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Application of a Multi-Hybrid Planter for Geospatial Assessment of Zone-Based Corn Hybrid and Soybean Seed Treatment Performance for Optimized Crop Production

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APPLICATION OF A MULTI-HYBRID PLANTER FOR GEOSPATIAL ASSESSMENT OF ZONE-BASED CORN HYBRID AND SOYBEAN SEED TREATMENT PERFORMANCE FOR OPTIMIZED CROP PRODUCTION

by

Rachel Hope Stevens

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APPLICATION OF A MULTI-HYBRID PLANTER FOR GEOSPATIAL ASSESSMENT OF ZONE-BASED CORN HYBRID AND SOYBEAN SEED TREATMENT PERFORMANCE FOR OPTIMIZED CROP PRODUCTION

Rachel Hope Stevens, M.S.
University of Nebraska, 2018

Adviser: Joe D. Luck

The ability to variably plant multiple hybrids or treatments during field operation has been identified as one option for mitigating in-field variation caused by soil, disease pressures, environmental and water conditions. While the system performance has been validated, producers still have questions concerning development of management zones, hybrid and treatment assignment, and economic advantage from implementation.

Assessment of a multi-hybrid planting platform was conducted during the 2016 and 2017 growing seasons. On-farm trials were performed on ten corn fields and five soybean fields in eastern Nebraska. Corn trials focused on placement of two contrasting hybrids for soil type and water availability interactions. Soybean trials focused on site-specific seed treatment of ILeVO® to combat sudden death syndrome. Management zones were created through use of Management Zone Analyst to cluster correlating layers into zones. Spatial layers utilized included yield maps, soil texture maps, and electrical conductivity maps. Performance of hybrid placement and zone delineation was assessed through in-season vegetative index readings, disease pressure evaluation and ultimately with yield comparisons at harvest. Above average moisture conditions led to mixed results for the 2016 and 2017 growing season. Economically, a single hybrid should been planted across all corn fields. Zone scenarios were created for each field. An optimum placement of...
hybrids was determined for each site but needs further validation as there were high amounts of temporal variability. Results for the soybean sites also showed mixed yield results. Economically, the ILeVO® treatment resulted in a higher marginal net return in one zone at one field site. Break-even analysis for that field site indicated the multi-hybrid technology could be paid off in as little as five soybean growing seasons. Based on the two years of data, soybean seed treatment shows promise for successful implementation of multi-hybrid planting. More years of data should be collected, including data from dryer growing seasons, to further test corn hybrid placement.
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Figure 8.2: Soil series zone scenario map for Case Study 1.

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CHAPTER 1 : A Review of Current Literature
1.1 An Introduction to Multi-Hybrid Planting

Multi-Hybrid planting was first introduced in 2012 at South Dakota State University. There, researchers, in collaboration with Raven Industries and DuPont Pioneer, began retrofiting a planter with additional offset rows in order to be able to switch varieties on the go. They developed an offset twin row unit planter capable of changing hybrids on the go. As their research advanced, a need arose for a more sophisticated system. This advancement was made possible through collaboration with Kinze Manufacturing Inc. For the updated system, the Kinze 4900 platform was retrofitted to accommodate two seed meters within one row unit. This also removed the gap from the offset twin row system.

1.2 Reasons for Multi-Hybrid Planting

Farmers, consultants, and researchers have long acknowledged the potential for variable hybrid management. Hybrid selection was found to be more important than precision nitrogen management in optimizing corn yield and quality (Miao et al., 2007). With increasing availability of technologies such as Global Navigation Satellite Systems (GNSS), more site specific practices can be adopted such as hybrid selection and variable rate technologies to increase yields and profits (Porter et al., 1998). As hybrid breeding advanced, the ability to breed a specific line to best suit a particular environment was developed. Genetics allowing corn to tolerate lower amounts of water, various diseases or pests or other environmental factors were developed. Even with this advancement in breeding, it is still difficult for a single hybrid to perform optimally across all field conditions. Many fields across the Midwest are highly variable; variability may come in
forms of soil texture, soil moisture, slope, elevation, or historical management. Due to this wide range of potential variability within a single field, a single hybrid is rarely suited for the whole field. It was with the acknowledgement of this constraint that multi-hybrid or multi-management planting was invented.

1.3 Types of Variability

There is one major constraint for multi-hybrid planting. Some level of variability must exist within the field. If no variability is present, variable rate technologies are not as applicable. Two main types of variability exist in precision agriculture applications: spatial and temporal variability.

1.3.1 Spatial Variability

It is because of spatial variability that the need for site-specific management of hybrids exists. Soil properties are the major contributor to variability across fields. This information is gathered in three separate ways: continuously, discretely, and remotely. Continuously collected data is an on-the-go measurement such as yield data. Pulling soil samples on a grid would be an example of discrete measurements. Finally, remote measurements could take the form of satellite images used to infer measurements at a field site (G. B. Senay et al., 1998). Spatial variability may come in the form of water holding capacity, topography, historical management, soil texture, or organic matter. These are all considered permanent factors that attribute to variability. Other spatial factors that can affect yield are transient and consist of factors like disease and insect pressures, and issues with planting and application by equipment. McKinion et al., and Porter et al., found that high amounts of spatial variability were still present, even in the
absence of variability in soil type and elevation, possibly attributed to disease, pests, or microclimate. Various layers have been proposed to quantify spatial variability. Terrain attributes, namely slope and wetness index, were significantly correlated with thickness of the A horizon, pH, soil textures, phosphorus levels and organic matter values (Moore et al., 1993). Adamchuk et al., and Franzen et al., found that topography could be used to characterize yield maps for use as soil management zones. Bare soil imagery may also provide a reasonable means to delineate zones of spatial variability (Schepers et al., 2000).

1.3.2 Temporal Variability

In addition to spatial variability across the field, variability across seasons exists. Temporal variability is defined as how a measured attribute varies across time. This is significantly harder to quantify in comparison with spatial variability. Changing patterns in weather and crop response result in unstable yield patterns from year to year. This is a highly dynamic relationship composed of weather, soils, vegetation, landscape position, and management practices (Jaynes et al., 2003). Lamb et al., found that five years of yield history was not enough to accurately determine a stable yield pattern for predicting future yield and for fertilizer recommendations. Jaynes and Colvin found that temporal stability did not exist for six years of corn and soybean yields. Alternatively, a combination of terrain and yield across years was effective in partitioning and identifying yield cluster membership for a soybean field (Jaynes et al., 2005). While low correlations between years of yield data can occur, this does not indicate that the variation is not intrinsic. Fuzzy classification can identify temporal patterns of variability within a field. Patterns
resulting from variability between years can still be identified and management decisions proposed (Lark and Stafford, 1997). In addition to the spatial variability seen during the growing season, that spatial pattern also varies from year to year (Jaynes and Colvin, 1997). Some of the transient spatial variability can add to the magnitude of the temporal variability as one factor can cause more effect than others do in a given year (Jaynes and Colvin, 1997). Temporal variability is expressed in numerous aspects year to year including amount and timing of precipitation, reference evapotranspiration, air temperatures during the growing season and fluctuations of air temperatures during different crop maturity stages such as pollination, soil temperatures during planting, and other environmental factors. All off these factors can be compounding. Coupled with changes in spatial variability, the ability to quantify temporal variability becomes increasingly difficult. Making recommendations based on yield can be very difficult when dealing with the volatility of weather impacts on overall yield (Huggins and Alderfer, 1995). Normalization of each year of yield data can help provide some ability to interpret across years (Sadler et al., 1995). The relationship of crop growth to climate interactions is difficult to measure even without the complexity of nutrient cycles in relation to temporal factors. It is prudent not to make any decision particularly in regards to chemical inputs based on less than six years of yield data (Jaynes and Colvin, 1997).

1.4 Site Specific Crop Management

Site-specific crop management (SSCM) has been introduced as a method of economically managing crops and resources. In order to justify this approach three main criteria must be met; the presence of within field variation resulting in changes in crop
yield, the identification of those variables and the ability to translate the measurement of the variables into management changes (Miller et al., 1999). Determination of whether enough variation is present is a major obstacle to adoption of SSCM. Uniformity trials and opportunity indices can be calculated as means of determination (Pringle et al., 2003). Yield monitoring is essential in this endeavor as a means to quantify variability within the field. Plant et al., points out that “the most daunting task of SSM is to identify and sort out limitation to yield.” Groupings of like areas of the field together for the purpose of similar treatments and management practices are at the root of SSCM. These groupings are considered management zones.

1.5 Management Zones

Management zones are defined as areas of the field with similar productive potential (McCann et al., 1996), or areas that have similar characteristics in topography and soil resulting in similar yields and crop inputs (Schepers et al., 2004). High levels of variability can be found across fields in the Midwest. When managed uniformly, variability is averaged or ignored when considering inputs or other field management decisions, often resulting in inappropriate decisions for subfield areas (Moral et al., 2010). For this reason, subfield zones should be created. Each zone should have relatively small variability within the zone and show a difference between other zones. Additionally, within each zone, the factors influencing yield should be similar (Plant et al., 1999). In addition to spatial variability in a single year, temporal variability affects yields across years (Lamb et al., 1997). Consequently, many factors affect the ability to accurately identify and define management zones.
Multiple reasons exist for creating management zones throughout the growing season. Reasons include zone creation for nitrification inhibitors (Ferguson et al., 2003), hybrid and plant densities (Shanahan et al., 2004), productivity zones (Kitchen et al., 2005), soybean management zones (Jaynes et al., 2005), iron chlorosis (Kyaw et al., 2008), irrigation (Jiang et al., 2010) and general site specific crop management (Farid et al., 2016; Li et al., 2008; Ping and Dobermann, 2003). While outcomes differ, each method relies on the ability to group like areas of the field together.

1.6 Clustering

Clustering can be defined as the grouping of data points in a field into sub field zones with similar characteristics or yield performance. The main objective of clustering is to reduce variability; each sub field zone should have less variation than the field as a whole. Because of the shared similarities, these zones can be treated uniformly (Stafford et al., 1999). Yield results, amount of inputs, and impact on the environment should be similar within zones (Schepers et al., 2004). These groupings can be helpful in order to make generalized decisions for their management purposes based on their similar characteristics (Lark, 1998). Only areas that have predictable variation should be considered for management zone determination (Shanahan et al., 2004). Kitchen et al., identified a more advanced method of representing each zone by a response curve unique to each zone.

Clustering has typically relied on the interactions of yield with soil texture, soil series, or other soil related attributes, such as elevation, slope position, or other terrain attributes. Another approach directly uses yield data collected over several years.
Because this method relies directly on field observations, assumptions about the relationship between soil and yield are eliminated (Jaynes et al., 2005).

1.6.1 Clustering Steps

Three steps for clustering were identified by Jaynes et al., to produce management zones. The three-part cluster analysis includes partitioning, interpretation, and profiling (Jaynes et al., 2003). The first step, partitioning, utilizes a clustering algorithm to place individuals into clusters. Interpretation attempts to determine the characteristics and behaviors of the clusters. The final step attempts to relate the zones to additional data such as soil or terrain. This step can help predict the behaviors of each zone. Most clustering will, to some extent, fall into these three steps.

1.6.2 Clustering Techniques

Various clustering techniques have been proposed to accurately group like areas of fields. However, no single algorithm has been widely adopted (Roberts et al., 2012). Initially, management zones were determined with map overlays of soil surveys, yield, or aerial imagery. Producers used these layers to make judgement calls for zone boundaries. While producer knowledge of the field can be one of the most useful data sources, the layers used and classification is at the discretion of the producer and can lead to bias. Unsupervised clustering seeks to eliminate that variability by utilizing clustering algorithms on many spatial layers for management zone determination (Fraissé et al., 2000).
1.6.2.1 Hard Clusters vs Fuzzy Clustering

Two main methods exist for clustering: hard or soft (fuzzy) clustering. Hard cluster sets result in the division of each point into one distinct group. This grouping however is not natural for environmental conditions. By putting data into discrete clusters, it is possible that data points assigned to a cluster could have more in common with other data points in another cluster than to a typical member of their cluster (Lark and Stafford, 1997). A commonly used method of unsupervised clustering is soft or fuzzy clustering. Fuzzy clustering was introduced for topographic clustering and subsequently yield clustering, as a more natural fit for these data sets (Burrough et al., 1992). In fuzzy clustering, data points can be assigned partial membership to multiple classes using a weighting exponent (Fridgen et al., 2004). Numerous iterations are run, until the change between membership classes falls below a defined threshold. Landscape, soil data, yield data, and imagery have been successfully grouped using fuzzy clustering methods (Ahn et al., 1999; Burrough et al., 1992; McBratney and de Gruijter, 1992; Odeh et al., 1992).

1.6.3 Cluster Interpretation

Statistical functions are available to help interpret clusters. Multiple discriminant analysis can be used to indicate the difference in clusters and the influence of individual layers on cluster determination (Jaynes et al., 2003). Similarly, Martín et al., utilized both quadratic discriminant analysis (QDA) and k-nearest neighbor (k-NN) discriminant analysis to determine the relationship among yield across years and other field characteristics. It was determined that k-NN did a better job in explaining yield clusters than QDA.
1.6.4 Data Layers for clustering

Many data layers have been used for clustering of management zones with varied success. Interaction between soil and yield has been the most common grouping. Soil classes defined by yield classes were an accurate representation of soil variability (Lark et al., 1999). Distinct clusters could be formed from season to season utilizing several years of yield data and fuzzy clustering techniques (Stafford et al., 1999). In general, order two soil surveys of most counties were not mapped to a scale suitable for site-specific management (Franzen et al., 2002). Because of this, several alternatives are feasible. Conducting more extensive grid or zone sampling and interpolating between those points provides an appropriate measure of fertility variability. Using those same soil samples to categorize soil structure and texture can provide a more detailed look at soil type variability across the field. However, a limitation with this method is that conducting soil sampling on this scale is often costly and time consuming and appropriate analysis must be conducted to ensure variability is accurately mapped. Another approach includes collecting electrical conductivity data for use in soil-landscape models (Fraisse et al., 2000). It was determined for the previously mentioned study that soil EC and elevation were the most influential factors for classifying claypan soils. Similarly, combinations of \( \text{EC}_a \) and elevation matched up with both yield and soil productivity zones in claypan soils (Kitchen et al., 2005). Ferguson et al., found that use of apparent EC recognized portions of the field susceptible to \( \text{NO}_3^{-} \)-N loss for nitrogen application management zones. Correlations of chlorophyll index and sand or elevation can also be used in creating management zones corresponding to varying nitrogen response curves.
Landscape attributes have also been used in conjunction with yield data for management zone creation. Attributes including soil brightness, elevation, and EC$_a$ were used to create management zones and found to create zones corresponding to chemical properties of the soil (Schepers et al., 2004). However, these classes do not always accurately line up with terrain and additional data layers could be required for assigning clusters (Jaynes et al., 2003). Landscape attributes of elevation, soil brightness and apparent electrical conductivity were shown to account for 47-95% of the spatial variation of yields (Shanahan et al., 2004). Jaynes et al., found that when yield was clustered into groups corresponding with both terrain attributes and precipitation amount, several terrain attributes including slope, curvature, aspect, depression depth and apparent electrical conductivity were highly related to these clusters. Again, EC$_a$ was identified as a principal source of variation and subsequent clustering shows promise for creating management zones that match soil variability (Moral et al., 2010). In a study conducted by Rodrigues et al., soil acidity was more correlated with corn yields temporarily. Generally, electrical conductivity and topographic attributes proved to be well correlated with grain yields for management zone determination.

Clustering of historical yield data alone also has merit as variation exposed in yield data does not need to rely on any surrogate data for clustering. If the patterns are stable across yields, the assumption can be made that the zone reacts similarly to environmental and weather variability as well as management decisions and could be used as management zones (Jaynes et al., 2005).
1.7 Smoothing

After zones are created, some sort of smoothing is necessary. Zones created are often fragmented, disjointed, or too small for treatment. Short-range speckle should be removed to create zones that are more continuous. A minimum zone size should be determined based on size of operations conducted within the field. In a crisp classification, it is possible for individual points classified to belong to a different class than all of its surrounding neighbors. In this instance, it would be wise to determine if this individual could fit into the class assigned to its neighbors given that the ratio of membership to its original class and the majority class of the neighboring individuals falls below a predefined threshold. This method of spatial weighted averaging results in spatially coherent regions (Lark, 1998). Ping and Dobermann, found by first clustering data, then filtering maps, the result was continuous map units that kept the original resolution of the maps. This response is for situations where a mapped area may be distinct from surrounding individuals, however, too small for management to effectively take place. Alternatively, a nearest neighbor filter can be used to assign points to that of the majority of the region.

1.8 Management Zone Analyst

Management Zone Analyst (MZA) (Version 1.0.1, University of Missouri, Columbia, MO) is a program created to perform clustering of data layers. The program utilizes fuzzy c-means unsupervised clustering. Multiple data layers, ranging from yield data, to topographic attributes, to aerial imagery can be input into the software for clustering. Any combination of data layers is available for users to match the desired
zone purpose. Since MZA uses unsupervised classification, user input is not needed to train the model. Commonly used unsupervised classifications include the Iterative Self-Organizing Data Analysis Technique (ISODATA). This technique requires data layers to have a normal distribution and forms zones by reducing the Euclidean distance to a class mean. MZA utilizes c-mean algorithm, which does not require data sets to have a normal distribution. Distance to the centroids of zones is reduced by the sum of squared distances to the centroid. Fuzzy c-means allows for membership to multiple classes by individuals and uses a weighting exponent to express membership to each class.

1.8.1 Measures of Similarity

Three measures of similarity are available for clustering in MZA. Euclidean assumes similar variances and consequently gives equal weight to all the variables included. As a result, clusters are generally spherical. Diagonal distance also assumes similar variances in data. Compensation for the spherical clusters is made by weighting with the variances of all measured variables. The third measure of similarity is Mahalanobis distance. This measure is appropriate for data sets with unequal variances.

1.8.2 Classification

The program focuses on three main matrices, the data matrix Y, the cluster centroid matrix V, and the fuzzy membership matrix U for classification. The program seeks to classify data based on cluster centers and define their membership to each cluster. Iterations assigning membership to classes are run until the movement of individuals between classes is at a minimum.
1.8.3 Output

In addition to descriptive statistics, Management Zone Analyst also outputs two performance indices, the fuzziness performance index, and the normalized classification entropy. The fuzziness performance index (FPI) is an indicator of the fuzziness of each cluster. As values approach one this indicates that clusters have large amounts of membership sharing, while values approaching zero signify little sharing of classes, thus, very distinct classes. The Normalized Classification Entropy (NCE) indicates the disorganization created when clusters are formed. Data that is grouped closely together and spatially cohesive has values near zero. Data points that are more dispersed and may contain many outliers have values closer to one. Ideal clusters are formed when both FPI and NCE are at a minimum. This would result in small membership sharing, or more distinct clusters, (FPI) and the most organization among clusters (NCE). Multiple outcomes are possible when using MZA. As a result, multiple attempts at clustering a field utilizing different layers and analyzing the performance indices is recommended.

1.8.4 Usage

This program has been used for classification in dozens of studies (Bobryk et al., 2016; Brock et al., 2005; Farid et al., 2016; Kitchen et al., 2005; Moral et al., 2010; Mueller et al., 2010; Rodrigues et al., 2015; Schenatto et al., 2016; Zhang et al., 2009) and has proved to be an intuitive and valuable program for clustering fields into appropriate management zones. The functionality allows users to input the desired spatial layers and assess viability of those layers for clustering. By utilizing the performance indices, users are able to determine the best fit clustering for the field in question.
Without performance indices, users would need to randomly select the number of zones, which may result in increased error.

1.9 Difficulties with Management Zone creation

An initial and often major obstacle for management zone creation is dealing with temporal variability. The ability to create zones that will act similarly across all years is a challenge yet to be dealt with. Some progress has been made in classifying zones by performance in hot/cold or wet/dry years; however, no method has been faultless in correctly forming zones for all years. It is noted that the more years of yield history available for partitioning, the better the models are able to group into stable zones. It has been found that cluster analysis is able to identify common areas across the field, even when correlation amongst years was low (Brock et al., 2005).

Collection of data for zones can be time consuming and often expensive. In cases where historical yield data is not available or limited to only a few years, obtaining enough information to form accurate zones can be a limitation. Additionally, work on weighting certain years yield maps for zone creation should be given priority (Fraisse et al., 2000). In situations with limited yield data, grid soil sampling can provide a moderately dense data set for analysis, albeit expensive. Collection of surrogate data such as electrical conductivity can help mediate this. Additional work relating surrogate variables to both spatial and temporal yield patterns is needed for future classification and for identifying response to management inputs (Jaynes et al., 2005; Stafford et al., 1999).
The assessment of zones after creation also merits more examination. Looking at how these zones perform in additional growing seasons is imperative to assess the appropriateness and consistency of the zones (Lark and Stafford, 1997).

1.10 Testing Management Zones

After management zones are created, a method for testing whether these zones are correct is necessary. Various methods are used to introduce the alternate check strip into the management zone map. Full-length field strips can be used in situations where field passes run the full length of the field. In paired strips across the field, the various treatments are assigned to each different management zone. The width of the planted check strip should be a unit of the harvest header width, ideally one to two times the width (Doerge and Gardner, 1999). Yield differences in treatments can be analyzed across the whole field by using GIS software. A shorter check strip method can be used, which is perhaps more useful in situations where field passes are broken up by terraces, waterways, or other obstacles. These field strips should at least be around 300 feet in length if data is to be collected using a yield monitor. This will ensure that any erroneous data points from incorrect GPS offsets can be removed, and enough data points are still available for analysis. A third method is a check block method. Blocks of the opposing zone are placed in each zone segment. While still introducing the alternate treatment, there are limitations with this method in the ability to collect enough information across any spatial variability existing in the field.
1.11 Use of Management Zones for Hybrid Placement

Spatial interactions with multiple hybrids and treatments were first studied by Katsvairo et al., and Miao et al. Hybrid selection poses a unique opportunity for precision management and merits further study (Miao et al., 2006). While opportunities exist to improve yield and grain quality through hybrid selection, more research is needed to evaluate both the spatial interaction with hybrids and grain quality as well as identify the field features influencing the landscape. While hybrid by location interaction can exist within fields, a spatial yield difference does not always occur. This problem will pose a problem for adoption of site-specific hybrid selection (Katsvairo et al., 2003). Methods developed utilizing a split planter comparison method can be a way of comparing two hybrids and spatial interactions (Doerge and Gardner, 1999).

With the commercialization of multi-hybrid planters, the need for accurate hybrid-zone maps has increased. Delineation of management zones is seen as the first step in creating these prescription maps. Questions arise on when discussing zone creation and utilization. What data layers are needed to create accurate zones? What is the best way to assign hybrids to these zones? How much variability is required to provide an economic advantage for multi-hybrid planting? How do we assess the performance of these zones and hybrids across years? As more questions develop, research focused on these aspects is advised.

1.12 Existing Multi-hybrid Planting Platforms

Two main multi-hybrid planting systems are commercially available. The Kinze 4900 MH was first released on the market in 2014. This features the same set up as the
Kinze 4900 16 row, front fold planter equipped with electric drives, vacuum seed meters and pneumatic downforce. Hybrids are delivered from two separate bulk tanks with 120-bushel total capacity to two electric drives situated in each row unit. These drives are synchronized, which reduces the possibility of skips when transitioning between zones.

Am Envisio Pro monitor (Raven Industries, Sioux Falls, SD) controls the drives by a prescription map loaded in the monitor. This allows for a nearly instantaneous transition between zones. This planter is also capable of variable rate seeding and turn compensation. In furrow liquid fertilizer or frame mounted dry fertilizer can also be applied variably.

Precision Planting vSet Selects (Precision Planting, Tremont, IL) allow multi-hybrid planting to be retrofitted onto existing Kinze and John Deere Planters. This utilized the existing vSet meters and vDrives for precise placement and control of seed metering. This allows for flexibility in other system parameters such as tool bar size, number of rows and compatibility.

This project was completed using the Kinze 4900 MH platform, but the processes used can be applied to any multi-hybrid system.

1.13 Current Extent of Research

Research was first conducted at South Dakota State University to determine the feasibility of planting multiple hybrids within a field. Research indicated as much as 0.38 Mg ha⁻¹ advantage with multi-hybrid planting in the 2013-2014 growing seasons. In the 2015 and 2016 growing season, there were no effects by using multi-hybrid planting in corn or soybean systems (Sexton et al., 2016). The Ohio State University is currently
testing the performance of these systems as well; however, the focus is more on performance of the hybrids, not on zone creation. Several seed companies are also conducting research. Pioneer, Becks, and AgriGold have all deployed systems to test various hybrid pairing in fields. The majority of this research is centered on appropriateness of hybrid selection, with validity of zone creation a secondary objective.

1.14 Existing Rational for Multi-Hybrid Zone Creation

No consensus has been arrived at for creating management zones. Pioneer uses a combination approach of calculated soil units and yield history to create hybrid management zones. The Ohio State University collaborates with local agronomists to prepare management zones for producer’s fields. Other methods of zone creation for multi-hybrid planting are proprietary or have not be made public.

1.15 Challenges with Multi-Hybrid planting

Other than issues with creating and testing management zones, additional obstacles are present when it comes to multi-hybrid planting. Hybrids should be selected with similar maturity dates, pollination dates, and disease ratings. Similar disease ratings should be selected in order to optimize use of fungicides. Hybrids with similar dry-down rates should be selected so that crops would be ready to harvest in a similar time frame. Relative maturity is not a strong indicator of dry-down, consequently, other indicators of drying should be used (K. Ward et al., 2016). Difference in moisture and test weights between hybrids can also have an impact on yield recorded. Relative maturity should be kept within five days, difference in moisture at 5% and within five pound per bushel in test weight between hybrids (Doerge and Gardner, 1999). A difference in moisture
greater than 5% would necessitate recalibration of the yield monitor. Moisture error can
effect yield readings significantly, with an error of 1% in moisture translating to up to
0.157 Mg per hectare in yield errors (Taylor et al., 2011). Multi-hybrid planting increases
both the cost and time to a farming operation. Creating additional prescriptions and
managing acquisition, transport and loading of multiple hybrids adds to the complexity of
the planting season. In a skewed ratio of hybrids, multi-hybrid planting could also
increase the frequency of planter fills (Jeschke and Shanahan, 2015).
1.16 References


CHAPTER 2  : Spatial Analysis and Zone Delineation for Multiple Corn Hybrids for Use in Multi-Hybrid Planting
2.1 Literature Review
2.1.1 History of Corn Breeding

Up until the 1930’s corn had been grown and propagated in the same way for 50-100 years. Corn varieties were planted in a field and allowed to open pollinate. During harvest, ears with desirable traits such as uniformity or shank size, were selected as the next years seed stock. Because fields were open pollinated, these progeny were not genetically identical, however they did possess similar characteristics, particularly if selected for a certain feature (Russell and Sandall, 2017). Selection for these characteristics did not necessarily mean selection of higher yielding seed; consequently, there was no discernable increase in overall crop productivity from 1870 to 1930. Around 1930, two separate researchers, Edward East and George Shull, began to notice a phenomenon called hybrid vigor. By self-pollinating individual plants over many generations, inbred lines could be created (Hallauer, 2009). While these lines themselves were not the most productive lines, crossing two different inbred lines created a more vigorous plant than the parent lines. Today, the majority of corn seed is created from single cross hybrids created from fine-tuned inbred lines, (Russell and Sandall, 2017) conferring characteristics such as increased standability, stalk strength, disease resistance, drought tolerance and protein content.

More recently, advancements in biotechnology have provided the industry with corn hybrids capable of producing pesticides or resisting herbicides (Sandall et al., 2017). The first pesticide producing crop was approved in 1995, followed by Bt corn a year later (National Research Council (US) Committee on Genetically Modified Pest-Protected
Plants, 2000). Since then, corn has been modified to confer resistance to several herbicides and pests.

2.1.2 Optional Traits

In addition to traits such as Roundup® (glyphosate) or Liberty® (glufosinate) resistance, hybrids have been bred or modified for drought tolerance, disease resistance, and stalk and root strength. Drought tolerance is of particular interest in fields with variability in soil type or topography. Many genes contribute to drought tolerance. Consequently, these genes may respond differently in various environments adding to the complexity of breeding. Different aspects of the plant confer some levels of drought tolerance: extensive root systems for better water uptake, aggressive silking for higher fertilization rates (UNL IANR Cropwatch Network, 2015), resistance to insects that damage root zone, deeper kernels to retain yield, adjustments in stomatal control to reduce excessive transpiration of water, and reduced tipback (Pioneer Hi-Bred International, 2009). These drought tolerant traits have been developed both through traditional breeding and genetic modification. Plants with more drought tolerant traits require less water per bushel of grain produced. This ultimately results in a higher water use efficiency for the crop. This trait would be very beneficial in water limiting, dryland growing conditions, or dry environmental conditions.

2.1.3 Soil Variability

Variability in soil texture, water holding capacity and soil structure create very different environments for crops to grow. Soil variability is often correlated with soil and terrain attributes such as mineral weathering, erosion, deposition and sedimentation,
leaching of minerals, and horizonation. Some of the terrain attributes most correlated with soil attributes are slope and wetness class (Moore et al., 1993).

Fields are seldom uniform in all aspects. Typically, producers must deal with this variability by selecting one “best fit” hybrid. This hybrid is an attempt to match all the variation in soil types, topography, water holding capacity and other environmental conditions to the capabilities of a single hybrid. Conditions suited for a high performing hybrid may not comprise the entire field. Similarly, conditions warranting a hybrid suited towards water limiting or more challenging growing conditions are not uniformly distributed across the field. These differences in soil types may warrant different hybrid genetic selections to maximize on the conditions present (Shanahan et al., 2004). There is an advantage to be able to tailor a specific hybrid or genetics to specific soil characteristics (Dudding et al., 1995). It is acknowledged that hybrids possessing a drought tolerant trait may confer this ability at the expense of overall yield. Consequently, it is prudent to only position these hybrids in locations that would benefit from the trait in an effort to not reduce yield in higher yielding portions of the field. Alternatively, higher yielding hybrids have not necessarily been bred for water limiting conditions, and would suffer lower yields in comparison with those bred for drought tolerance. Many fields possess these two contrasting situations and could benefit from inclusion of two hybrids in an attempt to match existing variability.

2.1.4 In-field Variability and Relation to Single Hybrid Performance

Both the type of hybrid planted and the growing season conditions have an impact on grain yield and characteristics of grain production, such as starch and protein content
and yield (Randjelović et al., 2011). A 2010 study identified a difference among genotypes, environments and their interaction (Anley et al., 2013). Signor et al., identified variety specific responses to the environment. They quantified that as much as 80% of corn yield was due to environmental effects. These specific interactions can have great effect on overall yield. The ability to quantify this interaction would be useful for production.

2.1.5 Current Methods for Adapting to Soil Variation

Many different practices have been suggested in an attempt to deal with soil variability. With the increasing availability and financial feasibility of precision agriculture equipment, variable rate applications are becoming more common. Spraying and planting features such as pulse-width modulation, smaller control modules and encoding systems have enabled many different platforms to have variable rate capabilities both in varying rates as you move through the field and across the width of the implement. The use of electric meters on planters have revolutionized the way seed is dispersed by row, both by cutting down on moveable, wearable parts, and increasing the precision and accuracy of seed timing and placement. The use of electric drives enables planters to vary the population throughout the whole field and across the planter (Mangus et al., 2017) as well as switch between hybrids in a multi-hybrid setup.

2.1.6 Variable Rater Fertilizer

Variable rate fertilization is one means to help match management practices to in-field variation. To implement variable rate fertilizer, a baseline assessment of soil fertility must be measured. This can be conducted by two different soil sampling approaches,
zone or grid sampling (Ferguson et al., 2007). Using zone, or directed sampling, fields are divided into zones with similar soil properties, histories, or yield potential. Good producer knowledge of the field is particularly helpful. Within these created zones, several soil samples are pulled and aggregated. A single soil sample value is assigned to each zone. Consequently, fertilizer rates can be calculated and assigned based on the average value for the zone. Zones should not exceed 16.2 hectares in area. Additionally, fields with a history of manure application, or situations where producer knowledge of the field is not available may not be good candidates for zone sampling (Ferguson and Hergert, 2009). Another method of soil sampling includes grid sampling. Grid points are laid out across a field at a routine spacing. Spacing is commonly 1 or 2 hectare grids. The denser the grid points, the higher resolution of nutrient values will be available for variable rate fertilization maps (CropWatch Network, 2015). While this added density can be beneficial for more accurate mapping, it is also cost prohibitive. The size of grid should be selected as dense as possible, but still fit within financial constraints. At each grid point, soil samples are pulled and labeled. This provides a single value at each measured point across the field. This data can then be interpolated into a surface and an estimated value between each point given. Based on that dataset, a variable rate fertilization map can be created. Assessing the variability of soil attributes across a field is a valuable dataset for both variable rate fertilizer and variable rate seeding.

