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Does applying humic acids with fall fertilizer increase yield and/or affect soil and crop nutrient contents in a corn (Zea Mays L.) and soybean (Glycine Max L. Merr) rotation?

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by

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INTRODUCTION

Rationale

Crop production in the Midwest has seen a major influx of new technologies over the last decade. The competitive marketplace has pushed growers into trying new products that may offer them increased yield and profit. New products are brought to the market so rapidly that there is not enough research to demonstrate the value of these technologies. This makes it challenging for growers and retailers to determine which products will add value to their fields or their customers. One of these technologies that is being utilized is humic acids. The humic acid industry has been steadily growing, with more and more fertilizer retailers and specialty crop input companies offering a humic acid product. This increase in availability has led to increased use of these products in crop production.

The challenge for humic acids and other new crop production technologies is to determine how and if they can truly benefit the crop. Research has shown that crop performance can be improved in certain applications, but the industry claims are much broader than the supporting evidence provided by research. Industry claims of a humic acids capability to improve phosphorus (P) and potassium (K) availability and uptake of soil applied fertilizer is a common example of a claimed benefit that lacks adequate evidence. The benefits of applying humic acids outside of the growing season, such as with post-harvest fertilizer, is another area where the industry claims are not supported by outside research. Finally, published research is limited on some key crops that the industry claims humic acids can benefit. For example, soybeans have received very little research attention. Yet the corn-soybean rotation is the most common cropping system across the Midwest, and a focus on the specific benefits of humic acids to both crops in this rotation is in need of attention.

As humic acid sales and use continue to grow, it is becoming increasingly crucial to document humic product efficacy. From a retail perspective, the agronomist, the sales representative, and the parent company need to understand the benefits and limitations of the products they want to sell their customers. It is also important for them to understand which application methods offer the most return when using a new product like a humic acid. Adequate research documentation enables them to not only deliver products that provide the customers with increased yield and profitability, but also to confidently and sustainably sell a value-added product that makes the retail outfit more profitable. If, for example, the benefits of humic acids applied with fall fertilizer can be proven, it would offer the grower unique benefits as well. Yield increases above the cost of the application will demonstrate humic acid application as a means to increase productivity and profitability of the grower. Proven increases in fertilizer use efficiency would offer the grower further profitability advantages by reducing fertilizer input costs, while maintaining or increasing yield. Increases in fertilizer use efficiency could offer broad environmental benefits by decreasing the amount of fertilizer applied, thereby reducing the movement of excessive nutrient loads into the environment. For these reasons a research study was developed to study whether humic product application increases fertilizer use efficiency.

The objective of this research study is to determine the benefits of applying a humic acid together with post-harvest P and K fertilizers in a corn and soybean rotation. The most specific benefit is hypothesized to be increased yield of both corn and soybean crops. Increases in nutrient availability and/or uptake by the corn and soybean crops will also be investigated.

To test for these benefits, a humic product was applied in a field trial every fall with P and K fertilizers, compared to the control of P and K fertilizers alone in alternating field strips. The trial was conducted over four years of alternating corn and soybean, beginning with the 2017 soybean crop and concluding with the 2020 corn crop. Yield advantages determined by yield monitor will be the primary indicator for crop benefits. Post-harvest soil samples as well as in-season tissue samples will be analyzed for possible responses in soil and plant nutrient contents.

Objectives

1. Determine whether the application of a humic product with fall fertilizer increases the yields and profitability of corn and soybeans.
2. Determine whether the application of a humic product with fall fertilizer increases soil nutrient availability and plant nutrient uptake.

BACKGROUND

The Nature of Humic Acids

To begin reducing the confusion around humic acids use in crop production, it is first important to understand the nature of humic acids. Humic acids are diverse in their chemical structure; they are composed of organic molecules randomly linked together, resulting in highly reactive, complex chemical structures. Humic acids have unique complexation and ion properties, resulting from the negatively charged carboxyl groups and phenolic groups in their structure. Humic acids can bind to soil mineral surfaces and have both hydrophilic and hydrophobic properties (Mikkelsen, 2005).

Humic substances are composed of a mixture of plant and microbial constituents, such as carbohydrates, proteins, lipids, and partially degraded lignin. The constituents exist in various stages of decomposition (Pena-Mendez et al., 2005). Under suitable geographical and climatic conditions, this humic material may form geologic deposits, including leonardite. Leonardite can be mined, and then it is often treated with an alkali solution to separate soluble humic substances from the insoluble humin material (Mikkelsen, 2005). From this stage in industrial production of commercial humic products, there are several other additives that may be included, depending on the processor. The soluble humic substances may be further broken down to separate the humic acids and fulvic acids. The humic acid may be combined with binders or fertilizer additives. In this research study we will focus on pure humic acid, separate from different processing methods or additives that may become part of the end product.

Humic substances are widely available to manufacturers but are currently marketed as a proprietary technology. This allows retailers to sell humic products at a significantly greater margin than many of the more traditional crop inputs. There is also enough positive publicity around humic acids to increase grower interest. For these reasons the humic product marketplace is diverse and expanding rapidly. The product diversity in the industry further complicates the perceived benefits of humic acids. Humic acids by nature are not uniform, and the mechanisms that cause the formation of humic substances can vary depending on geographical, climatic, physical, and biological circumstances (Pena-Mendez et al., 2005). This leads to similar, but not identical humic acids that are brought to market. Further complicating the industry is that several different manufacturers have made humic products with many different additives. This research study will evaluate Hydra-Hume DG-A “Coated”, which is a granular leonardite product composed of 70% active humic acids and no other listed active ingredients. This product is readily available commercially.

Proven Benefits of Humic Acids in Crop Production

Plant Growth Benefits

The number of published studies that have evaluated the efficacy of humic products on a wide variety of crop species is increasing rapidly. They cannot all be summarized in this paper, but this brief overview will provide context around the work that was done here. Laboratory studies as early as 1979 showed that the addition of humic acids to plant growth solutions generally increased corn root and shoot growth (Tan and Nopamornboi, 1979). Research has continued through the years and has found positive results, regarding plant growth, yield, and nutrient uptake.

Much of the humic acid research has focused on crops that are not incorporated in this study. For example, a field study of lettuce (*Lactuca sativa* L.m), high levels of humic acid applied to the soil showed increases in nitrogen (N) content of the lettuce, and P availability in the soil (Mesut et al., 2005). In an in-field study on spinach (*Spinacia oleracea*), similar results were found that applying humic acid to the soil increased N and P content of the spinach, as well as increased leaf biomass for economic yield (Ayas and Gulser, 2005). Another in-field study on potatoes (*Solanum tuberosum*) found that applying humic acids through fertigation increased potato growth parameters and tuber production, as well as increased macro- and micronutrient concentrations in the potato leaves (Selim et al., 2012). It should be noted that in these studies, humic acids were applied at rates far higher than those commonly recommended for corn and soybeans. Specifically, the rates of humic acid in these studies ranged from 60-300 kg ha^{-1}, whereas most commercial recommendations are for 10-20 kg ha^{-1}. However, an in-field study in wheat (*Triticum aestivum* L.) found that applications of humic acid at only 3 kg ha^{-1} increased wheat plant height, number of tillers per plant and grain yield over the untreated control (Khan et al., 2010). In another in-field study, humic acids were applied through drip irrigation to aerobic rice (*Oryza sativa*) (Vanitha and Mohandass, 2014). Plant height, root length, tiller density, and total chlorophyll content increased significantly with the addition of humic acids. The authors discussed that this increased root growth may be due to the plant hormone-like properties of humic acids and may be the cause for increased nutrient uptake mentioned in this and other studies (Vanitha and Mohandass, 2014). In general, the results showed that the addition of humic acids increased crop growth and productivity, improved water stress mitigation, and resulted in greater economic yield (Vanitha and Mohandass, 2014).

Research has also shown that improvements in crop quality may be possible through the use of humic acids. In a field study, soil applications of humic acids at common commercial rates were found to positively affect almost all growth and yield parameters of field mustard (*Brassica Compestris* L.), including increased seed oil content (Rajpar et al., 2011). In addition, Seleim et al. (2012) showed the addition of humic acids increased starch content, total soluble solids, and protein content of potatoes. The wide variety of research on humic acids across many crops provides a solid foundation in support of their potential benefits to crop growth.

In this study the focus will on a corn and soybean rotation. A brief review of humic acid research on the crops shows significant effects as well. As mentioned earlier, laboratory studies found increases in root and shoot growth of corn through the addition of humic acids (Tan and Nopamornbodi, 1979). This study also found increases in N concentration in the plant and increased biomass through the addition of humic acids. Sharif et al. (2006) found that soil addition of humic acids in the 50-100 mg/kg range caused significant increases in corn root and shoot growth in a pot experiment. They also found increases in plant N concentration and soil P concentrations. In the laboratory, the study was also able to determine that biological soil processes were also improved, including increases in bacteria and fungi populations, as well as increased CO_2 evolution. El-Mekser et al. (2014) showed that in a field study the application of humic acids during the growing season increased corn plant height, and grain yield, while reducing days to flowering. Research by Verlinden et al. (2009) studied the effects of humic acids across grass, corn, potato, and spinach. This study found a general increase in yield and nutrient uptake of P, K, and magnesium (Mg). Corn specifically had a fairly marginal yield increase, but the improvements in nutrient uptake were notable (Verlinden et al., 2009). Research on soybeans is less available, but a growth chamber study concluded that the addition of humic acids to a nutrient solution increased chlorophyll concentration in soybeans compared to the nutrient solution alone (Chen et al., 2004). Finally, an in-field study conducted in Iowa farm fields found that the application of humic products statistically increased soybean grain yield, as well as corn grain yield (Olk et al., 2013). These studies offer sufficient evidence that applications of humic acids can be beneficial under some circumstances to several different crop species, including the crops utilized in this study, and their use warrants further investigation.

