Water Quality Criteria for Use of Saline/Degraded Water for Irrigation

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Introduction

Current fresh water use in arid and semiarid lands is not sustainable, as use exceeds replenishment and demand for water continues to increase. The primary use of fresh water in arid and semiarid regions is for irrigation; in California approximately 70% of water use is by agriculture. Increasing demands for fresh water for municipal and industrial use throughout the world, are coupled with increasing world food needs and restrictions on surface water diversions due to environmental constraints. The irrigated acreage in the western U.S. is already decreasing due to water availability and diversion of water to other uses. Agriculture will either need to reduce acreage under irrigation, which is undesirable since it will reduce food supply, or irrigate with alternative water sources and more effectively utilize existing water supplies. Use of saline and marginal quality waters is possible, but sustained use requires consideration of the impacts of these waters on both crop production and maintenance of good soil physical properties. In many instances waters previously considered not useable or impractical for irrigation can be used with careful management. Earlier water criteria may in some instances be overly conservative due to simplifying assumptions used in their evaluation. In other instances, hazards related to soil physical properties were underestimated. Using computer simulations we demonstrate that some marginal waters considered unusable from state analyses, can in fact be used intermittently without adverse impacts on yield or soil properties.

Water quality criteria related to soil physical properties

A major restriction on use of marginal waters is the large concentrations of sodium relative to calcium and magnesium. A sodic soil has been classified as a soil with an exchangeable sodium percentage above 15, equivalent to an SAR value of the soil water of approximately 13 (where SAR is defined as $Na/(Ca+Mg)^{0.5}$, with concentrations expressed in mmol L^{-1}). Earlier water quality criteria (Ayers and Westcot, 1985), considered that the sodicity hazard could be evaluated by consideration of the salinity and SAR of the irrigation water. Utilizing the relationships it has been concluded that it is safe to use waters with SAR at or below SAR 5, although they concluded that irrigation with “very low salinity water (less than EC_w= 0.2 dS/m) almost invariably results in water infiltration problems regardless of the SAR”. The water quality criteria of Ayers and Wescot (1985) and others, appear primarily based on relationships developed earlier by McNeal and Colman(1968) and McNeal et al., (1968 and 1970), along with information synthesized from field observations. Additionally flocculation studies by Quirk and Schofield (1954) and others supported the concept that there were threshold values of SAR below which no adverse impacts would be expected. More recent information (Suarez et al. 2006 and Suarez et al. 2008) indicates that the sodium hazards are greater than previously considered and that there is no evidence for a safe threshold value, as any increase in SAR resulted in a decrease in infiltration. The changes in infiltration as related to SAR are shown in Figure 1 and 2 below for the last rain event in loam and clay soil respectively. The differences in infiltration between the EC 1 dS m^{-1} and EC 2 dSm^{-1} waters at various SAR levels were comparable for the both rain events shown as well as for the irrigation events. This suggests that the effects of EC are not as great as implied by the Ayes and Westcott (1985) stability relationship (Fig 21 in their publication). Also seen by examination of Figure 1 and 2 is that although the loam and clay soil had differences in infiltration, the relative changes in infiltration between the two soils are comparable. These results suggest that soil texture may not be a important factor in terms of predicting changes in relative infiltration rates. In contrast to most of the earlier studies these studies are based on measurements taken over the course of almost one year with periodic wetting and drying cycles that included alternate rain and irrigation cycles. Other studies (Suarez and Gonzalez, 2013, in preparation) indicate that the infiltration rates continue to decrease with time during the season of irrigation events. This indicated that short term changes, such as during a single event or a short term laboratory column experiment, underestimate the sodicity hazard.