2.1.6.1 Variable Rate seeding

A newer concept, variable rate seeding, has become increasingly popular in the last several years. Similar to zone sampling, the field can be divided into groupings or
management zones. These zones are categorized based on soil characteristics, fertility, water holding capacity, and overall crop productivity. After analyzing these criteria, different seeding rates are assigned to each zone. Alternatively, population rates can be varied without a management zone structure based on a combination of data layers leading to a gradient population map. Theoretically, a producer could push the population in higher productive areas resulting in higher yields, and back off population in portions of the field that may have more yield limiting conditions. Many more variables are involved in this practice than with variable rate fertilization, and consequently, the results can be much more dynamic, heavily influenced by environmental conditions and weather impacts. Much more detailed information on field characteristics and specific factors involved in yield response to different planting populations is needed for successful variable rate seeding maps. This information is currently not available or very cost prohibitive. Consequently, no firm evidence shows that variable rate seeding provides any economic return (Bullock et al., 1998). Changing seeding rates in dryland corners of center pivot irrigated sites has been a successful use of varying population rates across a field (Koch and Khosla, 2003).

2.1.6.2 Variable Hybrid

Variable hybrid or management is a very similar concept to variable rate seeding. Zones are created, and characteristics are assessed for each zone. Based on these zone characteristics, a hybrid is assigned. A typically approach includes creating a zone that has water limiting conditions, and another zone that is higher yielding with adequate moisture. A hybrid with a drought tolerant trait would be assigned to the water limiting
zone, while a higher yielding hybrid would be placed in the more productive zone. These hybrids are often characterized as offensive hybrids that are high yielding and high performers, verses defensive hybrids that are protective against pressures, often equipped with resistances and tolerances to pests and harsh environments (Stringfield, 1964). The theory is an offensive or racehorse hybrid will out perform a defensive hybrid in productive ground, however, they are riskier to plant as they have less tolerance in low yielding environments. However a defensive or workhorse hybrid has the potential to outperform an offensive hybrid in less productive or water limiting conditions but do not have the ability to take advantage of high yielding conditions as a racehorse hybrid would (iGrow, 2011). While selecting different hybrids may optimize yield, Ward et al., points out that by doing so, additional variability is introduced into the system that can affect things in the short term such as disease maintenance, and harvest dry down, and additionally in the long term when looking at crop nutrient removal or organic matter levels.

2.1.7 Importance and Rationale

Spatial variability is a common challenge for farmers. This variability is defined as the change in attributes across space. This can occur in the form of soil texture, soil moisture, water-holding capacity, fertility, elevation, or slope. As more variability exists, it becomes increasingly hard to manage a field uniformly. With a single soil type, even elevation, and uniform fertility, a single decision can be made that would be suitable for the whole field. Across the Midwest, it is not likely that you will find a field that is truly uniform. Even if one variable is uniform, other factors may not be, ultimately resulting in
variation in yield. If the yields across a field are uniform, the need for multi-hybrid planting is reduced.

Hybrids are selected for a field to best match the inherent characteristics present in soil, water availability, and environmental condition. Because fields can be highly variable, it is likely that a single hybrid will not match all field conditions present. Consequently, a producer is forced to make a hybrid selection that will either match only part of the field characteristics, or choose a hybrid that would be an average performer across multiple field conditions. When encountering this situation, it would be an advantage to be able to select multiple hybrids to match the variability present (Jeschke and Shanahan, n.d.).

It is possible that by planting hybrids that match the measured variability seen within a field, an increase in total yield across a field, or an increase in profit potential can be realized with multi-hybrid planting.

### 2.2 Goals and Objectives

The main goal of the study was to determine the feasibility of planting two different hybrids to match the inherent variability present within a field. Specific objectives were to: 1) assess hybrid yield by zone delineation and verify zone structure 2) evaluate hybrid performance against supplemental field attributes to determine layers with correlation to yield performance 3) restructure zones based on highest yielding hybrids of paired strips to determine appropriate hybrid maps for the specific growing season and 4) determine if the multi-hybrid planter approach would be profitable based on yield results.
2.3 Materials and Methods
2.3.1 Site Description and Crop Management

Eleven field sites were selected for the study, five for the 2016 growing season and six for the 2017 growing season. Field sites were located in eastern Nebraska and used in partnership with local farmers as well as University agriculture research stations. Fields ranged from 16-60 hectares and were typically under a traditional corn soybean rotation. The topography of the area is generally rolling with an average of 12 meters of relief. Several field sites were located on a historic flood plain called the Todd Valley in Saunders County, resulting in more gentle topography, around 7 meters of relief, than the fields located in western Saunders County, with around 27 meters of relief. Fields were situated across 14 different soil types. Predominant soil types included Yutan silty clay loam, Moody silty clay loam, and Tomek silt loam comprising 69 percent of the soils collectively. The Yutan soils—comprising 31 percent of the study area— are formed in loess deposits and consist of very deep, well drained soils in the upland position with slopes ranging from 2-17 percent. While originally classified as a mollisol, due to severe erosion, the surface soil no longer has the depth or color requirements for that classification and is now classified as an alfisol. These changes are significant for the management of this soil series, as they impact the organic matter content and water holding capacity of the soil. The Moody soils—comprising 26 percent of the study area— are formed in loess and consist of very deep, well drained soils in the upland position with slopes ranging from 0-17 percent. This soil is a mollisol with secondary carbonates found at 30 inches. The Tomek soils—comprising 11 percent of the study area—are formed in loess and consist of very deep, well drained soils located on stream terraces.
with slopes ranging from 0-2 percent. This mollisol has a very deep epipedon up to 127 cm. Other soils in the study locations are geographically associated with the three major soils listed. Tomek and Yutan soils are associated with Fillmore, Scott, Judson, Filbert and Pohocco. Crofton, Leisy, Thurman and Nora soils are associated with Moody silty clay loams.
Table 2.1: Field Details: name, growing season year, location, size, irrigation status, and soil types

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Year</th>
<th>Location (Lat, Long)</th>
<th>Size (acres)</th>
<th>Irrigation Status</th>
<th>Soil Series</th>
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<td>2016</td>
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<td>41.5</td>
<td>Rainfed</td>
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<tr>
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<tr>
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<td>41.613053, -96.585433</td>
<td>41.5</td>
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</tbody>
</table>
These fields have typically been managed as corn-soybean rotations. Two fields, SW and M40, had corn planted after corn once in the last five years. Site DP had soybeans for three consecutive years after a delayed planting season prevented corn from being planted in rotation. Management practices for fertilizer, irrigation, pest, and disease control varied among producers for each field. Growing season rainfall from the past thirty years, calculated as rainfall received in the months of May through the end of September, compared to 2016 and 2017 are found in Table 2.2 and Table 2.3. Thirty year growing season average rainfall were recorded from the High Plains Regional Climate Center (Lincoln, NE). Graphs of 30 year growing season averages can be found in Figure 6.1 through Figure 6.6. Further details on irrigation status, size, location and soil types can be found in

Table 2.1.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>30 year Averages (cm)</th>
<th>2016 Growing Season Rainfall (cm)</th>
<th>2017 Growing Season Rainfall (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>48.34</td>
<td>64.90</td>
<td>M40</td>
</tr>
<tr>
<td>SS</td>
<td>50.17</td>
<td>70.08</td>
<td>AE</td>
</tr>
<tr>
<td>DP</td>
<td>48.34</td>
<td>64.90</td>
<td>AW</td>
</tr>
<tr>
<td>UNL1</td>
<td>48.69</td>
<td>60.33</td>
<td>ME</td>
</tr>
<tr>
<td>UNL2</td>
<td>48.69</td>
<td>59.77</td>
<td>UNL2</td>
</tr>
<tr>
<td>UNL3</td>
<td>48.69</td>
<td>59.77</td>
<td>UNL3</td>
</tr>
</tbody>
</table>
2.3.2 Planter Setup

A Kinze 4900 Multi-Hybrid planter was used for the study. The 4900 model is a sixteen row, pull type, front fold planter. Seed is stored in two 1,560 cubic meter bulk tanks mounted at the back of the planter. Weight is distributed across the frame by a hydraulic weight transfer mechanism. Bulk tank pressure was set to 2,986 pascals to ensure proper seed movement.

![Kinze 4900 Multi-Hybrid Planter](image)

Figure 2.1: Kinze 4900 Multi-hybrid Planter

Two identical vacuum seed meters were situated back to back in a single row unit to accommodate both hybrids. The rear meter was fed by the left bulk tank and the front meter was fed by the right bulk tank. Each of the seed meters were run by electric drives. This allowed for a very precise transition between the two seed meters and consequently the two separate hybrids.
Vacuum pressure for delivering seed to the meters was set to 4479 pascals as recommended by the manufacturer. Stock Kinze trash wheels were set to intersect rather than offset. Trash wheel depth was adjusted for each field based on residue type, amount, and moisture conditions. A standard row unit assembly was maintained: a set of double disc openers with inner scraper, and two rubber gauge wheels enclosing the seed tube and seed tube sensor. In 2017, Keeton seed firmers with Mojo pressure wires were added to enhance seed placement and seed to soil contact. In 2016, two rubber closing wheels followed to close the slot. In 2017, one side was switched to a Copperhead Ag Furrow Cruiser spiked closing wheel to reduce sidewall compaction. Depth of closing wheels was adjusted according to field conditions. Depths of gauge wheels were adjusted based on producer preference and field conditions.
Figure 2.3: Kinze 4900 Row Unit showing trash wheels, double disc openers, trash wheels, Keeton seed firmers, and closing wheels.

Downforce was controlled by a pneumatic system. Pressure was adjusted based on field conditions. Talc and graphite were used to aid in seed movement as needed.

Planter settings can be found in Table 2.4.

Table 2.4: Planter settings for 2016 and 2017 field sites

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Year</th>
<th>Time (hrs)</th>
<th>Unit pressure (N/cm²)</th>
<th>Gauge Wheel setting</th>
<th>Trash Wheels</th>
<th>Seed Depth (cm)</th>
<th>Closing Wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>2016</td>
<td>4.75</td>
<td>3.4</td>
<td>4,3</td>
<td>-</td>
<td>5.1</td>
<td>2</td>
</tr>
<tr>
<td>SS</td>
<td>2016</td>
<td>9</td>
<td>7.6</td>
<td>4,3</td>
<td>-</td>
<td>5.7</td>
<td>2</td>
</tr>
<tr>
<td>SW</td>
<td>2016</td>
<td>3</td>
<td>3.9, 1.4, 0.7</td>
<td>4,3</td>
<td>-</td>
<td>5.7</td>
<td>2</td>
</tr>
<tr>
<td>DP</td>
<td>2016</td>
<td>9</td>
<td>10.3</td>
<td>4,4</td>
<td>Up</td>
<td>5.1</td>
<td>2</td>
</tr>
<tr>
<td>UNL1</td>
<td>2016</td>
<td>8</td>
<td>37.9</td>
<td>3,3</td>
<td>-</td>
<td>5.7</td>
<td>1</td>
</tr>
<tr>
<td>M40</td>
<td>2017</td>
<td>3.75</td>
<td>172.4</td>
<td>5,4</td>
<td>2</td>
<td>5.7</td>
<td>3</td>
</tr>
<tr>
<td>AE</td>
<td>2017</td>
<td>10</td>
<td>137.9</td>
<td>4,3</td>
<td>2</td>
<td>5.7</td>
<td>4</td>
</tr>
<tr>
<td>AW</td>
<td>2017</td>
<td>11</td>
<td>137.9</td>
<td>4,3</td>
<td>2</td>
<td>6.3</td>
<td>4</td>
</tr>
<tr>
<td>ME</td>
<td>2017</td>
<td>6</td>
<td>137.9</td>
<td>4,4</td>
<td>3</td>
<td>5.7</td>
<td>3</td>
</tr>
<tr>
<td>UNL2</td>
<td>2017</td>
<td>6.5</td>
<td>3.4</td>
<td>4,3</td>
<td>3</td>
<td>4.4</td>
<td>2</td>
</tr>
<tr>
<td>UNL3</td>
<td>2017</td>
<td>3.5</td>
<td>241.3</td>
<td>4,3</td>
<td>3</td>
<td>4.4</td>
<td>2</td>
</tr>
</tbody>
</table>

2.3.3 Acquisition of Spatial Data Layers

The amount and type of spatial data layers differed by field. Data layers included historical yield, electrical conductivity, elevation and slope, and calculated wetness.
potential. Yield was collected using a yield monitor system. Electrical conductivity data was collected using a Veris® MSP3 at 60-foot passes (Veris Technologies, Inc., Salina, KS). Elevation was calculated from GPS data from harvest or planting files. Slope and wetness potential were calculated using SMS Advanced® Terrain Analysis tool (Version 17.2, AgLeader Technology, Ames, IA) Table 2.5 shows the data layers available for each field included in the study. Historical yield data provided indication of spatial information for fields where supplemental data layers were not available or did not provide clarity on spatial variability. Overall, data layers that did not correlate well with three or more layers were discarded. This allowed for an average yield scenario to be built for each field. While arguments could be made for keeping outliers as representatives of extreme years, the objective was to create a best fit scenario for the fields in an “average” year.

**Table 2.5: Data layers available for each field for spatial evaluation**

<table>
<thead>
<tr>
<th>Location</th>
<th>Years of Yield Data</th>
<th>Electrical Conductivity</th>
<th>Wetness Potential</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>SS</td>
<td>3</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DP</td>
<td>3</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UNL1</td>
<td>6</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>M40</td>
<td>4</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>AE</td>
<td>13</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>AW</td>
<td>12</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>ME</td>
<td>13</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>UNL2</td>
<td>9</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>UNL3</td>
<td>10</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
2.3.4 Management Zone Delineation

Several clustering options are available for management zone creation. While many of these options are defensible and produce appropriate management zones, Management Zone Analyst (MZA) (University of Missouri, Columbia, MO) was selected for both its robustness and its adaptability to on-farm research. This program allowed for integration of multiple data layers and provided the user guidelines on zone selection. MZA was also something that producers could potentially utilize themselves and did not require expensive software to complete. This kept the study within the constraints of an On Farm Research project. While a producer could use this program, several additional steps were included to increase precision of zones and fine-tune the prescription maps.

2.3.4.1 Grid Preparation in SMS

When utilizing multiple data layers, individually collected data points are not aligned in a way to processes these data together. Data layers were exported from SMS Advanced on a common grid aligned with a set field boundary. The grid size was set to 3 meters by 3 meters. Three by three meter grids were selected as the smallest size in order to maintain the density and precision of original datasets while still correctly representing less dense data sets. This allowed for precision in delineating management zones.

2.3.4.2 Processing Data in Arc

The individual spatial files set to a common grid were uploaded to ArcMap (Version 10.4.1, ESRI, Redlands, CA). Data were projected to a common coordinate system: North American Datum 83. Data were then exported as a comma separated value file and combined into one document for processing in MZA.
2.3.4.3 Management Zone Analyst

The combined .csv document was loaded in to Management Zone Analyst (MZA). Individual attributes were added to the selected layers menu. MZA provides the option to compute statistics and provides the number of observations, number of variables, mean, standard deviation, coefficient of variation, minimum and maximum values, sums of squares, variance covariance matrix, and a correlation matrix. These statistics assist the user in deciding which data layers to include in clustering and provide guidelines for which measure of similarity should be selected to delineate zones.

Several adjustments can be made before zones are delineated. Three measures of similarities can be selected: euclidean, diagonal, and mahalanobis. Euclidean or diagonal were chosen as the measure of similarity as the variables were assumed to have covariances equal to zero. The fuzziness exponent was kept at 1.3 for all iterations run. The measure of similarity used for each field can be found in Table 2.6. The number of iterations and convergence criterion were also adjustable but were kept at the default values of 300 iterations and a convergence of 0.0001. The minimum and maximum zones were two and six. The correct number of zones was based on the fuzziness performance index and the normalized classification entropy. Number of zones was selected when FPI and NCE were at a minimum.

Table 2.7 shows the optimum number of zones for each field.
Table 2.6: Measures of similarity used in Management Zone Analyst to determine clusters.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Year</th>
<th>Measure of Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>2016</td>
<td>Euclidean</td>
</tr>
<tr>
<td>SS</td>
<td>2016</td>
<td>Euclidean</td>
</tr>
<tr>
<td>SW</td>
<td>2016</td>
<td>Euclidean</td>
</tr>
<tr>
<td>DP</td>
<td>2016</td>
<td>Euclidean</td>
</tr>
<tr>
<td>ARDC3</td>
<td>2016</td>
<td>Euclidean</td>
</tr>
<tr>
<td>M40</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
<tr>
<td>AE</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
<tr>
<td>AW</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
<tr>
<td>ME</td>
<td>2017</td>
<td>Diagonal</td>
</tr>
<tr>
<td>ARDC2</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
<tr>
<td>ARDC1</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
</tbody>
</table>

Table 2.7: Number of clusters for optimum fit. Generated from Management Zone Analyst and determined from the Fuzziness Performance Index and Normalized Classification Entropy.

<table>
<thead>
<tr>
<th>Name</th>
<th>Optimum Number of Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>2</td>
</tr>
<tr>
<td>SS</td>
<td>2 or 3</td>
</tr>
<tr>
<td>SW</td>
<td>2 or 3</td>
</tr>
<tr>
<td>DP</td>
<td>4</td>
</tr>
<tr>
<td>UNL1</td>
<td>2</td>
</tr>
<tr>
<td>M40</td>
<td>2</td>
</tr>
<tr>
<td>AE</td>
<td>2</td>
</tr>
<tr>
<td>AW</td>
<td>2</td>
</tr>
<tr>
<td>ME</td>
<td>2</td>
</tr>
<tr>
<td>UNL2</td>
<td>2</td>
</tr>
<tr>
<td>UNL3</td>
<td>2</td>
</tr>
</tbody>
</table>

2.3.4.4 Prescription Map Processing

After the appropriate number of zones was selected, cluster points were imported back into Arc Map. These points were merged with the original grid layout. Outliers and
erroneous data points were removed manually, and then the grids were dissolved into polygons using the dissolve tool. Polygon edges were smoothed with the generalize and integrate tools and finalized. Zone maps were then imported to SMS. Hybrid and population treatments were assigned to each zone. If more than two zones were ideal, zones with the same treatment were merged into one zone. Check strips of the alternate treatment were placed throughout each zone in line with past harvest data to ensure check strips matched header widths. A minimum length of 91.44 meters was plotted to ensure accurate harvest data collection with a yield monitor. Widths of strips depended on available area and were placed in multiples of harvest header width. After rates and treatments were assigned to each zone and strip, the prescription map was exported as a shape file to be used in the Raven Envisio Pro monitor. Prescription maps can be found in Figure 6.7 through Figure 6.16.
Hybrids were selected in conjunction with producers, seed dealers and agronomic consultants. Two hybrids were selected for each field; one was selected as an offensive hybrid geared towards higher production, the other as a defensive hybrid geared towards a water limiting environment. The offensive hybrid would typically be placed in portions of the field that had more fertile soils, higher water holding capacity and overall a higher yield trend. The defensive hybrid was placed in portions of the field that typically were not as productive and had more water limiting conditions. This placement provided an opportunity to place hybrids with drought tolerant traits in portions of the field that could
benefit from it while optimizing production in high yielding portions of the field. Hybrids selected for each field and associated trait packages are listed in Table 2.8.

Table 2.8: Hybrid Selection by field, maturity classification, population. A single population was planted at each site, except for pivot corner in site DP which were planted to a lower population rate.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Year</th>
<th>Hybrid</th>
<th>Maturity (in Days)</th>
<th>Population (in seeds/acre)</th>
<th>Price of seed per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>2016</td>
<td>Defensive: 211-00DGVT2PRIB Offensive: 209-51VT2PRIB</td>
<td>111 109</td>
<td>74131.55 74131.55</td>
<td>$222.33 $222.33</td>
</tr>
<tr>
<td>SS</td>
<td>2016</td>
<td>Defensive: P1271AM Offensive: P1197AM</td>
<td>112 111</td>
<td>70177.87 70177.87</td>
<td>$210.47 $210.47</td>
</tr>
<tr>
<td>DP</td>
<td>2016</td>
<td>Defensive: P1498AM Offensive: P1257AMXT</td>
<td>114 112</td>
<td>84015.76/69189.45 84015.76/69189.45</td>
<td>$251.98 $283.47</td>
</tr>
<tr>
<td>M40</td>
<td>2017</td>
<td>Defensive: 211-00DGVT2PRIB Offensive: 209-51VT2PRIB</td>
<td>111 109</td>
<td>80309.18 80309.18</td>
<td>$240.86 $240.86</td>
</tr>
<tr>
<td>AE</td>
<td>2017</td>
<td>Defensive: A6499 Offensive: P1197AM</td>
<td>112 111</td>
<td>69189.45 69189.45</td>
<td>$216.16 $207.51</td>
</tr>
<tr>
<td>AW</td>
<td>2017</td>
<td>Defensive: 830-39AMX Offensive: 5F-709AM</td>
<td>109 110</td>
<td>69189.45 69189.45</td>
<td>$207.51 $233.45</td>
</tr>
<tr>
<td>ME</td>
<td>2017</td>
<td>Defensive: 732-99AM Offensive: P1197AM</td>
<td>111 112</td>
<td>76602.6 76602.6</td>
<td>$229.74 $229.74</td>
</tr>
<tr>
<td>UNL2</td>
<td>2017</td>
<td>Defensive: P1151AM Offensive: DKC62-98RIB</td>
<td>111 112</td>
<td>69189.45 69189.45</td>
<td>$207.51 $207.51</td>
</tr>
<tr>
<td>UNL3</td>
<td>2017</td>
<td>Defensive: P1498AM Offensive: P1257AM</td>
<td>114 112</td>
<td>69189.45 69189.45</td>
<td>$207.51 $207.51</td>
</tr>
</tbody>
</table>
Table 2.9: Offensive and defensive hybrids, maturity date and trait packages for each study site. Defensive hybrid is listed first for each location.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Year</th>
<th>Hybrid</th>
<th>Maturity</th>
<th>Trait Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>2016</td>
<td>211-00DGVT2PRIB 111</td>
<td>Genuity® DroughtGard® VT Double PRO® RIB Complete® corn blend</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>209-51VT2PRIB 109</td>
<td>Genuity® VT Double PRO® RIB Complete® corn blend</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>2016</td>
<td>P1271AM 112</td>
<td>Optimum® AcreMax®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1197AM 111</td>
<td>Optimum® AcreMax®</td>
<td></td>
</tr>
<tr>
<td>DP</td>
<td>2016</td>
<td>P1498AM 114</td>
<td>Optimum® AcreMax® AQUAmax®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1257AMXT 112</td>
<td>Optimum® AcreMax® XTreme</td>
<td></td>
</tr>
<tr>
<td>UNL1</td>
<td>2016</td>
<td>P1498AM 114</td>
<td>Optimum® AcreMax® AQUAmax®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1257AM 112</td>
<td>Optimum® AcreMax®</td>
<td></td>
</tr>
<tr>
<td>M40</td>
<td>2017</td>
<td>211-00DGVT2PRIB 111</td>
<td>Genuity® DroughtGard® VT Double PRO® RIB Complete® corn blend</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>209-51VT2PRIB 109</td>
<td>Genuity® VT Double PRO® RIB Complete® corn blend</td>
<td></td>
</tr>
<tr>
<td>AE</td>
<td>2017</td>
<td>A6499 112</td>
<td>Genuity® STX RIB SmartStax® VT2RIB VT Double Pro® RIB Complete® Corn Blend</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1197AM 111</td>
<td>Optimum® AcreMax®</td>
<td></td>
</tr>
<tr>
<td>AW</td>
<td>2017</td>
<td>830-39AMX 110</td>
<td>Optimum® AcreMax® Xtra AQUAmax®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5F-709AM 109</td>
<td>Optimum® AcreMax® AQUAmax®</td>
<td></td>
</tr>
<tr>
<td>ME</td>
<td>2017</td>
<td>732-99AM 112</td>
<td>Optimum® AcreMax®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1197AM 111</td>
<td>Optimum® AcreMax®</td>
<td></td>
</tr>
<tr>
<td>UNL2</td>
<td>2017</td>
<td>P1151AM 111</td>
<td>Optimum® AcreMax® AQUAmax®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>DKC62-95RIB 112</td>
<td>Genuity® VT Double PRO® RIB Complete® corn blend</td>
<td></td>
</tr>
<tr>
<td>UNL3</td>
<td>2017</td>
<td>P1498AM 114</td>
<td>Optimum® AcreMax® AQUAmax®</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>P1257AM 112</td>
<td>Optimum® AcreMax®</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.10: Offensive and defensive hybrids, and description of trait packages (herbicide resistance, insect protection and drought traits) for each study site. Defensive hybrid is listed first for each location.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Hybrid</th>
<th>Herbicide Resistance</th>
<th>Insect Protection</th>
<th>Drought Traits</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>211-00DGVT2PRIB</td>
<td>Roundup Ready 2</td>
<td>Above ground insect protection</td>
<td>DroughtGard®</td>
</tr>
<tr>
<td></td>
<td>209-51VT2PRIB</td>
<td>Roundup Ready 2</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>P1271AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1197AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td>DP</td>
<td>P1498AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1257AMXT</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above and below ground insect protection</td>
<td>Optimum® AQUAmax®</td>
</tr>
<tr>
<td>UNL1</td>
<td>P1498AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1257AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td>M40</td>
<td>211-00DGVT2PRIB</td>
<td>Roundup Ready 2</td>
<td>Above ground insect protection</td>
<td>DroughtGard®</td>
</tr>
<tr>
<td></td>
<td>209-51VT2PRIB</td>
<td>Roundup Ready 2</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td>AE</td>
<td>A6499</td>
<td>Conventional</td>
<td>Above and below ground insect protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1197AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td>AW</td>
<td>830-39AMX</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above and below ground insect protection</td>
<td>Optimum® AQUAmax®</td>
</tr>
<tr>
<td></td>
<td>5F-709AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td>Optimum® AQUAmax®</td>
</tr>
<tr>
<td>ME</td>
<td>732-99AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P1197AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td>UNL2</td>
<td>P1151AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td>Optimum® AQUAmax®</td>
</tr>
<tr>
<td></td>
<td>DKC62-95RIB</td>
<td>Roundup Ready 2</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
<tr>
<td>UNL3</td>
<td>P1498AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td>Optimum® AQUAmax®</td>
</tr>
<tr>
<td></td>
<td>P1257AM</td>
<td>Roundup Ready 2, Liberty Link</td>
<td>Above ground insect protection</td>
<td></td>
</tr>
</tbody>
</table>
2.3.6 Planting Factors

Fields were planted by order of producer preference when possible, followed by distance between fields and time constraints of the operator. Issues arose at several fields that should be discussed but likely do not affect the overall results of the study, or cannot be compensated for. Planting date can be found in Table 2.11.

Table 2.11: Planting dates for 2016 and 2017 Field Sites

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Year</th>
<th>Planting Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>2016</td>
<td>6-May</td>
</tr>
<tr>
<td>SS</td>
<td>2016</td>
<td>26-Apr</td>
</tr>
<tr>
<td>SW</td>
<td>2016</td>
<td>26-Apr</td>
</tr>
<tr>
<td>DP</td>
<td>2016</td>
<td>15-May</td>
</tr>
<tr>
<td>UNL1</td>
<td>2016</td>
<td>15-Apr</td>
</tr>
<tr>
<td>M40</td>
<td>2017</td>
<td>14-May</td>
</tr>
<tr>
<td>AE</td>
<td>2017</td>
<td>8-May</td>
</tr>
<tr>
<td>AW</td>
<td>2017</td>
<td>9-May</td>
</tr>
<tr>
<td>ME</td>
<td>2017</td>
<td>7-May</td>
</tr>
<tr>
<td>UNL2</td>
<td>2017</td>
<td>24-Apr</td>
</tr>
<tr>
<td>UNL3</td>
<td>2017</td>
<td>25-Apr</td>
</tr>
</tbody>
</table>

Difficulties maintaining GPS signal on site SS and site SW resulted in the operator planting with row markers instead of RTK or SF1 or SF2. Because the signal defaulted to WAAS, some of the point row and turn row shutoffs were not as precise, leaving gaps or overlap.

It was discovered on site M40 that one row unit seed meters had been switched for all previous fields in the 2016 growing season resulting in that row planting the opposite hybrid for sites UNL1, SS, SW and part of M40. This issue was rectified over halfway through the field. The row of the alternate hybrid will be ignored in all data analysis as experimental error for the 2016 data.
Site UNL2 had the opposite hybrid planted on the outside turnrow for half the field perimeter. The issue was marked and corrected for the rest of the field.

Portions of site AW did not have ideal planting conditions. Areas near the tile risers were wetter and resulted in some sidewall compaction. At planting, the whole field was highly variable in soil moisture and soil conditions.

Adjustable planter settings are shown in Table 2.4. Distribution and location of fields is shown in Figure 2.5.

Figure 2.5: Corn field distribution in the 2016 and 2017.
2.3.7 Data Collection

2.3.7.1 Aerial Imagery Collection

Aerial imagery was collected in season for each location. Imagery was collected before tassel in order to collect an image with the largest amount of green vegetation possible. An aircraft flying at an elevation of 1,829 meters collected imagery in 2016. This was equipped with an UltraCamLp Photogrammetric Digital Aerial camera (Vexcel Imaging GmbH, Graz, Austria) mounted in the nadir position. The images collected were georeferenced and orthorectified. Four bands were collected: red, green, blue and near infrared. Resolution was around 15.24 cm GSD.

Imagery in 2017 was collected by drone. Two fields were flown with the DJI Inspire 1 (iFlight Technology Company Limited, Shenzhen, China) equipped with a MicaSense Red Edge camera (MicaSense, Seattle, WA). The bands collected were red, green, blue, and red edge (475, 560, 668, 717 nm). Three fields were flown with a senseFly Ag eBee (Parrot, Paris, France) fixed wing. This platform was equipped with MicaSense Parrot Sequoia, which collects green, red, red edge, and near infrared bands (550, 660, 735, 790 nm).

2.3.7.2 Yield Data Collection

Harvest dates varied by crop maturity date, moisture content and weather events. Each field was harvested by the producer’s combine. Yield monitors were calibrated on each machine before the field was harvested. All were impact plate systems. Some fields were verified by grain scale weight. Harvest dates and moisture are in Table 2.12. All fields were completed within four days of starting at that field site with the exception of
site DP, which was harvested on September 30th and October 30th and consequently
analyzed both as a single field and as two separate fields. Data were removed from yield
monitors directly after harvest. Data were imported in to Ag Leader SMS for storage and
analysis.

<table>
<thead>
<tr>
<th>Name</th>
<th>Harvest Date</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>7-Nov-16</td>
<td>14%</td>
</tr>
<tr>
<td>SS</td>
<td>28-Oct-16</td>
<td>15%</td>
</tr>
<tr>
<td>SW</td>
<td>28-Oct-16</td>
<td>15%</td>
</tr>
<tr>
<td>DP</td>
<td>29-Sep-16</td>
<td>20%</td>
</tr>
<tr>
<td></td>
<td>30-Oct-16</td>
<td>15%</td>
</tr>
<tr>
<td>UNL1</td>
<td>3-Nov-16</td>
<td>15%</td>
</tr>
<tr>
<td>M40</td>
<td>10-Nov-17</td>
<td>16%</td>
</tr>
<tr>
<td>AE</td>
<td>3-Nov-17</td>
<td>14%</td>
</tr>
<tr>
<td>AW</td>
<td>2-Nov-17</td>
<td>13%</td>
</tr>
<tr>
<td>ME</td>
<td>26-29-Oct-17</td>
<td>16%</td>
</tr>
<tr>
<td>UNL2</td>
<td>02-Nov-17</td>
<td>15%</td>
</tr>
<tr>
<td>UNL3</td>
<td>31-Oct-17</td>
<td>15%</td>
</tr>
</tbody>
</table>

Results for one field, SW, were not analyzed due to an issue with check strip
location and contamination during planting and harvest.

