Report for 2004AZ52B: Controlling Salt Accumulation to Enhance Sustainability of Subsurface Drip Irrigation

- Dissertations:
  - Roberts, Trent, "Salt accumulation with subsurface drip irrigation: modeling and field results," School of Natural Resources, University of Arizona, thesis in process.

Report Follows

A. Problem and Research Objectives

Irrigation water often contains significant concentrations of dissolved salts. Effective management practices for controlling salt accumulation are needed so that the efficiency of water use with subsurface drip irrigation (SDI) can be maximized. It is well-known that adequate leaching is the only permanent solution to prevent salt accumulation. However, the very nature of SDI effectively prevents leaching of salts from the zone of soil above the drip tubing. This problem is exacerbated in arid climates where there is insufficient rainfall to leach salts. Hence, periodic leaching with sprinklers is needed with SDI to leach salts from shallow soil depths. However, the use of supplemental sprinkler irrigation is expensive and labor-intensive. Furthermore, the need to periodically use sprinklers threatens the long-term economic sustainability of SDI, because of the increased costs. More research is urgently needed to enable prediction of the optimum amount and timing of supplemental sprinkler irrigation with SDI systems so that growers can effectively implement salinity management practices. Solving this problem will encourage growers to adopt this proven, efficient, and sustainable cropping system, with benefits for all citizens of Arizona.

The objectives of this project were to 1) identify those factors potentially influencing salt accumulation with SDI, 2) pursue modeling to predict salt accumulation and forecast needed management practices, and 3) validate predictions with data collected in field experiments.

B. Methodology

Field Experiment

The purpose of the field experiment was to validate output from the model, and provide the physical basis for adjustment of model parameters. The field experiment will be conducted at the University of Arizona Maricopa Agricultural Center. The surface soil texture was sandy loam. The experiment included all possible factorial combinations of two irrigation water salinities (ECw 1.6 and 2.5 dS m^{-1}), two depths of drip tubing installation (18 cm, 25 cm), and crop germination with and without sprinkler irrigation. Each treatment was replicated three times in a split-split plot design, for a total of 24 plots. Each plot was 4 m x 5 m (4 beds wide). Drip irrigation tubing was injected at the appropriate depths in raised beds located 1.0 m apart. Cantaloupe (*Cucumis melo* L. Reticulatis group) was planted on 26 March, 2006 on the raised beds and was germinated by irrigating with the SDI system, or with sprinklers, depending on the treatment. Sprinkler irrigation was terminated on 14 April, 2004 and all plots were irrigated with the SDI system after that date. Amounts of water applied are shown in Table 1. Harvests were conducted during June 2005. Yield and quality (%brix) were measured within each plot.

Table 1 Water use in the cantaloupe experiment.

Depth of SDI tubing (cm)	**Sprinklers**	**Water Salinity (dS/m)**	**Water Applied (cm)**
18	-	1.6	53.2
	-	2.5	62.0
	+	1.6	37.1
	+	2.5	41.0
25	-	1.6	56.0
	-	2.5	51.1
	+	1.6	38.3
	+	2.5	32.7

Broccoli (*Brassica olearacea* L. Italica group) was planted in the same plots on 29 September, 2004, after appropriate soil tillage operations. Again, the crop was germinated by using either the SDI system, or with sprinklers, depending on the treatment. Broccoli was harvested on 2 February 2005, and yield and quality were evaluated in each plot.

The low salinity irrigation water (EC_w = 1.6 dS m^{-1}) is the normal water supplied at MAC. The high salinity treatment was achieved by constant injection of a concentrated NaCl solution using an injection pump. The resulting salinity was 2.5 " 0.4 dS m^{-1}. Bromide was used as a tracer for monitoring solute movement in soil. The Br^- ion is a biologically conserved tracer that is present in only trace concentrations in most soils. Potassium bromide was injected into all irrigation water delivered through the drip tubing, at a constant concentration of 5 mg Br L^{-1} by using a proportioning pump.

Soil samples were collected within each plot in 3-cm increments to a depth of 30 cm. Samples were collected near the bed center and at each bed shoulder. Thus, a total of 30 soil samples were collected per plot at each sampling event. Samples were collected after cantaloupe and broccoli harvests. The samples were extracted with distilled water (2:1, water:soil), and electrical conductivity was measured using a conductivity cell, and Br^- concentrations were measured by using an ion chromatograph.

Modeling

Irrigation system, soil, and environmental factors that could affect solute distribution will first be identified. Initially, we expect the most important factors to be depth of drip tubing installation, spacing of laterals, soil texture, initial soil salinity, irrigation water salinity, amount of water applied, amount of rainfall, and potential evapotranspiration. In addition, crop salt tolerance will influence the optimum timing of leaching irrigation with sprinklers.