Effects on Soil Phosphorus Availability

For this study of nutrient use efficiency, any effect of humic product application on P availability or uptake is of special importance. In the majority of other published studies, the humic product was applied during or shortly before the growing season. In this study, by contrast, the humic product was applied shortly after harvest of the previous crop. Applying humic products following harvest with P and K fertilizers is a commonly recommended practice across the Midwest region of the United States. The limited research around this application timing makes this study valuable.

Applying the humic product following harvest means the humic acids were not applied with a significant amount of N. This allowed the study to test for crop improvements that are not associated with N fertilizer use, and instead focus solely on industry claims around increases in P and K availability. Also, this study was conducted in a field with soils formed of calcareous parent material, with a pH values greater than 7. Under these conditions, P availability becomes a more central issue: The increased soil calcium concentration enhances formation of poorly soluble calcium phosphate species, thus potentially limiting P availability to plants (Hopkins and Ellsworth, 2005). In such conditions, high rates of P fertilizer are sometimes needed even when soil extractable P is high. Organically complexed P, such as in biosolids, manure, or a mixture of liquid P and humic substances, can enhance P nutrition and increase yields (Hopkins and Ellsworth, 2005). Wandruszka (2006) concluded that, “Humic materials both native and added appear to increase recovery of Olsen P. In the presence of metal cations, strong complexes between inorganic P and humates are formed”. Wang et al. (1995) found that application of a humic product with P fertilizer to an alkaline soil can increase the soil availability and uptake of P by wheat plants in a pot experiment and increase yield of wheat as shown in a field trial (Wang et al., 1995). Monitoring for increases in P availability or uptake with humic product application was a key goal of this study.

APPROACH

Trial Field Details

The trial field was in Washington County, Wisconsin, near West Bend, Wisconsin. A map of the exact location of the field in southeastern Wisconsin is shown in Figure A1, within the Appendix. The field is owned by Gundrum Brothers Farm, which was the cooperator in this experiment. The field had slightly rolling terrain, was of high fertility, and had been managed in a corn and soybean rotation for the last 10 years. Mean soil properties across the study area at the beginning of the trial were pH 7.2, organic matter 2.2%, Bray 1-extractable P 178 ppm, ammonium acetate-extractable K 200 ppm, and cation exchange capacity (CEC) 13.6 meq 100g^{-1}. The trial area was plotted onto several different soil series: Dodge, Hochheim, Theresa, and Juneau; the soil type map is shown in Figure A2 in the appendix. The taxonomic information for these soils can be found in Table 1 below. The prior two years of corn yield data on this field averaged 234 Bu A^{-1}. The prior two years of soybean yield data averaged 52 Bu A^{-1}.

Table 1. Soil Series present in trial area, and associated taxonomic information (Soil Survey Staff, 2019).

Soil Types Within Trial Area.	
Soil Series	**Soil Taxonomy**
Dodge	Fine-Silty, Mixed, Superactive, Mesic Typic Hapludalfs
Hochheim	Fine-Loamy, Mixed, Active, Mesic Typic Argiudolls
Theresa	Fine-Loamy, Mixed, Superactive, Mesic Typic Hapludalfs
Juneau	Coarse-Silty, Mixed, Superactive, Nonacid, Mesic Typic Udifluvents

Trial Development and Plot Layout

Humic Acid Application

To determine the field efficacy of humic acids in promoting nutrient uptake and grain yield of corn and soybean, a multi-year research trial was developed using post-harvest applications of P and K fertilizers in strips with and without a set rate of humic product. The strips with humic product combined with P and K fertilizers alternated with strips that contained only the fertilizers. A map of the study design can be found in figure A3 of the appendix. The humic acid product was Hydra-Hume DG A “coated”, which is a dry granular humic acid product, made up of 70% active humic acids derived from leonardite. The Hydra-Hume was applied with a blend of monoammonium phosphate and potassium chloride at the product’s most commonly recommended rate of 10 lb A^{-1}. Within each year, the fertilizer analysis and application rates were consistent across the strips with or without Hydra-Hume application. Following corn harvest and prior to a soybean crop, a fertilizer blend with the NPK analysis of 6-17-30 was applied at 250 lb A^{-1}. Following a soybean crop and prior to a corn crop a fertilizer blend of 5-25-31 was applied at 350 lb A^{-1}. Fertilizer applications were made using an AGCO Terragator airflow machine (Model # 8300B), to allow for consistent application of the humic product. The Terragator utilized a Raven Viper 4 monitor with guidance to ensure straight and even application. The application width of the airflow machine was 70 feet; hence the strips were 70 ft wide. The trial consisted of six replicates: six strips with the humic acid and six strips without. The entire study area encompassed about 30 acres of a 75-acre field. The strips were marked in the field with flags at the time of humic product and fertilizer application. The applications to the strips were repeated in the same fashion for four years. Year one and three applications were made after corn harvest, before the off-season going to a soybean crop, and year two and four applications were made after soybean harvest, before the off-season going to a corn crop.

Planting and Harvesting

Planting of corn and soybeans followed conventional practices of the cooperator. The soybean planter was a 32-row 15-inch spacing John Deere 1790. The corn planter was a 16-row 30-inch spacing John Deere 1770NT. At planting, trial markers were used to ensure proper planting lines across the strip. A John Deere GS3 monitor with guidance was used to maintain straight and even planter passes. The planter passes were 40 feet wide, which means they did not match the exact width of the fertilizer and humic product strips. For this reason, care was taken in planting to provide exactly even and parallel rows across the entire trial area. The trial was harvested with a John Deere 9670 combine. The soybean head was 30 feet wide, and the corn head was 20 feet wide. The widths of both the corn and soybean heads did not allow for complete harvesting of the entire strip. When harvesting soybeans, a 5-foot border was left between strips, and a 5-foot buffer was left in the center of each strip. This ensured that the combine head was full for each recorded pass. When harvesting corn, yield data was taken from two passes in the middle of each strip. Yield data were recorded for each individual strip.

Cropping Practices

Normal cooperator cropping practices were followed in the entire trial area throughout each growing season. In soybeans, they included a spring vertical tillage application to prepare the seed bed, a weed control program consisting of a pre-emergence application of a soil residual herbicide and a post-emergence application of glyphosate to control any escaping weeds. In corn, they included a spring vertical tillage pass to prepare the seed bed, and a weed control program consisting of a pre-emergence application of soil residual herbicide and a post-emergence herbicide application to control any escaping weeds. Corn received additional fertilizer in the form of starter fertilizer, urea ammonium nitrate applied pre-emergence with herbicide, and top-dressed urea applied at the V6-V8 corn growth stage. Any insect and disease control methods were conducted as needed following integrated pest management practices.

Data Collection and Analysis

The primary parameter for describing benefits from the humic acid application was grain yield. Yield was measured from each strip using a calibrated yield monitor on the John Deere 9670 combine. Yield data were collected and sorted using SST Summit software. Yield data outputs from SST can be found in figures A4-A6 of the appendix.

Soil sampling and tissue testing were the primary assessments of nutrient availability and uptake. Each strip was soil sampled at two specific GPS referenced positions every fall following harvest. The sampling points were located in the center rows of each 70-ft strip and were equidistant from the longitudinal center of each strip (generally 1/3 and 2/3 of the way through the length of each strip). A soil sample was collected at each georeferenced point, composed of five individual soil cores that were taken to a depth of 6 inches, in a 10-ft radius around each sampling point. The soil samples were analyzed by Rock River Labs (Watertown, WI). Tissue samples were collected each year from three of the six replicates at the R2 growth stage for both corn and soybeans. Tissue samples were composed of 15 randomly selected ear leaves in corn, and 25 randomly selected newest fully developed leaves in soybeans, as recommended by Kelling et al. (2002). Tissue nutrient analyses were performed by Rock River Laboratories.

All collected data were statistically analyzed to determine the significance of humic product effects. An analysis of variance was performed using the GLM procedure of SAS to determine treatment and year effects, and to assess their potential interactions, for multi-year and individual year analyses of yield data and soil nutrient data using the least significant difference method. Treatment differences with P values < 0.05 were considered significant.

RESULTS

Weather Patterns

Over the four years of this study, the weather patterns were generally favorable for crop growth, with above average precipitation during each year of the study, and temperatures that were near to above average for every year except for 2019, based on deviations from the 30-year (1981-2010) monthly mean, maximum, and minimum temperatures and total monthly precipitation as presented below in Table 2. When looking specifically at the primary growing season months of May through September, a few notable weather patterns emerge. In 2017 there was a late season water deficit through the months of August and September. Temperatures were also above average in September, which may have increased the likelihood of late season water stress that year. In 2018 rainfall was well above average in August. The rainfall was associated with many cloudy and rainy days, and therefore solar radiation was below average during the critical period of grain fill for the corn crop that year. The conditions likely contributed to stalk cannibalization and eventual lodging of the corn crop that occurred that season. The lodging made it impossible to obtain accurate yield data through the combine's yield monitor, and for this reason grain yield data from this year will not be presented. In 2019, below average temperatures resulted in slow crop growth and a crop that was delayed in reaching maturity. 2020 was an exceptional growing year with temperatures at or above average throughout the growing season, and adequate rainfall throughout the entire growing season including the months of July and August, when water stress is otherwise common in this area.

Table 2. Deviations from the 30-year average (1981-2010; West Bend, WI, United States) for monthly maximum (Tmax), minimum (Tmin), and average (Tavg) temperature, and total precipitation for the three years of study. (Midwestern Regional Climate Center, 2021).