2.3.7.3 Supplemental Attributes by Zone

Descriptive statistics are presented in Table 2.13 for the independent variables
used in the regression analysis presented in 2.4.5. These data points were extracted by
harvest point location from spatially interpolated layers using the extract multi values to
points function in ArcMap.
**Table 2.13: Descriptive statistics for independent variables used in regression analysis.**

<table>
<thead>
<tr>
<th></th>
<th>Elevation (m)</th>
<th>Slope (%)</th>
<th>Shallow EC (dS/m)</th>
<th>Deep EC (dS/m)</th>
<th>Wetness Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M40 (2016)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>362.9</td>
<td>0%</td>
<td>30.03</td>
<td>46.06</td>
<td>5.036</td>
</tr>
<tr>
<td>Median</td>
<td>366.4</td>
<td>2%</td>
<td>39.3</td>
<td>55.43</td>
<td>7.973</td>
</tr>
<tr>
<td>Mean</td>
<td>365.8</td>
<td>2%</td>
<td>40.34</td>
<td>56.02</td>
<td>8.222</td>
</tr>
<tr>
<td>Max</td>
<td>369.1</td>
<td>7%</td>
<td>55.02</td>
<td>69.1</td>
<td>16.342</td>
</tr>
<tr>
<td><strong>SS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>409.6</td>
<td>0%</td>
<td>19.4</td>
<td>26.78</td>
<td>1.964</td>
</tr>
<tr>
<td>Median</td>
<td>426</td>
<td>11%</td>
<td>35.21</td>
<td>53.3</td>
<td>4.265</td>
</tr>
<tr>
<td>Mean</td>
<td>425.3</td>
<td>12%</td>
<td>35.73</td>
<td>54.75</td>
<td>4.475</td>
</tr>
<tr>
<td>Max</td>
<td>437.6</td>
<td>37%</td>
<td>55.46</td>
<td>208.77</td>
<td>10.053</td>
</tr>
<tr>
<td><strong>DP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>398.2</td>
<td>0%</td>
<td>2.863</td>
<td>3.853</td>
<td>2.516</td>
</tr>
<tr>
<td>Median</td>
<td>401.4</td>
<td>4%</td>
<td>20.835</td>
<td>33.468</td>
<td>6.812</td>
</tr>
<tr>
<td>Mean</td>
<td>401.5</td>
<td>5%</td>
<td>21.606</td>
<td>33.278</td>
<td>7.068</td>
</tr>
<tr>
<td>Max</td>
<td>405.6</td>
<td>61%</td>
<td>43.018</td>
<td>57.765</td>
<td>14.199</td>
</tr>
<tr>
<td><strong>UNL1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>353.8</td>
<td>0%</td>
<td>14.19</td>
<td>23.49</td>
<td>4.284</td>
</tr>
<tr>
<td>Median</td>
<td>355.3</td>
<td>2%</td>
<td>28.3</td>
<td>43.11</td>
<td>7.541</td>
</tr>
<tr>
<td>Mean</td>
<td>355.5</td>
<td>3%</td>
<td>31.61</td>
<td>47.3</td>
<td>7.787</td>
</tr>
<tr>
<td>Max</td>
<td>359.4</td>
<td>14%</td>
<td>70.3</td>
<td>111.71</td>
<td>14.999</td>
</tr>
<tr>
<td><strong>M40 (2017)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>404</td>
<td>0%</td>
<td>16.16</td>
<td>16.26</td>
<td>3.49</td>
</tr>
<tr>
<td>Median</td>
<td>407.1</td>
<td>6%</td>
<td>25.57</td>
<td>31.91</td>
<td>6.121</td>
</tr>
<tr>
<td>Mean</td>
<td>407.1</td>
<td>7%</td>
<td>26.48</td>
<td>31.59</td>
<td>6.285</td>
</tr>
<tr>
<td>Max</td>
<td>410.7</td>
<td>32%</td>
<td>45.32</td>
<td>47.82</td>
<td>14.523</td>
</tr>
<tr>
<td><strong>AE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>381.01</td>
<td>0%</td>
<td>10.36</td>
<td>18.91</td>
<td>4</td>
</tr>
<tr>
<td>Median</td>
<td>383.6</td>
<td>2%</td>
<td>25.03</td>
<td>39.62</td>
<td>7.779</td>
</tr>
<tr>
<td>Mean</td>
<td>383.7</td>
<td>3%</td>
<td>26.51</td>
<td>43.7</td>
<td>8.005</td>
</tr>
<tr>
<td>Max</td>
<td>390.5</td>
<td>18%</td>
<td>49.93</td>
<td>77.02</td>
<td>15.835</td>
</tr>
<tr>
<td><strong>AW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>383</td>
<td>0%</td>
<td>17.47</td>
<td>22.87</td>
<td>3.86</td>
</tr>
<tr>
<td>Median</td>
<td>399.4</td>
<td>8%</td>
<td>40.94</td>
<td>54.45</td>
<td>6.726</td>
</tr>
<tr>
<td>Mean</td>
<td>398.6</td>
<td>8%</td>
<td>39.06</td>
<td>52.16</td>
<td>6.963</td>
</tr>
<tr>
<td>Max</td>
<td>411.9</td>
<td>25%</td>
<td>47.42</td>
<td>62.57</td>
<td>15.616</td>
</tr>
<tr>
<td><strong>ME</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>362.9</td>
<td>0%</td>
<td>30.03</td>
<td>46.06</td>
<td>5.036</td>
</tr>
</tbody>
</table>
### Data Analysis Method

#### 2.3.8.1 Yield Data Processing

Data were processed in SMS software (Version 17.2, AgLeader, Ames, IA) and subsequently cleaned in Yield Editor (Version 2.0.7, USDA, ARS) to remove erroneous data points. Low yielding, high yielding, narrow swath widths, abrupt velocity changes, and data points outside a set standard deviation were removed to clean yield data. Filters used for each field varied, however maintained the ultimate goal of reducing the overall coefficient of variation for the fields. Fields were also corrected for moisture to 15.5%. This was important as the two separate hybrids can have differing moisture at harvest time. This correction helped account for that variation and allow the hybrids to be compared equally. Clean data points were then imported back into Ag Leader SMS and ArcMap. Yield in each check strip was recorded. Near the edges of the check strip, some of the outer rows of that harvest pass were occasionally contaminated with the zone hybrid and not the check strip hybrid. Only harvest passes with a whole header width of

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>2%</th>
<th>39.9</th>
<th>55.42</th>
<th>7.973</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>365.8</td>
<td>2%</td>
<td>40.34</td>
<td>56.02</td>
<td>8.222</td>
</tr>
<tr>
<td>Max</td>
<td>369.1</td>
<td>7%</td>
<td>55.02</td>
<td>69.1</td>
<td>16.342</td>
</tr>
</tbody>
</table>

#### Data Analysis Method

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the check strip hybrid were analyzed. Strips adjacent to the check strip of the zone hybrid were assessed for yield comparison. These adjacent strips were then compared using the MIXED procedure in SAS (Version 9.4, SAS Institute Inc., Cary, NC). Mean separation was performed with Fisher’s LSD. A macro, PDMIX800 was used for mean separation output letter groupings (Saxton, n.d.). This gave a basis for significance within each management zone. Significance was determined at a 95% confidence interval. Strips were also compared using the GLIMMIX procedure in SAS for interactions within zones.

2.3.8.2 Aerial Imagery Processing

Aerial imagery was processed in ArcMap. Normalized difference vegetation index (NDVI) and normalized difference red edge (NDRE) were calculated for all fields when possible. NDRE could not be calculated for the 2016 aerial imagery due to the bands collected by the camera. For the 2016 data, only NDVI was calculated. Both NDVI and NDRE were calculated for the 2017 fields. NDVI was selected due to its popularity and robustness as a vegetative index. However, for the time frame that the images were collected, NDVI tends to be over saturated and differentiation between treatments is often difficult to detect. For this reason, NDRE was also used. Differences between the hybrids were often more detectible, because NDRE was not saturated at this point.

To remove the influence shadows and soil had on the overall calculations, image cleaning was completed to remove this potential error. Pixels were sorted by unsupervised classification. Pixels corresponding with soil, shadows, tree rows, or field roads were removed from the images, leaving only the pixels corresponding with the
plants. This cleaning allows for a more accurate comparison between adjacent strips of differing hybrids.

After indices were calculated and the influence of soil removed, check and adjacent strips were isolated from the zones as a whole. An average of the NDVI or NDRE values were recorded for each strip. These adjacent strips were then compared using the GLIMMIX procedure in SAS (Version 9.4, SAS Institute Inc., Cary, NC). Mean separation was performed with Fisher’s LSD. This gave a basis for significance within each management zone. Significance was determined at a 95% confidence interval.

2.3.8.3 Field Variable Regression Analysis

Soil and terrain attributes were aggregated for each field. Data were interpolated by kriging method for electrical conductivity. Terrain attributes were calculated with Ag Leader SMS. The calculated attributes were plotted on a grid scale determined by SMS. These layers were then sampled by point location of the yield file to associate yield, electrical conductivity, elevation, slope, wetness potential, as well as treatment and zone attributes. This data was then processed in R (R Core Team, 2013) using a smooth regression in the ggplot package (Wickham, 2009). Example code can be found in 6.9.1.

2.3.8.4 Zone Scenario Analysis

Optimum zone scenario maps representing the optimum placement of hybrids during the given growing season was desired. To achieve this, yield results from each field were analyzed for differences in paired strips. Of the paired strips, the lower yielding treatment was excluded from analysis. The remaining higher yielding treatments
were then used for analysis. These check strips were interpolated by kriging to create a surface of highest yielding treatments spatially. This surface was then converted to a polygon and zone lines smoothed and simplified by merging transition zones and clipping to field boundaries.

These results were then analyzed to determine significance within the restructured zones. If restructuring resulted in at least one zone with significant differences between yields of hybrids, the alternative zone map is presented in Figure 2.50 and Figure 2.51 and Appendix Figure 6.165 through Figure 6.168.

2.3.8.5 Profitability Analysis

Marginal net return was calculated for each hybrid in each zone. Marginal net return was calculated as the average tons per hectare in the zone multiplied by a market price of $125.97 per Mg. Seed costs were subtracted from this value for the final marginal net return. Price per bag was calculated from the UNL 2018 Crop Budget (Klein et al., 2017).

2.4 Results and Discussion

2.4.1 As Applied Planting Data

As applied planting maps can be found in Figure 6.17 through Figure 6.26. The distribution of population from the as applied maps, number or data polygons and measures of error can be found in Table 2.14. Minimum seeding rate values were zero for all fields, and reached as high as 5,394,814 seeds per hectare. This extremely high value can be attributed to a controller malfunction at the beginning of the 2016 planting season. Error rates were calculated for planted population versus target rate. Error rates ranged
from 3.27% to -19.75%. Average rates were lower than target rates for all fields except site UNL1. This field had the very high max values due to the controller malfunction, pulling the average rate above the target rate and resulting in a -19.75% error. Standard deviation values ranged from 16,567 to 177,975 seeds per hectare. CV% also ranged from 19-217%. These large values for both standard deviation and coefficient of variation indicate the need for cleaning of the as applied planting data. Error in data collection could be due to number of units planting at point rows, ramp up or ramp down issues (abrupt speed changes and the subsequent effects on sensor recording), or abrupt speed changes in a pass. Average values for population may include portions of the field where not all units are planting, such as point rows, overlapping passes, or zero rate areas. This resulted in a decrease in the average value. By eliminating these locations from overall analysis, a more accurate picture of what was planted in the field is available. Abrupt changes in speed also affected the recorded population rates. It is assumed that in some cases the speed may not have affected the planted rate as much as the recorded planted rate indicated. These would be artifacts of controller response in reading machine parameters and not actually translated into a change in rate. Finally, ramp up and ramp down affected the recorded values as the planter started into and left passes. The monitor often would take several seconds to settle on the target rate, often initially over shooting, followed by a moment of undershooting the target value. These values are also considered to be artifacts.
Figure 2.6: Site M40 2016 As Applied Planting Map

Table 2.14: Raw As Applied Planting Date for All Corn Fields, 2016 and 2017

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>MIN (kds/ha)</th>
<th>MAX (kds/ha)</th>
<th>AVG (kds/ha)</th>
<th>Target (kds/ha)</th>
<th>Error</th>
<th>STD (kds/ha)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40 (2016)</td>
<td>7662</td>
<td>0</td>
<td>480.89</td>
<td>69.68</td>
<td>74.07</td>
<td>5.93%</td>
<td>16.57</td>
<td>24%</td>
</tr>
<tr>
<td>SS</td>
<td>11330</td>
<td>0</td>
<td>488.40</td>
<td>61.09</td>
<td>70.12</td>
<td>12.89%</td>
<td>25.98</td>
<td>43%</td>
</tr>
<tr>
<td>SW</td>
<td>9442</td>
<td>0</td>
<td>230.89</td>
<td>67.83</td>
<td>70.12</td>
<td>3.27%</td>
<td>17.51</td>
<td>26%</td>
</tr>
<tr>
<td>DP</td>
<td>34900</td>
<td>0</td>
<td>496.59</td>
<td>77.16</td>
<td>80.99</td>
<td>4.73%</td>
<td>17.48</td>
<td>23%</td>
</tr>
<tr>
<td>UNL1</td>
<td>8869</td>
<td>0</td>
<td>5394.81</td>
<td>82.20</td>
<td>68.64</td>
<td>-19.75%</td>
<td>177.98</td>
<td>217%</td>
</tr>
<tr>
<td>M40</td>
<td>8806</td>
<td>0</td>
<td>479.78</td>
<td>76.96</td>
<td>80.25</td>
<td>4.09%</td>
<td>17.70</td>
<td>23%</td>
</tr>
<tr>
<td>AE</td>
<td>17551</td>
<td>0</td>
<td>499.88</td>
<td>64.40</td>
<td>69.14</td>
<td>6.86%</td>
<td>17.25</td>
<td>27%</td>
</tr>
<tr>
<td>AW</td>
<td>22366</td>
<td>0</td>
<td>502.15</td>
<td>64.32</td>
<td>69.14</td>
<td>4.96%</td>
<td>23.53</td>
<td>37%</td>
</tr>
<tr>
<td>ME</td>
<td>16636</td>
<td>0</td>
<td>249.80</td>
<td>73.95</td>
<td>76.54</td>
<td>3.39%</td>
<td>14.35</td>
<td>19%</td>
</tr>
<tr>
<td>UNL2</td>
<td>15465</td>
<td>0</td>
<td>478.62</td>
<td>65.70</td>
<td>69.14</td>
<td>4.96%</td>
<td>17.53</td>
<td>27%</td>
</tr>
<tr>
<td>UNL3</td>
<td>11566</td>
<td>0</td>
<td>482.42</td>
<td>65.70</td>
<td>69.14</td>
<td>4.96%</td>
<td>19.43</td>
<td>30%</td>
</tr>
</tbody>
</table>

Due to the mentioned errors, the as-applied planting data was cleaned to better quantify the variability present during planting. Cleaned as applied planting data can be
found in Table 2.15. Cleaning removed anywhere between 650 and 2500 data polygons. The field sites where more locations were removed had more complex field boundaries and inclusions, resulting in more overlap and point rows as the planter moved into the turn rows. Minimum populations for the cleaned data were around 49,505 seeds per hectare. Maximum values were around 96,371 seeds per hectare. Average populations ranged between 67,459 and 79,074 seeds per hectare. This resulted in as applied rates much closer to the target populations. Consequently, error was reduced to below 4% for all fields. In the most severe case, error was reduced by nearly 22%. Standard deviations also decreased significantly to 3,212-6,919 seeds per hectare. Coefficient of variation (CV) was reduced to between 4-10%. Based on these standards, it is assumed that cleaning the data was successful in removing outliers and error.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>MIN (kds/ha)</th>
<th>MAX (kds/ha)</th>
<th>AVG (kds/ha)</th>
<th>Target (kds/ha)</th>
<th>Error</th>
<th>STD (kds/ha)</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40 (2016)</td>
<td>7008</td>
<td>54.37037</td>
<td>86.3950617</td>
<td>72.02469</td>
<td>74.07407</td>
<td>2.77%</td>
<td>3.85</td>
<td>5.35%</td>
</tr>
<tr>
<td>SS</td>
<td>8842</td>
<td>49.38272</td>
<td>88.8641975</td>
<td>67.77778</td>
<td>70.12346</td>
<td>3.55%</td>
<td>6.64</td>
<td>9.80%</td>
</tr>
<tr>
<td>SW</td>
<td>8396</td>
<td>49.48148</td>
<td>83.9012346</td>
<td>68.46914</td>
<td>70.12346</td>
<td>2.36%</td>
<td>5.01</td>
<td>7.32%</td>
</tr>
<tr>
<td>DP</td>
<td>32457</td>
<td>54.49383</td>
<td>96.2222222</td>
<td>79.40741</td>
<td>80.98765</td>
<td>1.95%</td>
<td>7.14</td>
<td>8.99%</td>
</tr>
<tr>
<td>UNL1</td>
<td>7758</td>
<td>49.80247</td>
<td>86.3950617</td>
<td>67.53086</td>
<td>68.64198</td>
<td>1.62%</td>
<td>3.51</td>
<td>5.19%</td>
</tr>
<tr>
<td>M40 (2017)</td>
<td>8155</td>
<td>62.07407</td>
<td>91.2839506</td>
<td>78.74074</td>
<td>80.24691</td>
<td>1.88%</td>
<td>3.51</td>
<td>4.45%</td>
</tr>
<tr>
<td>AE</td>
<td>15447</td>
<td>51.85185</td>
<td>88.8395062</td>
<td>67.65432</td>
<td>69.1358</td>
<td>2.14%</td>
<td>3.95</td>
<td>5.84%</td>
</tr>
<tr>
<td>AW</td>
<td>18412</td>
<td>49.38272</td>
<td>86.3703704</td>
<td>68.32099</td>
<td>69.1358</td>
<td>1.18%</td>
<td>5.19</td>
<td>7.59%</td>
</tr>
<tr>
<td>ME</td>
<td>15469</td>
<td>61.7284</td>
<td>88.8641975</td>
<td>75.1358</td>
<td>76.54321</td>
<td>1.84%</td>
<td>3.41</td>
<td>4.53%</td>
</tr>
<tr>
<td>UNL2</td>
<td>13901</td>
<td>51.85185</td>
<td>88.7901235</td>
<td>68</td>
<td>69.1358</td>
<td>1.64%</td>
<td>4.67</td>
<td>6.86%</td>
</tr>
<tr>
<td>UNL3</td>
<td>10231</td>
<td>56.79012</td>
<td>83.8518519</td>
<td>68.79012</td>
<td>69.1358</td>
<td>0.50%</td>
<td>3.42</td>
<td>4.97%</td>
</tr>
</tbody>
</table>

Hybrids and population rates were controlled on an individual row basis, resulting in very fine precision along hybrid transition zones. The majority of these changes
occurred within a few seeds based on visual inspection, and completely within 1 to 2 meters.

2.4.2 Aerial Imagery and Vegetation Indices

Results of NDVI and NDRE imagery for all field sites can be found in Table 2.16 through Table 2.17.

Table 2.16: NDVI values by zone. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Table 2.17: NDRE values by zone. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>NDRE Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defensive</td>
<td>Offensive</td>
</tr>
<tr>
<td>M40 (2017)</td>
<td>AE</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td>Offensive</td>
<td>Offensive</td>
</tr>
<tr>
<td></td>
<td>AW</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td>Defensive</td>
<td>Offensive</td>
</tr>
<tr>
<td></td>
<td>ME</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>b</td>
</tr>
<tr>
<td>Offensive</td>
<td>Offensive</td>
</tr>
<tr>
<td></td>
<td>UNL2</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>b</td>
</tr>
<tr>
<td>Defensive</td>
<td>Offensive</td>
</tr>
<tr>
<td></td>
<td>UNL3</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>a</td>
</tr>
</tbody>
</table>

2.4.2.1 2016 Results

NDVI was calculated for the four fields in 2016. Results can be found in Figure 2.7 through Figure 2.10. NDVI imagery can be found in Figure 6.35 through Figure 6.38.
Offensive hybrid 209 had a higher NDVI value than the defensive hybrid, 211, in the defensive zone. There was no difference in NDVI values between the hybrids in the offensive zone. This indicates that within the defensive zone, the offensive hybrid had more leaf greenness, with the possibility of greater overall plant health. These two hybrids had fairly distinct hybrid color throughout the whole growing season, so leaf greenness in this case may not be related to plant health but rather a function of genetic coloring.

Figure 2.7: Site M40 NDVI values by zone. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 2.8: SS NDVI values by zone. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
NDVI levels for site SS show no difference between the offensive hybrid, P1197, and the defensive hybrid, P1271 in the defensive zone or the offensive zone. Green color difference was difficult to detect visually during any stage during the growing season. Plant nutrient status and overall health appeared to be uniform.

![Figure 2.9: Site DP NDVI values by zone. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.](image)

NDVI values at field DP were not different within the offensive zone. Offensive hybrid, P1257, had higher NDVI readings than the defensive hybrid, P1498, in the defensive zone. Since the majority of the offensive zone was under center pivot irrigation, the defensive and offensive hybrids may have had more access to water and consequently had more overall leaf greenness, and consequently, uniformity.
NDVI values were higher for P1257, the offensive hybrid, in comparison to the defensive hybrid, P1498, in both the offensive and defensive zones at site UNL1. Hybrids had distinctly different leaf color and architecture that could have affected the NDVI readings.

In three fields, M40, UNL1, and DP, NDVI was able to detect a difference in the hybrids in at least one zone. In one field, SS, NDVI was not able to detect a difference between the hybrids. NDVI was affected by leaf color difference between hybrids which may or may not be a result of plant health and performance.

**2.4.2.2 2017 Results**

NDVI and NDRE values were calculated for all six fields during the 2017 growing season. Results can be found in Figure 2.11 through Figure 2.22. NDVI images can be found in Figure 6.39 through Figure 6.44. NDRE images can be found in Figure 6.45 through Figure 6.50.
Site M40 showed no difference in NDRE values for the offensive hybrid, 209, or the defensive hybrid, 211, in either zone. NDVI also had no difference between the hybrids in the defensive zone, but did indicate a difference in values for the offensive zone. Leaf color differences were noticeable between hybrids visually, but was not detected by NDRE and NDVI readings.

Figure 2.11: NDRE values for Site M40. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 2.12: NDVI values for Site M40. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 2.13: NDRE values for site AE. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 2.14: NDVI values for site AE. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
NDRE values for site AE showed a difference in hybrids in both the offensive and defensive zone, with the offensive hybrid, P1197, having lower NDRE readings in both zones. NDVI values showed no differences between the offensive hybrid, P1197, and the defensive hybrid, A6499. Leaf color was detectable visually; however, leaf architecture was possibly more influential toward vegetative readings. On the day imagery was collected, A6499 leaves were rolled as a protective measure against the heat. P1197 leaves were unrolled. The imagery may be highlighting the difference in chlorophyll content on the underside versus top side of leaves. In bright sunlight or hot conditions, chlorophyll will align itself parallel to the incident light to reduce absorption of light. (Taiz and Zeiger, 2010) Some of the difference in reflectance could be due to this physiological response.

![Figure 2.15: NDRE values for site AW. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.](image1)

![Figure 2.16: NDVI values for site AW. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.](image2)

NDRE values for site AW showed no difference in the offensive hybrid, 5F-709, and the defensive hybrid, 830-39, in either of the offensive or defensive zone. Similarly,
NDVI values were not different in either zone for the two hybrids. Hybrids were very similar in color visibly.

**Figure 2.17:** NDRE values for site ME. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

NDRE values for site ME showed a difference in values for the offensive zone, with higher readings from P1197, the offensive hybrid, than 732-99, the defensive hybrid. There was no difference in readings for the defensive zone. NDVI values for the field again showed a difference between the P1197 and the 732-99 for the offensive zone, but no difference for the defensive zone.

**Figure 2.18:** NDVI values for site ME. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
In field UNL2, NDRE values indicated that 62-98 offensive hybrid had higher vegetative readings in the offensive zone, but no difference in the defensive zone. NDVI values indicated a difference between treatments, with the 62-98 Offensive hybrid recording higher values in both the offensive and defensive zones.
NDVI values for site UNL3 show no difference in hybrids for both the offensive and defensive zone. Similarly, NDRE values show no difference between the offensive hybrid P1257 and the defensive hybrid P1498 in either offensive or defensive zone. Color of hybrids was similar making it difficult to see a visual difference during the growing season.

NDVI and NDRE values were able to detect a difference between hybrids in at least one of the zones of three separate fields, UNL2, AE, and ME. In three fields, UNL3, AW, and M40, NDVI and NDRE were not able to detect any difference between offensive and defensive hybrids in any zone.

### 2.4.2.3 Aerial Imagery Discussion

Aerial imagery across seasons did not do a consistent job in indicating hybrid performance, or identifying the two different hybrids in each zone. This was gauged by whether the defensive hybrid had higher vegetative index values in the defensive zone,
and the offensive hybrid higher values in the offensive zone, assuming hybrid placement was correct.

2016 data did not show any defined patterns, particularly any which matched the zone prescription. If a difference was detected, the offensive hybrid was always higher. In two fields, M40 and DP, there was no difference in the offensive zone, but there was in the defensive zone. The offensive hybrid had higher NDVI values in the defensive zone. Site SS did not have any difference between zones, and site UNL1 had higher offensive NDVI values in both zones. As NDVI is not directly correlated with yield, but rather biomass, no interpretation or prediction of effect on hybrid performance could be made in season.

Data from 2017 NDVI and NDRE values did not show consistent trends in vegetative indices or hybrid performance. Sites ME and UNL1 both had higher NDRE values for the offensive hybrid in the offensive zone, but no difference in hybrids in the defensive zone. Sites M40, AW, and UNL3 did not have any differences between zones. Site AE recorded higher values by the defensive hybrid in both zones. Overall, results were mixed for NDRE and NDVI for the 2017 growing seasons. No yield predictions could be reliably made.

Section 2.4.6 compares results from aerial imagery with yield performance by zone and hybrid delineation.
2.4.3 Yield Results on a Field Basis

Yield results from all fields in 2016 and 2017 are presented in Table 2.18:

Average yield, standard deviation, and CV on a whole field basis. Yield maps showing yield distribution and patterns across field sites are found in Figure 6.51 through Figure 6.60. Average yield represents the average across all zones and hybrids. The highest yielding field in 2016 averaged 14.89 Mg Ha\(^{-1}\). The lowest yielding field averaged 13.02 Mg Ha\(^{-1}\) in 2016. Average yield values in 2017 ranged from 14.46 to 10.32 Mg Ha\(^{-1}\). Standard deviation ranged from around 1.75-2.87 Mg Ha\(^{-1}\). This resulted in coefficients of variation around 10-20%. Some of this variation was a result of in field variation due to soil, or water distribution across the field. Additional variation came as a result of hybrid differences across the field.

<table>
<thead>
<tr>
<th>Name</th>
<th>Harvest Date</th>
<th>Moisture %</th>
<th>Average Yield (Mg/ha)</th>
<th>Standard Deviation (Mg/ha)</th>
<th>CV %</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>07-Nov-16</td>
<td>14%</td>
<td>14.89</td>
<td>1.75</td>
<td>12%</td>
</tr>
<tr>
<td>SS</td>
<td>28-Oct-16</td>
<td>15%</td>
<td>13.02</td>
<td>2.45</td>
<td>19%</td>
</tr>
<tr>
<td>DP</td>
<td>29-Sep-16</td>
<td>20%</td>
<td>13.01</td>
<td>2.36</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>30-Oct-16</td>
<td>16%</td>
<td>14.29</td>
<td>2.08</td>
<td>15%</td>
</tr>
<tr>
<td>UNL1</td>
<td>03-Nov-16</td>
<td>15%</td>
<td>14.35</td>
<td>1.86</td>
<td>13%</td>
</tr>
<tr>
<td>M40</td>
<td>10-Nov-17</td>
<td>16%</td>
<td>14.46</td>
<td>2.00</td>
<td>14%</td>
</tr>
<tr>
<td>AE</td>
<td>03-Nov-17</td>
<td>14%</td>
<td>11.35</td>
<td>1.48</td>
<td>13%</td>
</tr>
<tr>
<td>AW</td>
<td>02-Nov-17</td>
<td>13%</td>
<td>10.32</td>
<td>2.87</td>
<td>28%</td>
</tr>
<tr>
<td>ME</td>
<td>27-Oct-17</td>
<td>16%</td>
<td>13.64</td>
<td>2.17</td>
<td>16%</td>
</tr>
<tr>
<td>UNL2</td>
<td>02-Nov-17</td>
<td>15%</td>
<td>11.76</td>
<td>1.97</td>
<td>17%</td>
</tr>
<tr>
<td>UNL3</td>
<td>31-Oct-17</td>
<td>15%</td>
<td>10.41</td>
<td>1.81</td>
<td>17%</td>
</tr>
</tbody>
</table>

Table 2.19 shows 2016 and 2017 yields in comparison with historical averages. Number of years included in the historical average is denoted in the table.
Table 2.19: Average yield in comparison with historical yield.

<table>
<thead>
<tr>
<th>Name</th>
<th>Harvest Date</th>
<th>Average Yield (Mg Ha⁻¹)</th>
<th>Historical Yield Average (Mg Ha⁻¹)</th>
<th>Number of Years</th>
<th>Difference in yield (Mg Ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M40</td>
<td>07-Nov-16</td>
<td>14.89</td>
<td>11.86</td>
<td>3</td>
<td>3.02</td>
</tr>
<tr>
<td>SS</td>
<td>28-Oct-16</td>
<td>13.02</td>
<td>12.37</td>
<td>1</td>
<td>0.65</td>
</tr>
<tr>
<td>DP</td>
<td>29-Sep-16</td>
<td>13.61</td>
<td>7.91</td>
<td>1</td>
<td>5.70</td>
</tr>
<tr>
<td>UNL1</td>
<td>03-Nov-16</td>
<td>14.35</td>
<td>11.30</td>
<td>3</td>
<td>3.05</td>
</tr>
<tr>
<td>M40</td>
<td>10-Nov-17</td>
<td>14.46</td>
<td>12.49</td>
<td>4</td>
<td>1.96</td>
</tr>
<tr>
<td>AE</td>
<td>03-Nov-17</td>
<td>11.35</td>
<td>10.48</td>
<td>6</td>
<td>0.87</td>
</tr>
<tr>
<td>AW</td>
<td>02-Nov-17</td>
<td>10.32</td>
<td>9.92</td>
<td>6</td>
<td>0.41</td>
</tr>
<tr>
<td>ME</td>
<td>27-Oct-17</td>
<td>13.64</td>
<td>13.62</td>
<td>6</td>
<td>0.02</td>
</tr>
<tr>
<td>UNL2</td>
<td>02-Nov-17</td>
<td>11.76</td>
<td>10.48</td>
<td>4</td>
<td>1.28</td>
</tr>
<tr>
<td>UNL3</td>
<td>31-Oct-17</td>
<td>10.41</td>
<td>11.17</td>
<td>5</td>
<td>-0.77</td>
</tr>
</tbody>
</table>

2.4.4 Yield Results on a Zone Basis

Yield results for the 2016 and 2017 growing seasons were analyzed for differences in overall yield performance within zones and fields including interaction of zone and hybrids. Results of this analysis are found in Figure 2.23.
Figure 2.23: Yield by zone results. Mg ha$^{-1}$ are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within field.
2.4.4.1 2016 Yield Results Zone Basis

Yield results on a zone basis without zone influence for the 2016 growing season are displayed in Figure 6.61 through Figure 6.64. Yield of each treatment was assessed by zone.

Yield results for all field sites can be found in Figure 2.23. Three field sites indicate that there was no difference in either hybrid in either zone. Three of the field sites indicated that the offensive hybrid was the higher yielding hybrid within each zone. The defensive hybrid yielded higher than the offensive hybrid in both zones at one field site. Finally, several field sites had mixed results with different combinations of hybrids yielding the same across different zones. Results on an individual zone basis are presented in Figure 6.61 through Figure 6.70. Discussion on a field basis is presented below.

Yield results without zone interaction for site M40 are found in Figure 6.61. Results for M40 with hybrid and zone interactions indicates no yield difference between offensive hybrid 209 and defensive hybrid 211 was detected in the offensive or defensive zone. However, yield of the defensive hybrid in the offensive zone, and offensive hybrid in the defensive zone were shown to be the same. Yields in the offensive zone were around 15.4 Mg Ha$^{-1}$ while yields in the defensive zone ranged from 14.5 – 14.7 Mg Ha$^{-1}$. A yield gap is present between the two zones, which may indicate that the zone delineation separating out “high” and “low” yielding zones was successful. However, environmental response or hybrid selection resulted in no difference between the hybrids in their respective zones. This field site received 16.6 cm of rainfall above the 30 year
average. Growing season conditions were excellent with limited water stress. Consequently, placement of a defensive hybrid was not necessary for the 2016 growing season. It is interesting to note the yield gap between the offensive and defensive zones that occurred even in a “wet” year. It is possible that in a dry year, this yield gap would be even more pronounced.

Yield results without zone interaction for site SS are found in Figure 6.62. Results for SS with hybrid and zone interactions indicates no yield difference between offensive hybrid P1197AM and defensive hybrid P1271AM was detected in the offensive or defensive zone. Yield values in the defensive zone were statistically same as those in the offensive zone. The yields in the offensive zone trend higher than the defensive, suggesting some validity of the zone structure. Field layout made it challenging to adequately assess zone delineation and include adequate check strip numbers and placement. Waterways, terraces and an irregular field border all contributed to this issue. Redesigning field check strip layout would be beneficial for future studies at this field site.

Yield results without zone interaction for site DP are found in Figure 6.63. Results for DP with hybrid and zone interactions will be discussed. Two different harvest dates resulted in drastically different moisture levels for the two dates. Moisture was corrected to 15.5% for these two dates so that harvest data could be analyzed as an entire field. The offensive hybrid, P1257AMXT, yielded higher than the defensive hybrid, P1498AM, in both offensive and defensive zone. Difference in yield ranged from 1.54 Mg ha\(^{-1}\) in the defensive zone, to 1.41 Mg ha\(^{-1}\) in the offensive zone. Rainfall was above
average for the 2016 growing season with 16.6 cm of rain above the 30 year average. Adequate moisture was received across the field, so there was no need for a defensive hybrid. While this field was irrigated, a single pass was made across the field, putting on 1.9 cm of water. This amount was negligible in respects towards total growing season rainfall. As a result, the irrigated and non-irrigated portions of the field were uniform with each other throughout the growing season and harvest.

Yield results without zone interaction for site UNL1 can be found in Figure 6.64. Results for UNL1 with hybrid and zone interactions indicates the offensive hybrid, P1257AM, yielded higher than the defensive hybrid, P1498AM, in both the offensive and defensive zone. The defensive hybrid yielded similarly across both zones, around 14.1-14.4 Mg Ha$^{-1}$, however, the offensive hybrid in the defensive zone also yielded similarly to the defensive hybrid in the offensive zone. Around 11 cm of rainfall above the ten year average was recorded at this field site, providing adequate moisture throughout the whole growing season. Consequently, there was no real need for a defensive hybrid during this growing season. This was evidenced by the superior performance of P1257AM.

