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Embracing Variable Rate Technology in Arizona Crops:
Geographic Visualization of Field Zone Management

Pedro Andrade-Sanchez and John T. Heun

I. Introduction

The concept of "Zone Management" in US agriculture emerged in the early 2000's; it derived from the paradigm shift towards site-specific management of production inputs. The technological driver that fueled this change was the introduction of satellite-based global positioning systems (GPS) of sub-meter precision. Since then, Precision Agriculture (PA) has evolved as an academic discipline to study the relationships between digital technology, its user interface, and the characteristics of the farming system where it is intended to be implemented. Moreover, PA is an intensively practical and applied discipline, embraced by a large segment of practitioners and service providers in the US agricultural community and abroad.

The rate of adoption of PA technologies is highly variable. Over the last twenty years, we have witnessed the overwhelming adoption of machine steering control technology, which provides economic advantages across the whole spectrum of farm size, crops grown, farming practices, etc. Currently, sightings of farm fields not worked with auto-steer tractors are very infrequent in Arizona. On the other hand, Variable Rate Technology (VRT), which makes possible extending even further the efficiency gains in input utilization of modern uniform-rate management, remains at low levels of adoption. Aside from the reasons behind the status of VRT adoption, Cooperative Extension personnel at the University of Arizona has successfully tested VRT for fertility management, pesticide applications, and seed planting on both field and specialty crops. The outcomes of these tests point to an untapped set of potential benefits in VRT in Arizona farming systems. The purpose of this bulletin and subsequent publications organized as the "UA Extension VRT Series" is to inform stakeholders of commercially available options to implement VRT in many of their farming practices, as well as presenting case studies and guidelines for software-based data processing and application equipment hardware setup.

II. Zone Management

The simplest description of Zone Management (ZM) is the breaking up of a field into smaller areas with the intention of treating them differently by varying input application quantity and/or timing. With tractor/sprayer power units running GPS/GNSS-based auto-steer, adding the right hardware, controller, and set of instructions makes it possible to change application rates according to the zone in which the machine is currently located in [1,6]. The specific objectives for a grower to farm using ZM vary widely depending on the production function of the specific input, and the capacity of soil/crop to respond to changes [4,5]. For instance, implementing ZM with a savings approach can increase farm profits by reducing the total amount used of a given input without negatively affecting overall productivity. A maximizing yield approach will look for the optimal rates depending on the crop needs and the soil type of each zone. In such case, ZM may not reduce the overall input utilization, but will increase its efficiency. Generally speaking, ZM must be carefully tailored to the biophysical conditions of each field and to the production function of the crop grown. Moreover, it is of critical importance that the farm enterprise takes into account financial factors to ensure a return on the investment in acquiring VRT.

As we will see in the next section of this publication, Zone Management starts with careful geographic delineation of field sub-regions with homogeneous yield-limiting factors. ZM is largely responsive to in-field variability of soil properties and soil conditions. For the implementation of ZM in fertility, the target is to define zones of similar productivity potential, so that fertilizer materials can be applied with variable rates that match the nutrient needs. ZM for biotic factors affecting crop productivity can be very complex because zones should respond to the dynamics of pests and pesticide applications should be compatible with Integrated Pest Management practices. One example of ZM implementation for pest management with high potential in Arizona is cotton, where variable rates of fumigants can control plant-parasitic nematodes causing root knot based on the amount of sand in the soil. The theoretical basis for this approach rests on knowledge that these nematodes prefer well drained, aerated soils and their density in the soil profile is highly correlated to soil texture.

Successful implementation of ZM relies on solid scientific understanding of biotic and abiotic stressors and their impact on crop productivity. At the same time, ZM implementation must be the result of careful thought of practical aspects such as the size and location of the management zones to allow efficient deployment of farm machinery [6]. The human interface with technology is also a key aspect because advanced farming operations such as VRT require skilled farm labor.

III. Digital Templates to Create Management Zones

Growers have a deep knowledge of their fields; they can easily locate areas within a field that exhibit different yield response due to soil types or topographical features that have a definite impact. Zone Management fits perfectly in this farm knowledge structure because delineating management zones is a process guided by the user. In other words, the user has complete control to select the number and size of zones, as well as their location and distribution in a field. In all these cases, the ultimate goal is that these management zones represented as geographic polygons, will be used as digital templates for further processing in Farm Management (FM) software. Once templates are imported into the FM software of the user's preference, prescription files can then be created to enable VRT of production inputs. Detailed descriptions of the process to generate prescription files will be covered in this VRT publication series as a separate UA Extension bulletin. In this section, we will review several options to acquire information to support the decisions that will lead to define geographically in-field management zones.

