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Prescription map creation for optimal variable-rate seeding in Arkansas soybean fields

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Abstract

Proper soybean seeding rate selection is required to maximize profitability. Until recently, agricultural fields represented the smallest possible management unit, and current seeding rate recommendations were developed for uniform, whole-field application. However, the optimum planting density may vary within a field because of spatial changes in soil properties and management history. The normalization of variable-rate seeding (VRS) technology allows for in-field adjustments of plant population, but few actionable recommendations exist to inform practical implementation and maximize benefits from technology adoption. Development of such data driven recommendations would help optimize crop production through increased efficiency, profitability, and sustainability. The project objectives were to assess the agronomic and economic potential of VRS for production soybean and develop a methodology for data-driven prescription map creation. This proceeding describes the projects' major findings. A randomized complete block seeding rate strip trial with four replications was established in two production soybean fields of Arkansas using a 12-row planter equipped with VRS technology and real-time kinematic capabilities. Five seeding rate treatments were selected to bracket the typical range: 185,000, 247,000, 309,000, 370,000 and 432,000 seeds ha^{-1}. Stand counts were collected to evaluate planter performance. Field elevation and web soil survey data were downloaded from public repositories. Soil samples were collected to characterize in-field changes in soil texture, pH, and nutrient availability. Statistical analysis was computed to identify the drivers of in-field yield variability, model crop response to spatial changes in the identified drivers, and creation of relevant prescription maps. Separate analyses were computed for each field and spatial dependencies were accounted for. A 100-fold cross-validation with a 10% calibration and 90% validation data-split was performed to improve the computed model predictive capabilities. Findings demonstrated that VRS should only be recommended if in-field soybean yield response to field conditions and seeding rate is structured and varies spatially. Economic analysis should be computed to fine-tune the created agronomic optimum prescriptions for maximized profitability.

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Future research will emphasize optimization of the developed computations, automation into an algorithm, and evaluation of temporal stability and variability in the created prescriptions. Eventually, integration into a web-tool will make these findings and the developed method accessible to agricultural stakeholders.

Keywords. *Cross-Validation, Spatial Dependencies, In-field Variability, Optimized Crop Management, Decision-Support*

Introduction

Site-specific, data-driven management of agricultural fields remains a challenge for modern crop production systems (Lowenberg-DeBoer and Swinton 1997; Bhakta et al., 2019). Optimized crop management requires accurate characterization of between and within-field variability, and effective resource use across the identified site-specific dynamics. While recent advances in precision agriculture engineering have provided producers with variable-rate capabilities, few recommendations exist to help producers determine if the new technologies would be beneficial to their operation and how they should be applied to their unique production goals and environment to maximize benefits and return on investment (Clark and McGuckin, 1996). Sources of spatial variability include field characteristics (e.g., elevation, slope, aspect), soil properties (e.g., texture, pH, nutrient availability), and management history (e.g., land-leveling, crops in rotation, cultivar selection, lime and fertilizer applications) (Bell et al. 1995; Cox et al. 2003; Kravchenko and Bullock 2000; Maestrini and Basso 2018). Complex interactions occurring between genetic, environmental, and management factors further complicate management of spatial variability by making it difficult to predict crop response to whole-field or site-specific operation parameter selection (Cooper et al. 2021). Moreover, inaccurate characterization of spatial variability from suboptimal sampling strategies or sensor accuracy may result in suboptimal management decision that reduce resource use efficiency and may complicate future management attempts (De Caires et al. 2021).

Soybean (*Glycine Max* L.) is a staple crop globally and the mid-southern U.S. has unique characteristics (e.g., wide planting window, high solar radiation, numerous options for cultivar selection) that support high potential yield (Salmeron, et al., 2014). Potential soybean yield is determined at planting, and proper seeding rate selection is essential to optimize resource use and maximize profitability (Evan and Fischer, 1999; Chen & Wiatrak, 2011. Typical soybean seeding rates range from 272,000 to 370,000 seeds ha^{-1} and current Arkansas recommendations target whole-field applications, optimizing agronomic and economic production with a single seeding rate prescription (Ashlock et al. 2000). However, site-specific variability from spatial changes in soil properties, management history, fate and transport of nutrients, and distribution of water substantially affect soybean growth and yield within a field (Cox et al. 2003; Kravchenko and Bullock, 2000). Such variability may affect yields and could be managed using precision technologies. Typically, higher planting densities are needed in the least productive areas (Cariochi et al. 2019), and variable-rate seeding (VRS) could be used to account for finer scale variability and optimize resource use beyond whole-field recommendations (Šarauskis, et al., 2022). Management zone delineation allows for differentiation between zones with different agronomic characteristics and site-specific adjustments of the operation parameters. Different delineation methods and parameters (e.g., soil properties, plant health, yield history) have been used in published literature (Dennerley et al. 2018; Breunig et al. 2020; Jaynes et al. 2005). However, few guidelines are available to help producers determine the method that will yield the best results for their cropping system.

