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Combining Site Specific Data with Geospatial Analysis to Identify Variable Rate Irrigation Opportunities in Irrigated Agricultural Fields.

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Abstract.
Increasing demand for improving irrigation water use efficiency (IWUE) across irrigated croplands has producers looking for new opportunities to conserve water and maintain their crop production levels. Variable Rate Irrigation (VRI) technology may provide opportunities to enhance IWUE, but as with site-specific crop management of other crop inputs, all fields may not benefit from an approach which utilizes VRI. To consider the potential benefits of VRI, it will be necessary to examine multiple site-specific spatial data layers (e.g., crop yield, soil type/texture, and terrain) as well as the current conditions within a field using geospatial analysis techniques.

The goal of this study was to identify trends and valuable relationships among various spatial data layers collected throughout the growing season to determine if possible management zones can be defined. Location specific studies were conducted in summer of 2013 which resulted in soil classification and crop growing season volumetric water content of the soil profile. The result of this study provided information on the soil electrical conductivity (EC) relationship with soil properties including clay content and organic matter. Full-field data layers analyzed include soil EC, topographic wetness index (TWI), and crop yield to find any correlations that could be used to begin defining management zones throughout the field. For this specific field it has been determined that yield trends are closely related to EC trends. When comparing EC with soil properties the result was a positive relationship with clay content and inverse relationship with organic matter.

Keywords. Site-specific crop management, irrigation water use efficiency, soil moisture content, electrical conductivity, terrain analysis
Introduction

Variable Rate Irrigation (VRI) allows for site specific watering depths that provide the potential to optimize water use. There are numerous factors that impact the effectiveness of irrigation, including soil properties, runoff, run-on, tillage practices, crop condition, and weather. As producers desire to maximize their water use efficiency, methods to use readily available data for developing relationships among field properties and crop yield to aid in irrigation would be beneficial.

Yield mapping has revolutionized the way producers view spatial crop productivity in an attempt to maximize input use efficiency. When additional layers of data are available it may be beneficial to analyze them to help explain yield variability, and offer further insights into improving production practices. There is interest in characterizing soil and topographic variability throughout fields to pair with yield maps (Kitchen et al., 2003).

Mapping soil electrical conductivity (EC) provides the ability to recognize differences in soil properties on a large scale and can quickly be obtained. EC has been found to correlate well with different soil particle sizes with clay soils having a high conductivity relative to sands. Recognizing locations of clay-pan soils for instance, may explain variations in infiltration and water storage leading to yield differences for different precipitation crop years (Kitchen, et al., 2003). Combining real-time kinematic (RTK) global positioning system (GPS) coordinates with EC, a spatial variability map of soils may be better defined. There is opportunity to use EC maps to target soil moisture monitoring sites and also water holding properties of the soil on a large spatial scale to aid in irrigation strategies (Hedley and Yule, 2009).

Topography has effects on the hydrologic response of rainfall catchment and impacts the available water for crop production. Access to digital elevation models (DEMs) has become easier through public datasets and RTK GPS elevation values recorded during field operations for use in terrain analysis. Computerized terrain analysis tools have made it possible to readily quantify topographic attributes (Kitchen et al., 2003); one in particular is terrain analysis using digital elevation models (TauDEM) which is free software accessible using a geographic information system (GIS) software which can compute various topographic layers from DEMs (Tarboton, 2013). Topographic wetness index (TWI) is widely-used in precision agriculture, and has been utilized in modeling the spatial distribution of soil moisture and surface saturation (Cheng et al., 2011).

The goal of this project was to provide information regarding the interactions among various crop production data layers to identify potential zones where VRI may be beneficial. Specific objectives were to analyze yield data by comparing it with soil EC and TWI on a full-field scale in order to find any correlations that are valuable for irrigation planning. Data from the 2013 growing season including average soil moisture conditions, soil EC, TWI, soil silt percent, soil clay percent, soil organic matter percent were compared to identify trends in soil water conditions throughout the field. Soil EC was compared with soil clay content and organic matter in attempt to maximize the use of the spatial EC data with six locations where soil samples were obtained.

Materials and Methods

Research was performed on a 69 ha irrigated field located in Hamilton Co., Nebraska that consisted of Hasting, Crete, and Fillmore silt loam soils. Crop rotation practices include corn and soybeans with occasional wheat.

