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Effects of Corn (Zea mays L.) Stover Removal and Leaching on Soil Test and Whole Plant K Levels in Corn and K Fertilization/High-Input Treatments on Soybean Using Site-Specific Management to Increase Soybean (Glycine max) Production in South Dakota

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EFFECTS OF CORN (Zea mays L.) STOVER REMOVAL AND LEACHING ON SOIL TEST AND WHOLE PLANT K^+ LEVELS IN CORN AND K^+ FERTILIZATION/HIGH-INPUT TREATMENTS ON SOYBEAN USING SITE-SPECIFIC MANAGEMENT TO INCREASE SOYBEAN (*Glycine max*) PRODUCTION IN SOUTH DAKOTA

BY

NICK J. SCHILTZ

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Plant Science

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2016

EFFECTS OF CORN (Zea mays L.) STOVER REMOVAL AND LEACHING ON SOIL TEST AND WHOLE PLANT K^+ LEVELS IN CORN AND K^+ FERTILIZATION/HIGH-INPUT TREATMENTS ON SOYBEAN USING SITE-SPECIFIC MANAGEMENT TO INCREASE SOYBEAN (*Glycine max*) PRODUCTION IN SOUTH DAKOTA

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

C. Gregg Carlson, Ph.D. Date
Thesis Advisor

David Wright, Ph.D. Date
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Dean, Graduate School Date

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I found a real home at South Dakota State University in Brookings, SD. I came here not knowing where I was in the world in August 2010 and acquired a newfound sense of worldliness; an education and fellowship with many lifelong friends.

I'd like to first thank and cherish my major advisor, mentor, and friend, Gregg Carlson. I still remember the first time he lectured in one of my first courses, PS-100 Opportunities in Plant Science, in September 2010. A man who I have talked hours with about not only agriculture, but life in general, I owe a world of debt to that I can never possibly repay. During my early twenties, I couldn't have picked a better man to emulate and learn from.

My mother and father, Polly and Leon Schiltz, raised me to get a quality education and work hard. I credit my early agricultural education, real-world applicably, my start in farming, courage and devotion to my father; my friend and business partner. My mother is the strongest person I have met, and dealing with her breast cancer, she thought only of me getting an education and encouraged me to pursue a graduate degree. Seeing her obtain her master's in 2005 while I was 14 and watching her prepare to defend encouraged me and has been quite the ironic experience. I distinctly remember her practicing in the living room on her defense.

From high school, I want to thank Deb Nagle, Deb Faugstad, Dave Capitani, Lee Okerlund, Steve Hartman, Dolores Knudson, Ron Parker, and Keith Fritz for their different roles in my growth and development during my younger years.

At South Dakota State University, I am an alumnus of Sigma Phi Epsilon fraternity. A true devout believer of the ‘Sound Mind, Sound Body’ mentality, my best friends are in SigEp. No matter where life takes us, we always remain close friends, separated only by distance, but held tightly together. Without SigEp, I surely would not be in graduate school. Friendship is family to me, and a fraternity brings that. Seeing my brothers go through graduate school across the United States was an inspiration for writing this thesis. For those that aided in this research in 2014 and 2015, I am forever grateful for your hard work. In particular, these guys are Eric Mayforth, Austin Kott, and Jonathan Schmitt. Our lives changed together and forever at 1:30 CST that day at the intersection of US HWY-28 and US HWY-30 near Huron, South Dakota, USA. HFF.

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To everybody else I was cherished to know, hang out with, or come across, I am grateful for you all. Brookings, South Dakota, will always be another home for me. Whenever I needed to blow off steam, I could run down all of Brookings' busy streets; in cold or warm days. I'll never leave Brookings, spiritually and semi-physically. I stopped viewing South Dakota State University as just a place but rather a home during my graduate school days. And I will miss SDSU very much.

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ABSTRACT

EFFECTS OF CORN (Zea mays L.) STOVER REMOVAL AND LEACHING ON SOIL TEST AND WHOLE PLANT K^+ LEVELS IN CORN AND K^+ FERTILIZATION/HIGH-INPUT TREATMENTS ON SOYBEAN USING SITE-SPECIFIC MANAGEMENT TO INCREASE SOYBEAN (*Glycine max*) PRODUCTION IN SOUTH DAKOTA

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Potassium is important for crop production. Corn stover removal has the potential to reduce exchangeable and soluble soil potassium (K^+) needed for optimal plant growth in addition to grain yield. An experiment was conducted in Aurora, SD, USA, to observe the effects of corn stover removal on water soluble and exchangeable soil test K^+ (STK) levels and corn grain yields across a five-year period. Abundant K^+ reserves were recorded between the initial and final sampling periods. While corn grain yields were affected by removing corn biomass, exchangeable and solution K^+ levels were relatively unaffected by stover removal.

Potassium fertilizer has the potential to mitigate yield decreases associated with corn stover removal. An on-farm cooperation amongst producers who have had an extensive history of corn stover removal was initiated. Two K^+ fertilization rates were spread per acre across half-mile strips in spring 2014; 250 lbs K_2O and 0 lbs K_2O. Initial (spring) and final (fall) soil sampling quantified STK values. Stomatal conductance and tissue sampling indicated K^+ fertilization influences on crop physiology and K^+ concentrations, respectively. Yield monitor data from treatment strips were cleaned and analyzed. Yield difference maps were generated through statistical software programs to examine yield responses to K^+ fertilizer. While yield increases were not economically sufficient, a wide degree of site-specific variability existed between sampling periods and points, site locations, and season.

Nitrogen (N) fertilization has the potential to increase soybean grain yield. On-farm cooperators applied nitrogen fertilizer in the encapsulated urea nitrogen (ESN) form in two rates across half-mile strips at R1 growth stage in July 2014; 0 lbs N/acre and 75 lbs N/acre strips (replicated at least twice per field). Spatial variability in yield responses across soil topography and elevations was seen. While yield gains were statistically significant after applying ESN, economic analysis proved applications of ESN on soybean at R3 to be uneconomical in some localities while advantageous in others.

Offsite K^+ movement may occur following precipitation after corn physiological maturity, presumably through leaching off of corn biomass material. Whole corn plant portions were collected and tested for K^+ following rainfall event. The portion of K^+ leached relative to total plant K^+ concentration indicated that corn stover biomass has great offsite movement, occurring as a function of rainfall inch rather than cumulative rainfall amounts.

STATEMENT OF THE PROBLEM

It is probable that collecting corn stover biomass has a detrimental impact upon soil test potassium (STK) levels. Fertilizer recommendations are based on grain removal (Gerwing, 2005), not reflecting K^+ removed in stover biomass. In order for producers to remain economically self-sufficient, it must be addressed whether corn stover removal reduces STK and grain yield. Are current fertility recommendations accurate for South Dakota, USA, grain producers?

The role precipitation plays in removing plant available K^+ following physiological maturity is vaguely understood. Current research is available concerning K^+ plant uptake across growth stage, but does not address plant K^+ concentrations following physiological maturity (Below, 2013). The objective of this study was to examine the leaching potential of K^+ off of corn biomass following maturity.

In-season nitrogen fertilization on soybean crops is not a common practice for South Dakota producers, but current research suggests nitrogen uptake through symbioses in the soil will not meet the fertilizer demands of producing 100-bushel soybean grain yields. Statistically significant soybean grain yields have been reported with slow-release nitrogen sources (Barker and Sawyer, 2001). The objective was to examine the grain yield and economic validity of slow-release nitrogen fertilization on soybean fields through on-farm trials.

CHAPTER 1

EFFECTS OF CORN (Zea Mays L.) STOVER REMOVAL ON SOIL TEST K^+ (STK) LEVELS IN CONTINUOUS CORN UNDER VARYING RESIDUE MANAGEMENT PRACTICES

Introduction

Continuous corn (*Zea mays* L.) stover (cobs, husks, leaves, tassels, and shanks) removal has the potential of reducing plant-available potassium (K^+) for successive year's crops and subsequent grain yields (Sindelar, 2013). Corn stover is commonly left in the field to decompose with the mineralized nutrients (K^+) available to meet the nutrient requirements of succeeding crops, in addition to commercial K^+ fertilization. South Dakota corn producers harvest the corn grain while less frequently the corn stover. Ethanol production is prominent throughout the Northern Great Plains, USA, with 14.3 billion gallons produced in 2014 (USDOE, 2015). Removing and collecting corn stover biomass provides an opportunistic economic value for agricultural producers who do not maintain livestock operations and improving producer income levels, especially in tough economic periods.

An important goal set forth by the United States Department of Energy in 2007 was to advance cellulosic ethanol (starch/cellulosic components) energy production to over 16 billion gallons by 2022 (USDOE, 2008)) with the chief candidate being corn stover (Farrell, 2006). Corn ethanol is expected to reach production levels of 36 billion gallons per year by 2022 (USDOE, 2008) with 16 3 billion gallons met by crop residues (USDOE, 2010). South Dakota corn growers will be tasked to meeting this goal since in 2014, Sioux Falls, SD-based Poet Biorefineries, Inc. opened the nation's first cellulosic ethanol plant in Emmetsburg, Iowa (Des Moines Register, 2014). It is assumed a rapid development will ensue once the fermentation process is established, expecting to produce a demand of approximately 75 million tons of stover biomass per year (Perlack, 2005).

Removing corn stover biomass has important yield advantages for South Dakota's corn growers. Biomass accumulations negatively influence corn grain yields, identified as the 'continuous corn yield penalty' (Below, 2013). Corn stover biomass reduction has the capability to increase corn grain yields by 13% (Porter, 1997), 20% (Below, 2013) 22% (Wilhelm and Wortmann, 2004a) and as great as 29% (Peterson and Varvel, 1989). Sustainable residue collection can be achieved at 20% (Nelson, 2002) and 30% (McAloon, 2000). Removing too much corn stover biomass results in a degradation of soil properties (Sindelar, 2013), including soil test potassium (STK) and yield potential. Wilhelm (2004b) conducted an experiment under irrigated conditions in Nebraska and concluded that corn grain yield was reduced 0.13 Mg per hectare when 1 Mg ha^{-1} stover was removed. Barber (1979) conducted an experiment measuring treatments of corn rotations with residue returned, residue removed, and six years of fallow. While not experienced in the short-term study conducted, Barber did cite that long-term practices will lead to a depletion of organic matter content. In his Indiana experiment (Barber, 1979), after 10 years of corn stover removal, organic matter levels had decreased about 10%. A likewise yield reduction was reported over 12 years in his Iowa study. There is little literature concerning safe removal levels of corn residue as it relates to potassium availability and corn grain yield in South Dakota.

Fertilizer recommendations in South Dakota are made using field-based soil test results and corn yield goals (Gerwing, 2005). International Plant Nutrition Institute estimates that 200 bushel per acre corn will remove 54 lbs K_2O (grain) and an additional 220 lbs K_2O (stover concentration). Many South Dakota soils test very high for STK (Chapter 2). International Plant Nutrition Institute (IPNI) reported median STK values for South Dakota at 247 ppm (Fixen et al, 2010). South Dakota producers are reluctant to apply potash fertilizer, solely using soil reserves to meet uptake requirements since it is believed K^+ is not yield-limiting. Median STK levels decreased 21 ppm from 2005 to 2010 (Fixen, 2010) across South Dakota and other top grain producing states. Future yield acceleration will be tied to understanding residue removal impacts upon STK levels and soil quality.

Very limited amounts of literary material are available on the effects of corn stover removal on STK values and corn grain yields in the Northern Great Plains. The dynamics of nitrogen application rate, irrigation practice, and sampling depth influences on the removal of K^+ availability have not been tested in South Dakota in a continuous corn system.

Objectives for this study include:

1) Determine how corn stover influences STK levels and corn grain yields in a residue maintained or removed environment
2) Examine how nitrogen rate, irrigation practice, and sampling depth affect STK levels
3) Analyze various K^+ pools (exchangeable K^+ and solution K^+) to examine total K^+ availability

MATERIALS AND METHODS

The research for this study was conducted at the South Dakota State University Research and Experimental Station near Aurora, South Dakota, from the growing seasons of 2008 through 2012. Site characteristics and soil information can be found in Clay et al (2015). Continuous corn was grown in 20 ft. by 20 ft. blocks for five consecutive seasons from 2008 to 2012. Dekalb brand seed corn 48-12STXRIB (Genuity Roundup/Genuity SmartStax Refugee-In-The-Bag) (Monsanto Company, St. Louis, MO) was planted at 32,000 seeds/acre in early May each spring. The experimental design was a strip split-plot randomized complete block design, encompassing eight separate blocks. Residue treatments were either corn stover removed (60% removal) for each year or residue retained (0% removal). Nitrogen was applied at the V2 leaf stage at rates of 0, 75, and 150 lbs N/acre increments each season. In 2012, urea-ammonium-nitrate (UAN) (28%) was used instead of urea. Tillage treatments varied from no-tillage to tillage. The tillage implement was a fall chisel followed by spring cultivator. The no-till treatments were not tilled before planting. Water was applied as irrigation with an overhead irrigator at 1-inch of water per week from July 10th to August 10th as needed. The dryland plots relied upon natural precipitation. No phosphorus or potassium fertilizer was applied annually to plots. Crop protection followed similar local cultural practices.

Soil samples were taken at the 0-6, 6-12, and 12-24 inch increments in the spring of 2008 and at the conclusion in fall 2012. Soil samples were air-dried, ground, and sieved immediately following soil sampling. Laboratory analysis for extracting available K^+ followed protocols outlined in the North Central handbook for testing for exchangeable K^+ (Warnacke, 2012). The amount of K^+ was measured by the use of a Jenway model PFP7 industrial flame photometer (Bibby Scientific, Burlington, NJ).

Standard calibration solutions were created for 0, 1, 3, 5, 7, and 9 ppm readings (Jenway PFP7 Flame Photometer Operator's Manual). Samples were diluted with Nanopure filtered water to obtain values within machine accuracy. Each sample was analyzed on three replications. Soil water soluble K^+ levels was accomplished similar to the NH_4OH extraction, using Nanopure water as an extractant.

Corn grain yield data was collected each fall by use of a two-row plot combine and a weigh wagon. Yield data was adjusted to 15% grain moisture and compared between 2008 and 2012 for yield differences associated between treatment practices.

Meteorological and Weather Data

Meteorological data for growing degree days and precipitation was calculated through the SDSU Extension service, iGrow, for the nearest weather station closest to each site. Calculations were made in accordance with Reese et al (2014).

Statistical Analysis

PROC GLM procedure of SAS 9.3 (SAS Institute, Inc., Cary, NC) was used to determine influence on 2008, 2012, and a 'K balance' STK levels, as well as 2008, 2012, and 'Yield balance' corn yields. N Rate*Till*Water*Block was used as error terms while other treatments were listed as factors.

RESULTS AND DISCUSSION

Meteorological and Weather Data

2008

	Precipitation (inches)		Growing Degree Day units (GDD)'s	
Month	2008	1981-2010 Average	2008	1981-2010 Average
January	0.02	0.35	0	0
February	0.03	0.76	0	0
March	0.87	1.92	4	0
April	1.71	4.05	106	84.5
May	4.47	7.02	356	355.75
June	10.07	11.32	805	826.8
July	11.67	14.57	1457	1457.7
August	12.34	17.64	2052	2023.35
September	13.8	20.83	2446	2348.4
October	17.87	22.88	2585	2467.7
November	18.44	23.83	2630	2467.7
December	18.58	24.31	2630	2467.7

Table 1.1. 2008 Precipitation and Growing Degree Day accumulations compared to the 30-year average at South Dakota State University, Aurora, SD, agricultural experiment station.

2012

	Precipitation (inches)		Growing Degree Day units (GDD)'s	
Month	2012	1981-2010 Average	2008	1981-2010 Average
January	0.05	0.35	11	0
February	0.57	0.76	11	0
March	1.47	1.92	212	0
April	3.79	4.05	380	84.5
May	10.13	7.02	746	355.75
June	11.84	11.32	1346	826.8
July	13.07	14.57	2148	1457.7
August	15.05	17.64	2673	2023.35
September	15.5	20.83	3075	2348.4
October	16.31	22.88	3196	2467.7
November	16.67	23.83	3226	2467.7
December	17.2	24.31	3233	2467.7

Table 1.2. 2012 Precipitation and Growing Degree Day accumulations compared to the 30-year average at South Dakota State University, Aurora, SD, agricultural experiment station.

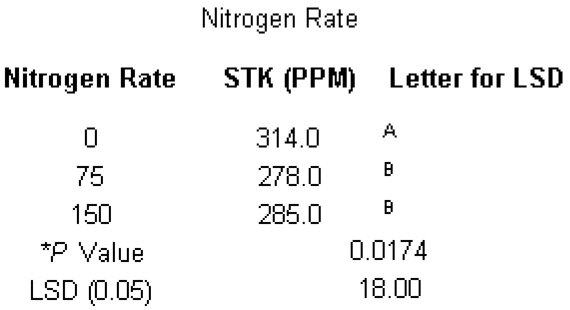
Precipitation was drier in 2008 than the 30-year average, but rainfall was plentiful from May through June during the critical time period of vegetative development (Table

1.1). Conditions were drier later in the summer during the later reproductive stages. 2012 was a historically dry season across the upper Midwest. Rainfall amounts were, on the contrary, wetter early on and only fell below the 30-year average in July-August (Table 1.2).

Growing degree days are calculated in corn production to estimate plant growth stage and gauge development against multi-year averages. In 2008 and 2012, GDD's were similar to the 30-year average (Tables 1.1 and 1.2). More GDD's were recorded in 2012 since temperatures were warm early in the spring and into the fall. Since growing degree days are a function of high and low temperatures, it can be assumed that temperatures accurately reflected the 30-year average. While increases in temperature may signify higher rates of plant growth and development, a failure to accumulate rainfall will diminish plant productivity.

Exchangeable STK Results

Results for soil sampling analysis on the exchangeable K^+ pool are provided in Tables 1.3 through 1.9. STK levels were compared between treatments singularly and subsequent interactions. P-values are reported within each treatment and interaction alphabetical letters specify statistical significance between treatments at the 95% probability level. Only data from the top 0-6" sampling depth are provided. We only report significant interactions. All other interactions not reported are not statistically significant and have been omitted. Statistically significant exchangeable STK values were only assessed in the 2012 growing season and a subsequent 'K Balance' (2012 STK values - 2008 STK values).