The HYDRUS-2D model (Simunek et al., 1999) will be used to predict solute distributions as a function of SDI system, soil, and environmental conditions. Water flow will be described using the Richards' equation:

$$\frac{\partial \theta}{\partial t} = \nabla \cdot (K \nabla h) - \frac{\partial K}{\partial z} \qquad (1)$$

where ***2*** is the volumetric water content, *h* is pressure head (negative for unsaturated conditions), *K* is the unsaturated hydraulic conductivity, *t* is time, and *z* is depth. There are limited cases for which Richards' equation can be solved using analytical techniques (Warrick, 2003). However, because Richards' equation is highly nonlinear, most cases of interest must be solved by numerical methods. The initial plan is to fully utilize HYDRUS-2D to carry out the numerical computations for water flow.

Solute flow will be described using the advective (convective) dispersion equation (ADE) (Warrick, 2003):

$$\frac{\partial c}{\partial t} = \nabla \cdot (D \nabla c) - v \cdot \nabla c - S \qquad (2)$$

∇ with *c* a solute concentration, a vector gradient operator, · a vector dot product, *D* an apparent diffusion coefficient (or hydrodynamic dispersion, accounting for dispersion and diffusion), *v* an apparent (vector) velocity and *S* a sink/source term. For the simpler cases dealing with conservative solutes and well-defined sink/source terms (such as linear adsorption and first order kinetics), HYDRUS-2D (Simunek et al., 1999) will be used, and water and solute transport are coupled automatically.

C. Principal Findings and Significance

The lowest salt concentrations (measured by soil EC) were found near and below the SDI tubing (Figs. 1 and 2), because irrigation with SDI effectively dilutes salts near the tubing and leaches salt below the tubing. Salt concentrations near the soil surface were lower when the drip tubing was installed at 25 cm depth, compared to 18 cm depth. The use of sprinklers for germination resulted in lower water use (Table 1), and resulted in approximately a 20% yield increase (data not shown). Examination of Figs. 1 and 2 reveals that in most cases use of sprinklers at the beginning of the season resulted in lower soil salt concentrations at the end of the season. Despite the 50% higher salt content of water in the high salinity treatment, this did not appear to result in higher salt concentration in the soil.

Salt concentrations were high near the soil surface (<10 cm) in all treatments, which could inhibit germination of subsequent crops unless sprinklers are used. In the subsequent broccoli experiment, percent emergence and yield of broccoli were lower without sprinklers than where sprinklers were used (data not shown).

A limited number of HYDRUS-2D model runs have been completed. Two examples are shown in Fig. 3. Figure 3A should be compared to the actual data shown in Fig 2A. The predicted salt distribution was similar to the actual distribution, although salt concentrations were under-predicted at very shallow soil depths. Figure 3B should be compared to the actual data shown in Fig. 2C. In this case it is evident that the model predicted significantly higher salt concentrations than actually occurred.

Because of the short duration of this study, not all analyses have been completed by this time. The second cropping season was completed in February 2005, and samples have not yet been analyzed. The following still remains to be completed: 1. Br analyses from season 1. 2. EC and Br analyses from season 2. 3. Further comparisons of field data with predictions from HYDRUS 2-D.

