The International Society of Precision Agriculture presents the
15th International Conference on
Precision Agriculture
26–29 JUNE 2022
Minneapolis Marriott City Center | Minneapolis, Minnesota USA

Effectiveness of Different Precision Soil Sampling Strategies for Site-Specific Nutrient Management in Row-Crops

Matthew Tucker[1], Simerjeet Virk[1], Glen Harris[1], Jay Lessl[2], Matt Levi[1]

[1]Crop and Soil Sciences Department, University of Georgia, Tifton, GA 31793

[2]Agricultural and Environmental Services Laboratories, University of Georgia, Athens, GA 30602

A paper from the Proceedings of the
15th International Conference on Precision Agriculture
June 26-29, 2022
Minneapolis, Minnesota, United States

Abstract.

Soil sampling is an important component of site-specific nutrient management in precision agriculture. While precision soil sampling strategies such as grid or zone have been around for a while, the adoption and utilization of these strategies varies considerably among the growers, especially in the southeastern United States. The selection of an appropriate grid size or management zone further differ among the users depending on several factors. In order to better understand how some of the commonly used precision sampling strategies influence the depiction of soil nutrient variability and site-specific nutrient application requirements, a study was conducted across ten different sites to be planted in corn, cotton or peanuts in 2022. Soil sampling maps using grid sizes of 0.40, 1.01, 2.02, 3.03 and 4.04 ha were created for each site while management zones were delineated using an unsupervised clustering method from either a single or a combination of two to three different spatial data layers including soil EC, yield, imagery, and topography. Spatial nutrient maps (soil pH, P and K) from 0.40-ha grid sampling were treated as to represent the actual in-field nutrient variability and were also used to perform comparison and correlation analysis with nutrient maps created using other sampling strategies. Preliminary results for grid-based strategies showed varying trend among the sites. In some cases, the 1.01 ha grid best represented the spatial nutrient variability with a trend towards decreasing spatial resolution and accuracy with an increase in grid size. This trend was not evident in other sites, possibly due to the degree of variability as well the placement of sampling points for different size grids within the field. Analysis of nutrient maps based on zone sampling strategies indicated varying levels of correlation with actual nutrient maps, which was influenced by the type and

---

The authors are solely responsible for the content of this paper, which is not a refereed publication. Citation of this work should state that it is from the Proceedings of the 15th International Conference on Precision Agriculture. EXAMPLE: Last Name, A. B. & Coauthor, C. D. (2018). Title of paper. In Proceedings of the 15th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

resolution of the spatial data used for zone delineation. Similar trends for both grid- and zone-based strategies were observed for variable-rate nutrient application maps. Future research is focused on utilizing other geospatial statistical measures to compare and evaluate the accuracy of different sampling strategies as well as performing an economic analysis to determine cost-effective sampling strategies.

Keywords.
Soil Sampling, Site-Specific, Nutrient Management, Variable-Rate Application, Row-Crops

Introduction

Proper nutrient management in row-crops is crucial for producing high yielding and high-quality crops. Most agricultural production fields in the Southeastern U.S. have high amounts of spatial variability regarding soil physical properties and nutrient levels, due to variations in climate, landscape, and single rate broadcast applications. Single rate broadcast applications can cause variation in nutrient levels causing areas of yield loss that can take years to improve. Precision agriculture techniques and technologies allow fields to be divided into uniform- and non-uniform sized areas that can be managed separately of the adjacent area. Variable-rate applications of soil amendments and fertility have proven to be cost effective and increase yields to the areas potential, when conducted appropriately. Variable-rate technology achieves right place and right rate of the 4R's of nutrient management (IPNI, 2012). Soil sampling is an important component of site-specific nutrient management in precision agriculture. Precision soil sampling techniques such as grid- or zone- based sampling methods are utilized to determine spatial variability of nutrients and pH within a field, and are most commonly used for variable-rate applications (Ackerson, 2018).

