Irrigation salinity: the state of knowledge and emerging issues

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Introduction

Current irrigation practices in arid and semi-arid regions are not sustainable. These regions are experiencing increasing population and development with increasing demands for limited fresh water for municipal and industrial use. In arid areas fresh water use is currently in excess of sustainable quantities. In the southwestern U.S. there are reductions in water deliveries to irrigated areas and total irrigated acreage is currently declining and projected to decline further. Reductions in water deliveries are the result of various factors, including drought, court mandated surface water flow releases for environmental concerns, purchases of irrigation water by municipal water organizations, and restrictions on the discharge of drainage waters.

The southwestern U.S. as well as other regions of the world, are predicted to be drier as a result of global climate change. In addition, the already documented warming in winter and spring in the southwestern U.S. means that the winter snowpack will be smaller and the early and rapid spring runoff cannot be captured with our current surface storage capacity. Many predict the demise or at least drastic reduction in irrigated acreage in the southwestern U.S. as a result of these combined factors. This result would have a major social and economic impact, as irrigated agriculture produces 40% of the agricultural revenue and most of the U.S. fruits and vegetables. Nonetheless, at current food prices, irrigated agriculture cannot compete against the urban sector for fresh water resources in an economically competitive water market.

Improvements in irrigation efficiency and leaching control are possible and can reduce the use of fresh water by irrigated agriculture. However these improvements are not sufficient as they provide only a partial solution to sustaining irrigation. Most regions have abundant quantities of low quality saline, drainage and municipal waste waters, most of which could potentially be used for irrigation. These resources will almost certainly be a major source of irrigation water in the future. Use of these waters requires new strategies for water management including new knowledge of factors affecting infiltration and crop production and development of numerical models that consider the numerous interactions, enabling evaluation of various management practices. We also need to develop alternative crops, and new varieties that are tolerant to salinity, ion imbalances and toxic elements.

Water quality criteria for irrigation

Current water quality criteria were developed in the era of abundant fresh water supplies. The objectives were simple criteria that would avoid problems under most conditions. These criteria currently reject waters that in *some* instances can be detrimental. Often the criteria have been developed into regulatory standards, further restricting use of low quality waters. In many instances use of recycled and brackish water, currently considered unsuitable, can result in some reduction in potential yield. Nonetheless this can be acceptable and still desirable if the absolute yield is considered in the context of society needs and grower profitability. This may require incentives for the farmers to exchange fresh water for saline and degraded waters, or to compensate for needed amendments. The criteria do not consider that in many regions, the crop water requirements can be met by a combination of rain, fresh water and saline water, thereby diminishing the predicted salinity impact when considering the saline water. The criteria also do not consider that in Mediterranean climates winter rain leaches the soil. Thus salinity is low in the early stages of plant growth which are often the most salt sensitive, suggesting that the criteria overestimate salt damage. Use of degraded waters may either reduce yield or cause additional management expenses. Treated wastewaters have elevated pH, alkalinity, and sodium, relatively low Ca/Mg ratios, high concentrations of dissolved organic matter, all adverse to infiltration and soil structure, as well as ion imbalances and elevated concentrations of potentially toxic elements. Use of these waters may require periodic application of amendments and/or leaching, utilizing new knowledge about factors affecting infiltration and crop production. Environmental concerns about recycled water include plant uptake of toxic elements, pharmaceuticals, endocrine disrupters etc. as well as off-site impacts to discharge areas.

Water suitability for irrigation and sodicity hazard related to infiltration has been established primarily from laboratory experiments, These are almost all based on packing sieved and ground soil into columns for short term experiments of saturated hydraulic conductivity with waters of decreasing electrical conductivity (EC) and constant sodium adsorption ratio (SAR). As mentioned above, rain is an important factor in the soil water budget of most irrigated areas and it impacts the soil chemical and physical conditions. We have examined both calcareous soils from the Upper Great Plains of the U.S. and a non calcareous soil from the arid southwestern U.S. in year- long outdoor studies with conditions of combined simulated rain and irrigation and wetting and drying cycles with waters of varying SAR and at an electrical conductivity of either 1.0 and 2.0 dS/m, and varying pH.

