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Measurement of In-Field Variability for Active Seeding Depth Applications in Southeastern US

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Abstract. *Proper seeding depth control is essential to optimize row-crop planter performance, and adjustment of planter settings to within field spatial variability is required to maximize crop yield potential. The objectives of this study were to characterize planting depth response to varying soil conditions within fields, and to discuss implementation of active seeding depth technologies in Southeastern US. This study was conducted in 2014 and 2015 in central Alabama for non-irrigated maize (Zea mays L) and cotton (Gossypium hirsutum L). Planting was performed using a 6-row John Deere Max Emerge Plus planter equipped with heavy duty downforce springs. Three seeding depths and three downforce settings were selected for both crops, and the experiment was conducted in two fields exhibiting typical Coastal Plain features but characterized by different soil properties and terrain attributes. Soil electrical-conductivity and soil water content were used to measure within field spatial variability, and actual planting depth was characterized after emergence. Results demonstrated that actual planting depth was significantly affected by within field spatial variability, and actual planting depth response to field spatial variability was more accentuated during corn versus cotton planting. Soil electrical conductivity provided sufficient description of in-field variability to explain site-specific planting depth response in 4 out of 5 field trials. Soil water content was not a significant predictor of planting depth response to in-field spatial variability.*

Keywords. *Precision Agriculture, Planting, Spatial Variability, Active Seeding Depth Control*

Introduction

Agriculture continues to face many challenges such as increasing crop yields per unit area to provide for the growing world population, while reducing input use to ensure farm profitability and environmental stewardship (Friedrich, 2015). Seeds commercially available today can be highly optimized for specific conditions, but more efficient management strategies are required to support higher crop yields (Evans and Fischer, 1999). One solution to conventional management strategies can be accomplished through Precision Agriculture which increases machine automation and permits adjustments of equipment performance to within field spatial variability. Hence, adoption of Precision technologies enables farmers to improve field efficiency of various farm operations (Auernhammer and Schueller, 1999; Winstead, et al., 2010), and recent focus has been given to planting which represents perhaps the most critical field operation during a growing season (Srivastava et al., 2006).

Optimum planting performance requires placing individual seeds at a prescribed depth and population. Mistakes at this stage potentially results in suboptimal emergence rate, reduced plant population, and increased plant competition for water, nutrient and sunlight, therefore reducing crop yields and farm profitability (Karayel and Özmerzi, 2007). Seed germination requires sufficient water and temperature to rupture the seed coat and trigger the development of the seed embryonic tissues (Martin and Thrailkill, 1993). However, soil temperature and available water often vary across a field and within the soil profile, and deeper planting depths are usually desirable to provide consistent soil temperature and water content across the field. Nevertheless, excessively deep planting depths can generate too much resistance to seedling emergence, often resulting in significantly reduced plant populations. Minimum water and temperature requirements for germination along with seedling strength vary with crop and variety, and proper planting depth control is essential to optimize planting performances (Morrison and Gerik, 1983).

Standard row-crop planters control seeding depth through a pair of gauge-wheels mounted on individual row-units. Seeding depth is manually adjusted prior to planting operation by changing the position of a T-handle controlling the distance between the bottom of the furrow disc openers and the bottom of the gauge-wheels operating on the soil surface. Row-unit downforce is then selected to regulate the amount of additional weight transferred from the planter main toolbar onto individual row-units, establishing the load exerted by the gauge-wheels on the soil around the seed furrow (Morrison, 1988). Proper downforce is essential to maximize planter performances, and adequate downforce provides sufficient force onto the soil to achieve the targeted depth while permitting appropriate soil firming within the seedbed to optimize seed-to-soil contact. However, excessive downforce must be avoided as it can generate side-wall compaction and negatively impact early root development of seedlings, therefore reducing crop yield potential (Raper and Kirby, 2006).

Planter performances are also influenced by soil conditions at planting whereas they can vary significantly within fields (Hanna et al., 2010). Therefore, proper adjustments of seeding depth and row-unit downforce to in-field spatial variability are required to optimize row-crop planter performances (Knappenberger and Köller, 2011; Weatherly and Bowers, 1997). Research is currently being conducted to develop Precision planting technologies with such capabilities. One approach for active seeding depth control would involve the use of prescription mapping or real-time sensing of key soil properties (Bowers and Bowen, 1975; Price and Gaultney, 1993), but determination of specifications for such technology still requires a better understanding of soil-planter interactions, and planter response to within field spatial variability. The objectives of this study were 1) to characterize corn and cotton planting depth response to within field spatial variability, 2) to evaluate the potential of using soil electrical conductivity and soil water content as measurement of within field spatial variability for active seeding depth applications, and 3) to discuss implementation of active seeding depth by downforce technologies in Southeastern U.S.