While previous research has been conducted to identify manageable variability and delineate management zones within agricultural fields, no practical implementation guidelines for VRS are available. Development of such recommendations requires proper characterization of spatial variability (Kitchen et al. 2005; Maestrini and Basso 2018; Schepers et al. 2004) and accurate prediction of crop response to in-field seeding rate adjustments (Bullock et al. 1998; Sanchez et al. 2019). Future integration into a web-tool would allow producers to make informed decisions regarding VRS technology acquisition and application. The project objective was to develop a methodology that can be used to generate practical, data-driven VRS recommendations for optimized crop management. Major findings, practical applications, and future developments will be discussed in this proceeding.

Materials and methodology

Site Description and Experimental Design

A seeding rate trial was conducted in 2021 (Field A) and 2022 (Field B) near Gould, AR, USA. Three and four soil series were represented in fields A and B, respectively. The previous crop was soybean in both fields. Five seeding rates were selected to bracket the typical midsouth soybean seeding rates range: 180, 247, 309, 370, and 432 thousand seeds ha^{-1}. The treatments were applied in a randomized complete clock strip design with four blocks (Figures 1 and 2). This design is recommended for on-farm research because it allows producers without access to precision technologies to conduct relevant experiments without unduly incumbering farm management (Bramley et al 2006). The fields were planted on June 6, 2021, and May 21, 2022, using a 12-row planter equipped with auto-guidance technology, variable-rate seeding capabilities, and real-time kinematic (RTK) positioning accuracy. Each seeding rate strip was applied as two consecutive passes for 24 total rows per strip. The soybean cultivar was AG48X9 and the row spacing was 91 cm. Both fields were furrow-irrigated. Water was delivered using polypipe (Polytube™, Delta Plastics of the South, Little Rock, AR) located along the field crown. Nutrient and pest management was accomplished using current University of Arkansas Cooperative Extension guidelines. Harvest was performed using a 12-row combine equipped with a yield monitor and RTK positioning accuracy.