3.1. Google Earth. This source of imagery is very popular for being easily accessible and free of cost. All that is needed is a computer with internet connection. After locating a particular field, the user can browse through images of the same field taken in different years/seasons and save the image(s) as picture(s). A central feature of Google Earth is that it allows the user to draw polygons to delineate zones (see Figure 1) based on soil features visible in the image. In Google Earth, the electronic versions of these polygons can be saved and exported as *.kml/*.kmz files, and then converted into ESRI shape files (.shp) using free utilities such as online kml-shp converters or open-source GIS software.

3.2. USDA-NRCS Web Soil Survey. This is an excellent on-line source of digitized soil information presented geographically through a user-friendly web interface [7]. This resource is free of cost and is intended to be available for all states and territories of the United States. The process to obtain soil survey data for a particular field is very simple: first locate the field by navigating and scale zooming, then use the "draw a polygon" function with mouse clicks to define the area of interest (AOI). The digital output of the soil survey is a downloadable zipped folder containing geographic information of the soil units identified inside the AOI, as well as pdf-formatted documentation with detailed

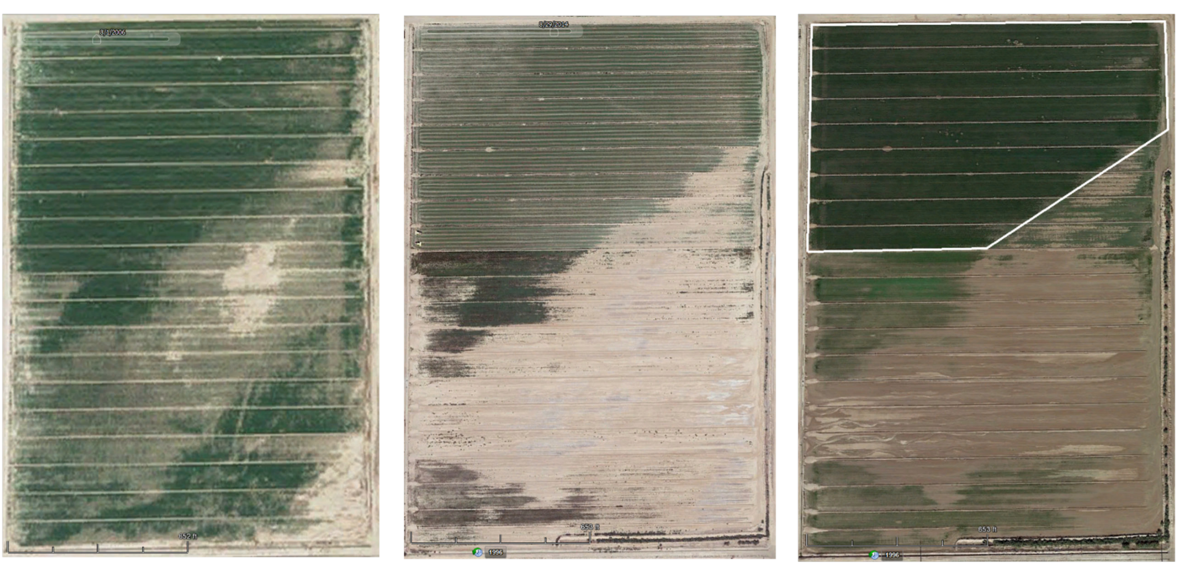

Figure 1. Google Earth imagery of the same 56-acre field in SW Arizona captured on 8/1/2006 (left), 8/29/2014 (center), and 11/15/2016 (right). Image on right shows in the upper portion a polygon of a zone as an arbitrary example of a manually drawn polygon of 22 acres where soil is more fertile