	2017				2018				2019				2020			
Month	Tmax °F	Tmin °F	Tavg °F	Total Precipitation (in)	Tmax °F	Tmin °F	Tavg °F	Total Precipitation (in)	Tmax °F	Tmin °F	Tavg °F	Total Precipitation (in)	Tmax °F	Tmin °F	Tavg °F	Total Precipitation (in)
January	2.7	4.9	4.02	1.17	1.2	-0.7	0.24	-0.19	-2.9	-2.4	-2.62	1.41	5.4	7.4	6.4	0.49
February	8.6	8.7	8.68	-0.19	-1.6	-1.5	-1.89	0.93	-3.9	-3.7	-3.78	0.71	0.3	1.3	0.8	-0.65
March	-1.6	-0.2	-0.9	1.38	-1	-1.3	-1.38	-1.16	-3.2	-3.6	-3.4	-1.11	1.8	4.9	3.34	0.89
April	4.4	4.5	4.45	1.29	-9.4	-7.5	-8.53	-0.23	-0.4	-0.2	-0.32	0.19	-3	-2.8	-3.1	-1.46
May	-2.6	-0.8	-1.72	0.32	6.3	6.2	6.25	1.48	-4.7	-1.6	-3.17	0.59	-1.5	-0.5	-0.98	0.93
June	0.9	2	1.45	1.68	-0.9	2.1	0.6	-1.74	-2.3	-1.7	-2.12	0.31	2.5	1.3	1.99	-0.13
July	-1.5	0.1	-0.71	0.2	1.1	1.3	1.18	-0.82	2.1	3.3	2.7	0.77	2.9	4.2	3.55	1.47
August	-3.1	-2	-2.6	-0.41	2.1	1.9	1.95	7.47	-1.3	-1.6	-1.54	0.57	2.3	0.3	1.24	4.79
September	2.8	1.6	2.13	-2.47	1.2	1.9	1.75	1.9	1.1	5.2	3.16	3.51	-3	0.7	-1.25	-0.3
October	2.8	5.3	4.09	0.32	-3	-0.5	-1.77	2.61	-3.3	-0.8	-2.01	5.24	-5.7	-3.7	-4.68	-0.06
November	-0.8	-0.9	-0.83	-1.08	-8	-4.7	-6.25	0.34	-7.4	-6.4	-7.14	0.91	8.1	5.2	7.04	-0.08
December	-5.1	-3.3	-4.17	-1.23	1.2	4.7	3.03	0.1	3.6	3.8	3.72	0.67	1.2	2.3	1.93	-0.59
Annual	7.5	19.9	13.89	0.98	-10.8	1.9	-4.82	10.69	-22.6	-9.7	-16.52	13.77	11.3	20.6	16.28	5.3

Combine Grain Yield

Statistical analysis for yield data across multiple years was only possible for the soybean growing seasons of 2017 and 2019 due to the loss of corn yield for 2018, which resulted in only one year of corn yield data. In the multi-year ANOVA analysis of soybean yield data (Table 3), the year effect was significant (P = 0.01), while the treatment effect (P=0.64), and the treatment/year interaction (P=0.31) were not significant. Due to the significance of the year effect, grain yield data will be presented for individual years.

Table 3. Multi-Year analysis of Soybean Grain Yield. Probability of statistical significance as determined by the least significant difference method was produced from ANOVA Proc Mixed analysis.

Multi-Year Analysis of Soybean Yield (2017,2019)			
Effect	Num DF	Den DF	Pr>F
Treatment	1	5	0.639
Year	1	5	0.0137
Treatment/Year	1	4	0.309

Soybean grain yields, and their statistical analysis are presented below for both 2017 and 2019 (Table 4). The overall average grain yield in 2017 was 64.2 Bu A^{-1} and 66.6 Bu A^{-1} in 2019. This 4% increase in soybean yields could be partially attributed to improved soil moisture availability throughout the 2019 grain fill period. In 2017 the humic product application increased soybean yields by 0.17 Bu A^{-1}, an increase of 0.3%. In 2019 the application of the humic product resulted in a grain yield 0.34 Bu A^{-1} lower than the control, a decrease of 0.5%. In both 2017 and 2019 these small variations in yield between the treatments were not significant (2017, P=0.77: 2019, P = 0.76).

Table 4. Soybean grain yield response to humic product application for 2017 and 2019 compared to an unamended control. Probability of statistical significance as determined by the least significant difference method was produced from SAS Proc Mixed analysis.

		Soybean Yield	
Year	**Treatment**	**Grain Yield (Bu A^{-1})**	**Pr>F**
2017	Control	64.1	0.777
	Humic	64.3	
	Mean	64.2	
2019	Control	66.8	0.763
	Humic	66.4	
	Mean	66.1	

Corn grain yields were collected only in 2020, due to lodging of the corn crop and subsequent inaccurate yield data from the combine's yield monitor in 2018. The 2020 yield data as well as their statistical analysis are presented below (Table 5). The overall average grain yield for 2020 was 229.5 Bu A^{-1}. The humic product application resulted in a grain yield that was 2.78 Bu A^{-1} lower than the control treatment. This 1% yield reduction in the humic treatment was not statistically significant (P=0.5359).

Table 5. Corn grain yield data response to humic product application for the 2020 corn crop compared to the control. Probability of statistical significance as determined by the least significant difference method was produced from SAS Proc Mixed analysis.

Corn Yield			
Year	**Treatment**	**Grain Yield (Bu A^{-1})**	**Pr>F**
2020	Control	230.9	0.5359
	Humic	228.2	
	Mean	229.5	

Tissue Nutrient Concentrations

Crop tissue was analyzed for concentrations of N, P, K, calcium (Ca), Mg, sulfur (S), zinc (Zn), boron (B), manganese (Mn), iron (Fe), and copper (Cu). Tissue tests were taken from only three of the six replicates. For this reason, statistical analyses were unable to be performed; the SAS program refused to provide output, due to the mixed and unbalanced data. In the absence of statistical analysis, the results are presented below with only means and standard deviations. Due to the year-to-year variability of tissue tests, based many crop factors at the time of sampling, it is assumed that the effect of the year will be significant, and results will be presented by individual year.

Soybean nutrient concentrations are presented in Table 6. They are very similar between the humic treatment and the control. They did not differ by more than two standard deviations for any nutrient, where two standard deviations is an approximate measure of significance at $P<0.05$. The most responsive nutrient was S. Its concentration was higher with humic product application in both 2017 and 2019, with a 3% increase in 2017 and an 8% increase in 2019. No other nutrient concentration differed between the humic product treatment and the control by at least one standard deviation in both soybean growing seasons. Other nutrient concentrations differed between the humic and control treatments by at least one standard deviation in one of the two soybean seasons, including a 3% increase in N and a 2% increase in Fe in 2017, and a 9% increase in Mn, a 6% increase in Cu, and a 6% decrease in Zn concentration in 2019.

Table 6. Soybean tissue nutrient responses to humic product application in 2017 and 2019 compared to the control. Tissue tests were taken at R2 growth stage. Treatment responses in **bold** are greater than one standard deviation.

		Soybean Tissue Nutrients										
Year	**Treatment**	**N (%)**	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**S (%)**	**Zn (ppm)**	**B (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Cu (ppm)**
2017	Control	5.07	0.40	2.10	0.74	0.26	0.23	25	37	50	80	7.10
	Humic	5.23	0.41	2.11	0.72	0.27	0.23	24	37	56	81	7.11
	Δ (Humic-Control)	**0.160**	0.0033	0.017	-0.023	0.0067	**0.0067**	-0.67	0.00	6	**1.3**	0.0100
	Mean	5.15	0.41	2.11	0.73	0.27	0.23	25	37	53	80	7.10
	Std Deviation	0.134	0.022	0.056	0.026	0.014	0.0063	1.2	0.52	6.8	1.0	0.428
2019	Control	5.86	0.62	2.10	0.71	0.36	0.26	31.78	26.11	45.35	83.54	7.43
	Humic	5.88	0.59	2.09	0.71	0.35	0.28	29.82	26.53	49.78	77.56	7.90
	Δ (Humic-Control)	0.0218	-0.031	-0.00500	0.0013	-0.014	**0.021**	**-1.953**	0.4133	**4.423**	-5.983	**0.47**
	Mean	5.87	0.60	2.09	0.71	0.36	0.27	30.80	26.32	47.57	80.55	7.67
	Std Deviation	0.0610	0.041	0.0349	0.027	0.025	0.016	1.447	0.4947	4.334	8.146	0.43

Corn nutrient concentrations are presented in Table 7. The nutrient concentrations in the corn tissue were also very similar between the humic treatment and the control. They did not differ by more than two standard deviations for any nutrient, as was the case with soybean. Nutrient concentrations that differed between the humic treatment and the control by at least one standard deviation in one of the two corn years included an 11% reduction in P, an 18% reduction in Fe, a 10% reduction in Cu in 2018, a 9% increase in K and an 11% decrease in S in 2020. No nutrient concentration differed by least one standard deviation in both of the corn growing seasons.

