Assessing Crop Yield and Profitability with Site-Specific Seed Rate Management in Corn and Soybean Cropping Systems

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Abstract.

Integrating the information about soil and topographic properties for variable rate seeding is a prerequisite for improved crop production and thus profit. However, limited studies have explored geospatial and machine learning approaches to understand factors influencing crop yield and profit under variable rate seeding. The objectives of this study were to: a) observe the effect of variable seeding rate based on soil and topographic properties on soybean and corn grain yield, b) determine if optimum seeding rate changes with crop management zones, and c) determine the feasibility of variable rate seeding (VRS) compared to uniform rate seeding (URS) based on profit analysis. This study was conducted in two fields located in Miami County, Ohio from 2017 to 2022. Sensor-based information on apparent soil electrical conductivity (CEC), soil type, soil organic matter (SOM), elevation, roughness, aspect, topographic position index (TPI), terrain ruggedness index (TRI), and slope were collected. Yield data on soybean and corn at different planting populations for all years were obtained. Both geospatial and random forest analyses showed that elevation, OM, CEC, and seed rates were the most important factors influencing yield for both corn and soybean. Preliminary analysis of clusters created based on SOM, CEC, and elevation showed that yield and optimum seed rate varied across different management zones indicating a potential for site-specific seed rate management.

Keywords: *Site-specific management, machine learning, profitability, management zones*

Introduction

Planting density influences crop yield in corn and soybean production systems. As seed is one of the most expensive inputs (Langemeier et al., 2022), it is important for growers to plant the right amount of seed that will optimize input cost and maximize profit especially in corn and soybean production systems in the north-central United States (Hamman et al., 2021). While most of the earlier studies were based on experiment plot level studies (Carciochi et al., 2019; Cox et al., 2011), current trend has shifted more towards on-farm research as the importance of within field variability of field properties on crop growth is realized (Gaspar et al., 2020). With the development of precision agriculture tools and technologies, it has been possible to conduct field-scale research and utilize the information in making sound input management decisions. Many studies have been conducted to determine appropriate variables to predict yield response to seed rate and management zone delineation at the field scale. Historical yield maps, soil properties, and topography are some of the common variables used to determine the management zones (Smidt et al., 2016). However, developing a "prescription" seed rate for each management zone which will optimize yield or profit is still a challenge in using VRS technology. The recent development of machine learning techniques such as random forest has opened new avenues to analyze spatially correlated big-data. Hence, in this study we are interested to use machine learning and geostatistics to identify factors influencing crop yield response to seed rate and determine agronomic and economically optimum seed rate for corn and soybean production. Hence, the objectives of this study were to: a) identify field variables influencing crop yield response to seed rate based on geostatistical and machine learning methods; b) determine optimum seeding rate to maximize yield and profit within management zones based on identified explanatory variables.

Material and Methods

Study Site and Experimental Design

Seeding rate treatments were conducted at two fields, Field 1 and Field 2, located in Miami County, Ohio. Experimental design consisted of completely randomized design of rows for treatments with three to four replications (Fig. 1). The treatment for corn consisted of five seed rates (28, 32, 36, 40, and 44 thousand seeds per acre) planted in two fields in 2018, 2019, 2020, 2021, and 2022. The treatment for soybean consisted of four seed rates (80, 120, 160, and 200 thousand seeds per acre) planted in two fields in 2017, 2018, 2019, and 2020.

Data Collection and Preprocessing

Soil samples were collected in 2021 at 20 cm depth and analyzed for soil properties such as soil organic matter (SOM) and cation exchange capacity (CEC). Topographic properties of the field, such as slope, elevation, aspect, roughness, Terrain Roughness Index (TRI), and Topographic Position Index (TPI) were also assessed. The topographic properties were computed using digital elevation model (DEM) data, with 0.76 m resolution, available from the Ohio Geographically Referenced Information Program using ArcGIS software. Corn and soybean yield data (in bushels per acre) were collected using John Deere yield monitor installed on a combine at the time of harvesting using recommended calibration procedures. The information for seed price, and receipt price per bushel from Ohio State University Crop Budgeting was used to calculate partial budget for seed rate in different clusters in a field. Cumulative precipitation and the cumulative growing degree days were calculated from the available weather data collected from PRISM Network.

Data Aggregation and Analyses

Yield polygon data was created by developing a rectangle with the length equal to harvester swath width (6.32 m) and width equal to the distance between logged data points (2 m) in a row around each logged yield data point. This yield polygon data was then used to extract information from other variables and relate to corn and soybean yield. To extract information for soil and topographic data, zonal statistics function of the Spatial Analyst tool in the ArcGIS Pro Version 3.1.0 (ESRI, Redlands, CA, USA) was used.