TWI was used to quantify topographic control on hydrological processes by combining the local upslope contributing area and slope (Figure 1). TWI can be used to locate potential areas that are prone to runoff and run-on due to topography. In many fields, varying soil infiltration rates at different depths may affect crop yields; TWI may help identify potential zones in a field that would benefit from VRI. A 3 m DEM obtained from the national elevation dataset (Gesch et al., 2014) was used to perform the topographic analysis. The first step was to resample the DEM from 3 m to 30 m and convert the points to raster by using the point to raster tool in GIS (ArcMap v10.2, ESRI, Redlands, CA) and using the mean of the points for the raster assignment. TauDEM (Tarboton, 2013) was used in ArcMap to compute the wetness index (Equation 1).

TWI was calculated as follows:

\[ TWI = \ln\left(\frac{\alpha}{\tan(\beta)}\right) \]

(1)

Where:
\( \alpha \) = specific catchment area and
\( \beta \) = slope.
Soil EC was collected on 7 & 8 April 2014 before planting. A Veris MSP platform was used to obtain shallow (30 cm) and deep (1 m) EC readings with spacing between passes at approximately 12 m. A 30 m raster was created out of the EC values (Figure 2) with the point to raster tool in ArcMap where the raster value assigned was the mean of the points within the 30 m area, it was then snapped to the TWI raster.

Yield data were collected from the harvest records from several seasons. Microsoft Excel was used to clean the data. Filters included any rows that contained travel distance less than 2 m, swath widths less than 9.1 m, and grain moisture values equal to 0. While yield maps for the previous ten years were provided, only a selected few were used since numerous field trials had been conducted in previous seasons making the data difficult to effectively normalize the data. The selected maps were loaded into ArcGIS where they were converted into a 30m raster by point to raster (ArcMap tool) and took the mean of all points in each 30m box and snapped the result to the TWI raster.

Soil samples were collected at six locations (Figure 3) covering a range of soil types and topographic positions.
and seven depths (from 0.3 through 2.13 m below ground surface). The samples were sent to Ward Laboratories, Inc. (Kearney, Nebr.) for analysis on percent sand, silt, clay and percent organic matter. A Giddings probe was used to install aluminum access tubes (5.08 cm) at each location for accurate determination of volumetric water content ($\theta_v$) with a neutron gauge (Troxler 4302). In 2013, soil moisture was measured at seven depths (15, 46, 72, 107, 137, 168, and 198 cm) eight times before harvest (13 and 27 June, 9 and 24 July, 8 and 20 August, 3 September, 2 October) and once after harvest (20 November). The ratios between the observed counts and the standard counts were converted to volumetric water content $\theta_v$ by a linear calibration determined from the laboratory determined $\theta_v$ of the soil samples obtained during access tube installation.

![Figure 3: Soil sample and moisture monitoring location points with outlines of center pivot application areas (aerial photography is from 2012).](image)

Scatter plots were created and correlation coefficients calculated for wheat in 2004, two different hybrids separating the field in 2010, and two different corn hybrids in 2013. Since the hybrids for 2004 and 2013 varied within the field, they were analyzed separately. In Figure 6, 2010 Corn 1 Yield and 2010 Corn 2 Yield are the axis titles used for the differing hybrids for that year and 2013 Corn East Yield and 2013 Corn West Yield are the axis titles used to separate the hybrids in 2013 which happened to halve the field into two pieces, east and west. To explore how shallow EC, deep EC, and TWI related to yield for this field, the sample Pearson's product moment correlation coefficient $r$ was calculated for each relationship (Equation 2). The strength of the correlation is indicated by the absolute value of $r$ while the direction of the correlation (i.e., positive or negative) is indicated by the sign of $r$. The test statistic follows a $t$ distribution with degrees of freedom ($n - 2$) when the true $r$ equals zero (i.e., no correlation), so two-tailed $p$-values report the statistical significance of the sample $r$ value from zero.

The test statistic was calculated as shown in Equation 2:

$$t = \frac{r \times \sqrt{n-2}}{\sqrt{1 - r^2}} \quad (2)$$

Where:

$n =$ number of data pairs and
The neutron probe data were used to calculate an average of the root zone volumetric water content for 1.5 m to examine how soil properties affected volumetric water content. It has been recognized that average root zone volumetric water content determined from nine measurements throughout six months may not fully portray the temporal patterns of volumetric water due to the timing of the readings.