2.4.4.2 2017 Yield Results Zone Basis

Yield results for the 2017 growing season are displayed in Figure 6.61 through Figure 6.70. Yield of each treatment was assessed by zone.

Yield results without zone interaction for site M40 can be found in Figure 6.65. Results for M40 with hybrid and zone interactions indicates the offensive hybrid, 209, did not yield differently from the defensive hybrid, 211, in the offensive or defensive zone. Yield of the defensive hybrid in the defensive zone was similar to yields of both
hybrids in the offensive zone. Yield of the offensive hybrid in the defensive zone was lower than yield of either hybrid in the offensive zone. There does appear to be some difference in overall yield potential between the offensive and defensive zones, suggesting that the zone delineation was correct. Yield ranged from 14.8-15.2 Mg ha\(^{-1}\) in the offensive zone, and between 13.3 and 13.9 Mg ha\(^{-1}\) in the defensive zone. Rainfall recorded at this field site totaled 57.5 cm, almost 10 cm above the 30 year average of 48 cm. This would indicate that there was no need for a defensive hybrid placement. The 2017 growing season was the second year of corn in a row, opening up the possibility for increased effectiveness of a defensive hybrid. Using a defensive hybrid in corn on corn scenarios can aid in issues that may arise due to lack of crop rotation such as disease and insect resistance as well as lodging or issues with standability due to additional protective traits in the defensive hybrid that were not possessed by the offensive hybrid. Emergence can also be compromised with increased residue leading to cool, wet soils and slower emergence. The defensive hybrid may have provided some of these protective features, but ultimately, there was no difference in hybrids within zones.

Yield results without zone interaction from site AE can be found in Figure 6.66. Results for AE with hybrid and zone interactions indicates the offensive hybrid, P1197AM, did not yield differently than the defensive hybrid, A6499, in the offensive or defensive zone. Yield of hybrids was also similar across zones, with yield values ranging from 11.26 Mg ha\(^{-1}\) to 11.52 Mg ha\(^{-1}\) across the whole field. Several hot days around July 6\(^{th}\) resulted in a noticeable difference in physiological response to the hot conditions. The defensive hybrid A6499 rolled its leaves during the warmest part of the day for several
days in response to the conditions, as observed during scouting, while the offensive hybrid, P1197, did not. This response can help conserve water and maintain cellular function. This does not appear to have contributed to the overall yield of either hybrid.

Yield results without zone interaction from site AW can be found in Figure 6.67. Results for AW with hybrid and zone interactions indicates the offensive hybrid, 5F-709AM, performed similarly to the defensive hybrid, 830-39AMX, in the offensive and defensive zone. Yield of hybrids was similar across zones. A large amount of variability was present at this field site in both zones. Rainfall was six cm above the 30 year average, providing adequate water during the growing season.

Yield results without zone interaction from site ME can be found in Figure 6.68. Results for ME with hybrid and zone interactions indicates the offensive hybrid, P1197AM, yielded higher than the defensive hybrid, 732-99AM, in both the offensive and defensive zones. Yield of the offensive hybrid was highest in the offensive zone. Yield of the offensive hybrid in the defensive zone was similar to yield of the defensive hybrid in the offensive zone. Yield of the defensive hybrid in the defensive zone was lowest. P1197AM yielded 0.62 Mg ha\(^{-1}\) more in the offensive zone and 1.18 Mg ha\(^{-1}\) higher in the defensive zone. Moisture was adequate across the growing season for this location. Rainfall was supplemented by center pivot irrigation in the irrigated portion of the field. The offensive hybrid should have been planted across both the offensive and defensive zones.

Yield results without zone interaction for site UNL2 can be found in Figure 6.69. Results for UNL2 with hybrid and zone interactions indicates the offensive hybrid,
DKC62-98RIB, yielded the same as the defensive hybrid, P1151AM, in the offensive zone. In the defensive zone, there was also no difference between the two hybrids. When analyzed without zone interaction, the offensive hybrid yielded higher in the offensive zone, but both hybrids yielded the same in the defensive zone. This indicates that the offensive hybrid was placed correctly in the offensive zone. In this scenario, during a year with water limiting conditions, the defensive hybrid may have the potential to outperform the offensive hybrid within that zone. However, rainfall was recorded 11 cm above the 30 year average. Water limiting conditions were not an issue for the 2017 growing season and the traits provided by the defensive hybrid were not needed.

Yield results without zone interaction for site UNL3 can be found in Figure 6.70. Results for UNL3 with hybrid and zone interactions indicates the offensive hybrid, P1257AM, yielded significantly lower than the defensive hybrid, P1498AM, in both the offensive and defensive zone. The defensive hybrid in the defensive zone yielded similarly to the offensive hybrid in the offensive zone. In the past couple years, P1257AM has outperformed P1498AM in a variety of field settings. Consequently, the results from site UNL3 are somewhat of a surprise. Based on GDD accumulated at the field site, P1257AM was silking on July 16th. For eight days, high temperatures were above 32.2 degrees Celsius, potentially inhibiting silking and pollination. Based on GDD, P1498AM was silking on July 14th. For a three day window between July 13-15, temperatures did not reach above 32.2 degrees Celsius, potentially allowing silking and pollination to progress without inhibition. This is a possible explanation for reduced yields from a generally high yielding hybrid. The drastic difference between the two
hybrids doesn’t appear to be spatially related, but rather uniform across the field. This uniformity could again point to a uniform weather even that affected one hybrid more than the other.

2.4.4.3 Yield Results Discussion

No trends emerged from the ten study fields across two growing seasons. The hypothesized outcome of defensive hybrid performing best in the defensive zone, and offensive hybrid performing best in the offensive zone was not achieved. One field showed partial achievement of this zone delineation and performance, with one hybrid “winning” in the desired zone and the other zone showing no difference between the hybrids. Some explanation of zone and hybrid performance can be attributed to two wet growing seasons. Drought conditions for which the defensive hybrid was selected never occurred; both years recorded above average rainfall and were generally excellent growing conditions for overall yield performance. Other contributions to the achieved results include incorrect zone structure for the year, or incorrect hybrid selection. These are harder to quantify as they are compounding issues.

An important conclusion highlights the performance of defensive hybrids in several fields where no difference in hybrid occurred. This occurred at sites SS, AE, and AW. In two above average wet years, there was no yield penalty for planting a defensive hybrid typically geared towards maintaining yield in dry conditions. Since there was no yield penalty, this hybrid and zone combination could be planted most years in anticipation of a dry year. In a dry year, it might provide some additional benefit while still not reducing yield in a wet, or average moisture year. This would provide a producer
a way to reduce the risk they may experience in a dry year with yield limiting conditions, without sacrificing yield in any other weather scenario. While that scenario would be ideal, results from the 2016 and 2017 are not indicative of this situation.

Four fields, DP, UNL1, ME, and UNL3, had a single hybrid “win” in both zones. In three of those cases, DP, UNL1, and ME, the offensive hybrid outperformed the defensive hybrid. Site DP and ME are very flat fields with no large topographic change. Both were irrigated sites with adequate moisture. Site DP contained typical pivot corners, however site ME had relatively small areas not covered by the center pivot due to neighboring pivot locations. It would take a very dry growing season for a discrepancy in yield to occur across these fields. It is assumed after this growing season that these fields would not be a good candidate for multi-hybrid planting in the future. Site UNL1 did have a fair amount of topographic change, but was heavily influenced by the environmental conditions for the year. Repetition of the same zones in this site in future years would be beneficial. Site UNL3 also had one hybrid perform the best across the whole field. In this case, it is surmised that hot weather conditions affecting pollination impacted yield as much as zone structure did. Repetition of this zone format in future years with some restructuring of zone check strips would be beneficial for verification.

In field UNL2, there was no difference in hybrid performance in each individual zone, but there was a difference in overall yield performance by zone. When looking at yield results on an individual zone basis, the offensive hybrid yielded higher than the defensive hybrid in the offensive zone, but there was no difference in the defensive zone. This field would be an excellent candidate to repeat the study. This field site has great
potential for multi-hybrid planting, particularly due to sandy outcroppings that lead to reduced water availability.

M40 in both years showed mixed results on interactions of hybrids by zones. Yield in the offensive zone was higher than the defensive zone, however one hybrid in the defensive zone usually was similar to yield in the offensive zone. This hybrid relationship switched from year to year indicating high temporal instability. This temporal instability will be important to remember moving forward as some of these study sites are repeated.

Zone stability is a concern from year to year. While only one field was repeated from the 2016 to 2017 growing season, the results indicate high influence of temporal variability on zone delineation. While the results from each season indicate no difference between hybrids within individual zones, the scenario zone delineation based on paired strip data resulted in greatly different scenario zones for the 2016 and 2017 growing seasons. The map comparison can be found in Figure 2.50 and Figure 2.51. Repetition of this study on the same field sites would help provide a look at the effect temporal variability has on zone structure and delineation.

Based on results from 2016 and 2017, multi-hybrid planting would not be a feasible investment as no firm delineation of zones results in a clear advantage to using two hybrids in a field. Unless further years of yield data show stability in zones and a distinct yield advantage for using two separate hybrids, it will be hard for producers to justify multi-hybrid planting.
2.4.5 Yield Results with Spatial Interaction

2.4.5.1 2016 Spatial Correlations

Yield files from the 2016 growing season were analyzed in comparison with spatial soil factors including elevation, shallow and deep EC, slope gradient, wetness potential and soil series. Figure 2.24-Figure 2.35 highlight variables of interest for each field site. Variables of interest were selected based on the influence of the layer on overall yield results. Layers that did not show any strong influence on treatment yield were not termed layers of interest. Results from all categories can be found in Figure 6.71 through Figure 6.106.

Figure 2.24: Site M40 2016 yield data by soil and treatment regression. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Figure 2.25: Site M40 2016 yield by treatment by deep EC regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 2.26: Site M40 2016 yield by treatment by deep EC regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 2.24 through Figure 2.26 show the relationship between yield and soil series and deep EC for field M40 (2016). While not all soil types were present in both
hybrid numbers, comparison of yield by soil attributes show that hybrid 211 yielded lower in the Fillmore and Moody soils than hybrid 209. While both hybrids are not placed within the Crofton soil, the performance of 211 in that particular soil series is noticeably lower than other soil and yield combinations. Figure 2.25 shows the relationship between yield and deep EC by zone. Yield levels by both hybrid 211 and 209 are fairly similar across the whole range of EC values within the offensive zone. Similarly within the defensive zone, the hybrids had similar yield values below a threshold of 28 dS/m. Above that value, the offensive hybrid, 209, performs at a higher capacity than the defensive hybrid, 211. When deep EC was analyzed across the whole field, it was demonstrated that below 20 dS/M, the defensive hybrid yields higher than the offensive hybrid. The performance of the hybrid is inverse above that value with defensive yields decreasing as deep EC increases. As EC is related to soil texture and water holding capacity, lower values indicate larger particle sized soils with less water holding capacity. Ultimately this means the defensive hybrid performed better in coarser textured soils.
Figure 2.27: Site SS yield by treatment and soil series regression. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 2.28: Site SS yield by treatment and deep EC regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Figure 2.29: Site SS yield by treatment by slope by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 2.30: Site SS yield by treatment by wetness potential by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 2.27-Figure 2.30 highlight several attribute relationships. Figure 2.27 demonstrates the difference in hybrid performance across multiple soil types. Hybrid
P1197 is more consistent yielding across soil types than P1271. Mean yield values were lowest in Steinaur soils, and highest in Nodaway soils. EC values across the field indicate that below 50 dS/M both hybrids performed similarly. However, above that value, the yield of the defensive hybrid decreased, while the offensive hybrid increased as the EC values increased. Figure 2.29 shows that within the defensive zone, the defensive hybrid had slightly higher yield values, and was fairly consistent across a wide range of slope gradients. Within the offensive zone, the offensive hybrid had slightly higher yields until a slope gradient around 18% at which point the defensive hybrid was higher yielding. The analysis of wetness potential in Figure 2.30 shows that the hybrid assigned to the zone (i.e. offensive hybrid in offensive zone) performed better than their counterparts. This would suggest that wetness potential was influencing overall yield by separating out top performing hybrid by zone.

Figure 2.31: Site DP yield by treatment by elevation by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Figure 2.32: Site DP yield by treatment by wetness potential by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 2.33: Site DP yield by treatment by soil series regression. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 2.31 through Figure 2.33 show the correlations between elevation, wetness potential and soil series at field DP. Yield values were fairly stable across the range of
elevation in the offensive zone. In the defensive zone, the offensive hybrid was higher yielding until an elevation around 402.5 meters. At that point, the offensive hybrid dropped off drastically, while the defensive hybrid maintained a similar yield across all elevation ranges. The elevation change was not drastic across the field, so the substantial drop off of yield of P1257 is of interest. Within the offensive zone, hybrids were fairly uniform across wetness potential. Within the defensive zone, the defensive hybrid was stable across all wetness ranges, however the offensive hybrid fluctuated a fair amount and ultimately decreased below the levels of the defensive hybrid at a value of 10 wetness potential. Comparison with soil series shows that for all soil series, P1498 yielded lower. Overall, higher levels of elevation and wetness potential seem to have affected P1257 the most.

Figure 2.34: Site UNL1 yield by treatment by soil series regression. Mg ha⁻¹ are corrected to 15.5% moisture.
Figure 2.35: Site UNL1 yield by treatment by wetness potential by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 2.34 and Figure 2.35 show the correlation of soil series and wetness potential with yield for field UNL1. Yield for both hybrids were lower in Filbert and Fillmore soils. Yield was generally higher in Scott and Yutan soils. Overall, P1498 yielded lower than P1257 across all soil types. Wetness potential was uniform between zones, with P1257 yielding higher in both offensive and defensive zones. P1257 was higher in the defensive zone until a wetness potential of around 12, after which point it dropped off. It seems that these factors were not a large influencer towards yield. Overall, P1257 yielded better than P1498 under all independent variables.

2.4.5.2 2017 Spatial Correlations

Yield files from the 2017 growing season were analyzed in comparison with spatial soil factors including elevation, shallow and deep EC, slope gradient, wetness potential and soil series. Figure 2.36 through Figure 2.48 highlight variables of interest
for each field site. Variables of interest were selected based on influence of layer on overall yield results. Layers that did not show any strong influence on treatment yield were not termed layers of interest. Results from all categories can be found in Figure 6.107 through Figure 6.164.

Figure 2.36: Site M40 yield by treatment and deep EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
Figure 2.36 and Figure 2.37 show the correlation between deep and shallow EC and yield for site M40. For both variables, yield from both treatments were fairly uniform within the offensive zone. Differences in yield emerged in the defensive zone. Hybrid 209 yielded similarly to 211 until a reading of 28 dS/M at which point yield of 209 increased above 211 and was fairly uniform around 15 Mg Ha$^{-1}$ across the rest of the range of EC. It appears that EC was an influencing factor in the defensive zone for yield, exhibiting a fair amount of variability in hybrid performance. Both shallow and deep EC produced very similar results for the 2016 and 2017 yield correlations. This stability is an indicator that EC is a consistent influence on yield from year to year.
Figure 2.38: Site AE yield by treatment by elevation by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 2.39: Site AE yield by treatment by soil series regression analysis. Mg ha$^{-1}$ are corrected to 15.5% moisture.
Figure 2.40: Site AE yield by treatment by wetness by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 2.41: Site AE yield by treatment by shallow EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
Several variables were of interest in field AE and are displayed in Figure 2.38 through Figure 2.41. Hybrid results were mixed in each of the zones below an elevation of 385 meters. Some differentiation did begin to occur above that elevation, particularly in the offensive zone. Within the offensive zone, the offensive hybrid began to decrease at a faster rate than the defensive hybrid, suggesting the defensive hybrid may yield higher than the offensive hybrid at higher elevations and steeper slopes. This can also be seen in the defensive zone, as the defensive hybrid begins to increase in yield at higher elevation levels. Yield by soil type was similar among treatments, with similar distribution of data. Both hybrids had the lowest yields in the Pohocco series and highest yields in Judson. The relationship of wetness to yield is shown in Figure 2.40. Within the defensive zone, the offensive hybrid yielded higher than the defensive hybrid at the middle ranges of wetness potential, however the defensive hybrid yielded highest at low wetness potential. This is a good indicator that at low wetness potential the defensive traits such as drought tolerance were effective at preserving yield. Within the offensive zone, the hybrids performed similarly, with the defensive hybrid averaging slightly higher across the middle ranges of wetness. Shallow EC correlations found in Figure 2.41 indicate mixed results in the offensive zone at values lower than 40 dS/m. Above that value, the offensive hybrid performed better. Within the defensive zone, the offensive hybrid yielded higher at values between 15 and 30 dS/m while the defensive hybrid began performing better than the offensive hybrid at an EC value above 30. This would indicate in some of the finer textured soils, typically those that hold very tightly to water, the defensive hybrid did a better job utilizing the water present for yield gain.
Figure 2.42: Site AW yield by treatment by slope gradient by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 2.43: Site AW yield by treatment by wetness potential regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Slope gradient and wetness potential interactions with yield for field AW are found in Figure 2.42 and Figure 2.43. Slope gradient appears to be very uniform by
hybrid in the defensive zone, with both hybrids slightly decreasing in yield with higher slope grades. Results were mixed in the offensive zone, with more fluctuations by the hybrids. At a slope grade between 15 and 20% the offensive hybrid yield began to decrease and the defensive hybrid remained stable. This is an indicator of the stability of the defensive hybrid in potentially water and nutrient limiting areas in highly sloped and possibly eroded conditions. Across the whole field, yield of both hybrids generally increased with an increasing wetness potential. Around a value of 10, the defensive hybrid yield appears to reach a threshold while the offensive hybrid continued to increase with increasing wetness. The higher values of wetness potential occurred in some lower areas of the field adjacent to small creeks and in natural drainage channel throughout the field. The offensive hybrid did a better job of utilizing water in median wetness classes but excelled at dealing with wetness potential that may typically stunt plant growth and development due to a saturated root zone, ponding, or leaching of nutrients from the root zone.
Site ME was a fairly uniform field spatially. Consequently, supplemental attributes did not reveal any major trends in final yield production. Trends in wetness potential shown in Figure 2.44 indicate that yield was stable across a wide range of wetness potential in both P1197 and 732-99 in the defensive zone. More variability was present in the offensive zone. At wetness potentials below 11, 1197 and 732-99 performed similarly. Above that point, a discrepancy in hybrid performance does emerge with performance of P1197 decreasing and 732-99 yield remaining stable.
Figure 2.45: Site UNL2 yield by treatment by shallow EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 2.46: Site UNL2 yield by treatment by slope gradient regression analysis. Mg ha⁻¹ are corrected to 15.5% moisture.

Shallow EC and slope gradient are found in Figure 2.45 and Figure 2.46 for site UNL2. Yield values and trends for both hybrids were fairly similar across offensive and
defensive zones. In both zones, yield of the hybrids decreased as dS/M increased. Across the whole field, in response to slope, 1151AMAQ trended lower than 62-98VT2. Generally, as slope increased, yield decreased. At the highest slope ranges, 62-98VT2 had begun to increase again. However, the error is also increasing with increasing slope gradient. Both 1151AMAQ and 65-98VT2 yielded higher at more level slope categories.

Figure 2.47: Site UNL3 yield by treatment by soil series by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha\(^{-1}\) are corrected to 15.5\% moisture.
Figure 2.48: Site UNL3 yield by treatment by wetness potential regression analysis. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 2.47 and Figure 2.48 represent relationship between soil series and wetness potential with yield for site UNL3. Treatment P1257 yielded lower in the Yutan soil series than the other soil types present in the field. P1498 had opposite relationships with soil series in the offensive vs defensive zones. Filbert and Fillmore soils had the highest yielding P1498 values for the offensive zone, while Tomek and Yutan had lower yielding values. In the defensive zone, Tomek and Yutan had the higher yielding values, while Filbert and Fillmore had the lower yielding points. P1257 yielded lower in almost all soil series by zone. Wetness potential showed mixed results for hybrid performance. Up to a wetness potential around 9, P1498 yielded higher. From a wetness of 9-14, P1257 yielded higher. Above 14, P1498 yielded higher again. This does indicate some possibility for delineating zones based on wetness potential of the field.
2.4.5.3 Spatial Correlation Summary

No single data layer distinguished between hybrids by yield across all fields. Each field had a layer or a combination of layers that was uniquely able to distinguish some of the difference in performance of hybrids by yield. Soil type, elevation, slope, wetness potential, and shallow and deep EC all were an influencing factor in at least one field. It is highly likely that a combination of these factors results in the most influence on overall yield by treatment. Further analysis showing the compounding effects of these attributes on yield by treatment would be of interest.

2.4.6 Yield Results Comparison to Imagery

Few patterns emerged comparing yield results and aerial imagery results. In most of the cases, differences detected in yield didn’t translate to differences detected in aerial imagery. Two cases are the exception to that. In 2016, site UNL1 showed a difference in both the offensive and defensive zones with the offensive hybrid yielding highest and having the highest NDVI values across the field for yield and NDVI. Inversely, in 2017, site AW did not show any difference in yield, NDRE, or NDVI. All other field sites had mixed results as to which zones had differences in yield or vegetative indices in the hybrids. If a difference was detected in a zone, whether that difference was in NDRE, NDVI, or yield, it was generally the hybrid prescribed for that zone that had the higher values. For example, in site ME, the offensive hybrid yielded higher in the offensive zone. The offensive hybrid had higher NDRE and NDVI values in the offensive zone, but showed no difference in the defensive zone. This pattern of which hybrid had a higher
value carried across all fields. In no cases did one hybrid yield highest but have a lower vegetative index for that zone.

2.4.7 Scenario Zone Delineation

Alternative zone maps are presented in Figure 2.50 and Figure 2.51 and Appendix Figure 6.165 through Figure 6.168 showing show optimum placement of zones based on 2016 and 2017 growing seasons. Yield results from hybrid by zone interaction are found in Figure 2.49. Yield results by field without zone influence are found in Figure 6.169 through Figure 6.174. Results discussed will be based on the hybrid by zone interaction results.

Figure 2.49: Zone scenario yields after zone restructuring. Mg ha$^{-1}$ are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within fields.
Offensive and defensive zones in site M40 were restructured to include three paired strips in the defensive zone, and six paired strips in the offensive zone. No hybrid difference was detected in the defensive zone. However, the offensive hybrid, 209, yielded higher than the defensive hybrid, 211. Across zones, the defensive hybrid in the offensive zone yielded the same as both hybrids in the defensive zone. Additionally, the offensive hybrid in the offensive zone yielded similarly to the defensive hybrid in the defensive zone. This zone scenario resulted in a difference in one zone, compared to no differences in the as planted zones.

Offensive and defensive zones in site SS were restructured to include four paired strips in the offensive zone and six paired strips in the defensive zone. The offensive hybrid yielded higher than the defensive hybrid in the offensive zone. The defensive hybrid yielded higher than the offensive hybrid in the defensive zone. A fairly complex relationship exists across zones. The defensive hybrid in the defensive zone was individually similar to each hybrid in the offensive zone. The offensive hybrid in the defensive zone was also individually related to each hybrid in the offensive zone. This zone scenario resulted in a difference in hybrids in both zones, compared to no difference in the as planted zones. This restructuring resulted in a yield difference of 0.6 Mg Ha\(^{-1}\) in the defensive zone and 0.7 Mg Ha\(^{-1}\) in the offensive zone.

Out of 21 check strips at site DP, the offensive hybrid yielded higher in 20. Because this large portion of the field would all require a single hybrid, no zone restructuring was necessary. A single hybrid should be planted across the whole field in
environmental conditions like 2016. It is possible that zone restructuring to separate pivot corners from the majority of the field would be necessary for a drier year.

Similarly, 13 out of 13 check strips at site UNL1 should have been planted to the offensive hybrid. No alternative zone map is presented as a single hybrid should have been planted across the field in a growing season like 2016.

Offensive and defensive zones in site M40 were restructured to include four paired strips in the offensive zone and eleven strips in the defensive zone. There was no difference in the hybrid yields in the offensive zone. The defensive hybrid, 211, yielded higher than the offensive hybrid, 209, in the defensive zone. Additionally, the offensive hybrid in the offensive zone was similar to all other treatments in both zones. The offensive hybrid in the defensive zone yielded similarly to the defensive hybrid in the offensive zone. This zone scenario resulted in a difference in one zone compared to no difference in the as planted zones.

Offensive and defensive zones in site AE were restructured to include ten paired strips in the offensive zone and ten paired strips in the defensive zone. The offensive hybrid, P1197, yielded 0.5 Mg Ha$^{-1}$ higher than the defensive hybrid, A6499, in the offensive zone. The defensive hybrid, A6499, yielded 0.6 Mg Ha$^{-1}$ higher than the offensive hybrid, P1197, in the defensive zone. Relationships across zones exist with the defensive hybrid in the defensive zone independently similar to each hybrid in the offensive zone. Similarly, the defensive hybrid in the offensive zone was independently related to both hybrids in the defensive zone. This zone scenario resulted in a yield difference in each zone compared to no difference in the as planted zones.
Offensive and defensive zone in site AW were restructured to include twelve paired strips in the offensive zone and eight paired strips in the defensive zone. The offensive hybrid, 5F-709, yielded 0.8 Mg Ha\(^{-1}\) higher than the defensive hybrid, 830-39, in the offensive zone. The defensive hybrid, 830-39, yielded 0.8 Mg Ha\(^{-1}\) higher than the offensive hybrid, 5F-709, in the defensive zone. A complex interaction on hybrid across zones exists and can be seen in Figure 2.49. The offensive hybrid in the offensive zone was independently similar to both hybrids in the defensive zone. The defensive hybrid in the offensive zone was also independently related to both hybrids in the defensive zone. This zone scenario resulted in a yield difference in both zones compared to no difference in the as planted zones. Zones created had a substantial yield gap between hybrids, indicating good potential for multi-hybrid zones.

Out of 28 check strips in site ME, only three should have been planted to the defensive hybrid. These locations were not congruently located in the field. No alternative zone map is presented as the offensive hybrid should have been planted across the vast majority of the field in a year like 2017.

Offensive and defensive zone in site UNL2 were restructured to include twelve paired strips in the offensive zone and eight paired strips in the defensive zone. The offensive hybrid, 62-98, yielded higher than the defensive hybrid, 1151, in the offensive zone. The defensive hybrid yielded higher than the offensive hybrid in the defensive zone. A complex interaction on hybrid across zones exists and can be seen in Figure 2.49. The offensive hybrid in the offensive zone was independently similar to both hybrids in the defensive zone. The defensive hybrid in the offensive zone was also independently
related to both hybrids in the defensive zone. This zone scenario resulted in a yield
difference in both zones compared to no difference in the as planted zones.

Out of 17 check strips in site UNL3, all of them should have been planted with
the defensive hybrid. No alternative zone map is presented as the defensive hybrid should
have been placed across the entire field in a year like 2017.

Zone restructuring was successful in creating zones with yield differences for
several of the fields. It should be noted that while these zones worked for the 2016 and
2017 growing seasons, in-field testing of these zones is necessary to test validity from
season to season and under highly variable field conditions. Stability of zones is an issue:
the zone scenario created for site M40 in 2016 is very different from the zones scenario
created for the 2017 data as shown in Figure 2.50 and Figure 2.51. This highlights the
instability of yield and hybrid performance across differing growing season conditions. It
is possible that many years of zone analysis will be necessary to attempt to determine
zones. It is also possible that zones in certain fields will never be stable as they are
heavily influenced by interactions between spatial soil attributes and temporal weather
conditions. Long-term analysis will be the only way to assess the feasibility of creating
zones for multi-hybrid planting.
2.4.8 Profitability Analysis

Profitability calculations for 2016 and 2017 growing season can be found in Figure 2.52. Profitability for zone scenarios can be found in Figure 2.53.
2.4.8.1 Profitability of Multi-Hybrid Sites

Figure 2.52: Marginal net return in $ per hectare for hybrid and zone locations. Marginal net return is calculated as Mg per hectare times a market price of $125.97 per metric ton. Seed costs were calculated based on UNL 2018 Crop Budget.
Marginal net return results matched with the yield results for all field sites. Three of the study sites DP, UNL1, and ME showed that it was more profitable to plant the offensive hybrid across the whole field. One field, UNL3 indicated that planting the defensive hybrid would provide the most profit. The remainder of the sites showed no difference in yield by treatment by zone. When looking at profitability across zones, we do see similar profitability of the offensive hybrid in the defensive zone with the defensive hybrid in the offensive zone. This is largely due to similar yield results of the hybrids as well as cost of seed. Generally, cost of hybrids was very similar for offensive and defensive pairings. Similar trait packages resulted in consistent price of seed. Price of hybrid only differed in three fields and ultimately did not result in any difference in overall profitability. Field DP had the largest difference in price per hybrid with the offensive hybrid costing $283 per hectare, and the defensive hybrid costing $252 per hectare. The overall yield advantage of the offensive hybrid covered the additional cost of the seed in this case, and no difference in profitability was evident. Price for labor and generation of complex prescription maps were not accounted for. Time and money required to complete this essential task should be considered before adoption.

While yield results were correlated with MNR for all field sites, it is important to note that this could be influenced by price of hybrids. Difference in price of seed was negligible in the study fields, however, large difference in price of trait packages could result in a difference in yield and profitability results. While the yield may show significance of one hybrid, profitability may indicate planting the other hybrid for
optimum economic return. All of the results in Figure 2.52 indicate that a single hybrid planted across the whole field would have been best from a profitability perspective.

2.4.8.2 Profitability of Zone Scenarios

Profitability was assessed for the zone scenarios created in section 2.4.7. Several fields did not have zone scenarios created; these fields all should have been planted to a single hybrid. Consequently, no profitability analysis was conducted for them.

Profitability results for the remaining fields can be found in Figure 2.53.

Figure 2.53: Marginal Net Return for zone scenario analysis in $/hectare. Marginal net return is calculated as Mg per hectare times a market price of $125.97 per metric ton. Seed costs were calculated based on UNL 2018 Crop Budget.
Of the six fields that zone scenarios were created for, five showed the desired higher profitability with the offensive hybrid in the offensive zone. Five fields showed the desired higher profitability with the defensive hybrid in the defensive zone. In both years, M40 resulted in a difference in profitability in one zone only. In 2016, there was no difference in profitability in the defensive zone. In 2017, there was no difference in profitability in the offensive zone. Overall, profitability results matched with the zone scenario yield results. Price of each hybrid was the same for the majority of the fields; only fields AE and AW showed a difference in prices by hybrid. Because prices were relatively similar, this didn’t result in an difference in profitability for either of these fields. Zone scenarios were effective at optimizing both yield and profitability in the correct hybrid and zone pairings. This data will be useful for comparison to future datasets and zone restructuring.

2.5 Conclusion

Aerial imagery did not do a consistent job of highlighting differences between hybrids during either growing season. NDVI and NDRE did not consistently detect differences between hybrids. Vegetative indices were not well correlated with final yield results. In only two cases did aerial imagery match the yield results for the zones. The rest of the field sites had mixed results on what hybrids and zones resulted in any difference in NDVI, NDRE and yield.

Instability of environmental, zone, and hybrid factors made it difficult to assess zone delineation. Multiple field sites showed no yield advantage for either hybrid in the zones. Above-average rainfall in both growing seasons contributed to highly productive
growing seasons across all sites. There was little need for a defensive hybrid in most cases. Three field sites should have been planted to an offensive hybrid uniformly from a yield perspective. One field should have been planted to a defensive hybrid uniformly. The rest of the field sites showed no difference in hybrids for each zone or mixed results of relationships between hybrids and zones.

Smooth regression of spatial attributes indicated several attributes showed some influence on treatment yields. No single attribute was best at predicting yield. Elevation, slope, wetness potential, shallow or deep EC and soil series all showed some level of influence in at least one field.

Economics for each field showed that profitability was generally correlated with yield results. For fields with highest yield in the offensive hybrid, the offensive hybrid provided the highest economic return. For fields with no difference in yield, results indicated no difference in profitability of hybrids. This is largely due to similar price per bag of offensive versus defensive hybrid. It is important to consider economics when utilizing multi-hybrid planting. All of the fields showed that a single hybrid could have been planted across the whole field for optimum economic return.

Zone scenario adjustments show promise for correctly positioning zones by post analysis. Zones created with this method were able to distinctly place hybrids into zones. A difference in yield in at least one zone was possible through post processing. These zones correctly could place the offensive hybrid in offensive zone and defensive hybrid in the defensive zone resulting in higher yields by the hybrid assigned to each zone.
Profitability resulted in the offensive hybrid providing the most return in the offensive zone, and the defensive hybrid in the defensive zone for the majority of the fields.

