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Spatial and Temporal Distributions of Salinity and Boron in an Irrigated Field Under Shallow Groundwater Management

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1 INTRODUCTION

As western irrigation water projects have expanded, so has the amount of drainage water needing disposal. During the 1970's and 1980's, drainage water in the San Joaquin Valley of California was used to replenish wetlands and other wildlife habitats. Drainage waters in San Joaquin Valley carry significant concentrations of selenium, arsenic, boron, and other trace elements. Eventually it was discovered in habitats receiving drainage that trace elements were moving up the aquatic food chain and becoming more concentrated, resulting in high levels of exposure for those animals near the top of the food chain. In some habitats, reproductive failures and deformities were observed in waterfowl.

Because of the adverse impacts on wildlife, disposal of agricultural drainage water into wetland refuges was halted, and alternative disposal solutions were sought. One strategy for drainage water source control is to restrict drain outflow so that a shallow water table is maintained that allows certain crops to utilize groundwater to satisfy a portion of their water requirements. Hutmacher et al. (1996) have shown that cotton crops can obtain 20-50% of their water requirement from shallow groundwater. Timing and amounts of surface irrigation impact the extent to which crops will use shallow groundwater; judicious use of deficit irrigation in combination with shallow groundwater management is necessary to achieve optimal results (Ayars et al., 1999).

One complication resulting from restricted drain flow is the potential for salinizing the soil profile. If root zone salinity increases significantly, there may be reductions in crop yield that would render the source reduction strategy unworkable. Another danger is increased root zone concentrations of phyto-toxic trace elements such as boron. Salinity and boron occur together in the landscape on the west side of the San Joaquin Valley, but their variability is yet unknown. Significant changes in salt and boron distributions could occur when a field is newly managed according to a shallow groundwater source reduction strategy. The parameters and processes controlling salt and trace element movement likely vary in space and time.

The objectives of our study were to measure and describe the spatial and temporal variations in salinity and boron content of a field in the San Joaquin Valley of California managed according to a shallow groundwater management drainage reduction strategy.

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constituents in soil solution extracts as were measured in the shallow groundwater and drainage waters using the same analytical methods
Statistical and geostatistical data analyses were performed on the spatial and temporal data using standard methods described, for example, by Yates and Warrick (2002).

3 SELECTED RESULTS

3.1 *General spatial and temporal trends*

We found a section in the middle of the field, stretching from the southwest corner to the northeast corner, has a high (40 - 60%) sand content down to about 120 cm (150 cm in the northeast corner). This coarse material is apparently related to an old stream channel that once bisected the field. The spatial patterns in the bulk density maps are similar to those for the sand content, at least to the 120-cm depth. The bulk density is larger in the areas with higher sand content.

High boron in soils is often associated with high soil salt concentrations in arid and semiarid irrigated areas. We found that the measured soil boron content is directly related to salinity ($r^2 = 0.81$) for all soil depths measured. The linear correlation between salinity and boron also extends to the shallow groundwater. Salinity and boron are clearly correlated in this field both in space and time, probably because they share a common origin, namely the alluvium derived from sedimentary marine deposits of the coast range of mountains on the western side of the San Joaquin Valley. The correlation between boron and salinity in soils and groundwater most likely exists throughout Broadview Water District.

3.2 *Temporal trends and stability*

According to Blackmore (2000), the time average of a spatial variable can give insight into the spatial time trend of that variable, and the time averaged coefficient of variation (CV) can give insight about the time stability of this trend. We analyzed the spatial time average of salinity, boron, and leaching fraction (Fig. 1). The time averages all have similar spatial patterns. The highest concentrations of boron and salinity are where apparent leaching fraction is 10% or less, and medium salinity and boron concentrations are where leaching fractions are between 10 and 20%. The lowest concentrations of salinity and boron are associated with leaching fractions greater than 20%. The highest leaching fractions are further associated with areas of sand content and bulk density. Lower leaching fractions occur where there is higher clay content and lower bulk density.

The temporal stability maps were produced by calculating the CV at each grid point (Blackmoore, 2000). The leaching fraction stability map shows that the leaching fraction was relatively stable (low CV) in zones where leaching fraction was less than 20% (Fig. 1). In areas with high sand content and high leaching, the leaching fraction was less stable (high CV). Salinity had the highest CV, between 50 and 90%. The least stable zones for salinity were the areas with increasing salinity along the north, south, and west edges of the field. Greater stability was seen in the areas with higher leaching in the center of the field and an area of lower leaching in the northwestern part of the field. Boron showed greater time stability than salinity or leaching fraction. The areas with the highest boron time stability were the same areas showing the greatest salinity stability. In the northeastern corner of the field the leaching fraction was the least stable, but boron was the most stable. The least stable areas for boron and salinity were where boron and salinity content increased. Two areas near the center of the field were unstable for both leaching fraction and boron.