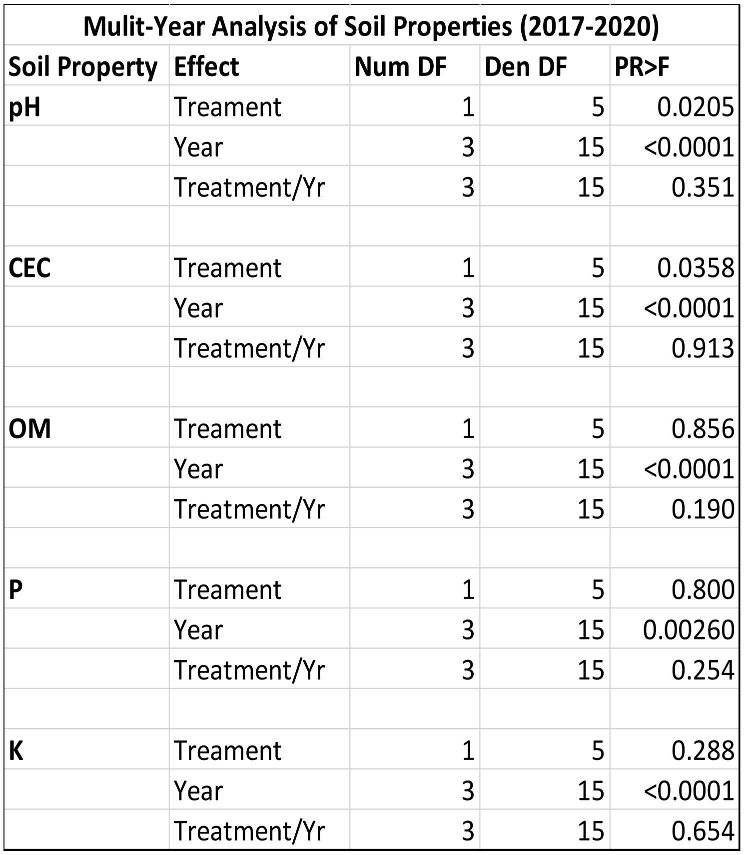
Table 7. Corn tissue nutrient response to humic product application for 2018 and 2020 corn crops compared to control. Tissue tests were taken at R2 growth stage. Results highlighted in **bold** are greater than one standard deviation of difference.

		Corn Tissue Nutrients										
Year	**Treatment**	**N (%)**	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**S (%)**	**Zn (ppm)**	**B (ppm)**	**Mn (ppm)**	**Fe (ppm)**	**Cu (ppm)**
2017	Control	2.74	0.33	1.83	0.44	0.24	0.16	23	12	33	162	9.44
	Humic	2.59	0.30	1.98	0.41	0.22	0.14	19	11	30	134	8.47
	Δ (Humic-Control)	-0.150	**-0.035**	0.145	-0.035	-0.015	-0.015	-4.0	-1.0	-3.0	**-28.5**	**-0.965**
	Mean	2.67	0.31	1.90	0.42	0.23	0.15	21	11	31	148	8.95
	Std Deviation	0.180	0.022	0.175	0.042	0.015	0.019	4.8	1.9	3.4	18.7	0.941
2019	Control	3.38	0.33	2.11	0.37	0.14	0.18	17.94	5.46	34.26	131.8	10.82
	Humic	3.18	0.33	2.31	0.37	0.15	0.16	17.55	4.82	37.02	134.6	10.02
	Δ (Humic-Control)	-0.194	-0.0060	**0.206**	-0.0042	0.0064	**-0.019**	-0.3867	-0.643	2.763	2.80	-0.8000
	Mean	3.28	0.33	2.21	0.37	0.15	0.17	17.74	5.14	35.64	133.2	10.42
	Std Deviation	0.355	0.010	0.197	0.043	0.013	0.015	1.478	1.04	4.084	12.79	0.9258

Soil Properties

Soil samples were collected each year of the trial in the fall following harvest and prior to fertilizer and humic product applications. The samples were analyzed for pH, CEC, percent organic matter (OM), Bray P1 extractable P content (P), and NH_4 acetate-extractable K content (K). A multi-year ANOVA analysis of these soil properties (Table 8) showed a significant effect of the year for each property pH ($P<0.0001$), CEC ($P<0.0001$), OM ($P<0.0001$), P ($P=0.00260$), and K($P<0.0001$). The multi-year analysis also showed a significant effect of the humic product treatment for pH ($P=0.0205$) and CEC ($P=0.0358$). The remaining soil properties did not show a significant effect of the humic product treatment in the multi-year analysis OM ($P=0.856$), P ($P= 0.800$), and K ($P=0.288$). The treatment–year interactions were not found to be significant for any of the soil properties tested pH ($P=0.351$), CEC ($P= 0.913$), OM ($P = 0.190$), P ($P=0.254$), and K ($P= 0.654$). Due to the significance of the year effect, soil property data will be presented for individual years.

Table 8. Multi-Year statistical analysis of soil properties (pH, CEC, OM, P, K). Probability of statistical significance was determined by the least significant difference method from the SAS Proc Mixed analysis.

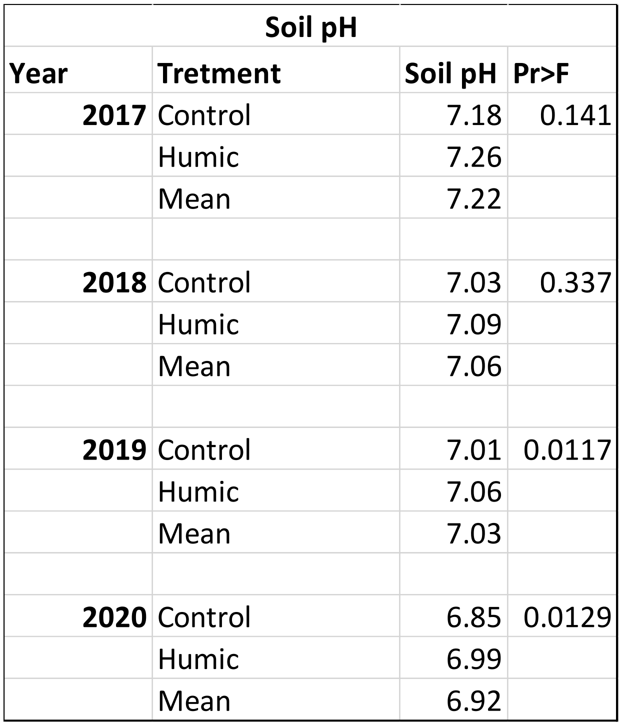


Mulit-Year Analysis of Soil Properties (2017-2020)

Soil Property	Effect	Num DF	Den DF	PR>F
pH	Treament	1	5	0.0205
	Year	3	15	<0.0001
	Treatment/Yr	3	15	0.351
CEC	Treament	1	5	0.0358
	Year	3	15	<0.0001
	Treatment/Yr	3	15	0.913
OM	Treament	1	5	0.856
	Year	3	15	<0.0001
	Treatment/Yr	3	15	0.190
P	Treament	1	5	0.800
	Year	3	15	0.00260
	Treatment/Yr	3	15	0.254
K	Treament	1	5	0.288
	Year	3	15	<0.0001
	Treatment/Yr	3	15	0.654

The soil pH values as determined through soil testing along with their statistical analysis are presented below (Table 9). The overall average for pH was 7.22 in 2017, 7.06 in 2018, 7.03 in 2019, and 6.92 in 2020. Compared to the control, the pH of the humic product treatment was 1.5% higher in 2017, 0.8% higher in 2018, 0.7% higher in 2019, and 2.1% higher in 2020. The pH values of the humic treatment were significantly different from those of the control treatment in 2019 (P=0.012) and 2020 (P=0.013).

Table 9. Soil pH response to humic product application for 2017-2020 compared to the control. Probability of statistical significance was determined by the least significant difference method from the SAS Proc Mixed analysis.



Soil pH			
Year	**Tretment**	**Soil pH**	**Pr>F**
2017	Control	7.18	0.141
	Humic	7.26	
	Mean	7.22	
2018	Control	7.03	0.337
	Humic	7.09	
	Mean	7.06	
2019	Control	7.01	0.0117
	Humic	7.06	
	Mean	7.03	
2020	Control	6.85	0.0129
	Humic	6.99	
	Mean	6.92	

Soil CEC values for 2017-2020, and their statistical analysis are presented in Table 10. The overall CEC was 15.4 meq $100g^{-1}$ in 2017, 13.3 meq $100g^{-1}$ in 2018, 12.0 meq $100g^{-1}$ in 2019, and 13.4 meq $100g^{-1}$ in 2020. The CEC for the humic treatment was higher than for the control in every year of the study. The humic treatment CEC was 6.2% higher in 2017, 7.2% higher in 2018, 4.3% higher in 2019, and 8.5% higher in 2020. However, none of these numeric differences were significant ($P>0.05$)

Table 10. Soil CEC response to humic product application for 2017-2020 compared to control. Probability of statistical significance as determined by the least significant difference method produced from SAS Proc Mixed analysis.

	Soil CEC		
Year	**Tretment**	**Soil CEC (meq 100g^{-1})**	**Pr>F**
2017	Control	14.9	0.268
	Humic	15.8	
	Mean	15.4	
2018	Control	12.8	0.210
	Humic	13.8	
	Mean	13.3	
2019	Control	11.8	0.111
	Humic	12.3	
	Mean	12.0	
2020	Control	12.8	0.157
	Humic	13.9	
	Mean	13.4	

Soil OM concentrations for 2017-2020, and their statistical analysis are presented in Table 11. The overall OM level was 3.04 % in 2017, 2.50% in 2018, 2.51 % in 2019, and 2.60% in 2020. Compared to the control, OM content for the humic treatment was 1.4% lower in 2017, 2.4% higher in 2018, 8.7% higher in 2019, and 2.7% higher in 2020. The difference in OM between the humic treatment and the control was significant only in 2019 (P=0.006).

Table 11. Soil OM response to humic product application for 2017-2020 compared to the control. Probability of statistical significance was determined by the least significant difference method from SAS Proc Mixed analysis.

