Soil Behavior Upon Wetting with Saline-Sodic Water
Part 2 - Chemical Responses

by Kimberly Robinson, MS Degree Candidate
James W. Bauder, Professor of Soil and Water Quality
Krista E. Pearson, Research Assistant
Department of Land Resources and Environmental Sciences
Montana State University-Bozeman

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Results - Soil Chemical Responses

Two different criteria are currently recognized in the scientific literature as indices of dispersion risk or potential for dispersion. These are the sodium adsorption ratio (SAR) with a reported threshold of 12, and the exchangeable sodium percentage (ESP) with a reported threshold of 15%.

Baseline (pre-existing) chemical characterization was completed for each soil material. Samples were analyzed by MDS Harris Laboratories, Lincoln, NE. In an effort to achieve consistency in test procedures, all subsequent chemical analyses were completed by this same laboratory. Baseline conditions were assessed to determine changes that occurred in soil chemistry when soil materials were exposed to a variety of water quality x wetting regime combinations. On average, the lowest baseline salinity (EC) values were measured in the fine sandy loam soils while the finer textured soils (silty clay loam, clay loam) generally had greater baseline EC values. This same pattern held consistent for SAR and ESP. In only three instances baseline EC exceeded 2 dS/m. Baseline SAR and ESP were generally < 2 and nearly equivalent (i.e., ESP = SAR) for all samples with less than 34% clay (g clay/100 g dry soil). This is to be expected in as much as coarse textured, well-drained soils typically have greater naturally occurring leaching fractions and lesser exchange capacities than fine textured soils, which generally have higher inherent salinity levels and exchange capacities than coarse-textured soils (Figure 3).

Upon initial characterization of baseline conditions, 5 soil materials, all derived from the same location, were deleted from the study pool due to inherently high salinity and SAR. Follow-up inspection indicated presence of a high water table at this site. For purposes of illustration, the order of presentation was determined by initially ranking the soil samples by percent clay and then plotting the baseline saturated paste extract salinity, reflected by the line of solid diamonds in Figure 4. In subsequent analyses, the chemical signature data were ranked by percentage clay, with samples with the least percentage clay appearing on the far left of Figure 4 and the samples with the greatest percentage clay appearing on the far right of Figure 4. In Figure 4, the lowest, left-most closed diamond represents the baseline sample with the least percentage clay and lowest EC value before treatment.

The baseline data clearly suggest that under present conditions, only two of the sampled soils are at any substantial risk of dispersion. Results of the assessment or soil chemical responses to wetting with saline-sodic water are summarized in the following six figures. Figure 4 illustrates the salinity (EC_{sat}) of a saturated paste extract from each of 49 soil samples upon exposure in each of the six combinations of water quality x wetting regime, relative to the baseline. A single wet-dry cycle with synthesized Powder River water (closed square symbols) resulted in an increase in EC of approximately 1 dS/m on average. The increase was greatest for soil materials initially having the lowest baseline EC (coarser textured) and was least (on average) for the soils initially having higher EC values. It is noteworthy that only three of the soil samples initially had baseline salinity levels greater than 2 dS/m. In fact, only eight of the soil samples had baseline EC values equal to or greater than the EC of synthesized Powder River water.

As would be expected, a wetting-drying regime of 5 cycles resulted in a significant increase in EC of the saturated paste extract. EC increased 4-6 dS/m above the baseline when repeatedly wetted with simulated CBM product water, resulting in an average EC of approximately 7.5 dS/m. This represents more than a two-fold increase over the EC of the synthesized CBM product water. Subsequent wetting a single time with simulated (+ symbol) rainfall resulted in a decrease in the EC of 41 of 49 samples. This decrease, averaging approximately 2 dS/m, represents a significant change when considering the flocculating effect of salinity in overcoming sodium-induced dispersion.

