fully replenished.

We were interested in evaluating the effects of irrigation water of moderate SAR, particularly as combined with low C, to identify the mechanisms reducing HC and the reversibility of the process using surface-applied gypsum and H_2SO_4. As a reduction in HC can be associated with both clay dispersion and swelling, we quantified both processes for the soil we tested.

MATERIALS AND METHODS

The soil used in this study was surface sample (0–15 cm) of Milham clay loam (fine-loamy, mixed, superactive, thermic Typic Haplargid) from a pistachio orchard on the west side of the San Joaquin Valley, CA. The soil had a history of irrigation with California aqueduct water (EC 0.6 dS m^{-1} and SAR 3). The field soil forms many fine cracks (<1 mm) when dry and in general, has good permeability.The soil is not considered a shrink–swell soil. Slaking and slumping of aggregates during irrigation or rainfall were evident both in the field and in our column studies, suggesting that the formation of a washed-in layer during the first application of water could determine the initial HC. A local farm advisor considers this soil to be one of the finest agricultural soils in the San Joaquin Valley and the least prone to problems associated with poor quality irrigation water (Blake Sanden, personal communication, 1995).

The mineralogy of the clay fraction is dominated by smectite and the whole soil had a cation exchange capacity (CEC) of 24.6 ± 0.5 $cmol_c\ kg^{-1}$ using the Bower method of Na^+ saturation, followed by ethanol rinsing and extraction of the adsorbed Na^+ with NH^+_4 (U.S. Salinity Lab Staff, 1954).

The soil contained 9% by weight $CaCO_3$ equivalency as determined by the calcimeter method, which measures total pressure produced upon reaction of the soil with acid in a capped serum bottle (Loeppert and Suarez, 1996). Particle size analysis was done by the hydrometer method (Gee and Bauder, 1986) and gave 31% clay, 32% silt, and 37% sand.

Leaching studies were conducted on machine-packed soil columns, using waters ranging in SAR from 1 to 8, and C from 100 to 0 $mmol_c\ L^{-1}$. Five replicate columns were used for each SAR water tested. Soil columns were prepared using a motor-driven soil compactor, as described by Richard et al. (1965). Essentially, the procedure involved the following.

1. Air-dried soil was sieved to <2 mm.
2. The soil was then placed in a double-walled ceramic pot and allowed to slowly wet (from the walls inward) with Riverside tapwater (SAR ≈1, electrical conductivity (EC) = 0.6 dS m^{-1}).
3. Once the soil was near saturation, the top of the pot was covered to minimize evaporation, and a hanging water column was attached to pull -22 kPa suction on the soil water.
4. After 7 d of equilibration, 90 g of the moist soil (73 g dry weight) was scooped into a brass cylinder of 5-cm length and 5-cm diam.
5. The bottom of the column was covered with cotton gauze held in place with rubberbands.
6. Part of the motor-driven compactor, a spring-loaded holder, was clamped to the column (exerting a force on the top of the column).
7. Under the constant pressure of the spring-loaded holder, an eccentric raised and dropped the column 2 cm onto a hard surface ≈3 times per sec.

8. Each column was compacted for exactly 2 min. This mechanical packing procedure gave reproducible columns of uniform bulk density of 1.30 ± 0.05 g cm^{-3}. This soil has a similar bulk density in the field, although the variability is substantially higher.

We tested four SAR waters, SAR 1, 3, 5, and 8, using five columns for each SAR. We sequentially leached the columns with six different C for each SAR, going from high to low electrolyte (100, 50, 25, 10, 5, and 2.5 $mmol_c\ L^{-1}$). The different SAR and C waters were made using ratios of reagent grade NaCl, $CaCl_2$, $MgCl_2$, Na_2SO_4, $CaSO_4$, and $MgSO_4$, as needed. Bicarbonate was added at a constant 0.05 m*M* as $NaHCO_3$, to all of the waters. The Cl/SO_4 and Ca/Mg equivalent ratios were maintained at 1.5:1 in all of the waters. These ratios are typical of agricultural drainage waters in the western USA.

The columns were also leached with deionized H_2O following the 2.5 $mmol_c\ L^{-1}$ leachings. Between each leaching, the columns were placed in a pressure chamber and equilibrated to -22 kPa for ≈48 h. Upon leaving the pressure chamber, each column was promptly weighed. The weight of each column after being leached with 100 $mmol_c\ L^{-1}$ water was selected as representative of nonswelling. The net gain in weight for each column after leaching with each subsequent lower electrolyte water was assumed to be due to swelling, and calculated as a percent H_2O increase as compared with the quantity of H_2O in the nonswollen columns. Internal swelling of a soil causes a loss of large pore spaces and an increase in fine porosity. The large pore spaces, that readily drain under low tension, are converted to small pores that retain water. Thus, an increase in water retention is a measure of internal swelling and a loss of free-draining, large pores. This concept was originally applied to measure the swelling of soil clays on filter paper (McNeal et al., 1966).