	Soil OM		
Year	**Tretment**	**Soil OM (%)**	**Pr>F**
2017	Control	3.03	0.419
	Humic	2.98	
	Mean	3.00	
2018	Control	2.47	0.288
	Humic	2.53	
	Mean	2.50	
2019	Control	2.41	0.00590
	Humic	2.62	
	Mean	2.51	
2020	Control	2.57	0.369
	Humic	2.64	
	Mean	2.60	

Extractable soil P concentrations for 2017-2020, and their statistical analysis are presented in Table 12. The overall extractable P concentration was 167 ppm in 2017, 180 ppm in 2018, 186 ppm in 2019, and 179 ppm in 2020. The humic treatment had extractable soil P levels that were 0.5% lower in 2017, 0.3% lower in 2018, 6.7% lower in 2019, and 2.9% higher in 2020 compared to the control treatment. None of these differences were significantly different ($P>0.05$)

Table 12. Extractable soil P response to humic product application for 2017-2020 compared to the control. Probability of statistical significance was determined by the least significant difference method from SAS Proc Mixed analysis.

Soil Extracteable P			
Year	**Tretment**	**Soil P (ppm)**	**Pr>F**
2017	Control	167	0.925
	Humic	166	
	Mean	167	
2018	Control	180	0.965
	Humic	180	
	Mean	180	
2019	Control	192	0.211
	Humic	180	
	Mean	186	
2020	Control	177	0.555
	Humic	182	
	Mean	179	

Extractable soil K concentrations for 2017-2020, and their statistical analysis are presented in Table 13. The overall soil extractable K concentration was 248 ppm in 2017, 296 ppm in 2018, 230 ppm in 2019, and 176 ppm in 2020. Extractable soil K was numerically greater in the humic product treatment than in the control in each year of the study. The extractable K values were 5.1% higher in 2017, 1.9% higher in 2018, 0.8% higher in 2019, and 8.5% higher in 2020 for the humic product treatment. Only the 2020 difference was significant (P=0.0452).

Table 13. Extractable soil K response to humic product application for 2017-2020 compared to the control. Probability of statistical significance was determined by the least significant difference method from SAS Proc Mixed analysis.

Soil Extracteable K			
Year	**Tretment**	**Soil K (ppm)**	**Pr>F**
2017	Control	242	0.240
	Humic	254	
	Mean	248	
2018	Control	293	0.615
	Humic	298	
	Mean	296	
2019	Control	229	0.843
	Humic	231	
	Mean	230	
2020	Control	168	0.0452
	Humic	183	
	Mean	176	

DISCUSSION

The results of this study showed little to no effects of including humic acid with post-harvest P and K fertilizer applications on crop yield, soil nutrient availability, or crop nutrient content. The primary parameter of interest for this study was the humic product's effect on grain yield for both corn and soybeans. No significant increases in grain yield were found in any of the three years of the trial (P>0.05). The second area of interest was to test industry claims stating that humic products increase soil nutrient availability and uptake. Through tissue testing a few small trends emerged, including slightly higher S tissue tests for both years of soybeans in response to the humic product treatment. The tissue tests also revealed that in one year of corn the tissue K concentration was higher, and in one year of soybeans the N concentration was higher in the humic product treatment compared to the control. These differences from the control were not significant however as they were less than two standard deviations. Also, for each example of increased tissue nutrient concentrations there are other examples of lower tissue concentration in response to the humic product treatment. Through soil testing, there were very few significant differences in extractable P or K that were found in response to humic product application. One interesting trend that emerged was that soil extractable K was higher for the humic product treatment for each year of the study, but only the 2020 season resulted in a significant effect (P=0.0452). However, soil extractable P, which was of greater interest to this study, was lower in the humic product treatment than the control two out of the four years, and there were no significant differences between the treatments in any season (P>0.05). The lack of consistent significant effect in extractable P and K, makes it difficult to conclude that the humic product influenced available soil nutrients. Significant differences in other soil properties were also found between the humic treatment and the control. Including higher pH in 2019 (P=0.0117) and 2020 (P=0.0129), and higher OM in 2019 (P=0.006). However, the lack of consistency of these significant effects, and the fact that soil properties like pH and OM do not change very rapidly and would not likely be affected by the addition of 10 lb A^{-1} of a humic product make it unlikely that these results are related to the humic product treatment. Based on these results, a reasonable conclusion is that the addition of humic acid to fall fertilizer will not benefit a corn and soybean rotation. Yet there are a few key attributes to this particular study that may have inhibited a response to humic acids.

First, the field utilized in the study was chosen based on the cooperator’s preferences. The cooperator believed the field was fairly uniform and lent itself well to a multi-year trial based on location, ownership, and field shape and topography. However, the field is also an exceptionally well yielding field, and has very high native fertility. The field has been one of the top producing farms in the area, with corn yields very commonly over 220 Bu A^{-1}, and soybean yields over 50 Bu A^{-1}. The field also has excessively high P and K fertility, with average soil test levels of 178 ppm Bray 1-extractable P and 200 ppm NH_4 acetate-extractable K. Recent research has suggested that environmental stress mitigation is the primary mechanism by which humic acids elicit a crop response (Calvo et al., 2014). Olk et al. (2021) also suggested that field studies conducted in less favorable field conditions may lead to more pronounced and more frequent crop responses. The capability of this field to consistently produce high crop yields show that environmental stresses are often limited under these field conditions. The exceptionally high fertility may also limit any nutrient stress which the plant may experience.

The high soil nutrient levels may have especially obscured significant effects of humic product addition on increased soil and plant nutrient content; there was never any nutrient deficiencies at the outset. This study focused on humic acid effects on nutrient availability because, until now, industry claims have often identified this mechanism for humic acid benefits to crop growth. However, researchers largely believe that the fundamental mechanism for plant responses to humic acids is not related to soil nutrient availability (Olk et al., 2021). This would mean high soil fertility alone would not inhibit a crop response from humic acids, and in at least one case crop yield response to humic products were slightly clearer in cases of higher soil nutrient availability (Olk et al., 2021).

Researchers have also shown that significant crop responses to humic acids can occur in high yield environments (Olk et al., 2021). Based on this previous research, it should be concluded that the high yield and fertility environment used for this trial may have made it more difficult to detect a response to humic acid application, but it certainly would not make it impossible for a significant response to occur.

A second factor that may have reduced the impact of the humic acid application may have been favorable weather conditions. Table 2 shows the deviations from the 30-year average for monthly maximum, minimum, and average temperature, as well as total monthly precipitation. During the years of the study there were very few incidences of water stress in the trial location, with the only significant water deficit occurring in August-September of 2017. Research has found that crop responses to humic acid application can be heightened during incidences of drought stress (Olk et al., 2021). Conversely, negative crop responses to humic acid applications have been observed in overly wet soil conditions (Olk, et al., 2021). Such weather effects on humic acid efficacy would support the theory that the primary mechanism for humic acids to benefit crop growth is by mitigating environmental stresses. In this case there was very little environmental stress arising from lack of rainfall, which combined with the limited stresses associated with the field conditions discussed above, further reduce the likelihood of a crop response to humic acid application.

The final factor that may have limited the impact of humic acid application was uncertainty concerning the optimal rate of humic acid application. This study evaluated the common regional application rate of 10 lb A^{-1} of Hydra-Hume DG-A “Coated” with post-harvest fertilizer. This is the lowest recommended rate for this product, which is labeled for application at 10-40 lb A^{-1}. As with other humic products, no guidelines exist for selecting the optimal rate of product application for the particular setting of this research. If the selected rate were too low for this study area, benefits to crop growth would have less likely been attained.

An additional challenge associated with humic acid product rates is the incomplete knowledge of product composition. Although the Hydra-Hume product is refined to increase the level of active humic acid (70% humic acids according to label), its actual biological activity compared to other humic acid products is unknown. The humic product market lacks a universally recognized standard procedure for measuring the humic acid content and biological activity of various products (Olk et al., 2018). For these reasons, finding an effective rate for humic acid application can be very difficult. The product, crop, and soil properties will all play roles in determining an effective rate, and this degree of information was not available in this case.

Future work on how humic products may benefit a corn and soybean rotation through applications with fall fertilizer would certainly be warranted, as this is still a popular application for humic products. Future studies would be wise to focus on how humic products affect a crop under environmental stress. Future studies should select areas or fields that suffer from moisture stress in particular to maximize potential responses from humic products. If more work was to be done to explore the effects of humic products on soil nutrient availability or plant nutrient uptake, selecting a field with low fertility would also be important. Finally, testing additional products or at least multiple rates, would be an important step in designing future research on the crop response from humic products.

CONCLUSION

The application of the humic product Hydra-Hume DG A “Coated” at 10 lb A^{-1} with fall fertilizer in a corn and soybean rotation did not have significant effects on yield of corn and soybean, or significantly increase soil nutrient availability or crop nutrient concentration. These results show that although humic acids are well researched to provide plant benefits, and in some cases increase nutrient availability, they will not always have an effect in every situation. The results of this trial show that factors such as timing of application, level of environmental stress, soil nutrient availability, and use rate, may be important considerations to make before a grower would decide to use a humic product.

