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# SOIL ELECTRICAL CONDUCTIVITY CLASSIFICATION: A BASIS FOR SITE-SPECIFIC MANAGEMENT IN SEMIARID CROPPING SYSTEMS

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## ABSTRACT

Site specific management (SSM) has the potential to improve both economic and ecological outcomes in agriculture. Effective SSM requires strong and temporally consistent relationships between identified management zones, underlying soil physical, chemical and biological parameters defining yield potential, and crop yield. In a farm-scale (250 ha) experiment in semiarid northeastern Colorado, each of eight 31-ha fields was individually mapped for soil apparent electrical conductivity ($EC_a$) and classified into four management zones (ranges of $EC_a$). Soil analyses revealed a strong negative relationship between $EC_a$ zones and soil parameters associated with innate fertility ($P \leq 0.06$). The objective of the present study was to further evaluate $EC_a$ as a basis for SSM by examining its relationship to actual yield using two years of yield maps for winter wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.). Within-field wheat yields were strongly related to $EC_a$, particularly when regressing mean wheat yields within $EC_a$ classes against mean $EC_a$ within $EC_a$ classes ($r^2 = 0.95$ to 0.99). Yield response curves revealed a boundary line of maximum yield that decreased with increasing $EC_a$. In this semiarid dryland system, $EC_a$-based management zones can be used in the SSM of wheat for: (1) yield goal determination, (2) soil sampling to assess residual fertilizer concentrations and soil attributes affecting herbicide efficacy, and (3) prescription maps for metering fertilizer, pesticide and seed inputs. Inconsistent relationships were found between $EC_a$ and corn yields indicating that, while soil factors controlled wheat yields, corn yields were more influenced by weather.

## INTRODUCTION

In recent years, the efficiency of traditional whole-field management has come into question due to increasing costs of agricultural inputs (fertilizer and pesticides) and environmental concerns associated with their inappropriate use (leaching and runoff, acidification, compaction, and toxin accumulation). This has prompted an interest in land management at a smaller level of resolution, what has been termed "farming by soil" (Larson and Robert, 1991) or management of the soil resource in space and time. Site-specific management (SSM) is an effort to match production inputs and land management with varying soil condition and crop requirements. It includes three components: (1) farming based on soil condition or yield potential, (2) managing within-field zones of differing soil condition, and (3) managing the non-crop period to reduce leaching, erosion and compaction (Pierce and Lal, 1991). Because it optimizes input efficiency, SSM has the potential to improve both economic (Reetz and Fixen, 1995) and ecological outcomes in agriculture (Wallace, 1994).

The implementation of SSM is now possible through emerging technologies including a real-time and accurate Global Positioning System, Geographic Information Systems for spatial analysis and mapping, and variable rate applicators. Lacking is an effective and economical basis for identifying management zones and for calculating and metering appropriate site-specific inputs. Such prescription maps must be temporally consistent given normal fluctuations in dynamic soil properties such as moisture and temperature. They must also delineate within-field variations in soil condition, the combined physical, chemical, and biological characteristics of soil that define productivity. Efforts to create these maps have involved both sampling (soil tests) and scanning (soil surveys, aerial photographs, crop yield maps, or topography) methods (Larson and Robert, 1991). Sampling techniques are accurate but expensive, so maps are generally produced using interpolation to span wide sampling intervals. Conversely, scanning techniques provide lower quality data albeit at appropriate levels of resolution. In semiarid regions characterized by large-scale, dryland, low-input farms, the exclusive use of intensive grid sampling for management zone determination is cost prohibitive (McCann et al., 1996). Therefore, scanning methods capable of integrating and delineating soil attributes associated with productivity are required if SSM is to be economically feasible in these regions.

One scanning option showing promise for SSM is soil apparent electrical conductivity ($EC_a$). Large-scale sensors using direct contact or electromagnetic induction technologies are available to measure $EC_a$ (mS $m^{-1}$), most simply defined as the ease with which an electrical current passes through soil. Clay type and percentage, soil moisture (in conjunction with pore size, tortuosity, and water-filled pore space as they vary with depth), salinity of the soil solution, and temperature affect $EC_a$, with one or more of these factors dominating its measurement according to individual soil characteristics. Depending on the soil factor(s) controlling $EC_a$ and the strength of the relationship between this factor(s) and other soil properties, $EC_a$ may function as a direct and/or indirect indicator of multiple soil parameters (Doolittle et al., 1994; Jaynes et al., 1995). For some soils, $EC_a$ appears to integrate soil parameters related to productivity thereby providing a template of potential yield (Jaynes et al., 1993; Kitchen et al., 1999).