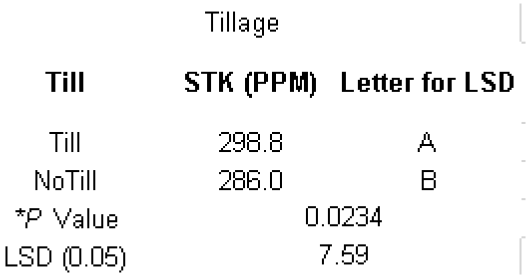


Nitrogen Rate

Nitrogen Rate	STK (PPM)	Letter for LSD
0	314.0	A
75	278.0	B
150	285.0	B
*P Value	0.0174	
LSD (0.05)	18.00	

Table 1.3. Exchangeable STK levels between across the nitrogen applications in 2012 with significance denoted in letters at a=0.05.

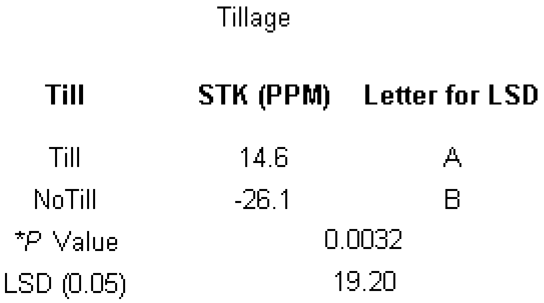
Nitrogen rates did influence STK level in 2012 at $P<0.01$ (Table 1.3), but did not statistically affect the K^+ balance from 2012 to 2008 (not reported). The highest STK levels were reported in the 0 lbs N/acre plot with a subsequent decrease as N rates increased. A possible reason for this could be a function of plant growth as more nitrogen was made available for the crop, a greater demand for potassium uptake occurred. Since nitrogen deficiencies may have occurred, plant uptake of K^+ was reduced, decreasing the demand for K^+, leading to greater STK levels. Bar-Yosef (2014) highlighted the importance of an adequate nitrogen supply since the need for K^+ is correlated to nitrogen availability. Statistically between sampling years, these differences were greater in the 0 lbs N/a than in the 75 and 150 lbs N/acre plots. While this may be the case, the largest draw on exchangeable STK occurred in the 75 lbs N/acre plot than under increasing nitrogen rates. This draw was much larger than the other N rates used, but was not statistically significant at the 95% confidence interval from the 150 lbs N/a treatment (Table 1.3). Most nitrogen applications for South Dakota corn production are made around the 150 lbs N/a, so this draw may be more realistic and should be rigidly followed for future STK draws.



Tillage

Till	STK (PPM)	Letter for LSD
Till	298.8	A
NoTill	286.0	B
*P Value	0.0234	
LSD (0.05)	7.59	

Table 1.4. Exchangeable STK levels between tillage treatments in 2012 with significance denoted in letters at a=0.05.

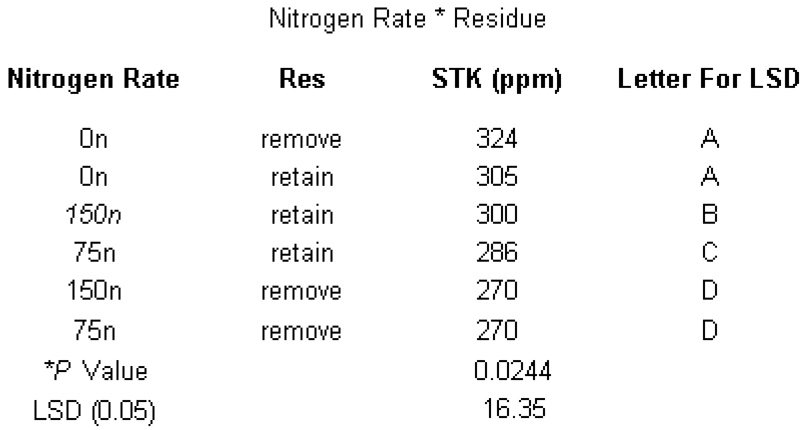


Tillage

Till	STK (PPM)	Letter for LSD
Till	14.6	A
NoTill	-26.1	B
*P Value	0.0032	
LSD (0.05)	19.20	

Table 1.5. Exchangeable STK levels between tillage treatments in ‘K Balance’ with significance denoted in letters at a=0.05.

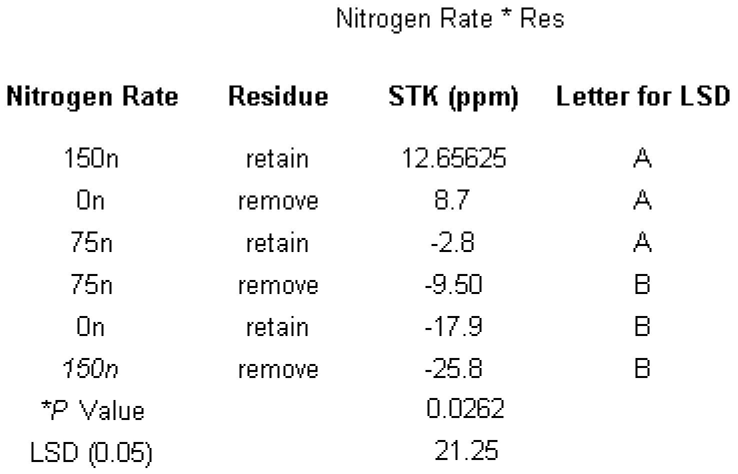
Tillage treatments influenced exchangeable STK values in 2012 at the P<0.0234 (Table 1.4) and the K Balance (Table 1.5) at P<0.0032. Exchangeable STK values were higher in the tilled treatments than in the notilled treatments, perhaps a reflection of higher mineralization rates that occurred in the tilled environments. As more corn stover is made available for decomposition, net higher releases of K^+ occurred, equating to higher exchangeable levels. The K Balance (Table 1.5) illustrated a trend for much higher STK values in the tilled treatments than in the notilled plots. Across the 5 year period, the tilled treatments gained appreciable levels of STK while the notilled plots lost an appreciable amount of STK. It is expected a similar process that occurred in the 2012 sampling date occurred across the 5 year period where more K^+ was released through mineralization (Table 1.4). Water availability is a major concern for South Dakota corn producers. For many, notilled practices are the primary cultivation. Under this scenario, it may be more appropriate to consider the STK draws associated with notilled treatments reflective of current South Dakota agriculture.



Nitrogen Rate * Residue

Nitrogen Rate	Res	STK (ppm)	Letter For LSD
0n	remove	324	A
0n	retain	305	A
150n	retain	300	B
75n	retain	286	C
150n	remove	270	D
75n	remove	270	D
**P* Value		0.0244	
LSD (0.05)		16.35	

Table 1.6. Exchangeable STK levels between nitrogen by residue plots in 2012 with significance denoted in letters at a=0.05.

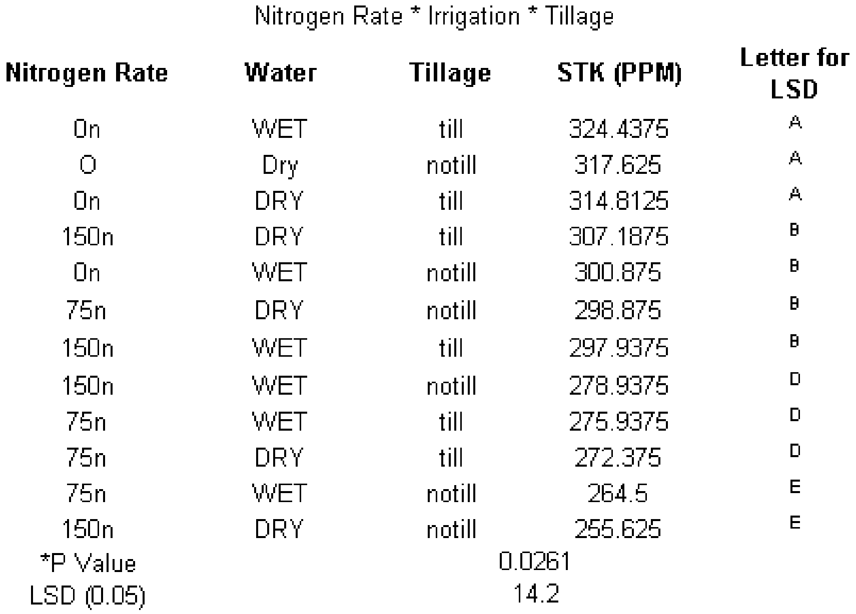


Nitrogen Rate * Res

Nitrogen Rate	Residue	STK (ppm)	Letter for LSD
150n	retain	12.65625	A
0n	remove	8.7	A
75n	retain	-2.8	A
75n	remove	-9.50	B
0n	retain	-17.9	B
150n	remove	-25.8	B
**P* Value		0.0262	
LSD (0.05)		21.25	

Table 1.7. Exchangeable STK levels between nitrogen by residue plots treatments in ‘K Balance’ with significance denoted in letters at a=0.05.

Nitrogen rates did influence exchangeable STK levels in 2012 at the P<0.0244 (Table 1.6) and the K Balance at P<0.0262 (Table 1.7). In 2012, the highest STK value was recorded in the 0 lbs N/acre with residue removed plots while the greatest draw that took place at the 150 lbs N/a and 75 lbs N/a with reside removed in both instances. It was stated above that the 150 lbs N/a may be more reflective of South Dakota corn production, and the greatest draw was expected to have occurred wherever corn stover was removed and not returned for mineralization. Table 1.7 provides a K Balance for the 5-year period. The greatest removal of STK took shape in the 150 lbs N/a with the corn stover removal treatment while in a similar nitrogen treatment where residue was returned, a net gain of STK was reported. Where residue was returned, a slower draw on STK occurred, regardless of nitrogen application rate (Table 1.7). As stated above, since residue collection programs will increase in frequency in succeeding years, a significant draw on STK will occur on a magnitude of 26 ppm a year (Table 1.7).

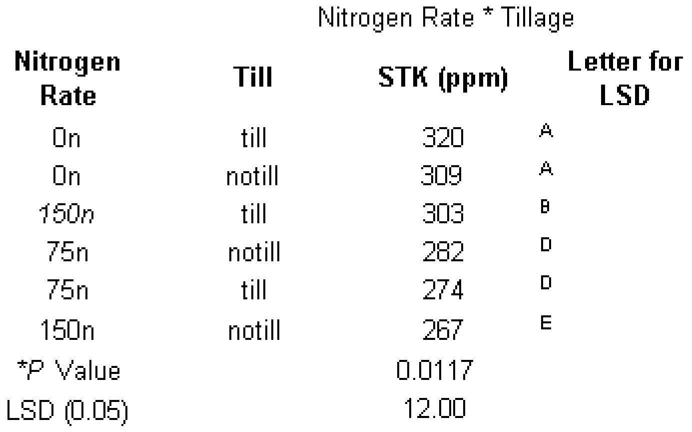


Nitrogen Rate * Irrigation * Tillage

Nitrogen Rate	**Water**	**Tillage**	**STK (PPM)**	**Letter for LSD**
0n	WET	till	324.4375	A
O	Dry	notill	317.625	A
0n	DRY	till	314.8125	A
150n	DRY	till	307.1875	B
0n	WET	notill	300.875	B
75n	DRY	notill	298.875	B
150n	WET	till	297.9375	B
150n	WET	notill	278.9375	D
75n	WET	till	275.9375	D
75n	DRY	till	272.375	D
75n	WET	notill	264.5	E
150n	DRY	notill	255.625	E
*P Value			0.0261	
LSD (0.05)			14.2	

Table 1.8. Exchangeable STK levels between nitrogen by irrigation by tillage plots treatments in 2012 with significance denoted in letters at a=0.05.

A three-way interaction between nitrogen rate, irrigation (water) practice, and tillage treatment was also reported in 2012 (Table 1.8). While the complexities of each interaction may not be appropriate to clearly decipher, it is expected that under increasing nitrogen application rate combined with an ample supply of soil moisture where residue is removed each year, the greatest decrease in STK would occur in these plots. Accumulated growing season (January-August) precipitation was slightly lower in 2008 and on par in 2012 (Tables 1.1 and 1.2). While the 0 lbs N/a with wet irrigation practice and tillage treatments resulted in the highest STK concentrations, the 150 lbs N/a that was kept under dryland conditions with a notilled environment resulted in the largest draw on STK (Table 1.8). A case could be made as to why the nitrogen x irrigation x tillage treatments tested high for K since corn stover biomass was returned and incorporated into the soil with varying irrigation practices. In particular, a clear trend was not indicated through the impact of water on STK values. This may be partially due to adequate water supply being available to the crop in 2012 (Table 1.2). Evidence for this speculation is highlighted through the water treatments not significantly influencing STK values in 2012 or in a K^+ Balance (data not reported). Irrigation may not be as intense as in neighboring Corn Belt states, so a 150 lbs N/a under a dryland practice with notilled treatments may accurately reflect a majority of South Dakota agriculture, in which the lowest STK values were documented, on a magnitude of 68 STK ppm decrease (Table 1.8).



Nitrogen Rate * Tillage

Nitrogen Rate	Till	STK (ppm)	Letter for LSD
0n	till	320	A
0n	notill	309	A
150n	till	303	B
75n	notill	282	D
75n	till	274	D
150n	notill	267	E
**P* Value		0.0117	
LSD (0.05)		12.00	

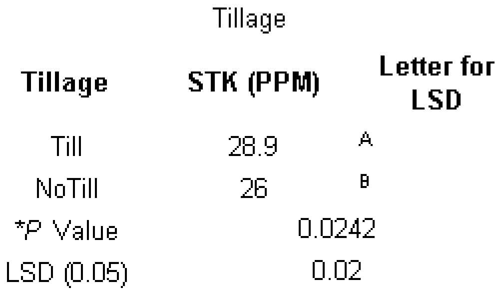
Table 1.9. Exchangeable STK levels between nitrogen by tillage plots treatments in 2012 with significance denoted in letters at a=0.05.

A nitrogen rate by tillage interaction was reported in 2012 at the $P<0.0117$ level. It was assumed that as the nitrogen rate decreased, less K^+ would be taken into plant growth, resulting in a net decrease in plant K^+ accumulation than in plots with increasing nitrogen application rates. This phenomena was noted in Table 1.9 with the 0 lbs N/acre under tilled treatments resulting in the largest STK. As nitrogen rate increased, the draw on STK increased. As such, each tilled (or incorporated) nitrogen treatment tested higher for STK than in its comparative nitrogen rate plot where residue was notilled (Table 1.9). This followed a similar trajectory as in Table 1.5 where the tilled plots tested significantly higher for STK than its notilled counterparts.

While it appears that residue collection programs that would otherwise make less stover biomass for recycling and mineralization would have a detrimental effect on STK values under varying management practices, a draw on STK values was not seen under any circumstance on the exchangeable K^+ pool, unless interacted with another management practice (Tables 1.6 and 1.7). Longer-term studies (greater than 5 years) need to be conducted to continue to examine the effects of continuous stover removal on exchangeable K^+ levels. It seems imperative that a future reduction in STK values would occur under longer-term (10+ years) management programs.

Solution STK Results

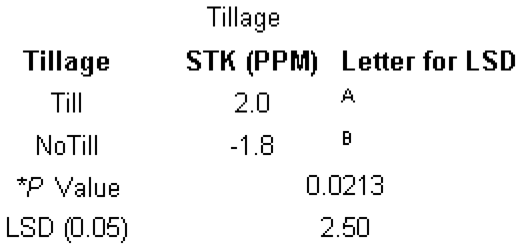
The readily-plant available form of water soluble K^+ was also tested in this study and results are found in Tables 1.10 through 1.14. Refer to Methods and Materials for extraction techniques. Similar analysis was conducted as in the exchangeable K^+ pool above.



Tillage

Tillage	STK (PPM)	Letter for LSD
Till	28.9	A
NoTill	26	B
*P Value	0.0242	
LSD (0.05)	0.02	

Table 1.10. Soil solution K^+ soil test results between tillage treatments in 2012. Provided letters denote significance at a=0.05.



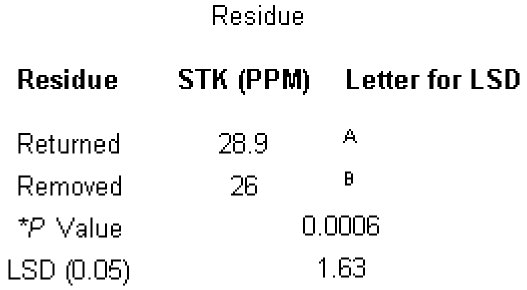
Tillage

Tillage	STK (PPM)	Letter for LSD
Till	2.0	A
NoTill	-1.8	B
*P Value	0.0213	
LSD (0.05)	2.50	

Table 1.11. Soil solution K^+ soil test results between tilled treatments at the K Balance. Provided letters denote significance at a=0.05.

Tillage treatments in the solution K^+ pool were significant at the $P<0.0242$ level in 2012 (Table 1.10). Across notilled and tilled environments, there was a significant difference at the 2012 sampling date and a statistically significant difference was recorded at the K Balance (Table 1.11). As stated above, a majority of South Dakota agriculture incorporates the use of notill, which may be more reflective of current progressions.

Tilled treatments impacted the K Balance from 2012 to 2008 at the $P<0.0213$ level (Table 1.11). Tilled treatments led to an increase in STK values while in the notilled plots, a net decrease of STK was documented. The gains in STK can be attributed to an increased incorporation of corn stover residue, leading to a greater release of inorganic K^+ into the soil through mineralization. Table 1.10's trend for higher STK in the tilled treatment is in agreement with the 2012 sampling results where STK values were higher for the tilled treatments.