The effect of pH has not been generally included in evaluations of impacts of irrigation water on infiltration water. However, it has been demonstrated that pH, independent of SAR, has an important effect on hydraulic conductivity (Suarez et al., 1984). This study examined the pH range of 6-9 and observed adverse effects with increasing pH. The UNSATCHEM model (Suarez and Simunek, 1997) has incorporated those data to include a reduction function on hydraulic properties that considers EC, SAR and pH, although the interactive effects have not been fully evaluated. For high pH waters (above 8.5) acidification may be needed.
Based on these newer studies Suarez (2012a) developed new water quality criteria. The relationships shown in Figure 3 consider the increased sensitivity to infiltration losses at lower SAR and account for the adverse effects of elevated pH as well. This Figure provides is to be utilized in environments where there is no appreciable rain. In most irrigated landscapes including Mediterranean type climates, some rainfall does occur and thus the rain hazard must be considered. In the presence of appreciable rain, the hazard is clearly greater at higher SAR; however any SAR above 2 will result in significant loss of infiltration, regardless of the antecedent salinity level in the soil. These criteria represent relative effects; however the relative effects have different impacts, depending on texture. A 20% loss of infiltration on a sandy soil will not likely have an adverse impact on crop production, however a 20% reduction in a clay soil, could be highly adverse. In some regions, such as Imperial Valley the low infiltration rates. Amendment application appear necessary when using many degraded waters.

Again models can be utilized to keep infiltration losses and sodicity and pH effects to a minimum. Result in applications that are at or near the evapotranspiration needs of the crop, thus infiltration losses may be directly related to total water infiltrated and crop yield.

Leaching Recommendations

Leaching recommendations have generally been based on leaching requirements; calculation of the maximum soil salinity that can be tolerated without yield loss. The simple approach taken was to calculate an average rootzone salinity assuming a fixed leaching fraction, steady state conditions and management of the system for maximum yield Ayers and Westcot, 1985).

Average rootzone salinity

The average rootzone salinity calculation does not likely represent the salinity stress experienced by the crop. Plants extract water in a pattern that decreases with depth. The calculation of salinity in the rootzone is generally calculated based on the input leaching fraction, division of the rootzone into 4 quarters and the assumption that 0.4, 0.3, 0.2 and 0.1 represents the relative water uptake in these intervals. The calculation of an average salinity rather than a water uptake value leads to over-estimation of salt stress and thus overestimation of leaching requirement (Letey et al., 2011).

Fixed leafing fraction

The major simplification in earlier guidelines was that the leaching fraction is a fixed input variable controlled by the irrigator. Thus under high salinity and low water volume inputs, predicted yields are very low. Using a dynamic model that considers the effect of stress on water uptake, some yield is lost but soil salinity is moderated by the reduced plant water uptake. These large differences in leaching fraction, relative yield and salinity between the guidelines and model simulations are dramatically illustrated in Figures 5 and 6 below (Suarez, 2012b). In many instances, especially with water scarcity and low availability, it may be economically feasible to accept some yield loss, utilize marginal waters at lower cost and thus maximize profit to the grower. The leaching requirement needs to be replaced by plant-water soil models and economical evaluation of the predictions.

Boron toxicity

Boron toxicity calculations and boron water quality criteria are currently similar to salt tolerance; calculated from average rootzone boron and steady state. As demonstrated by Goldberg and Suarez (2006) high boron waters can be used for over one year if leaching is minimized (thus minimizing the boron loading) and such waters can be used in a cyclic manner.

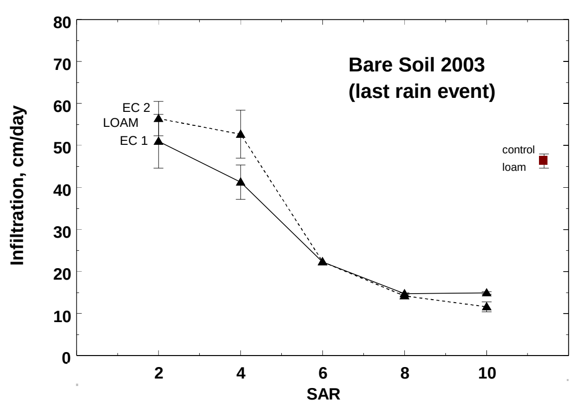

Figure 1

Relationship among infiltration rate, SAR and EC for loam soil during the last rain event (Suarez et al., 2006).