There are numerous methods that growers and researchers use to collect soil samples for determining spatial nutrient variability and to inform variable-rate applications. The most common grid-based approach is utilizing 1.01- and 2.02-ha grids for soil sampling. Wollenhaupt (1994) found that grids should be no larger than 0.40 ha to capture the spatial nutrient variability. The author also found that grid-based sampling produced maps with higher accuracy when compared to zone-based sampling. Many management zone (MZ) based strategies have also been investigated by researchers in the past including using farmer experience and aerial imagery (Fleming et al., 2004), stable yield maps from multi-year yield data (Flowers et al., 2005), topography (Kravchenko et al., 2000), and electrical conductivity (EC) (Johnson et al., 2003). Farmer experience and soil color maps created from aerial imagery identified homogeneous subregions within fields, but the effectiveness varied across different fields (Fleming et al., 2004). Flowers et al. (2005) found multi-year yield maps to be nearly as effective at delineating soil nutrient variability as a 1.01-ha grid. Johnson et al. (2005) investigated the use of EC and found that there was no consistent relationship between EC and yield variability. However, the addition of other data layers could be used to establish MZs, that correlate to crop yield.

The adoption and utilization of these strategies varies considerably among the growers, especially in the southeastern United States (Mooney et al., 2010). The selection of an appropriate grid size or management zone further differ among the users depending on several factors. Regarding soil sampling, questions often received from growers are (1) what is the best grid size for soil sampling and (2) what information is needed to soil sample based on management zones? While grid-based soil sampling is easier to implement and widely used in the Southeastern U.S., but it can be become labor intensive and costly dependent on the grid size used. Similarly, zone-based soil sampling can decrease the number of samples taken from a field; however, it is difficult to implement and validate. The objective of this study was to better understand how some of the commonly used precision sampling strategies influence the depiction of soil nutrient variability and influence site-specific nutrient application requirements within the selected fields.

Methodology

Study Locations

This study was conducted across ten different sites to be planted in common row-crops (cotton, corn, or peanuts) in 2022. The selected fields ranged from 4.04 to 40.47 ha, the total acreage for the project was 167.5 ha. The sites were all located in the coastal plains and have soil types representative of that area. The soil sampling methods and other procedures followed were consistent among all locations.

Grid Sampling

Sampling grids were created for all fields in sizes of 0.40, 1.01, 2.02, 3.03, and 4.04 ha (1.0, 2.5, 5.0, 7.5, 10.0 ac). Sampling points were placed at the center of each grid using geographic information systems (GIS) software (Fig. 1). Points were located in the field using a handheld Trimble global positioning system (GPS) unit. Composite soil samples were collected for each grid using the point sampling method. The point sampling method was performed by collecting twelve to fifteen 15.24 cm cores in a 6.09 – 9.14 m radius around each point. Data from each sample was imported into AgLeader SMS Advanced (AgLeader Technology, Ames, IA) for analysis and interpolation. Spatial maps, for three soil chemical properties (pH, P, and K), were created for each grid size using Inverse distance weighted (IDW) interpolation method. The IDW interpolation uses an algorithm to predict values of unmeasured locations by weighting measured values based on the spatial distance from the unmeasured locations. Interpolation creates a 9.14 x 9.14 m raster map, where each cell is georeferenced and contains values for each of the chemical properties. This data was exported to JMP Pro 15 (SAS Institute, Cary, NC) for correlation analysis to compare the efficacy of the 1.01, 2.02, 3.03, and 4.04 ha grid-sampling methods to the 0.40-ha grid, where the 0.40-ha grid-sampling method was treated as a reference layer and assumed to represent the true spatial variability within each field. Lime, phosphorus (P^2O^5) and potassium (K^2O) fertilization recommendation maps were created for each grid strategy to compare and evaluate the differences in recommended rates spatially.