The different waters were infiltrated into the columns using a constant head Mariotte bottle. The water was maintained at 1 cm above the soil surface. A computer program was written that interfaced two balances, one to measure the water entering the column, and one to measure the quantity of leachate. The columns were leached for precisely 10 min, during which time the computer recorded the simultaneous balance readings. After some experimentation, it was observed the infiltration rate typically changed <3% during the last 3 min of the leaching. We averaged six readings at 30-sec intervals during the last 3 min, and used these values to determine the HC using Darcy's Law.

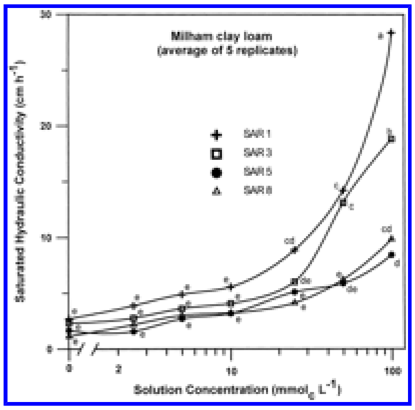
Dispersed clay in the column leachates was determined using a Malvern Zetasizer 3 (Malvern Instruments, Worcester, MA), in which the intensity of scattered laser light from the samples was compared with standards made from dispersed soil clay. To clay concentrations up to 150 mg L^{-1}, the standards produced a linear r^2 value >0.99. Samples were diluted as necessary to achieve this range of clay concentration.

After the deionized water leaching, the columns were amended with a top dressing equal to 5 Mg ha^{-1} gypsum, or equivalent H_2SO_4 (3 Mg ha^{-1}). Reagent grade, powdered gypsum (0.98 g per column) and H_2SO_4, diluted to 0.1g mL^{-1} (5.9 mL per column) were applied without disturbing the surface of the soil. The amount of gypsum and acid exceeded the gypsum requirement to remove exchangeable sodium by more than eight times to ensure full reclamation. The amended columns were leached with deionized water for five sequential, 10-min periods with equilibration to -22 kPa after each leaching.

RESULTS AND DISCUSSION

▲ TOP
▲ ABSTRACT
▲ INTRODUCTION
▲ MATERIALS AND METHODS
▪ RESULTS AND DISCUSSION
▼ CONCLUSIONS
▼ REFERENCES

The hyraulic conductivity of the columns decreased as a function of increasing SAR and decreasing electrolyte concentration (Fig. 1) . Data points with the same letter did not have significantly different ($P < 0.05$) HC values. In general, there was no significant difference in HC at total electrolyte concentrations below 25 $\text{mmol}_c\ L^{-1}$.

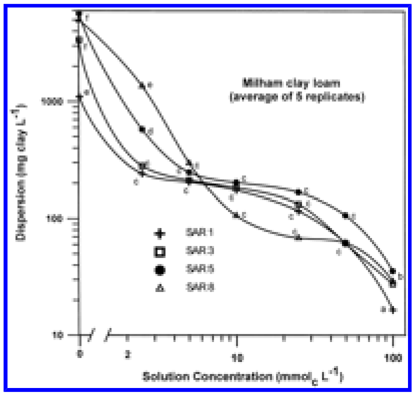


View larger version (27K):
[in this window]
[in a new window]

Fig. 1. Hydraulic conductivity as a function of SAR and electrolyte concentration. Statistically significant differences ($P < 0.05$) indicated by different letters

As the C of the waters was reduced, the cumulative quantity of dispersed clay in the leachate increased (Fig. 2) . In particular, the data in Fig. 2 show there was a significant increase in the quantity of dispersed clay when the applied water was below 5 $\text{mmol}_c\ L^{-1}$ and tended to increase in the order SAR 8 > 5 > 3 > 1.