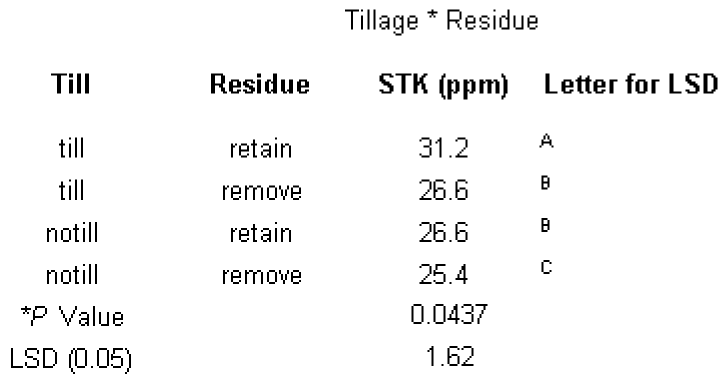
Residue

Residue	STK (PPM)	Letter for LSD
Returned	28.9	A
Removed	26	B
*P Value	0.0006	
LSD (0.05)	1.63	

Table 1.12. Soil solution K^+ soil test results between residue treatments in 2012. Provided letters denote significance at a=0.05.

Where residue was returned to the soil, STK levels were greater, but only statistically significant in 2012 (Table 1.12). These values were significant at the $P<0.0006$ level. Across site years, residue returned plots gained 1.2 ppm water soluble K^+

while where residue was removed, a negative K^+ balance of 0.8 ppm soluble K^+ occurred (data not reported).

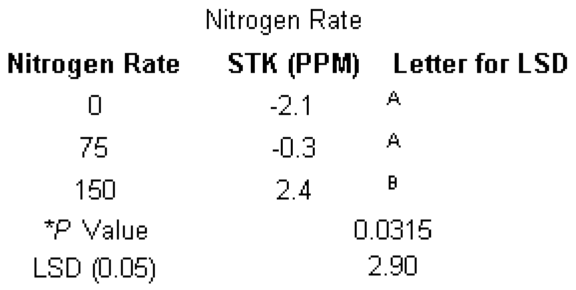


Tillage * Residue

Till	Residue	STK (ppm)	Letter for LSD
till	retain	31.2	A
till	remove	26.6	B
notill	retain	26.6	B
notill	remove	25.4	C
*P Value		0.0437	
LSD (0.05)		1.62	

Table 1.13. Soil solution K^+ soil test results between residue treatments in 2012. Provided letters denote significance at a=0.05.

A tillage by residue interaction occurred with the solution K^+ pool at the $P<0.0437$ level (Table 1.13). In plots where residue was maintained (or retained), STK values were higher, in agreement with Table 1.12. Since this organic matter was maintained, tillage treatments incorporated the residue into the soil, leading to higher STK values (Table 1.13).



Nitrogen Rate

Nitrogen Rate	STK (PPM)	Letter for LSD
0	-2.1	A
75	-0.3	A
150	2.4	B
*P Value		0.0315
LSD (0.05)		2.90

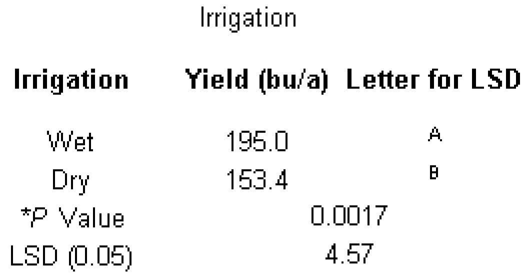
Table 1.14. Soil solution K^+ soil test results between residue treatments in 2012. Provided letters denote significance at a=0.05.

Nitrogen rates influenced the soil solution K Balance at the $P<0.0315$ level. As nitrogen rates increased, a net increase in K^+ occurred, contrary to expected results. Similar trends that occurred in the exchangeable K^+ pool took shape in the solution K^+ pool. Across both K^+ pools and 2012 and K Balance analysis, tillage treatments impacted STK values (Tables 1.4, 1.5, 1.10, and 1.11). Nitrogen rates statistically influenced exchangeable STK levels in 2012 ($P<0.0174$), and the solution K^+ pool's K balance ($P<0.0315$), but did not affect values in 2012 for soil solution K^+. In 2012, as N rates increased, STK levels decreased, due in large part to potassium demand as plant growth increased. The 150 lbs N/A treatment gained water soluble K^+ across the five growing seasons while the 0 lbs N/A plots lost K^+, which was statistically significant (Table 1.14).

Across the five-year study conducted, residue collection programs did not significantly influence STK values alone (data not reported). On the contrary, trends were developed for an increased STK value in plots where residue was maintained (Tables 1.12 and 1.13). These interactions only occurred in the soil solution K^+ pool, and a lesser trend was noted in the exchangeable K^+ pool (Tables 1.6 and 1.7).As discussed in Table 1.8 and subsequent analyses, a trend for the three main factors associated with nitrogen rate x irrigation x water is correlated to the lowest STK level. While residue collection programs may not singularly dictate gains or losses in overall STK, when interacted with a single or double factor, trends may lend credence to higher STK in the soil solution pool than in the exchangeable pool. This has important implications for South Dakota agriculture. While solution K^+ has the greatest ability to be taken into the plant, this represents only a small fraction of plant available K^+ (Askegaard, 2003). A flux, referred to as a chemical equilibrium of K^+, has been proposed by Bray and DeTurk (1939). It was described as the equilibrium that which soil solution K^+, exchangeable K^+, and nonexchangeable (interlayer or fixed) K^+ collectively maintains. Any change in K^+ concentration amongst the pools affects the distribution of K^+ held in equilibrium. Technically, Bray and DeTurk postulated that if a soil had a decrease in activity of solution K^+, K^+ would be released from the exchangeable or particle edges to replenish this pool. This replenishment can be exponential (Luebs, 1956).

Corn Grain Data

Corn grain yield results are displayed in Tables 1.15 through 1.27. An associated 'Yield Balance' was generated showing the reflection of yields from 2012 to 2008 and were computed across all treatments. Analysis of variance was used to determine significance at the alpha=0.05 level. Residue collection and tillage programs began in fall 2008 after harvest, similarly with tillage. For 2008, only nitrogen rate and irrigation are discussed. All treatments and their subsequent interactions are analyzed thereafter.

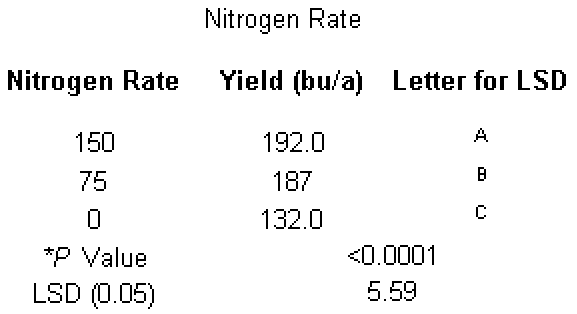


Irrigation

Irrigation	**Yield (bu/a)**	**Letter for LSD**
Wet	195.0	A
Dry	153.4	B
*P Value	0.0017	
LSD (0.05)	4.57	

Table 1.15. Corn grain results between irrigation treatments in 2008. Provided letters denote significance at a=0.05.

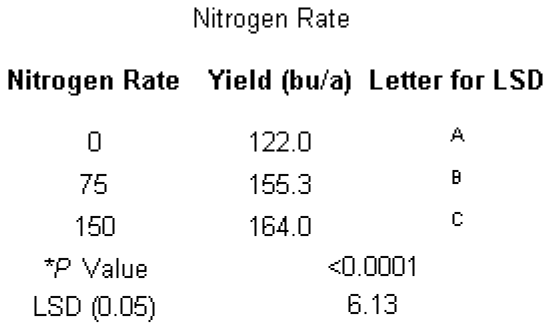
In accordance with Table 1.1, growing season precipitation fell below the 30-year average, providing an advantage for in-season water applications. Irrigation practices influenced corn grain yield at $P<0.0017$ in 2008 (Table 1.15). A large discrepancy was indicated between wet and dryland plots. Corn grain yields were highest in the wet plots while lower in the dryland plots (Table 1.15).



Nitrogen Rate

Nitrogen Rate	Yield (bu/a)	Letter for LSD
150	192.0	A
75	187	B
0	132.0	C
*P Value	<0.0001	
LSD (0.05)	5.59	

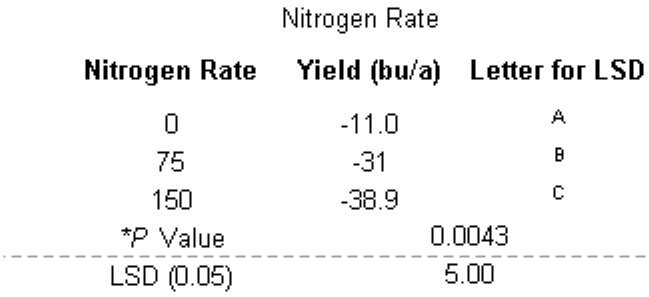
Table 1.16. Corn grain results between nitrogen rate treatments in 2008. Provided letters denote significance at a=0.05.



Nitrogen Rate

Nitrogen Rate	Yield (bu/a)	Letter for LSD
0	122.0	A
75	155.3	B
150	164.0	C
*P Value	<0.0001	
LSD (0.05)	6.13	

Table 1.17. Corn grain results between nitrogen rate treatments in 2012. Provided letters denote significance at a=0.05.

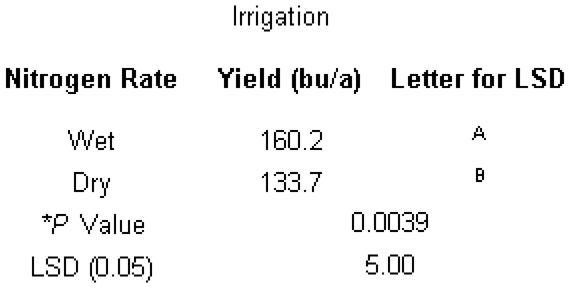


Nitrogen Rate

Nitrogen Rate	Yield (bu/a)	Letter for LSD
0	-11.0	A
75	-31	B
150	-38.9	C
*P Value	0.0043	
LSD (0.05)	5.00	

Table 1.18. Corn grain results between nitrogen rate treatments in a calculated yield balance. Provided letters denote significance at a=0.05.

Nitrogen rates influenced corn grain yield in 2008 at the P<0.0001 level (Table 1.16), P<0.0001 in 2012 (Table 1.17), and the yield balance at P<0.0043 (Table 1.18). As nitrogen rates increase, expected corn grain yields should follow a likewise trend. Grain yields increased linearly as nitrogen rate increased. Since corn is responsive to nitrogen application rates, recorded yield results are as expected. Similarly, the lowest grain yield was at 0 lbs N/a. In Table 1.18, the largest draw on corn grain yield was at the 150 lbs N/a rate. Discussed earlier under the exchangeable K pool, this N rate is very reflective of South Dakota agriculture.

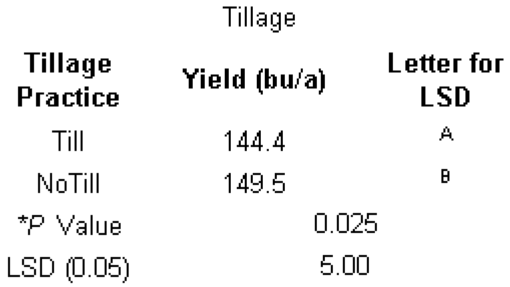


Irrigation

Nitrogen Rate	Yield (bu/a)	Letter for LSD
Wet	160.2	A
Dry	133.7	B
*P Value	0.0039	
LSD (0.05)	5.00	

Table 1.19. Corn grain results between irrigation treatments in 2012. Provided letters denote significance at a=0.05.

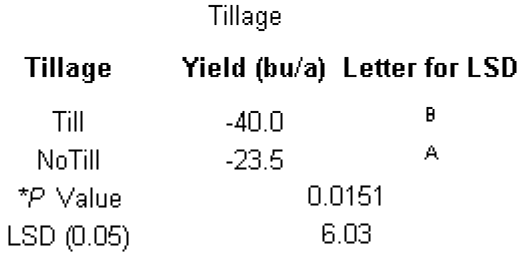
.Following a similar trend as in Table 1.15, irrigation significantly influenced corn grain yields at the P<0.0039 level (Table 1.19). Table 1.2 indicated that 2012 accumulated growing season moisture on par with the 30-year average. Despite a close resemblance to normal rainfall, there was still an advantage for irrigation (Table 1.19).



Tillage

Tillage Practice	**Yield (bu/a)**	**Letter for LSD**
Till	144.4	A
NoTill	149.5	B
*P Value	0.025	
LSD (0.05)	5.00	

Table 1.20. Corn grain results between irrigation treatments in 2012. Provided letters denote significance at a=0.05.

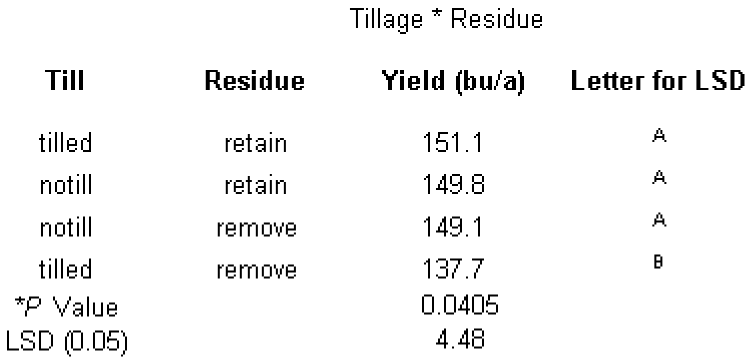


Tillage

Tillage	**Yield (bu/a)**	**Letter for LSD**
Till	-40.0	B
NoTill	-23.5	A
*P Value	0.0151	
LSD (0.05)	6.03	

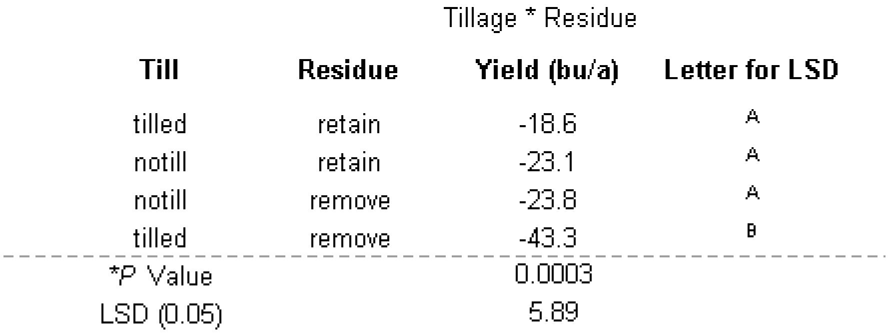
Table 1.21. Corn grain results between tillage treatments in yield balance. Provided letters denote significance at a=0.05.

Tillage treatments significantly influenced corn grain yield in 2012 at the P<0.025 level (Table 1.20) and the yield balance at P<0.0151 (Table 1.21). In 2012, higher yields were reported under notilled conditions, as well as a lower yield reduction across the five-year period. Under a yield balance, a substantial decrease in corn yield was documented in the tilled conditions.


Tillage * Residue

Till	Residue	Yield (bu/a)	Letter for LSD
tilled	retain	151.1	A
notill	retain	149.8	A
notill	remove	149.1	A
tilled	remove	137.7	B
*P Value		0.0405	
LSD (0.05)		4.48	

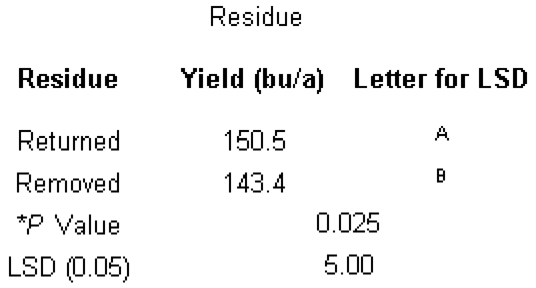
Table 1.22. Corn grain results between tillage and residue treatments in 2012. Provided letters denote significance at a=0.05.


Tillage * Residue

Till	Residue	Yield (bu/a)	Letter for LSD
tilled	retain	-18.6	A
notill	retain	-23.1	A
notill	remove	-23.8	A
tilled	remove	-43.3	B
*P Value		0.0003	
LSD (0.05)		5.89	

Table 1.23. Corn grain results between tillage and residue treatments in yield balance. Provided letters denote significance at a=0.05.

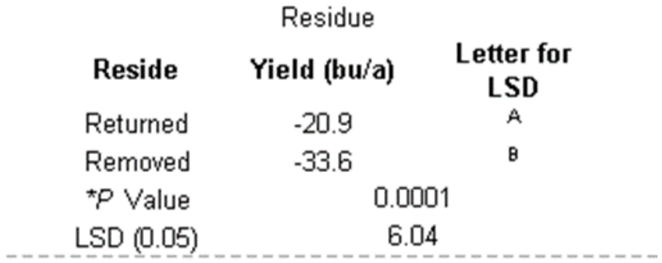
Tillage x residue interactions were significant at the P<0.0405 level in 2012 (Table 1.22) and at P<0.0003 in the calculated yield balance (Table 1.23). Speculation as to how these interactions would influence corn grain yield data expected that the corn grain yields would be highest in the tilled and retained environments while the lowest would occur in plots kept notilled with residue removed. In 2012, tilled and residue retained yielded the highest yield, but was not statistically significant than the other treatments (Table 1.22). A calculated yield balance (Table 1.23) resulted in the greatest draw occurring in the tilled and removed environments.



Residue

Residue	Yield (bu/a)	Letter for LSD
Returned	150.5	A
Removed	143.4	B
*P Value	0.025	
LSD (0.05)	5.00	

Table 1.24. Corn grain results between residue treatments in 2012. Provided letters denote significance at a=0.05.