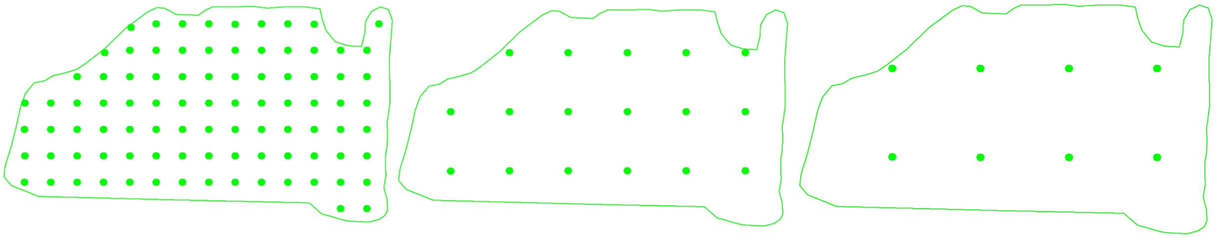


Fig 1. Example of point sampling locations based on 0.40, 2.02, and 4.04 ha grids for one of the sites used in this study.

Management Zones

Soil electrical conductivity (EC) was collected for all fields using a Veris U3000 system (Veris Technologies, Salina, KS). Topography layers (digital elevation, slope, aspect, water flow, wetness index) were created with RTK elevation data from previous field work and LiDAR. Satellite imagery from Planet was collected to create maps of bare soil brightness index (SBI) and normalized difference vegetation index (NDVI). SSURGO soil type maps were downloaded from USGS Earth Explorer. MZ's were delineated for each field using Management Zone Analyst (MZA) for clustering of single spatial layers or a combination of two to three spatial layers, shown in Fig. 2. MZA uses an unsupervised c-means clustering algorithm to identify and group points with similar characteristics. MZA's cluster performance indices (FPI and NCE) were used to determine the optimal number of zones for each field. MZ's were used to select soil sampling points within the zones, as shown in Fig 3. The soil test values for these sampling points were used and interpolated to create nutrient variability maps from each MZ soil sampling method. This data was then correlated to the 0.40-ha grid to determine the amount of spatial variability captured and compared with each zone delineation method, based on spatial data layers used to create the MZ's. Lime, phosphorus, and potassium fertilization recommendations were created for each zone method and compared to the fertilizer recommendation maps based on 0.40-ha grid-sampling method.

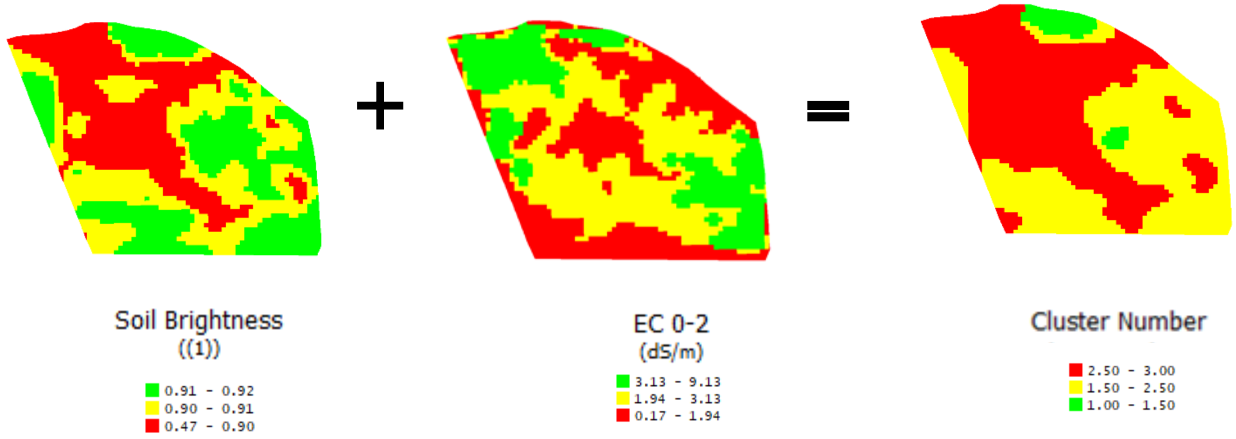


Fig 2. Example of clustering analysis where SBI and EC are used as input layers to create the clustered layer from MZA.