Material and Methods

This study was conducted at the E.V. Smith Research Center (Shorter, AL USA; 32.441762 N, 85.897455 W) on non-irrigated maize and cotton. Planting was performed using a standard 91 cm row spacing, 6-row John Deere planter with MaxEmerge Plus row-units (John Deere, Moline, IL USA). Individual row-units were equipped with a Dawn coulter assembly - ripple coulter and two 36 cm trashwheels -, a double disc opener, two gauge-wheels, and two rubber closing wheels, and retrofitted with Precision Planting (Tremont, IL USA) eSet meter adds-on to maximize the likelihood of achieving uniform seed spacing. Seeding depth and row-unit downforce were adjusted manually. Seeding depth setting was adjusted by changing the position of a depth T-handle while row-unit downforce was controlled by adjusting a preload exerted by standard, mechanical heavy duty springs. Planter seeding depth on individual row-units was calibrated in the lab for each possible T-handle setting based on the following procedure. Graduated 2''x6'' boards were placed below planter gauge-wheels to ensure no contact between the soil and the opening discs during calibration, and the planter was lowered until all row-unit weight was carried by the gauge-wheels. Planter seeding depth was then measured as the distance between the top surface of the boards (in contact with the gauge-wheels), and the bottom of the opening discs. Three treatment depths were selected for corn and cotton to represent planting depths used across farms in Alabama. Typically, corn is planted between 4.4 and 6.3 cm and 2.5, 5.1, and 7.6 cm treatment depths were selected for corn. On the other hand, cotton is usually planted between 1.2 and 1.9 cm, and 0.6, 1.3, and 2.5 cm treatment depths were selected for cotton. Individual treatment depths were then associated to their corresponding T-handle setting, which were used throughout this study. None, medium, and heavy row-unit downforce were also selected as downforce treatments for corn and cotton, and each setting corresponded to a targeted applied downforce of 0 kN, 1.1 kN, and 1.8 kN onto individual row-units based on manufacturer's specifications (John Deere, 2003).

Field trials were conducted in two fields (referred to as A and B) exhibiting typical Coastal Plain features while being distinctly characterized by different soil properties and terrain attributes (Table 1). Each field was split in half, with each half planted to one of the two crops. The experiment was arranged as a split plot design, with half fields constituting the whole plots, and seeding depth x row-unit downforce combinations constituting subplots. Treatments were replicated 4 times in field A, and 3 times in field B (smaller field width). Therefore, and by design, individual treatment combinations were replicated 4 times in field A, and 3 times in field B. The experiment was conducted in strips, with one planter pass corresponding to one treatment combination (or plot). Individual plot dimensions were 5.5 m width (planter width) x 100 m length in field A, and 5.5 m width x 180 m length in field B. The experiment was conducted during 2014 and 2015 growing seasons, rotating crops between half fields in 2015. All sites were strip-tilled prior to planting to a depth of 30 cm using a 6-row Remlinger Precision Strip-Till unit (Remlinger Mfg, Kalida, OH USA). The two fields were strip-tilled for the first time in 2014, and strip-tillage maintained 30% to 50% soil surface residue coverage after planting. Corn and cotton were planted at 65,480 and 128,495 seeds.ha^{-1}, respectively. Corn was planted into soybean (*Glycine max L*) residues in 2014 and cotton residues in 2015. Cotton was planted into corn residues in 2014 and 2015. Planting was performed at 8 km/h, and corn and cotton were planted at different dates, hence affecting soil temperature and soil moisture conditions.

Table 1. Overall soil properties and terrain attributes for fields A and B selected in this study.