Correct hybrid and zone pairings were difficult to achieve and not stable between years. Even at field sites with ten year of historical yield data, zone structure could not be verified. Additional years of testing of the management zones used in this study are needed to verify zone performance in average or dry years. Based on two years of analysis, multi-hybrid planting would not be economically feasible at these field sites. Analysis would indicate the potential for yield and economic success based on simulated zones. Better or revised zone delineation is necessary to accommodate the implementation of a multi-hybrid planter. Use of this technology in a more consistently dry environment may show more benefit. Based on this study, many more years of yield analysis are needed to truly determine performance and validity of a zone layout for multi-hybrid planting of corn.
2.6 References


Koch, B., Khosla, R., 2003. The Role of Precision Agriculture in Crop Production. J. Crop Prod. 9, 361–381. https://doi.org/10.1300/J144v09n01_02


CHAPTER 3  : Spatial Analysis and Zone Delineation for Fluopyram Use on Soybean Seed via Multi-hybrid Planting for Management of Sudden Death Syndrome
3.1 Introduction and Literature Review: Soybeans

3.1.1 Potential Uses of Multi-hybrid Planting for Soybeans

Multiple applications can be considered for the use of multi-hybrid planting in soybeans. Two varieties can be selected for contrasting genetic traits such as standability, height, canopy width, or maturity date. Varieties could be planted as a pair with one to tolerate iron chlorosis deficiency and one as a higher yielding alternative. Similarly, varieties with more resistant traits to soil borne diseases, such as sudden death syndrome could be selected and placed in portions of the field where sudden death syndrome is present. For the purpose of this research, a single variety was considered, coupled with two contrasting seed treatments for SDS. The term multi-hybrid planting is still often used for this type of application, even though the practice actually represents a multi-treatment or multi-management planting. All of these terms are used interchangeably in this chapter.

3.1.2 Sudden Death Syndrome

Sudden Death Syndrome (SDS) in soybeans (Glycine max) is a soil borne disease caused by Fusarium virguliforme (Aoki et al., 2003). This fungus can overwinter in the soil and residue in survival structures called chlamydospores that can withstand freezing temperature. Infection occurs early in the spring, sometimes days after germination. Cool, wet growing seasons favor the development of SDS (Giesler and Broderick, 2014). Overall, development is favored in high yielding fields and irrigated conditions, as well as soils consisting of higher sand content, lower pH, and higher phosphorus levels.
SDS was first found in Arkansas in 1971 and in Nebraska in 2004 and can be transported among fields on agricultural equipment or residue. This movement results in the gradual infection of field sites. Yield reduction from SDS can be minimal, or result in total yield loss, depending on infection of field site and severity of disease during the growing season.

3.1.2.1 Symptoms

Foliar symptoms do not appear on soybean plants until pod fill. Toxins produced by the fungus are translocated to the foliage of the plant, where damage occurs. Initially, chlorotic spots begin to appear and then merge to become unified within the veins. Subsequently, these areas become necrotic as the disease develops. While obvious symptoms appear in the foliage, the fungus itself does not move more than a few inches from the crown of the plant (Giesler and Broderick, 2014). Defoliation may occur, however petioles are retained.

Roots also display symptoms of the fungus, characterized by rotting on the tap root. This is often undistinguishable from other diseases affecting the root system. The fungus can be visible as cobalt blue growths on the root system in high moisture soil conditions of highly infected plants. While similar looking to brown stem rot, SDS retains white pith, and browning of the stem and vascular tissues is contained to the outer stem layers, however not visible from the outside (Mueller et al., 2016). As the disease progresses, symptoms may affect the pods. Pods may abort or pod fill may be reduced.
3.1.2.2 Management

Since SDS is soil borne, it occurs in the same place year after year, only moving if the infected soil is moved. Because the disease is consistent in location, and cannot be eradicated, site-specific management is possible. Consequently, a management strategy should be developed to deal with the effects of the disease. SDS resistant varieties should be selected for the field. While no varieties are completely resistant, planting a variety with as much resistance as possible is crucial. Planting should be delayed at infested field sites, as early planting encourages SDS development (Navi, 2008). Crop rotation can be implemented, however spores can last many years and this may not significantly reduce infection. Care should be taken in selecting crops for rotation as many legumes are host crops. SDS levels can increase with poor drainage and compacted areas. Tillage can help reduce levels by reducing compaction and warming the soils quicker in the spring (Mueller et al., 2016).

3.1.3 Soybean Cyst Nematode

Soybean Cyst Nematode (SCN) is correlated with SDS pressures. Fields with SCN do not necessarily have SDS, and vice versa. However, fields that have SCN may suffer from worse pressures of SDS than fields without SCN (Xing and Westphal, 2006). Root injury from SCN creates an entry point for SDS infection. Because of this, it is important to consider the life cycle and management of SCN in conjunction with SDS.

Soybean Cyst Nematode (*Heterodera glycines*) was first identified in Japan nearly 75 years ago. It first appeared in the United States in 1954, and in Nebraska in the 1980s.
Since then, SCN has been identified in 58 counties in Nebraska and costs Nebraska producers around $40 million dollars in lost yield (Wilson and Giesler, 2017).

3.1.3.1 Life Cycle

SCN lifecycles last around 24-30 days. In the spring, as moisture and temperature levels increase, nematode eggs hatch and these young will seek plant roots to infect. After infected, the juvenile will move through the vascular tissue secreting enzymes to make feeding sites. At these feeding sites, the nematode continues to grow until the females rupture the root tissue. At this point, the females will be fertilized, and eggs will fill their body cavity, referred to as cysts (Chen, 2012). Eventually these bodies will be free in the soil where they will continue their lifecycle. In some instances, this may not take place for years, as the eggs can survive within the cysts and remain dormant.

3.1.3.2 Symptoms

SCN detection in soybeans can be difficult to distinguish. An initial symptom is lower than expected yields. Visual symptoms include smaller statured plants, a non-descript chlorosis, or plant death. Areas of severe infection may show up in oval or elliptical shapes throughout the field (Giesler and Wilson, 2011). These symptoms appear similar to what would be experienced with compaction, deficiencies, water extremes, (both drought and water saturated soils), disease or plant herbicide injury. Nodulation on root symptoms may be reduced in infected soils. Additionally, the female cyst bodies may be visible on the root system. Close inspection can distinguish cyst bodies from nodulation. Soil sampling is required to confirm the presence and population of SCN in the soil.
3.1.3.3 Management

SCN cannot be eradicated from a field. Populations can be reduced, but not eliminated. Movement of soil on equipment, tires, or shoes is discouraged, as this can move SCN to an non-infested field. Without assistance, SCN can only move a few inches per year.

Selection of varieties is very important for management. Four items should be considered when selecting varieties. The yield level and resistance of the cultivar should be known. Additionally, the population levels and specific race profiles should also be known (Niblack, 2005). Varieties should be selected for the field with some level of SCN resistance. This resistance is often dependent on race of SCN, so determination of SCN type is necessary and specific race resistance should be selected. Resistance sources should be rotated as to not encourage resistance to these genes. Multiple genes should be included each year, or rotated from year to year to ensure long term effectiveness of resistant varieties (Giesler and Wilson, 2011). This is becoming more challenging as resistance to these traits is increasing in SCN populations. Crop rotations can also be implemented as a management strategy. Rotation to a non-host crop can reduce the number of SCN eggs in a field. Diligent weed management is also recommended as many common winter and summer annuals are host crops for SCN. It is critical that a variety with SCN resistance is planted each year soybeans are grown. Planting a susceptible variety even one year in a six year rotation can result in SCN populations higher at the end of year six than at the beginning of year one and negate all other practices done to reduce population numbers (Giesler and Wilson, 2011).
3.1.4 ILeVO®

ILeVO® is a product from Bayer Crop Science (Bayer AG, Leverkusen, Germany) released in 2012. The active ingredient, fluopyram, shows promise in reducing infection from SDS and impacts of SCN. ILeVO® is a seed-applied fungicide that reduces early season infection. Two different rates are given on label, a “half rate” labeled for SCN and a “full rate” labeled for SDS. The product is said to provide plants with an overall improvement in the growth and health of plants, even when no SDS is present. Research studies conducted by DuPont Pioneer across 91 locations tested the efficacy of ILeVO® for both SDS and SCN control. Across all field sites, the ILeVO® treatment resulted in a 0.13 Mg ha⁻¹ advantage over a base treatment of fungicide and insecticide. In high SDS and SCN field sites, the ILeVO® treatment gave a 0.4 Mg per hectare advantage over the base treatment of fungicide and insecticide (O’Bryan and Burnison, 2015). A study conducted at Iowa State University showed that while ILeVO® did not affect the severity of foliar symptoms of SDS, it did reduce the incidence of root rot (Zaworski, 2014). A study conducted in the Kansas River Valley indicated that more susceptible varieties of soybeans showed a greater response to the ILeVO® seed treatment (Adee, 2016). The Nebraska On-Farm Research Network also conducted three field studies to evaluate ILeVO®. Two of the sites had moderate levels of SDS and reported a 0.19 to 0.25 Mg per hectare increase. The third site had low disease ratings and SCN populations and did not have a yield response from the ILeVO® treatment. (Arneson et al., 2016) These studies indicate there is a positive yield response for using ILeVO®. However, price per hectare of ILeVO® is around $37 per hectare and it may be difficult
to justify the additional cost of production. In fields where SDS is spotty or in patches across the field, it can be difficult to determine at what field incidence and what percentage of the total field is affected to use ILeVO® and justify the additional expenses. While ILeVO® may increase yield, it is not a given that that yield will cover the overall cost of the product across a whole field.

3.1.5 Rationale for Using Multi-hybrid on SDS

For this reason, the ability to site specifically apply ILeVO® to portions of the field affected by SDS is beneficial. By applying only in portions of the field that need it, input costs are reduced compared to treating the whole field. Additionally, yield in the SDS and SCN affected areas are increased. This opportunity is a perfect scenario for multi-hybrid or multi-management planting. Not only is variability present within the field, but the distribution of infested zones is typically fixed from year to year. Additionally, even with changes in environmental conditions, in fields with severe SDS, the results from using a seed treatment could be fairly predictable. Conversely, in fields with lower levels of SDS, environmental conditions may have more impact on the result of ILeVO®.

3.2 Goals and Objectives

Objectives for the soybean sites include correct delineation of zones, separating portions of the field with SDS and those without. Specific objectives were to: 1) assess yield of a standard base fungicide and ILeVO® seed treatments by zone delineation and verify zone structure 2) evaluate treatment performance against supplemental field attributes to determine layers with correlation to treatment performance 3) restructure zones based on highest yielding treatment of paired strips to determine appropriate prescription maps
highlighting areas of the field with yield inhibiting levels of SDS and 4) determine if the multi-hybrid planter approach would be profitable based on yield results.

3.3 Materials and Methods

3.3.1 Site Description and Crop Management

Five field sites were used in the study, two in the 2016 growing season and three in the 2017 growing season. Field sites were located in two eastern Nebraska Counties, Seward and Saunders, and were used in partnership with local farmers. Fields ranged from 10.5 to 58 hectares and were under a traditional corn-soybean, or corn-corn-soybean rotation. Fields in Saunders County had rolling topography with 10 meters of relief. Fields in Seward County had 1 meter of relief and were located along the Little Blue River and frequently flooded. Fields were located across eight different soil types. Dominant soil types included Tomek silt loam, Yutan silty clay loam, and Muir silt loam, comprising 76.5 percent of the soils collectively. The Tomek soils—comprising 29 percent of the study area—are formed in loess and consist of very deep, well drained soils located on stream terraces with slopes ranging from 0-2 percent. Tomek soils are a mollisol with a very deep epipedon up to 127 centimeters. The Yutan soils—comprising 26 percent of the study area—are formed in loess deposits and consist of very deep, well drained soils in the upland position with slopes ranging from 2-17 percent. While originally classified as a mollisol, due to severe erosion, the surface soil no longer has the depth or color requirements for that classification and is now classified as an alfisol. The Muir soils—comprising 22 percent of the study area—are formed in alluvium and consist of very deep, well drained soils on stream terraces and risers with slopes ranging from 0 to 7 percent. Muir soils have a fairly deep mollic epipedon ranging up to 91 centimeters
and consisting of the Ap, A and Bw1 horizons. Other soils in the study location are geographically associated with the three major soil series. Hobbs silt loam is located at a lower landform and has a thinner surface epipedon. Filbert, Fillmore and Pohocco are all geographically associated with Tomek and Yutan Soils.

Study fields have typically been under a corn-soybean rotation. Fertilizer, irrigation, pest, and disease control management varied by field and producer. Each field had historical levels of Sudden Death Syndrome. Presence of soybean cyst nematode varied amongst fields. Growing season rainfall estimates for each field for the past thirty

Table 3.1: Soybean field sizes, locations, irrigation status, and soil series

<table>
<thead>
<tr>
<th>Field</th>
<th>Year</th>
<th>Area (Hectares)</th>
<th>Location</th>
<th>Crop Rotation</th>
<th>Irrigation Status</th>
<th>Soil Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>2016</td>
<td>10.59063</td>
<td>41.389954, -96.810319</td>
<td>Corn-Soybean</td>
<td>Irrigated</td>
<td>Nodaway silt loam Yutan, eroded-Judson complex</td>
</tr>
<tr>
<td>PM</td>
<td>2016</td>
<td>21.61428</td>
<td>40.927293, -97.123881</td>
<td>Corn-Soybean</td>
<td>Irrigated</td>
<td>Hobbs silt loam Muir silt loam Muir silt loam</td>
</tr>
<tr>
<td>WH</td>
<td>2017</td>
<td>32.66221</td>
<td>41.354436, -96.709986</td>
<td>Corn-Corn-Soybean</td>
<td>Irrigated</td>
<td>Nodaway silt loam Tomek silt loam Yutan silt loam Yutan, eroded-Aksarben Yutan, eroded-Judson complex</td>
</tr>
<tr>
<td>NB</td>
<td>2017</td>
<td>58.13719</td>
<td>41.289260, -96.527340</td>
<td>Corn-Soybean</td>
<td>Irrigated</td>
<td>Filbert silt loam Fillmore silt loam Judson silt loam Pohocco-Pahuk complex Tomek silt loam Yutan silt loam Yutan silt loam Yutan, eroded-Judson complex</td>
</tr>
<tr>
<td>KE</td>
<td>2017</td>
<td>38.01216</td>
<td>41.215477, -96.466400</td>
<td>Corn-Soybean</td>
<td>Irrigated</td>
<td>Filbert silt loam Fillmore silt loam Nodaway silt loam Pohocco silty clay loam Tomek silt loam Yutan silt loam Yutan silt loam Yutan silt loam Yutan silt loam Yutan, eroded-Judson complex</td>
</tr>
</tbody>
</table>

Growing season rainfall estimates for each field for the past thirty years.
years, as well as growing season rainfall for 2016 and 2017 are found in Figure 7.1 through Figure 7.4. Thirty year averages and growing season rainfall were recorded from the High Plains Regional Climate Center (Lincoln, NE). Further details on crop rotation, irrigation status, size, location and soil types can be found in Table 3.1.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>30 year growing season Averages (cm)</th>
<th>2016 Growing Season Rainfall (cm)</th>
<th>2017 Growing Season Rainfall (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>50.17</td>
<td>70.08</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>46.91</td>
<td>51.18</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Field Name</th>
<th>30 year growing season Averages (cm)</th>
<th>2017 Growing Season Rainfall (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH</td>
<td>50.17</td>
<td>52.12</td>
</tr>
<tr>
<td>NB</td>
<td>52.53</td>
<td>54.13</td>
</tr>
<tr>
<td>KE</td>
<td>48.69</td>
<td>59.77</td>
</tr>
</tbody>
</table>

3.3.2 Planter Setup
A Kinze 4900 Multi-Hybrid planter was used for the duration of the study. The 4900 model is a sixteen row, pull type, front fold planter. Seed is stored in two 1,560 cubic meter bulk tanks mounted at the back of the planter. Weight is distributed across the frame by a hydraulic weight transfer mechanism. Bulk tank pressure was set to 2488 pascals to ensure proper seed movement. Two identical vacuum seed meters were situated back to back in a single row unit to accommodate both hybrids. The rear meter was fed by the left bulk tank and the front meter was fed by the right bulk tank. Each of these seed meters were run by electric drives. This allowed for a very precise transition between the two seed meters and consequently the two separate hybrids. Vacuum pressure was set to 4479 pascals. Stock Kinze trash wheels were set to intersect rather
than offset. Trash wheel depth was adjusted for each field based on residue type, amount, and moisture conditions. A standard row unit assembly was maintained: a set of double disc openers with inner scraper, and two rubber gauge wheels enclosing the seed tube and seed tube sensor. In 2017, Keeton seed firmers with Mojo pressure wires were added. In 2016, two rubber closing wheels followed to close the slot. In 2017, one side was switched to a Copperhead Ag Furrow Cruiser spiked closing wheel to reduce sidewall compaction. Depth of closing wheels was adjusted according to field conditions. Depths of gauge wheels were adjusted based on producer preference and field conditions. Downforce was controlled by a pneumatic system. Pressure was adjusted based on field conditions. Talc and graphite were used to aid in seed movement as needed.

![Image](image_url)

**Figure 3.1**: Row unit configuration on Kinze 4900 Multi-Hybrid Planter showing trash wheels, double disc openers, trash wheels, Keeton seed firmers, and closing wheels.

### 3.3.3 Management Zone Delineation

Several clustering options are available for management zone creation. While many of these options are defensible and produce appropriate management zones,
Management Zone Analyst (MZA) from the University of Missouri was selected both for its robustness and its adaptability to on-farm research. This program allowed for integration of multiple data layers and provided the user guidelines on zone selection. MZA was also something that producers could potentially utilize themselves and did not require expensive software to complete. This kept the study within the constraints of an On Farm Research project. While this program could be used by a producer, several additional steps were included to increase precision of zones and fine tune the prescription maps. Rather than utilizing spatial components of each field such as soil type, EC, or wetness potential, only historical yield was used. The desired feature to cluster was Sudden Death Syndrome—by only using yield maps, this helped ensure that clusters most closely represented low yielding areas due to SDS. Zones were created to match the distribution of SDS in the field for use of ILeVO®.

### 3.3.3.1 Grid Preparation in SMS

When utilizing multiple data layers, individually collected data points were not aligned in a way to processes this data together. Data layers were exported from Ag Leader SMS on a common grid aligned with a set field boundary. The grid size was set to three meters by three meters. Three by three meter grids were selected as the smallest size in order to maintain the density and precision represented while still correctly representing less dense data sets. This allowed for precision in delineating management zones.
3.3.3.2 Processing Data in ArcMap

The individual spatial files set to a common grid were uploaded to ArcMap (Version 10.4.1, ESRI, Redlands, CA). Data were projected to a common coordinate system: North American Datum 83. Data were then exported as a comma separated value file and combined into one document for processing in MZA (Version 1.0.1, University of Missouri, Columbia, MO).

3.3.3.3 Management Zone Analyst

The combined comma separated value document was loaded in to Management Zone Analyst (MZA). Individual files were added to the selected layers menu. MZA provides the option to compute statistics and provides the number of observations, number of variables, mean, standard deviation, coefficient of variation, minimum and maximum values, sums of squares, variance covariance matrix, and a correlation matrix. These statistics assist the user in deciding which data layers to include in clustering and provide guidelines for which measure of similarity should be selected to delineate zones. Several adjustments can be made before zones are delineated. Three measures of similarities can be selected: Euclidean, diagonal, and Mahalanobis. Euclidean or diagonal were chosen as the measure of similarity as the variables were assumed to have covariances equal to zero. The fuzziness exponent was kept at 1.3 for all iterations run. The measure of similarity used for each field can be found in Table 3.4. The number of iterations and convergence criterion were also adjustable but were kept at the default values of 300 iterations and a convergence of 0.0001. The minimum and maximum zones were two and six. The correct number of zones were based on the fuzziness performance.
index and the normalized classification entropy. Number of zones were selected when FPI and NCE were at a minimum.

Table 3.4: Measure of similarity used in Management Zone Analyst for Clustering soybean data layers.

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Year</th>
<th>Measure of Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>2016</td>
<td>Euclidean</td>
</tr>
<tr>
<td>PM</td>
<td>2016</td>
<td>Euclidean</td>
</tr>
<tr>
<td>WH</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
<tr>
<td>NB</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
<tr>
<td>KE</td>
<td>2017</td>
<td>Euclidean</td>
</tr>
</tbody>
</table>

3.3.3.4 Prescription Map Processing

After the appropriate number of zones were selected, cluster points were imported back into Arc Map. These points were merged with the original grid layout. Outliers and erroneous data points were removed and then the grids were dissolved into polygons. Polygon edges were smoothed and finalized. Zone maps were then imported to SMS. Hybrid and population treatments were assigned to each zone. If more than two zones were ideal, zones with the same treatment were combined into one zone. Check strips were placed throughout each zone in line with past harvest data to ensure check strips matched header widths. After rates and treatments were assigned to each zone and strip, the prescription map was exported as a shape file to be used in the Raven Envisio Pro monitor.
### 3.3.4 Variety and Treatment Selection

Varieties were selected in cooperation with producers, seed dealers and agronomic consultants. Varieties were selected to have a high genetic level of resistance to SDS and SCN. Base level seed treatments were picked out by the producer and varied among fields. The ILeVO® treatment was the base treatment with the addition of ILeVO® at a rate of 34.9 mL/140,000 seed unit. The ILeVO® treatment was assigned to the zones of the field corresponding with historical levels of sudden death syndrome. The standard treatment was assigned to the other zones of the field. Varieties selected for each field, resistance rankings, and treatments are listed in Table 3.5.

<table>
<thead>
<tr>
<th>Field</th>
<th>Variety</th>
<th>SDS Resistance Rankings</th>
<th>SCN Resistance Ranking</th>
<th>Standard Treatment</th>
<th>ILeVO® Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>P31T11R</td>
<td>7 Race 3: 9, Race 14: 8</td>
<td>Evergol Energy (14.8 mL/unit), Gauch (23.7 mL /unit), PPST2030 (29.6 mL/unit), Allegiance (8.3 mL/unit), PPST120+ (29.6 mL/unit)</td>
<td>34.9 mL/unit</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>P31T11R</td>
<td>7 Race 3: 9, Race 14: 8</td>
<td>Evergol Engery SB, Allegience-FL, Gaacho 600 Flowable</td>
<td>34.9 mL/unit</td>
<td></td>
</tr>
<tr>
<td>WH</td>
<td>P31T11R</td>
<td>7 Race 3: 9, Race 14: 8</td>
<td>Evergol Energy (14.8 mL /unit), Gauch (23.7 mL/unit), PPST2030 (29.6 mL/unit), Allegiance (8.3 mL/unit), PPST120+ (29.6 mL/unit)</td>
<td>34.9 mL/unit</td>
<td></td>
</tr>
<tr>
<td>NB</td>
<td>NK34-P7</td>
<td>8 Race 3, Race 14</td>
<td>CruizerMax</td>
<td>34.9 mL/unit</td>
<td></td>
</tr>
<tr>
<td>KE</td>
<td>P31T11</td>
<td>7 Race 3: 9, Race 14: 8</td>
<td>PPST2030</td>
<td>34.9 mL/unit</td>
<td></td>
</tr>
</tbody>
</table>
3.3.5 ILeVO®

The ILeVO® product treatment showing mode of application, product use, active ingredients, and EPA regulation can be found in Figure 3.2. The ILeVO product cost $0.34/mL or $10.19/oz. This is equivalent to around $37.49/hectare.

Figure 3.2: ILeVO® product label and active ingredients

3.3.6 Planting Factors

Fields were planted in order of producer preference as well as proximity to other field locations. Issues arose at several locations, some of which do not affect the overall results.

Site PM was flooded shortly before planting. Some tillage occurred in approximately half of this field to remove residue that had been deposited. Because of the flood, site PM had a very late planting date.

Site KE was tilled the previous fall and had very dry planting conditions resulting in poor emergence. Several irrigation passes were required to get an adequate stand established.
During the planting of site NB, issues arose with maintaining vacuum pressure. Several adjustments were made, however, vacuum pressure drifted as low as 8 inches of water. The correct seeding rate was still maintained even with this lower vacuum pressure.

Site WH was tilled several passes before planting. Two passes were planted across the entire field to achieve 15 inch row spacing. Consequently, a half rate of 197,531 ksd per hectare was planted each pass across the field in order to reach the target population of 395,062 ksd per hectare.

Planting dates, populations, and adjustable planter settings are shown in Table 3.6. Distribution and location of fields is show in Figure 3.3.

![Figure 3.3: Soybean Field locations, 2016 and 2017. 2016 field sites denoted in blue, 2017 field sites denoted in orange.](image-url)
Table 3.6: Planter settings for soybean fields, 2016 and 2017

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Planting Date</th>
<th>Planter Population Setting (ksds/ha)</th>
<th>Depth (cm)</th>
<th>Gauge Wheel Setting (notches)</th>
<th>Trash Wheels (notches)</th>
<th>Unit Pressure (N)</th>
<th>Closing Wheel (notches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>5/15/16</td>
<td>407.4</td>
<td>3.8</td>
<td>4/3</td>
<td>2</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>PM</td>
<td>6/7/16</td>
<td>407.4</td>
<td>3.8</td>
<td>3/3</td>
<td>1</td>
<td>66.75</td>
<td>2</td>
</tr>
<tr>
<td>WH</td>
<td>4/23/17</td>
<td>395.1</td>
<td>4.45</td>
<td>3/3</td>
<td>8</td>
<td>75.62</td>
<td>2</td>
</tr>
<tr>
<td>NB</td>
<td>5/15/17</td>
<td>345.7</td>
<td>3.8</td>
<td>3/2</td>
<td>1</td>
<td>889.64</td>
<td>3</td>
</tr>
<tr>
<td>KE</td>
<td>5/16/17</td>
<td>345.7</td>
<td>3.8</td>
<td>3/2</td>
<td>8</td>
<td>889.64</td>
<td>4</td>
</tr>
</tbody>
</table>

3.3.7 Data Collection

3.3.7.1 Soybean Cyst Nematode

Soil samples were pulled to test for population density of SCN. Soybean cyst populations are found in Table 3.7 and maps of distribution of SCN can be found in Figure 7.15 through Figure 7.17. SCN levels ranged from 0 eggs/100 cc of soil to a maximum of 580 eggs/100 cc soil, which were considered low levels. In 2016, site WM tested positive for SCN, with one sample in the SDS zone with a population of 40 eggs/100 cc soil. The other field in the 2016 growing season, site PM, did not test positive for SCN. Fields planted in the 2017 growing season all tested positive for some level of SCN. Site WH, had the lowest levels of 40 eggs/100 cc soil. Consequently, subfield samples were not analyzed due to low levels. Site NB had higher levels, with values ranging from 0-80 eggs/100 cc soil. All the samples that tested positive at this field site were contained within the SDS zone. Finally, site KE had the highest levels of the 2017 growing season, with levels as high as 580 eggs/100 cc soil. Interestingly, at this field site, the average SCN population in the SDS zone was lower than the standard zone, with populations averaging 133 versus 510 respectively.
Table 3.7: Soybean Cyst Nematode populations by field and zone

<table>
<thead>
<tr>
<th>Field</th>
<th>Sample Average (eggs/100 cc soil)</th>
<th>SDS Zone Average (eggs/100 cc soil)</th>
<th>Standard Zone Average (eggs/100 cc soil)</th>
<th>Number of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>13</td>
<td>40</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>PM</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>WH</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>6</td>
</tr>
<tr>
<td>KE</td>
<td>284</td>
<td>133</td>
<td>510</td>
<td>5</td>
</tr>
<tr>
<td>NB</td>
<td>26</td>
<td>40</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

3.3.7.2 Aerial Imagery Collection

Aerial imagery was collected in season for each location. Imagery was collected after identification of SDS to determine the largest amount of variation between treatments but before overall senescence of the field. Imagery in 2016 was collected by an aircraft flying at an elevation of 1,829 meters. This was equipped with a UltraCamLp Photogrammetric Digital Aerial camera (Vexcel Imaging GmbH, Graz, Austria) mounted in the nadir position of the aircraft. The images collected were geo referenced and orthorectified. Four bands were collected: red, green, blue and near infrared. Resolution was around 15.2 cm GSD.

Imagery in 2017 was collected by drone. Fields were flown with an Ag eBee senseFly (Parrot, Paris, France) equipped with a MicaSense Parrot Sequoia camera. The bands collected were red, green, blue, and red edge (550, 660, 735, 790 nm). Fields were flown early to mid September.

RGB imagery can be found in Figure 7.18 through Figure 7.22. NDVI imagery is in Figure 7.23 through Figure 7.28. NDRE imagery is in Figure 7.28 through Figure 7.30.
3.3.7.3 Disease Ratings Collection

Disease ratings were collected for each check strip in each study field. Disease ratings were calculated using the SICU method of SDS scoring (Schmidt, 2007). Disease ratings were measured as closely to R6 as possible but before plants have begun to senesce. The disease index was calculated as the product of the disease incidence and disease severity divided by nine. The disease index ranges from zero, no disease, to 100, all plants prematurely dead. Disease incidence is calculated as the percentage of plants with visible leaf symptoms and are recorded in increments of five. Disease severity is calculated as the severity of SDS on leaf surfaces of plants showing symptoms and is scored in increments of 0.5 ranging from 1-9. A score of one indicates when between one and ten percent of the leaf surface is chlorotic or one to five percent is necrotic. A score of six corresponds to 1/3 defoliation from premature leaf drop. A rating of nine is premature death of the plant. All ratings in between are increasing levels of severity between the benchmarks listed. Disease ratings were calculated two times throughout the 2016 growing season and once during the 2017. Data collected in 2016 did not contain all necessary check strips and consequently cannot be statistically analyzed, but will be provided in the results to demonstrate trends in disease levels.

3.3.7.4 Yield Data collection

Harvest dates varied by crop maturity date, moisture content and weather events. Each field was harvested by the individual producers combine. Yield monitors were calibrated on each machine before the field was harvested. All were impact plate systems. Harvest dates and moisture are in Table 3.8. All fields were completed in one day. Data
were removed from yield monitors directly after harvest. Data were imported to Ag Leader SMS for storage and analysis. Harvest maps can be found in Figure 7.35 through Figure 7.39.

Table 3.8: Soybean field harvest dates for 2016 and 2017

<table>
<thead>
<tr>
<th>Field</th>
<th>Date</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>13-Oct</td>
<td>2016</td>
</tr>
<tr>
<td>PM</td>
<td>21-Oct</td>
<td>2016</td>
</tr>
<tr>
<td>WH</td>
<td>12-Oct</td>
<td>2017</td>
</tr>
<tr>
<td>NB</td>
<td>18-Oct</td>
<td>2017</td>
</tr>
<tr>
<td>KE</td>
<td>17-Oct</td>
<td>2017</td>
</tr>
</tbody>
</table>

3.3.7.5 Statistics on Supplemental Attributes by Zone
Descriptive statistics are presented in Table 3.9 for the independent variables used in the regression analysis presented in 3.4.6 Error! Reference source not found.. These data points were extracted by harvest point location from spatially interpolated layers. Attributes available for comparison varied by field location. Only one site had phosphorus available for analysis, similarly, only one location had EC data collected.
Table 3.9: Descriptive statistics on independent variables used in regression analysis

<table>
<thead>
<tr>
<th></th>
<th>Elevation (m)</th>
<th>Slope Grade</th>
<th>Shallow EC (dS/m)</th>
<th>Deep EC (dS/m)</th>
<th>Wetness Potential</th>
<th>Phosphorus (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>417.40</td>
<td>0.0021</td>
<td>-</td>
<td>-</td>
<td>4.07</td>
<td>-</td>
</tr>
<tr>
<td>Median</td>
<td>421.90</td>
<td>0.0469</td>
<td>-</td>
<td>-</td>
<td>7.09</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>422.80</td>
<td>0.0577</td>
<td>-</td>
<td>-</td>
<td>7.40</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>431.80</td>
<td>0.1857</td>
<td>-</td>
<td>-</td>
<td>14.86</td>
<td>-</td>
</tr>
<tr>
<td><strong>PM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>441.30</td>
<td>0.0005</td>
<td>-</td>
<td>-</td>
<td>4.70</td>
<td>9.56</td>
</tr>
<tr>
<td>Median</td>
<td>442.20</td>
<td>0.0060</td>
<td>-</td>
<td>-</td>
<td>8.34</td>
<td>26.78</td>
</tr>
<tr>
<td>Mean</td>
<td>442.20</td>
<td>0.0081</td>
<td>-</td>
<td>-</td>
<td>8.60</td>
<td>26.12</td>
</tr>
<tr>
<td>Max</td>
<td>442.70</td>
<td>0.0770</td>
<td>-</td>
<td>-</td>
<td>14.91</td>
<td>45.53</td>
</tr>
<tr>
<td><strong>WH</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>391.80</td>
<td>0.0011</td>
<td>-</td>
<td>-</td>
<td>4.28</td>
<td>-</td>
</tr>
<tr>
<td>Median</td>
<td>395.40</td>
<td>0.0211</td>
<td>-</td>
<td>-</td>
<td>7.55</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>395.30</td>
<td>0.0288</td>
<td>-</td>
<td>-</td>
<td>7.82</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>403.70</td>
<td>0.1883</td>
<td>-</td>
<td>-</td>
<td>14.99</td>
<td>-</td>
</tr>
<tr>
<td><strong>NB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>379.10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Median</td>
<td>380.60</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>380.60</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>385.30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>KE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>359.40</td>
<td>0.0011</td>
<td>18.24</td>
<td>34.83</td>
<td>4.72</td>
<td>-</td>
</tr>
<tr>
<td>Median</td>
<td>364.20</td>
<td>0.0210</td>
<td>32.48</td>
<td>49.19</td>
<td>8.01</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>364.10</td>
<td>0.0236</td>
<td>33.77</td>
<td>50.34</td>
<td>8.93</td>
<td>-</td>
</tr>
<tr>
<td>Max</td>
<td>368.10</td>
<td>0.1359</td>
<td>62.13</td>
<td>79.74</td>
<td>15.85</td>
<td>-</td>
</tr>
</tbody>
</table>

3.3.8 Data Analysis Method

3.3.8.1 Yield Data Processing

Data were processed in Ag Leader SMS and subsequently cleaned in Yield Editor to remove erroneous data points. Low yielding, high yielding, narrow swath widths, abrupt velocity changes, and data points outside a set standard deviation were removed. Filters used for each field varied, however, the combination used maintained the ultimate
goal of reducing the overall coefficient of variation for the fields. Fields were also corrected for moisture to 13%. This was important as the two treatments may have had differing moisture at harvest time. This correction helped account for that variation and allow the treatments to be compared. Clean data points were then imported back into Ag Leader SMS and ArcMap. Yield in each check strip was recorded. Near the edges of the check strip, some of the outer rows of that harvest pass may be the zone treatment and not the check strip treatment. Only harvest passes with a whole header width of the check strip treatment were analyzed. Strips adjacent to the check strip were assessed for yield. These adjacent strips were then compared using the MIXED procedure in SAS 9.4 (SAS Institute Inc., Cary, NC). Mean separation was performed with Fisher’s LSD. A macro, PDMIX800 was used for mean separation output letter groupings (Saxton, n.d.). This gave a basis for significance within each management zone. Significance was determined at a 95% confidence interval. Strips were also compared using the GLIMMIX procedure in SAS for interactions within zones.