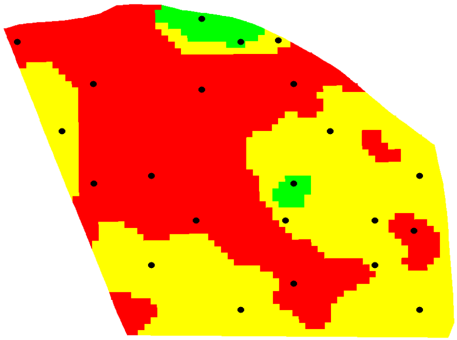


Fig 3. Soil sampling locations from grid sampling averaged together for each of the management zones.

Sampling methods for comparison

The soil nutrient maps and the corresponding fertilizer recommendation maps from different sampling methods used in this study were compared and correlated to nutrient maps and recommendations from the 0.40-ha grid sampling method. The sampling methods were (1) 1.01ha ac grid sampling, (2) 2.02 ha grid sampling, (3) 3.03 ha grid sampling, (4) 4.04 ha grid sampling, (5) EC, (6) SBI, (7) NDVI, (8) EC + SBI, (9) EC + NDVI, (10) NDVI + SBI

Correlation Analysis

Interpolated point data were exported from SMS Advanced and imported into JMP Pro 15 for correlation analysis. All data were subjected to the same statistical methods for each field.

Results and discussions

Grid Sampling

Grid based soil sampling strategies showed a high correlation between the 1.01 ha grid and the 0.40 ha grid method for some sites. This trend was not evident for all sites, likely due to the amount of spatial variability present in the fields and/or the placement of the sampling points for different grid sizes within the fields. Table 1 below shows the correlation coefficients for six of the ten fields. For some fields, the correlation coefficient decreased with an increase in the grid size, which was expected. While for other fields, the coefficients seemed to be random, and the grids were found to have little to no correlation to the 0.40-hectare grid for the three nutrients (pH, P, and K). Fig. 4 and 5 illustrate how the location of the sampling points can impact the interpolation, so the correlation coefficients seem to be random.

Table 1. Correlation coefficients of different grid sizes compared to 1-ac grid for pH, P, and K.

Grid Size (ha)	Field 1			Field 2		
	pH	P	K	pH	P	K
0.40	1	1	1	1	1	1
1.01	0.82	0.80	0.57	0.87	0.96	0.66
2.02	0.45	0.59	0.48	0.75	0.69	0.62
3.03	-0.39	0.47	0.54	0.76	0.92	0.38
4.04	-0.15	0.42	0.20	-0.19	0.92	0.52
	Field 3			Field 4		
	pH	P	K	pH	P	K
0.40	1	1	1	1	1	1
1.01	-0.07	0.56	0.62	0.37	0.37	0.72
2.02	0.38	0.56	0.55	0.35	0.39	-0.08
3.03	0.22	0.12	0.28	0.25	0.21	0.65
4.04	-0.09	0.51	0.37	0.24	0.33	0.60
	Field 5			Field 6		
	pH	P	K	pH	P	K
0.40	1	1	1	1	1	1
1.01	0.50	-0.21	0.86	0.39	0.86	0.47
2.02	-0.16	0.04	0.59	0.45	0.73	0.54
3.03	-0.05	0.22	0.52	0.35	0.58	0.47
4.04	-0.12	-0.31	0.45	0.39	0.69	0.24