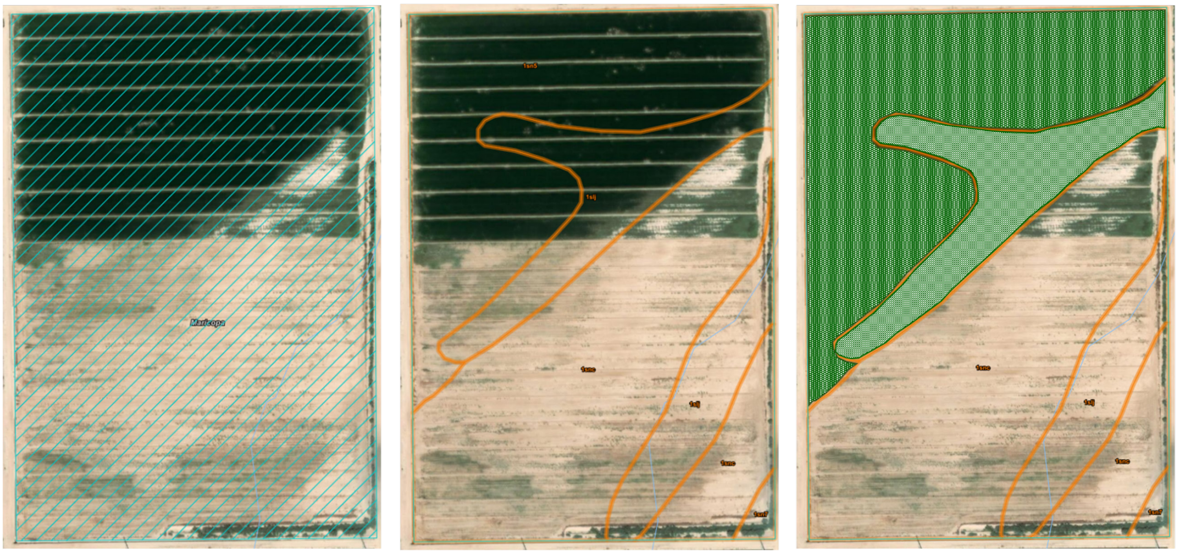

Figure 2. USDA-NRCS Web Soil Survey maps with imagery as background of a 56-acre field in SW Arizona. Image on the left depicts the field and associated area of interest (AOI); diagonal lines indicate the geographic extent of the field. Image on the center shows contour lines and areas of soil units present in this AOI. The image on the right shows an arbitrary example of creating two management zones in the area with more fertile soil units.

description of the soil units found in the field in question. Note that the output geographic information in this folder is very useful as it is already in .shp format. Figure 2 presents screenshots of the USDA-NRCS online soil survey for the same southwest Arizona field depicted in Figure 1. The outcome of this tool is a map with a set of contour lines that define areas of different soil units. The map on the right in Figure 2 suggests this field can be can be broken into management zones based on these soil units. To help visualize ZM in this field, green-colored polygons are two soil units with productive fine sandy loamy textures; while the Wellton and Tucson Loam series (not colored areas) are low performing soils that account for 44% of the area in this field.

3.3. Digital Yield Maps. When available, digital yield maps are of high utility for creating in-field management zones. The basis for their relevance is that yield response is an integration of all soil and atmospheric variables and management decisions taken during the growing cycle; it also integrates the effect of past crop rotations and seedbed preparation tillage [5]. GPS/GNSS-enabled yield monitoring technology keeps evolving and improving. It is a reliable source of geographic information, but requires frequent calibration to provide data sets with adequate yield accuracy. In spite of this, it is worth mentioning that even yield monitors that are not optimally calibrated still generate data with relative accuracy, which works well for visualizing in-field variability and delineating management zones.

Yield monitoring is a standard feature in new grain combines, and optional for new cotton and hay harvesting equipment. Older harvester equipment can be retrofitted with stand-alone systems developed by third-party outfits for the most common machines. Access to digital yield maps is potentially available in farming areas, like those in Arizona, where farmers rely heavily on contracting and custom-hire harvest operations that tend to use the latest harvester models. Knowing this, farmers can obtain a double benefit of their custom-hire harvest: the main being a timely crop harvest and the secondary benefit is access to the electronic data files generated on their fields. As an example, Figure 3 displays the fluctuations in cotton yield across a 28-acre field in Eastern Arizona. Visual inspection of the maps shows the extent of yield variability, as well as consistency, across adjacent harvester passes. The contour map is a digital representation that smooths out the geographic distribution of yield data. These maps offer an excellent template to define management zones.