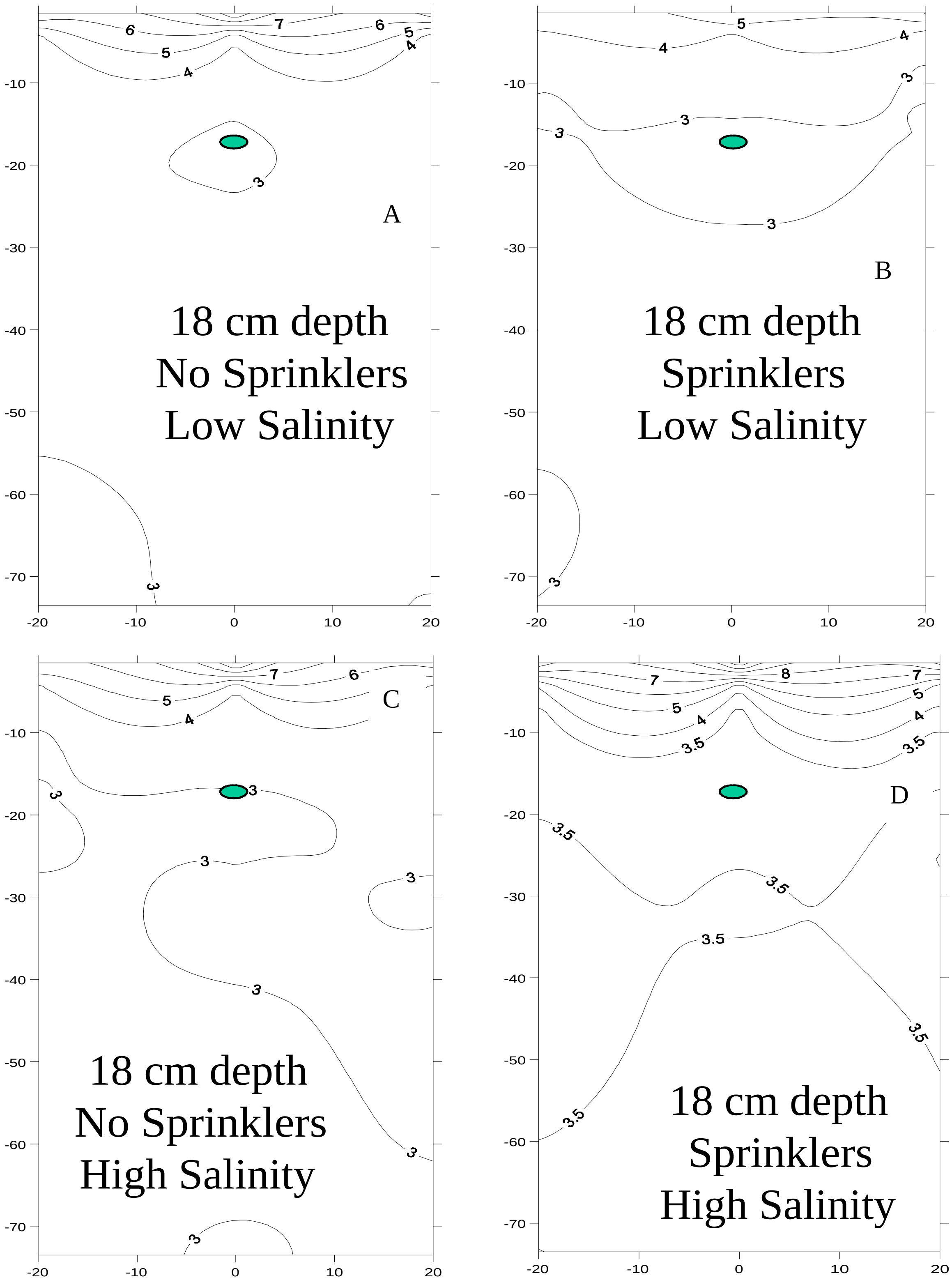

Figure 1 Distribution of electrical conductivity in plots with SDI tubing installed at 18 cm depth, from the first cropping season.