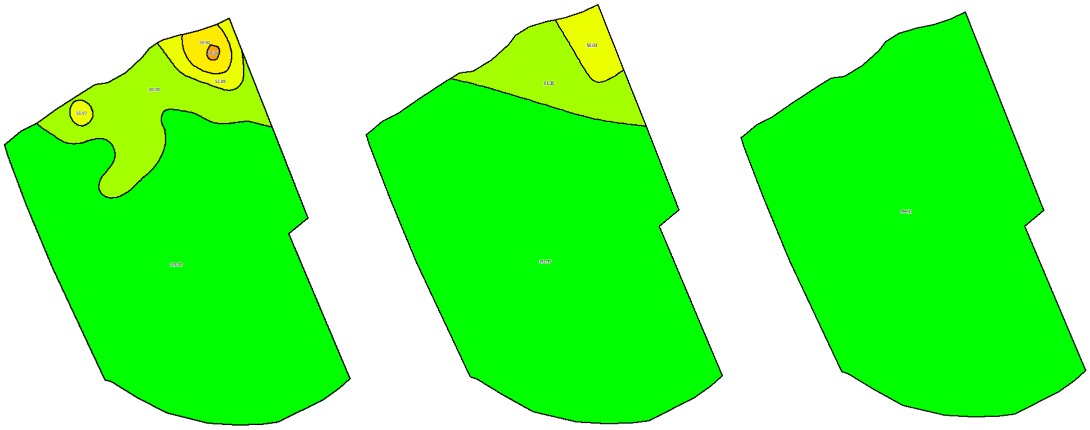


Fig 4. Spatial P map for 0.40-, 2.02-, and 4.04-ha grid maps for field 6 illustrating the variability depicted by each one of the sampling strategies.

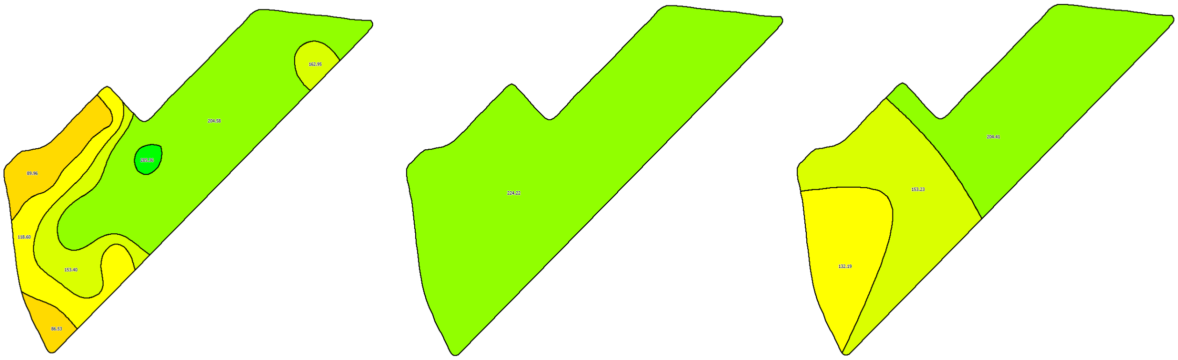


Fig 5. Spatial K map for 0.40-, 2.02-, and 4.04-ha grid maps for field 4 illustrating the randomness in variability among the sampling strategies.

Tables 2 through 4 illustrate the percentage of the land area in Field 1 that fall into the ranges of nutrient levels used for variable rate prescription maps across the different grid sizes. For pH, the percentage of land area for the 1.01-, 2.02-, and 3.03-ha grid methods that would not receive any lime, but ideally should have, was between 30% and 50%. The 4.04-ha grid method would have called for 33% more of the field to receive lime that did not require it. For P, as the grid sizes increased the percentage of land that would be under fertilized increased. K also had variability in the amount of land that would be fertilized, the 1.01- and 4.04- ha grid methods would be over fertilizing nearly 10% of the field, while the 3.03- ha grid method would under fertilize over 10% of the field. Similar results were found for the other fields, explaining grid size has an impact on variable-rate prescription maps and the corresponding fertilizer application rates.

