ADVANCES IN SOIL MAPPING FOR IMPROVED IRRIGATION MANAGEMENT

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INTRODUCTION

With increasing concerns about environmental impacts of irrigated agriculture and the continual economic pressures due to rising energy prices and declining water supplies, many producers are looking at various alternatives for reducing or at least minimizing the increase in irrigation costs. One option is improving irrigation management which can be defined generally as applying the right amount of water at the right place and at the right time. Over the past 30 years, research and on-farm studies have shown that savings of 20-30% in the amount of water applied and significant reductions in nitrogen leaching, are possible using soil water budgeting techniques for irrigation scheduling at the field level. Because nitrates move readily with water in the soil profile, water and nutrient management are closely tied together. Currently, researchers and some progressive minded producers are investigating the use of precision agriculture concepts to improve water and nutrient management. Regardless of the management level used, it is necessary to account for differences in soil conditions within a field with better and more detailed information.

Traditionally, soil scientists have used aerial photography maps, field observations of topography, soil texture, and other soil parameters along with well documented descriptions of reference soil pedons, to make soil maps. The USDA-NRCS has mapped nearly all of the agronomically significant areas within the U.S. to aid producers in their crop production practices. Generally, NRCS soil survey data or data obtained from soil sampling at a few selected sites in each field, have insufficient detail about water holding capabilities and consequently are marginally adequate for managing irrigations under average field conditions.

Some producers have opted to take many more soil samples usually in some sort of a grid pattern, to get a better understanding on soil variability in a field. The increased cost for the improved accuracy depends mainly on the sampling density. The accuracy of the generated maps is also affected by the interpolation method used to create a continuous mapped surface from the actual field data points.

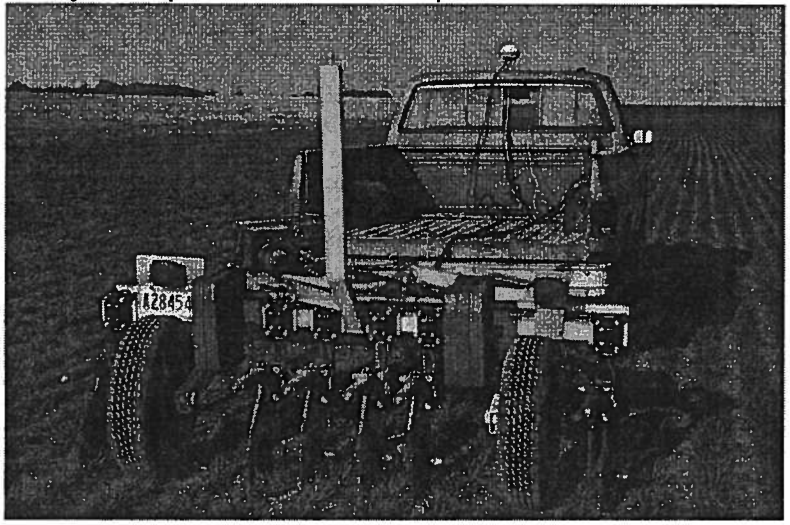
Since it is not possible to physically measure leaching below the root zone for an entire field, physically based simulation models are often used to estimate environmental impacts from agricultural practices. These models mathematically describe the physical processes occurring at a point so spatial variability is accounted for by running the model at the various points in a field using appropriate input values. Since greater accuracy of the input parameters usually instills greater confidence in the model results, it is desirable to have parameter values as good as economically possible. Obtaining the necessary data using labor-intensive field sampling is not economically justified so other less expensive approaches are needed. An affordable approach for improving the accuracy of soil mapping is to use electrical conductivity (EC) measurements as a surrogate measurement for several soil parameters.