	Field A	**Field B**
Hillslope component	Intermediate fluvial terrace	Upland
Soil morphology	Altavista Silt Loam or similar (fine-loamy, mixed, semiactive, thermic Aquic Hapludults)	Luverne Sandy Loam or similar (fine, mixed, semiactive, thermic Typic Hapludults)
Slope	0% to 2%	1% to 5%
Drainage	Slower	Faster
Water table	Shallower	Deeper

Overall soil conditions and within field spatial variability in field A and B were characterized through in-field measurements of volumetric soil water content and apparent soil electrical-conductivity (EC). Soil water content data were collected at planting at 3.8 cm depth using a soil water content probe (Spectrum Technologies, FieldScout TDR 300 Soil Moisture Meter, Aurora, IL USA), and based on the following sampling strategy. Data were first collected in grid (systematic strategy) at the intersection between individual plots, and 5 or 8 equidistant transects drawn across fields A and B, respectively. Data were also collected at additional sampling sites placed at random between the first and last transects delimited for grid sampling, and ultimately 6 or 9 sampling sites were identified within each planter strip for field A or B, respectively. Soil EC data were collected at 1 Hz sampling frequency and 7 to 15 km.h^{-}1 ground speed using a Veris 3100 (Veris technologies, Inc., Salina, KS USA), and apparent soil EC was measured from 0 cm to 30 cm within the soil profile. Soil EC data were collected early in the spring to ensure sufficient soil water content for proper contact between the soil and coulter electrodes. Soil EC data were then interpolated within individual fields to extrapolate soil EC values at individual sampling sites previously identified. Kriging methodology was used for data interpolation as providing better fit to the data than other interpolation methods. Computations were performed using R software (R Core Team, 2016) and the “automap” package (Hiemstra et. al, 2008) which provided an automatic routine to optimize semi-variogram fitting. Five percent of the original data sets were selected at random and set aside for model validation, while computations were performed on the remaining 95% of the data. Experimental variograms were fitted using Matern models, and results were used to estimate soil EC at the locations previously extracted for data validation. Model performance was evaluated through computation of root-mean-squared error (RMSE) between observed and predicted soil EC values at those sites, and obtained RMSE values ranged from 1.1 to 1.5 mS/m. Therefore, computed interpolation models provided good fit to measured soil EC data, and soil EC values were extrapolated at individual sampling site where soil water content data were collected.

Actual planting depth for corn and cotton was also measured at individual sampling sites. Individual depth measurements for corn were performed by excavating an emerged plant and measuring the distance between the soil surface and visible seed. Individual depth measurements for cotton were performed by extracting a two weeks old emerged seedling and measuring the distance between the soil surface and the seed source, characterized by the point where the hypocotyl and radicle meets (Agri-Growth Inc, 1998). Actual planting depth at a given sampling site was then characterized as the average between 4 and 8 measurements for corn and cotton, respectively.

Actual planting depth data were analyzed through successive ordinary least square and geographically weighted regression analyses. Ordinary least square regression analyses were used to characterize field-scale planting depth response to planter settings selection within each field trial, while geographically weighted regressions characterized local planting depth response to planter settings selection, therefore permitting identification of spatial heterogeneity within individual field trials. Finally, Global Moran’s I index were calculated throughout the study to measure spatial auto-correlations among model residuals. Computations for data analysis were performed using ArcGIS® software (ESRI, 2011).

Results and Discussion

Identification of Planting Depth Response to Within Field Spatial Variability

Field-scale planting depth response to seeding depth and row-unit downforce planter settings selection was first modeled using ordinary least square (OLS) regressions. Seeding depth and row-unit downforce were significant predictors of actual planting depth within each field trial, and computed models provided fair to good fits to corn and cotton actual planting depth data (Table 2 and Table 3). Lower goodness of fit for 2015-A corn trial indicated smaller planting depth response to treatment combinations within this particular trial. Non-spatial analysis of residuals validated the assumptions of normality and homoscedasticity for OLS regression, and global Moran’s I index were computed to measure spatial auto-correlation among OLS residuals. No spatial relationships were identified among residuals within 2014-A, 2014-B, and 2015-B cotton trials, and OLS models accounted for all explainable sources of variation in actual planting depth within these trials. Results also indicated positive spatial auto-correlation –clustering- among residuals within all corn trials and within the 2015-A cotton trial, demonstrating statistically significant site-specific variability in actual planting depth within these trials. Corn was planted at deeper depth than cotton while 2015-A cotton trial was characterized by significantly deeper overall actual planting depths than other cotton trials, and results suggested that deeper planting depths augmented soil-planter interactions, hence accentuating planting depth response to within field spatial variability.

Table 2. Modeling of field-scale planting depth response to planter setup using ordinary least square regressions, and computation of Global Moran's I index to evaluate site-specific effects within individual corn trials.