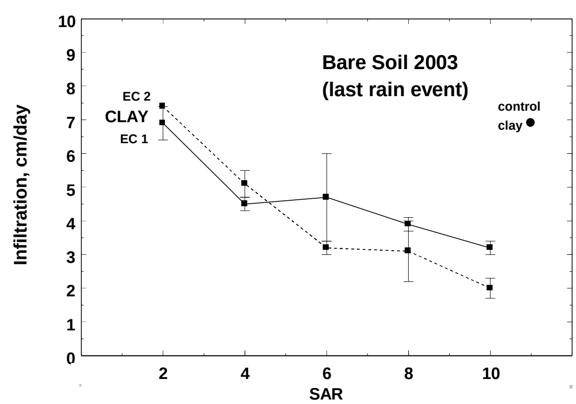

Figure 2

Relationship among infiltration rate, SAR and EC for clay soil during the last rain event (Suarez et al., 2006).

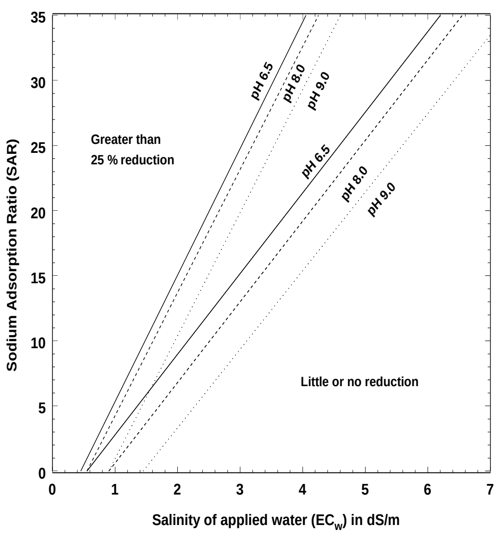

Figure 3

Sodicity hazard of irrigation water on water infiltration as related to EC, SAR and pH in the absence of rainfall (Suarez, 2010).

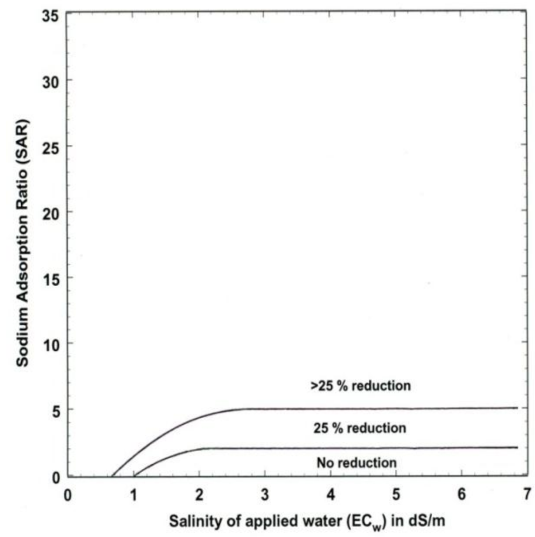

Figure 4

Sodicity hazard of irrigation water on water infiltration as related to EC, SAR and pH in the presence of substantial rainfall (Suarez, 2010).

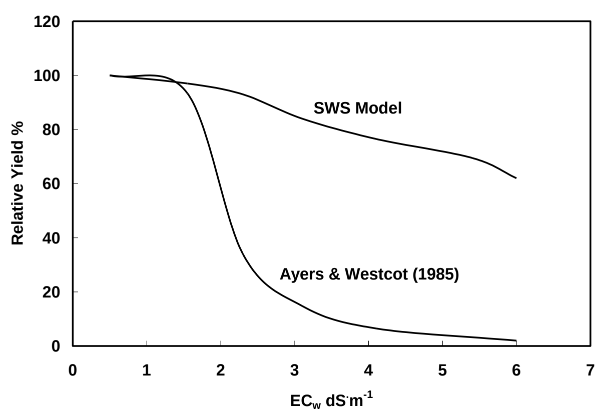

Figure 5

Comparison of SWS model (Suarez et al., 2010) and Ayers and Westcot (1985) predicted crop relative yield as related to irrigation water EC, for a crop with an h_{50}=-50 m (-0.5MPa), ET_p=200 cm and 209 cm applied water.

