# Delineating Site-Specific Management Units on an Irrigated, Arid-Zone Soil

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## 1 INTRODUCTION

Site-specific crop management has been proposed as a means of managing the spatial variability of edaphic (i.e., soil related), anthropogenic, topographic, biological, and meteorological factors that influence crop yield. In recent years research has shown that spatial measurements of apparent soil electrical conductivity ($EC_a$) are useful in directing soil sampling for precision agriculture applications (Corwin and Lesch, 2003, 2005a; Corwin et al., 2003). It is hypothesized that in instances where $EC_a$ correlates with crop yield, spatial $EC_a$ information can be used to direct a soil sampling plan that identifies sites that adequately reflect the range and variability of various soil properties thought to influence crop yield. The objectives of this study are (i) to utilize an intensive geo-referenced $EC_a$ survey to direct soil sampling, (ii) to identify edaphic properties that influence cotton yield, and (iii) to use this spatial information to delineate site-specific management units (SSMUs).

## 2 MATERIALS AND METHODS

A 32.4-ha cotton field located in the Broadview Water District on the west side of the San Joaquin Valley in central California was used as the study site. Broadview Water District is located approximately 100 km west of Fresno, CA. The soil at the site is Panoche silty clay (thermic Xerorthents).

Spatial variation of cotton yield was measured at the study site in August 1999 using a four-row cotton picker equipped with a yield sensor and global positioning system (GPS). A total of 7706 cotton yield readings were collected (Fig. 1a). Each yield observation represented a total area of approximately 42 $m^2$. On March 2000 an intensive $EC_a$ survey was conducted. The methods and materials used in the $EC_a$ survey were those outlined by Corwin and Lesch (2003, 2005a). The fixed-array electrodes were spaced to measure $EC_a$ to a depth of 1.5 m. Over 4000 $EC_a$ measurements were collected (Fig. 1b).

Using the spatial $EC_a$ data and a response-surface sampling design, soil samples were located and collected at 60 locations reflecting the observed spatial variation in $EC_a$ while simultaneously maximizing the spatial uniformity of the sampling design across the study area. Figure 1b shows the spatial $EC_a$ survey data and the locations of the 60 core sites. Soil core samples were taken at each site at 0.3-m increments to a depth of 1.8 m: 0-0.3, 0.3-0.6, 0.6-0.9, 0.9-1.2, 1.2-1.5, and 1.5-1.8 m. All soil samples were analyzed for soil physical and chemical properties thought to influence cotton yield: gravimetric water content ($\theta_g$), bulk density ($\rho_b$), pH, B, $NO_3$-N, $Cl^-$, salinity ($EC_e$), leaching fraction (LF), % clay, and saturation percentage (SP).

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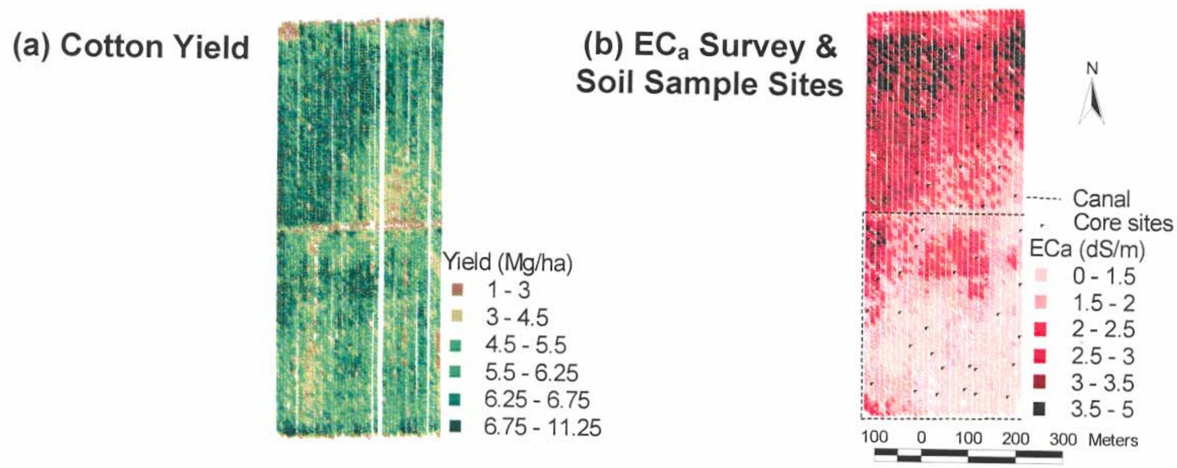


Figure 1. Maps of (a) cotton yield and (b) $EC_a$ measurements including 60 soil core sites. Modified from Corwin et al. (2003) with permission.