--- Field Trials ---		---- Model Fit ----		---- Spatial Auto-Correlation ----	
Season	**Field**	**Adj. R^2**	**RMSE**	**G. Moran's I**	**Conclusion**
2014	**A**	78.8%	0.6 cm	0.23 ***	Clustered
	B	88.6%	0.5 cm	0.16 ***	Clustered
2015	**A**	26.7%	0.8 cm	0.32 ***	Clustered
	B	72.5%	0.7 cm	0.13 ***	Clustered

***: Statistically significant at the 0.01 level; **: Statistically significant at the 0.05 level

Table 3. Modeling of field-scale planting depth response to planter setup using ordinary least square regressions, and computation of Global Moran's I index to evaluate site-specific effects within individual cotton trials.

--- Field Trials ---		---- Model Fit ----		---- Spatial Auto-Correlation ----	
Season	**Field**	**Adj. R^2**	**RMSE**	**G. Moran's I**	**Conclusion**
2014	**A**	51.4%	0.3 cm	-0.06	Random
	B	48.7%	0.3 cm	0.02	Random
2015	**A**	65.8%	0.4 cm	0.33 ***	Clustered
	B	37.6%	0.4 cm	0.11	Random

***: Statistically significant at the 0.01 level; **: Statistically significant at the 0.05 level

Geographically weighted (GW) regressions were then computed to model local actual planting depth response to planter settings selection within all corn trials and 2015-A cotton trial, and results are presented Table 4 and Table 5. Adjusted R^2 for GW regression models were 1.2% to 30.6% higher than corresponding adjusted R^2 for OLS regression models, and GW models reduced planting depth residuals root-mean-squared error by 0.1 cm to 0.2 cm. Therefore, results demonstrated the existence of significant spatial heterogeneity within all corn trials and 2015-A cotton trial, and similarities between nearby planting depth observations in these trials resulted from the action of some spatial parameters acting on areas larger than sampling site resolution. Global Moran's I index were also calculated to measure spatial auto-correlation among GW residuals, and results indicated that GW regressions accounted for all significant spatial effects exhibited by OLS residuals within 2014-A, 2014-B, and 2015-A corn trials, while some positive auto-correlations among observations persisted in 2015-B corn trial 2015-A cotton trial.

Table 4. Modeling of local actual planting depth response to planter settings selection using geographically weighted regressions, and evaluation of spatial heterogeneity within individual corn trials.

--- Field Trials ---		---- Model Fit ----		---- Spatial Auto-Correlation ----	
Season	**Field**	**Adj. R^2**	**RMSE**	**G. Moran's I**	**Conclusion**
2014	**A**	81.8%	0.5 cm	0.00	Random
	B	90.0%	0.4 cm	0.07	Random
2015	**A**	57.3%	0.6 cm	0.04	Random
	B	75.0%	0.6 cm	0.10 **	Clustered

***: Statistically significant at the 0.01 level; **: Statistically significant at the 0.05 level

Table 5. Modeling of local actual planting depth response to planter settings selection using geographically weighted regressions, and evaluation of spatial heterogeneity within individual 2015-A cotton trial.

--- Field Trials ---		---- Model Fit ----		---- Spatial Auto-Correlation ----	
Season	**Field**	**Adj. R^2**	**RMSE**	**G. Moran's I**	**Conclusion**
2015	**A**	67.0%	0.4 cm	0.27 ***	Clustered

***: Statistically significant at the 0.01 level; **: Statistically significant at the 0.05 level

Measuring Within Field Spatial Variability

Results demonstrated the existence of spatial heterogeneity within all corn trials and 2015-A cotton trial, and the next step for data analysis was to evaluate the ability of soil EC and soil water content data to describe spatial correlations identified among actual planting depth observations within those trials. Results demonstrated the existence of significant relationships between soil EC data and actual planting depth within all trials, except 2015-B for corn. For 2014-A corn trial, actual planting depth was negatively correlated to soil EC, and 1 $mS.m^{-1}$ increase in soil EC was correlated to a 0.05 cm reduction in actual planting depth throughout the trial. Including soil EC to previous OLS regression for this trial increased model adjusted R^2 by 1.3% and accounted for all significant spatial effects formerly identified. Results also demonstrated significant relationships between actual planting depth and soil EC within 2014-B and 2015-A corn trials, and within 2015-A cotton trial, but observed correlations were significant only in some sections of the trials. Both positive and negative correlations between actual planting depth and soil EC data were observed within a given trial (Figure 1), and 1 mS/m increase in soil EC resulted into -0.15 to +0.4 cm change in actual planting depth. Accounting for local soil EC effects in these three trials increased model adjusted R^2 by 4.5% to 10.7%, and explained all significant spatial effects formerly identified. Varying soil water content within trials did not correlate with actual planting depth measurements. For 2014-B corn trial, soil EC and soil water content measurements did not provide adequate measurement of within field spatial variability to describe spatial heterogeneity in this trial. Hence, results suggested that spatial effects observed in 2014-B corn trial resulted from the action of other spatial parameters not captured by soil water content and soil EC measurements.