3.4. Field-ready, On-the-go Soil Sensors – Apparent Electrical Conductivity (ECa). The first commercially available ECa sensors for soil analytics at field scale were based on the principle of electromagnetic induction. These systems are non-contact and very sensitive research-grade instruments that have been used extensively in large-scale soil salinity scientific studies. With the advent of Precision Agriculture, new field-ready ECa sensors have been developed to fit the needs of grower and applicator users. These sensors measure bulk soil electrical resistivity (inverse of conductivity) with the use of electrodes that engage the soil while the sensor cart is pulled through the field. ECa surveying with GPS/GNSS is a powerful

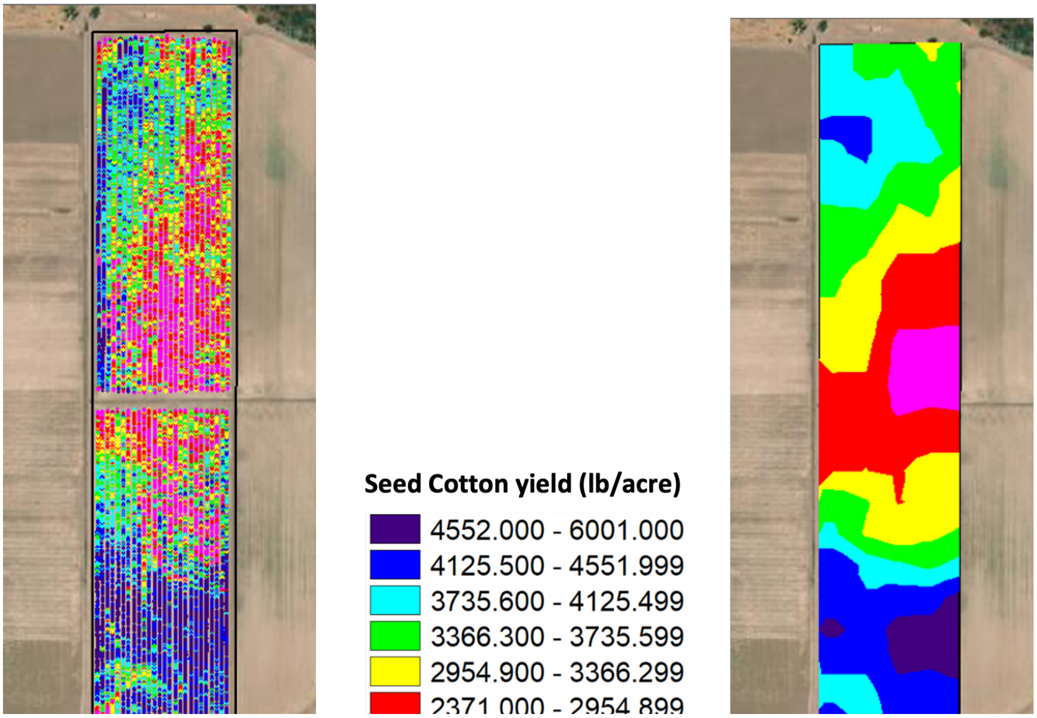

Figure 3. Yield map of a cotton field. Image on the left contains points of 15 ft. diameter that were classified on seven equal-count ranges of yield. Contour image (right) was generated with the same data set using on Inverse Distance Weighting of 125 ft. cell size raster. Both maps use the same color classification and yield ranges