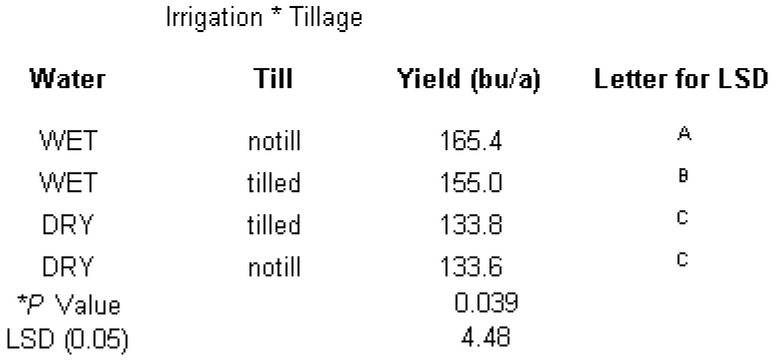


Residue

Reside	Yield (bu/a)	Letter for LSD
Returned	-20.9	A
Removed	-33.6	B
*P Value	0.0001	
LSD (0.05)	6.04	

Table 1.25. Corn grain results between residue treatments in the yield balance. Provided letters denote significance at a=0.05.

Residue collection programs influenced corn grain yield at the P<0.025 level in 2012 (Table 1.24) and the calculated yield balance at P<0.0001 (Table 1.25). When residue was returned, a particular yield advantage was documented over the residue removed plots. Across the five year period, it is estimated that the value of maintaining corn stover is 12.7 bushels (Table 1.25).

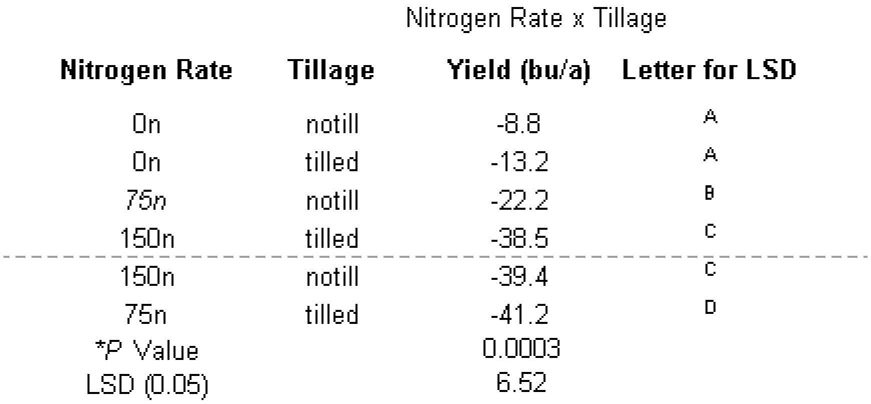


Irrigation * Tillage

Water	Till	Yield (bu/a)	Letter for LSD
WET	notill	165.4	A
WET	tilled	155.0	B
DRY	tilled	133.8	C
DRY	notill	133.6	C
*P Value		0.039	
LSD (0.05)		4.48	

Table 1.26. Corn grain results between irrigation and tillage treatments in 2012. Provided letters denote significance at a=0.05.

An irrigation x tillage practice interaction significantly influenced corn grain yields in 2012 (Table 1.26) at P<0.039, but not the calculated yield balance (data not reported). Under each management practice, wetland plots out-yielded the dryland plots in all situations, which were significantly different. This is in accordance with Table 1.19. Table 1.20 indicated a yield advantage for plots which were kept notilled. With the interaction of irrigation with tillage practices, no clear trend was indicated in regards to tillage program (Table 1.26). Since many South Dakota producers incorporate the use of a field cultivator before the spring planting pass, it is expected the highest yield would have occurred in the wet x tilled plots. The wet by notilled plots out-yielded the expectation.



Nitrogen Rate x Tillage

Nitrogen Rate	Tillage	Yield (bu/a)	Letter for LSD
0n	notill	-8.8	A
0n	tilled	-13.2	A
75n	notill	-22.2	B
150n	tilled	-38.5	C
150n	notill	-39.4	C
75n	tilled	-41.2	D
**P* Value		0.0003	
LSD (0.05)		6.52	

Table 1.27. Corn grain results between nitrogen rate and tillage treatments in the yield balance. Provided letters denote significance at a=0.05

A nitrogen rate by tillage interaction was documented and significant at the P<0.0003 level for the calculated yield balance (Table 1.27). In accordance with Table 1.18, the largest decrease in corn grain yield occurred at the 150 lbs N/a application rate. A similar trend as in Table 1.18 was outlined in Table 1.27. As nitrogen rate increased, so did the overall draw on corn grain yield. In Table 1.21, the largest draw on yield was associated in tilled plots. When the interaction was combined, no clear trends were seen (Table 1.27). Under current South Dakota corn production levels, a 150 lbs N/a application rate with notilled treatments may be normal. Under these situations across a 5-year period, a yield reduction of nearly 40 bushels/acre was seen (Table 1.27).

According to Mallarino (2003) and Gerwing (2005), STK levels should not have been yield-limiting under any circumstances. Any yield difference should be directly attributable to differing management practices under separate treatments. While subtle statistical differences occurred between treatments associated with corn grain yield, residue collection treatments resulted in greater yield deficits under a complete removal than a stover returned program (Table 1.22. 1.23 and 1.24). Under the five years conducted in this study, a negative long-term effect of stover removal was seen across corn grain yields of nearly 13 bushels per acre (Table 1.25). Under a residue removal program that incorporates tillage, we document that corn grain yields can be reduced by 43 bushels/acre (Table 1.25). While current studies have stated that corn stover removal may be beneficial (Below, 2013; Porter, 1997; Wilhelm and Wortmann, 2004; Peterson and Varvel, 1989), we indicate a continual removal of corn stover biomass to hinder sustained crop yield gains. While the trends were similar, our results contradict Barber (1979) who postulated that corn grain yields between residue returned and residue removed treatments were not statistically different.

CONCLUSION

A rapid development into cellulosic energy production is expected and soon to be a reality. Corn stover biomass accumulation can have a negative effect on corn grain yield following successive years of cultivation. Safe stover removal practices that maintain top corn yield potential while preserving environmental quality can be had. How stover removal affects STK levels and corn grain yields across long-term studies was conducted under varying management practices. While few management programs directly affected STK levels and corn grain yields, residue removal treatments did not influence exchangeable K^+, but did influence STK levels when interacted with nitrogen application rates. Soil solution K^+ pools were affected by residue collection in 2012, but not the overall K balance. As such, corn grain yields were also detrimentally impacted by residue removal, progressing further with interactions containing common South Dakota agricultural management practices. Future studies need to continue to address the impact of corn stover biomass removal on STK levels and corn grain yield as once implementation of the industry begins, residue collection programs will proliferate in both quantity and time periods greater than the length of study in which we conducted.

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CHAPTER 2

SOYBEAN [GLYCINE MAX] YIELD RESPONSE WITH K^+ FERTILIZATION FOLLOWING CONSECUTIVE YEARS OF CORN (Zea mays L.) STOVER REMOVAL IN SOUTH DAKOTA, USA

INTRODUCTION

Little on-farm research showing the impact of K^+ fertilizer on fields grown to soybeans following consecutive years of corn stover removal presently exists. Fertilizer represents a significant capital expense for producers. Growers have expressed concerns over the increasing frequency of phenotypic and tissue test K deficiencies present in fields while their soil test results indicate high or very-high STK levels.

On-farm calibration revealed STK levels recommended little to no K fertilizer in fields that had a high probability of a yield response to K fertilizer at Iowa State University, leading to a reclassification of K interpretation classes in 2002 (Mallarino, 2003). The widely used K recommendations used before 2003 were different than those developed after 2003 (Figure 2.1).

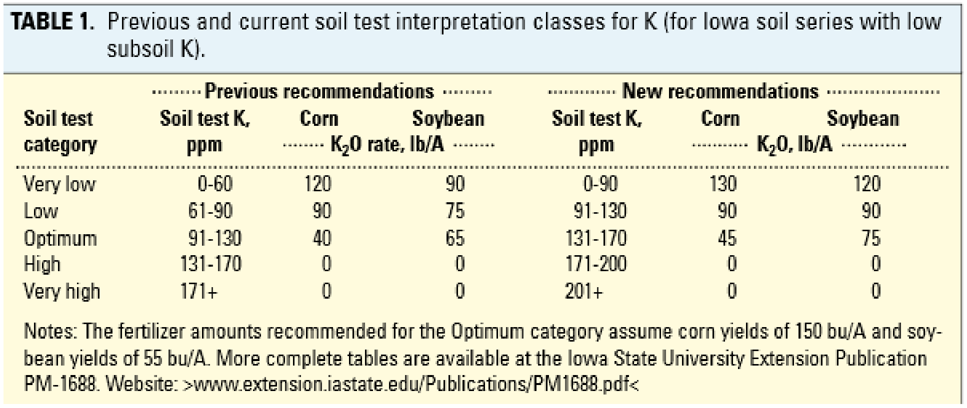


TABLE 1. Previous and current soil test interpretation classes for K (for Iowa soil series with low subsoil K).

	Previous recommendations			New recommendations		
Soil test category	Soil test K, ppm	Corn	Soybean	Soil test K, ppm	Corn	Soybean
		K_2O rate, lb/A			K_2O, lb/A	
Very low	0-60	120	90	0-90	130	120
Low	61-90	90	75	91-130	90	90
Optimum	91-130	40	65	131-170	45	75
High	131-170	0	0	171-200	0	0
Very high	171+	0	0	201+	0	0

Notes: The fertilizer amounts recommended for the Optimum category assume corn yields of 150 bu/A and soybean yields of 55 bu/A. More complete tables are available at the Iowa State University Extension Publication PM-1688. Website: >www.extension.iastate.edu/Publications/PM1688.pdf<

Figure 2.1. Previous vs. new K recommendations. Adapted from Mallarino, 2003).

South Dakota State University's (SDSU) Soil Test Laboratory (before its closing) used the NH_4OH extraction method (Warnacke, 2012), similar to Iowa State University. The algorithms used to determine K recommendations in South Dakota grain production is outlined in Gerwing, 2005. It has been reported that the average STK for South Dakota is 247 ppm (Fixen et al, 2010) and the average soybean yield is 43 bushels per acre. K fertilizer would not be recommended for South Dakota soybean producers using these numbers (Gerwing, 2005).

Recall NASS estimates of an average application rate in South Dakota of 29 lbs K_2O per acre. International Plant Nutrition Institute (IPNI) indicates that 1.3 lbs K_2O is removed with 1 bushel of soybean. If a South Dakota grower achieves a 60-bushel/acre soybean yield, 78 pounds of K_2O per acre will be removed in grain yield. Obviously, the South Dakota grower has undersupplied K fertilizer by 49 pounds per acre, relying on native K-bearing mineralogy, STK, and mineralization of the previous crop to meet the nutritional demand for K^+. There has been a reluctance to apply K fertilizer in South Dakota, primarily limited to wheat rotations since KCl has been shown to decrease the disease precedence of yield-limiting pathogens (Diaz-Zorita et al, 2004). The previously documented NASS estimates falls below neighboring soybean-producing states that apply 63-106 pounds in corn-soybean rotations, respectively, where median STK numbers fall below critical levels, ranging from 144-170 with 50-55% of samples testing below that range (Fixen et al, 2010).

Knowing at what STK level results in a 0% probability of a yield response to K fertilizer is unsettled. International Plant Nutrition Institute reports the critical level for STK values to be in the range of 120-200 ppm for soils having a high intrinsic cation exchange capacity (Fixen et al, 2010). SDSU's recommendations for fertilization indicate that above 161 ppm K, no K fertilizer is recommended (Gerwing, 2005), not in accordance with Iowa State recommendations (Figure 2.1). Tremendous variability exists and leads to frustration when determining K fertilization rates.

Field calibration analyzing sufficient STK readings for optimum row crop production (corn, soybeans) has been heavily scrutinized for over 100 years. Cyril Hopkins was one of the first to test the yield response of KCl fertilization on Illinois fields grown continuously to corn, reaching the conclusion that Illinois fields were well-supplied with K^+ after not seeing a positive yield response to K fertilizer (Hopkins, 1915). It was assumed long ago that cultivated soils had a high intrinsic ability to hold and store K^+, especially in arable soils that had a high percentage of 2:1 minerals (Khan, 2014). Hanway and Weber (1971) illustrated that despite fields where STK levels showed low available K^+, yields from K_2O addition were generally small and insignificant. No obvious effect on plant physiological development was noted, but leaves from the low K testing soils appeared lighter in green color (Hanway and Weber, 1971). Khan (2014) concluded that STK levels are unreliable for predicting crop yield responses. Of the 2100 yield response trials conducted (774 of which were undertaken in North America), it was reported that KCl fertilization was unlikely to increase yield 93% of the time, rather resulting in decreasing yields (Khan, 2014). This is in agreement with Farmaha (2011) who documented that on a Flanagan-Drummer silty loam soil in Illinois, soybean grain yields linearly decreased as K application rates (0, 42, 84, and 168 kg K ha^{-1} yr^{-1}) increased in the no-tillage broadcast K application system they analyzed. Mallarino (2013) reported that K applications increased soybean grain yield in only 5 of the 14 site years. Borges (2001) showed that while K fertilizer increased corn and soybean yields, the statistically significant yields were highest at the lowest rate; 35 lbs K_2O/acre.

However, various authors have reasoned that soybean yields can be reduced by 50% (Nelson et al, 1946) or only marginally at 10-20% (Mallarino et al, 1991) due to K deficiencies. Physiologically, these losses have been attributed to a decrease in pod formation (Coale and Grove, 1990) and enzymatic activity (Huber, 1984), among many other factors. Jones (1977) concluded that soybeans experienced responsive yields tied to potassium fertilizer.

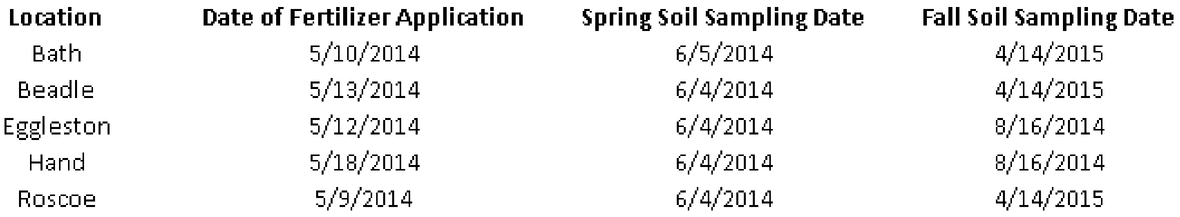
Objectives for this study include:

1.) Determine whether K^+ fertilizer provided positive yield responses for soybeans in fields experiencing corn stover removal
2.) Determine whether South Dakota State University's fertility recommendations are accurate for K_2O recommendations by using on-farm research
3.) Measure the in-field variation associated with soybean grain yield response to K fertilization.

MATERIALS AND METHODS

It has been proposed that growers conduct their own on-farm research by using strips to estimate if yield responses exist (Khan, 2014). We tested the hypothesis that potash applications to fields experiencing extensive histories of corn stover removal will experience yield gains to K^+ fertilizer. This was intended as a pilot program initiated to examine whether applying K^+ fertilizer could achieve soybean yield responses, paving the way for K^+ fertilizer rate response studies. Our work expands on Mallarino (2001) who discussed the possibility of large in-field variation in STK and yield responses, illustrating the importance of strip trials across landscapes.

On-farm strip research fields were conducted across central South Dakota from Huron to Aberdeen, SD, in the growing season of 2014. Five fields were chosen in cooperation with South Dakota Wheat Growers Cooperative and SDSU Extension. Selected fields had a history (greater than two years) of corn stover removal. 250 lbs of K_20/acre or 417 lbs of KCl potash (0-0-60) was spread preplant in early May 2014 across one 70 by 2640 foot pass with an air-flow TerraGator (AgCo Corporation, Duluth, Georgia) machine. KCl is soluble in water, allowing plant roots to rapidly uptake the mineral nutrient, leading to significant early season vegetative growth (Mallarino, 2013). Site characteristics are displayed in Appendix B. Fertilizer applications were made by the local South Dakota Wheat Growers Cooperative branch.



Location	Date of Fertilizer Application	Spring Soil Sampling Date	Fall Soil Sampling Date
Bath	5/10/2014	6/5/2014	4/14/2015
Beadle	5/13/2014	6/4/2014	4/14/2015
Eggleston	5/12/2014	6/4/2014	8/16/2014
Hand	5/18/2014	6/4/2014	8/16/2014
Roscoe	5/9/2014	6/4/2014	4/14/2015

Figure 2.2. Specified dates for K^+ fertilization, spring soil sampling, and fall soil sampling dates for each site location.

Soil samples were taken at the 0-6 inch increment on 100-foot transects in spring and fall 2014 (a few in early 2015). Refer to Figure 2.2 for specific sampling dates for each location. Early season sampling was conducted in sampling points outside of the plot (50-feet across) so as not to sample inside of the fertilized strip and to limit the degree of drift that may have occurred during the application process. The sample locations were georeferenced as taken. Fall soil sampling was used to estimate end of season STK levels. Figure 2.3 will assist in identifying how strips and soil sampling periods are being compared throughout. Soil samples were oven-dried (120^{C}), ground, and exchangeable K^+ was quantified using the NH_4OH extraction method. Soil samples were again collected late in the season and analyzed for seasonal (temporal) differences, responses to fertilization, and a temporal + fertilizer addition response.

Soybean plants were sampled and analyzed throughout locations on each fertilization strip for leaf K^+ concentration and stomatal conductance since K^+ has been linked to conductance inside of the plant (see Appendix B for dates and locations). Our hypothesis was that there would be elevated levels of conductance in soybean plants growing in the K^+ fertilized strip since more K^+ was made available through the spreading of potash fertilizer. Five soybean samples were analyzed during the R3 growth stage and conductance was measured across a fractionation of the soybean plant. We examined the newest trifoliate and the oldest trifoliate (appearing chlorotic; not necrotic). At the conclusion of the season, yield difference maps were generated for each site location.

Analyzing Temporal Soil Sampling Differences

There are three different comparisons that we will make. Please refer to Figure 2.3 for the graphic for how comparisons/analyses are made between treatment strips.