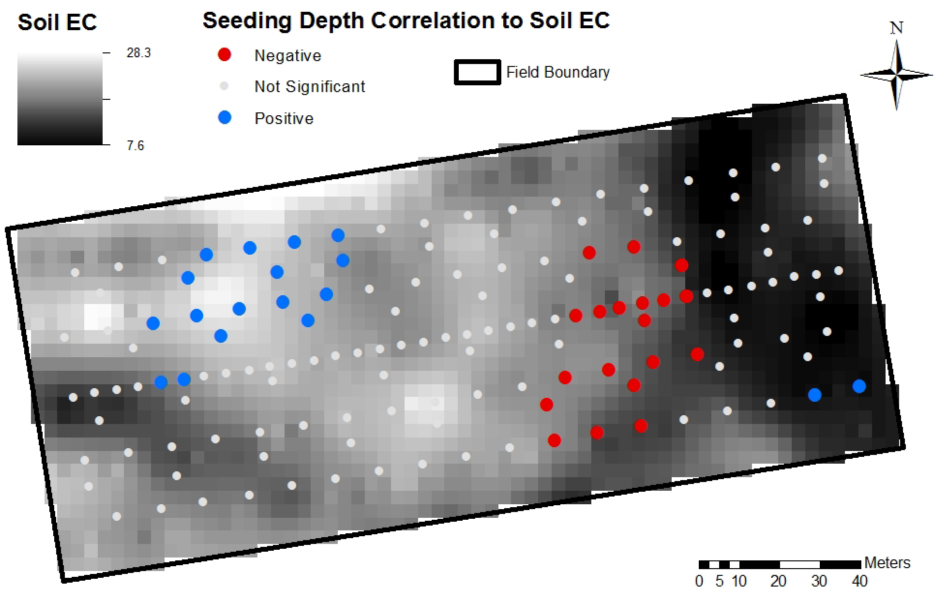

Figure 1. Evaluation of correlations between soil EC and actual planting depth to explain site-specific planting depth response. Example of 2015-A cotton trial.

Active Seeding Depth Applications in Southeastern US

Results demonstrated that planting depth performance of standard row-crop planters was significantly affected by varying soil conditions within fields, therefore attesting of the need for Precision technologies permitting in-field adjustments of planter settings to these varying soil conditions. Planting depth response to within field spatial variability increased with increasing planting depths, and results suggested that Precision planting technologies with site-specific capabilities could be more beneficial for crops having deeper planting depth requirements. Site-specific variability in planting depth observed within 4 out of 5 trials was significantly correlated to changes in soil EC within fields, and results suggested that soil EC could represent key soil properties for development of active seeding depth technologies in Southeastern US Coastal Plain soils. Nevertheless, relationships between actual planting depth and measured soil EC were much contrasted because soil EC depends on the combinations between a multitude of factors not limited to soil physical properties and terrain attributes (White et al., 2012). Results also suggested that soil EC should be associated with additional information for better characterization of planting depth response to within field spatial variability. Soil water content measurements did not provide an adequate measure of field spatial variability to explain planting depth response to within field spatial variability. Therefore, results did not identify soil water content as a key soil property to consider for development of active seeding depth technologies within field conditions represented in this study. However, soil water content usually exhibits strong spatial and temporal variability within a field. These data were collected at low resolution, and obtained results do not preclude soil water content to be used for active seeding depth applications providing sufficiently high sampling resolution. Increasing sampling resolution would also permit more precise characterization of planting depth response to field spatial variability and identification of spatial parameters influencing row-crop planter seeding depth performance.

Conclusions

The following conclusions were drawn from this study:

- Actual planting depths were significantly affected by within field spatial variability
- Planting depth response to within field spatial variability was accentuated during corn versus cotton planting.
- Soil electrical-conductivity measurements provided adequate description of in-field variability to describe site-specific planting depth response in 4 out of 5 trials.
- Soil water content measurements were not significant predictors of planting depth response to in-field spatial variability.