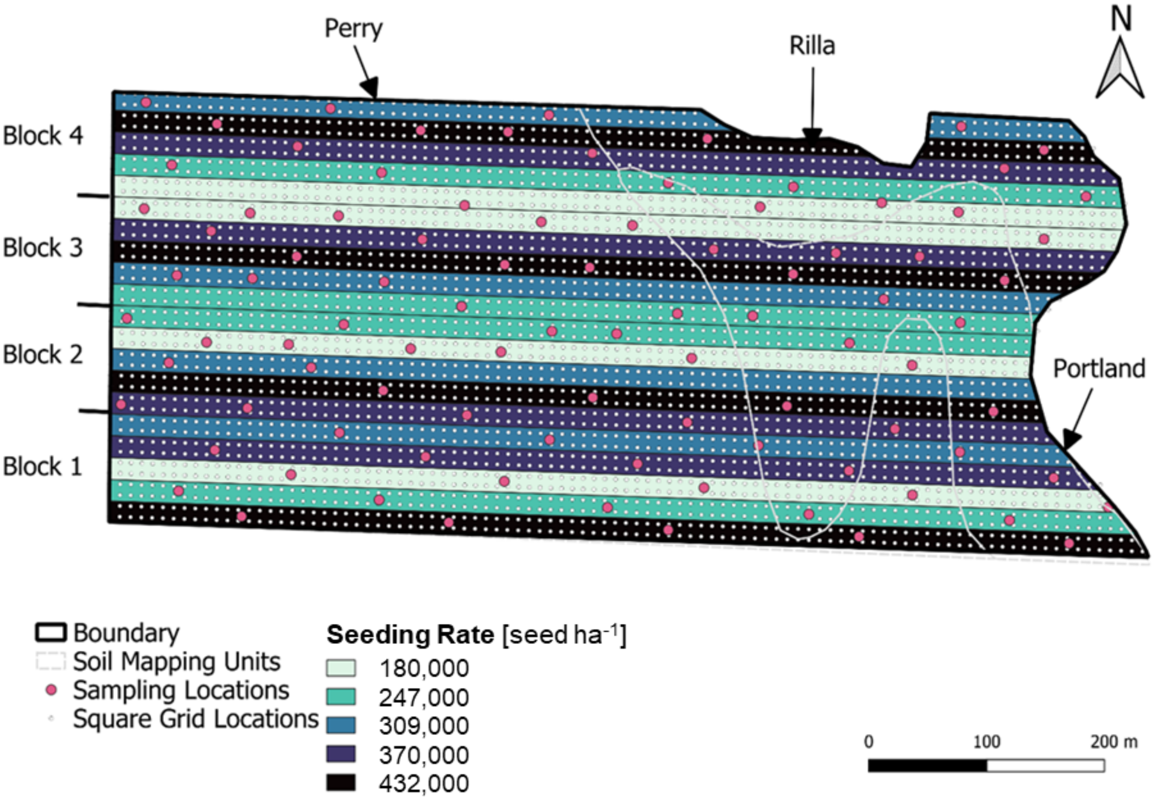

Figure 1. Seeding rate treatment layout, soil mapping unit, and data collection strategy in field A. Soil mapping unit information was downloaded from the Web Soil Survey (Soil Survey Staff et al., 2023). The sampling locations describe where soil samples and stand count data were collected. The square grid locations determine where soil pH, nutrient availability, soil texture, and elevation were estimated in preparation for statistical analysis.