Random forest and spatial regression models indicated that elevation, soil CEC and soil organic matter (SOM) were the most important factors influencing yield. Hence, these factors were used to determine clusters or management zones in the field. ANOVA and LSD mean separation test was done to determine optimum seeding rate in each cluster for maximum yield. Profit analysis was done to determine the whether the optimum seed rate in each cluster for maximum yield also gave higher profit.

Results

The fields showed substantial variability in soil and topographic properties. The elevation in the field ranged from 242 to 248 m with 6 m difference across the field and the slope ranged from 0 to 0.75%. The average elevation of the field 1 and field 2 were 244.1 and 243.23 m respectively. The Northwest part of the study area had higher elevation compared to the Southeast area. The CEC in the field ranged from 5.4 to 20.1 meq per 100 grams with field 1 average of 12.56 and field 2 average of 11.18 meq per 100 grams. The SOM in the fields ranged from 1.6 to 5.9% with an average of 2.94% and 2.67% in Field 1 and Field 2 respectively. CEC and SOM were particularly high in areas with lower elevation. From both spatial regression model and random forest regression, elevation, slope, and organic matter were identified as the most important factors influencing the crop yields beside the seed rate. Hence, the information for elevation, CEC, and SOM were used to conducted clustering analysis. The results indicated that three clusters were optimum in both Field 1 and Field 2 (Fig 1).

With few exceptions, corn yield showed either quadratic or quadratic plateau response to seed rate in different clusters across multiple years (Fig 2). Corn yield increased up to a certain point with increasing seed rate before it plateaued or decreased. Conversely, soybean yield response to seed rate varied greatly in different clusters across multiple years (Fig 3). In some years, it increased with increasing seed rate and in some years the trend reversed such that yield decreased with increasing seed rate. The agronomic optimum seed rate for corn in Field 2 Cluster 1 was about 35 thousand seed per acre, except in 2018 where optimum seed rate was 43 thousand seeds per acre. This might be due to higher precipitation in 2018. The agronomic optimum seed rate for cluster 3 ranged from 35 to 42 thousand seed per acre depending on year under study. For soybean, overall, the optimum seed rate ranged from 61 to 82 thousand seeds per acre across multiple clusters in multiple years.

Fig 1. Clusters based on elevation, SOM, and CEC in Field 1 and 2 located in Miami County, Ohio.