In a farm-scale study in semiarid northeastern Colorado, management zones based upon four ranges of $EC_a$ were found to effectively delineate a number of soil parameters (Johnson et al., 2001). Soil properties related to yield potential (moisture, whole and particulate organic matter, total C and N, extractable P, microbial biomass C and N, and potentially-mineralizable N) and surface residue mass were negatively correlated with $EC_a$, while soil properties associated with erosion (bulk density, clay content and pH) were positively correlated. Other research indicates that spatial patterns in $EC_a$ do not change with temporal variation in soil moisture and/or temperature (Lund et al., 1999; Sudduth et al., 2000). These findings advance $EC_a$ classification as a basis for SSM.

The objectives of this study were to examine the relationships between $EC_a$-based management zones and actual yield, using two years of yield maps from two fields each of corn (*Zea Mays* L.) and winter wheat (*Triticum aestivum* L.), and to consider the significance and potential application of these $EC_a$-yield relationships for SSM in semi-arid regions.

## MATERIALS AND METHODS

This research was conducted on the farmer-owned and managed Farm-Scale Intensified Cropping Study in northeastern Colorado (40.6° N, 103.0° W) where highly variable precipitation averages 420 mm annually. The site encompasses a contiguous section of farmland (approximately 250 ha) divided into eight approximately 31-ha fields. In 1999, it was converted from a conventionally-tilled wheat-fallow system to a no-till winter wheat–corn–proso millet (*Panicum miliaceum* L.)–fallow rotation with each crop present in two replicates each year.

A Trimble AG132 D global positioning system (Trimble Navigation Ltd., Sunnyvale, CA)[1] with sub-meter accuracy was used to produce three geo-referenced data layers for analysis and comparison. Data layers included a map of $EC_a$ (approximately 0-30 cm depth), the map of $EC_a$ classified into four zones, and yield maps (two years of corn and winter wheat). Yields were mapped using a Micro-Trak yield monitor (Micro-Trak Systems Inc., Eagle Lake, MN)[1] and Farm HMS software (Red Hen Systems, Ft. Collins, CO)[1]. Each field was $EC_a$ mapped in March 1999 by direct contact using a Veris 3100 Sensor Cart (Veris Technologies, a division of Geoprobe Systems, Salina, Kansas)[1] and classified into four management zones (low, medium-low, medium-high, and high ranges of $EC_a$) using ERDAS Imagine (ERDAS, Atlanta, GA)[1]. Data layers were projected to UTM coordinates in the NAD83 and redefined as grid files (10-m grid-cell resolution) with identical geo-referenced northwest and southeast points (boundary control points) using ArcInfo (ESRI, Redlands, CA)[1]. In this format, data layers were superimposed to create a "grid stack" wherein corresponding geo-referenced data could be exported in spreadsheet format for statistical evaluation. Yield and $EC_a$ were compared using regression and ANOVA for a randomized complete block design with $EC_a$ zone treatment factors. Soil characteristics (0-30 cm depth) of the $EC_a$-management zones are given in Table 1. Additional information on the experimental site, $EC_a$ classification process, and soil collection and analysis is provided by Johnson et al., 2001.

**Table 1.** Within-$EC_a$ class means and significance across crop treatments for selected soil properties (0-30 cm depth).

| | $EC_a$ ranges | $EC_a$ means | Water content | Bulk density | Clay | pH | SOM | Total C | Total N |
|---|---|---|---|---|---|---|---|---|---|
| | dS $m^{-1}$ | dS $m^{-1}$ | kg $kg^{-1}$ | g $cm^{-3}$ | % | | Mg $ha^{-1}$ | Mg $ha^{-1}$ | Mg $ha^{-1}$ |
| $EC_a$ Class | | | * | † | * | ** | ** | ** | ** |
| Low | 0.00 – 0.17 | 0.12 | 0.207 | 1.32 | 22.8 | 6.33 | 124.8 | 43.8 | 4.08 |
| Med. Low | 0.12 – 0.23 | 0.17 | 0.187 | 1.39 | 24.3 | 6.42 | 115.9 | 35.2 | 3.45 |
| Med. High | 0.14 – 0.29 | 0.23 | 0.185 | 1.39 | 27.3 | 6.72 | 110.4 | 32.2 | 3.09 |
| High | 0.18 – 0.78 | 0.30 | 0.178 | 1.42 | 28.1 | 6.92 | 112.6 | 32.7 | 3.10 |

†, *, ** Comparisons of $EC_a$ class treatments are significant at the 0.10, 0.05, and 0.01 levels, respectively.