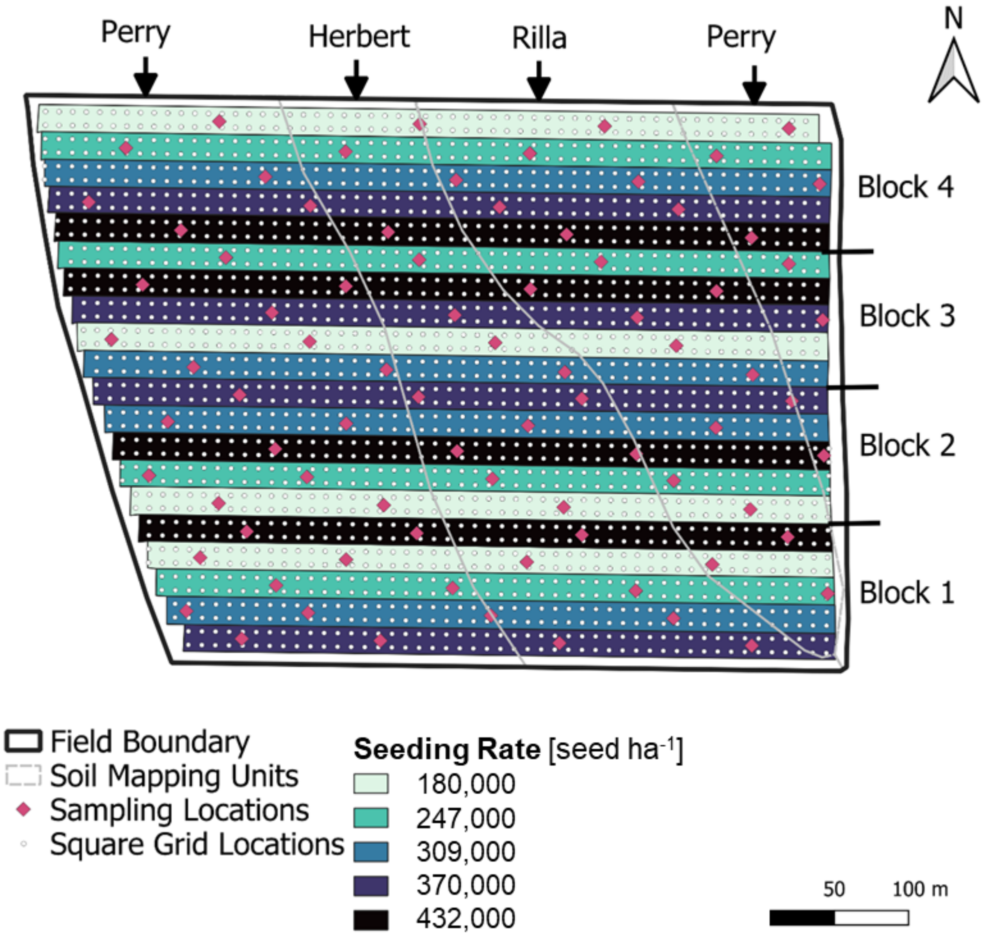

Figure 2. Seeding rate treatment layout, soil mapping units, and data collection strategy in field B. Soil mapping unit information as downloaded from the Web Soil Survey (Soil Survey Staff et al., 2023). The sampling locations describe where soil samples and stand count data were collected. The square grid locations determine where soil pH, nutrient availability, soil texture, and elevation were estimated in preparation for statistical analysis.

Data Collection and Analysis

A total of 91 and 80 sampling locations were identified in fields A and B using stratified random sampling, respectively (Figures 1 and 2). All sampling locations were in the middle of a treatment strip. At each location, soil samples and plant population were collected. The soil samples were collected before the growing season in both years and submitted to the University of Arkansas System Division of Agriculture Fayetteville Soil Test Laboratory for routine soil testing and soil texture analysis. Stand counts were collected at the three expanded trifoliate (V3) soybean growth stage along two rows representing 0.00004 ha^{-1} and used to quantify final plant population. The collected yield monitor data were adjusted to 13% moisture and the planter as-applied maps and yield monitor data were processes to remove outliers caused by changes in travel speed at the field edge. Digital elevation models providing field elevation data were downloaded from the United States Geological Survey public data repository (USGS 2023). Downloaded data were less than 3 years old and resolution was 1m.

Plant population and as-applied seeding rate data were analyzed to assess planter performance. The distribution of yield data was compared between treatments and fields. Soil mapping units, pH, phosphorus and potassium, field elevation, percent clay and sand, and soil texture were considered as possible drivers of in-field yield variability. Yield was downloaded from the producers' calibrated yield monitor in the form of a point shapefile, and cleaned by the equipment manufacturer (John Deere, Moline, IL, USA). The cleaned data were downloaded from the manufacturer's web portal in the form of a polygon shapefile. Yield was estimated as the average yield data collected within a 4.5 m radium from each square grid point using a spatial intersect function. There were 3586 and 2153 square grid points in fields A and B, respectively (Figures 1 and 2). Each grid point corresponded to planter/combine passes. The distance between two consecutive grid points in a row or column was 11 m, same as the planter/combine width. Soil pH, nutrient availability, and texture were estimated from the soil test results using Kriging. Soil mapping unit and field elevation were determined using spatial intersection functions.

Data were analyzed using linear modeling. Separate analyses were computed for each field. Spatial dependencies were accounted for using Zuur et al (2009)'s method. A 100-fold validation was performed using a 10% calibration and 90% validation data split. Results were used to identify the parameters that contribute to in-field soybean yield variability and establish the model that best describes soybean yield within each field. The best model found in each field was used to predict soybean yield assuming a seeding rate 180, 247, 309, 370, and 43 thousand seeds ha^{-1}. The grid points were grouped into management zones that accounted for 2 x 2 = 4 side-by-side grid points within a treatment strip. The 5 seeding rates x 4 points = 20 predicted yield values associated with each grid points were compared using analysis of variance. The smallest site-specific seeding rates that maximized predicted yield (statistically) were used to generate a-posteriori soybean seeding rate prescriptions for each field. The associated predicted yield data were mapped to show how much in-field soybean yield variability is not expected to be accounted for with variable soybean seeding rate.

Results

Planter Performance

In field A (2021), the planter failed to acceptably seed the highest and lowest (180,000 and 432,000 seed ha^{-1}) seeding rates according to stand count data (Figure 3), although the as-applied seeding rate data reported acceptable seeding rates. An explanation for this is that the rotation of the seed plate may not have been fast enough at the highest seeding rate and may have planted extra seeds due to inability to maintain proper vacuum and unsure singulation at the lowest seeding rate. However, this is likely not the case for the intermediate seeding rate treatments, although the planter did tend to plant below-target rates for the higher seeding rates, possible due to improper equipment calibration before planting (Virk, et al., 2020; Figure 3). In field B (2022), differences between plant populations and the as-applied seeding rates were not different (Figure 3). Despite failing to plant the target rate for all treatments, significantly different plant populations were achieved in field A and B (data not shown).