3.3.8.2 Aerial Imagery Processing

Aerial imagery was processed in ArcMap. NDVI and NDRE were calculated for all fields when possible. NDRE could not be calculated for the 2016 aerial imagery due to the limited bands collected by the camera, thus only NDVI was calculated. Both NDVI and NDRE were calculated for the 2017 fields. NDVI was selected due to its popularity and robustness as a vegetative index. However, for the time frame that the images were collected, NDVI tends to be over saturated and differentiation between treatments is often difficult to see. As green leaf area index increases, NDVI tends to be over saturated and
differentiation between treatments is often difficult to see (Nguy-Robertson et al., 2012). For this reason, NDRE was also used. Differences between the hybrids were often more detectible, because NDRE was not saturated at this point.

To remove the influence shadows and soil had on the overall calculations, image cleaning was completed to remove this potential error. Pixels were sorted by unsupervised classification. Pixels corresponding with soil, shadows, tree rows, or field roads were removed from the images, leaving only the pixels corresponding with the plants. This cleaning allows for a more accurate comparison between adjacent strips of differing treatments.

After indices were calculated and the influence of soil removed, check and adjacent strips were isolated from the zones as a whole. Averages of the NDVI or NDRE values were recorded for each strip. These values were then compared using the GLIMMIX procedure in SAS 9.4 (SAS Institute Inc., Cary, NC). Mean separation was performed with Fisher’s LSD. This gave a basis for significance within each management zone. Significance was determined at a 95% confidence interval. Data was analyzed by treatment within each zone separately.

### 3.3.8.3 Field Variable Regression Analysis

Soil and terrain attributes were aggregated for each field. Data was interpolated by kriging method for electrical conductivity. Terrain attributes were calculated with Ag Leader SMS. The calculated attributes were plotted on a grid scale determined by SMS. These layers were then sampled by point location of the yield file to associate yield, electrical conductivity, elevation, slope, wetness potential, as well as treatment and zone
attributes. This data was then processed in R (R Core Team, 2013) using a smooth regression in the ggplot package (Wickham, 2009). Example code can be found in 7.10.1.

3.3.8.4 Scenario Zone Delineation

Zone scenario maps representing the optimum placement of hybrids during the given growing season was desired. To achieve this, yield results from each field were analyzed for differences in paired strips. Of the paired strips, the lower yielding treatment was excluded from analysis. The remaining higher yielding treatments were then used for analysis. These check strips were interpolated by kriging to create a surface of highest yielding treatments spatially. This surface was then converted to a polygon and zone lines smoothed and simplified by merging transition zones and clipping to field boundaries.

These results were then analyzed to determine significance within the restructured zones. If restructuring resulted in at least one zone with significant differences between treatments, the alternative zone map is presented in Figure 7.70 through Figure 7.72. Zone scenario was not completed for site NB, as the zones planted appeared to be optimum for effectiveness at treating ILeVO®.

3.4 Results and Discussion

3.4.1 As Applied Planting Data

As applied planting maps can be found in in Figure 7.10 through Figure 7.14. Table 3.10 shows the distribution of population from the raw as applied maps, as well as the number of polygons contained in each map. Across all fields, the minimum value recorded was zero. The maximum value recorded was 2,456,790 seeds per hectare. This is assumed to be an artifact of the controller and not an actual planted rate. Error rates
ranged from 1.36% to 14.65% between target and actual rate planted. The actual rate was always lower than the target; some of this error was likely an artifact of the system. As discussed with the manufacturer, the controller was not designed for soybean seeding and consequently cannot accurately record at such high population rates. Some lag time with the controller feedback loop was noted. The standard deviation amongst fields ranged from 30.40-110.62 ksd per hectare. The highest standard deviation, 110.62, would result in a population for the field falling between 235,802.5 and 456,296.30 seeds per hectare. This range seemed large for the dataset, and indicated a need for cleaning. Total CV also ranged from 16% to 31% suggesting cleaning of erroneous data points would be beneficial. Some other sources of error include averaging across the width of the planter, changes in speed, and ramp up time. Each row on the planter reported an individual population. Table 3.10 values are derived from the average of all of those values. In areas of the field where some of the units were not planting (as clutch rows turned off, overlapping passes, and zero rate areas) the average of all the units was pulled down. Removing these locations would provide a more accurate look at overall distribution of population. Changes in speed also affected the controller response. An abrupt increase in speed may have decreased the population being planted, and similarly, increased the population as the planting speed rapidly decreased. Some of this may just be an artifact recording feedback, but not actually occurring. Some of these locations may be true. As a result, it is hard to eliminate some of those issues from the planting map. Finally, ramp up time may be contributing to variance in populations. As the planter started into a pass, several seconds would pass before the display would settle on the population. It is
surmised that a smaller area than indicated on the maps is actually being affected by this issue. Seed counts showed that the correct seeding rate was being planted very quickly after starting into the pass, even before the controller had settled on a population.

Table 3.10: Raw As Applied Planting Data

<table>
<thead>
<tr>
<th>Field</th>
<th>N</th>
<th>MIN (ksd/ac)</th>
<th>MAX (ksd/ac)</th>
<th>AVG (ksd/ac)</th>
<th>Target (ksd/ac)</th>
<th>Error</th>
<th>STD</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>21160</td>
<td>0</td>
<td>554.7</td>
<td>163</td>
<td>170</td>
<td>4.12%</td>
<td>27.06</td>
<td>17%</td>
</tr>
<tr>
<td>PL</td>
<td>12170</td>
<td>0</td>
<td>766</td>
<td>150.62</td>
<td>155</td>
<td>2.83%</td>
<td>40.48</td>
<td>27%</td>
</tr>
<tr>
<td>WM</td>
<td>6723</td>
<td>0</td>
<td>668.1</td>
<td>140.83</td>
<td>165</td>
<td>14.65%</td>
<td>44.8</td>
<td>31%</td>
</tr>
<tr>
<td>WH</td>
<td>32535</td>
<td>0</td>
<td>629.4</td>
<td>157.82</td>
<td>160</td>
<td>1.36%</td>
<td>12.31</td>
<td>16%</td>
</tr>
<tr>
<td>NB</td>
<td>27832</td>
<td>0</td>
<td>949</td>
<td>131.87</td>
<td>140</td>
<td>5.81%</td>
<td>30.34</td>
<td>23%</td>
</tr>
<tr>
<td>KE</td>
<td>18592</td>
<td>0</td>
<td>995.3</td>
<td>131.36</td>
<td>140</td>
<td>6.17%</td>
<td>31.74</td>
<td>24%</td>
</tr>
</tbody>
</table>

Because of these errors, the planting data was cleaned to get a better representation of the distribution of population planted across each field. Distribution of data after cleaning can be found in Table 3.11. Cleaning removed between 1200 and 3200 data points from files. Minimum population for most fields was around 296,296 seeds per hectare. Maximum values were around 518,518 seeds per acre. The average seeds per acre ranged from 340,740 to 414,814. This brought all the averages substantially closer to the target rate, resulting in seeding rate errors below 3% for all fields and in the most drastic case, reduced error by almost 12%. Standard deviations were all significantly decreased and range from 11,605 to 25,432 seeds per acre. Overall, coefficient of variation was reduced to between 3 and 6%. Based on the new data ranges, it appears cleaning was beneficial in removing outliers and potential error. The majority of minimum values that were deleted occurred as the planter was moving into the headlands and row clutches were shutting off, or on passes where the planter was not completing a
full pass. Maximum values that were deleted were from areas where the planter slowed down abruptly and then increased speed back to normal field travel. Distance covered in these locations was typically less than 18 meters.

**Table 3.11: Cleaned As Applied Planting Data for 2016 and 2017 Soybean Field Sites**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>MIN (ksd/ac)</th>
<th>MAX (ksd/ac)</th>
<th>AVG (ksd/ac)</th>
<th>Target (ksd/ac)</th>
<th>Error</th>
<th>STD</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>19944</td>
<td>121.4</td>
<td>209.9</td>
<td>168.67</td>
<td>170</td>
<td>0.78%</td>
<td>7.94</td>
<td>5%</td>
</tr>
<tr>
<td>PL</td>
<td>10447</td>
<td>126.35</td>
<td>209.87</td>
<td>161.61</td>
<td>165</td>
<td>2.05%</td>
<td>10.3</td>
<td>6%</td>
</tr>
<tr>
<td>WM</td>
<td>5124</td>
<td>130</td>
<td>196.87</td>
<td>160.33</td>
<td>165</td>
<td>2.83%</td>
<td>9.14</td>
<td>6%</td>
</tr>
<tr>
<td>WH</td>
<td>31188</td>
<td>120</td>
<td>198.81</td>
<td>159.96</td>
<td>160</td>
<td>0.02%</td>
<td>5.46</td>
<td>3%</td>
</tr>
<tr>
<td>NB</td>
<td>24610</td>
<td>120.04</td>
<td>179.5</td>
<td>138.9</td>
<td>140</td>
<td>0.79%</td>
<td>5.3</td>
<td>4%</td>
</tr>
<tr>
<td>KE</td>
<td>16102</td>
<td>120.01</td>
<td>159.97</td>
<td>138.83</td>
<td>140</td>
<td>0.84%</td>
<td>4.71</td>
<td>3%</td>
</tr>
</tbody>
</table>

Treatments were controlled on an individual row basis, resulting in high precision for treatment switches along curves. Treatment changes in check strips typically occurred within 1 meter. While seed meters would turn off and on nearly instantly at the line of transition, this does not account for the number of the seeds currently in the seed tube. Accounting for these as well as the seeds starting to be planted by the alternate meter, the zone of transition would be about 1 to 2 meters.

### 3.4.2 Disease Ratings

Disease ratings were scored twice in the 2016 growing season, and once in the 2017 growing season. Figure 3.4 and Figure 3.5 show the disease ratings by field and date for the 2016 growing season.

Disease ratings for site WM can be found in Figure 3.4 for both sampling dates. Growth stage was R4-R5. Initially, the ILeVO® treatment had a disease index of 0.11 on
the first sampling date, and increased to 0.84 for the second sampling date. Disease index for the standard treatment started at 1.28 for the first sampling date, and increased to 2.56 for the second sampling date.

Disease ratings for field PM can be found in Figure 3.5 for both sampling dates. Growth stage was R4-R5. Initially, disease index for the ILeVO® treatment was extremely low at 0.0028 and increased to 0.47 on the second sampling date. Disease index for the standard treatment started at 1.44 and increased to 4.14 for the second sampling date.

![Figure 3.4: Disease Index for field WM, August 31 and September 8, 2016](image)

![Figure 3.5: Disease Index for Field PM on August 31 and September 8, 2016](image)
Statistical analysis cannot be made due to number and replication of ratings for either field. In both cases, the ILeVO® treatment maintained lower levels of disease index at both sampling dates. Disease levels in each zone did increase between sampling dates. The disease index increased more between the two sampling dates for the standard treatment in field WM. Similarly, field PM also had a greater increase in disease index between sampling dates for the standard treatment than the ILeVO® treatment.

The ILeVO® treatment had lower disease ratings than the Standard treatment. This would indicate that the ILeVO® product suppressed or reduced the amount of toxins produced by SDS that result in disease symptoms. However, no determination can be made due to the lack of statistical analysis.

One field, KE during the 2017 growing season was not scored due to very low disease ratings up until senescence at which point, it was impossible to rate disease levels. At senescence, disease levels were assessed and were still too low to rate. An additional field in the 2017 growing season, site NB, was not scored due to an issue with timing.

Disease ratings were only taken on one field, site WH, in 2017. Growth stage was at R5 to R6. Differences in disease index across the whole field can be found in Figure 3.6. The standard treatment had a disease rating of 4.45 while the ILeVO® treatment had a disease rating of approximately 1, resulting in a significant difference in disease levels amongst treatments. Differences in disease index by zone can be found in Figure 3.7. Within the SDS zone, the ILeVO® treatment had a disease rating of 1.87 while the standard treatment had a disease index of 6.47. This difference however was not
significant. Within the unaffected zone, the ILeVO® treatment had a disease rating of 0.07 while the standard treatment had a disease index of 2.43. The ILeVO® treatment was nearing significance in this zone with a p value of 0.0553. These results indicate that as a whole field, visible disease symptoms were lower in the ILeVO® treatment. The toxins that cause the visual symptoms were reduced or movement was prohibited in the ILeVO® treatment. On a zone basis however, no difference between treatments was detected.

![Figure 3.6: 2017 Disease Index for whole field WH, September 7, 2017.](image)

![Figure 3.7: 2017 Disease Index by Zone, site WH, September 7, 2017.](image)

It should be noted that these disease ratings are overall fairly low. (Disease Index can range from 0 to 100, with 100 resulting in premature death of plants) While portions
of the field had higher disease indices around 25, overall, both on a field and zone basis, disease index levels stayed fairly low in both the 2016 and 2017 growing season. However, reduced yields are still possible at this level of disease index. This site specific property of SDS makes management by site severity all the more desirable. The more disperse the distribution of SDS, the more necessary the use of site specific management will be.

3.4.3 Aerial Imagery and Vegetation Indices

NDVI values for 2016 imagery are found in Figure 3.8 through Figure 3.10.

![NDVI Values](image)

Figure 3.8: NDVI values for field WM, collected early August. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Field WM showed no difference in the ILeVO® and standard treatment in the SDS zone or the standard zone. NDVI values ranged from 0.6 to 0.68 across the field.
NDVI values for site PM were calculated on a whole field basis, from the field length strip data. NDVI was also calculated on a simulated zone basis. Simulated zones were determined by where disease ratings appeared to be highest throughout the field, and where visual detection of foliar symptoms occurred. On a whole field basis, there was no difference between the ILeVO® and standard treatments. On a simulated zone basis, there was a difference between NDVI values by treatment in all three delineated zones. Zone 1 had the highest levels of SDS, and the lowest NDVI values. Zone 2 had intermediate levels of SDS and intermediate NDVI values. Zone 3 had the lowest levels
of SDS but still showed a difference in NDVI readings for the zone. The simulated zone map can be found in Figure 7.70.

NDRE and NDVI values are shown in Figure 3.11 through Figure 3.14 for the 2017 growing season. Figure 7.23 through Figure 7.30 in the appendix show the collected NDRE and NDVI imagery.

Lower NDRE values in 2017 can be attributed to the later collection date. Senescence had already begun at the top nodes in both sites NB and KE when flown. This affected the amount of reflected NIR and consequently the NDRE values.

![Figure 3.11: NDRE by Zone, site WH, collected early September. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.](image-url)
Figure 3.12: NDVI by zone, site WH, collected early September. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

In field WH, NDRE values indicated a difference between treatments, with the ILeVO® treatment recording higher values in both the SDS and standard zones. NDVI values also indicated that the ILeVO® treatment had higher NDVI values in both the standard and SDS zones.

Figure 3.13: NDRE by Zone, sites NB, collected early September. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 3.14: NDVI by zone, sites NB, collected early September. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

In field NB, the ILeVO® treatment had higher NDRE readings in both the SDS and standard zone than the standard treatment. NDVI values showed that the ILeVO® treatment had higher values than the standard treatment in the SDS zone, but no difference was detected in the standard zone.

Figure 3.15: NDRE by Zone, site KE, collected early September. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 3.16: NDVI by zone, site KE, collected early September. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

In field KE, NDRE values showed no difference in the ILeVO® and standard treatments in the SDS or standard zones. Similarly, there was no difference in treatments in either zone when looking at NDVI values. The P values indicate that in the case of the SDS zone for both NDRE and NDVI, we are very confident that there is no difference between treatments. Vegetative index results were highly variable across the fields.

For fields with higher vegetation indices from the ILeVO® treatment, the NDRE and NDVI results suggest higher leaf chlorophyll content. NDRE and NDVI can measure stress levels in plants and suggest that as the plants reached maturity and even into senescence, the ILeVO® treatment contained healthier plants under less stress and retained a higher chlorophyll content. This was particularly evident by the date that sites NB and EFE were flown. In the case of sites NB, some of the standard strips had begun to senesce more than the ILeVO® treatments next to them. This shows up in the imagery and in the vegetation indices.
3.4.4 Yield Results on a Field Basis

Yield results from all fields in 2016 and 2017 are presented in Table 3.12. Yield maps showing yield distribution and patterns across field sites are found in Figure 7.35 through Figure 7.39. Average yield represents the average across all zones and treatments. The highest yielding field in 2016 averaged 4.57 Mg Ha\(^{-1}\). The lowest yielding field averaged 4.07 Mg Ha\(^{-1}\) in 2016. Average yield values in 2017 ranged from 3.99 to 4.67 Mg Ha\(^{-1}\). Standard deviation ranged from around 0.48-0.68 Mg Ha\(^{-1}\). This resulted in coefficients of variation around 12-15%. Some of this variation was a result of in field variation due to soil, or water distribution across the field. Additional variation came as a result of treatment differences across the field.

<table>
<thead>
<tr>
<th>Field</th>
<th>Harvest Date</th>
<th>Moisture</th>
<th>Average Yield (Mg/Ha)</th>
<th>Standard Deviation</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>WM</td>
<td>13-Oct-16</td>
<td>12%</td>
<td>4.57</td>
<td>0.65</td>
<td>14%</td>
</tr>
<tr>
<td>PM</td>
<td>21-Oct-16</td>
<td>14%</td>
<td>4.07</td>
<td>0.48</td>
<td>12%</td>
</tr>
<tr>
<td>WH</td>
<td>12-Oct-17</td>
<td>12%</td>
<td>4.67</td>
<td>0.68</td>
<td>14%</td>
</tr>
<tr>
<td>KE</td>
<td>17-Oct-17</td>
<td>12%</td>
<td>3.99</td>
<td>0.61</td>
<td>15%</td>
</tr>
<tr>
<td>NB</td>
<td>18-Oct-17</td>
<td>11%</td>
<td>4.20</td>
<td>0.60</td>
<td>14%</td>
</tr>
</tbody>
</table>

3.4.5 Yield Result on a Zone basis

Yield results for the 2016 and 2017 growing seasons were analyzed for differences in overall yield performance within zones and fields. Results of this analysis are found in Figure 3.17.
3.4.5.1 2016 Harvest Results

Yield results on an individual zone basis for the 2016 growing season are displayed in Figure 7.31 and Figure 3.18.

Figure 7.31 shows the zone yield results for site WM 2016. Results for WM with hybrid and zone interactions, indicates the ILeVO® treatment yielded 4.71 Mg Ha⁻¹, while the standard treatment yielded 4.52 Mg Ha⁻¹. Within the standard zone, the ILeVO® treatment yielded 4.83 Mg Ha⁻¹, while the standard treatment yielded 4.65 Mg Ha⁻¹. None of the yield differences were found to be statistically significant. The number of check strips able to fit in this field was limited, consequently implementing more check strips in the field could potentially allow for detection of yield differences. Field layout should be adjusted for future studies to include more check strips in each zone. This would help in detecting differences in treatments in each zone.
Yield results for site PM can be found in Figure 3.18. Site PM was not broken up into zones, rather a split planter method was used to place the two different treatments. These strips ran the length of the field and were randomized across the width of the field. Assessing the whole length of the field, the ILeVO® treatment yielded higher at 4.15 Mg Ha⁻¹, while the standard treatment yielded 3.94 Mg Ha⁻¹. High levels of SDS were found to be contained mostly to the North half of the field. This is an indication that this field could be divided into multiple zones for treatment application. The north half of the field could be planted with the ILeVO® treated seed, while the south half of the field could be planted with the standard treatment. This would reduce amount and cost of inputs and additionally providing the highest return on investment possible. A scenario zone analysis is found in Figure 7.73.

![Yield Results](image)

**Figure 3.18: Site PM Yield Results by treatment. Mg ha⁻¹ are corrected to 13.0% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.**

Overall, results were mixed for the 2016 growing season. In the zone planted field, there was no yield difference between treatments. This could have resulted from a lack of statistical power and it was determined that more check strips need to be incorporated in the zone planted field for better detection of differences. In the strip
planted field, the ILeVO® treatment yielded higher than the standard. Within the strip planted field, zone delineation should be assessed to determine portions of the field needing the ILeVO® treatment, resulting in maintained yield and reduced input costs.

### 3.4.5.2 2017 Harvest Results

All field sites during the 2017 growing season were zone applied fields. Analysis by zone can be found in Figure 7.32 through Figure 7.34. Analysis on a whole field basis by zone and hybrid are found in Figure 3.17.

Yield results on a zone basis for site WH can be found in Figure 7.32. On a whole field basis, in the SDS zone, the ILeVO® treatment yielded similarly to the standard treatment. Within the standard zone, the ILeVO® treatment yielded the same as the standard treatment. Yield of both treatments in the standard zone was significantly higher than yield of both treatments in the SDS zone. These results are similar to the disease ratings collected in season. Overall disease was low in this field. In a year with a more severe outbreak, yield differences between treatments within zones could have been possible.

Yield results for site NB indicate that within the SDS zone the ILeVO® treatment was higher yielding at 4.23 Mg Ha⁻¹ compared to 3.6 Mg Ha⁻¹ for the standard treatment. Within the standard zone, there was no difference in yield for the two treatments. The ILeVO® treatment yielded the same as both treatments in the standard zone. This is an ideal scenario for zone delineation and multi-treatment approaches to planting. In this situation, a more expensive, but higher yielding treatment can be applied to a subfield zone to maximize production. Within the larger portion of the field, the more expensive
treatment (ILeVO®) is not needed and standard treatment that is just as effective towards yield production can be planted. This would be the ideal planting scenario for site NB. Economics for this field are particularly interesting and can be found in Table 3.13.

No difference in yield between treatments was found in either zone for field KE. Yield across zones was also similar. No disease levels were of noticeable detection during the growing season, contributing to the lack of yield difference between treatments. Factors influencing yield could be of interest for future application of treatment at this site. Regression analysis showing interactions of independent variables with yield can be found in Figure 3.26 through Figure 3.29.

In three fields WM, WH and KE, no difference was detected between treatments. Simulated zones were analyzed in WH and KE to determine the appropriate zone boundaries for both fields and can be found in Figure 7.74 and Figure 7.75. Site NB results were ideal for the project. Yield was increased or maintained in the SDS zone with the ILeVO treatment, but no difference was detected between treatments in the standard zone. This is the goal of zone delineation for multi-treatment planting. Analysis should be conducted in future years to verify distribution of SDS and performance of ILeVO® across all fields.

3.4.5.3 Summary of Yield Results

Of the five fields analyzed for the study, three showed no difference between the ILeVO® and standard treatments within zones. A lack of check strips and low disease levels during the growing season likely contributed to this response. Repeating this study with additional check strips and across multiple years to test zones during a year with
higher levels of SDS would ensure appropriate delineation of zones. One field, NB responded as hypothesized, with the ILeVO® treatment yielding the highest in the SDS zone, but yielding the same as the standard treatment within the standard zone. The strip planted field, PM, showed a difference between treatments, with the ILeVO® treatment yielding higher than the standard treatment across the field, leading to the possibility of future zone delineation.

3.4.6 Yield Results with Spatial Interaction

3.4.6.1 2016 Yield interactions

Yield files from the 2016 growing season were analyzed in comparison with spatial soil factors including elevation, shallow and deep EC, slope gradient, wetness potential and soil series. Figure 3.19 through Figure 3.22 highlight variables of interest for each field site. Results from all categories can be found in Figure 7.40 through Figure 7.69.
Figure 3.19: Site WM 2016 yield data by elevation by treatment by zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 13.0% moisture.

Figure 3.20: Site WM 2016 yield by wetness and treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 13.0% moisture.

Figure 3.19 and Figure 3.20 show the relationship of yield with elevation and wetness potential for site WM. Both the ILeVO® and standard treatment were highly
variable in regards to elevation in the SDS zone. The standard treatment was uniform across all elevations within the standard zone. The ILeVO® treatment performed particularly well between 423 and 425 meters elevation. The ILeVO® treatment yielded higher across all wetness potentials. Both treatments decreased in yield as wetness potential increased.

Figure 3.21: Site PM 2016 yield by wetness by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.
Figure 3.22: Site PM 2016 yield by phosphorus levels by treatment and zone regression. Treatment regressions are separated by severe, moderate and low SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 3.21 shows the relationship between yield and wetness potential for site PM. Overall, the ILeVO® treatment yielded higher across all wetness potentials above 7. As wetness potential increased above 12.5, the standard treatment decreased in yield. At that same wetness potential, the ILeVO® treatment began to increase in yield indicating the ILeVO® treatment did well under wet circumstances. The ILeVO® treatment yielded consistently higher across phosphorus levels shown in Figure 3.22 in all three zones. At levels above 40 ppm, the standard treatment increased to meet the levels of the ILeVO® treatment in both the moderate and no SDS zones. Within the Severe SDS zone, the ILeVO® treatment stayed higher yielding. Traditionally, SDS symptoms are worse as phosphorus values increase. The results from the moderate to low SDS zones indicate that the ILeVO® treatment is not as effective at higher phosphorus ppm. However, the severe SDS category shows that ILeVO® was able to maintain yield at this high ppm
value. This indicates that the severity of the SDS and the interaction of the phosphorus does appear to affect yield. Portions of the field with lower SDS levels may not exhibit this relationship as strongly.

3.4.6.2 2017 Yield interactions

![Graph showing yield interactions](image)

Figure 3.23: Site WH 2017 yield by wetness by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 3.23 shows the relationship of yield to wetness potential in site WH. Both treatments are fairly uniform in both the SDS and Standard Zones. Within the SDS zone, the ILeVO® treatment may have trended slightly higher, however both remain very uniform across varying wetness potentials.
Figure 3.24: Site NB 2017 yield by soil type by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Mg ha⁻¹ are corrected to 13.0% moisture.

Figure 3.25: Site NB 2017 yield by elevation by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 13.0% moisture.

Figure 3.24 and Figure 3.25 show the relationship of yield to soil type and elevation for site NB. Within the SDS zone, the ILeVO® treatment yielded higher across
all soil types. Within the standard zone, both treatments performed similarly across soil types. Elevation had some effect on treatment within the SDS zone. The ILeVO® treatment yield generally increased as elevation increased. The standard treatment was highly variable across elevation within that zone. Both treatments were fairly uniform across elevations in the standard zone.

Figure 3.26: Site KE 2017 yield by soil by treatment regression. Mg ha⁻¹ are corrected to 13.0% moisture.
Figure 3.27: Site KE 2017 yield by deep EC by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 3.28: Site KE 2017 yield by wetness by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.
Figure 3.29: Site KE 2017 yield by slope by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 3.26 through Figure 3.29 show the relationship of yield to soil, deep EC, wetness and slope in field KE. Both treatments yielded similarly across all soil types. Lowest yields for both treatments were found in the Fillmore, Nodaway, and Pohocco soils. Figure 3.27 shows the uniformity of the ILeVO® and standard treatments across EC ranges. EC did not appear to have much effect on overall yield. However, within in the standard zone, yield decreased at EC values above 60 dS/m. The relationship of wetness potential found in Figure 3.28 indicates that the ILeVO® treatment yielded higher at wetness less than 13. Above that point, the standard treatment yield increased dramatically. Wetness potential appeared to have some influence on yield by treatment. The impact of slope on yield can be found in Figure 3.29. The standard treatment yield dropped off drastically at slopes above 0.05, while the ILeVO® treatment remained fairly uniform across all slopes.
3.4.6.3 **Yield interactions summary**

For the most part, yield was not highly correlated with the independent variables. Wetness potential did appear to display some trends between the ILeVO® and standard treatments. As wetness potential increases, the ILeVO® treatment generally was able to maintain or increase yields relative to the standard treatment. Other variables were not uniformly correlated across fields.

In the field where phosphorus levels were collected, P appeared to have some correlation with severity of SDS and yield. The ILeVO® treatment appeared to be more effective in a high P, high SDS situation. Collecting P values for all field sites should be a priority for future analysis.

### 3.4.7 Yield Results Comparison to Imagery

Overall, yield results were not well correlated with aerial imagery. NDVI readings matched the yield results for both sites WM and KE: no difference was detected in treatments in zones. NDRE and NDVI values for site WH indicate a difference in treatments, but this difference was not translated into overall yield. NDVI did not detect a difference in treatments that was present in the yield results for field PM. Finally, NDRE detected a difference in both zones for site NB. NDVI showed a difference in the SDS zone, but not the standard zone. This matched the yield results for the field.

Aerial imagery may not be the best predictor of yield performance for fields with SDS. Timing is very important for accuracy of results. Aerial imagery was collected very late for site NB (around four weeks before harvest) which may contribute to the reduced accuracy of NDVI results. While this timing was not able to detect as much difference in
overall leaf canopy, it did detect a difference in early senescence of the standard treatment in the ILeVO® zone.

3.4.8 Yield Results Comparison to Disease Index

As disease ratings in 2016 were not collected in such a way that statistical analysis can be conducted, comparison to yield is challenging. General trends will be compared to yield results. Some visual symptoms were present in site WM. The ILeVO® treatment had lower disease ratings than the standard treatment. This was not correlated with the yield results, as there was no difference in treatments across the field.

Visual indication based on aerial imagery would suggest a difference between disease symptoms at the north end of site PM. Ratings for the ILeVO® treatment remained below one, while the standard treatment was around 2.6. While these disease ratings are very low, the trend does match with reduced yield in the standard treatment and higher yield in the ILeVO® treatment.

Disease ratings that were analyzed statistically were only collected on site WH. At this field site, there was no difference in disease ratings by treatment or zone, even though disease was visually detected. This does match the yield results of no statistical difference in either treatment in either zone. When these two treatments were tested across the field, regardless of zone, the ILeVO® treatment did have lower disease ratings. Similarly, when yield was analyzed across the whole field, the ILeVO® treatment yielded higher than the standard treatment.
Disease ratings were not collected for site NB. At the time of disease rating collection, plants had senesced too far for accurate ratings. Visually, the plants treated with the ILeVO® product maintained leaf greenness and attachment longer than the standard treatment.

Finally, disease ratings were not collected for site KE due to very low presence of SDS across the field. This was evident in the yield results as no difference was detected between the ILeVO® and standard treatment.

Overall, disease ratings appeared to be somewhat correlated with yield results. Fields with a difference in disease ratings resulted in a yield difference in treatments. Fields that did not show any statistical difference in disease ratings resulted in no yield difference in treatments.

3.4.9 Scenario Zone Delineation

Alternative zone maps presented in Appendix Figure 7.70 through Figure 7.72 showing show optimum placement of zones based on 2016 and 2017 growing seasons. Yield results from treatment by zone interaction are found in Figure 3.30. Yield results by field without zone influence are found in Figure 7.74 and Figure 7.75. Results discussed will be based on the hybrid by zone interaction results.
Within field WM, ILeVO® yielded the highest in six of seven paired strips. Because of this, no alternative zone scenario was created. It is assumed that the ILeVO® treatment should have been planted across the whole field for optimum yield and economic return.

The strip trial data from site PM, found in Figure 7.73 was broken into three zones based on visual interpretation of yield and aerial imagery. “Severe SDS” was at the north end of the field where yield and visual symptoms were the worst. This zone would be comparable to the SDS zone in the other zone delineated fields. “Moderate SDS” is in the middle portion of the field and represents a portion of the field where some levels of SDS were present, but not as severe as “Severe SDS.” Finally, “No SDS” represents a portion of the field where visual symptoms of SDS were very low. Ultimately, by
dividing the field into zones, the portion of the field with SDS was isolated. This is reflected in the yields of “Severe SDS” with the ILeVO® treatment yielding 0.5 Mg Ha⁻¹ higher than the standard treatment. Results were mixed in the “Moderate SDS” zone with the ILeVO® treatment yielding the same as standard treatment. Within the “No SDS” zone, both treatments yielded similarly. Portions of both the “Moderate” and “No SDS” showed similar yields to the ILeVO® treatment in the “Severe SDS” zone. The standard treatment yielded similarly across all zones. In respect to yield, planting the ILeVO® treatment in the “Severe SDS” zone would be a beneficial way to ensure a return on investment by using the ILeVO® treatment only in the portion of the field that would see a yield benefit. Further testing on the “Moderate SDS” zone would be beneficial. In a year with higher disease levels, it may be beneficial to place the ILeVO® treatment in that zone as well.