Figure 5 illustrates the SAR as a result of the various wetting regime x water quality treatments. As with the EC data, the results of the initial baseline assessment were ranked from least to greatest percentage clay, which generally corresponded with SAR (left to right, closed diamonds in Figure 5). SAR of the saturated paste extract provides a representation of the sodicity of the soil water. Generally, SAR is used to assess the sodicity of irrigation water rather than the sodicity of the soil solution. However, well established relationships have been defined whereby SAR can be used to predict exchangeable sodium percentage (ESP) of the soil. In Figure 5, the continuous dotted horizontal lines represent the SAR values of the applied water, i.e., SAR of Powder River water = 4.54, and SAR of synthesized CBM product water = 13.09. Similar to EC, SAR values increased in association with the SAR of the treatment water. A single wetting with Powder River water increased SAR approximately 2 units in soils with lowest initial solution SAR. For soils with baseline SAR values greater than about 3, a single wetting with either Powder River water or CBM product water had little effect on solution SAR.

Upon single wetting events with either Powder River water or synthesized CBM product water, essentially all soils experienced both elevated SAR and ESP. SAR values increased in association with the SAR of the treatment water. A single wetting with Powder River water increased SAR approximately 2 units in soils with lowest initial solution SAR. For soils with baseline SAR values greater than about 3, a single wetting with either Powder River water or CBM product water had little effect on solution SAR. A single wetting with CBM product water increased soil solution SAR approximately 2 to 5 SAR units in soils, with the lowest baseline SAR showing the greatest increase in

SAR upon wetting. In general, however, the resultant SAR does not exceed approximately 7% and the resultant ESP does not exeed approximately 8%.

Treatment involving a regime of five wetting-drying cylces with either Powder River water of CBM product water resulted in solution SAR values nearly equal to the SAR of the treatment of water, i.e., SAR approaching a value of 10-12 (x symbols and closed circles, Figure 5). What is most noteworthy is the fact that SAR of the soil solution changed little or none when a five wet-dry cycle was followed by wetting with distilled water.

Following a single wet-dry regime with synthesized CBM product water (EC = 3.12, SAR = 13.09), the salinity of the soil extract of the soils with the least baseline EC increased approximately 1.5 dS/m, to a value of slightly greater than 2 dS/m. The increase in EC upon wetting with CBM product water was least for soils with the greatest initial EC. A wetting-drying regime of 5 cycles with CBM product water resulted in a significant increase in EC of the saturated paste extract. EC increased 4-6 dS/m above the baseline, resulting in an average EC of approximately 7.5 dS/m. This represents more than a two-fold increase over the EC of the synthesized CBM product water. Subsequent wetting a single time with simulated rainfall resulted in a decrease in the EC of 41 of 49 samples. This decrease, averaging approximately 2 dS/m, represents a significant change when considering the flocculating effect of salinity in overcoming sodium-induced dispersion.

Treatment involving a regime of five wetting-drying cycles with CBM product water resulted in solution SAR values nearly equal to the SAR of the treatment water, i.e., SAR approaching a value of 10-12. Hence, it is reasonable to conclude that soil solution SAR will equilibrate with the SAR of the applied water over time. However, if EC continues to increase, SAR will increase accordingly. In the present study, upon repeated addition of CBM product water, approximately 40% of the ESP values exceeded 15% and corresponding SAR values exceeded 12. Subsequent leaching with simulated rainfall reduced the ESP approximately 3%.

In summary, both EC and SAR increased with increasing EC and SAR and increasing frequency of wetting. However, SAR decreased little upon wetting with simulated rainfall while EC decreased substantially in response to a rainfall event.

Figure 6 illustrates the relationship between soil solution SAR and exchangeable sodium percentage (ESP) of the soil material. Previously published research reports a relationship between SAR of applied water and ESP of the soil as ESP of 15% = SAR of 12, i.e., SAR = 0.8 x ESP with respect to assumed risk of dispersion of fine material. The data presented in Figure 7 follow this same relationship, suggesting that the soil solution SAR is generally representative of the applied water SAR and the SAR can be used to approximate or estimate the resultant ESP.