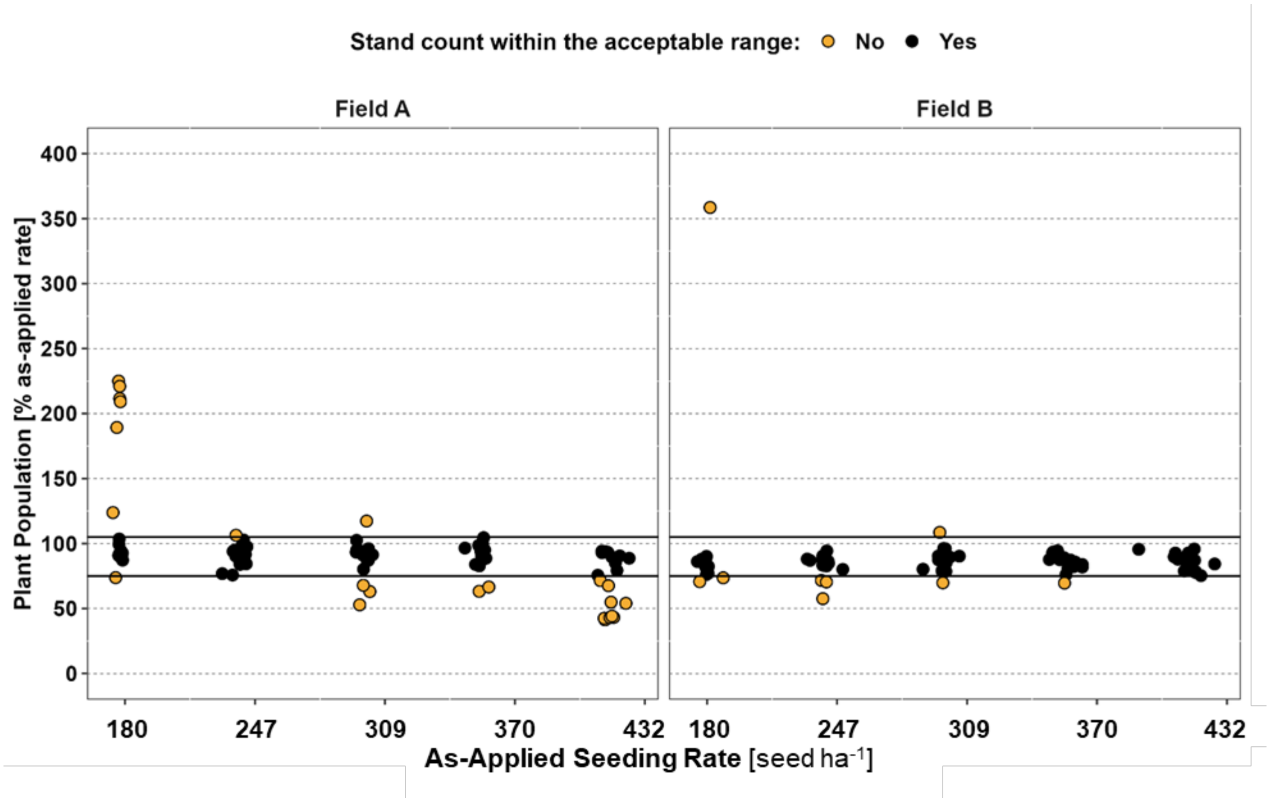

Figure 3. Plant population as a function of as-applied seeding rate in fields A and B. Plant populations within a range of 80 to 105% (indicated by black bars) of the target seeding rate were considered acceptable. Plant populations at data collection sites within the acceptable range are black and circles outside this range are yellow.