1) Temporal (Fall to Spring)
2) Temporal + Fertilizer Addition
3) Fertilizer Addition Difference

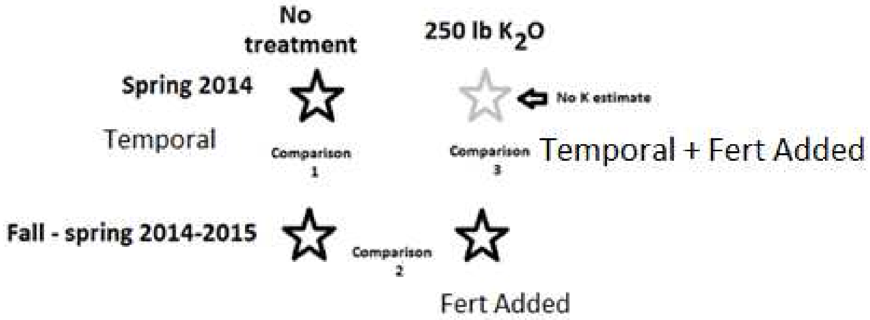


Figure 2.3. Model for specifying how soil samples are compared throughout the analysis.

Collecting Harvest Data

Each individual on-farm cooperator harvested their soybean field and plot area with their combines and collected yield data. Yield data was archived and imported to Spatial Management System Advanced (AgLeader Technology, Ames, Iowa). Yield monitor data was cleaned using Yield.Editor 2.0 (Sudduth, 2012) in accordance to procedures detailed in Appendix B.

Weather and Climate Data

Meteorological data for growing degree days and precipitation was calculated through the SDSU Extension service, iGrow, for the nearest weather station to each site. Growing degree day calculations were conducted in accordance with Reese et al (2014). Site meteorological information can be found in Appendix B.

Statistical Analysis

The kriging algorithm used in Surfer (Golden Software, Golden, Colorado) was used to estimate the STK levels that would have been in Comparison 3 at each site. Surfer kriging computer software (Golden Software, Golden, CO) was used for interpolation of STK when needed. Microsoft Xcel (Microsoft Corporation, Redmond, Washington) was used for analysis of variance/standard deviation analysis at each sampling point.

Landscape Positional Differences

Wherever possible within fields, yield differences are described across topographical sections according to the diagram below in Figure 2.4.

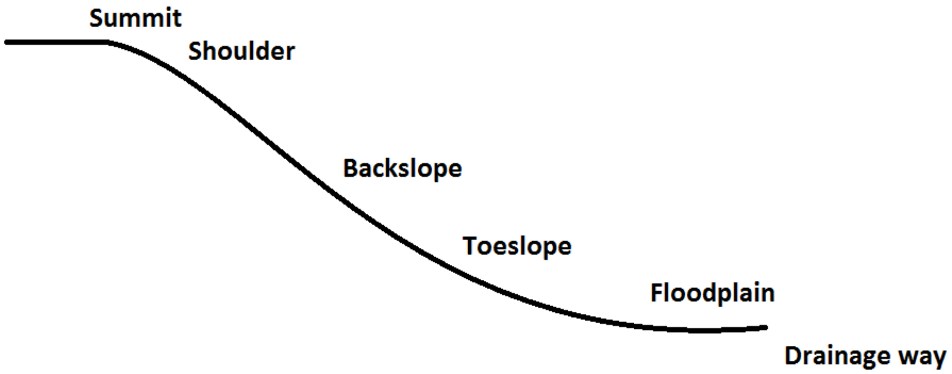


Figure 2.4. Terminology used to identify landscape positions.

RESULTS AND DISCUSSION

Precipitation and Temperature Data

Precipitation and growing degree day accumulations as well as discussion of meteorological data for each site location are graphically and textually presented in Appendix B.

Temporal Effects on STK Variability

The effect of time on STK values was tested by sampling each point on the No-K applied strip in spring and fall. Refer to Figure 2.2 for sampling dates and Appendix B for sampling points and STK values at each point. Table 2.1 displays the analysis of variance received at the Bath location between sampling periods. Numerical numbers associated Bath (Bath_1, Bath_2, etc.) correlate to sampling points conducted on 100-foot transects across the field between fall and spring.

Anova: Two-Factor Without Replication

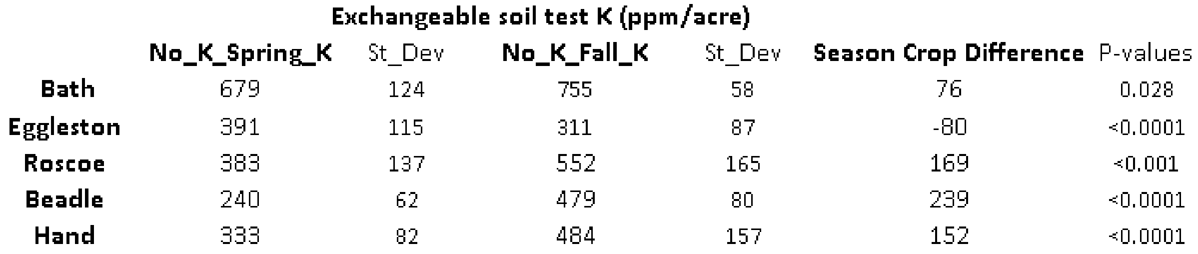
SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Bath_1	2.00	1434	717	11552
Bath_2	2.00	1265	633	14281
Bath_3	2.00	1252	626	10952
Bath_4	2.00	1179	590	12961
Bath_5	2.00	1277	639	39481
Bath_6	2.00	1401	701	64441
Bath_7	2.00	1421	711	9113
Bath_8	2.00	1416	708	29282
Bath_9	2.00	1743	872	56785
Bath_10	2.00	1542	771	1682
Bath_11	2.00	1517	759	4325
Bath_12	2.00	1401	701	1201
Bath_13	2.00	1465	733	7081
Bath_14	2.00	1479	740	925
Bath_15	2.00	1541	771	5513
Bath_16	2.00	1502	751	50
Bath_17	2.00	1352	676	3362
Bath_18	2.00	1319	660	6845
Bath_19	2.00	1393	697	12013
Bath_20	2.00	1525	763	7565
Bath_21	2.00	1584	792	3362
Bath_22	2.00	1539	770	1013
Spring_K_PPM	22.00	14938	679	16214
Fall_K_PPM	22.00	16609	755	3577

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	175279.48	21.00	8346.64	0.73	0.76	2.08
Columns	63460.02	1.00	63460.02	5.55	0.03	4.32
Error	240317.48	21.00	11443.69			
Total	479056.98	43.00				

Table 2.1. Analysis of variance for the temporal variability on the exchangeable STK values along the No-K applied strip at Bath. Numbers refer to sampling points based off of 100-foot transects.

The Bath site displayed a statistically significant gain in exchangeable STK between spring and fall sampling periods at the $P<0.05$ level. In particular, a wide variance was also received between sampling point (Table 2.1), and reflected across all site locations in Table 2.2.



Exchangeable soil test K (ppm/acre)

	No_K_Spring_K	St_Dev	No_K_Fall_K	St_Dev	Season Crop Difference	P-values
Bath	679	124	755	58	76	0.028
Eggleston	391	115	311	87	-80	<0.0001
Roscoe	383	137	552	165	169	<0.001
Beadle	240	62	479	80	239	<0.0001
Hand	333	82	484	157	152	<0.0001

Table 2.2. Temporal Effect on STK variability across site location on the 0 lbs K_2O/acre strip. Seasonal K Difference was computed as K_{Fall}-K_{Spring}.

Four of the five fields appreciably gained STK values between fall and spring sampling dates (Table 2.2). In some locations, the exchangeable STK gains were 76-239 ppm K while in other circumstances, fields lost 80 ppm K from spring to fall. Seasonal sampling periods were significant at the 95% level for 4 of the five fields. In fields where spring K ppm was higher than in the fall (negative balance), these differences were statistically significant at the $P<0.0001$ level. Caution should be taken since a questionable application of K^+ fertilization occurred at the Eggleston location. Fields that experienced a rapid increase in STK from spring to fall (positive balance), these differences were statistically significant at the $P<0.028$ level (Table 2.2). Other authors have reported higher exchangeable STK levels in the spring than fall (Liebhardt et al, 1977; Peterson et al, 1980). Table 2.2 indicates a clear trend for STK to increase in the 0 lbs K_2O/acre strip, despite fertilizer addition. We cannot decipher a reason for the dramatic crop differences (positive or substantially negative) seen along the No-K applied strip STK differences across the growing season.

Exchangeable STK levels were compared in fall 2014 following one growing season to determine spatial differences between the 0 lbs K_2O per acre strip between spring and fall sampling dates. Correlation analysis was conducted to relate STK level to seasonal differences in K level and displayed in Figure 2.5.

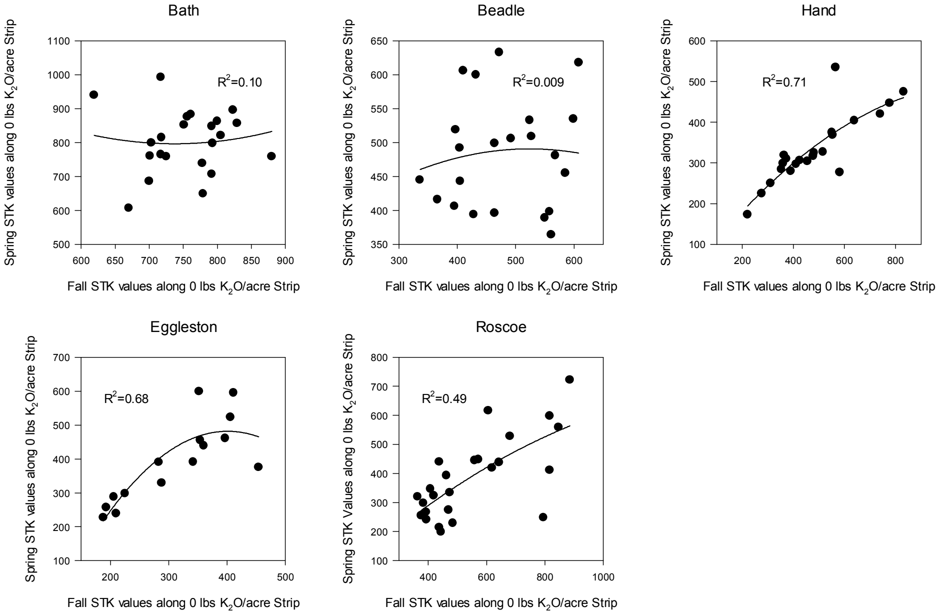


Figure 2.5. Exchangeable K temporal differences on No K-applied (fall) strips across site locations. X-axis relates to Fall STK values sampled along 100-foot transects on 0 lbs K_20/acre strip. Y-axis relates to the Spring STK values sampled along the same 100-foot transects along the No-K (0 lbs K_2O/acre) applied strip.

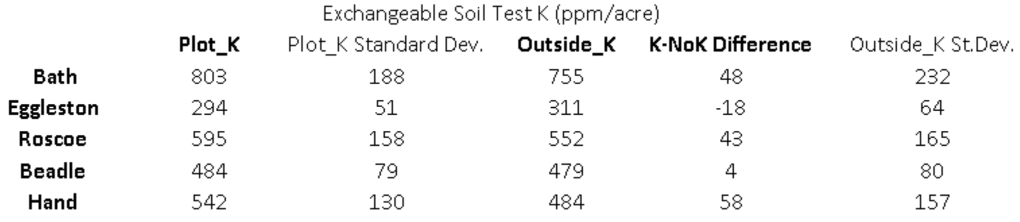
The results from Figure 2.5 indicate that there was a trend for higher Fall STK values to increase in comparison to spring STK sampling results.

Fertilizer Addition Effects on STK Levels

We wished to examine the effect of fertilizer addition on the K-applied strip if the fertilizer addition did increase STK values across a growing season. Assuming a 1 ppm rise per 8 lbs K_2O/acre (Hoeft et al, 2003), the difference between fertilization strips was higher than expected (Table 2.3). Table 2.3 illustrates exchangeable K^+ levels at each site location between strips along with standard deviation between sampling points. There was a trend for greater variance in outside sampling points versus inside of the plot, in accordance with values obtained in spring (Table 2.3). Each site showed a high variance for STK levels.

Spring soil sampling maps of exchangeable K^+ are provided in Appendix B across each location. Table 2.3 provides the strip averages along with standard deviation amongst sampling points used in each site location.

The results from Tables 2.3 indicate that there was a trend for exchangeable K^+ levels to increase in the treatment plot area over the untreated control in the fall sampling periods, presumably due in large part to K^+ fertilization. Temporal variability should be minimal during this analysis as comparisons were made solely between fertilization strips during the same sampling period. We expected a 31 ppm K increase (Hoeft et al, 2003) in the K-applied strip versus the No-K applied strip, but gains were appreciably higher (Table 2.3).



Exchangeable Soil Test K (ppm/acre)

	Plot_K	Plot_K Standard Dev.	**Outside_K**	**K-NoK Difference**	Outside_K St.Dev.
Bath	803	188	755	48	232
Eggleston	294	51	311	-18	64
Roscoe	595	158	552	43	165
Beadle	484	79	479	4	80
Hand	542	130	484	58	157

Table 2.3. Exchangeable K between strips across fertilizer addition effects. Plot_K refers to the K-applied strip while Outside_K is the No-K applied strip.

Correlation analysis was used to estimate fertilizer addition trends for fall STK values and differences between the 0 lbs $K_2$0/acre and potassium difference maps generated from soil sampling of the 250 lbs K_2O/acre strip in the fall are highlighted in Figures 2.6. K-Differences may be either positive or negative, reflecting the difference between soil sampling results from predicted STK values had no K^+ fertilizer been applied.

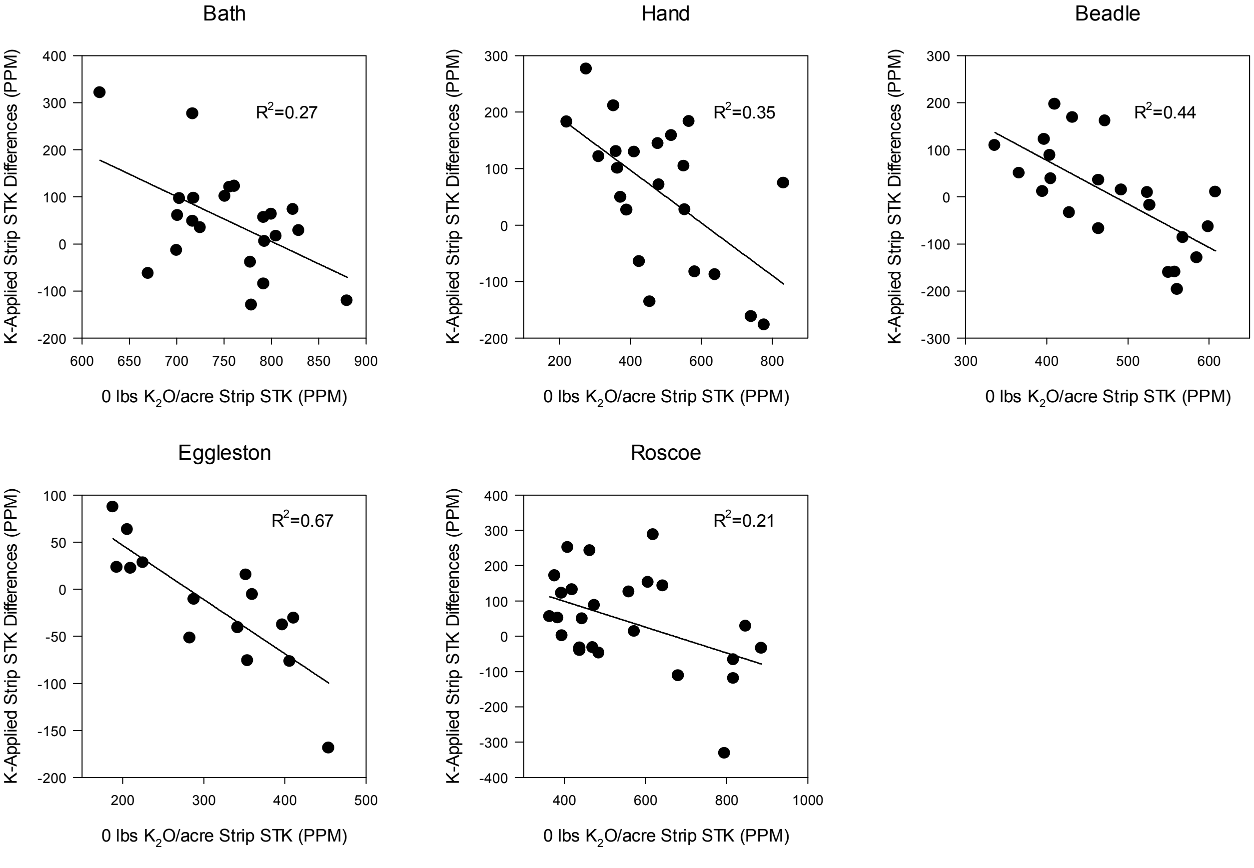


Figure 2.6. Exchangeable K fertilizer addition differences across site locations. X-axis relates STK values sampled along 100-foot points along a transect on the 0 lbs $K_2$0/acre strip. Y-axis relates the difference between STK values sampled along 100-foot transects

along the 250 lbs K_2O/acre strip and predicted STK values if no K-fertilizer had been applied. A positive difference indicates a response e to K-fertilizer while a subtraction illustrates a draw on STK associated with fertilizer.

The results from Figure 2.6 indicate that where no K^+ fertilizer was applied, soil sampling results indicated a positive advantage for applying fertilizer. As exchangeable K^+ values increased along the 0 lbs K_2O/acre strip, lesser gains associated with fertilizer were noted (Figure 2.6). These results from all five fields indicate that with low exchangeable K^+ levels, K^+ fertilizer can increase STK levels while were K^+ is tested highest along the strip, a lower response to K^+ fertilizer is expected.

Temporal + Fertilizer Differences Effect on STK Values

The effect of time and fertilizer addition on STK values was analyzed across site locations. Spring exchangeable STK levels on the K-applied strip (prior to fertilization) were calculated to estimate site-specific values by using Surfer (Golden Software, Golden, Colorado).

Fall K-applied STK levels were statistically compared with STK levels across the strip as a function of fertilizer and time. Each soil sampling point on this strip was compared between spring and fall sampling K results for significance. Results for Bath are provided in Table 2.4.