## RESULTS AND DISCUSSION

As predicted by previous findings of a significant negative relationship between $EC_a$–delineated management zones and soil properties related to yield potential (Table 1), yield maps collected during 1999 and 2000 revealed a negative relationship between $EC_a$ and winter wheat yields ($P \leq 0.01$). The regression of mean yield within $EC_a$ class against mean $EC_a$ within $EC_a$ class, for each wheat field, revealed strong and consistent relationships ($r^2 = 0.95$ to 0.99) (Fig. 1). From two years of data, the strength of these relationships appears to be more affected by individual field (soil variability) than by year (weather variability). This was true even though wheat yields were significantly greater in 1999 than in 2000. Whole-field yield averages were above average for the region in 1999 (2956 and 3561 kg $ha^{-1}$) and typical in 2000 (2352 and 2419 kg $ha^{-1}$).

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[1] Mention of a trademark, proprietary product or vendor does not constitute a guarantee of or warranty of the product by USDA nor imply its approval to the exclusion of other products that may be suitable.

Inconsistent relationships were documented between $EC_a$ and corn yields during the two years evaluated (Fig. 1). Disparity in the $EC_a$-yield relationship between wheat and corn has several possible explanations. First, wheat is a more suitable crop for the central Great Plains than corn because its growing season corresponds well with precipitation patterns for the region. In addition, the rotational sequence of wheat after fallow improves water availability to that crop. These factors reduce water stress on wheat to benefit yield and yield consistency across years. Conversely, the corn growing-season spans a period of low precipitation and high evaporative demand to diminish water availability and water-use efficiency. Furthermore, corn follows wheat in the rotation under study, making yields more susceptible to annual variations in precipitation. Corn crops in both 1999 and 2000 were highly drought stressed in July and August, a critical time in the growing season. Consequently yields were low in 1999 (2069 and 2571 kg $ha^{-1}$), and poor in 2000 (1380 and 1630 kg $ha^{-1}$). Variability in precipitation timing and quantity appear to diminish the impact of underlying soil condition on corn yields.

The regression of 1999 wheat yields against $EC_a$ provides a useful portrait of within-field yield variability and yield potential (Fig. 2A). These data were selected because they represent an above-average year for wheat and, therefore, the best available indicator of potential wheat yield for the study site. In highly heterogeneous soils, it may be important to collect yield data from specific fields for application to only those fields. Figure 2A illustrates that $EC_a$ is yield limiting, or more appropriately soil characteristics integrated by $EC_a$ and other soil properties with which they are correlated are yield limiting. As $EC_a$ increases, mean and maximum wheat yields decrease. In yield-response curves, maximum yield potential is known as the boundary line (Webb, 1972), estimated here by the regression line in Figure 2B. This line was defined by data falling at the 90th percentile of yield frequency, for each 0.01 increment of $EC_a$. Even with the inclusion of infrequently occurring high- and low-end $EC_a$ data, the points are reasonably linear ($r^2 = 0.77$). A line, so defined, can be used to identify maximum yield goals for site-specific nutrient determination within $EC_a$-delineated management zones. Nutrient inputs can be based upon the identified maximum potential yield or a percentage thereof. The economic and ecological implications of fertilizer over-application must be carefully considered. Nutrient rates based upon yield goals short of maximum may be most appropriate in areas where precipitation inputs are rarely sufficient to achieve maximum yield.

## CONCLUSIONS

The success of SSM relies on the creation of appropriate databases to describe spatial variability in past crop performance to be used as a basis for future management decisions. The exclusive use of $EC_a$ to explain yield variability may not be effective, a fact poignantly illustrated by the lack of consistent relationships between corn yield and $EC_a$ in this study. Similar limitations exist for yield maps. While yield maps are the most realistic integrators of all factors driving yield, they encompass both management-affected (soil-based) and non-controllable (weather) factors. This makes it difficult, if not impossible, to isolate and quantify those factors in yield heterogeneity that can be managed. The complementary suite of data layers provided by an $EC_a$–classified map, "ground-truth" soil assessment, and accumulated yield maps appear to best address both actual yield and intrinsic soil productivity factors.