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APPENDIX

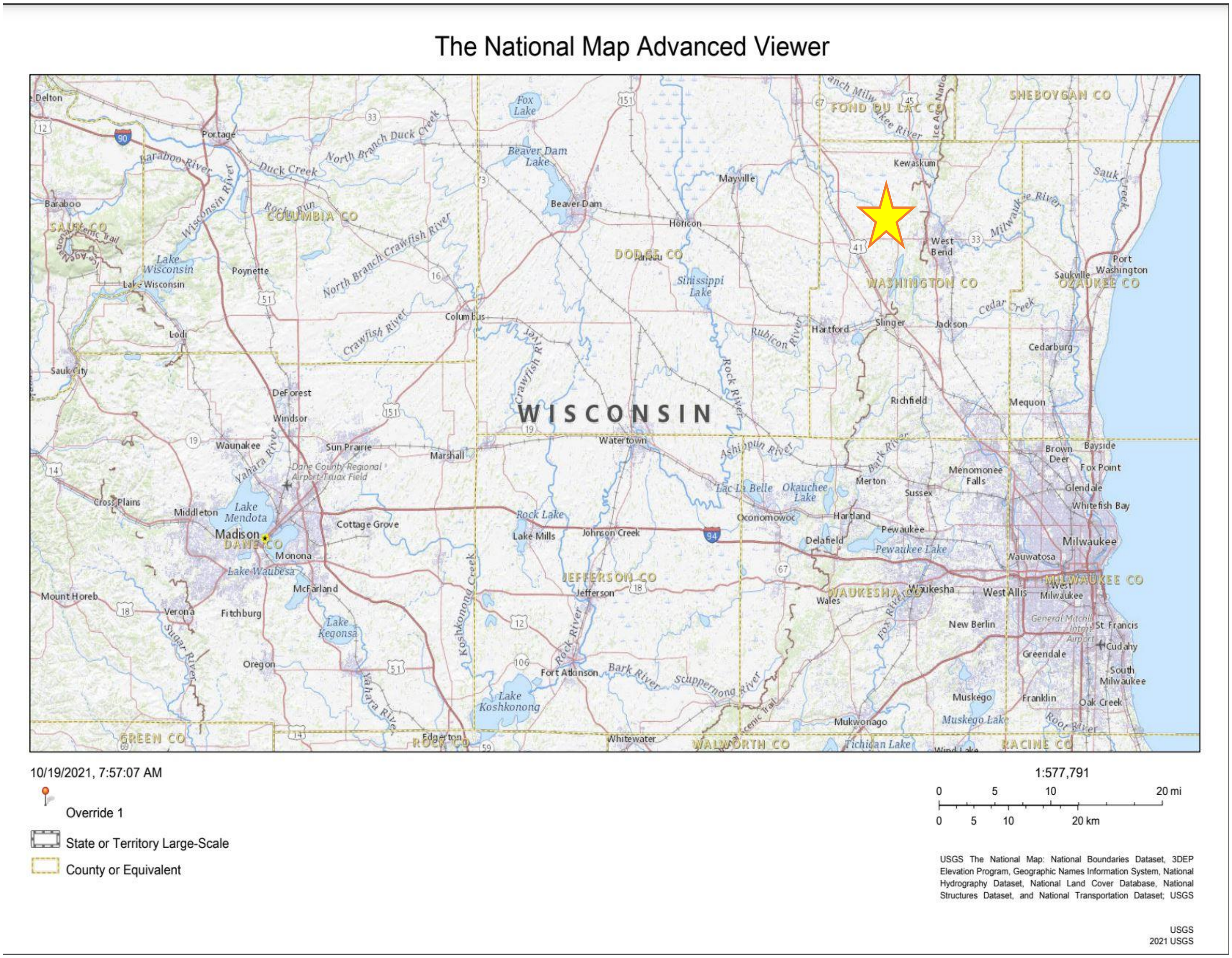
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Figure 1A: Regional map of southeast Wisconsin, with star showing location of field where study was conducted, near West Bend, WI (USGS, 2021).

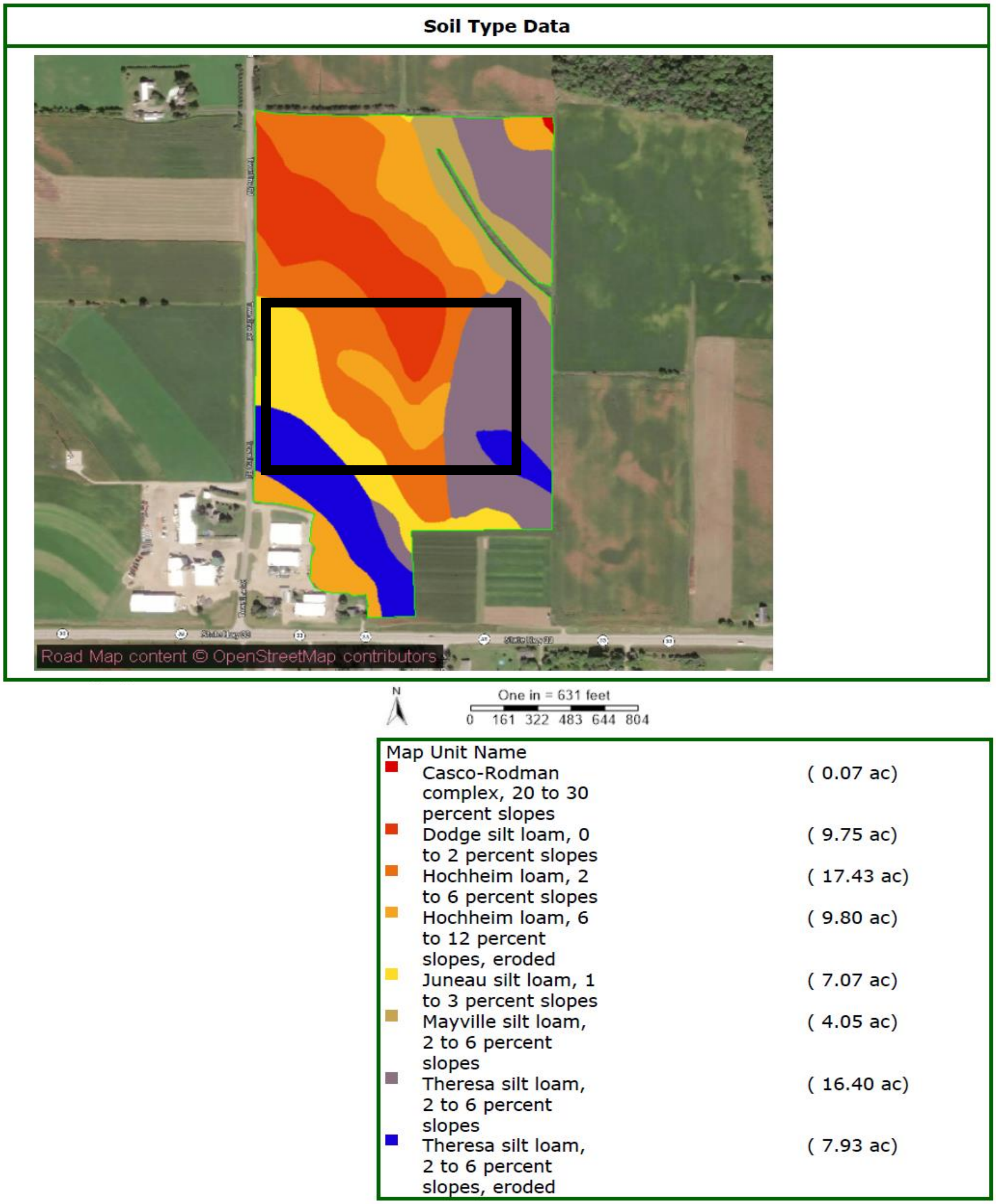


Figure A2: Map of soil types for field where study was conducted. The black box outlines trial area. Map output from SST precision agriculture software.