Anova: Two-Factor Without Replication

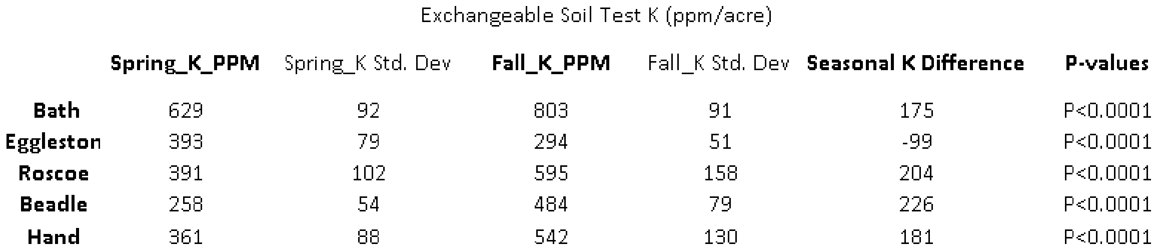
SUMMARY	*Count*	*Sum*	*Average*	*Variance*
Bath_1	2	1504.0	752.0	4050.0
Bath_2	2	1657.0	828.5	1104.5
Bath_3	2	1478.0	739.0	968.0
Bath_4	2	1590.0	795.0	42050.0
Bath_5	2	1416.0	708.0	22898.0
Bath_6	2	1606.0	803.0	72200.0
Bath_7	2	1561.0	780.5	18240.5
Bath_8	2	1583.0	791.5	21840.5
Bath_9	2	1536.0	768.0	26450.0
Bath_10	2	1486.0	743.0	22050.0
Bath_11	2	1368.0	684.0	11250.0
Bath_12	2	1500.0	750.0	10368.0
Bath_13	2	1540.0	770.0	17298.0
Bath_14	2	1550.0	775.0	1152.0
Bath_15	2	1436.0	718.0	38642.0
Bath_16	2	1297.0	648.5	16380.5
Bath_17	2	1287.0	643.5	26680.5
Bath_18	2	1109.0	554.5	17860.5
Bath_19	2	1071.0	535.5	10224.5
Bath_20	2	1212.0	606.0	12800.0
Bath_21	2	1329.0	664.5	20200.5
Bath_22	2	1391.0	695.5	21012.5
Soil_K_Fall	22	17674.0	803.4	8711.7
Soil_K_Spring	22	13833.0	628.8	8820.4

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	267754.3	21.00	12750.20	2.67	0.01	2.08
Columns	335301.8	1.00	335301.84	70.12	0.00000004	4.32
Error	100418.7	21	4781.841			
Total	703474.8	43				

Table 2.4. Analysis of variance results for spring soil sampling at ‘Bath’ field along temporal + fertilizer addition effects on 250 lbs K_20/acre strip. Numbers refer to sampling points based off of 100-foot transects along each potassium treatment strip.

K-applied STK levels (between fall and spring) were significantly different at $P<0.0001$ for the Bath location (Table 2.4), and across all other locations at the $P<0.0001$ level (Table 2.5). ANOVA results displayed a tremendous degree of sampling variability between each sampling point (Table 2.4), which is in agreement with Tables 2.1 and 2.2. Our sampling variability is validated by Murrell (no date provided) who assessed the temporal variability in K sampling and further discussed below in Discussion section.



Exchangeable Soil Test K (ppm/acre)

	Spring_K_PPM	Spring_K Std. Dev	**Fall_K_PPM**	Fall_K Std. Dev	**Seasonal K Difference**	**P-values**
Bath	629	92	803	91	175	P<0.0001
Eggleston	393	79	294	51	-99	P<0.0001
Roscoe	391	102	595	158	204	P<0.0001
Beadle	258	54	484	79	226	P<0.0001
Hand	361	88	542	130	181	P<0.0001

Table 2.5. Exchangeable STK temporal + fertilizer addition effects across site locations on 250 lbs K_20/acre strip.

Analyses of K-applied strips indicate that each field had statistically significant increases in STK levels (fall versus spring) at the $P<0.0001$ level (Table 2.5). Four of the five fields displayed a STK increase of 175-226 ppm between spring and fall soil sampling. We estimated above that the effect of fertilizer addition should have increased STK levels 31 ppm K between strips. Table 2.3 suggests values rose appreciably higher than 31 ppm. Since this analysis also includes the temporal aspect of sampling, it can be reasoned that ‘seasonal K difference – 31 ppm’ would equate to the effect of time along the strip. If this is the case, our treatment strips still appreciably gained STK values, confirming our results in Table 2.2 along the 0 lbs K_2O/acre. We did not anticipate this phenomenon to occur, so dramatic strip increases as a function of time and fertilizer addition were highly unexpected.

The Eggleston farm's STK level decreases (negative balance) may be attributable to a possible edge effect since the K-applied strip was placed close to the fence, leaving perhaps a compromised area for a valid comparison amongst treatment strips. This is due, in large part, to a questionable application of potassium. In fields where fall K ppm was higher than in the spring, these differences were statistically significant at the $P<.001$ level (Table 2.3). The application of 155 lbs K_2O/acre should have risen STK values at least 19 ppm (without considering uptake) (Hoeft et al, 2003), but a wide reduction in STK was noted (Table 2.5). While some authors have reported higher STK levels in the spring (Liebhardt et al, 1977; Peterson et al, 1980), we observed higher STK levels in the fall along the K-applied strip. The opposite was seen when a lower rate of K_2O was applied (Table 2.2), where STK levels showed a clear trend to decrease in the 0 lbs K_2O/acre strip. Increases associated with fertilizer addition range from 4-58 ppm (Table 2.3). Table 2.5 specified that STK levels rose 175-226 (fertilizer addition + temporal variability), indicating that the time factor may have made 149-222 ppm K available. This assumption closely resembles the results in Table 2.2 where fields gained 76-239 ppm K due in large part to seasonal differences.

Each 100-foot sampling point in the K-applied strip showed spatial variability (Table 2.4). There was a clear trend for greater variance across the spring sampling period than in the fall period in the K-applied strip (Tables 2.4 and 2.5); there was not a clear trend for greater variance in spring versus fall sampling between the 0 lbs K_20/acre strip (Table 2.2).

Late season soil samples were taken either during R7 (beginning plant maturity) or post-harvest in spring 2015 preplant (due to early onset of winter 2015) (Figure 2.2).

While soil samples were taken outside of the plot area in the spring, the treatment area was soil sampled to estimate K^+ levels following the 2014 growing season as reflected by crop uptake and K^+ fertilization, among other factors.

Correlation analyses was conducted to relate STK level to seasonal (temporal) plus fertilizer addition differences in K^+ level in the K-applied strip and is shown in Figure 2.8. Potassium difference maps were created showing the loss of available K^+ as a function of crop uptake or temporal variability for each field. It is confirmed that dramatic increases from fall to spring soil sampling occurred at site location (Figure 2.7).

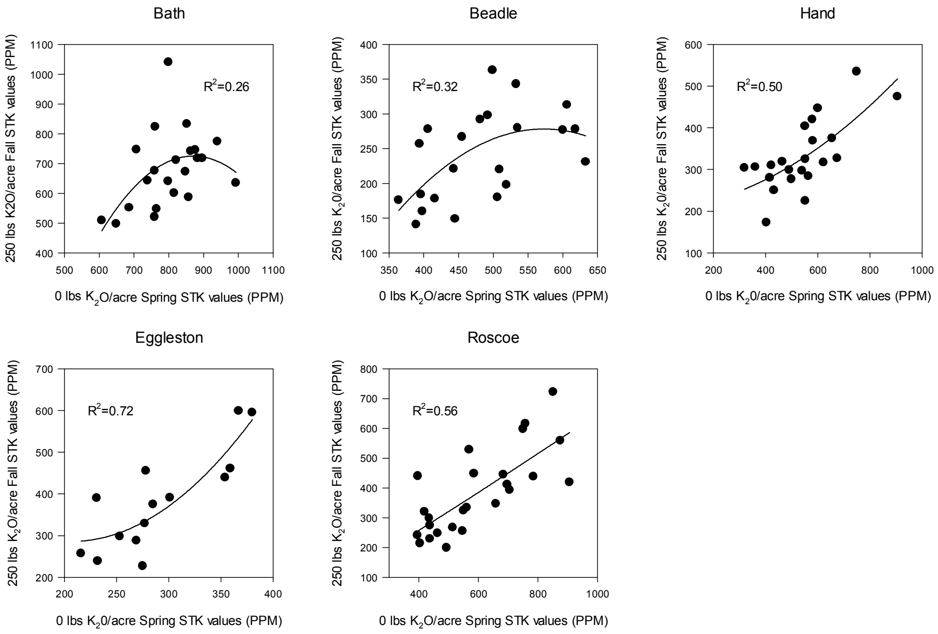


Figure 2.7. Exchangeable K temporal + fertilizer addition differences between 250 lbs K_2O/acre strip and 0 lbs K_2O/acre strip. Exchangeable K temporal differences on No K-applied (fall) strips across site locations. X-axis relates STK values sampled along 100-foot transects on 250 lbs K_20/acre strip. Y-axis relates to STK values sampled along 100-foot transects on 0 lbs K_20/acre strip

Fertilizer Addition/No Addition Differences on STK Values

STK strip differences along the No-K and K-applied strips were analyzed to examine whether gains along each strip were directly attributed to fertilizer addition. Whole field averages between No-K and K-applied strips were made as well as overall strip differences (positive or negative) and compared across all fields. Results are displayed in Figure 2.8. Analysis of variance between sampling sites are provided in Table 2.6.

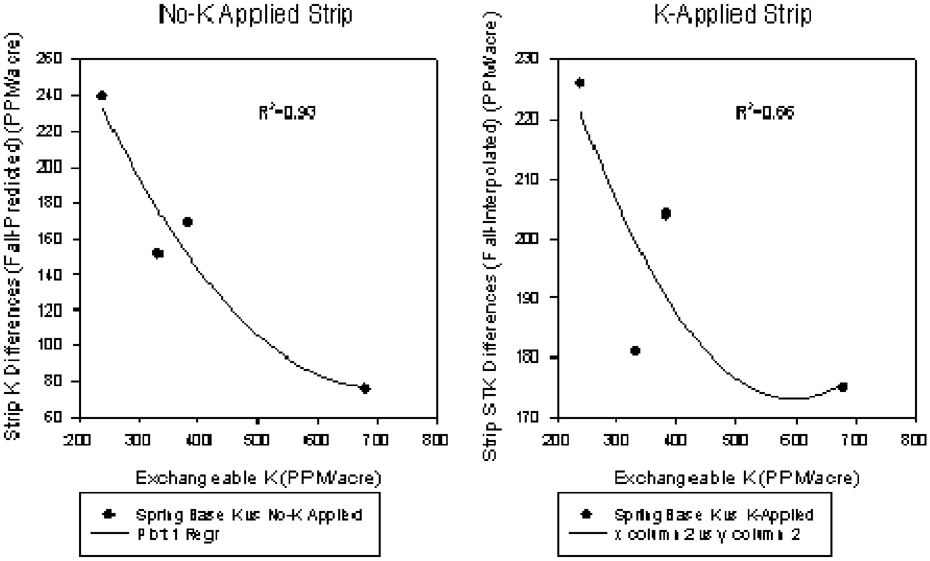
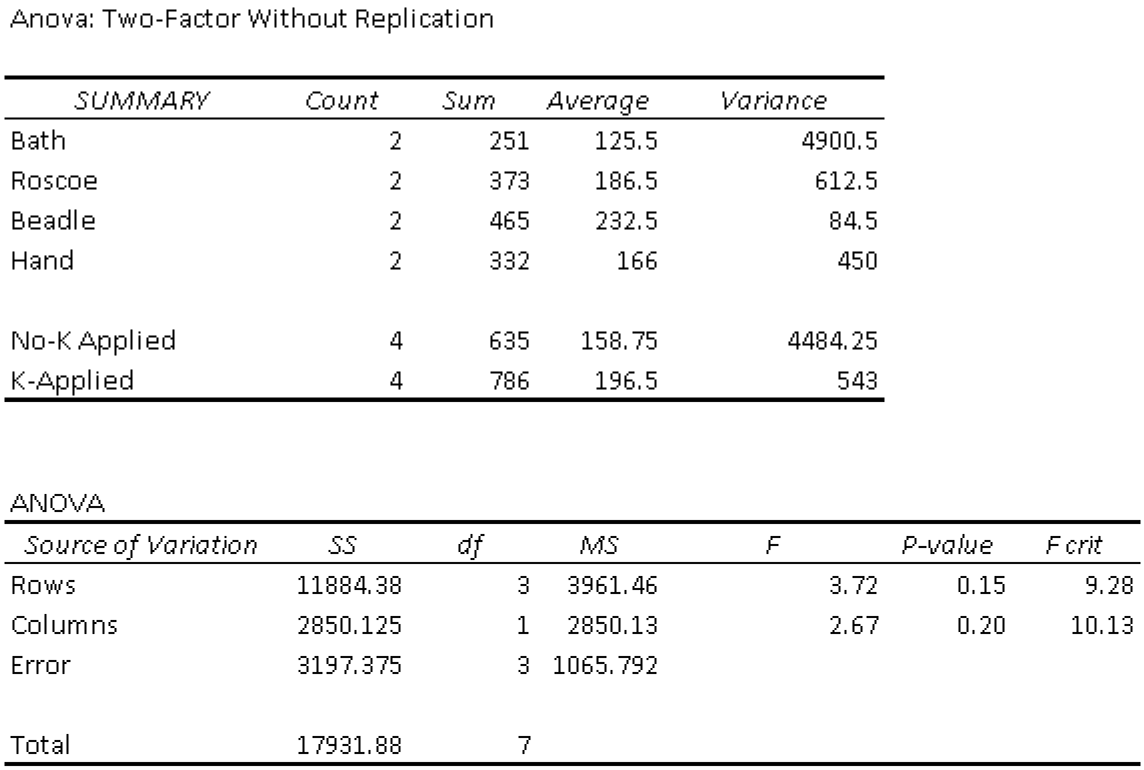


Figure 2.8. STK strip differences after one full season in relation to STK value. Exchangeable K is related to the STK levels obtained in the spring along each strip. Differences were computed as $K_{Fall} - K_{interpolated}$ and use as an average at each site location.



Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
Bath	2	251	125.5	4900.5
Roscoe	2	373	186.5	612.5
Beadle	2	465	232.5	84.5
Hand	2	332	166	450
No-K Applied	4	635	158.75	4484.25
K-Applied	4	786	196.5	543

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	11884.38	3	3961.46	3.72	0.15	9.28
Columns	2850.125	1	2850.13	2.67	0.20	10.13
Error	3197.375	3	1065.792			
Total	17931.88	7				

Table 2.6. Analysis of variances results for each site location showing the comparison between strip differences in K gains.

K-fertilization only minimally affected STK gains and was not significant at the 95% confidence interval (Table 2.6). There was a trend for high spring exchangeable K levels to reflect lower strip differences between fall and spring (Figure 2.8). These results are a confirmation of Figure 2.5. Since questionable application occurred at Eggleston, the field was omitted from analysis. A trend also developed for fields that tested lower for STK values, strip differences associated with fertilization were higher (Figure 2.8).

Discussion of Potassium Fertilizer Responses

Significant temporal responses to potassium soil testing in one season. Many studies have measured the temporal variability with STK levels between fall and spring sampling in the northern United States. Authors have reported gains ranging from 30-50 ppm between fall and spring seasons (Murrell, 2012; Liebhardt et al, 1977; Peterson et al, 1980). Higher seasonal gains were reported along treatment strips (Table 2.4 and 2.5) and on untreated strips (Tables 2.1 and 2.2) between spring to fall, contradicting previous research. The reasons for this dramatic increase in STK availability can be attributed to differences in soil moisture, freezing and thawing, and microbial activity, among many other factors (Murrell, no date provided). Since South Dakota soils test very high for K^+ weathering minerals (such as mica and feldspar), it is speculated that the seasonal gains may be associated with more K^+ being released from inherent parent material. Since soil samples were taken after the cycles of freezing and thawing and since two of the five fields were sampled late in the reproductive stages (though not physiological maturity), total potassium uptake was not complete. During this sampling period, the KCl fertilizer solubilized and became either plant-available or fixed. Lockman (1984) assessed the time of year variable with K soil testing by taking soil samples once a month from May 1980 and concluding in July 1983. In the plots where K was applied in the spring (March or April), STK levels rose 47 ppm. Where K was not applied, values fluctuated 25 ppm across the growing season. We reported similar trends for appreciable gains between the K-applied and No-K applied strips (Tables 2.2 and 2.5) While some authors have reported higher soil test levels in the spring (Liebhardt et al, 1977; Peterson et al, 1980), we observed higher soil test levels in the fall compared to the spring (Tables 2.1-2.2, Figure 2.5, Tables 2.4-2.5, Figure 2.7). The trend was also for a rapid rise in STK levels inside of the K-applied strips, much higher than calculated (Tables 2.3). The Eggleston K-applied strip decreased STK levels, which is directly attributable to a miscalculation in application and a possible edge effect. With only 155 lbs K_2O per acre (19 ppm expected rise) applied, STK levels still decreased in this field (Table 2.3). Instead, STK values decreased 18 ppm inside the K-applied strip.

The precipitation totals are important (Appendix B), particularly for K^+ soil testing results. While the direct relationship between soil moisture and STK level has only recently been analyzed, an increase in STK is correlated to stored or fixed potassium and its release in interlayer positions of clay minerals. The degree to which this process occurs depends largely on the mineral composition of soils, particularly between smectites (Stucki, 1996) and vermiculites (Bashard et al, 1968). The expectation is that when wet soils are dried, soils that otherwise test low in K^+ showed increases in K^+. Subsequently, soils that test high in K^+ may have lower values when moisture regimes change. Dowdy et al (1963) graphically reported these phenomena with a Bedford soil. The same soil was either added ("enriched") or left without K^+ application. Dowdy concluded that a lower K^+ testing soil released more K^+ when it was dried while the enriched Bedford soil fixed K^+ as it dried. Moisture readings were not taken during application as it was not believed a significant temporal response was going to occur. However, spring sampling conditions were taken at field capacity conditions while fall 2014 sampling dates were taken during a drought in very dry soil. For soil samples taken in spring 2015, soils were not as dry as in the previous fall and the freezing and thawing cycles were just completing by the time samples were taken. A depletion in soil solution K^+ can readily be replenished from other K^+ pools in the soil. This flux is equated to a chemical equilibrium of K^+ in soils reported by Bray and DeTurk (1939). It was described as the equilibrium that which soil solution K^+, exchangeable K^+, and nonexchangeable (interlayer or fixed) K^+ collectively maintains. Any change in K^+ concentration amongst the pools affects the distribution of K^+ held in equilibrium. The K^+ that is fixed or nonexchangeable is held very tightly in the clay mineral lattice and will not be released until a shift in the K^+ chemical equilibrium occurs, predominately by an environmental (temperature, moisture, etc.) change.