MEASURING ELECTRICAL CONDUCTIVITY

Electrical conductivity (EC) is a measure of the ease that electricity can move though a soil. Since it is influenced by a number of factors such as salinity, porosity, amount and composition of soil colloids, organic matter, and moisture content, it is a surrogate measurement for several different soil parameters important for irrigation management. The relationship for a particular field depends on the presence and magnitude of the various parameters. In the absence of saline conditions, percentages of sand, silt, and clay sizes that define soil texture, usually correlate very well with EC. EC values for clay soils are higher than sandy soils because the clay size particles have charged surfaces, and hold larger amounts of water. Useful information for irrigators includes the water holding capacity (WHC), infiltration rate, and the presence of any soil layer that impedes water flow. WHC is usually highly correlated with soil texture and organic matter (OM). Since it is relatively inexpensive to map large areas with these technologies, one goal is to relate various soil parameters with EC in order to generate maps for improving water management decisions.

Two types of equipment are commercially available to measure EC. The Veris 3100 equipment (Figure 1a) applies a constant electric current through the soil, and measures the voltage between two commutators in contact with the ground. EC is measured for 2 depths; 0 – 1 ft (0 to 0.3 m) and 0 – 3 ft (0 to 0.9 m). The Geonics EM38 (Figure 1b) unit utilizes a magnetic transmitter coil to induce a small electric current through the soil. A receiver coil picks up the attenuated current. Changing the orientation of the transmitter and receiver coils changes the depth of sampling. This equipment samples to a depth of about 2 ft (0.75 m) in the horizontal orientation and 5 ft (1.5 m) in the vertical orientation. Although the EM38 equipment was originally designed for hand-carrying through the field, it can be mounted on a custom-built non-metallic carriage and pulled through the field as well. Either of these units can be pulled at a speed of approximately 8-10 mph (13-16 kph) data collection rate was 12-16 ha per hour. With a sampling interval of 1 sec, the sample interval is about 8-12 ft (2.5-3.5 m) in the direction of travel. The swath width is 50 ft (17 m) perpendicular to the direction of travel resulting in approximately 75 readings per acre.

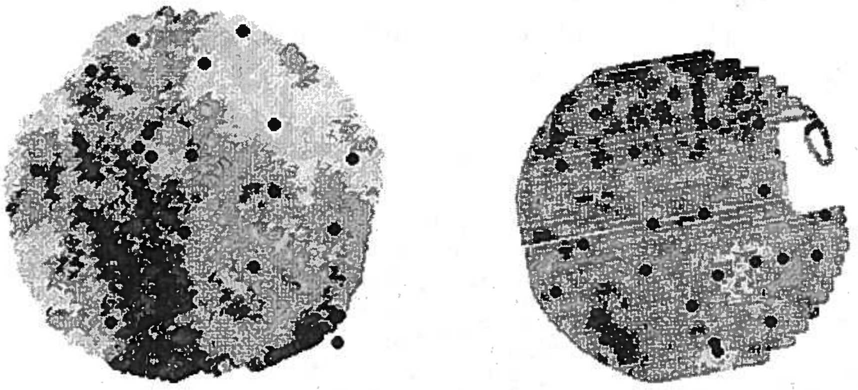
Both systems can be interfaced with Global Positioning System (GPS) equipment to provide geographic locations (i.e. latitude and longitude values) for every data point taken. Examples of the EC data are shown in Figure 2.



a. Veris 3100 unit

b. Geonics EM 38 unit

Figure 1. Commercially available equipment for measuring soil electrical conductivity.



Colorado Kansas

Figure 2. Maps of EC (0-1 ft depth) with soil sampling sites (dots).

ANALYSIS

To date our work has focused on collecting EC data on different soil types, in order to determine how the soil factors affect EC measurements. Two fields (northeastern Colorado and south central Kansas) were chosen where soils were quite variable and soil salinity was not a factor. Both fields were pivot irrigated and soils ranged from sandy loam to silty clay loam.

Although both types of equipment were used successfully on both fields, only the Veris data were used in this analysis. The 10000+ EC data points for each field were screened to eliminate obvious erroneous readings that sometimes occur if there is poor electrical contact between the commutators as the unit crossed deep pivot tracks or other ruts. Statistical software developed by the United States Soil Salinity Lab in Riverside, CA was used to select 20 sites per field where soil cores are taken to a depth of 4 ft (1.2 m). The selected sites are spread over the range of measured EC values as well as spatially distributed across the field to ensure that soil data collected are taken from statistically sound locations. Soil moisture contents were determined at 1 and 3 feet (0.3 and 0.9 m) with gravimetric sampling and the oven-dry method. The soil cores were logged by soil horizons. Samples were sent to a commercial lab for analysis of pH, CEC, OM, salts, % sand, % silt, %clay.