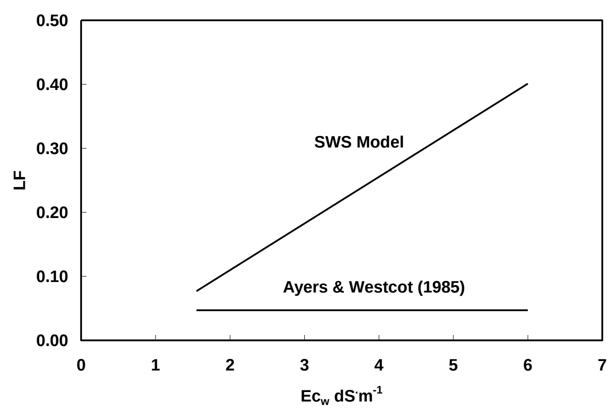

Figure 6

Comparison of SWS model (Suarez et al., 2010) and Ayers and Westcot (1985) predicted leaching fraction as related to irrigation water EC, for a crop with an h_{50}=-50 m (-0.5MPa) salt tolerance value, ET_p=200 cm and 209 cm applied water.

Literature Cited

Ayers, R.S., and D.W. Westcot. 1985. Water Quality for Agriculture, FAO Irrigation and Drainage Paper 29 rev 1. FAO, UN, Rome 174pp.

Goldberg, S. and D.L. Suarez. 2006. Prediction of anion adsorption and transport in soil systems using the constant capacitance model. In: J. Luetzenkirchen (ed.) Surface Complexation Modeling. Interface Science and Technology Series, Volume 11, Elsevier, Amsterdam. Chapter 18: 491-517.

Letey, J., G.J. Hoffman, J.W. Hopmans, S.R. Grattan, D.L. Suarez, D.L. Corwin, J.D. Oster, L. Wu and C. Amrhein. 2011. Evaluation of soil salinity leaching requirement guidelines. Ag. Water Manage. 98:502-506.

McNeal, B.L., and N.T. Coleman. 1968. Effect of solution composition on soil hydraulic conductivity. Soil Sci. Soc. Am. Proc. 30:308-312.

McNeal, B.L., W.A. Norwell, and N.T. Coleman. 1968. Effect of solution composition on the swelling of extracted clays. Soil Sci. Soc. Am. Proc. 30:313-317.

McNeal, B.L., J.D. Oster, and J.T. Hatcher. 1970. Calculation of electrical conductivity from solution composition data as an aid to in-situ estimation of soil salinity. Soil Sci. 110:405-414.

Quirk, J.P. and R.K. Schofield. 1955. The effect of electrolyte concentration on soil permeability. J. Soil Sci. 6:163-178.

Suarez, D.L. 2012. Irrigation water quality assessments. In: W.W. Wallender and K.K. Tanji (eds.) ASCE Manual and Reports on Engineering Practice No. 71 Agricultural Salinity Assessment and Management (2nd Edition). ASCE, Reston, VA. Chapter 11 pp:343-370.

Suarez, D.L. 2012. Modeling transient root zone salinity (SWS Model). In: W.W. Wallender and K.K. Tanji (eds.) Agricultural Salinity Assessment and Management. ASCE Manual and Reports on Engineering Practice No. 71 (2nd Edition). ASCE, Reston, VA. Chapter 28 pp:855-897.

Suarez, D.L., J.D. Wood, and S.M. Lesch. 2006. Effect of SAR on water infiltration under a sequential rain-irrigation management system. Agric. Water Manage. 86:150-164.

Suarez, D.L., J.D. Wood, and S.M. Lesch. 2008. Impact of sequential applications of rain and irrigation water on infiltration into a cropped soil. J. Environ. Qual. 37:S169-S179.

Suarez, D.L., J.D. Rhoades, R. Lavado, and C.M. Grieve. 1984. Effect of pH on saturated hydraulic conductivity and soil dispersion. Soil Sci. Soc. Am. J. 48:50–55.

Suarez, D.L., and J. Simunek. 1997. UNSATCHEM: Unsaturated water and solute transport model with equilibrium and kinetic chemistry. Soil Sci. Soc. Am. J., 61:1633-1646.

Suarez, D.L., and P. Taber. 2007. Extract Chem: Numerical software package for estimating changes in solution composition due to changes in soil water content. http://ars.usda.gov/Services/docs.htm?docid=14567