Statistical analyses were conducted in 3 stages: (i) determination of the correlation between $EC_a$ and cotton yield using data from the 60 sites, (ii) exploratory statistical analysis to identify the significant soil properties influencing cotton yield, and (iii) development of a crop yield response model based on ordinary least squares adjusted for spatial autocorrelation with restricted maximum likelihood.

# 3 RESULTS AND DISCUSSION

## *3.1 Correlation between cotton yield and $EC_a$*

The correlation of $EC_a$ to yield at the 60 sites was 0.51. This moderate correlation suggests that some soil property or properties influencing $EC_a$ measurements may also influence cotton yield, making an $EC_a$-directed soil sampling strategy a potentially viable approach at this site.

## *3.2 Exploratory statistical analysis*

Exploratory statistical analysis was conducted to determine the significant soil properties influencing cotton yield and to establish the general form of the cotton yield response model. The exploratory statistical analysis consisted of three stages: (i) a preliminary multiple linear regression (MLR) analysis, (ii) a correlation analysis, and (ii) scatter plots of yield versus potentially significant soil properties.

The preliminary MLR analysis indicated that the following soil properties were most significantly related to cotton yield: $EC_e$, LF, pH, % clay, $\theta_g$, and $\rho_b$. Table 1 shows the correlation analysis between $EC_a$ and soil properties and between yield and soil properties. In this particular field, $EC_a$ is highly correlated with salinity, $\theta_g$, % clay, and SP (the high correlation with B is an artifact); and cotton yield is highly correlated with salinity ($EC_e$).

A scatter plot of $EC_e$ and yield indicates a quadratic relationship where yield increases up to a salinity of 7.17 dS $m^{-1}$ and then decreases (Fig. 2a). The scatter plot of LF and yield shows a negative, curvilinear relationship (Fig. 2b). Yield shows a minimal response to LF below 0.4 and falls off rapidly for LF > 0.4. Clay percentage, pH, $\theta_g$, and $\rho_b$ appear to be linearly related to yield to various degrees (Figs. 2c, 2d, 2e, and 2f, respectively). Even

Table 1. Simple correlation coefficients between $EC_a$ and soil physicochemical properties and between cotton yield soil physicochemical properties. Modified from Corwin et al. (2003). * Significant at the $P \leq 0.05$ level. ** Significant at the $P \leq 0.01$ level. † Properties averaged over 0-1.5 m.

| Physicochemical property† | Fixed-aray $EC_a$ | Cotton yield |
|---|---|---|
| $\theta_g$ | 0.79** | 0.42** |
| $EC_e$ | 0.87** | 0.53** |
| B | 0.88** | 0.50** |
| pH | 0.33* | -0.01 |
| % clay | 0.76** | 0.36* |
| $\rho_b$ | -0.38** | -0.29* |
| $NO_3$-N | 0.22 | -0.03 |
| $Cl^-$ | 0.61** | 0.25* |
| LF | -0.50** | -0.49** |
| SP | 0.77** | 0.38* |

though there was clearly no correlation between yield and pH (r = -0.01; see Fig. 2d), pH became significant in the presence of the other variables, which became apparent in both the preliminary MLR analysis and in the final yield response model.