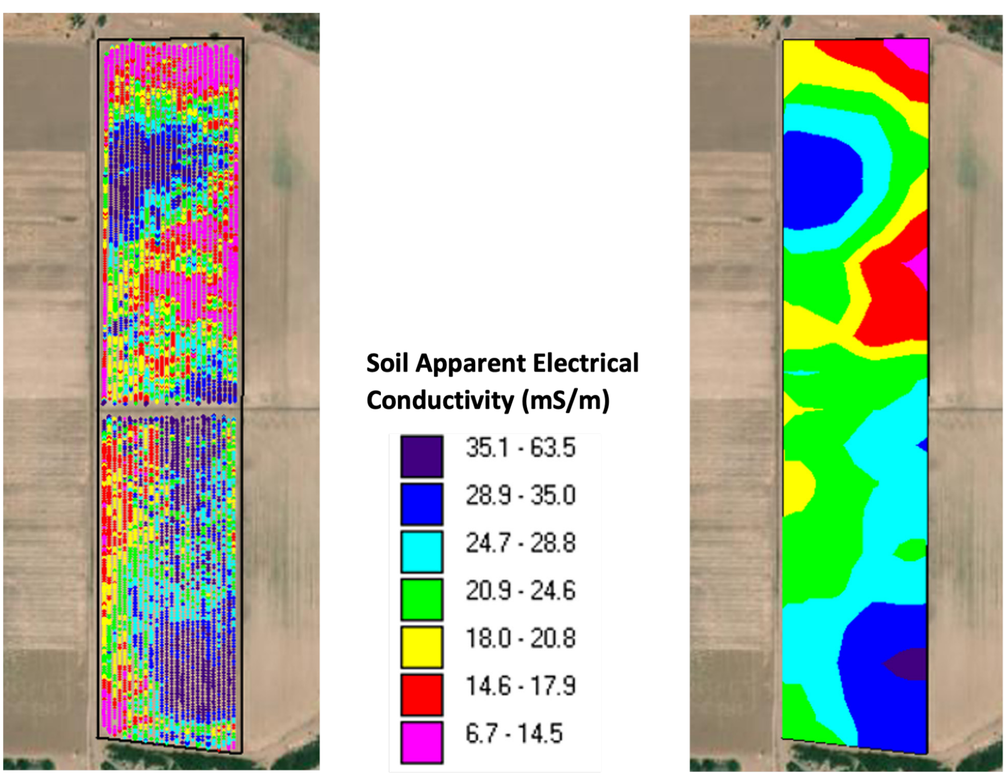

Figure 4. Soil ECa survey of a cotton field. Left Image contains 18 ft. diameter points that were classified on seven equal-count ranges of conductivity values. Contour image on the right was generated using Inverse Distance Weighting of 125 ft. cell size raster. Both maps use the same color classification and ECa ranges.