For the region and soils in this study, correlations between wheat yields and soil characteristics integrated by $EC_a$ support $EC_a$-classification as a useful framework for the SSM of dryland winter wheat. Zones based on $EC_a$ provide a basis for: (1) soil sampling to assess nutrient levels and soil attributes affecting herbicide efficacy, (2) setting yield goals, and (3) metering fertilizer, pesticide and seed inputs. The first two functions are essential for calculating fertilizer, herbicide, and seeding rates within management zones, while the last delineates the zones to which they will be applied. For this study site, continued evaluation of yield maps over a number of years may allow identification of management zones appropriate for corn. It is also possible that variable weather influences may diminish the yield impact of soil factors to such a degree that SSM is ineffective for corn in this region, given current technology.

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**Figure 1**

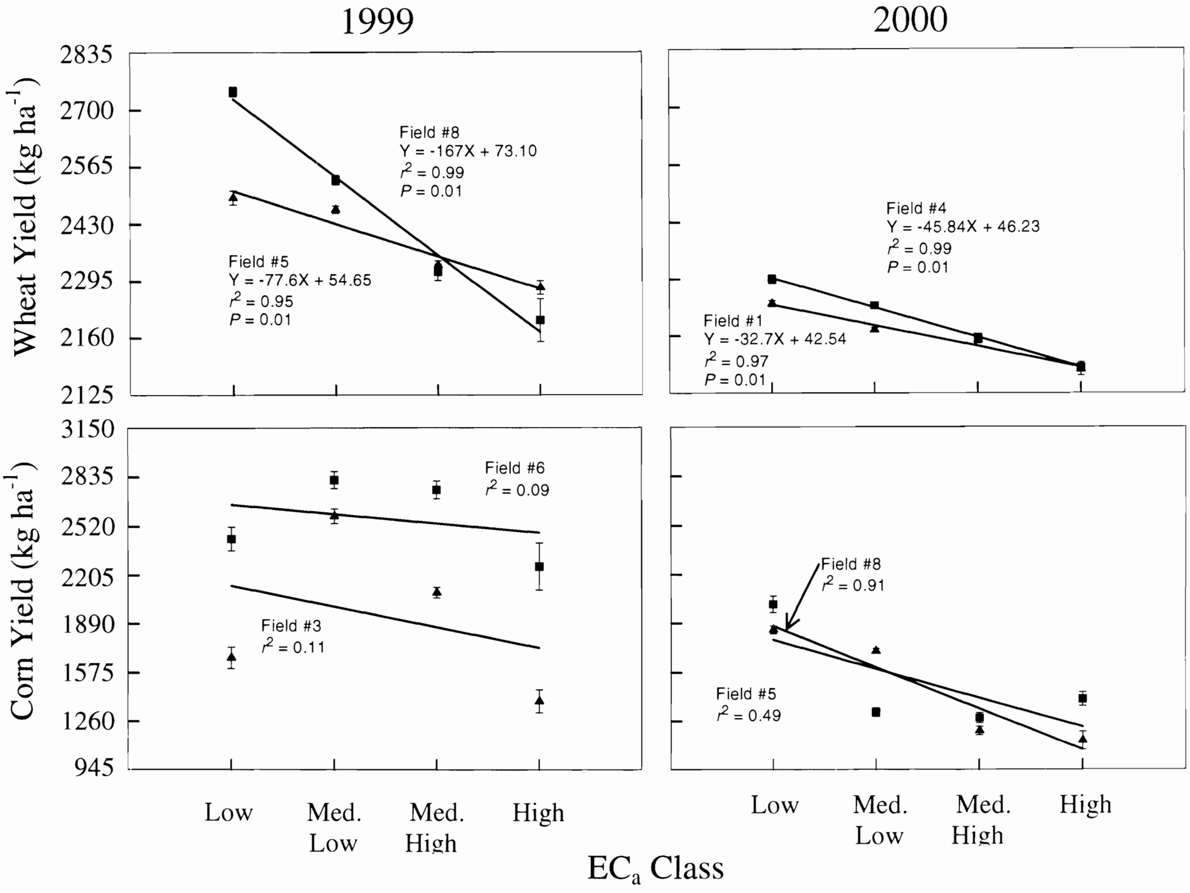

**Figure 2**