Rain has an adverse impact related to the SAR of the soil water at the time of infiltration. Contrary to results from column studies, there were little differences in the infiltration results from the two salinity levels. Based on these studies, we conclude that when considering rain as well as irrigation water, there is no threshold SAR value at which there is a reduction in soil infiltration. Any increase in SAR above the control results in a reduction in infiltration (Suarez et al. 2006, Suarez et al. 2008). Similar results, but with less infiltration rate loss, has been observed under experiments with irrigation only (Suarez and Gonzalez in preparation). Long term changes in infiltration are also greater than the changes observed in short term laboratory column studies (Suarez et al., 2008). These results indicate a need to modify the Ayers and Westcot (1985) guidelines. The impact of decreasing infiltration depends on site-specific conditions. For example for sandy soils a 20% reduction in infiltration over the course of a year is not significant but for a clay soil with limited infiltration, the impact could result in a corresponding reduction in water availability and crop yield.

In addition to EC and SAR there are other important factors that impact water suitability related to infiltration. Elevated pH adversely impacts saturated hydraulic conductivity in column studies conducted at constant EC and SAR (Suarez et. al. 1984), as well as infiltration measured in outdoor plots (Suarez and Gonzalez, in preparation) . Soils also differ in terms of their susceptibility to SAR, related to clay type, organic matter content, oxide content, among other factors. Climatic conditions (ET_0), crop water demands, irrigation system, tillage and other management practices also impact the adverse effect of sodium on infiltration. Degraded waters generally contain increased levels of alkalinity (thus elevated pH) and often contain elevated concentrations of minor elements such as boron that may adversely affect crop growth. In many instances use of these waters may be judged unsuitable based on steady state considerations however transient conditions suggest conditions under which they may be used. Examples are given for model simulations using high boron waters for irrigation and suggestions for optimal management.

Irrigation water salinity and leaching requirement

Leaching requirements for salinity control have been based on steady state analysis of irrigation water with simplifying assumptions about the relation of EC of soil water extract to EC of soil water, how plants integrate water uptake and soil salinity, and sensitivity to salts at different stages of growth. Converting soil water salinity to the salinity of the water extracted by the plant is generally done by specifying a leaching fraction.

The salinity status (EC) of soils as well as soil SAR is most commonly reported in terms of the saturation extract. This is considered by most to provide a good reference water content for comparisons among experiments and field conditions. The salt tolerance of crops is also reported in terms of the saturation extract EC. Alternatively other standards such as 1:2 and 1:5 soil:water extracts are also utilized in some regions, and water standards have been developed in terms of those extracts.

Plants respond to soil water EC and not the measured EC of a diluted, reference water content. Simple conversions of soil water EC (generally at field capacity) to saturation extract EC exist but can sometimes lead to significant errors. These errors increase for extraction methods at higher water contents. For gypsum containing soils, soil water salinity is considerably lower than estimated from the extracts. This salinity over-estimation leads to over-estimation of salt damage in gypsum containing soils. Additionally EC is not linear with dilution as assumed, this is usually a minor error but it results in overestimation of the soil water salinity. These factors can be evaluated using the Extract Chem. model (Suarez and Taber, 2007). This model also serves to allow more accurate conversion of 1:2 and 1:5 extract information. The model also enables us to evaluate the existing guidelines based on different extraction methods.