Historically, an SAR threshold of 12 and/or an ESP threshold of 15% have been used as the diagnostic criteria for irrigation water suitability, i.e., irrigation with water exceeding SAR = 12, which results in an ESP of 15% or more, will result in significant potential for dispersion. Using such a criteria when referring to Figure 6, it becomes apparent that either repeated wetting-drying or wetting-drying followed by a single wetting with distilled water (simulating rainfall) elevates the ESP and SAR closer to these thresholds. The SAR = 12 threshold and the ESP = 15% threshold have been plotted on Figure 6 for purposes of illustration. The baseline data, falling in the far lower left corner of Figure 6 (represented by closed diamonds) clearly suggest that under present conditions, only two of the sampled soils are at any substantial risk of dispersion. Upon single wetting events with either Powder River water or synthesized CBM product water, most points are shifted right, reflecting both elevated SAR and ESP. In general, however, neither does the resultant SAR exceed approximately 7 nor does the resultant ESP exceed approximately 8%.

Numerous research reports suggest that both the SAR-dispersion and the ESP-dispersion relationship are continuous, with some instances of dispersion occurring at ESP and/or SAR substantially less than the 15% and 12 values, respectively (Agassi et al., 1985, Crescimanno et al., 1995; Lima et al., 1990; McIntyre, 1979; Northcote and Skene, 1972; Rengasamy et al., 1984; Sumner, 1993). Hence, caution is added here regarding the use of a single absolute ESP or SAR threshold as a diagnostic for dispersion risk. In the present study, upon repeated addition of CBM product water (5 X CBM, closed circle symbols in Figure 6), approximately 40% of the ESP values exceed 15% and corresponding SAR values exceed 12. The subsequent addition of simulated rainfall (as distilled water) results in a shift of some of these data points to below the reported ESP-SAR thresholds.

Figure 7 illustrates the soil saturated paste extract EC and SAR following each of the treatment combinations. As previously noted, typically the EC and SAR of irrigation water are used as diagnostic indicators or criteria for irrigation water suitability. Soil solution data can merely provide a general index of quality of applied water, i.e., soil solution chemistry reflects chemistry of the applied water. As can be seen in Figure 8, soil solution salinity and SAR reflect the various treatment combinations. Imposed on Figure 7 are two different sets of threshold values. The two diagonal lines correspond to the thresholds reported by Hansen et al. (1999) with respect to EC x SAR combinations distinguishing no risk, moderate risk and severe risk of dispersion. The 90-degree vertical x horizontal lines represent the EC threshold for salinity (i.e., EC = 3.0 dS/m) and the SAR value normally considered the diagnostic for sodic soils (i.e., SAR > 12), respectively. These two thresholds have been repeatedly published by numerous other researchers. As can be seen, the data points cluster, relative to the EC-SAR combination of the respective treatment, with one exception. A single wetting with distilled water following a regime of five wet-dry cycles with CBM product water results in a shift of most data points left, closer to the threshold criteria (solid circles shift to open circles).

On initial inspection of Figure 7, one would logically assume or conclude that all data points falling to the right of the right-most diagonal line represent EC x SAR combinations which pose little or no risk with respect to dispersion. The logical conclusion thus is that dispersion is generally not a high risk under conditions of the study reported herein. However, with respect to salinity, Figure 7 presents a higher risk situation. Relying solely on the published plant tolerances to salinity (threshold of EC = 3 dS/m), three significant points become evident from Figure 7: 1) essentially all of the EC data points associated with repeated wetting and drying with simulated CBM product water exceed the 3 dS/m threshold, 2) subsequent wetting with simulated rainfall does not result in sufficient reduction in salinity to lower the EC to < 3 dS/m following repeated wetting with CBM product water, and 3) with repeated wetting and drying with simulated Powder River water, a significant number of soils demonstrate EC values greater than the 3 dS/m threshold. These latter soils are thus approaching the categorization of saline. Not surprisingly, irrigators along the Powder River have historically relied on only one or two irrigations per season, primarily because of the known risk of salinization resulting from repeated irrigation during the latter part of the irrigation season.