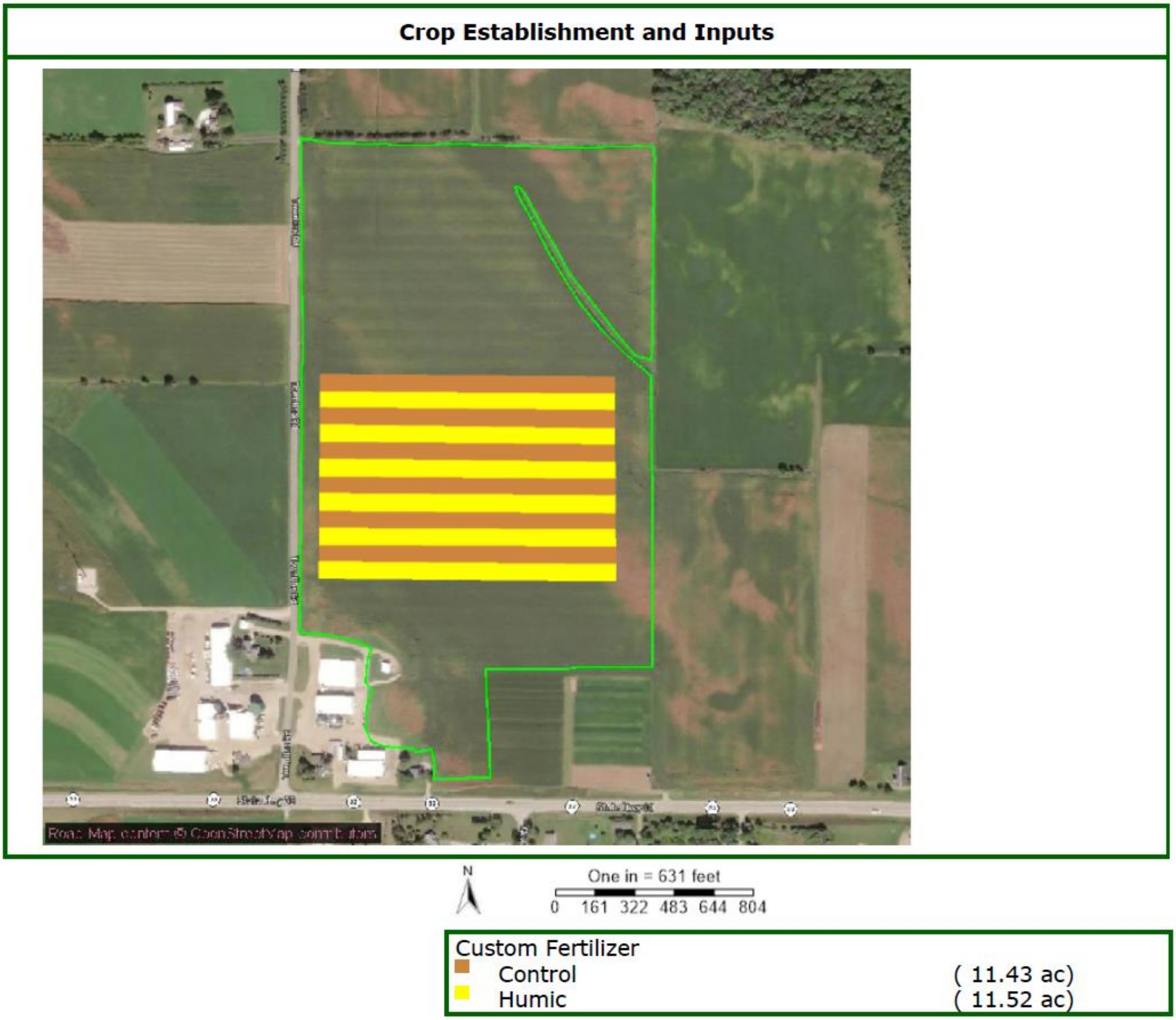
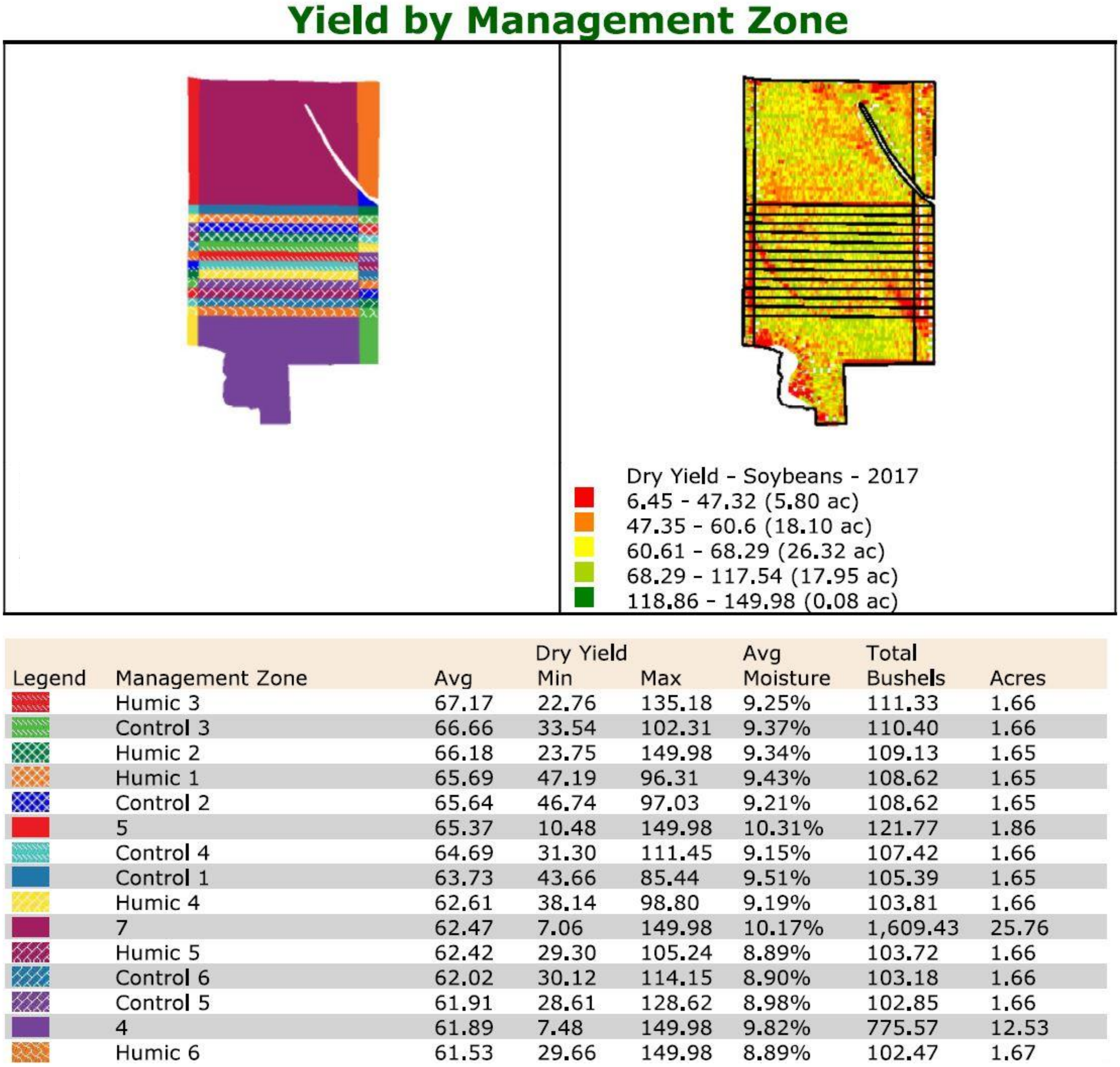


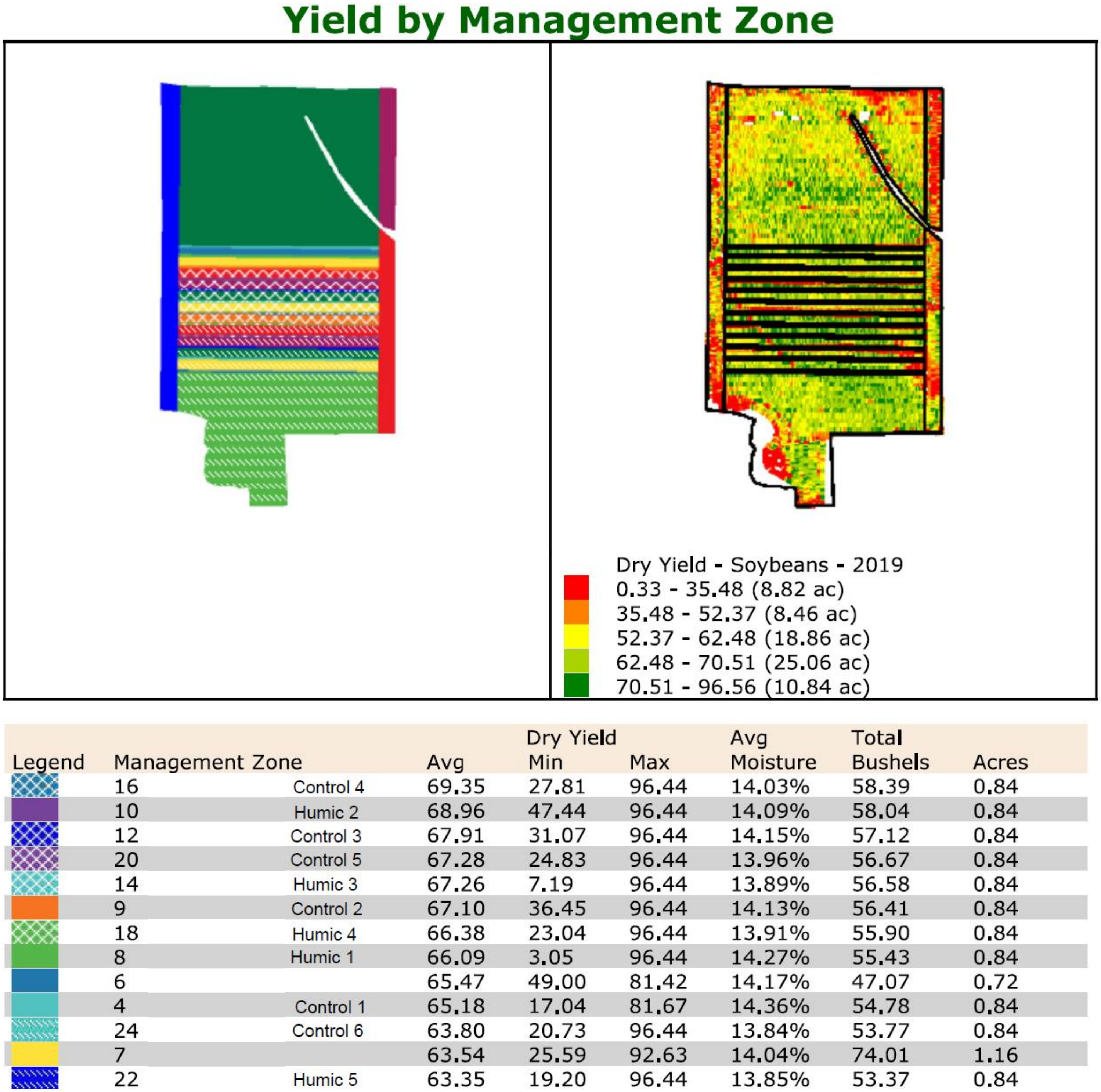
Figure A3: Map of trial design. Map is an application map from SST precision agriculture software, which categories the application as “Crop Establishment and Inputs” Control strips mark applications of fall fertilizer. Humic strips mark application of fall fertilizer plus 10 lb A^{-1} of Hydra Hume.