A statistical technique called **cluster analysis** was used to partition the entire EC data set into subsets called clusters that display the smallest within-cluster variation and the largest between-cluster variation. Three pieces of information were associated with each data point in the field. The shallow Veris reading is an integrated value for 0 to 1 ft depth. The deep Veris reading is an integrated value for the 0 to 3 ft depth. Subtracting the shallow reading from the deep reading gives an EC value for the 1 to 3 ft depth. For the combined Colorado and Kansas data set, 5 clusters (classes) gave sufficient separation between classes without being too complex. Three general ranges of EC values were identified for the 1-3 ft depth and three general ranges for the 0-1 ft depth. The low range for the 1-3 ft depth was subdivided into medium and high ranges at the 0-1 ft depth. The medium range for the 1-3 ft depth was subdivided into low and medium ranges at the 0-1 ft depth. The fifth class included the high ranges for both 0-1 ft and 1-3 ft depths. These 5 clusters (classes) are mapped below in Figure 3.

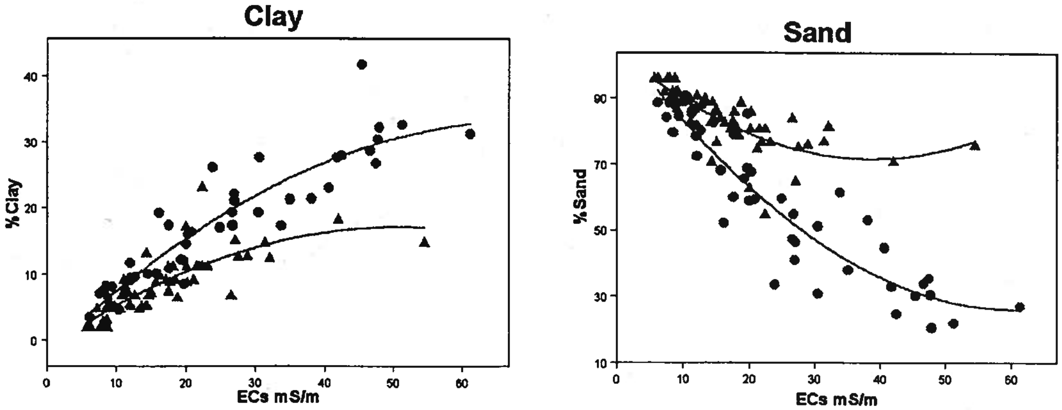
Colorado

Kansas

Figure 3. Maps of 5 clusters at two locations.

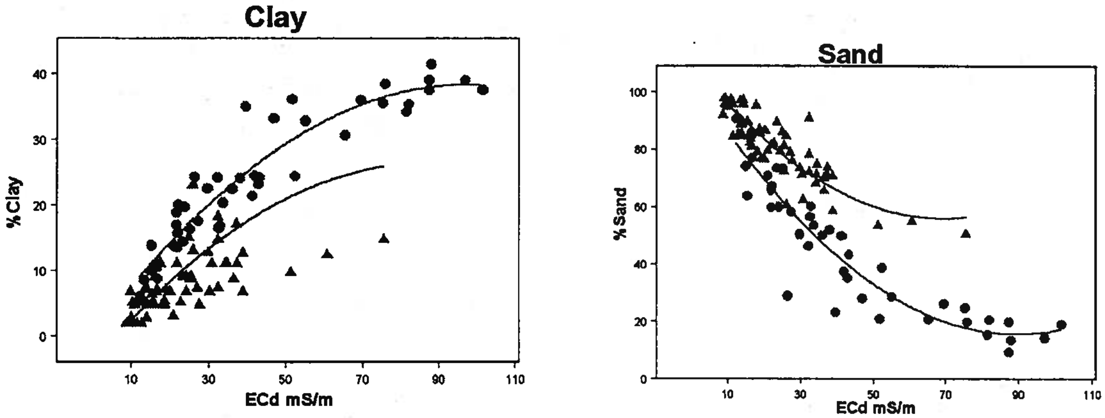
Soil samples to a depth of 4 ft (1.2 m) were taken by soil horizons at sites located in each cluster. These samples were analyzed for soil texture (%sand, %silt, %clay) in a commercial soil lab using standard lab procedures. Values for the %sand, %silt, and %clay for each soil horizon were combined and summarized for two soil layers – 0 to 1 ft (0 - 0.3 m) and 1 to 3 ft (0.3 - 1.2 m). A **nonlinear regression procedure** was used to develop polynomial equations describing the relationships of EC vs. %clay and EC vs. %sand that are shown in Figure 4.