Fig. 2. Dispersed clay in the leachates from the columns as a function of SAR and electrolyte concentration. Statistically significant differences ($P < 0.05$) indicated by different letters



View larger version (25K):
[in this window]
[in a new window]

The relative increase in swelling followed a similar trend as dispersed clay (Fig. 3) . In general, swelling increased as total electrolyte decreased and as SAR increased. Swelling is not often implicated as an important factor reducing HC, except in fine textured, smectitic soils at ESP >15 (Shainberg and Letey, 1984; Shainberg, 1990; Sumner, 1993). These data support the hypothesis that both internal swelling and clay dispersion occurred simultaneously in this soil. It is likely that internal swelling decreases pore size, particularly large pores, quickly reducing the saturated HC of the soil. A decrease in average pore size will also allow more dispersed clay and microaggregates to be trapped. Even though internal swelling (as measured by a change in water holding capacity at -22 kPa) was not of the same magnitude as found in high ESP systems (McNeal et al., 1966), we believe that it is important because Poiseuille's law states that the flow of water in a capillary pore is proportional to the fourth power of the radius of the pore (Jury et al., 1991). Therefore, small changes in the geometry of the large conducting pores can significantly decrease HC. These narrower pores will also be more likely to trap dispersed particles.

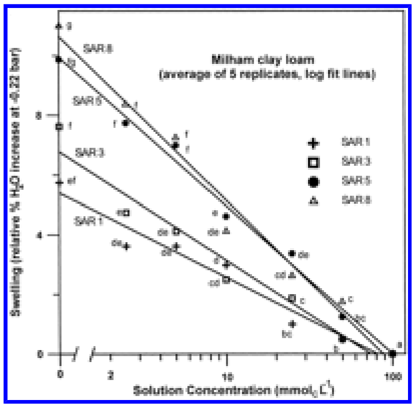


Fig. 3. Swelling as a function of SAR and electrolyte concentration. Statistically significant differences ($P < 0.05$) indicated by different letters

View larger version (31K):
[in this window]
[in a new window]

Figure 4 shows the dramatic increase in HC following the addition of gypsum to the undisturbed soil surface; however, this effect was short lived and the HC quickly decreased in subsequent leachings. This change in HC was correlated with the extent of internal swelling in the soil (Fig. 5) suggesting that this process, which is thought to be reversible, plays a major role in controlling the hydraulic properties of this soil. The changes in swelling and HC are attributed to an ionic strength effect. With each subsequent leaching, there was less gypsum and the C of the infiltrating water gradually decreased, and swelling increased. The soils originally leached with the higher SAR waters had the lowest HC values and the most internal swelling, even after reclamation. This suggests there was pore plugging by dispersed clay and slaked particles during the prereclamation leachings, and this loss of HC is thought to be largely irreversible (Sumner, 1993). Surprisingly, there was no dispersed clay in any of the leachates following the amendment addition. If narrow pores that had trapped dispersed particles were suddenly made larger by the higher ionic strength water, it seems possible that some clay should have been freed and found its way into the leachate. Even though dispersed clay occurred during the first leachings, the changes in HC following gypsum addition appeared to be mostly due to internal swelling.

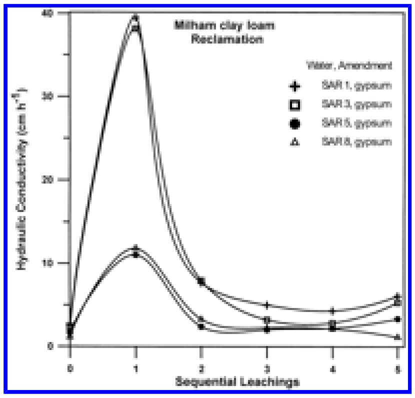


Fig. 4. Hydraulic conductivity of the soil following a surface application of gypsum (5 Mg ha^{-1} equivalent) and leached with deionized water

View larger version (27K):
[in this window]
[in a new window]

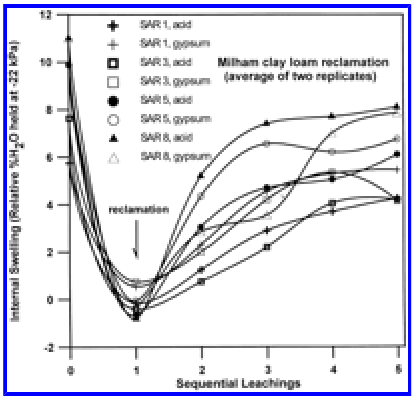


Fig. 5. Internal swelling of the soil following surface application of gypsum or H_2SO_4 and leached with deionized water. Internal swelling was measured by the amount of water held by the soil at -22 kPa relative to the amount of 100 mmol$_c$ L^{-1} solution held at the same tension

View larger version (39K):
[in this window]

[in a new window]

A mass balance of Na^+ shows that not all of the exchangeable sodium was removed during the reclamation step, even though excess amounts of gypsum and acid were applied (Table 1). The rapid infiltration immediately following the gypsum application allowed some of the Ca^{2+} to pass through the column unreacted. After five leachings (10 min each), 22 to 23% of the exchangeable sodium remained in the soils that had originally been leached with SAR 5 and 8 water. Thus, the swelling was somewhat greater in these soils even after reclamation.