Yield by Management Zone

Legend	Management Zone	Avg	Dry Yield Min	Max	Avg Moisture	Total Bushels	Acres
🟥	Humic 3	67.17	22.76	135.18	9.25%	111.33	1.66
🟩	Control 3	66.66	33.54	102.31	9.37%	110.40	1.66
🟩	Humic 2	66.18	23.75	149.98	9.34%	109.13	1.65
🟧	Humic 1	65.69	47.19	96.31	9.43%	108.62	1.65
🟦	Control 2	65.64	46.74	97.03	9.21%	108.62	1.65
🟥	5	65.37	10.48	149.98	10.31%	121.77	1.86
🟦	Control 4	64.69	31.30	111.45	9.15%	107.42	1.66
🟦	Control 1	63.73	43.66	85.44	9.51%	105.39	1.65
🟨	Humic 4	62.61	38.14	98.80	9.19%	103.81	1.66
🟥	7	62.47	7.06	149.98	10.17%	1,609.43	25.76
🟥	Humic 5	62.42	29.30	105.24	8.89%	103.72	1.66
🟦	Control 6	62.02	30.12	114.15	8.90%	103.18	1.66
🟪	Control 5	61.91	28.61	128.62	8.98%	102.85	1.66
🟪	4	61.89	7.48	149.98	9.82%	775.57	12.53
🟧	Humic 6	61.53	29.66	149.98	8.89%	102.47	1.67

Figure A4: 2017 soybean yield data, as sorted and outputted by SST precision agriculture software. Yield data were sorted in SST by creating individual management zones for each strip in the trial. A “Yield by Management Zone” output was then utilized to determine yield for each individual strip. Unlabeled strips are management zones that were created by the program through this process but are not part of the study area.

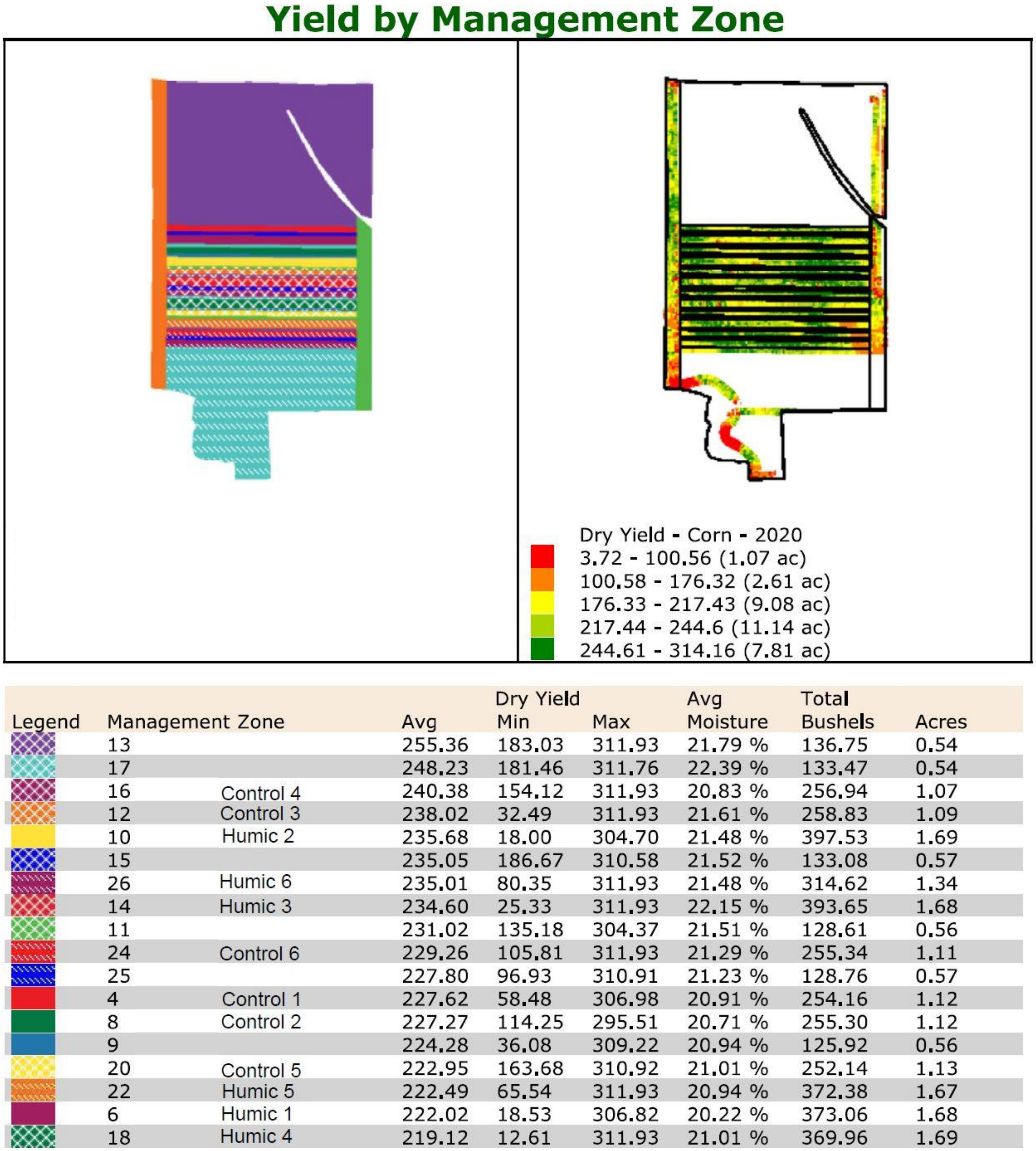


Yield by Management Zone

Dry Yield - Soybeans - 2019
🟥 0.33 - 35.48 (8.82 ac)
🟧 35.48 - 52.37 (8.46 ac)
🟨 52.37 - 62.48 (18.86 ac)
🟩 62.48 - 70.51 (25.06 ac)
🟩 70.51 - 96.56 (10.84 ac)

Legend	Management Zone		Dry Yield Avg	Min	Max	Avg Moisture	Total Bushels	Acres
▩	16	Control 4	69.35	27.81	96.44	14.03%	58.39	0.84
🟪	10	Humic 2	68.96	47.44	96.44	14.09%	58.04	0.84
▩	12	Control 3	67.91	31.07	96.44	14.15%	57.12	0.84
▩	20	Control 5	67.28	24.83	96.44	13.96%	56.67	0.84
▩	14	Humic 3	67.26	7.19	96.44	13.89%	56.58	0.84
🟧	9	Control 2	67.10	36.45	96.44	14.13%	56.41	0.84
▩	18	Humic 4	66.38	23.04	96.44	13.91%	55.90	0.84
🟩	8	Humic 1	66.09	3.05	96.44	14.27%	55.43	0.84
🟦	6		65.47	49.00	81.42	14.17%	47.07	0.72
🟦	4	Control 1	65.18	17.04	81.67	14.36%	54.78	0.84
▨	24	Control 6	63.80	20.73	96.44	13.84%	53.77	0.84
🟨	7		63.54	25.59	92.63	14.04%	74.01	1.16
▨	22	Humic 5	63.35	19.20	96.44	13.85%	53.37	0.84

Figure A5: 2019 soybean yield data, as sorted and outputted by SST precision agriculture software. Yield data were sorted in SST by creating individual management zones for each strip in the trial. A “Yield by Management Zone” output was then utilized to determine yield for each individual strip. Unlabeled strips are management zones that were created by the program through this process but are not part of the study area.



Yield by Management Zone

Dry Yield - Corn - 2020

🟥 3.72 - 100.56 (1.07 ac)
🟧 100.58 - 176.32 (2.61 ac)
🟨 176.33 - 217.43 (9.08 ac)
🟩 217.44 - 244.6 (11.14 ac)
🟩 244.61 - 314.16 (7.81 ac)

				Dry Yield		Avg	Total	
Legend	Management Zone		Avg	Min	Max	Moisture	Bushels	Acres
▨	13		255.36	183.03	311.93	21.79 %	136.75	0.54
▨	17		248.23	181.46	311.76	22.39 %	133.47	0.54
▨	16	Control 4	240.38	154.12	311.93	20.83 %	256.94	1.07
▨	12	Control 3	238.02	32.49	311.93	21.61 %	258.83	1.09
🟨	10	Humic 2	235.68	18.00	304.70	21.48 %	397.53	1.69
▨	15		235.05	186.67	310.58	21.52 %	133.08	0.57
▨	26	Humic 6	235.01	80.35	311.93	21.48 %	314.62	1.34
▨	14	Humic 3	234.60	25.33	311.93	22.15 %	393.65	1.68
▨	11		231.02	135.18	304.37	21.51 %	128.61	0.56
▨	24	Control 6	229.26	105.81	311.93	21.29 %	255.34	1.11
▨	25		227.80	96.93	310.91	21.23 %	128.76	0.57
🟥	4	Control 1	227.62	58.48	306.98	20.91 %	254.16	1.12
🟩	8	Control 2	227.27	114.25	295.51	20.71 %	255.30	1.12
🟦	9		224.28	36.08	309.22	20.94 %	125.92	0.56
▨	20	Control 5	222.95	163.68	310.92	21.01 %	252.14	1.13
▨	22	Humic 5	222.49	65.54	311.93	20.94 %	372.38	1.67
■	6	Humic 1	222.02	18.53	306.82	20.22 %	373.06	1.68
▨	18	Humic 4	219.12	12.61	311.93	21.01 %	369.96	1.69

Figure A6: 2020 corn yield data, as sorted and outputted by SST precision agriculture software. Yield data were sorted in SST by creating individual management zones for each strip in the trial. A "Yield by Management Zone" output was then utilized to determine yield for each individual strip. Unlabeled strips are management zones that were created by the program through this process but are not part of the study area.