Table 2. Percentage of area in field 1 for different pH ranges across all grid sizes used in this study.

pH	0.40 ha	1.01 ha	2.02 ha	3.03 ha	4.04 ha
Very Low	2%	0%	0%	0%	0%
Low	2%	3%	0%	0%	7%
Medium	52%	24%	6%	23%	82%
Optimal	44%	72%	94%	77%	11%
High	0%	1%	0%	0%	0%

Table 3. Percentage of area in field 1 for different phosphorus (P) ranges across all grid sizes.

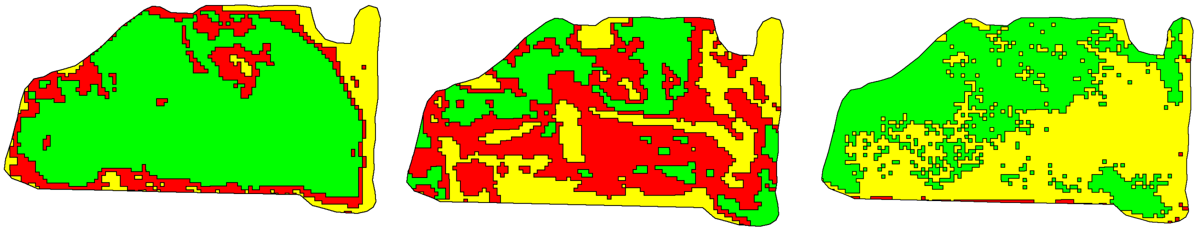
P	0.40 ha	1.01 ha	2.02 ha	3.03 ha	4.04 ha
Very Low	0%	1%	0%	0%	0%
Low	2%	1%	6%	2%	2%
Med Low	12%	2%	10%	8%	7%
Med High	24%	20%	15%	11%	9%
High (Optimal)	48%	54%	57%	58%	61%
Very High	14%	21%	12%	21%	21%

Table 4. Percentage of area in field 2 for different potassium (K) ranges across all grid sizes.

K	0.40 ha	1.01 ha	2.02 ha	3.03 ha	4.04 ha
Very Low	0%	0%	0%	0%	0%
Low	0%	0%	0%	0%	0%
Med Low	4%	0%	0%	0%	0%
Med	27%	28%	15%	1%	39%
Med High	39%	48%	53%	54%	40%
High (Optimal)	31%	24%	32%	44%	21%
Very High	0%	0%	0%	0%	0%

Management Zones

The correlation coefficients for all MZ delineation methods for soil pH were above 0.82, with EC + NDVI (r=0.89) being highest correlated to the 0.40-ha grid sampling method, used as actual nutrient variability. EC + NDVI also had the highest correlation for P with a correlation coefficient of 0.90. NDVI had the lowest correlation to P (r=0.68). EC as a single layer had the highest correlation for K (r=0.82) and SBI had the lowest (r=0.59). Similar results were observed for other fields. The results from the MZ soil sampling methods varied on the amount of variability captured depending on the type and number of spatial layers used to create the management zones.



(a) **(b)** **(c)**

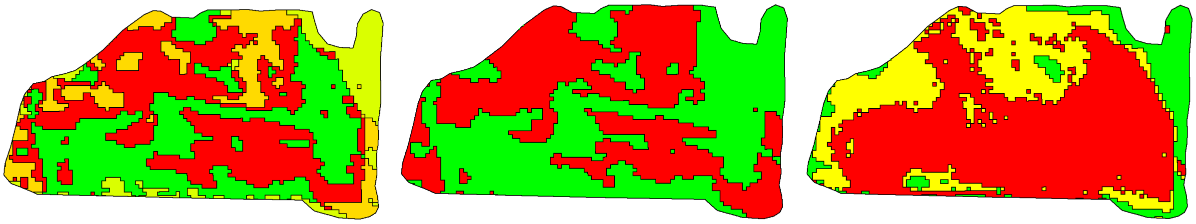

(d) (e) (f)

Fig 6. Management zones created from different spatial layers for Field 1. (a) NDVI, (b) EC, (c) SBI, (d) NDVI+EC, (e) SBI+EC, and (f) SBI+NDVI.

