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Mapping, Monitoring, and Assessment of Salinity Using Apparent Soil Electrical Conductivity

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1 INTRODUCTION

It is estimated that 7% of the world's land area (930 million ha) is salt affected (Szabolcs, 1994). Although accurate worldwide data are not available, it is estimated that roughly half of all existing irrigation systems (totaling about 250 million ha) are affected by salinity and waterlogging (Rhoades and Loveday, 1990; Szabolcs, 1994). Even though salinity buildup on irrigated lands is responsible for a declining resource base for agriculture, the exact extent to which irrigated soils are salinized, the degree to which productivity is being reduced by salinity, the increasing or decreasing trend in soil salinity development, and the location of contributory sources of salt loading to ground and drainage waters are not known.

Geospatial measurements of apparent soil electrical conductivity (EC_a) have become one of the most frequently used measurements for monitoring, mapping, and assessing field variability for agricultural applications, particularly of salinity and water content (Corwin and Lesch, 2003, 2005a). Corwin and colleagues have demonstrated the utility of geospatial EC_a measurements in a variety of agricultural applications including (i) modeling salt loading to ground water (Corwin et al., 1999), (ii) delineating site-specific management units in precision agriculture (Corwin et al., 2003a; Corwin and Lesch, 2005a), and (iii) assessing soil quality (Corwin et al., 2003b). Although each of these agricultural applications of EC_a will be discussed in the oral presentation, only the latter will be presented herein due to space limitations; therefore, it is the objective of this extended abstract to present the practical technology and methodology for measuring, monitoring, mapping, and assessing soil salinity (and associated soil properties) using geospatial EC_a measurements to characterizing spatio-temporal changes in soil quality at a drainage water reuse site.

2 MATERIALS AND METHODS

This study is part of an on-going, multi-disciplinary collaboration investigating the sustainability of drainage water reuse on forage production as an alternative method for the disposal of drainage water in California's San Joaquin Valley (Kaffka et al., 2002; Corwin et al., 2003b). Details of the methodology can be found in Corwin et al. (2003b, 2005).

2.1 Study site description

The study site is a 32.4-ha saline-sodic field (fine, montmorillonitic, thermic, Typic Natrargid) located on Westlake Farm on the west side of the San Joaquin Valley.

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2.2 EC_a survey and EC_a-directed soil sampling

An initial EC_a survey was conducted on 12–16 Aug. 1999 using mobile electromagnetic induction (EM) equipment. The EC_a survey followed the protocols outlined by Corwin and Lesch (2005b). The survey consisted of a grid of EC_a measurements arranged in a 4 (row) x 12 (position within row) pattern within each of 8 paddocks for a total of 384 sites. The spacing between the 384 sites was approximately 20 m (N-S) and 30 m (E-W). All 384 sites were geo-referenced to sub-meter precision with GPS. Measurements of EC_a were taken using a EM38 unit[1] (Geonics Ltd., Mississaugua, Ontario, Canada) with the coil configuration oriented in the vertical (EM_v) and in the horizontal (EM_h) position. Follow-up EC_a surveys were conducted in Apr. 2002 and Dec. 2004.

The EC_a measurements taken in 1999 were used to establish the location of 40 sites where soil core samples were taken. A model-based, EC_a-directed soil sampling approach, specifically a spatial response surface (SRS) sampling design, was used to locate the 40 sample sites.

2.3 Soil core sampling, soil analses, and GIS

At each of the 40 sites, soil core samples were taken at 0.3-m increments to a depth of 1.2 m. To observe spatio-temporal changes, soil core samples taken 19–23 Aug. 1999 were compared to samples taken 32 months later (i.e., 15–17 Apr. 2002). Soil cores were analyzed for physical and chemical properties deemed important for soil quality assessment of an arid zone soil whose function was forage production for livestock. Soil chemical properties included: electrical conductivity of the saturation extract (EC_e); pH_e; anions (HCO_3^-, Cl^-, NO_3^-, SO_4^{--}) and cations (Na^+, K^+, Ca^{++}, Mg^{++}) in the saturation extract; trace elements (B, Se, As, Mo) in the saturation extract; $CaCO_3$; gypsum; cation exchange capacity (CEC); exchangeable Na^+, K^+, Mg^{++} and Ca^{++}; ESP; SAR; total C; and total N. Soil physical properties included saturation percentage (SP), volumetric water content (θ_v), bulk density (ρ_b), and clay content. To display and manipulate the spatial data a commercial geographic information system (GIS) was used (i.e., ArcView 3.1; ESRI, 1992)[1].

3 RESULTS AND DISCUSSION

Sustainability of drainage water reuse at the Westlake Farm site depends upon spatio-temporal changes to soil properties that either detrimentally impact forage production or detrimentally impact livestock health. EC_e, SAR, Mo, and B were established as the most important properties for evaluating the study site's soil quality (Corwin et al., 2003b).

3.1 Correlation between EC_a and soil properties

The 1999 and 2002 correlation coefficients between EC_a (both EM_h and EM_v) and soil properties over the 0–1.2 m depth indicated that the properties of EC_e, SAR, Mo, and B were significantly correlated with EC_a at the $p \leq 0.01$ level in both 1999 and 2002.

3.2 Spatio-temporal trends in EC_e, SAR, B, and Mo

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[1] The citation of particular products or companies is for the convenience of the reader and does not imply any endorsement, guarantee, or preferential treatment by the U.S. Department of Agriculture.