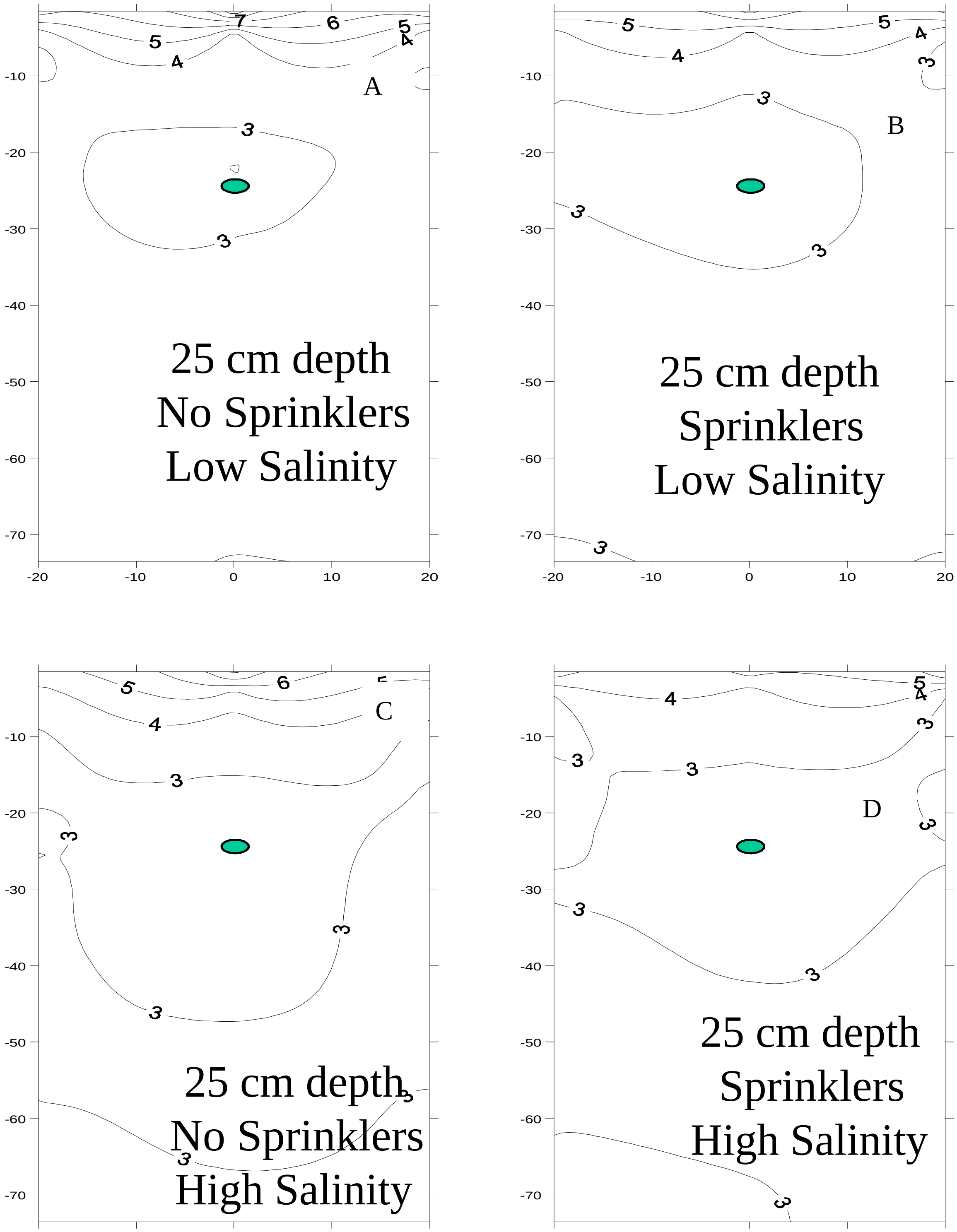

Figure 2 Distribution of electrical conductivity in plots with SDI tubing installed at 25 cm depth.

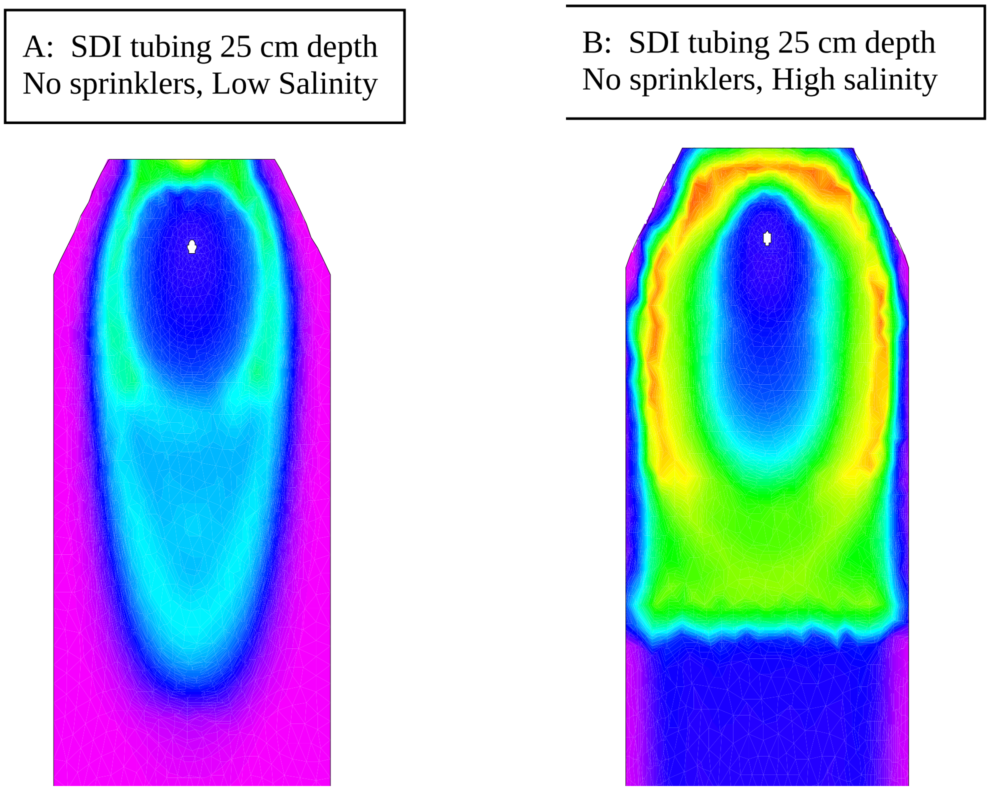

Figure 3. Simulated salt concentration profiles for the end of the first season, generated using HYDRUS 2-D.