Public Comment
Crop Salt Tolerance
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Comments by John Letey
on
Salt Tolerance of Crops in the Southern Sacramento-San Joaquin Delta
Draft Report July 14, 2009
By
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Typical of most reviews, praise on the very positive aspects of a report is constrained whereas perceived shortcomings are elaborated to the maximum extent. This report will not deviate from this pattern. I have many positive statements that could be made, but are not, on many sections of the report. This is not a balanced review. Note that I comment on only a small fraction of the 84 pages of the report. I would praise the contents of the pages that are not referred to.

P30+ - The contribution of rainfall is important and is extensively reviewed. Heavy emphasis is given to the quantitative aspects toward additional water supply. The casual reader may overlook the positive contribution of rain toward mitigating some consequences of salinity. For example, rain dilutes the salinity in the upper portions of the root zone even though the salts may not be leached deep into or out of the profile. Also rain that evaporates is evaporation of "pure" water and does not contribute to increased salinity as evaporation of soil-water would. In effect all rain that does not runoff is a positive contribution. Bradford and Letey (Irrig. Sci. 13:123-128) report findings and give other references that suggest that crop growth responds to the weighted average of the EC of various waters. For example if the amount of rainfall during a year equals the amount of irrigated water, the effective salinity level of the irrigation water is halved.

P38 – Although irrigation uniformity affects irrigation efficiency, they are distinctly different and must be discussed separately. Irrigation efficiency is important in designing irrigation projects, but has less utility in guiding irrigation management. Irrigation uniformity has significant consequences on irrigation management, particularly under saline conditions as will be pointed out in more detail later.

P39 – Water uptake patterns are indeed complex. The patterns are continually changing both with respect to time and position. This will be discussed more later.

P44 – I am continually intrigued by estimations on groundwater contribution to a crop. Water flows in response to soil hydraulic conductivity and gradients. Hydraulic gradients are responsive to irrigation management. One can irrigate to never have an upward gradient from the water table or a large gradient. The analyses by Gardner (1958) were done for steady-state conditions with no crop involved. In reality there will never be a condition in the field that represents the scenario he modeled. Nevertheless, Dr. Hoffman addresses an important aspect of managing saline environments. Obviously any model that will accurately assess this issue must allow water flow upward as well as downward.

P49 3rd para – "Rarely" should be replaced by "Never". Steady-state is mathematically defined as the water content and salinity at a given point remains constant with time. This is never the case in a field with the exception that I will now report. Irrigation is better described as applying a pulse that creates a "wave" action as it moves down the profile. The amplitude of the wave decreases with increased depth. Ultimately it dissipates and constant water content exists with time at the bottom of the root zone. If the "pulse" (irrigation schedule) is routinely followed, the shape of the salt and water distribution repeats itself with time after the irrigation. Eqn. 3.5 is valid because a steady-state condition (constant water content) does exist at the bottom of the root zone. Eqn. 3.6 is meaningless because there is no way to accurately relate the salinity at the bottom of the root zone with crop response to the salinity in the root zone where all of the action is. Dr. Hoffman comprehensively reports attempts to do this.

P53+ - Transient systems do converge to the steady-state condition when the input remains constant with time. This never occurs with irrigation. As pointed out above the steady-state condition is achieved at the bottom of the root zone if the "pulses" of water and salt at the surface are continually repeated. Furthermore, assuming the storage of water and salt does not change over the period of time does not lead to steady-state as mentioned in paragraph 2.

The fact that steady-state never exists in the root zone does not *a priori* negate the utility of steady-state approaches to the issue. Until recently, there were no other viable alternatives. The validity and utility of the analyses must, however, be carefully evaluated.

Eqs. 4.1 and 4.2 are valid mass balance equations that are not restricted to steady-state conditions. As pointed out above there is no basis for assuming that the LR (as opposed to LF) can be determined from ECa/ECd.

P54 – Approaches by various investigators using steady-state analyses are presented here. Some attempted to relate plant performance to ECd. Others calculated the steady-state salt concentration distribution through the root zone that would result from a continual flow of water of given salinity for various values of L. Hoffman and van Genuchten (1983) present the steady-state concentration with depth for various rooting patterns. The distribution is different for each rooting pattern. A basic premise is that the crop responds to the average root zone concentration and the number should be related to the Maas and Hoffman threshold concentration.

Ayers and Westcot (1976) assumed a 40-30-20-10 root distribution. They calculated the linear average root zone concentration from these numbers. The salt concentration increased with decreasing L. The increase was moderate in the upper part of the root zone, but very high toward the bottom of the root zone. Thus the linear average root zone salinity increased greatly with decreased values of L. Low L values (.05-.10) result in very high average root zone salinities.

Equation 4.3 can be used to calculate the linear average root zone concentration as related to irrigation water salinity and L for an exponential root distribution. Note – There is some ambiguity in the first term following 1/L. It could be interpreted as [(δ/Z) x L] or [δ/(Z x L)]. I mistakenly assumed the first until Dr. Hoffman corrected me that the latter was correct.