For 0 to 1 ft (0 - 0.3 m)



▲ for Colorado, • for Kansas

For 1 to 3 ft (0.3 - 1.2 m)



▲ for Colorado, • for Kansas

Figure 4. Plots of EC vs. %clay and EC vs. %sand for 2 depths).

The **regression procedure** of Saxton et al. (1986) was used to relate the soil texture expressed as %sand, %silt, and %clay to a water holding capacity in in./in (mm/mm). The functional form of the equation is:

$$\text{Water content (\%)} = \exp[(2.302 - \ln A) / B] \quad \text{where}$$

$$A = \text{fn}\,[(\%\ \text{clay}), (\%\text{sand})^2],$$
$$B = \text{fn}\,[(\%\text{clay}), (\%\text{sand})^2, (\%\text{clay})^2]$$

Water holding capacities were computed for both soil layers and combined to give a total depth for a 4 ft (1.2 m) soil profile that are shown in Figure 5. These maps indicate interesting patterns and significant differences in the water holding capacity of the various soils within a field. They could be very useful in identifying the critical areas that need to be monitored for irrigation scheduling. In the future, if it makes sense to variably apply water, some 'smoothing' of the boundaries would be necessary depending upon the capabilities of irrigation system.

Colorado

Kansas

Figure 5. Maps of water holding capacities (4 ft depth) for Colorado and Kansas locations.

DISCUSSION

Additional analysis was done for the Kansas location for verification and to compare the maps generated from EC data with the existing USDA-NRCS soil survey maps. A smoothing algorithm was used on the map in Figure 3 to produce the map shown in Figure 6 with cleaner and more usable delineations between the 5 clusters.

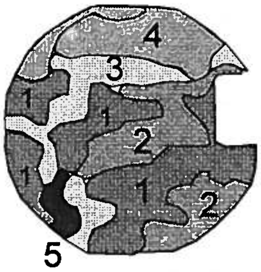


Figure 6. Delineations of soil textures by cluster analysis of EC data

Average values for the sand, silt, and clay fractions of the soil horizons where cores were taken within each of the 5 classes were classified according to the USDA soil texture triangle and are shown in Table 1. The texture classifications for the 0-1 ft depth are displayed (in different colors) for the 5 clusters (from Figure 6) to produce Figure 7a. The soil texture map shown in Figure 7b is developed from the published USDA-NRCS county soil survey map. The same process was repeated to produce the maps for the 1–3 ft depth shown in Figures 7c and 7d.

Table 1. Values of soil texture for 2 layers.

Cluster	0 to 1 ft depth				1 to 3 ft depth			
	%sand	%silt	%clay	texture	%sand	%silt	%clay	texture
1	82	8	10	loamy sand	79	8	23	sandy loam
2	86	7	7	loamy sand	69	17	14	sandy loam
3	65	22	13	sandy loam	52	30	18	loam
4	52	30	18	loam	54	25	21	sandy clay loam
5	67	17	16	sandy loam	34	34	32	clay loam