Yield

No statistical differences occurred in field A or B between seeding rate treatments (Figure 4). Average yield in field A was numerically greatest (4.45 t ha^{-1}) at 432,000 seed ha^{-1} and least (4.05 t ha^{-1}) at 180,000 seed ha^{-1} than the other seeding rate treatments. Field B average yield was numerically greatest (4.55 t ha^{-1}) at 247,000 seed ha^{-1} and least (4.27 t ha^{-1}) at 370,000 see ha^{-1}. Overall, greater average yields were observed in field B compared to field A and coefficient of variation ranged from 4 to 14% across fields (Figure 4). The lack of significant yield differences according to the effect of seeding rate may be due to soybean' ability to compensate for unfavorable growing conditions, such as by increasing or decreasing branches or pods per plants according to planting density (Agudamu and Shiraiwa 2015; Sushre et al. 2014), especially considering soil moisture nutrient availability was generally not an issue.

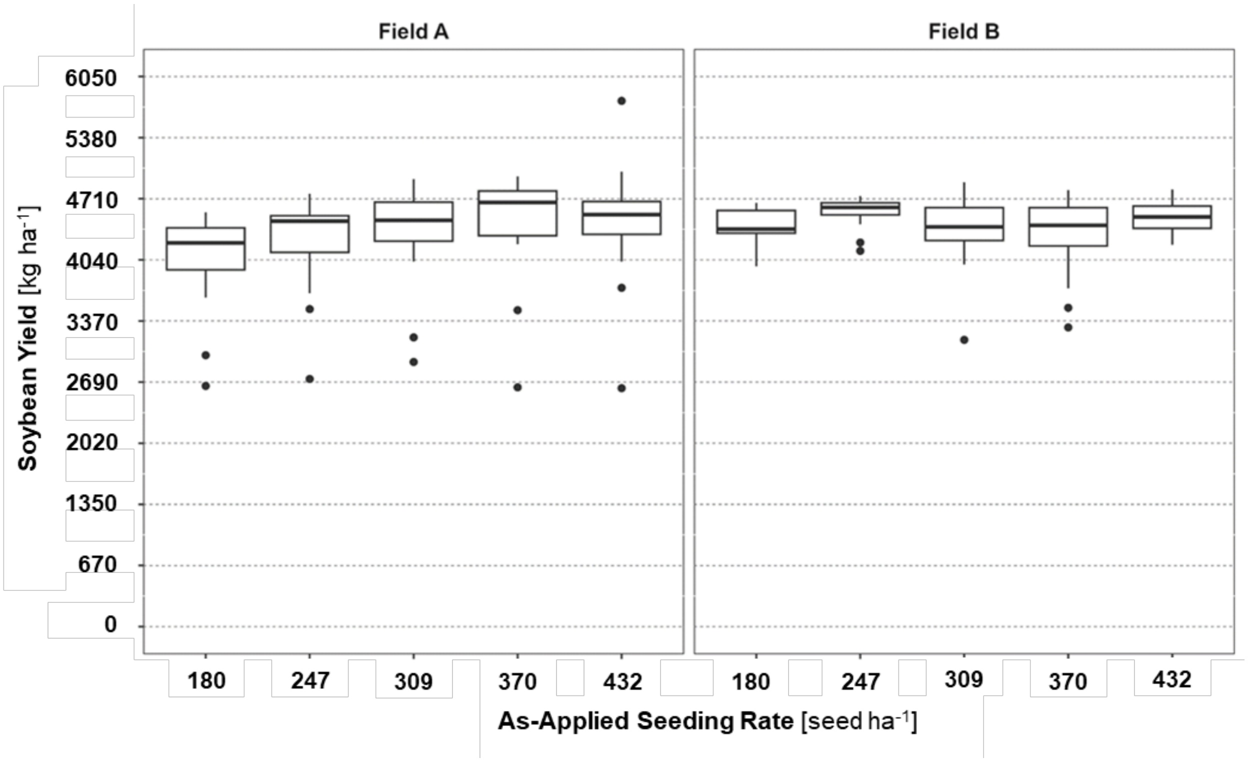

Figure 4. Yield as a function of as-applied seeding rate treatment in fields A and B. Boxplots indicate the average yield per treatment, quartile ranges, and yield outliers by treatment.