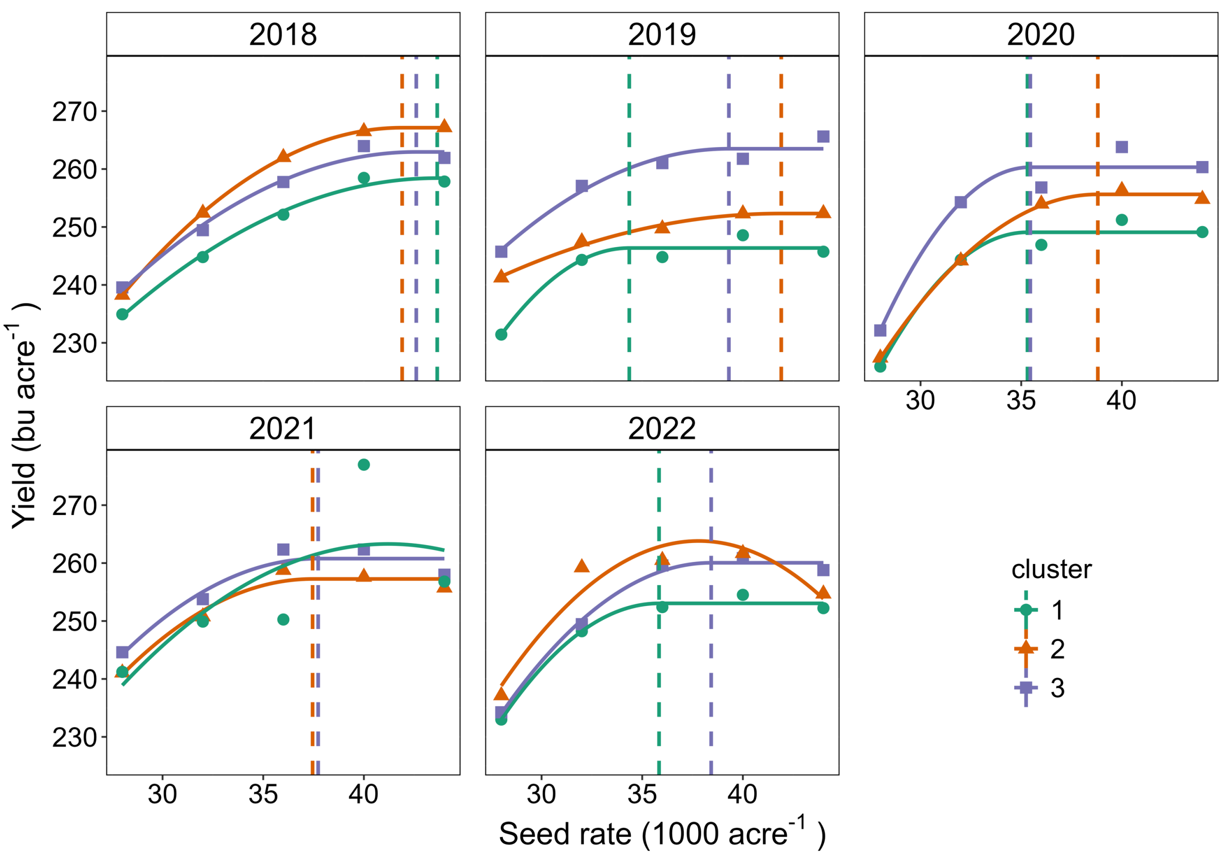

Fig 2. Relationship between corn yield and seed rate in different clusters in different years for Field 1 and Field 2 located in Miami County, Ohio.

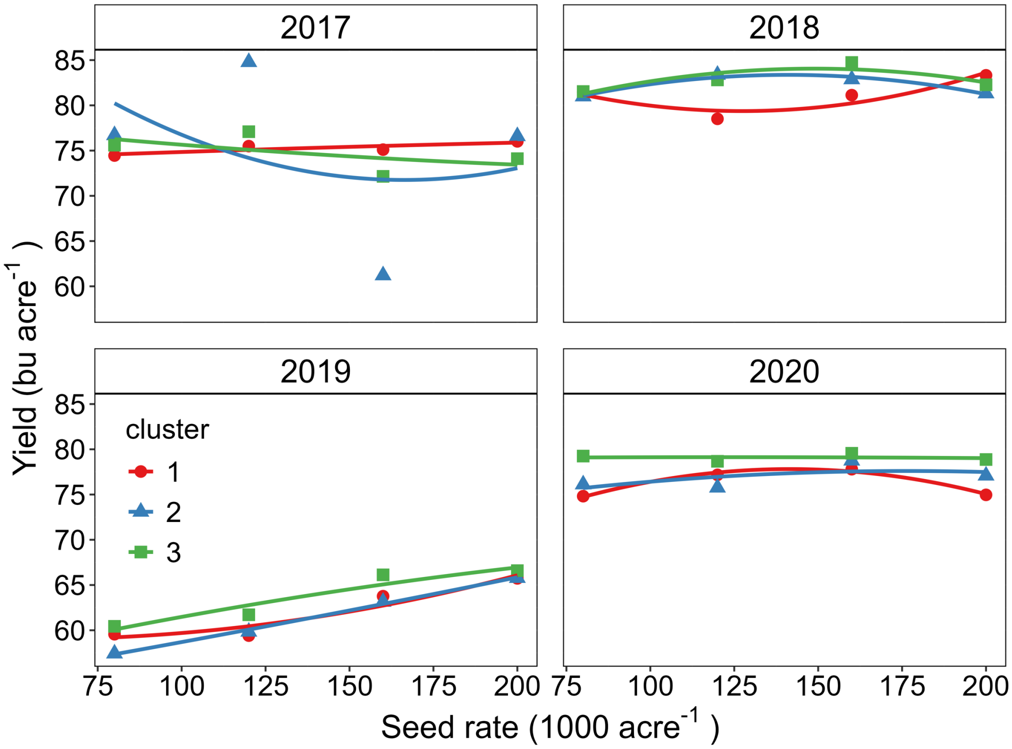

Fig 3. Relationship between soybean yield and seed rate in different clusters in different years for Field 1 and Field 2 located in Miami County, Ohio.

Conclusion

The relatively stable properties of the field such as elevation, organic matter, and cation exchange capacity were found to be the main variables impacting corn yield besides seed rate. In corn, seed rate had more influence compared to soybean. This might be due to the adaptive nature of soybean compared to corn. The results point out that response of seed rate to corn and soybean yield varied across the fields and even within the field at different clusters. Compared to soybean, corn showed consistency in its response to seed rate such that yield increased with increasing seed rate eventually reaching a plateau before decreasing. Moreover, optimum seed rate varied across years and in clusters. This indicates the feasibility of site-specific seed rate management for corn based on field conditions and weather prediction for a given year. In case of soybean, we can conclude that the necessary factors influencing soybean yield have not been captured adequately in this study. This warrants further studies to determine soybean response to seed rate before making site-specific seed rate management decisions in soybean. Further, economic analysis will be conducted to determine the economic optimum seed rate and strengthen the conclusion derived from this study.

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