Technically, Bray and DeTurk postulated that if a soil had a decrease in activity in solution K^+, K^+ would be released from the exchangeable or particle edges to replenish this pool. Luebs (1956) reported that this replenishment can be exponential in a rain event with very dry soils. It is unlikely that nonexchangeable K^+ would have been available to increase STK levels on the magnitude of 100 ppm with the results we saw since it is fixed. Early season meteorological data is provided in Appendix B. Abundant soil moisture was available early in the growing season, but leveled off later in the season. Since soil moisture decreased, STK may be held tightly throughout the later reproductive stages where potassium is in highest demand by the soybean crop (Hanway, 1971; Bender et al, 2015).

Four of our five fields are kept under minimum (spring disc/field cultivation) or no-till conditions. Nutrient stratification has been reported numerously in fields left under minimum tillage environments. Robbins (1991) tested the degree of potassium stratification over a 10-year no-till corn experiment. The surface to 8 inch increment soil tested 160-580 ppm K while the 4-inch depth tested 330-580 ppm K. It can be reasoned that subsequent inches below 8 inches would yield lower amounts of K^+ since surface applications of K^+ are not incorporated into the soil. We only examined the surface-6 inch increments, reporting soil testing numbers on par with STK levels on par with what Robbins reported in the surface-4 inch depth increment, explained primarily by geographical differences. Any depth lower would indicate the ability of the inherent mineralogy to weather and release K^+, which is expected to have a great ability.

A large issue with soil testing companies concerns whether or not soil test potassium is adequately quantified under current laboratory techniques. In Figure 2.1, new soil test recommendations were provided from extensive on-farm research Iowa State conducted since recommendations were not accurately associated with yield response. A partial reason why these changes occurred was a shift from field-moist samples to dried sampling analysis. Wetting and drying cycles can be vastly different from how potassium may be taken up in the field. Soil sampling companies typically extract soil cores and submit them to a soil testing lab that may dry or leave them as they are received. We chose to use the ammonium acetate extraction method since it is commonly accepted in the Northern Great Plains. When dried, soil moisture contents can range from 1-5% (Dowdy et al, 1963; Luebs et al, 1956). Great fluctuation in quantifying STK occurs when soil moisture contents of sample fall below 10% (Luebs et al, 1956). A large discrepancy in K^+ quantification will lead to a miscalculation of exchangeable K^+, leading to inaccurate K^+ fertilization and yield responses, a general distrust of fertility recommendations, and a high frequency of potassium deficiencies which are currently diagnosed throughout the upper Midwest.

There were clear or possible trends for potassium fertilizer to decrease STK levels across sampling periods and site locations (Figures 2.6 and 2.8). It can be reasoned that fields with a high inherent supply of indigenous K^+, potassium fertilization may decrease soil test levels, possibly salinity related. Figure 2.8 suggests that applications of potassium fertilizer will have less of an effect on increasing STK levels with soils that test high in exchangeable K^+. There is credence that potassium fertilizer may not have an effect on increasing soil test levels.

Yield Monitor Data

Each on-farm cooperator was asked to export comma separated variable files containing yield monitor data. CSV files were cleaned using Yield Editor 2.0.7 (Sudduth, K.A. et al, ASABE Paper 121338243) and yield difference maps were created for all site locations and highlighted below using Surfer. Generation of yield difference maps follows the protocols outlined in Appendix B. For most fields, LiDar imagery was available for superimposing yield differences over maps such as elevation, soil topography, or soil type. Each field was analyzed on three average yield criteria; plot (K-fertilization), check (no K-fertilization), and yield difference (Plot Yield – Expected Yield without Fertilizer Addition).

We used yield monitor data from each georeferenced soil sample point to quantify yield. We determined whether or not yield monitor points were significantly different since all STK samples recorded at sites were significant between treatments (data not reported).

Correlation analysis was conducted to estimate field average yield and yield differences associated with K-fertilization.

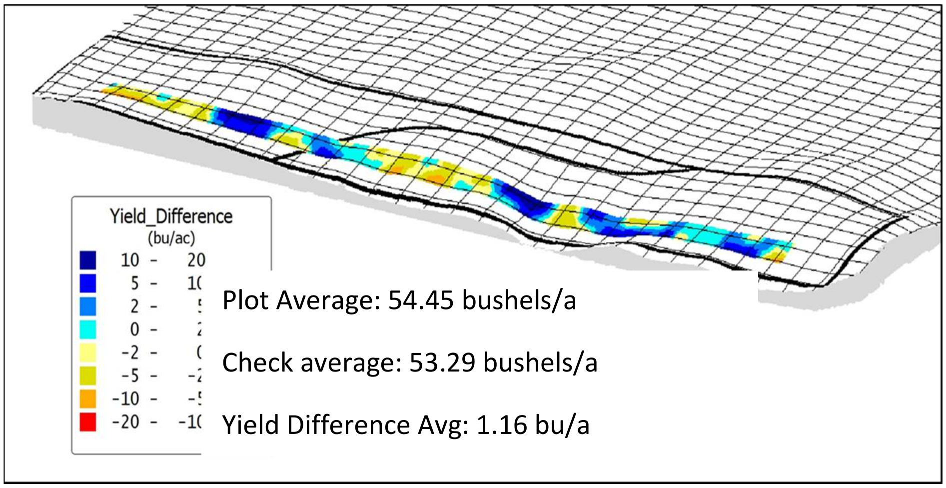


Figure 2.9. Yield difference map generated for 'Eggleston' farm superimposed on a LiDar map

Figure 2.10. Yield difference map for 'Roscoe' superimposed on elevation map. (Note: LiDar Imagery not available at this location).

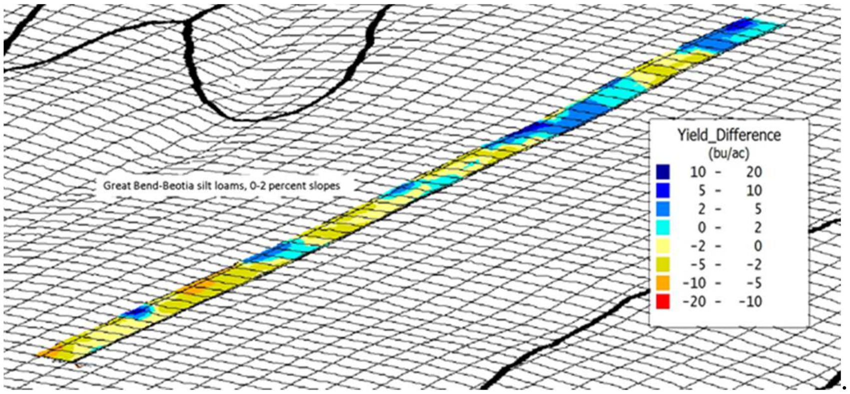
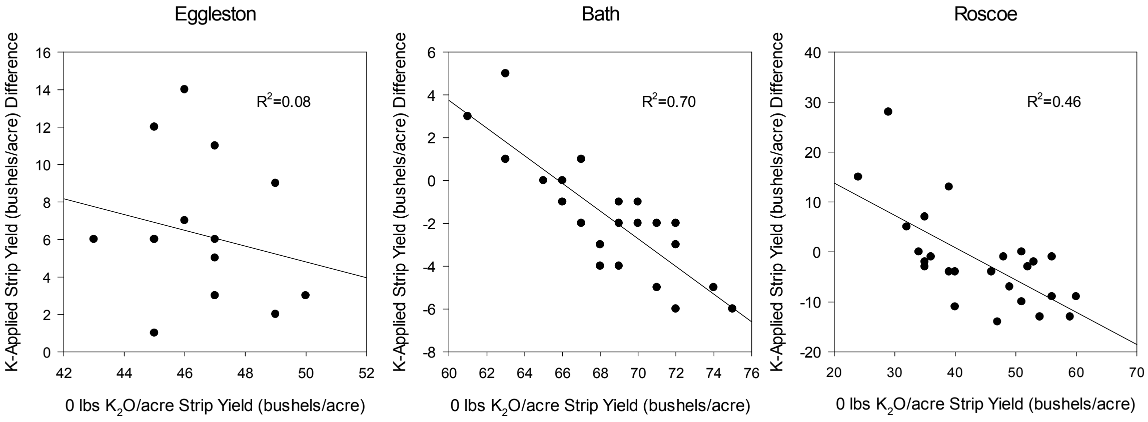


Figure 2.11. Yield difference map for 'Bath' superimposed on elevation map. (Note: LiDar Imagery not available at this location).



F*igure 2.12*. Fall average yield across site locations as it relates to average field yield at K fertilization strips (K+NoK). Yield Difference was computed as $\text{Yield}_{\text{K-Applied}} - \text{Yield}_{\text{NoK}}$ from georeferenced soil sampling points between. Fall average yield was calculated as $(\text{Yield}_{\text{K-Applied}} + \text{Yield}_{\text{No-K Applied}})/2$

Landscape Positional Yield Changes

In Figure 2.4, we defined how landscape positions were going to be broken down and evaluated. Wherever possible, this analysis was done. Yield data was only made available in three of the five fields (Roscoe, Bath, and Eggleston). Landscape terrain analysis was not available at Roscoe site. No landscape position differences were seen at Bath site (minimal topographical change), but the Eggleston site had a degree of topographical differences (Figure 2.13).

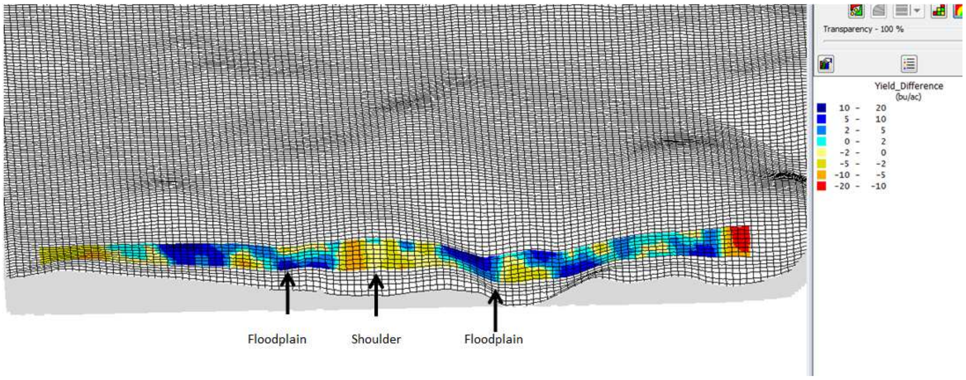


Figure 2.13. Topographical yield difference map at Eggleston

Yield advantages were apparent on the lower, flatter regions (floodplain) across the strip than on the higher, flatter regions (shoulder) regions.

Discussion of Yield Monitor Data

The yield difference map, which was directly attributable to the K treatments, experienced increases in the field ranging from approximately +30.0 bushels per acre to -14.2 bushels per acre in every field (Figures 2.9-2.11). Spatial differences along the two combined strips inside of the treatment plot are visibly seen and were specified through the computer software program, Surfer. On average, incremental yield advantages or differences were noted across all treatments. These advantages were subtle in nature and generally uneconomical when comparing yield advantages with soybean market prices and fertilizer product plus application costs (below), providing similar results as Hanway and Weber (1971). Various topographical areas yielded K-fertilizer advantages. In these instances of positive yield response, optimum economic potassium rates need to be determined. Since moisture readings were not collected, future studies should assess how soil moisture impacts potassium availability and subsequent soybean yield.

The yield variability can be associated with soil topography as positive yield differences (attributed to K-fertilization) in the toeslope/backslope and floodplain/depressional portions of the plot. In these areas, yield differences ranged from 5 to 20 bushels per acre. The speculation is that the positive yield advantages are a result of potassium fertilization. A hypothesized theory for the increased uptake of potassium is that since diffusion is directly related to soil moisture content, an increase in soil water levels leads to a higher degree of exchangeable K^+. Place and Barber (1964) proved that potassium uptake increases linearly with increasing soil moisture, using Rb as a tracer. Their results were further supported by Danielson and Russell (1957) who illustrated the relationship between soil moisture content and exchangeable K.

There were areas in the field where no yield advantages were recorded, either. These commonly were found across broad, flat elevated areas (summit, higher-shoulder regions). Our speculation is that the lack of yield responses may be salinity-related; the accumulation of soluble salts, such as sodium, may be hindering yield potential that otherwise be recorded by the potassium fertilizer.

The correlation analysis revealed that in high-yielding situations, K^+ fertilization may not only increase yields, but can also decrease yields (Figure 2.12). In lower yielding areas of fields, there may be an advantage to applying K^+ fertilizer. The Eggleston field received only 155 lbs K_20 per acre, and a positive yield response to K^+ fertilization was seen with decreasing yield potential (Figures 2.9 and 2.13), suggesting that yields can be increased from potassium fertilizer with lower rates, in agreement with Borges (2001).

Tissue K^+ Concentrations

Based upon the work conducted by Ebelhar and Varsa (2000), we examined how fertilizer treatments affected leaf K^+ concentrations. Wherever possible, sampling points were overlaid on yield difference maps and displayed in Figures 2.14-2.16. By the later reproductive stages, soil applied potassium would have had a high probability of solubilizing and being taken in by the plant. Previous research had shown a statistically significant difference in leaf K concentrations between fertilized and unfertilized plants during the reproductive stages (Ebelhar and Varsa, 2000). At the R6 growth stage of each site, soybean plant samples were collected and partitioned into various fractions visible during this reproductive stage. Collectively, twenty samples from the K^+ fertilization strip and control strip were collected. Each plant was segregated into new leaves, old leaves, pods (embryo kernels inside), petioles, and stems (devoid of any vegetative material). Samples were collected for all five producer fields and analyzed by Ward Laboratories (Ward Laboratories, Inc., Kearney, Nebraska) by microwave digestion for potassium concentration. All other macro and micronutrients were also analyzed for correlation. Refer to Appendix B for mineral concentrations.

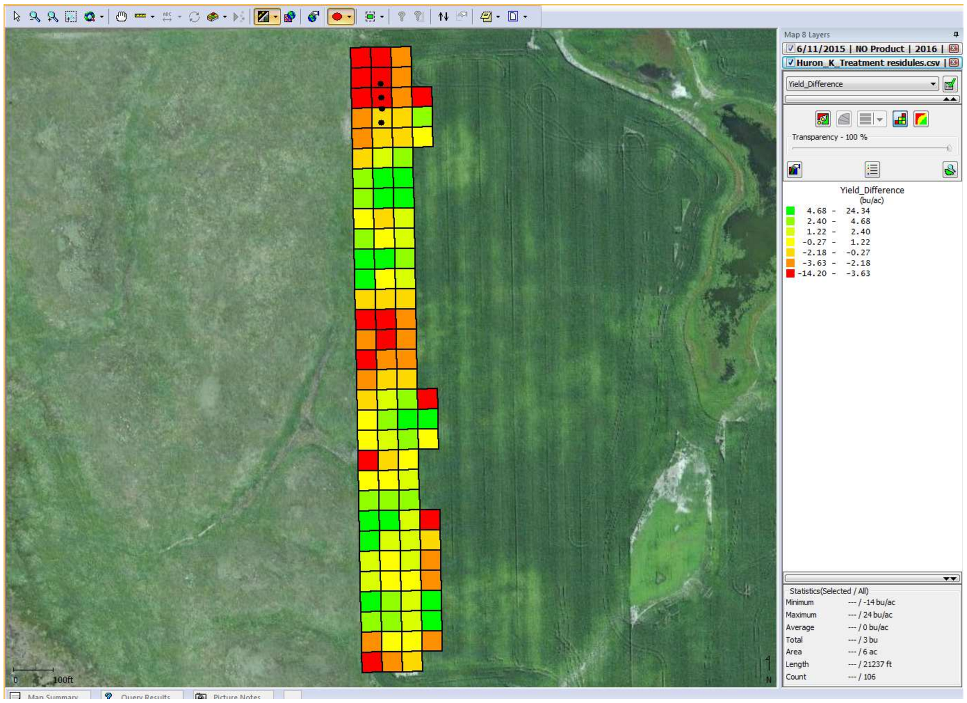
Tissue sampling results are provided in tables (Appendix B). There was no significance between macronutrient (P) and micronutrient concentrations (Ca, Mg, S, Zn, Fe, Mn, and Cu) between the K-fertilization strips, but K concentrations were significantly difference (Appendix B).

An average of the P-values for K was 0.058, suggesting significance amongst K concentration means across the partitioned soybean plant between strips at $P<0.06$. Interestingly, K-fertilization appeared to have a negative effect upon K concentrations since concentrations were lower in the strip receiving the 250 lbs K_2O per acre than the 0 lbs $K_2$0 per acre strip (Appendix B). These differences were recorded for all vegetative (new and old leaves, stems, petioles) and reproductive (pod with embryonic kernel inside) materials. Of the other nutrients sampled, no statistically significant difference was recorded between treatments. No visual K deficiencies (or differences) were seen between strips when sampling took place. Our results contradict those of Ebelhar and Varsa (2000) who conducted a varying potassium rate study in Illinois. While initial leaf tissue K^+ concentrations were the lowest for the broadcast treatment during the vegetative stages, K^+ concentrations leveled off during the reproductive stages. There was a positive correlation trend between K fertilizer rate and leaf K^+ concentrations, early plant growth, and yield.