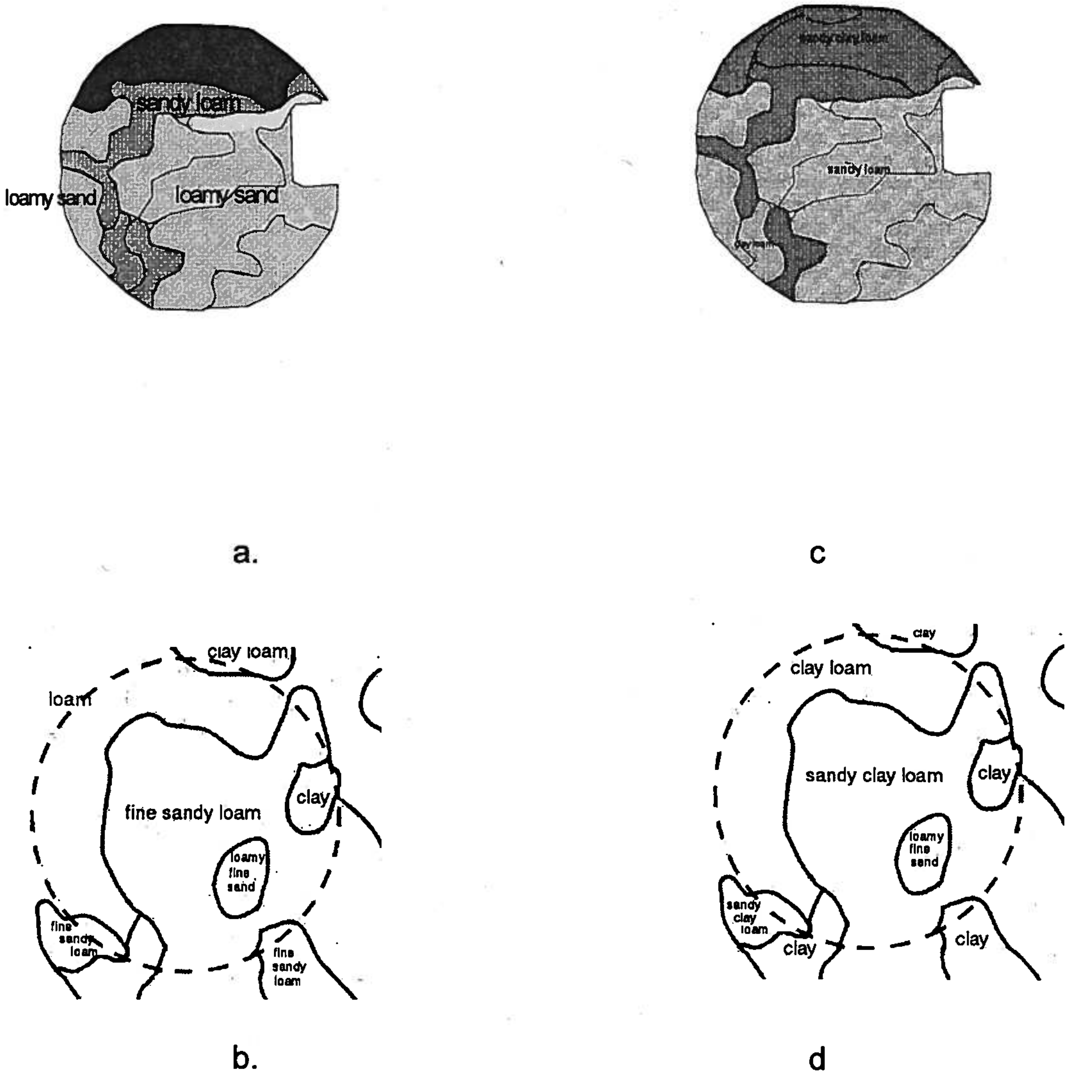


Figure 7. Comparison of soil maps from EC measurements with published USDA-NRCS.

This example is not intended to show the superiority of one approach over another. Rather, it illustrates that with new and economical technology we may get a different view of how soil varies across a field. Knowledge about the spatial variability of soil texture can help producers make better water management decisions, but it is important to understand the strengths and weaknesses of the processes used to obtain the information.

Since this approach to mapping is not being done commercially (to my knowledge), I do not know what the costs would be. The EC data could probably be collected for $1-3 /ac and of course the costs for lab analysis of the soil samples would depend on the number and detail of testing desired.

REFERENCES

Saxton K.E., W.J. Rawls, J.S. Romberger, and R. I. Papendick. 1986. Estimating Generalized Soil-water Characteristics from Texture. Soil Sci. Soc. Amer. J. 50(4):1031-1036