Hoffman and van Genuchten (1983) reported that the water-uptake weighted average salinity was the same for all root distributions and the equation equivalent to 4.3 for this averaging procedure is

$$C/Ca = \ln L/ (L-1)$$

Each procedure of analysis provides a different result with the difference often being quite large between them. Obviously, they can't all be right, but they could all be wrong. So what is the basis for selecting between them? Considering plant behavior, the linear averaging is not consistent with plant response. The linear average gives equal weight to the very high concentrations at the bottom of the root zone as to the much lower concentrations where the greatest mass of roots exist. Thus, it is expected that any linear average provides an overestimate of the detrimental effects of salinity. The water-uptake weighted average is more consistent with known plant behavior. This averaging procedure provides results that the salinity impact is the least detrimental of all the steady-state approaches.

I am taking the liberty to add another steady-state approach. I do this partly to make the steady-state report complete; but more importantly, point out that shortcomings of the analyses by my colleagues that I state above apply equally to me also. I thought that economic analyses related to irrigation under saline conditions were important. I persuaded my economic colleagues to join in the venture. I was to provide the scientific information and they were to do the economics. I understood the leaching requirement concept and that was my contribution. I was immediately informed that this was of little value to the economist, because maximum yield as prescribed by LR is not necessarily the economically optimal practice. They needed a relationship between yield and the amount and salinity of the water. The result was the development of a steady-state model that provided the relationships that the economists required (Letey et al. Soil Sci. Soc. Am. J. 49:1005-1009, Letey and Dinar, Higardia 54(1):32pp). Equation 4.3 in the present Hoffman report was the basic equation in the model. The unique feature of the model was that a reduction in yield led to a reduction in ET that led to increased leaching amount. This is nature's partial protective mechanism for plants under saline conditions. Another significant observation is that the yield curves asymptotically approached maximum yield with increasing water application. Thus a relatively large decrease in water application resulted in a relatively small yield decrement in this range. The leaching requirement (water application to achieve maximum yield) from the model is the same as would be prescribed using Eqn 4.3.

P56+ - Dr. Hoffman reviewed 4 transient-state models that he identifies as Grattan, Corwin, Simunek, and Letey models. Actually the Grattan model is a hybrid that includes steady-state and transient-state aspects. The Simunek and Letey models use the Darcy-Richards equation for water flow and the convection-dispersion equation for salt transport. The Grattan and Corwin models use the "tipping bucket" concept for water and salt flow. This is not a great distinction, but water flow in the Grattan and Corwin models are confined to downward flow.

Grattan Model – This model does consider transient conditions for water and salt flow. However, the connection between the salt profile and plant response is the same as Ayers and Westcot for steady-state conditions. Thus, I refer to it as a hybrid.

The 3 relationships at the bottom of page 56 require clarification. ECsw and ECe vary with time and depth. At what time and position are they related to ECi (irrigation water salinity) as presented in the first 2 equations? ECsw = 2 x ECe is only true when the soil-water content equals the amount of distilled water added to create the saturated extract.

The most significant difference in this analysis compared to Ayers and Westcot is incorporation of rain events. Including rain is an important contribution. Indeed, when they ran the model without rain, the results were very similar to those from the Ayers and Westcot steady-state analyses. As would be expected, including rain in the analyses gave the result that an irrigation water of higher salinity could be tolerated than if there was no rainfall. Only the quantitative results are in question.

Corwin Model – To my knowledge the Corwin model is accurately described. With regard to the five factors in evaluating models, the model does not have a feedback mechanism between the soil –water status, plant growth and potential transpiration; it does not allow compensated water uptake; and doesn't include salt precipitation or dissolution.

Simunek Model – To my knowledge the Simunek model is accurately described.

Letey Model – The Letey model is accurately described.

The main differences between the Simunek and Letey models are; (1) Simunek has submodels accounting for major ion chemistry and (2) Letey model includes a feedback mechanism to adjust the potential ET based on crop stress and allows compensated water uptake from non-stressed portions of the root zone to offset decreased water uptake from stressed portions of the root zone.

P60 last 4 lines – The lowest Lr from steady-state models was the water-uptake weighted model. The exponential model provided the highest Lr.

P62+ The numbers in the table 4.2 can be used to conclude that the transient-models prescribed a lower Lr than the steady-state models. No judgment as to the quantitative difference can be made because <0.13 could be 0.12, 0.05 or any other number less than 0.13. A substantial difference in Lr between one steady-state model and transient-state model is depicted in Table 4.3. Since Dr. Hoffman largely quoted me after Table 4.3, I obviously agree with what is stated.

Section 5.1.1- Equations 4.1 and 4.2 are mass balance equations and not necessarily steady-state assumptions.

Section 5.1.3 – An excellent comprehensive coverage of potential ET for beans in the area of interest is provided. Incidentally this information would be required as input to the transient-state models.