2 MATERIALS AND METHODS

2.1 *Field site*

The field site is located at the SE quarter of section 13, T13S, R13E, Mt Diablo Baseline (36 degrees 47.5 minutes N Lat and 120 degrees 29.6 minutes W Long) in the Broadview Water District on the west side of the San Joaquin Valley in California. The field is a quarter section with approximately 60 hectares in production (cotton-tomato-cotton rotation). It is drained by a subsurface drainage system consisting of seven laterals installed at a depth of 1.8 m.

Because the drainage system laterals were laid perpendicular to the slope on the field, it is possible to maintain a relatively uniform water table height under a large portion of the field with valves on the east side (less control would be possible if the drain laterals had been installed parallel to the surface slope). A more detailed account of these water table control methods is given in Ayars et al. (1996).

2.2 *Irrigation and drainage*

The field was irrigated using sprinklers and graded furrows. Sprinklers were used for germination and early season irrigation of tomatoes. Furrows were used later in the season for tomatoes, and for all irrigations of cotton. Irrigation scheduling was the responsibility of the cooperating farmer. We supported the irrigation scheduling by providing information on the midday leaf water potentials measured using a pressure chamber. Rainfall in the area is approximately 0.25 m per year, but it occurs almost entirely in the fallow months between November and February.

Irrigation water quality during our study was measured monthly by the Broadview Water District. The electrical conductivity was always less than 0.8 dS m^{-1} and the boron concentration less than 0.7 mg L^{-1}.

The drainage system operation was coordinated with the farm manager. The control options allowed us to regulate flow from individual laterals using butterfly valves, and water table position with the weir structures along the main drain line. Generally, this meant that the water table would start the growing season at a depth of 1.2 m, and then decline as the season progressed and crops consumed groundwater. At the end of each growing season drain controls were removed and the field drained in preparation for harvest. When drains were flowing, we sampled the drainage water periodically.

2.3 *Data collection*

The shallow groundwater response to irrigation and drainage management was measured using 3-m deep observation wells installed on a regular grid. The depth to shallow groundwater was sampled every other week as was a water sample for water quality. Water samples were refrigerated and transported to the lab for complete anion and cation analyses.

We sampled soil twice per year, once in the spring and once in the fall, using the same regular grid pattern as the observation wells to a depth of 1.80 m or until hitting the groundwater table, whichever came first. The soil cores were sectioned into 0.30 m increments, and we measured gravimetric water content, bulk density and particle size distribution on part of each sample. The remaining soils were used to make over-saturation paste (quantitative 1:1 water:soil) and extracted using vacuum extraction procedures (U.S. Salinity Lab Staff, 1954). The extraction samples did not dry while stored in the plastic bags, and remained close to field water content until extracted. We measured the same chemical

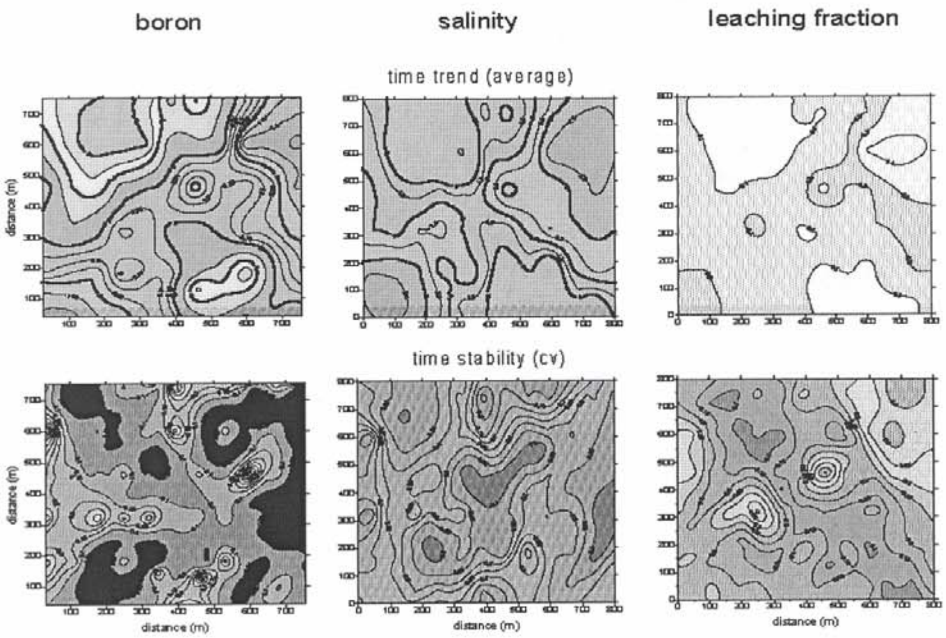

Figure 1. Spatial distributions of average time trends and stability for boron, salinity, and apparent leaching fraction.

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