Extent and timing of rain is an important aspect that needs to be considered when evaluating suitability of waters for irrigation. Rain is generally ignored. As a first approximation we can consider that crops respond to the average of the rain and irrigation water composition, thus indicating improved plant response relative to irrigation only conditions. Where winter rains and leaching occur, such as in Mediterranean climates, soil salinity is reduced during the early stages of crop growth, which are generally the most salt sensitive stages, thus increased salinity may be tolerated. Model simulations using UNSATCHEM (Suarez and Simunek, 1997), allow for evaluation of different management strategies related to leaching, transient conditions, sequential use versus blending etc.

Salt tolerance tables are used to recommend suitable crops based on irrigation water salinity and avoidance of yield loss. . Because salt tolerant crops are generally lower value crops, and often lower yielding crops, they should not be automatically recommended for saline conditions. Despite some yield loss, moderately salt tolerant crops such as alfalfa may out-produce more salt tolerant crops forage grasses, such as wheatgrass at salinities up to 15 dS/m. In some instances moderate salt stress may enhance product quality. Many plants adapt to salt stress by increased accumulation of secondary metabolites such as soluble solids, sugars, organic acids, and proteins, thus increasing quality and marketability. For example, salinity stress increases sugar and dissolved solids content of tomatoes and melons, increases content of beneficial antioxidant compounds in strawberries and increases oil and particularly the desired lesquerolic acid in lesquerella.

Soil salinity can now be actively monitored at the field scale. Remote sensing technology can be used to provide rapid and inexpensive detailed field salinity assessments (Corwin and Lesch, 2005, and Lesch, 2006) and site specific management including evaluation of the need for amendments. Using this technology in combination with modeling (Suarez, 2001), allows for site specific leaching and reclamation within a field. Reduction in the use of amendments and leaching water for sodic soil or saline soil reclamation can be achieved by blocking the fields into different gypsum requirement zones, based on variations in clay content and SAR. These technologies, have already been commercialized using air imagery. Current amendment requirements to lower the soil exchangeable Na levels do not consider the significant calcium inputs from dissolution of calcite, thus overestimating gypsum requirements. This reduction in salt loading can be especially important if reclamation occurs in combination with high soil carbon dioxide concentrations (warm soil temperatures combined with wet surface soil conditions).

Calculation of the leaching requirement is generally based on an assumed water uptake function, then calculation of salinity with depth (4 quarters) assuming EC is inversely related to water uptake. The root zone salinity is next averaged and compared to the published salt tolerance tables. This calculation overestimates the soil salinity experienced by the plant. Precipitation of calcite and the nonlinear interaction of water content and salinity mean that the osmotic pressure or EC is not as high as assumed in the lower depths of the soil. This calculation also does not account for the water uptake function used in the calculation of the soil EC. Plants extract less water from the deeper depths (which are more saline) and more water from the surface. This consideration also reduces the estimated salinity experienced by the plant. In addition, consideration that plants respond to salinity by preferentially growing roots and extracting water from non saline regions of the soil may further reduce the calculated need for leaching (Letey and Feng, 2007).

Literature cited

Ayers, R.S., and D.W. Wescot. 1985. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 rev. 1. Food and Agriculture Organization of the United Nations. Rome 174 pp.

Corwin, D.L. and S. M. Lesch. 2005. Apparent electrical conductivity measurements in agriculture. Computers and Electronics in Agriculture 46:11-45.

Lesch, S.M. 2006. Statistical software package for estimating field scale spatial salinity patterns from electromagnetic induction signal data ESAP v. 2.35. http://www.ars.usda.gov/Services/docs.htm?docid=8918

Letey. J. and G.L. Feng. 2007. Dynamic versus steady-state approaches to evaluate irrigation management of saline waters. Agric. Water Manage. 91:1-10.

Suarez, D.L. 2001 Sodic soil reclamation: Model and field study. Aust. J. Soil Res. 39:1225-1246.

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 model to predict major ion and boron composition of a soil solution at a desired water content. http://www.ars.usda.gov/Services/software/download.htm?softwareid=155

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. Infiltration into cropped soils: Effect of rain and SAR – impacted irrigation water. J. Environ. Qual. (In press).