Section 5.2 – Dr. Hoffman provides very detailed analyses for years 1952 through 2008 using the Ayers and Westcot and exponential functions to calculate the average root zone salinity for many cases. Rainfall, as expected, increases the salinity of the irrigation water that can be used. The quantitative results are completely dependent on the validity of the Ayers and Westcot and exponential steady-state equations to provide the accurate relationship between irrigation management and crop yield.

Section 6.2 para 1 – Letey (2007) did not give a direct comparison between his transient model and the exponential model. However, the exponential model served as the basic equation for the steady-state water production function model (WPF). To obtain maximum yield, the Rhoades equation agreed more closely (but very different) to the transient result than the WPF.

Last para – Based on Dr. Hoffman's analyses, all models specify that the water quality standard could be increased to as high as 0.9 to 1.1 dS/m. His final sentence refers to the irrigation efficiency and high leaching fractions observed in the field. I agree with his conclusion as to what the standard could be. However, as I discuss later, this conclusion can be challenged if only the steady-state analyses are used.

Recommendations

1. Scientists always want more information and recommend further research. Conducting experiments to determine Maas and Hoffman coefficients is challenging, particularly in the field. The lowest threshold value for any crop that I am aware of is 1 dS/m which was used for beans in the report. It is very unlikely that a significant change will be achieved by the proposed research. There are greater uncertainties from other factors than the uncertainty of the coefficients.

2. This recommendation raises the question as to whether the sensitivity to salinity (Maas and Hoffman coefficients) differ during the growing season or whether there is a time when the effects of salinity are more detrimental for the seasonal growth even if the coefficients do not change. Bradford and Letey (Irrig. Sci. 13:101-107 and Irrig. Sci 13:123-128) concluded from the analyses using a transient-state model, that lower salinity in the early stages rather than later stages of plant growth was more beneficial to yield even though the same tolerance coefficients were used throughout the season. Fortunately the crops in the area of

concern are mostly planted in the spring after winter rains have reduced the salinity in the upper root zone.

4.– The biggest difference between the steady-state and transient-state input data, is that the steady-state uses total values of water application and average water salinity, whereas the transient state models require these input on a temporal bases.

COMMENTARY

Irrigation management under saline conditions has been done with reasonable success for decades. The guidelines proposed by Ayers and Westcot have been extensively used. How can this be if the guidelines have major deficiencies? In my judgment, the Maas and Hoffman coefficients reported for many crops has been the major contributor to the success of managing crop production under saline conditions. The main factor contributing to success is planting the right crop for the right condition. Possibly no one else has made a more significant contribution than these two individuals for agricultural production. Their coefficients are the backbone of every model, both steady-state and transient-state. Unfortunately, I don't think that they have received the appropriate personal "medal of honor". In retrospect, I regret that while I was Director of the U.C. Salinity - Drainage Program that I did not take the opportunity to properly recognize them at one of the annual meetings.

The differences between the results from steady-state and transient-state analyses are not very large for high leaching fraction, but differences become extremely high at low leaching fractions. Fairly low irrigation efficiencies with high leaching fractions are generally reported. Thus one could expect the steady-state analyses to be valid. With modern technology and emphasis on water conservation, low leaching fractions can be achieved. The significance of the erroneous steady-state analyses becomes very important.

I also believe that there have been compensating errors in analysis. Low irrigation efficiencies are often associated to be caused by non-uniform irrigation. Although low uniformity contributes to low efficiency, the impact on uniformity on crop production must be analyzed differently than efficiency. The prescribed amount of irrigation is determined by dividing the potential ET by the efficiency. For example, if the irrigation efficiency was 80%, then PET/.8 would result in applying 25% more water than ET and give an expected leaching fraction of about 25.(The leaching fraction is not perfectly proportional to the percent water applied above ET.) <u>The leaching requirement for salinity control has often mistakenly been assumed to be taken care of by the irrigation inefficiency.</u>

If the field-wide leaching fraction is 20% under a non-uniform irrigation, some of the field will have a leaching fraction greater and some less than 20. If a 20% leaching fraction is required for salinity control, part of the field will be stressed. Letey et al. (Agron.J. 76:435-441) proposed a method to compute the field-average yield for a crop that received non-uniform irrigation. Unfortunately the analysis requires the actual water infiltration distribution across the field and numerous complex factors affect the ability to accurately make these measurements as applied to crop production (Letey, Irrig. Sci. 6:253-263). Thus, the problem still exists if the steady-state analyses predict a large yield reduction at the lower leaching fractions.

Focus on the details of the matter, such as the validity of various models and the implications from their use, have diverted attention from a more simple and obvious resolution. Many salt-sensitive crops are grown and produce high yields in the Coachella Valley of California. These crops are irrigated to produce a low leaching fraction. The climate is hot, dry, and mostly with no precipitation. These are the condition where one would expect the impact of saline waters to be greatest. Yet these crops are successfully grown using Colorado River water with a salinity of about 1.25 dS/m.

Therefore, I agree with the conclusion drawn by Dr. Hoffman that the water quality standard could be increased to as high as 0.9 to 1.1 dS/m and all crops normally grown in the South Delta would be protected. I come to the same conclusion from a different perspective.