Restructuring of the zones for site WH in Figure 7.74 resulted in a shift of three check strips to the standard zone, and five check strips to the SDS zone. It should be noted that those strips switched to the SDS zone did not show strong visual signs of SDS, but did appear to maintain leaf greenness and delayed senescence longer than the standard treatment. By adjusting the zone locations, yield differences became significant, with the ILeVO® treatment yielding 0.3 Mg Ha⁻¹ higher than the standard treatment. The standard treatment yielded higher in the standard zone, suggesting it would be optimal to use the ILeVO® treatment only in the SDS zone. Yield of the ILeVO® treatment in the SDS zone was similar to yields of the ILeVO® and standard treatments in the standard zone. This indicates a positive ability of the ILeVO® treatment to reduce effects of SDS.
This treatment plan would reduce cost by eliminating applications in portions of the field not benefiting from the product, while still maintaining yield in portions of the field affected by SDS. Because some of the strips moved to the ILeVO® zone did not show any symptoms of SDS, analyzing more years with the current zone structure to compare results in years with a more severe SDS outbreak would be beneficial before switching to the restructured zone.

In field KE, results shown in Figure 7.75, three of the paired strips were switched to the SDS zone, while four strips switched from the SDS zone to the standard zone. After restructuring zones, the ILeVO® treatment in the SDS zone yielded 0.1 Mg Ha\(^{-1}\) higher than the standard treatment. Conversely, within the standard zone, the standard treatment yielded higher than the ILeVO®. Yield was similar between the standard treatment in the standard zone and the ILeVO® treatment in the SDS zone. Yield of the ILeVO® treatments in the standard zone was also similar to both treatments in the SDS zone. The optimum scenario for this field would be to plant the ILeVO® only in the SDS zone. This would result in reduced input costs for the producer and increased or maintained yields in the SDS zone. Results of the zone delineation should be taken with caution. Since no levels of SDS were recorded during this growing season, the yield differences of the paired strips could be due to spatial variability of the field, rather than results of treatment against SDS. Consequently, any zone delineation created from that data could be skewed to not necessarily represent location of SDS. Distribution of levels of SCN do appear to be similar to the zone scenario created. It is possible that the ILeVO® treatment did influence the impact that SCN had on overall yields. In the portion
of the field with higher levels of SCN, the ILeVO® treatment did yield higher than the standard treatment. Within the rest of the field, the standard treatment yielded higher than the ILeVO® treatment. This portion of the field had lower levels of SCN. A map of SCN distribution can be found in Figure 7.17 for comparison to the zone scenario map found in Figure 7.72.

3.4.10 Profitability Analysis
3.4.10.1 Marginal Net Return

Profitability was calculated by marginal net return for each field site. Results were broken down by treatment in across the field. Marginal net return was calculated based on $338.04 market price per metric ton of soybeans times the zone average yield. Price of ILeVO® seed treatment was calculated as $37.49 per hectare and was subtracted from the net return. Cost of soybean seed was assumed to be uniform for all treatments and not subtracted from the net return. Figure 3.31 shows the marginal net return for all field zones and treatments.
Figure 3.31: Marginal net return in $ per hectare for treatment and zone locations. Marginal net return calculated as metric tons per hectare times a market price of $338.04 per metric ton and $37.49/hectare ILeVO® seed treatment cost ($0.34/mL).

At three field sites, WM, WH, and KE, there was no difference in marginal net return among treatments and sites. At one field site, NB the ILeVO treatment resulted in a $198 per hectare advantage over the standard treatment.

Site NB showed a particular benefit from using the ILeVO® treatment site specifically. While there was no benefit from using the treatment in the broader portion of the field (standard zone), there was benefit from using the ILeVO® treatment in the SDS zone. Yield of the ILeVO treatment in the SDS zone was similar to that of the ILeVO treatment in the standard zone. In this situation, a producer would be able to recover yield typically lost due to disease in the SDS Zone, resulting in an average economic benefit of $198 dollars per hectare. Additionally, the producer would be able to
save on costs by eliminating a $37.49 per hectare cost for treatment within the standard zone where no economic advantage was gained. This field would be ideal candidate for multi-hybrid or multi-treatment planting.

Results from site WM, WH, and KE indicate that a uniform treatment would be of the most benefit for these field sites, as there was no difference in marginal net return of treatments. Overall, one of the five fields tested showed a positive economic response for using the ILeVO® treatment in some portion of the field. While testing is essential, the use of ILeVO® to protect yield against the impact of Sudden Death Syndrome, and provide some economic advantage, appeared promising at this field site. Given that disease levels were low across the other locations, further analysis of economic advantage in years with higher disease levels would be prudent.

### 3.4.10.2 Scenario Analysis Marginal Net Return

Profitability was assessed for the zone scenarios created in section 3.4.9. Several fields did not have zone scenarios created; these fields all should have been planted to a single treatment or were already the optimum zone scenario. Consequently, no profitability analysis was conducted for them. Profitability results for the remaining fields can be found in Figure 3.32.
Scenario zones for site PM indicate that in the zones where SDS had more of a yield impact, such as the “Severe SDS” zone, the ILeVO® treatment resulted in an increase of $61 dollars per hectare. “Moderate SDS” in the middle portion of the field showed no difference between treatments. The standard treatment in the “Moderate SDS” zone was similar to all other treatments across all zones. Finally, “No SDS” zone, did not result in any differences in the marginal net return between treatments. The ILeVO® treatment in that zone was similar to all other treatments across all zones. Standard treatments across all zones performed similarly. Additionally, the ILeVO® treatment had similar marginal net returns across all zones.

Field WH resulted in a higher marginal net return by using the ILeVO® treatment in the SDS zone, but no difference in treatments in the standard zone. The ILeVO®
treatments profited similarly across zones, as did the standard treatments. Additionally, the standard treatment in the SDS zone and the ILeVO® treatment in the standard zone had similar marginal net returns. This would be an optimum zone scenario from a profitability standpoint.

The marginal net return analysis on field KE indicated no difference in profitability by using the ILeVO® treatment in the SDS zone. The ILeVO® treatment resulted in a lower marginal net return by using it in the standard zone. Both the as planted results and the zone scenario analysis were unable to discover an optimum situation for treatment placement for this field site. This is an indication that this field site may not be a good candidate for multi-treatment planting. Further analysis would be suggested as a means to better delineate SDS and SCN distribution throughout the field.

Overall, two of the three fields zone scenarios were created for showed a positive economic response for using the ILeVO® treatment in some portion of the field. The use of zone scenarios to highlight portions of the field with highest economic return by using ILeVO® appears promising.

3.4.10.3 Break-even Analysis

Break-even analysis was conducted for field sites showing economic benefit from using ILeVO® in portions of the field. Break-even analysis was not conducted on field sites where uniform application would be best, i.e. sites WM and KE, as conventional planters would be capable of that kind of application.
One field showed economic benefit of applying ILeVO® in portions of the field: NB. It was assumed the additional cost of a multi-hybrid add on is $20,000. Results in Table 3.13 and Table 3.14 reflect that assumption. Table 3.13 outlines the years to break even, assuming the area in the study field is the only field with SDS for the producer. Table 3.14 outlines the years to break even based on 91 hectares of soybeans with SDS. This number was derived from an average farm size of 364 hectares in rotation, resulting in 182.1 hectares in soybeans. Of that area, it was assumed half contained some level of SDS.

**Table 3.13: Break-even analysis for site NB. Years to pay off is assuming the field listed is the only field with SDS that will contribute to the break-even years.**

<table>
<thead>
<tr>
<th>Field</th>
<th>ILeVO® Economic Advantage</th>
<th>Area (hectares)</th>
<th>Economic Gain per Year</th>
<th>Years to Pay Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>$198</td>
<td>20.23</td>
<td>$3,993.38</td>
<td>5</td>
</tr>
</tbody>
</table>

**Table 3.14: Break-even analysis for site NB. Area and years to pay off is assuming an average farm size in Nebraska of 364 hectares (900 acres), of which half are in soybeans, and only half of those fields have SDS (91 hectares or 225 acres with SDS).**

<table>
<thead>
<tr>
<th>Field</th>
<th>ILeVO® Economic Advantage</th>
<th>Area (hectares)</th>
<th>Economic Gain per Year</th>
<th>Years to Pay Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>$198</td>
<td>91</td>
<td>$17,649.00</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Break-even analysis for site NB is promising, even when looking at the single field in the study. Considering only the 20 hectares in the SDS zone of site NB, an addition of multi-hybrid capabilities could be paid off in five years. If the acres with SDS were increased to 91 hectares, the investment could be paid off in just over a year.
3.5 Conclusion

Disease ratings for the field sites were mixed depending on the level of disease present. Several field sites did not show any difference in disease levels. Site WH field did have differences on a whole field basis, however, when broken down into zones, no difference in disease levels was present. Yield patterns were similar to those collected by disease ratings.

Aerial imagery results were also mixed. Both NDRE and NDVI were able to detect differences in treatments in several fields. No difference in vegetative indices were found at two field sites. Only one of the zone delineated fields had any difference in yield by zone. One field had a yield difference between zones, but not the treatments within zones. The majority of the fields did not have high enough levels of SDS to result in any yield differences among treatments. Within the strip planted field, PM, the ILeVO® treatment did have higher vegetation index values than the standard treatment. Overall, yield was not closely related to in-season imagery collected.

Out of all the independent variables analyzed, wetness potential seemed the most closely correlated with yield by treatment. Other variables were loosely related. Wetness potential seemed to be the most related across almost all field sites.

Restructured zones showed the potential to highlight correct distribution of SDS. Further testing of original zones, or strip planted data is advised before switching to the zone scenarios. Zone delineation of site PM indicated the ability to group areas of the field relating yield response to ILeVO® by severity of SDS.
Within the SDS zones, the ILeVO® treatment resulted in a higher marginal net return at one field site. Within the standard zones, there was no difference in profitability between treatments. Break-even analysis for field NB was around five years. Economics will be an important consideration when deciding whether to use the ILeVO® treatment. With a cost of $37.49 per hectare, the price may be a deterrent to application. Additionally, cost for prescription map creation and implementation should be included in costs for adoption. Yield and economic results for site NB provide an ideal scenario for using multi-treatment planting to optimize yield and profitability. While this site was an excellent example, careful consideration will be necessary when determining zone structure and application sites. To prepare for multi-hybrid planting, producers should take care to document areas of the field with SDS through yield mapping, aerial imagery, and field scouting. Thorough documentation will be key in preparing for use of seed treatments with multi-hybrid planting.
3.6 References


CHAPTER 4  : Split Planter Analysis as a Means of Zone Delineation and Zone Scenario Analysis for Multi-Hybrid Planting
4.1 Introduction

CHAPTER 2 and CHAPTER 3 both approached multi-hybrid planting through a management zone delineation method. Data layers were compiled and clustered to represent the natural variability across the field. While this method has merit, several alternative approaches can be taken to test hybrid performance and zone structures. It will discuss a split planter approach to hybrid selection and zone determination. A split planter approach is feasible even before a purchase of a multi-hybrid planter, allowing for several years to test zones prior to implementation. This can be a defensible way of ensuring zones and hybrids are selected correctly. This process is also possible on past years of yield data that were laid out with this method.

In a split planter study, two hybrids are planted side by side across the entire field. Traditionally, the planter is “split” with half of the planter in one hybrid, and half with a different hybrid. Additionally, with RTK GPS available on planters, it is possible to plant strips of one hybrid across the field, then return and plant the alternate strips of a different hybrid. If focusing on water variability across the field, hybrid selection should include one hybrid that would perform well in water limiting conditions containing a DroughtGuard or AquaMax trait, while the other would be considered a “racehorse” hybrid known for being higher yielding in optimum circumstances. Alternatively, if the focus is placed on pest pressure, select two hybrids, one with the resistance desired, and the other without. For examples presented in 0, hybrids were selected based on drought tolerance and high performing traits. These hybrids were then harvested by strips and results analyzed comparing treatment, yield and supplemental attributes such as
elevation, slope, or soil type. The results of these analyses can show appropriate zones for the field based on that years yield data and hybrid selection. Multiple years of analysis would be needed to check zone stability from year to year.

4.2 Literature Review

Split planter studies are ideal for testing multiple treatments across spatial variability present within the field. By using a paired strip method, hybrids are placed in close enough proximity to ensure similar spatial interactions. By multiplying this pattern across the field, performance of treatments can be assessed by attributes that vary across the field such as soil type, elevation or slope. This process in conjunction with a yield monitor for yield assessment allows a producer to test multiple hybrids in multiple locations across the field (Cox et al., 2004). This greatly reduces the time needed for a producer to analyze different hybrids. Prior to yield monitors, each test strip would need to be weighed separately. Due to this time constraint, a sparse amount of check or comparison strips were placed across the field. With the technology capabilities of a yield monitor, the time for sampling is reduced, and the number of replications can be greatly increased.

As hybrids or treatments are compared, some limitations do come into play. Relative maturity of hybrids should be within five days, and grain moisture should be within 5% for an equivalent comparison (Doerge and Gardner, 1999). Other factors may also influence the accuracy of yield data collected. In highly sloped fields, tilt of the combine, both fore and aft, and side to side, may contribute to yield error between passes
collected (Doerge and Gardner, 1999). Ultimately, split planter studies allow for a robust comparison of hybrids or treatments across variable field conditions.

4.3 Goals and Objectives

Objectives for the split planter sites include analysis of treatments by field attributes as a means to delineate potential field zones. Specific objectives were to: 1) assess yield of two contrasting treatments for variation across the field 2) evaluate treatment performance against supplemental field attributes to determine layers with correlation to treatment performance 3) create zones based on correlated supplemental attributes to divide the field into treatment zones 4) determine if the multi-hybrid planter approach would be profitable based on yield results.

4.4 Materials and Methods

Several guidelines should be followed for a successful split planter study: hybrid selection, planting and harvest setup, and field attribute data collection.

4.4.1 Hybrid Selection

Similar to the zone approach for multi-hybrid planting, two contrasting hybrids must be chosen. Hybrids with similar characteristics and ideal performance criteria are not a good combination for multi-hybrid planting as no difference in treatments will be seen. Hybrids should be selected to match some characteristic or attribute within the field. Typically, corn hybrids would be selected as an offensive and defensive hybrid. The offensive hybrid would be higher yielding in ideal circumstances, but have decreased yields in water limiting conditions. A defensive hybrid would not have the yield potential of the offensive hybrid, but under stressful or water limiting conditions it would maintain
yield better than the offensive hybrid. Care must be taken to select these contrasting hybrids. It is difficult to find hybrids that truly fall into these categories, as many are marketed as “multi-environment” hybrids, designed to perform well across varying soil and moisture conditions. Consulting with a seed dealer and agronomist is important to selecting these hybrids for a split planter study. This method of hybrid selection would be ideal for selecting and testing hybrids for water resistance. However, other situations arise that could be beneficial for testing by split planter. Testing of different traits in particular hybrids, testing of two seed treatments for disease or pest pressures, or comparison of maturity dates are all possibilities.

4.4.2 Planting and Harvest Setup

Appropriate setup for planting and harvesting is important for accurate data collection. Harvest header width needs to be a unit of the planter width, preferably half. Consider a twelve row planter, and six row header. In this instance, half of the planter would be planting the defensive hybrid and the other half an offensive hybrid. Since the header width matches half of the planter, contamination of hybrids should not be an issue. If the planter and the header match widths, a split planter approach can be used, however the first pass at harvest should be offset to accommodate for the half planter difference. At harvest time, care should be taken to ensure that the planter and harvest passes are matching to reduce any chance of contamination of a “mixed” header pass. Alternatively when harvest width and planting width match, the producer will need to plant every other pass across the field with a single hybrid, and then come back and plant the in-between
passes with the contrasting hybrid. While this is feasible given current automated steering
and as-applied tracking systems, it does add a layer of complexity.

4.4.3 Field Attribute Data Collection

After yield and hybrid data are recorded, these data can be compared with
supplemental attributes across the field. It is imperative to collect as many data layers as
possible to compare across hybrids and yields.

Soil series data is available online from USDA. Distribution of soil types and
textures provide insight into the water holding capacities of the soil, potential rooting
depth of crops, and soil features limiting to crop yield. Inclusion of these features can
explain temporal trends in yield data across years. While useful, USDA soil series data
may not be the most accurate for precision agriculture systems (Franzen et al., 2002). Soil
series trends may be close to accurate, but not as precise as needed for current production
and mapping systems.

Soil sampling data is recommended for collection. While grid analysis provides a
more spatially dense dataset to work with, zone sampling also provides useful
information for revealing potential variation in the field. Electrical conductivity data can
provide a very dense data set at a reduced cost in comparison to grid sampling. Passes
created with an electrical conductivity sensor can simultaneously be collecting pH and
organic matter. While specific nutrient values are not collected with electrical
conductivity platforms, it can still provide a dataset that closely represents the variability
by soil type, soil texture, or water holding capacity.
Terrain attributes such as slope, elevation, drainage and wetness potential are also useful for comparing across yield and hybrid classes. Some of these values can be collected with LIDAR or calculated from elevation data collected during in-field operations using a GPS system.

For this analysis, regression analysis of these attributes by yield and hybrid treatment will help find a baseline zone delineation to work with. In the end, a combination of these layers may provide the best results for creating Rx maps.

4.5 Case Study 1: Split Planter Study

A field was planted to two hybrids across its length in 2012. The 2012 growing season was characterized as a very dry year, and the need for a defensive hybrid was necessary in portions across the field. 33D47 was considered the offensive hybrid, and P1498 as the defensive. Figure 4.1 shows the distribution of hybrids across the field.

Figure 4.1: Hybrid placement for Case Study 1. Hybrid 33D47 is in the white strips and is the offensive hybrid. Hybrid P1498 is in grey and is the defensive hybrid.
4.5.1 Analyzing Split Planter Results

Yield data from a split planter study was analyzed to determine which hybrid performed the best across the field and within sub field zones. Yield by treatment (i.e., hybrid) was analyzed in comparison to soil series, elevation data, landscape position, slope grade, and wetness potential. Landscape position, slope and wetness potential were calculated using the Terrain Analysis function in AgLeader SMS. Figure 4.2 through Figure 4.6 show the smooth regression data as a function of treatment and yield. Each of these attributes was considered as a possible factor for zone delineation.

![Graph showing yield data by treatment and soil type]

**Figure 4.2: Yield by treatment by soil type. Mg ha$^{-1}$ are corrected to 15.5% moisture.**

Yields across soils types varied significantly. Both treatments had the highest yields in the Coleridge soil and lowest in the Moody soil. Between hybrids, some differences emerged in performance amongst soil types. P1498R yielded higher in the Coleridge, Judson, Monona, Moody and Nora soils. 33D47 yielded higher in the Zook soil. It should also be noted that while the average in the Monona soil was a little lower in
the 33D47 treatment, that treatment did have more extreme high yields in that soil series. Overall more variability was present in the 33D47 treatment. Based on the difference in hybrid performance, soil series could be a factor considered for zone delineation.

![Figure 4.3: Yield by treatment and elevation. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.](image)

Yield by elevation shows that below 376.7 meters, 33D47 was the higher yielding treatment. Above that point, P1498R was the higher yielding treatment. This switch in dominant hybrid would suggest that elevation could also be used to define hybrid zones.
Yield by landscape position indicates fairly dispersed yield in each category. Both 33D47 and P1498 averaged similarly in the Plains and Ridge positions. P1498 yielded higher in both the Side Slope and Valley categories. Having higher yield results in two categories and similar results in two of the categories would lend the assumption that P1498R could be planted across the whole field. Thus, landscape position would not likely be well suited for zone determination.
Figure 4.5: Yield by treatment and slope. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5\% moisture.

Yield was very similar across all slope ranges for 33D47 and P1498R. Consequently, slope would not be considered for zone determination.

Figure 4.6: Yield by treatment and wetness potential. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5\% moisture.
Results are mixed for yield interaction with wetness potential. Above a wetness potential of 10, 33D47 out yielded P1498R. However, there was not a clearly defined area where P1498R yielded higher. As a result, wetness potential will not be considered for zone determination.

Both soil series and elevation will be considered for zone determination based on the results in Figure 4.2 and Figure 4.3. Zone maps created from this data can be found in Figure 8.1 and Figure 8.2.

There are many other influential field factors that could be used for analysis other than those presented in Figure 4.2 through Figure 4.6. Potential zones can be determined from soil nutrient status, water holding capacity, or electrical conductivity zones. This method provides a tested and proven way of determining zones where each hybrid would be optimized. The more datasets available for comparison, the better. This would allow a greater dataset to pull from in order to find an attribute that successfully groups hybrids into zones.

4.5.2 Zone Scenario Analysis

Possible zones were created based on the smooth regression analysis in 4.5.1. Table 4.1 displays results from planting a single hybrid and a zone scenario based on elevation. Hypothetical zones were created based on the elevation of 376.7 meters. Elevations lower than that point were planted to 33D47 (Zone 1). Elevations higher than that were planted to P1498R (Zone 2). Zone 1 contained approximately 5.08 hectares. Zone 2 contained approximately 6.16 hectares. Planting the elevation zone scenario resulted in an increase between 0.48 and 0.62 Mg Ha\(^{-1}\). Delineation by elevation was
effective in separating varying yields by hybrids into cohesive zones, resulting in an increase in yield above a single hybrid selection.

Table 4.1: Zone Scenario based on elevation. Single hybrids listed represent yield if a single hybrid were planted across the whole field. Zone scenario represents the zoning of the two hybrids based on optimum placement. Two zones were created, split by 376.7 meters in elevation. Mg ha$^{-1}$ are corrected to 15.5% moisture.

<table>
<thead>
<tr>
<th>Hybrid Selection</th>
<th>Average Yield (Mg Ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33D47</td>
<td>8.69</td>
</tr>
<tr>
<td>P1498R</td>
<td>8.83</td>
</tr>
<tr>
<td>Zone Scenario</td>
<td>9.31</td>
</tr>
</tbody>
</table>

Table 4.2 displays results from planting a single hybrid and a zone scenario based on soil type. Zone 1 of the zone scenario contained the Zook soil series and was around 3.04 hectares. Zone 2 of the zone scenario contained the remaining soil series, Monona, Moody, Nora, Judson and Coleridge, and was around 8.10 hectares in size. Planting this zone scenario would have resulted in an increase of 0.34 and 0.6 Mg Ha$^{-1}$ above a single hybrid. Delineation by soil type was also effective in sorting varying yield by hybrids into cohesive zones.

Table 4.2: Zone Scenario comparison based on soil type. Single hybrids listed represent yield if a single hybrid were planted across the whole field. Zone scenario represents the zoning of the two hybrids based on optimum placement. Zone 1 was the Zook soil, Zone 2 contained all other soil types. Mg ha$^{-1}$ are corrected to 15.5% moisture.

<table>
<thead>
<tr>
<th>Hybrid Selection</th>
<th>Average Yield (Mg Ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33D47</td>
<td>8.76</td>
</tr>
<tr>
<td>P1498R</td>
<td>9.02</td>
</tr>
<tr>
<td>Zone Scenario</td>
<td>9.36</td>
</tr>
</tbody>
</table>

While both scenarios would have resulted in increased yield over a single hybrid, the zone scenario based on soil series resulted in a higher yield than the elevation
scenario. Both scenarios would be appropriate to test for validity in multiple growing season scenarios.

### 4.5.3 Profitability

Profitability was calculated for single hybrid placement across the field, or the zone scenario analysis. Marginal net return was calculated using $220 per bag of corn, a population of 69,189 seeds per hectare and a market price of $125.97 per metric ton.

Marginal net return for the elevation zone scenario resulted in an economic advantage of $59 to $77 dollars per hectare above a single hybrid placement. Elevation did an excellent job of separating out portions of the field where one hybrid yielded better than the other, resulting in a significant margin above a single hybrid approach.

**Table 4.3:** Marginal net return for single hybrid placement and zone scenario for Case Study 1. Zone scenario based on elevation ranges. Single hybrids listed represent profitability for that single hybrid if it had been the only hybrid planted in the field. Marginal net return was calculated using an estimate of $220/ bag or corn, a population of 69,189 seeds per hectare and a market price of $125.97 per hectare.

<table>
<thead>
<tr>
<th>Hybrid Selection</th>
<th>Marginal Net Return ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33D47</td>
<td>$ 904.97</td>
</tr>
<tr>
<td>P1498R</td>
<td>$ 922.54</td>
</tr>
<tr>
<td>Zone Scenario</td>
<td>$ 981.92</td>
</tr>
</tbody>
</table>

Using the zone scenario would result in $43 to $76 dollars per hectare increase in marginal net return per acre above a single hybrid planting when using the soil zone delineation. This is a very similar profit potential as achieved with the elevation scenario. Soil zones also did an excellent job of dividing the field into zones and providing a potential economic gain by using these zones.
Table 4.4: Marginal net return for single hybrid placement and zone scenario for Case Study 1. Zone scenario based on soil. Single hybrids listed represent profitability for that single hybrid if it had been the only hybrid planted in the field. Marginal net return was calculated using an estimate of $220/ bag of corn, a population of 69,189 seeds per acre and market price of $125.97 per hectare.

<table>
<thead>
<tr>
<th>Hybrid Selection</th>
<th>Marginal Net Return ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>33D47</td>
<td>$912.63</td>
</tr>
<tr>
<td>P1498R</td>
<td>$945.80</td>
</tr>
<tr>
<td>Zone Scenario</td>
<td>$989.06</td>
</tr>
</tbody>
</table>

Overall, the zone scenario for elevation in Table 4.3 resulted in a marginal net return of $981 dollars per hectare in comparison to the zone scenario for soil types in Table 4.4 of $989 per hectare. Based on this financial analysis, the soil zones should be chosen for further zone delineation and assessment. However, because of such a similar profit potential, elevation zones would also be appropriate for zone delineation.

4.6 Case Study 2

The field site for Case Study 2 was planted to two hybrids across the length of the field for the 2012 growing season. The 2012 growing season was characterized as a very dry year, and the need for a defensive hybrid was necessary in portions across the field to meet the demands of dry field conditions. Hybrid A was considered the defensive hybrid, and Hybrid B the offensive. Figure 4.7 shows the distribution of hybrids across the field.
Figure 4.7: Split planter hybrid placement for Case Study 2. Hybrid A is in the white strips is the defensive hybrid. Hybrid B is in grey and is the offensive hybrid.

4.6.1 Analyzing Split Planter Results

Yield data from a split planter study can be analyzed to determine which hybrid performed the best across the field and in sub field zones. Yield by treatment was analyzed in comparison to soil series, elevation data, landscape position, slope grade, and wetness potential. Figure 4.8 through Figure 4.12 show the smooth regression data as a function of treatment and yield. Each of these attributes was considered as a possible factor for zone delineation.
Yield by soil type indicated similarities between treatments. Both hybrids performed better in the Judson soil compared to the Nora. Hybrid B yielded better than Hybrid A in both the Judson and Nora soils. Consequently, soil series would not likely be an effective metric for determining zones.

Figure 4.8: Yield by treatment and soil type. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 4.9: Yield by treatment and elevation. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Yield by elevation shown in Figure 4.9 shows no distinct difference in hybrids across elevation types. Both hybrids follow the same trends across elevation, however, Hybrid B, the offensive hybrid, consistently yields higher than Hybrid A. Thus, elevation was not considered for further zone determination.

Figure 4.10: Yield by treatment and landscape position. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Yield by landscape position shows similar trends by treatment across position. Hybrid B yielded higher in all categories of landscape position. Landscape position would not be useful for determining zone structure.
Figure 4.11: Yield by treatment and slope. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Similar to yield by elevation, yield by slope shows the same general trends across slope gradient. Hybrid B consistently yielded higher than Hybrid A across all ranges. Consequently, slope gradient would not be a useful metric for determining zone structure.

Figure 4.12: Yield by treatment and wetness potential. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Yield by wetness potential reveals four possible zones. Below a wetness potential of five, Hybrid A yields higher. Between five and eight, Hybrid B yielded higher. Between eight and twelve, Hybrid A again was the higher yielding treatment. Above twelve, Hybrid B out yielded Hybrid A.

Wetness potential was the only metric that showed any difference in hybrid performance across the field. Zone determination will be assessed based on wetness potential.

4.6.2 Zone Scenario Analysis

Zones were created based on the regression analysis in 4.6.1. Table 4.5 shows the single hybrid performance in comparison to the zone scenario based on wetness potential. Wetness was the only attribute showing distinction between zones. Four zones were created: less than 5 (Zone 1), between 5 and 8 (Zone 2), between 8 and 12 (Zone 3), and greater than 12 (Zone 4) wetness potential. Zone 1 and 3 were planted to Hybrid B and totaled about 3.4 hectares. Zone 2 and 4 were planted to Hybrid A and covered about 10.4 hectares. Planting the zone scenario resulted in an increase between 0.08 and 0.37 Mg Ha\(^{-1}\) above a single hybrid. Depending on the single hybrid chosen, wetness potential could be an effective means of delineating zones.

Table 4.5: Zone scenario and single hybrid performance based on wetness potential. Single hybrids listed represent yield if a single hybrid were planted across the whole field. Zone scenario represents the zoning of the two hybrids based on optimum placement. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

<table>
<thead>
<tr>
<th>Hybrid Selection</th>
<th>Average Yield (Mg Ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid A</td>
<td>8.61</td>
</tr>
<tr>
<td>Hybrid B</td>
<td>8.32</td>
</tr>
<tr>
<td>Zone Scenario</td>
<td>8.69</td>
</tr>
</tbody>
</table>
Margins of yield increase were narrower in Case Study 2 than in Case Study 1. Because of this, more years of split planter analysis would be beneficial to assess zone stability from year to year. Wetness potential could be highly variable due to temporal weather conditions. As a result, these zones may not be stable or similar across highly variable years.

4.6.3 Profitability

Profitability was calculated for single hybrid placement across the field, or the zone scenario analysis. Marginal net return was calculated using $220 per bag of corn, a population of 69,189 seeds per hectare and a market price of $125.97 per metric ton.

Table 4.6: Marginal net return for single hybrid placement and zone scenario for Case Study 2. Zone scenario based on wetness potential. Single hybrids listed represent profitability for that single hybrid if it had been the only hybrid planted in the field. Marginal net return was calculated using an estimate of $220/ bag or corn, a population of 69,189 seeds per hectare and a market price of $125.97 per metric ton.

<table>
<thead>
<tr>
<th>Hybrid Selection</th>
<th>Marginal Net Return ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid A</td>
<td>$ 894.42</td>
</tr>
<tr>
<td>Hybrid B</td>
<td>$ 858.12</td>
</tr>
<tr>
<td>Zone Scenario</td>
<td>$ 904.33</td>
</tr>
</tbody>
</table>

Marginal net return for the wetness potential zone scenario resulted in an economic advantage of $10 to $46 dollars per hectare above a single hybrid placement. Wetness potential did an adequate job of separating the performance of hybrids into zones. However, with a small margin of only $10 above the marginal net return of Hybrid A, justification of multi-hybrid planting may be a challenge. Further years of split planter data and analyzing appropriate zones for hybrid and environmental conditions by year
will be essential to see if this particular zone delineation is stable, or if alternative zones based on other supplemental attributes would be appropriate for the field.

4.7 Conclusion

As multi-hybrid planting technology advances, steps should be taken to prepare for the technology. First, collect, store, and analyze data layers. Secondly, conduct split planter research to accurately determine appropriate zones for multi-hybrid planting. Of the case studies presented, three different data layers effectively grouped yield points by hybrid into cohesive zones. Yield was increased between 0.08 and 0.62 Mg Ha\(^{-1}\). Marginal net return was anywhere from $10 to $77 dollars per hectare higher by using the zone scenario instead of a single hybrid. Post processing of split planter data can be used to delineate zones by various field-related attributes. This will be a useful tool for testing various zones for multi-hybrid planting in the years leading up to adoption of the technology. Having multiple years of split planter data as well as multiple supplemental datasets for comparison will be extremely beneficial towards accurate zone creation for multi-hybrid planting and provide a practical (as opposed to theoretical) method of creating zones that can be tested multiple years prior to implementation.
4.8 References


CHAPTER 5 : Conclusions and Further Work
5.1 Summary and Conclusion

Multi-hybrid planting was assessed in three different settings: zone delineation for corn, zone delineation for soybeans, and split planter analysis. Multiple methods were employed in order to better understand the data layers and procedure necessary for mapping management zones for multi-hybrid planting.

No real benefit was seen by using multi-hybrid planting in the corn fields. While yield differences resulted for some fields sites, economically, all fields should have been planted to a single hybrid. Various attributes appeared to be correlated with yield. However, the influence of these attributes were not consistent by zone. Growing season conditions in both 2016 and 2017 were not conducive to testing offensive versus defensive hybrids. Growing season precipitation was such that the offensive hybrid yielded significantly higher across the majority of the fields or showed no difference compared to the defensive hybrid. This did provide some useful baseline information in that yield results for several fields indicated no negative consequence for using a defensive hybrid within specified zones. Traditionally, there is a risk of using a defensive hybrid. Conceptually, a defensive hybrid may exceed yields of the offensive hybrid in water limiting conditions, but under adequate water conditions, yield may be reduced when compared to the offensive hybrid. Results from several fields indicated that while there was no benefit for using the defensive hybrid in either zone, yield was not compromised. Therefore, if a producer planted defensive and offensive hybrids with a multi-hybrid approach, yield may not be optimized but also not necessarily compromised (i.e., in a drought season, risk would be minimized in those defensive zones).
Using paired check strip data, zone scenarios could be created to optimize placement of hybrids. The locations where the offensive hybrid performed best were structured into a new offensive zone via interpolation. Locations where the defensive hybrid performed optimally were grouped into a new defensive zone. Analysis on these zones indicated that the new scenario zones were optimal for placement of hybrids. This resulted in a difference in yield by zone as well as profitability by zone. The use of these scenario zones could assist in zone revision. However, multiple years of analysis with existing zone delineation would be advised before assuming the existing zones are incorrect and to ensure the scenario zones are stable from year to year. After these assumptions are verified, scenario zones could be implemented.