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References

Agri-Growth, Inc. (1998). *Guide to Herbicide Injury Symptoms in Cotton, with "Look-Alike" Symptoms.* (2nd ed.). Hollandale, MN, USA: Agri-Growth, Incorporated.

Auernhammer, H., & Schueller, J. K. (1999). Part 3.2. Precision Farming. In B. Stout, & B. Cheze (Eds.), *CIGR Handbook of Agricultural Engineering, Volume III Plant Production Engineering* (pp. 598-616). St. Joseph, MI, USA: American Society of Agricultural Engineers.

Bowers, C. G., & Bowen, H. D. (1975). Drying front sensing and signal evaluation for planters. *Transactions of the ASAE*, 18(6), 1051-1056.

ESRI. (2011). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Evans, L. T., & Fischer, R. A. (1999). Yield Potential: Its Definition, Measurement, and Significance. *Crop Science,* 39(6), 1544-1551.

Friedrich, T. (2015). A New Paradigm for Feeding the World in 2050. The Sustainable Intensification of Crop Production. *Resource Magazine,* 22(2), 18-18.

Hanna, H. M., Steward, B. L., & Aldinger, L. (2010). Soil Loading Effects of Planter Depth-Gauge Wheels on Early Corn Growth. *Applied Engineering in Agriculture,* 26(4), 551-556.

Hiemstra, P. H., Pebesma, E. J., Twenhöfel, C. J., & Heuvelink, G. B. (2009). Real-time automatic interpolation of ambient gamma dose rates from the Dutch radioactivity monitoring network. *Computers & Geosciences*, 35(8), 1711-1721.

John Deere. (2003). *Heavy-Duty Downforce Springs*. Retrieved from John Deere Planter Manual, Section : 95 - General

Attachments: http://manuals.deere.com/omview/OMA74223_19/AG_OUO6074_1282_19_04AUG00_1.htm

Karayel, D., & Özmerzi, A. (2007). Evaluation of Three Depth-Control Components on Seed Placement Accuracy and Emergence for a Precision Planter. *Applied Engineering in Agriculture, 24*(3), 271-276.

Knappenberger, T., & Koller, K. (2011). Spatial Assessment of the Correlation of Seeding Depth with Emergence and Yield of Corn. *Precision Agriculture, 13*(2), 163-180.

Martin, D. L., & Thrailkill, D. J. (1993). Moisture and Humidity Requirements for Germination of Surface Seeded Corn. *Applied Engineering in Agriculture., 9*(1), 43-48.

Morrison Jr, J. E., & Gerik, T. J. (1983). Planter Depth-Control Predictions and Projected Effects on Crop Emergence [Tillage]. *Paper-American Society of Agricultural Engineers. (USA)*.

Morrison, J. E. (1988). Interactive Planter Depth Control and Pneumatic Downpressure System. *Transactions of the ASAE, 31*(1), 14-18.

Price, R. R., & Gaultney, L. D. (1993). Soil moisture sensor for predicting seed planting depth. *Transactions of the ASAE*, 36(6), 1703-1711.

R Core Team. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from http://www.R-project.org/.

Raper, R. L., & Kirby, J. M. (2006). Soil Compaction: How to Do It, Undo it, or Avoid Doing It. *Proceedings of the 2006 Agricultural Equipment Technology Conference.* Louiseville, KY, USA: American Society of Agricultural and Biological Engineers.

Srivastava, A. K., Goering, C. E., Rohrback, R. P., & Buckmaster, D. R. (2005). Crop Planting. In *Engineering Principles of Agricultural Machines* (2nd ed., pp. 231-265). St. Joseph, Michigan: American Society of Agricultural Engineers.

Weatherly, E. T., & Bowers Jr, C. G. (1997). Automatic Depth Control of a Seed Planter based on Soil Drying Front Sensing. *Trans. of the ASAE,* 40(2), 295-305.

Winstead, A., Fulton, J., & Mullenix, D. (2010). *Considerations for Adopting and Implementing Precision Ag Technologies.* Retrieved from ACES - Alabama Cooperative Extension System: https://sites.aces.edu/group/crops/precisionag/Publications/Timely%20Information/Considerations%20for%20adopting%20PA.pdf

White, M. L., Shaw, J. N., Raper, R. L., Rodekohr, D., & Wood, C. W. (2012). A Multivariate Approach for High-Resolution Soil Survey Development. *Soil Science*, 177(5), 345-354.