Hence, although in many cases repeated irrigation with water of the EC x SAR combinations used here to simulate CBM product water may not pose an immediate risk of dispersion on most irrigable soils of the Powder River corridor and the Buffalo Rapids Irrigation District, the resultant salinity levels are likely to have significant adverse effect on plant production. Furthermore, in the event of significant rainfall during the irrigation season, availability of water of lower EC for irrigation, or repeated rainfall events during the non-irrigation season, it is likely that soil salinity values will be sufficiently lowered that the offsetting effect of electrolyte-induced flocculation will be diminished to the point where dispersion becomes more probable.

Summary

In summary, extensive soil sampling, treatment, and chemical characterization validates that the previously reported ESP-SAR relationship holds, even in the event of native soils and/or those soil materials irrigated with CBM signature water. Currently, only about 1-in-25 soil materials sampled exhibit ESP-SAR values exceeding previously reported thresholds. Single wetting events with either Powder River water or CBM signature product water resulted in elevation of both the ESP and SAR. However, the resultant levels do not appear to pose a risk of dispersion or salt stress to commonly grown crops for the most part. Repeated wetting and drying with CBM signature water, such in the case of sprinkler irrigation or routine flooding, resulted in significant elevation of EC, SAR and ESP, with approximately 50% of the resultant values exceeding the previously reported thresholds for salt injury to commonly grown crops of the area and the thresholds for dispersion. Subsequent leaching with simulated rainfall reduced the EC measurably, had little or no effect on SAR, and reduced the ESP approximately 3%.

Implications

The data presented here provide significant insight into the management and implications of CBM product water. The data suggest that different strategies for water management need to be applied to circumstances of single-event dispersals versus repeated irrigation. The data suggest that for the most part, repeated irrigation with CBM product water with an EC-SAR signature similar to that used in this study (EC = 3 dS/m, SAR = 13) will result in elevated salinity, sodicity, and exchangeable sodium percentage. Although resultant EC x SAR combinations may result in soil flocculation, the EC levels appear to be sufficiently high enough to have measurable adverse impact on most crops with the exception of highly salt tolerant species.

• Based on an inventory and assessment of a wide geographic distribution of irrigable soils within the Powder River corridor and the Buffalo Rapids Irrigation District, followed by X-ray defraction analyses of representative soil materials, it is apparent that the primary clay mineral fraction of soils of alluvial nature within the ephemeral and perennial stream channels and adjacent up gradient terraces and benches where irrigation is currently practiced is smectitic. Extensive independently conducted and published research has documented the significant risk potential of dispersion of soil predominated by smectite clay (correspondingly montmorillonitic) when exposed to water characterized as sodic. This is particularly the case in the presence of depressed or relatively low soil solution salinity (electrolyte concentration).

• Results of assessment of the current conditions of irrigated soils in the area of study indicates relatively few irrigable soils with elevated salinity-sodicity levels. In contrast, results of investigations carried out as part of this study substantiate the conclusion that repeated irrigation with saline-sodic water or water with a chemical signature comparable to the synthesized CBM product water used in this study will result in a general increase in soil salinity and sodicity.

• Dispersal and disposal of CBM product water comparable to that used in this study, by means of single, one-time applications of limited volumes of water appears to be an acceptable practice, at least with respect to consequential soil solution salinity and sodicity and soil exchange phase ESP. Although the consequence appears to be elevated soil salinity and sodicity, the effective elevation is most obvious on coarse–textured soils with limited susceptibility to dispersion and with naturally high leaching fractions. Neither the resultant salinity nor sodicity appear to be at levels detrimental to plant growth or soil physical structure.

• Repeated irrigation or dispersal of CBM product water to irrigable land parcels is likely to result in elevated soil salinity levels substantially higher than published thresholds for some currently irrigated crops of southeast Montana, specifically alfalfa, corn, and specialty crops.

• It appears that soil solution salinity will equilibrate at an EC value approximately 2-3 times the EC of the applied water; in contrast soil solution SAR appears to equilibrate at a level comparable to the SAR of the applied water. These results are consistent with previously reported findings.

• In the conditions of this study, soil solution SAR of soil repeatedly wetted with CBM water of SAR 13 equilibrated at approximately SAR = 10-12 on well-drained soils.