View this table: Table 1. Sodium balance following reclamation with gypsum and sulfuric acid
[in this window]
[in a new window]

In the soils treated with H_2SO_4, the initial HC values were very low during the first leaching (Fig. 6) . We observed that when the acid was applied, the soil surface ballooned upward due to entrapped CO_2. This gas entrapment below the surface impaired the movement of leaching water, a phenomena also reported by others (Miyamoto et al., 1975a,b). After equilibration to -22 kPa in the pressure chamber, the CO_2 had dissipated from the soil and the remaining leachings had HC values slightly greater than the gypsum treatment. The acid was also somewhat more effective in removing exchangeable Na^+ compared with the gypsum (Table 1). This effect has been reported in earlier studies (Overstreet et al., 1951; Prather et al., 1978) and has been attributed to the formation of soluble Ca^{2+} at depth within the soil, which increases the efficiency of exchange.

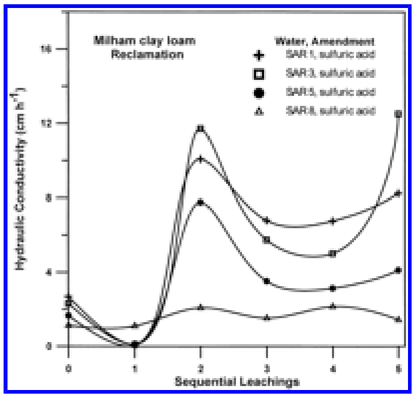


Fig. 6. Hydraulic conductivity of the soil following surface application of H_2SO_4 (3 Mg ha^{-1} equivalent) and leached with deionized water. The decrease in hydraulic conductivity immediately following acid application is attributed to a surface skin and trapped gas in the top of the soil

View larger version (27K):
[in this window]
[in a new window]

CONCLUSIONS

TOP
ABSTRACT
INTRODUCTION
MATERIALS AND METHODS
RESULTS AND DISCUSSION
CONCLUSIONS
REFERENCES

Separating the effects of slaking, swelling, and dispersion on HC presents a quandary. We base our conclusions on a comparison of the relative changes in swelling, dispersion, and HC. We believe that all three mechanisms occur in soils, each to varying degrees. Small amounts of internal swelling will narrow the pores and allow for more entrapment of slaked and dispersed particles. Internal swelling reduces the number of large, free-draining pores, which are mostly responsible for saturated water movement. The change in water holding capacity at -22 kPa was a good measure of this change in pore geometry. The dramatic increase in HC and the concurrent decrease in water holding capacity following surface-applied gypsum, is further evidence that swelling at low ionic strengths was an important mechanism in this soil. At SAR 5 and 8, reductions in HC could also be attributed to clay dispersion and pore plugging, although this trapped clay was not remobilized following amendment additions.

These findings suggest that diluted agricultural drainage waters, when used for irrigation, could cause both a temporary and longterm decrease in soil permeability. When drainage water or blended waters are used on this soil, an irrigation strategy involving amendment top dressings, before the rainy season, is recommended to maintain good soil structure and maximize leaching.

ACKNOWLEDGMENTS

The authors would like to thank James E. Strong, who wrote the computer program to record the weights of the drainage water and irrigation water with time. Funding for this work came from the U.C. Salinity/Drainage Program, Division of Agriculture and Natural Resources, Univ. of California.

Received for publication September 13, 1999.

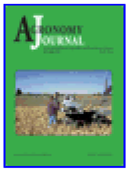
REFERENCES

TOP
ABSTRACT
INTRODUCTION
MATERIALS AND METHODS
RESULTS AND DISCUSSION
CONCLUSIONS
REFERENCES

- Abu-Sharar, T.M., F.T. Bingham, and J.D. Rhoades. 1987. Reduction in hydraulic conductivity in relation to clay dispersion and disaggregation. Soil Sci. Soc. Am. J. 51:342–346.[ISI]
- Curtin, D., H. Stephun, and F. Selles. 1994. Structural stability of chernozemic soils as affected by exchangeable sodium and electrolyte concentration. Can. J. Soil Sci. 74:157–164.[ISI]
- Frenkel, H., J.O. Goetzen, and J.D. Rhoades. 1978. Effect of clay type and content, exchangeable sodium percentage, and electrolyte concentration on clay dispersion and hydraulic conductivity. Soil Sci. Soc. Am. J. 42:32–39.[ISI]
- Gee, G.W., and J.W. Bauder. 1986. Particle-size analysis. p. 383–411. *In* A. Klute (ed.) Methods of Soil Analysis. no. 9. Part 1. SSSA, Madison, WI.