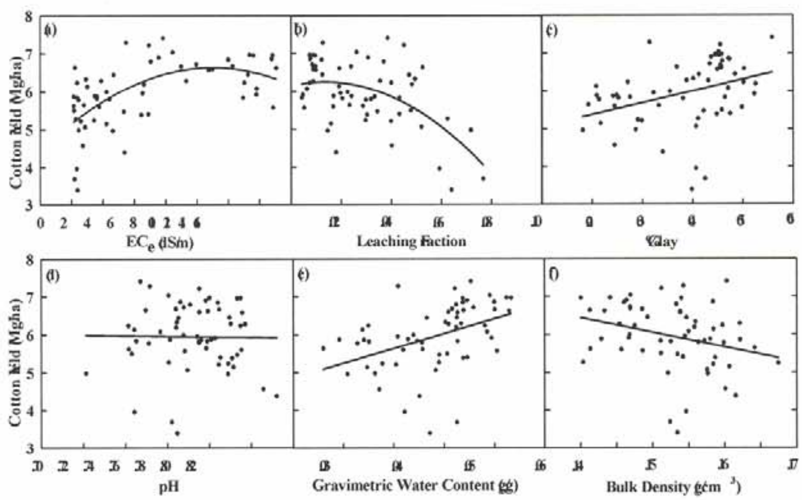


Figure 2. Scatter plots of soil properties and cotton yield: (a) electrical conductivity of the saturation extract ($EC_e$, dS $m^{-1}$), (b) leaching fraction, (c) percentage clay, (d) pH, (e) gravimetric water content, and (f) bulk density (Mg $m^{-3}$). Taken from Corwin et al. (2003) with permission.

Based on exploratory statistical analysis the general form of the yield response model was:

$$Y = \beta_0 + \beta_1(EC_e) + \beta_2(EC_e)^2 + \beta_3(LF)^2 + \beta_4(pH) + \beta_5(\%\ clay) + \beta_6(\theta_g) + \beta_7(\rho_b) + \varepsilon \qquad (2)$$

where the relationships between cotton yield ($Y$) and pH, percentage clay, $\theta_g$, and $\rho_b$ are assumed linear; the relationship between yield and $EC_e$ is assumed to be quadratic; the relationship between yield and LF is assumed to be curvilinear; $\beta_0, \beta_1, \beta_2, \ldots, \beta_7$ are the regression model parameters; and $\varepsilon$ represents the random error.

*3.2 Cotton yield response model development*

Using a restricted maximum likelihood approach to adjust for spatial autocorrelation, the most robust and parsimonious yield response model for cotton was Eq. (3):

$$Y = 19.28 + 0.22(EC_e) - 0.02(EC_e)^2 - 4.42(LF)^2 - 1.99(pH) + 6.93(\theta_g) + \varepsilon \qquad (3)$$

The $R^2$ value for Eq. (3) is 0.57. Sensitivity analysis reveals that LF is the single most significant factor influencing cotton yield. Bulk density and % clay were not significant.

# 4 CONCLUSION

Based on Eq. (3) and Fig. 2, four recommendations can be made to improve cotton productivity at the study site: (i) reduce the LF in highly leached areas (i.e., areas where LF > 0.5), (ii) reduce salinity by increasing leaching in areas where salinity is > 7.17 dS $m^{-1}$, (iii) increase the plant-available water in coarse-texture areas by more frequent irrigation, and (iv) reduce the pH where pH > 7.9. Figure 4 indicates the SSMUs associated with these recommendations.

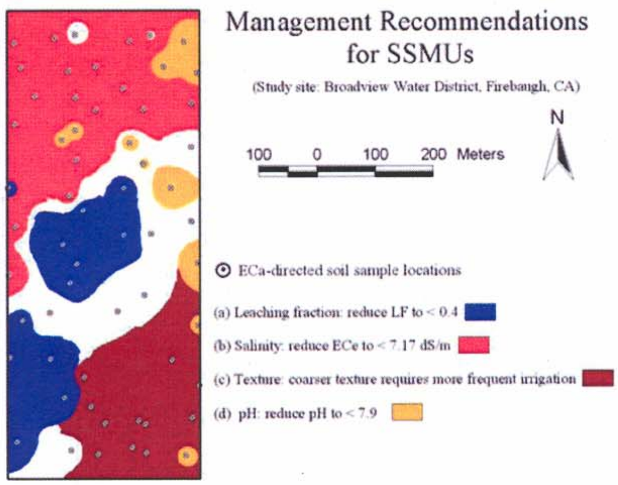


Figure 4. Site-specific management units and associated recommendations for a 32.4-ha cotton field in the Broadview Water District. Taken from Corwin and Lesch (2005b).

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