Table 1 shows the shift in means from 1999 to 2002. In the case of EC$_e$, the mean levels were reduced ($p \leq 0.01$) in the first two depth increments. The salinity results suggested that leaching of salts had occurred in the near surface depth of 0–0.6 m with negligible leaching below 0.6 m. Unlike EC$_e$, the mean SAR levels were significantly reduced ($p \leq 0.05$) across all four depth increments. For B, the mean level was significantly reduced ($p \leq 0.01$) in the 0–0.3 m depth increment, and significantly elevated ($p \leq 0.01$) in the 0.6–0.9 and 0.9–1.2 m depth increments. Mean Mo levels were reduced ($p \leq 0.01$) in all depth increments.

Table 1. Mean, range, standard deviation (SD), and coefficient of variation (CV) statistics of EC$_a$, SAR, B, and Mo for 1999 and 2002. N = 40. (Taken from Corwin et al., 2005).

Soil Property	Mean	Min.	Max.	SD	CV	Mean	Min.	Max.	SD	CV
Depth: 0–0.3 m	1999					2002				
EC$_a$ (dS/m)	13.0	5.6	35.7	7.5	57.8	11.43	4.83	30.60	6.06	53.05
SAR	28.2	8.3	70.2	16.5	58.7	23.46	5.62	59.50	14.4	61.39
B (mg/L)	17.0	1.1	42.5	8.2	48.2	14.21	2.64	33.23	7.35	51.75
Mo (μg/L)	862.3	442.0	3043	532.5	61.8	632.1	150.0	3291	592.1	93.66
Depth: 0.3–0.6 m	1999					2002				
EC$_a$ (dS/m)	20.2	13.5	34.5	5.3	26.0	17.46	6.11	34.00	6.55	37.48
SAR	51.4	30.3	89.5	12.9	25.1	40.31	9.13	78.87	15.31	37.99
B (mg/L)	19.0	13.6	38.1	5.6	29.7	19.06	6.69	32.35	6.09	31.97
Mo (μg/L)	750.5	180.0	2488	430.2	57.3	576.5	220.0	1783	375.8	65.18
Depth: 0.6–0.9 m	1999					2002				
EC$_a$ (dS/m)	22.5	9.7	43.2	6.5	28.7	22.49	7.94	37.90	6.96	30.96
SAR	59.0	24.0	107.6	16.6	28.1	53.35	16.26	91.90	16.00	30.00
B (mg/L)	17.5	9.4	31.3	4.8	27.2	21.49	11.17	34.19	5.84	27.17
Mo (μg/L)	780.5	183.0	1756	338.9	43.4	661.6	252.0	2372	451.5	68.24
Depth: 0.9–1.2 m	1999					2002				
EC$_a$ (dS/m)	25.2	8.0	49.7	7.9	31.5	24.30	7.84	45.30	8.14	33.51
SAR	64.9	16.8	120.2	19.5	30.0	57.46	16.51	103.1	17.96	31.25
B (mg/L)	17.9	6.5	31.8	6.3	35.0	21.71	7.89	39.0	6.59	30.36
Mo (μg/L)	946.9	330.0	2856	450.7	47.6	720.7	240.0	2991	451.5	62.65

To visually evaluate spatio-temporal EC$_e$ trends, 1999 baseline and spatio-temporal difference are shown in Fig. 1. The blue areas represent areas of decreases in salinity, while

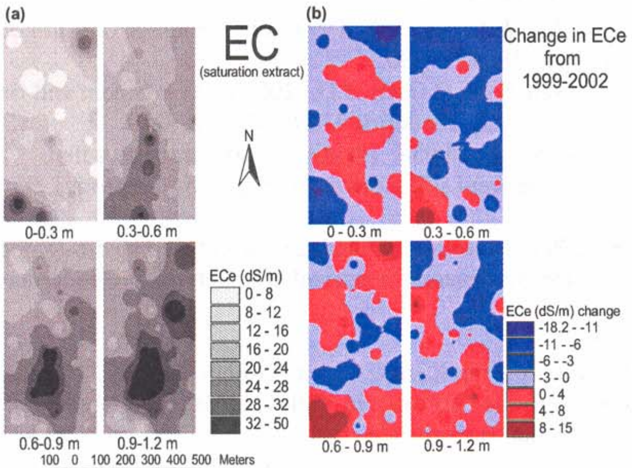

Figure 1. IDW interpolated maps of (a) EC$_e$ for 1999 at depth increments of 0–0.3, 0.3–0.6, 0.6–0.9, and 0.9–1.2 m and (b) change in EC$_e$ from 1999 to 2002 at depth increments of 0–0.3 and 0.3–0.6 m. (Taken from Corwin et al., 2005).

red areas indicate areas of increases from 1999 to 2002. It was found that EC_e and SAR displayed similar spatial patterns and temporal changes. Overall, salinity was leached from the top 0.6 m, B was leached from the top 0.3 m and accumulated in the 0.6-1.2 m depth increment, and sodium and Mo were leached from the top 1.2 m.

4 CONCLUSION

Data and statistical analyses demonstrate the flexibility and utility of EC_a-directed soil sampling as a basis for assessing management-induced spatio-temporal changes in soil quality. While only one type of management applied at one location was considered, the implication extends beyond the localized, though significant, finding that EC_a can be used to monitor drainage water reuse in a saline-sodic soil system. More importantly, when EC_a is correlated with soil properties associated with soil quality (and/or productivity), EC_a-directed soil sampling is an effective tool to broadly evaluate the spatio-temporal impact of management on soil resources. Assessment and interpretation guidelines are currently available to document the effects of current and alternative soil and crop management strategies on soil resources (Corwin and Lesch, 2003, 2005b).

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