Results & Discussion:

Variability among the spatial data layers (shallow and deep EC and TWI) was quantified in ha based on ranges selected within each data set (Table 1). Shallow and deep EC values exhibited greater variability in terms of field area within the different ranges. TWI showed less variability which was expected based on the field topography. For this particular field, any irrigation treatments would most likely need to be based primarily on changes in soil type and texture (from the EC data) rather than solely on terrain effects.

<table>
<thead>
<tr>
<th>Table 1: Spatial data layer variability for shallow EC, deep EC, and TWI within study field.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow EC</td>
</tr>
<tr>
<td>mS/m</td>
</tr>
<tr>
<td>15-25</td>
</tr>
<tr>
<td>25-35</td>
</tr>
<tr>
<td>35-45</td>
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<td>45-55</td>
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<td>55-65</td>
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</tbody>
</table>

At the six experiment locations there are neutron probe readings which allow for an average volumetric water content to be estimated throughout a portion of the 2013 growing season. Combining point data soil EC collected in the field at the locations where the soil samples were constructed allows for some specific point analysis (Figure 4). It is concluded that for this field the deep EC and shallow EC relate to organic matter and clay content very similar. The results indicate that as expected, soil EC increased as the clay content of the soil increases. The opposite relationship is seen between soil EC and organic matter in that as the organic matter content increases the soil EC decreases.

The average root zone volumetric water content results were compared with other features of the field which include EC, TWI, organic matter content, silt content, and clay content (Figure 5). Combining water content data with soil EC data collected in early 2014 indicates that deep EC and shallow EC result in the same trends. A relationship between average water content and organic matter for the root zone shows a positive relationship where the average volumetric water content increases as the percent organic matter in the soil increases. The relationship between average volumetric water content with clay and silt do not tend to show
any conclusive results with the six data points whether or not they strongly relate. As expected, areas with a higher TWI index value seemed to maintain a higher average root zone $\theta_v$ throughout the growing season.

Figure 5: Location specific average root zone volumetric water content vs. field and soil characteristics.

To determine whether a field could benefit from VRI it is beneficial to study yield on a full field scale to determine whether field properties, in particular shallow and deep EC along with TWI can be used in decision making about irrigation management zones. Results indicated that for years 2004 and 2010 all correlations are negative (Figure 6), it is also concluded that shallow EC has the strongest correlation to yield for these years. Corn yield in 2013 shows little correlation between yield and field properties, but spatial variability of yield has decreased significantly since 2010. This may have been the result of a farming practice or weather impacts on the crop.
The results of the average root zone volumetric water content were bimodal with three of the six results low and the other three relatively higher with both the low and high values being similar. The difference between the high and low water contents are at least 4.6 cm in the 1.5 m zone.

It is hard to conclude and draw management decisions from the full-field spatial data displayed in this paper. The six locations throughout the field where soil sampling and water content monitoring occurred provide
opportunities to suggest different management practices at similar places in the field. Soil EC can be used to find similar soil characteristics throughout the field and shows correlation to yield for this specific site. Soil water content depends on properties of the soil, some of these properties include texture, bulk density, hydraulic conductivity, and organic matter. Hydrologic process such as infiltration, runon, and runoff are also impacted by soil properties. Soil EC can be correlated to soil properties, by soil analysis and water content monitoring, a better understanding for soil EC and TWI values may provide some useful information when identifying management zones in an irrigated crop field.

As a preliminary study, organic matter displayed relationships to volumetric water content. While point samples of organic matter were obtained, there is interest in mapping of organic matter for the entire field to recognize potential zones where water application amounts could be altered to conserve water and still maximize yield. It is difficult to separate the impacts on yield. Knowing that the field has uniform nitrogen application leads to interest in determining how organic matter and water work together to maximize yield since it is hard to separate how each affect the crop.

**Conclusion or Summary**

The main goal was to use various crop production data layers in order to identify potential zones where VRI might be beneficial. After analyzing yield data with soil EC and TWI on a full-field scale and site data from the 2013 growing season including soil moisture conditions and soil properties it was determined that for this specific site relationships between EC correlated well with yield and soil properties (clay content and organic matter). Quantifying the variation for EC and TWI in terms of field area demonstrated that for this particular field, EC (i.e., soil type and texture) seemed to contribute more to variability. Due to the relatively flat topography, little variation was seen in TWI values. By combining readily available data with in-field soil properties and measured seasonal volumetric water content it may be possible to identify and evaluate potential management zones. Further research for this project will include additional field trials during the 2014 and 2015 growing seasons to monitor areas within the field based on different combinations of these field properties.

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