Overall, growing season conditions made it difficult to test zone delineation and hybrid selection. Replication of the study in water limiting growing seasons may provide better insight into how to appropriately create management zones for multi-hybrid planting.

Soybean fields were planted with a single hybrid and two separate treatments. The ILeVO® treatment was selected as a means to combat sudden death syndrome. Results were mixed for the 2016 and 2017 soybean sites. Several field sites showed no difference between the ILeVO® and standard treatment yields while one field did result in a significant yield difference for the ILeVO® and standard treatments. Profitability analysis for the field sites indicated that the ILeVO® treatment provided the highest economic return in the SDS zone in one of the five field sites. Use of the ILeVO® treatment shows promise in providing economic benefit to producers with severe SDS. In the four
remaining sites, SDS levels were low and consequently, no difference between treatments was detected. Zone scenario analysis was completed on site PM, the split planter study. Zone delineation successfully split the field into three zones corresponding to the level of SDS in the field. Ultimately, economic analysis showed that not all zones provided a yield increase with the ILeVO® treatment, and consequently, only the severe SDS zone should be planted to the ILeVO® treatment. One zone structured field resulted in a $198 per hectare increase by using the ILeVO® treatment. While both the 2016 and 2017 growing seasons had above average rainfall, a characteristic normally conducive to increased SDS pressures, all field sites had fairly low levels of SDS pressure. Repetition of this study in multiple growing seasons would be advantageous towards testing the zone delineation in higher disease pressures. Overall, management zones created to isolate treatment of ILeVO® for sudden death syndrome appeared useful in optimizing yield or profitability of treatments.

Producers can begin to prepare for multi-hybrid planting prior to technology adoption. By planting two contrasting hybrids as a split planter setup, yields across the full length field strips can be used to compare hybrid and yield to supplemental attributes. Two case studies presented indicate that post processing can successfully delineate management zones. Case study 1 resulted in a $43-77 per acre advantage over a single planted hybrid. Case study 2 resulted in a $10-46 advantage over a single planted hybrid. It is essential that split planter data be replicated across multiple years to verify zone delineation and stability of zones across many different temporal conditions.
Split planter analysis may be one of the best ways to begin preparing for multi-hybrid planting. Using yield data directly to create zones shows possible benefit over correlation of field attributes with historical yield. It is recommended that multiple years of split planter analysis be completed before utilizing multi-hybrid planting. Not only does scenario analysis help quantify management zones for planting but also permits testing of multiple hybrids to be used in a multi-hybrid study. This on-farm research approach may be superior to management zone creation from historical data and supplemental attributes and should be strongly considered as a means to delineate zones for multi-hybrid planting.

5.2 Challenges to adoption

Several different challenges to adoption should be discussed.

Field capacity and efficiency should be accounted for when considering multi-hybrid planting. If percentage of hybrids is unbalanced for a field, overall field efficiency and capacity can decrease. One hybrid may need more space than what is available in one bulk tank on the planter. If multi-hybrid capabilities were not being used, total capacity would be enough to complete the field. However, by splitting hybrids, capacity is restricted. By not being able to fill bulk tanks to full capacity, more filling time is necessary as well as possible drive time through a field to a location to refill.

Questions about the type and number of spatial data layers have yet to be answered. How many different data layers are necessary to appropriately quantify variability across the field? How many years of yield data are needed to build a representative dataset of normal yield patterns and distribution? The extent of the research indicates that even at
field sites with over ten years of yield data and multiple supplemental datasets, zone structure is still very dependent on temporal variability. Appropriate zones can vary from year to year due to temporal variability as evidenced by zone scenarios analysis for site M40 from 2016 and 2017. Would more years of yield data as well as other supplemental attributes help offset some of the effects of temporal variability? Further research and analysis with larger data sets available is necessary to answer this question.

Additionally, by what means can temporal variability be quantified? What is the best way to calculate the impact rainfall, temperatures and general weather conditions had on yield in a given year? Is it possible to scale spatial variability used in clustering algorithms based on temporal variability in the year they were collected? This research indicated that a large portion of the response of zones and hybrids could be influenced by environmental conditions. This was particularly true for two “wet” growing seasons. What exact impact did the moisture conditions for the 2016 and 2017 growing conditions have on results?

This leads to another important factor: what environmental conditions are we planning for? Should zone maps be created for an average, wet, or dry growing season? And what is classified as an average, wet, or dry year? Ideally, zones would be able to perform well in all circumstances. In practice, this is unlikely, simply based on the complex interactions of soil, water, hybrids, and temperatures from year to year. Since that is unlikely, is it best to plan for an average or dry year, assuming those are the situations that would receive the most benefit from multi-hybrid planting? Several of the corn sites in the study indicate that it was best to plan for a dry scenario every year. Since
no negative yield impact resulted from planting for a dry year scenario for those locations, it could be prudent to plan for that situation each year. In the years that situation comes to fruition, the hybrid placement will be correct to optimize production for that year.

Finally, hybrid selection is going to be a significant challenge moving forward. Hybrids are often marketed as multi-environment hybrids, rather than offensive or defensive. Distinctly offensive or defensive hybrids are difficult to find. In the current planting system, it makes more sense for hybrids to work across a variety of situations in an attempt to deal with the in-field variability. Unless some changes are made to the current plant breeding and development system, it may be difficult to find hybrids with enough differences to plant as an offensive/defensive pairing. Another issue with hybrids is their lifespan on the market. Hybrids are having a shorter lifespan than in years past. By the time a good hybrid pairing is selected for a field, one or both of those hybrids may no longer be available for sale. Seed companies need to provide more information on hybrid lineage and transparency of parent lines in order for producers to successfully select appropriate hybrid successors.

These are just several of the more commonly discussed issues presented with multi-hybrid planting. Multi-hybrid planting will be of benefit, however, several obstacles must be overcome before this practice becomes mainstream. Some applications show more immediate promise than others, such as using the technology for temporally stable issues like sudden death syndrome. In the meantime, it would be wise for producers to begin collecting as much yield and supplemental data as possible as well as begin performing
tests using split planter analysis. The producers who do will be much more prepared for multi-hybrid planting when the time for adoption comes.
CHAPTER 6  APPENDIX A: Corn

6.1  Historical Weather Data Corn

6.1.1  2016

Figure 6.1: 2016 weather data and 30 year average for field site UNL1

Figure 6.2: 2016 weather data and 30 year average for field site SS
Figure 6.3: 2016 weather data and 30 year average for field site M40

A.1.1 2017

Figure 6.4: 2017 weather data and 30 year average for field sites AE and AW
Figure 6.5: 2017 weather data and 30 year average for field sites ME, UNL2, and UNL3

Figure 6.6: 2017 weather data and 30 year average for field sites M40
6.2 Prescription Maps Corn

2016 Prescription -- M40

Figure 6.7: Prescription map for site M40
Figure 6.8: Prescription map for site SS
Figure 6.9: Prescription map for site DP
Figure 6.10: Prescription map for site UNL1
Figure 6.11: Prescription map for site M40 (2017)
2017 Prescription -- AE

Figure 6.12: Prescription map for site AE
2017 Prescription -- AW

Figure 6.13: Prescription map for site AW
2017 Prescription-- ME

Figure 6.14: Prescription map for sites ME
Figure 6.15: Prescription map for site UNL2
2017 Prescription-- UNL3

Figure 6.16: Prescription map for site UNL3
6.3 As Applied Planting Corn

Figure 6.17: Planting map for site M40 (2016)
2016 Planting-- SS

Figure 6.18: Planting map for site SS
2016 Planting – SS

Figure 6.19: Planting map for site DP
Figure 6.20: Planting map for site UNL1
2017 Planting-- M40

Figure 6.21: Planting map for site M40 (2017)
2017 Planting-- AE

Figure 6.22: Planting map for site AE

Hybrid Placement
1197 (36.13 ac)
A6499 (37.99 ac)
2017 Planting-- AW

Hybrid Placement
5F-709 (38.04 ac)
830-39 (32.18 ac)

Figure 6.23: Planting map for site AW
2017 Planting-- ME

Figure 6.24: Planting map for site ME
2017 Planting-- UNL2

Hybrid Placement
1151 (23.79 ac)
62-98 (50.84 ac)

Figure 6.25: Planting map for site UNL2
2017 Planting-- UNL3

Hybrid Placement
1257 (30.03 ac)
1498 (21.75 ac)

Figure 6.26: Planting map for site UNL3
6.4 Aerial Imagery

6.4.1 RGB

6.4.1.1 2016

Figure 6.27: RGB Aerial Imagery for field site M40 (2016)
Figure 6.28: RGB Aerial Imagery for field SS
Figure 6.29: RGB Aerial Imagery for field DP
Figure 6.30: RGB Aerial Imagery for field UNL1
Figure 6.31: RGB Aerial Imagery for field AE
Figure 6.32: RGB Aerial Imagery for field AW
Figure 6.33: RGB Aerial Imagery for field ME
Figure 6.34: RGB Aerial Imagery for field UNL2
6.4.2 NDVI

6.4.2.1 2016

Figure 6.35: NDVI Aerial Imagery for field M40 (2016)
Figure 6.36: NDVI Aerial Imagery for field SS
Figure 6.37: NDVI Aerial Imagery for field DP
Figure 6.38: NDVI Aerial Imagery for field UNL1
Figure 6.39: NDVI Aerial Imagery for field M40 (2017)
Figure 6.40: NDVI Aerial Imagery for field AE
Figure 6.41: NDVI Aerial Imagery for field AW
Figure 6.42: NDVI Aerial Imagery for field ME
Figure 6.43: NDVI Aerial Imagery for field UNL2
Figure 6.44: NDVI Aerial Imagery for field UNL3
6.4.3 NDRE

6.4.3.1 2017

Aerial Imagery: M40 NDRE

Legend

NDRE Value
High : 0.568248
Low : 0.0956318

0 0.0325 0.065 0.13 Miles
Figure 6.45: NDRE Aerial Imagery for field M40 (2016)

Figure 6.46: NDRE Aerial Imagery for field AE
Figure 6.47: NDRE Aerial Imagery for field AW
Figure 6.48: NDRE Aerial Imagery for field ME
Figure 6.49: NDRE Aerial Imagery for field UNL2
Figure 6.50: NDRE Aerial Imagery for field UNL3
6.5 Yield Maps

6.5.1 2016

Figure 6.51: Yield map for field M40 (2016)
Figure 6.52: Yield map for field SS
Grain Harvest 2016 - DP

Year: 2016
Operation: Grain Harvest
Area: 132.13 ac
Avg. Yield: 219.40 bu/ac
Avg. Moisture: 17.58 %

Yield (Dry)

- 254.36 - 309.99 (18.84 ac)
- 240.54 - 254.36 (20.55 ac)
- 228.70 - 240.54 (20.04 ac)
- 216.65 - 228.70 (19.48 ac)
- 201.80 - 216.65 (18.81 ac)
- 179.23 - 201.80 (17.84 ac)
- 60.04 - 179.23 (16.55 ac)

Figure 6.53: Yield map for field DP
Figure 6.54: Yield map for field UNL1
Figure 6.55: Yield map for field M40 (2017)
Grain Harvest 2017 - AE

Figure 6.56: Yield map for field AE

Year: 2017
Operation: Grain Harvest
Area: 59.02 ac
Avg. Yield: 180.07 bu/ac
Avg. Moisture: 14.22%
Figure 6.57: Yield map for field AW

Year: 2017
Operation: Grain Harvest
Area: 53.72 ac
Avg. Yield: 161.60 bu/ac
Avg. Moisture: 13.25 %

Yield (Dry) (bu/ac)
- 208.86 - 299.72 (5.866 ac)
- 186.43 - 208.86 (7.381 ac)
- 172.51 - 186.43 (7.950 ac)
- 159.83 - 172.51 (8.293 ac)
- 143.69 - 159.83 (8.385 ac)
- 128.81 - 143.69 (9.515 ac)
- 47.01 - 118.81 (7.630 ac)

Area (ac)

Yield (Dry) (bu/ac)
Figure 6.58: Yield map for field ME
Figure 6.59: Yield map for field UNL2
Figure 6.60: Yield map for field UNL3
6.6 SAS Code for Yield analysis

proc mixed;
  class zone rep trt;
  model Yield= zone Trt Trt*zone;
  random rep(zone);
  lsmeans Trt Trt*zone/diff;
  ods output diffs=ppp lsmeans=mmm;
  ods listing exclude diffs lsmeans;
  run;
  %include 'd:pdmix800.sas';
  %pdmix800(ppp,mmm,alpha=0.05,sort=yes);
  run;
  pdmix800 Macro (Saxton, n.d.)
## 6.7 Difference of Least Square Means, Hybrid by Zone Analysis

### Table 6.1: Difference of least square means with zone interaction from yield analysis

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<th>Trt Estimate</th>
<th>Error</th>
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### 6.8 Yield Results Zone Basis

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Figure 6.61: 2016 site M40 Yield Results. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 6.62: 2016 site SS Yield Results. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

![Figure 6.62](image)

Figure 6.63: 2016 Site DP Yield Results. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

![Figure 6.63](image)

Figure 6.64: 2016 Site UNL1 Yield Results. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

![Figure 6.64](image)
Figure 6.65: 2017 site M40 Yield data. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 6.66: 2017 site AE Yield Data. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 6.67: 2017 site AW Yield Results. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 6.68: 2017 site ME Yield Data. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 6.69: 2017 site UNL2 Yield Data. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 6.70: 2017 site UNL3 Yield Data. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
6.9 Independent Variables Regression

6.9.1 Example R Code for Smooth Regression

```r
#===================================
# Preparation
#===================================
setwd('C:/Users/rstevens4/Documents/Kinze Multi-Hybrid')
library(tidyverse)
library(tmap)
library(ggthemes)

#===================================
# Convert the data set into units/labels
#===================================

#--- import the data ---#
data <- read_csv('multi_points.csv')
data <- mutate(data, seed_txt=ifelse(ZONE2==1,'Offensive','Defensive'))
data <- mutate(data, trt_txt=ifelse(TREATMENT2==1,'P1271','P1197'))
data <- mutate(data, yield_mgha_txt=YIELD/15.93)
data <- mutate(data, elevation_m_txt=ELEVATION2*0.3048)
data <- mutate(data, soil_txt='Yutan',
               soil_txt=ifelse(SOIL_TYPE2==1,'Steinauer',soil_txt),
```
soil_txt = ifelse(SOIL_TYPE2 == 3, 'Pohocoo', soil_txt),
soil_txt = ifelse(SOIL_TYPE2 == 4, 'Nodaway', soil_txt)
)

data$seed_txt

data$trt_txt

data$yield_mgha_txt

data$elevation_m_txt

data$soil_txt

#=====================================  
#  Elevation  
#===================================== 

#--- filter the data based on the values of a variable ---
data_filtered <- filter(data, TREATMENT2 > 0)

# metric
elevation <- ggplot(data_filtered) +
geom_smooth(aes(y=yield_mgha_txt, x=elevation_m_txt, color=factor(trt_txt))) +
facet_grid(seed_txt~.) +
xlab('Elevation (M)') +
ylab(expression("Yield"~(Mg~Ha^{-1}))) +
labs(fill='Treatment') +
scale_color_manual(legend_title, values = c("black", "grey57")) +
theme_calc() +
Figure 6.71: Site M40 2016 yield data by soil, treatment and zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Figure 6.72: Site M40 2016 yield data by elevation, treatment and zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 6.73: Site M40 2016 yield data by elevation and treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.
Figure 6.74: Site M40 2016 yield data by shallow EC, treatment and zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.75: Site M40 2016 yield data by shallow EC and treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.76: Site M40 2016 yield data by slope, treatment and zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.77: Site M40 2016 yield data by slope and treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.78: Site M40 2016 yield data by wetness, treatment and zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.79: Site M40 2016 yield data by wetness and treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
6.9.3 Site SS

Figure 6.80: Site SS yield by treatment by elevation by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.81: Site SS yield by treatment and elevation regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.82: Site SS yield by treatment by shallow EC by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.83: Site SS yield by treatment and shallow EC regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.84: Site SS yield by treatment and slope regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.85: Site SS yield by treatment and wetness regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.86: Site SS yield by treatment by soil by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 6.87: Site SS yield by treatment by deep EC by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
6.9.4 Site DP

Figure 6.88: Site DP yield by treatment by deep EC regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha^-1 are corrected to 15.5% moisture.

Figure 6.89: Site DP yield by treatment by elevation regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha^-1 are corrected to 15.5% moisture.
Figure 6.90: Site DP yield by treatment by shallow EC by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.91: Site DP yield by treatment by shallow EC regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.92: Site DP yield by treatment by slope by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 6.93: Site DP yield by treatment by slope regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
Figure 6.94: Site DP yield by treatment by wetness regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.95: Site DP yield by treatment by soil series by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.96: Site DP yield by treatment by deep EC by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

6.9.5 Site UNL1

Figure 6.97: Site UNL1 yield by treatment by deep EC by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.98: Site UNL1 yield by treatment by deep EC regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.99: Site UNL1 yield by treatment by elevation by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.100: Site UNL1 yield by treatment by elevation regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.101: Site UNL1 yield by treatment by shallow EC by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.102: Site UNL1 yield by treatment by shallow EC regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.103: Site UNL1 yield by treatment by slope by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.104: Site UNL1 yield by treatment by slope regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 6.105: Site UNL1 yield by treatment by wetness potential regression. Mg ha$^{-1}$ are corrected to 15.5% moisture.
Figure 6.106: Site UNL1 yield by treatment by soil series by zone regression. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha-1 are corrected to 15.5% moisture.

6.9.6 M40 2017

Figure 6.107: Site M40 yield by treatment by soil series regression analysis. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.108: Site M40 yield by treatment by deep EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 6.109: Site M40 yield by treatment and elevation by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Figure 6.110: Site M40 yield by treatment by elevation regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 6.111: Site M40 yield by treatment by shallow EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.
Figure 6.112: Site M40 yield by treatment and slope by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 6.113: Site M40 yield by treatment by slope regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Figure 6.114: Site M40 yield by treatment and wetness potential by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.115: Site M40 yield by treatment by wetness potential regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.116: Site M40 yield by treatment and soil series by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha-1 are corrected to 15.5% moisture.

6.9.7 Site AE

Figure 6.117: Site AE yield by treatment by deep EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.118: Site AE yield by treatment by elevation regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.119: Site AE yield by treatment by shallow EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.120: Site AE yield by treatment by slope by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.

Figure 6.121: Site AE yield by treatment by slope regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 15.5% moisture.
Figure 6.122: Site AE yield by treatment by wetness regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.123: Site AE yield by treatment by soil series by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.124: Site AE yield by treatment by deep EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

6.9.8 Site AW

Figure 6.125: Site AW yield by treatment by deep EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.126: Site AW yield by treatment by deep EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.127: Site AW yield by treatment by elevation by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.128: Site AW yield by treatment by elevation regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.129: Site AW yield by treatment by shallow EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.130: Site AW yield by treatment by shallow EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.131: Site AW yield by treatment by slope gradient by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.132: Site AW yield by treatment by slope regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.133: Site AW yield by treatment by wetness potential regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.134: Site AW yield by treatment by soil series by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.135: Site AW yield by treatment by soil series regression analysis. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.136: Site ME yield by treatment by elevation by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.137: Site ME yield by treatment by elevation by zone regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.138: Site ME yield by treatment by shallow EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 6.139: Site ME yield by treatment by shallow EC by zone regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
Figure 6.140: Site ME yield by treatment by slope gradient by zone regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.

Figure 6.141: Site ME yield by treatment by wetness potential by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 15.5% moisture.
Figure 6.142: Site ME yield by treatment by soil series by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.143: Site ME yield by treatment by soil series by zone regression analysis. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.144: Site ME yield by treatment by deep EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.145: Site ME yield by treatment by deep EC by zone regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
6.9.10 Site UNL2

Figure 6.146: Site UNL2 yield by treatment by elevation regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 6.147: Site UNL2 yield by treatment by shallow EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
Figure 6.148: Site UNL2 yield by treatment by slope by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 6.149: Site UNL2 yield by treatment by wetness potential by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
Figure 6.150: Site UNL2 yield by treatment by wetness potential regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.151: Site UNL2 yield by treatment by soil series by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.152: Site UNL2 yield by treatment by soil series regression analysis. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.153: Site UNL2 yield by treatment by deep EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.154: Site UNL2 yield by treatment by elevation by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

6.9.11 Site UNL3

Figure 6.155: Site UNL3 yield by treatment by soil series regression analysis. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.156: Site UNL3 yield by treatment by deep EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.

Figure 6.157: Site UNL3 yield by treatment by deep EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 15.5% moisture.
Figure 6.158: Site UNL3 yield by treatment by elevation by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.159: Site UNL3 yield by treatment by elevation regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.160: Site UNL3 yield by treatment by shallow EC by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.161: Site UNL3 yield by treatment by shallow EC regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.162: Site UNL3 yield by treatment by slope by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.

Figure 6.163: Site UNL3 yield by treatment by slope regression analysis. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
Figure 6.164: Site UNL3 yield by treatment by wetness potential by zone regression analysis. Hybrid regressions are separated by defensive and offensive zone, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 15.5% moisture.
6.10 Zone Scenario Maps

Figure 6.165: Zone Scenario map for SS
Figure 6.166: Zone Scenario map for site AE
Figure 6.167: Zone Scenario map for site AW
Figure 6.168: Zone Scenario map for site UNL2
### 6.11 Difference of Least Square Means Scenario Analysis

Table 6.2: Difference of least square means with zone interaction from zone scenario analysis

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6.12 Yield Results Zone Restructuring

Figure 6.169: Site M40 2016 yield results from zone restructuring. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval.

Letters apply within zones.

Figure 6.170: Yield results from site SS zone restructuring. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 6.171: Yield results from site M40 2017 zone restructuring. Mg ha$^{-1}$ are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 6.172: Yield results from site AE zone restructuring. Mg ha$^{-1}$ are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 6.173: Yield results from site AW zone restructuring. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 6.174: Yield results from site UNL2 zone restructuring. Mg ha\(^{-1}\) are corrected to 15.5% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
CHAPTER 7  APPENDIX B: Soybeans

7.1 Historical Weather Data

Figure 7.1: 2016 rainfall and 30 year historical rainfall for field WM

Figure 7.2: 2016 rainfall and 30 year historical rainfall for field PM
Figure 7.3: 2017 rainfall and 30 year historical rainfall for field WH

Figure 7.4: 2017 rainfall and 30 year historical rainfall for field NB and KE
7.2 Prescription Maps Soybeans

2016 Prescription-- WM

Figure 7.5: Prescription map for site WM
Figure 7.6: Prescription map for site PM
Figure 7.7: Prescription map for site WH
2017 Prescription-- NB

Figure 7.8: Prescription map for site NB
2017 Prescription-- KE

Figure 7.9: Prescription map for site KE
7.3 As Applied Planting Soybeans

Figure 7.10: Planting map for field WM
2016 Planting-- PM

Figure 7.11: Planting map for field PM
2017 Planting-- WH

Figure 7.12: Planting map for field WH
Figure 7.13: Planting map for field NB
2017 Planting-- KE

Figure 7.14: Planting map for field KE
Figure 7.15: SCN population and distribution for field WM
Figure 7.16: SCN population and distribution for field NB
Figure 7.17: SCN population and distribution for field KE
7.5 Aerial Imagery

7.5.1 RGB

Figure 7.18: RGB Aerial Imagery for field WM
Figure 7.19: RGB Aerial Imagery for field PM
Figure 7.20: RGB Aerial Imagery for field WH
Figure 7.21: RGB Aerial Imagery for field NB
Figure 7.22: RGB Aerial Imagery for field KE
7.5.2 NDVI

Figure 7.23: NDVI Aerial Imagery for field WM
Figure 7.24: NDVI Aerial Imagery for field PM
Figure 7.25: NDVI Aerial Imagery for field WH
Figure 7.26: NDVI Aerial Imagery for field NB
Figure 7.27: NDVI Aerial Imagery for field KE
Figure 7.28: NDRE Aerial Imagery for field WH
Figure 7.29: NDRE Aerial Imagery for field NB
Figure 7.30: NDRE Aerial Imagery for field KE
7.6 SAS Code for Yield Analysis

proc mixed;
  class zone rep trt;
  model Yield= zone Trt Trt*zone;
  random rep(zone);
  lsmeans Trt Trt*zone/diff;
  ods output diffs=ppp lsmeans=mmm;
  ods listing exclude diffs lsmeans;
run;
%include 'd:pdmix800.sas';
%pdmix800(ppp,mmm,alpha=0.05,sort=yes);
run;
pdmix800 Macro (Saxton, n.d.)
### 7.7 Difference of Least Square Means

**Table 7.1:** Difference of least square means with zone interaction from yield analysis

<table>
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<tr>
<th>Field</th>
<th>Effect</th>
<th>zone</th>
<th>Trt</th>
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7.8 Yield Results on a Zone Basis

Figure 7.31: Site WM Yield results by Zone. Mg ha\(^{-1}\) are corrected to 13.0% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 7.32: 2017 site WH Yield Results. Mg ha\(^{-1}\) are corrected to 13.0% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 7.33: 2017 site NB Yield Results. Mg ha$^{-1}$ are corrected to 13.0% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 7.34: 2017 site KE Yield Results. Mg ha$^{-1}$ are corrected to 13.0% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
7.9 Harvest Maps

Grain Harvest 2016 - WM

Figure 7.35: Harvest map for site WM
Figure 7.36: Harvest map for site PM
Grain Harvest 2017 - WH

Figure 7.37: Harvest map for site WH
Grain Harvest 2017 - NB

Figure 7.38: Harvest map for site NB
Figure 7.39: Harvest map for site KE
7.10 Independent Variables Regression
7.10.1 Example R Code for Smooth Regression

```r
#===================================
# Preparation
#===================================
setwd('C:/Users/rstevens4/Documents/Kinze Multi-Hybrid/
library(tidyverse)
library(tmap)
library(ggthemes)

#===================================
# Convert the data set into units/labels
#===================================
#--- import the data ---#
data <- read_csv('multi_points.csv')

create new column headings for zones
data <- mutate(data, seed_txt=ifelse(ZONE2==1,'Offensive','Defensive'))
data <- mutate(data, trt_txt=ifelse(TREATMENT2==1,'P1271','P1197'))
data <- mutate(data, yield_mgha_txt=YIELD/15.93)
data <- mutate(data, elevation_m_txt=ELEVATION2*0.3048)
data <- mutate(data, soil_txt='Yutan',
soil_txt=ifelse(SOIL_TYPE2==1,'Steinauer',soil_txt),
soil_txt=ifelse(SOIL_TYPE2==3,'Pohocco',soil_txt),
soil_txt=ifelse(SOIL_TYPE2==4,'Nodaway',soil_txt)

}
data$seed_txt
data$trt_txt
data$yield_mgha_txt
data$elevation_m_txt
data$soil_txt

#===================================
# Elevation
#===================================
#--- filter the data based on the values of a variable ---
data_filtered <- filter(data,TREATMENT2 > 0)

# metric
```
elevation <- ggplot(data_filtered) +
geom_smooth(aes(y=yield_mgha_txt,x=elevation_m_txt,color=factor(trt_txt))) +
facet_grid(seed_txt~.) +
xlab('Elevation (M)') +
ylab(expression("Yield"~(Mg~Ha^-1))) +
labs(fill='Treatment') +
scale_color_manual(legend_title, values = c("black", "grey57")) +
theme_calc() +
theme(
legend.position='bottom', legend.direction = "horizontal"
)
ggsave(elevation,file='C:/Users/rstevens4/Documents/Kinze Multi-Hybrid/Graphs/elevation.jpg')

7.10.2 Site WM

![Graph](image)

Figure 7.40: Site WM 2016 yield data by wetness potential by treatment by zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^1\) are corrected to 13.0% moisture.
Figure 7.41: Site WM 2016 yield data by soil series by treatment by zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Mg ha\(^{-1}\) are corrected to 13.0% moisture.

Figure 7.42: Site WM 2016 yield by soil series and treatment regression. Mg ha\(^{-1}\) are corrected to 13.0% moisture.
Figure 7.43: Site WM 2016 yield by elevation and treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 13.0% moisture.

Figure 7.44: Site WM 2016 yield data by slope by treatment by zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 13.0% moisture.
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Figure 7.45: Site WM 2016 yield by slope and treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 13.0% moisture.

7.10.3 Site PM

Figure 7.46: Site PM 2016 yield by soil series by treatment and zone regression. Treatment regressions are separated by severe, moderate and no SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 13.0% moisture.
Figure 7.47: Site PM 2016 yield by soil series by treatment regression. Mg ha\(^{-1}\) are corrected to 13.0\% moisture.

Figure 7.48: Site PM 2016 yield by elevation levels by treatment and zone regression. Treatment regressions are separated by severe, moderate and no SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95\% confidence interval. Mg ha\(^{-1}\) are corrected to 13.0\% moisture.
Figure 7.49: Site PM 2016 yield by elevation by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 7.50: Site PM 2016 yield by slope levels by treatment and zone regression. Treatment regressions are separated by severe, moderate and no SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.
Figure 7.51: Site PM 2016 yield by slope by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 7.52: Site PM 2016 yield by wetness potential levels by treatment and zone regression. Treatment regressions are separated by severe, moderate and no SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.
7.10.4 Site WH

Figure 7.53: Site WH 2017 yield by soil series by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Mg ha-1 are corrected to 13.0% moisture.

Figure 7.54: Site WH 2017 yield by soil series by treatment regression. Mg ha-1 are corrected to 13.0% moisture.
Figure 7.55: Site WH 2017 yield by elevation by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 7.56: Site WH 2017 yield by elevation by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.
Figure 7.57: Site WH 2017 yield by slope by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.

Figure 7.58: Site WH 2017 yield by slope by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha-1 are corrected to 13.0% moisture.
Figure 7.59: Site WH 2017 yield by wetness potential by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 13.0% moisture.

7.10.5 Site NB

Figure 7.60: Site NB 2017 yield by soil type by treatment regression. Mg ha⁻¹ are corrected to 13.0% moisture.
Figure 7.61: Site NB 2017 yield by elevation by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 13.0% moisture.

7.10.6 Site KE

Figure 7.62: Site KE 2017 yield by soil series by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Mg ha\(^{-1}\) are corrected to 13.0% moisture.
Figure 7.63: Site KE 2017 yield by deep EC by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 13.0% moisture.

Figure 7.64: Site KE 2017 yield by elevation by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 13.0% moisture.
Figure 7.65: Site KE 2017 yield by elevation by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 13.0% moisture.

Figure 7.66: Site KE 2017 yield by shallow EC by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha$^{-1}$ are corrected to 13.0% moisture.
Figure 7.67: Site KE 2017 yield by shallow EC by treatment regression. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 13.0% moisture.

Figure 7.68: Site KE 2017 yield by slope by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha\(^{-1}\) are corrected to 13.0% moisture.
Figure 7.69: Site KE 2017 yield by wetness potential by treatment and zone regression. Treatment regressions are separated by standard and SDS zones, noted on the right side of the graph. Grey bands around regression lines indicate a 95% confidence interval. Mg ha⁻¹ are corrected to 13.0% moisture.
7.11 Zone Scenario Maps

Figure 7.70: Zone scenario map for site PM
Figure 7.71: Zone Scenario map for site WH
Figure 7.72: Zone scenario map for site KE
### 7.12 Difference of Least Square Means for Zone Scenario Analysis

Table 7.2: Difference of least square means with zone interaction from zone scenario analysis

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<th>Field</th>
<th>Effect</th>
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<th>Estimate</th>
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7.13 Zone Scenario Yield Results

Figure 7.73: 2016 site PM Zone Scenario Delineation. Mg ha\(^{-1}\) are corrected to 13.0% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.

Figure 7.74: Site WH Zone scenario delineation. Mg ha\(^{-1}\) are corrected to 13.0% moisture. Values with the same letter are not significantly different at a 95% confidence interval. Letters apply within zones.
Figure 7.75: Site KE zone scenario delineation. Mg ha\(^{-1}\) are corrected to 13.0\% moisture. Values with the same letter are not significantly different at a 95\% confidence interval. Letters apply within zones.
CHAPTER 8  APPENDIX C: Split Planter

8.1  Zone Scenario Maps Case Study 1

Case Study 1: Elevation Zone Scenario

Legend
Terrain Zone
Zone 1
Zone 2
Figure 8.1: Elevation zone scenario map for Case Study 1

Figure 8.2: Soil series zone scenario map for Case Study 1
8.2 Zone Scenario Maps Case Study 2

![Case Study 2: Wetness Potential Zone Scenario Map](image)

Figure 8.3: Wetness potential zone scenario map for Case Study 2