Seeding Rate Prescriptions

Significant drivers of within-field variability were identified, and soybean response varied with site-specific changes in field conditions. Therefore, VRS may be considered to optimize planting densities. In field A, soybean yield was significantly affected by the interaction between seeding rate and soil pH. The 432,000 seeds ha-1 seeding rate would have maximized yield in 94.3% of the field area (Figure 5). The 370,000 seed ha^{-1} seeding rate would have maximized yield in the remaining 5.7% of field area. The area of field A that would have benefitted from the lower seeding rate corresponded to a poorly drained area of the field. In field B, more variability was identified that could be capitalized on using VRS. Yield in 47.0%, 24.6%, 14.0%, 11.6%, and 2.8% of the area of field B would have been maximized with a seeding rate of 370,000, 247,000, 180,000, 432,000, and 309,000 seeds ha^{-1}, respectively (Figure 6).

Figure 5. A posteriori seeding rate prescription map for field A.

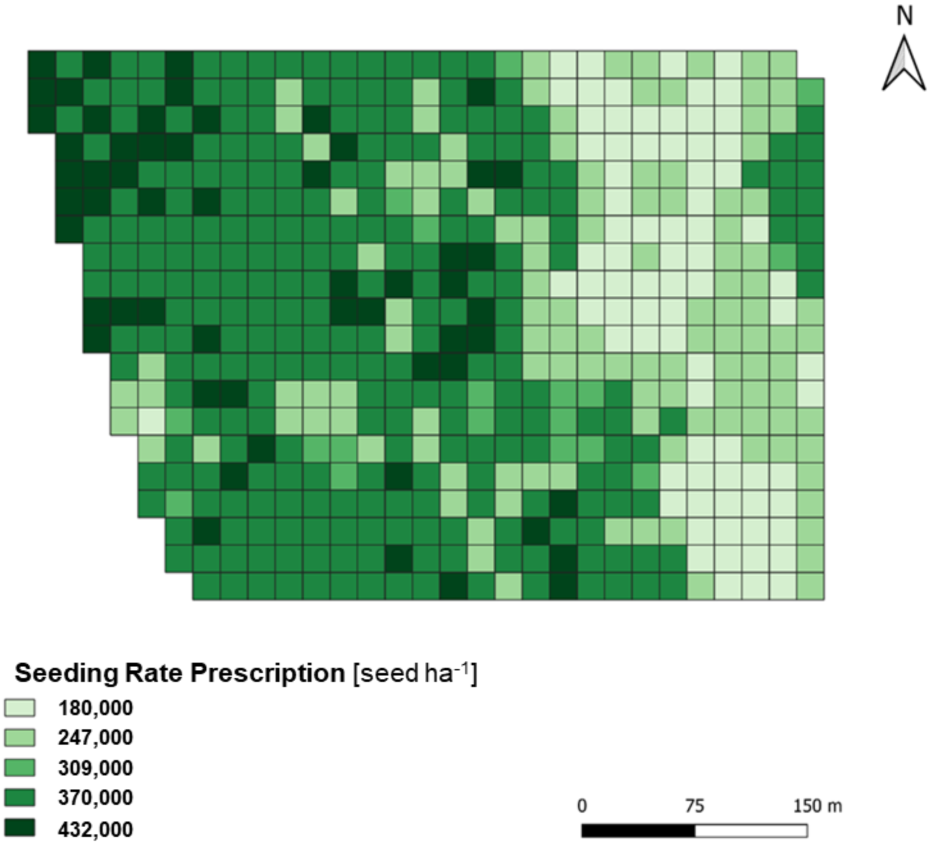

Figure 6. A posteriori s**eeding rate prescription map for field B.**

Conclusion or Summary

Results of this study indicate that current seeding rate recommendations are appropriate for whole-field applications considering some of the numerically highest yields were obtained with these rates. However, within-field variability was identified that could be better managed with VRS technology. Future research will investigate spatial and temporal stability of seeding rate prescription maps by repeating experiments in both field A and B. The created method for determining optimal seeding rates allows for data-driven seeding rate recommendations. A web-tool will be created that allows farmers to input essential data to find if VRS should be used to optimize production, and seeding rate recommendation outputs from the tool will be limited to seeding rates investigated in the on-farm study. For implementation of this research on-farm, producers may need to establish a seeding rate trial in fields where VRS is to be implemented. VRS will only be suggested and seeding rate map provided only if structured within-field variability is present in producer fields. In addition, ground-reference assessments of planter performance will need to be conducted to ensure acceptable planter performance.

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