• Application of salt-free water following elevation of soil solution salinity and SAR through repeated wetting effectively reduced soil solution salinity while having little or no effect on sodicity. The implication of this is that the flocculating effect of salinity may be reduced, thereby exacerbating the dispersive effects of sodium, as a consequence of uncontrollable rainfall or dispersals of relatively salt-free spring runoff to soils previously irrigated with saline-sodic water.

• Based on previously published EC x SAR combination thresholds for protection against fine particle dispersion, in few instances of this study were soil solution salinity x sodicity combinations measured which exceed these thresholds following single wetting events. In essentially all instances where saline-sodic water was applied, the resulting soil solution salinity and sodicity were significantly elevated to levels in close proximity to the previously published EC x SAR thresholds.

• Results of this study appear to be consistent with previously published reports of the relationship between exchangeable sodium percentage (ESP) and solution SAR, i.e., SAR = 0.8 x ESP (approximately). Utilizing an ESP threshold of 15, the majority of treated soil samples exceeding this value resulted from alternate wetting regimes with CBM product water followed by simulated rainfall.

• In the present study, repeated wetting and drying with CBM signature water, such as in the case of sprinkler irrigation or routine flooding, resulted in significant elevation of both SAR and ESP of the soil solution/soil exchange complex. Approximately 50% of the resultant ESP values exceed 15% and corresponding SAR values exceed 12. Subsequent leaching with simulated rainfall reduced the ESP approximately 3%.

References

Agassi, M., J. Morin and I. Shainberg. 1985. The effect of water drop impact energy and water salinity on the infiltration rates of sodic soils. Soil Sci. Soc. Am. J. 49:186-190.

Crescimanno, G., M Iovino, and G. Provenzano. 1995. Influence of salinity and sodicity on soil structural and hydraulic characteristics. Soil Sci. Soc. Am. J. 59:1701-1708.

Hanson, B., S. R. Grattan, and A. Fulton. 1999. Agricultural salinity and drainage. Div. Agric. and Natural Resources Publ. 3375, Univ. California Irrigation Prog. Univ. California, Davis. (Available from Univ. California, Comm. Services-Publications. 6701 San Pablo Avenue, 2nd Floor, Oakland, CA 94608-1239; 510-642-2431.

Lima, L. A., M. E. Grismer, and D. R. Nielsen. 1990. Salinity effects on Yolo loam hydraulic properties. Soil Sci. 150-451-458.

Maas, E. V. 1984. Salt tolerance of plants. In Handbook of plant science. B. R. Christie, Ed., CRC Press, Inc.

Mace, J. E., and C. Amrhein. 2001. Leaching and reclamation of a soil irrigated with moderate SAR waters. Soil Sci. Soc. Am. J. (Submitted)

McIntyre, D. S. 1979. Exchangeable sodium, subplasticity and hydraulic conductivity on some Australian soils. Aust. J. Soil Res. 17:115-120.

Miller, R. W. and R. L.Donahue. 1996. Soils in our environment. Seventh Ed. Prentice Hall, Engelwood Cliffs, NG 07632.

Northcote, K. H., and J. K. M. Skene. 1972. Australian soils with salikne and sodic properties. CSIRO Aust. Soil Publ. 27.

Rengasamy, P. R. S. B. Green, G. W. Ford, and A. H. Mehanni. 1984. Identification of dispersive behaviour and the management of the red-brown earthsl. Aust. J. Soil Res. 22:412-431.

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. Agric. Handb 60. U.S. Gov.t Print. Office, Washington, D.C.

Soil Improvement Committee, California Fertilizer Association. 1995. Western fertilizer handbook. 8th Ed. California Fertilizer Assoc. 1700 I Street, Suite 130,Sacramento, CA 95814. Available from Interstate Publishers, Inc., 510 North Vermilion Street, P.O. Box 50. Danville, IL 61834-0050. (800-843-0050).

Sumner, M. E., 1993. Sodic soils: New perspectives. Aust. J. soil Res. 31:683-750.