Table 5. Correlation coefficients for different MZ based soil sampling strategies compared to the 0.40- ac grid sampling, the assumed actual spatial variability.

MZ	pH	P	K
EC	0.87	0.82	0.82
NDVI	0.85	0.68	0.77
SBI	0.82	0.80	0.59
EC + NDVI	0.89	0.90	0.77
EC + SBI	0.86	0.84	0.69
SBI + NDVI	0.84	0.87	0.79

Conclusion and Future Research

This study shows the effect of soil sampling strategy on depiction of spatial nutrient variability and fertilization. While grid soil sampling indicated that a 1.01 ha grid is highly correlated to a 0.40 ha grid for all nutrients for some sites investigated in this study. For other fields, 1.01 or 2.02 ha grids showed the high correlation to a 0.40 ha grid for at least one nutrient. In some cases, none of the grid sizes had any significant correlation to the 0.40 ha grid sampling. Location of grid points and the amount of variability in the field seems to be a driving factor in producing high the correlation factors.

Management zones delineated by single and multi-layer methods using the unsupervised clustering algorithm had correlation coefficients higher than 0.82 for at least one nutrient. While none of the MZ soil sampling methods prove to be the best method. The MZ's used in this study were able to capture a considerable amount of the true spatial variability in most fields while reducing the number of soil samples by more than 50% than the 0.40-ha grid strategy.

Future research will be conducted to explore different geospatial statistical analyses to produce management zones from single or a combination of spatial data layers to determine the layers that best represent stable yield, for a given field. This will allow for the statistical analysis to be viewed spatially, so a user would be able to map the areas in the field where the correlation of nutrients to the zones is high or low. In addition, geo-statistical techniques will be useful for economic analysis to determine the efficacy of the VR prescription map and the amount of the field where fertility or soil amendments were over- or under- applied.

References

Fleming, K.L., Heermann, D.F. & Westfall, D.G. (2004). Evaluating Soil Color with Farmer Input and Apparent Soil Electrical Conductivity for Management Zone Delineation. Agron. J., 96: 1581-1587.

Flowers, M., Weisz, R. & White, J.G. (2005). Yield-Based Management Zones and Grid Sampling Strategies: Describing Soil Test and Nutrient Variability. Agron. J., 97: 968-982.

Kravchenko, A.N. & Bullock, D.G. (2000). Correlation of Corn and Soybean Grain Yield with Topography and Soil Properties. Agron. J., 92: 75-83.

Johnson, Cinthia & Mortensen, David & Wienhold, Brian & Shanahan, John & Doran, John. (2003). Site-Specific Management Zones Based on Soil Electrical Conductivity in a Semiarid Cropping System. Agronomy Journal. 95. 10.2134/agronj2003.0303.

Wollenhaupt, N.C., Wolkowski, R.P. & Clayton, M.K. (1994). Mapping Soil Test Phosphorus and Potassium for Variable-Rate Fertilizer Application. Journal of Production Agriculture, 7: 441-448.

IPNI (International Plant Nutrition Institute). 2012. 4R Plant Nutrition Manual: A Manual for Improving the Management of Plant Nutrition, metric version. Bruulsema, T.W., Fixen, P.E., Sulewski, G.D. (eds.), International Plant Nutrition Institute, Norcross, GA, USA.

Mooney, Daniel F., Roberts, R. K.,………Steven W. & Mishra, A. 2010. "Precision Farming by Cotton Producers in Twelve Southern States: Results from the 2009 Southern Cotton Precision Farming Survey," Research Reports 91333, University of Tennessee, Department of Agricultural and Resource Economics.

Ackerson, J. P. (2018). Soil Sampling Guidelines, AY-368-W, Agronomy, The Education Store, Purdue University, Lafayette, USA, 6pp.