- Jury, W.A., W.R. Gardner, W.H. Gardner. 1991. Soil physics. 5th ed. John Wiley & Sons, Inc., New York.
- Loeppert, R.H., and D.L. Suarez. 1996. Carbonate and gypsum. p. 437–474. *In* D.L. Sparks et al. (ed.) Methods of Soil Analysis. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI.
- McNeal, B.L., D.A. Layfield, W.A. Norvell, and J.D. Rhoades. 1968. Factors influencing hydraulic conductivity of soils in the presence of mixed salt solutions. Soil Sci. Soc. Am. Proc. 32:187–190.[ISI]
- McNeal, B.L., W.A. Novell, and N.T. Coleman. 1966. Effect of solution composition on the swelling of extracted soil clays. Soil Sci. Soc. Am. Proc. 30:313–317.[ISI]
- Miyamoto, S., R.J. Prather, and J.L. Stroehlein. 1975a. Sulfuric acid and leaching requirements for reclaiming sodium-affected calcareous soils. Plant Soil. 43:573–585.[ISI]
- Miyamoto, S., J. Ryan, and J.L. Stroehlein. 1975b. Potentially beneficial uses of sulfuric acid in southwestern agriculture. J. Environ. Qual. 4:431–436.[ISI]
- Overstreet, R., J.C. Martin, and H.M. King. 1951. Gypsum, sulfur, and sulfuric acid for reclaiming an alkali soil of the Fresno series. Hilgardia 21:113–127.
- Prather, R.J., J.O. Goertzen, J.D. Rhoades, and H. Frenkel. 1978. Efficient amendment use in sodic soil reclamation. Soil Sci. Soc. Am. J. 42:782–786.[ISI]
- Quirk, J.P., and R.K. Schofield. 1955. The effect of electrolyte concentration on soil permeability. J. Soil Sci. 6:163–178.[ISI]
- Richard, S.J., J.E. Warneke, and L.V. Weeks. 1965. A soil compactor and procedure used for preparing soil cores for measuring physical properties. Soil Sci. Soc. Am. Proc. 29(5):637–639.
- Shainberg, I. 1990. Soil response to saline and sodic conditions. Chap. 5. p. 91–112. *In* K.K. Tanji (ed.) Agricultural salinity assessment and management. Am. Soc. Civ. Eng., New York.
- Shainberg, I., and J. Letey. 1984. Response of soils to sodic and saline conditions. Hildgardia 52:1–57.
- Shainberg, I., J.D. Rhoades, and R.J. Prather. 1981. Effect of low electrolyte concentration and hydraulic conductivity of a sodic soil. Soil Sci. Soc. Am. J. 45:273–277.[ISI]
- Sumner, M.E. 1993. Sodic soils: New perspectives. Aust. J. Soil Res. 31:683–750.[ISI]
- U.S. Salinity Lab Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook 60. Available at http://www.ussl.ars.usda.gov/hb60/hb60.htm (verified 28, Aug. 2000).
- Yousaf, M., O.M. Ali, and J.D. Rhoades. 1987. Dispersion of clay from some salt-affected arid land soil aggregates. Soil Sci. Soc. Am. J. 51:920–924.[ISI]

This article has been cited by other articles:



AGRONOMY JOURNAL ▸HOME

E. Amezketa, R. Aragues, and R. Gazol

Efficiency of Sulfuric Acid, Mined Gypsum, and Two Gypsum By-Products in Soil Crusting Prevention and Sodic Soil Reclamation

Agron. J., May 13, 2005; 97(3): 983 - 989.

[Abstract] [Full Text] [PDF]

This Article

- **Abstract** **FREE**
- **Figures Only**

- **Full Text (PDF)**
- **Alert me when this article is cited**
- **Alert me if a correction is posted**

Services

- **Similar articles in this journal**
- **Similar articles in ISI Web of Science**
- **Alert me to new issues of the journal**
- **Download to citation manager**
- **Search for citing articles in:**
  ISI Web of Science (4)

PubMed

- **Articles by Mace, J.E.**
- **Articles by Amrhein, C.**

Agricola

- **Articles by Mace, J.E.**
- **Articles by Amrhein, C.**

HOME HELP FEEDBACK SUBSCRIPTIONS ARCHIVE SEARCH TABLE OF CONTENTS

The SCI Journals Agronomy Journal Crop Science
Vadose Zone Journal Journal of Environmental Quality
Journal of Natural Resources and Life Sciences Education