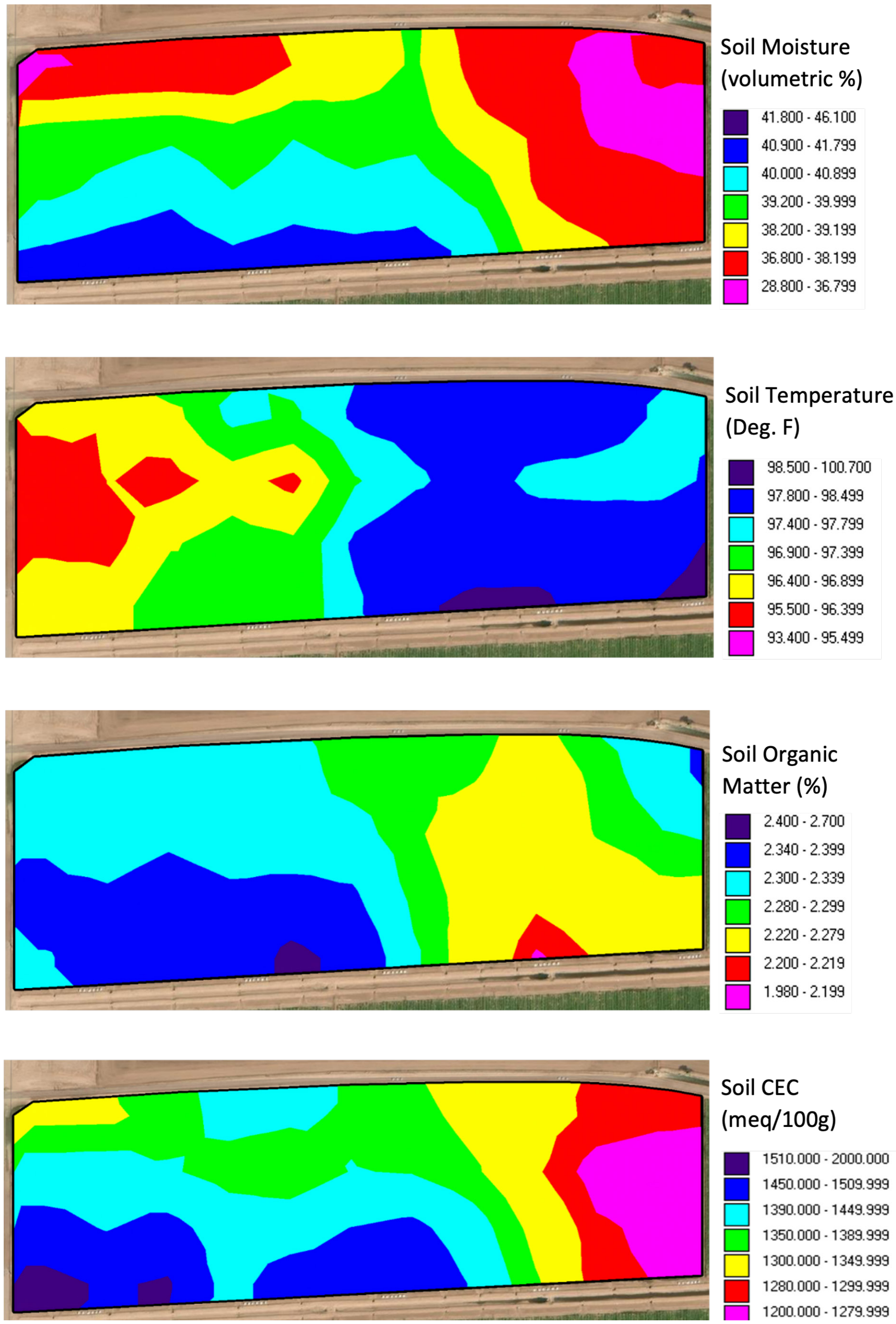

Figure 5. Contour maps of soil optical sensor output data collected simultaneously in a field in SW Arizona. Interpolation technique was based on Inverse Distance Weighting of 125 ft. cell size raster. All maps use the same color classification of seven equal-count ranges.

method to characterize the within-field variability of soils because the sensor output has a strong correlation with soil texture and other properties that affect the conduction of electricity in the soil profile [2,3,5]. ECa field mapping is particularly useful to visualize potential management zones because the variation in ECa in Arizona is closely associated with productivity, and growers can couple this digital version of a field with their professional experience managing it. The maps in Figure 4 correspond to the same field in Section 3.3 (Eastern Arizona). The ECa survey was conducted right before planting (Figure 4) and the yield monitored at the end of the season (Figure 3). Only by visual inspection of maps in both Figures 3 and 4 does the degree of association become evident between soil type and productivity.

3.5. Field-ready, On-the-go Soil Sensors – Soil Spectrometry. This technique has been evolving over time as an approach to characterize the chemical composition of soil at the field level. The earlier versions did not operate on a continuous mode but rather on a by-point basis. Sensor systems built to quantify soil properties have been available for quite some time but still have not reached the grower/applicator mainly because sensor operation requires special care and frequent calibration. The cost was also relatively high. Only recently have optical sensors come into the market as low-cost systems retrofitted to soil engaging implements, such as planters. It is very likely that these sensors will enhance our ability to characterize in-field soil physical and chemical composition variations. On going tests of these sensors in Arizona show promising results; their application in zone management is being carefully assessed and an understanding of their accuracy and operational limitations is being developed. Figure 5 presents maps of four soil variables that were collected simultaneously with an optical sensor in a field in Yuma AZ.

IV. Conclusions

Digital technology is changing at a very fast rate. Innovations in computer science and sensor technology are broadening the range of input options to use in variable-rate precision agriculture. Zone management has great potential in the farming systems of Arizona to increase the efficiency of input utilizations and therefore bring meaningful benefits in both economic and environmental terms. A first step in the implementation of geographically distributed variable rate technology is visualizing and understanding the extent of variability present in growers' fields. This visualization is an intuitive guideline for the user to digitize the information in ways that only the grower can make the best interpretation. There many options and methods to digitize the knowledge growers have of their fields. The next step in the journey towards implementing variable-rate technology is the use of Farm Management software to generate instructions, or prescription files, that variable-rate controllers can translate and execute in the application machinery.

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AUTHORS

Pedro Andrade-Sanchez
Associate Specialist & Professor, Biosystems Engineering

John T. Heun
Staff Engineer, Biosystems Engineering Dept. - Precision Agriculture

CONTACT

Pedro Andrade-Sanchez
pandrade@cals.arizona.edu

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