Since K^+ is considered a mobile cation, K^+ concentrations were expected to be highest in newly developed tissue. At R6, this includes not only the newest trifoliate, but also the rapidly developing seed pod. The K-fertilization strip had an average K^+ concentration of 1.228% for the newest trifoliate while the oldest leaves were higher at 1.392%. We did see a similar expected trend between new leaves and pod K^+ concentrations since higher K^+ values were recorded in the pod regions between the K and No-K strips. The differences are recorded in Appendix B. They indicated a low difference between pod K^+ concentrations in the K-applied and non K-applied strip. K^+ concentrations were statistically significantly higher in the No-K applied strip than in the K-applied strip.

Stomatal Conductance

Stomatal conductance was measured and recorded at the R6 growth stage. While leaf K^+ concentrations indicate amounts of tissue K^+, stomatal conductance is thought to be related to the physiological mechanisms that K^+ functions in the plant. As K^+ concentrations increase, greater carbon dioxide enters the plant as water vapor exits. The rate at which this process take place is dependent upon the boundary layer resistance and concentration gradient that water vapor diffuses into the atmosphere, and this rate is controlled by the stomatal apparatus with the guard cells. The rates that which guard cells open and close are directly proportional to leaf K^+ concentrations (Farquhar and Sharkey, 1982). The data showing the stomatal conductance as it relates to K^+ fertilization is provided in Appendix B. Weather conditions are known to influence leaf porometer readings and were collected with the mobile cellular phone application, WeatherBug (Earth Network, Germantown, Maryland), and are found in Appendix B. The results of the conductance experiment are shown in Table 2.7. Figure 2.14-2.16 indicates where stomatal conductance was recorded along K-applied strips. Stomatal conductance conducted on the No-K applied strips was taken approximately 100-feet across from the K-applied points (not reported).



Map 8 Layers

☑ 6/11/2015 | NO Product | 2016 |

☑ Huron_K_Treatment residules.csv |

Yield_Difference

Transparency - 100 %

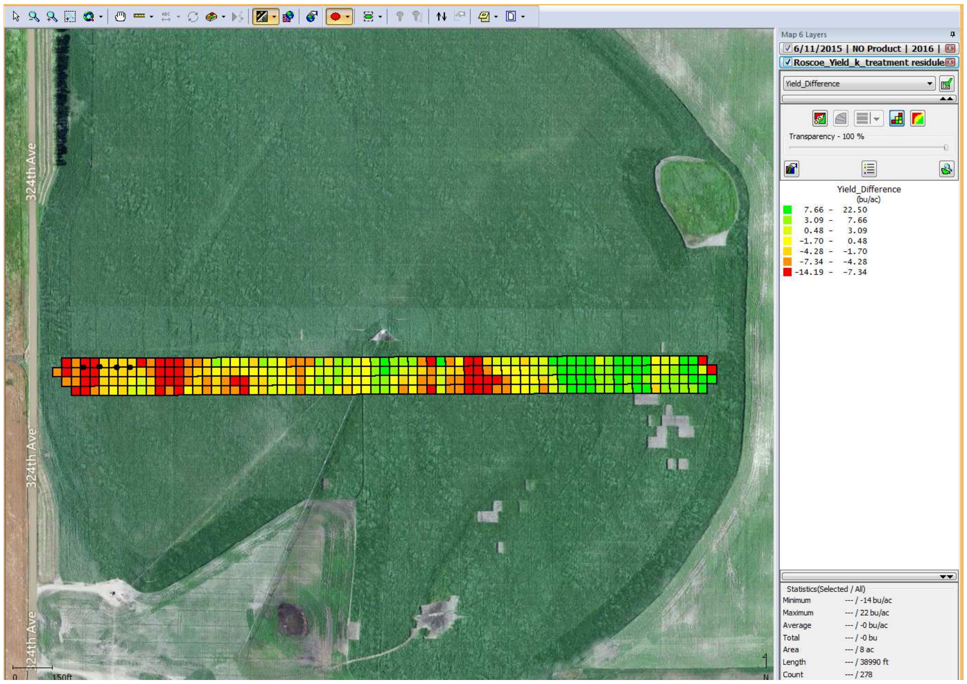
Yield_Difference
(bu/ac)

🟩	4.68 - 24.34
🟩	2.40 - 4.68
🟨	1.22 - 2.40
🟨	-0.27 - 1.22
🟧	-2.18 - -0.27
🟧	-3.63 - -2.18
🟥	-14.20 - -3.63

Statistics(Selected / All)

Minimum	--- / -14 bu/ac
Maximum	--- / 24 bu/ac
Average	--- / 0 bu/ac
Total	--- / 3 bu
Area	--- / 6 ac
Length	--- / 21237 ft
Count	--- / 106

Figure 2.14. Tissue sampling and stomatal conductance sampling points highlighted in black dots superimposed on yield difference map for Eggleston.



Map 6 Layers

☑ 6/11/2015 | NO Product | 2016 |

☑ Roscoe_Yield_k_treatment residule

Yield_Difference

Transparency - 100 %

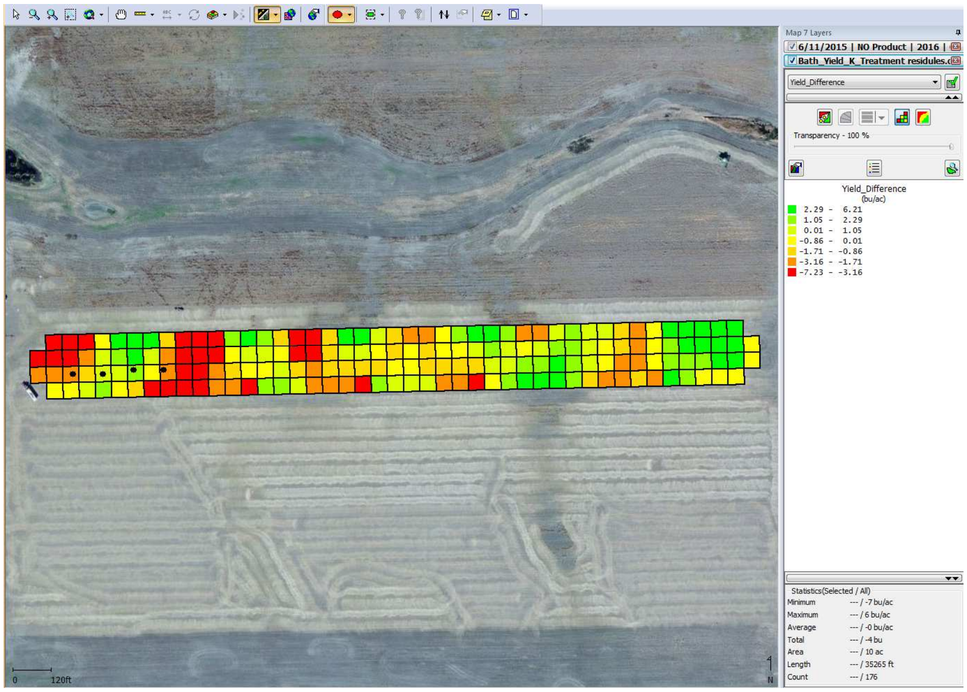
Yield_Difference
(bu/ac)

🟩	7.66 - 22.50
🟩	3.09 - 7.66
🟨	0.48 - 3.09
🟨	-1.70 - 0.48
🟧	-4.28 - -1.70
🟧	-7.34 - -4.28
🟥	-14.19 - -7.34

Statistics(Selected / All)

Minimum	--- / -14 bu/ac
Maximum	--- / 22 bu/ac
Average	--- / -0 bu/ac
Total	--- / -0 bu
Area	--- / 8 ac
Length	--- / 38990 ft
Count	--- / 278

Figure 2.15. Tissue sampling and stomatal conductance sampling points highlighted in black dots superimposed on yield difference map for Roscoe.



☑ 6/11/2015 | NO Product | 2016 |

☑ Bath_Yield_K_Treatment residules.c

Yield_Difference

Transparency - 100 %

Yield_Difference (bu/ac)

🟩	2.29 - 6.21
🟩	1.05 - 2.29
🟨	0.01 - 1.05
🟨	-0.86 - 0.01
🟨	-1.71 - -0.86
🟧	-3.16 - -1.71
🟥	-7.23 - -3.16

Statistics(Selected / All)

Minimum	--- / -7 bu/ac
Maximum	--- / 6 bu/ac
Average	--- / -0 bu/ac
Total	--- / -4 bu
Area	--- / 10 ac
Length	--- / 35265 ft
Count	--- / 176

Figure 2.16. Tissue sampling and stomatal conductance sampling points highlighted in black dots superimposed on yield difference map for Bath.

For the fields that we received yield monitor data, there was a trend for a decrease in yield associated with K fertilization. This yield decrease was anywhere from 0 to 14.20 bushels per acre (Figures 2.14-2.16).

Values (mmol/m^{2}s)	**Upper Leaves**	**Lower Leaves**	p-values
Eggleston_K	202.04	66.86	0.08
Eggleston_No_K	215.44	39.38	0.01
Roscoe_K	686.98	479.66	0.15
Roscoe_No_K	719.22	405.18	0.07
Hand_K	391.8	100.72	0.00
Hand_No_K	279.2	39.2	0.00
Bath_K	605	508.64	0.22
Bath_No_K	479.96	378.46	0.18
Beadle_K	208.46	199.78	0.43
Beadle_No_K	181.34	115.18	0.01

Table 2.7. Stomatal Conductance values (mmol/m^{2}s) measured for upper and leaves between K-fertilization strips.

A wide degree of variation was received when using the leaf porometer with individual soybean plants in both the treatment and non-treatment areas. Conductance values were higher across all site locations in the upper leaves compared to the lower leaves. These differences were significant at the 95% confidence interval in 4 of the 10 strips, while 6 of the 10 at the 90% confidence interval.

There was a trend for higher conductance values on the lower leaves along the K-applied strip than on the No-K applied strip (Table 2.7), but there appeared to be little correlation between conductance values along treatment strips on the upper leaves. The influence of K^+ fertilization did not appear to provide a clear influence on conductance readings since two of the five site locations had higher conductance readings in the upper leaves on the K-fertilization strip.

K^+ concentration influences the degree of carbon dioxide entrance into the stomatal apparatus. We discussed earlier that we did not experience an increase in leaf K^+ concentration in the K-applied strip. Instead, we received higher values in the No K-applied strip. This is in accordance to our stomatal conductance values received above in Table 2.7.

Economic Analysis

Unlike nitrogen where yearly applications are used in many cropping systems, potassium fertilizer rates and practices varies based upon soil test results, financial expenses, current or projected market futures, and can be considered a capital expense over time due to its relative stability in the root zone. Our discussion will use potassium fertilizer applied in the potash form of 0-0-60 (N-P-K). Assuming a market price of $405/ton for potash, the cost per pound of potassium fertilizer is $0.36/lb K_2O. We used 250 lbs of K_2O/acre for our experiments, which is a cost of $90/acre. Many agricultural producers have fertilizer retailers or cooperatives apply this product, with prices for application ranging from $5-7 per acre. A producer may spend between $95-97 per acre for the potassium fertilizer in which we spread.

We only saw incremental half-mile long strip gains from potassium fertilizer, ranging from 0.50 bushels to 2 bushels (Figures 2.9-2.11). We will assume a market price of $9/bushel for soybeans, yielding $4.50 to $18 per acre for income. It would be uneconomical for agricultural producers to apply whole field potassium under these conditions. However, along the toeslope/backslope and floodplain areas of the half-mile strip, we saw yield gains of 10-20 bushels, which would net a gross income of $90-180 per acre. Under these circumstances, it would be appropriate to apply potassium fertilizer. On the summit and upper shoulders of each K-applied strip, we saw little advantage to fertilization, indicating a significant draw on finances (Figure 2.9-2.11, 2.13).

Future Work

It seems imperative that a yearly draw on potassium fertilizer as a function of crop uptake will lead to potassium values decreasing to a critical low. Future work needs to focus on the dynamics of indigenous mineral weathering and how STK values change yearly as a result.

Since we saw yield advantages in many instances, future scientists should focus research into examining why these increases occurred. We hypothesized as to the reasons above. Within these landscape positions where potassium fertilizer provided yield advantages, potassium rate studies should be conducted to determine economically optimal fertilization rates. We attempted to examine why potassium fertilizer decreased, did not affect yield, or provided marginal yield gains. Future work should also be geared towards examining the correlation between soil salinity and potassium fertilizer. The temporal variability with exchangeable STK levels needs to be better defined for soils testing high in exchangeable K^+. The mineralization potential of soils having a high intrinsic capability of releasing K^+ from inherent parent material needs to be better understood through a leaching experiment that attempts to quantify a soil's ability to replenish potassium following events that otherwise would reduce the amount of exchangeable K^+.

CONCLUSION

While South Dakota producers may not be fully compensating for nutrient removal (especially in corn stover removal situations), incremental yield gains from K^+ fertilization are minimal and generally uneconomical across a full treatment strip. Site-specific yield gains, however, are tangible and very economical. STK values did increase following K^+ fertilization, but generally did not increase yields, had a detrimental effect on leaf K^+ concentration, and stomatal conductance. Agronomists and consultants must factor in temporal variability with STK quantification since we observed unforeseen fluctuations in STK sampling along 100-foot transects. Future research needs to address extraction methods for quantifying available potassium.

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CHAPTER 3

LEACHING QUANTIFICATION OF POTASSIUM (K^+) IN A CONTINUOUS CORN (Zea Mays L.) SYSTEM FOLLOWING PRECIPITATION

INTRODUCTION

According to Marschner (1995), potassium (K^+) is the second highest absorbed and exported mineral in grain production. Assessing the nutrient concentrations partitioned to the vegetative and reproductive tissues is identified as the ‘harvest index’ or ‘HI’ (Below, 2013). HI reflects the percentages of nutrients removed by the grain compared with total plant uptake, ranging from 10-80% for many nutrients (Below, 2013). For potassium, it is estimated that 28% of the total K^+ uptake is removed with grain, indicating significant K^+ concentrations remaining in corn stover left to decompose in fields following grain harvest (Below, 2013). K^+ is held in an inorganic form in corn dry matter, so rainfall has the ability to leach soluble K^+ from stover biomass. Mallarino (2011) illustrated that seasonal offsite movement of K^+ occurs with precipitation.

Ample research is available concerning potassium concentrations and uptake patterns across the growing season (Mengel and Barber, 1974; Below et al, 2013; Karlen et al, 1987), concluding at physiological maturity. Little research is presently available concerning K^+ leaching from corn stover biomass following physiological maturity. Mallarino (2011) assessed the change in K^+ concentration in baled corn stover across time, illustrating that the largest decrease occurs from black layer to grain harvest, but unlike phosphorus, a steady decline was noted for K^+, the magnitude of which was dependent upon the amount of precipitation. Schomberg (1999) measured K^+ loss from corn residue under irrigated plus rainfall and rainfall moisture regimes. The percent of K^+

remaining in the corn residue decreased from 100 to 10% with 10 inches of rainfall. In particular, K^+ releases were exponential between treatments.

International Plant Nutrition Institute estimates that 200 corn bushels per acre contains 220 lbs K_2O in the corn stover, almost four times the amount of K_2O removed yearly with grain. Grimes and Hanway (1967) documented that it took 72 days for most of the K^+ held in corn stover to leach into the soil. Unlike nitrogen (N), K^+ is water soluble and is displaced in the soil. It has been reasoned that close to 1 kg K ha^{-1} is displaced for every 100 mm of precipitation in a field (Johnson and Goulding, 1992). Ample research has been conducted concerning the ability of K^+ to leach in the soil, including anion interactions (Tinker and Nye, 2000), large topsoil exchangeable K^+ levels (Kayser, 2012), and interactions with varying nitrogen rates (Kayser, 2012), but little concerning aboveground losses from corn stover biomass.

Potassium is commonly removed from the soil in two processes; the loss of K^+ in corn grain removal and leaching of K^+ below the root interception zone (Askegaard, 2003). Offsite movement of other macronutrients because of nitrogen's high degree of subsurface leaching (Dinnes et al, 2002) and phosphorus's surface runoff into groundwater supplies and lakes has been assessed (Alfaro, 2004), but little attention has been paid to K^+ because of its relatively benign impact upon the environment. Research analyzing K^+ leaching has also been scarce due to well-supplied soils with native indigenous K^+, not considered yield-limiting (Kolahchi, 2007). A similar situation is occurring in South Dakota (Chapter 2).

Grimes and Hanway (1967) assessed the impact crop residues had on increasing exchangeable STK levels, postulating that large exchangeable K^+ increases occurred following corn harvest to spring, suggesting that STK values would be much higher in the zone surrounding the plant residue following decomposition; added K^+ residues from fall = added exchangeable K^+ in the spring. Chapter 2 discussed the temporal variability with K^+ soil sampling, suggesting minimal to large (20-45%) gains in spring STK values. The mechanism through which K^+ is added to the soil has been thought to be through mineralization, but is not specifically identified (Grimes and Hanway, 1967).

From an economic standpoint of collecting biomass, the loss of inorganic K^+ represents a deteriorated value for the potential biofuel. Under K-limiting conditions, crops will need to rely on nonexchangeable K^+ instead of the readily available exchangeable K^+. Plant extraction of this form of K^+ is heavily unfeasible and will not solely meet plant uptake demands. An agricultural system with negative K^+ balances is not economically or environmentally viable (Oborn et al, 2005), and crop yields will stagnant or decrease over time.

Our work sought to expand on published work on nutrient uptake and partitioning of various macronutrients across the growing season into the winter months, specifying K^+ concentrations across stover fraction as a function of seasonal precipitation (Below, 2013). Mallarino (2011) determined that K^+ is lost from the corn stover biomass in a field setting throughout the winter months (December-March). With plant concentrations of K^+ known, we can compare leached K^+ to total K^+ concentrations, equating approximations of removing K^+ across stover fraction.

Objectives for this study include:

1) Determine how much K^+ is leached from various plant parts in corn

2) Establish a laboratory protocol for examining potassium leaching using biomass matter

MATERIALS AND METHODS

The study was conducted at the South Dakota State University Research Station near Aurora, South Dakota, in east-central South Dakota. Dekalb brand seed corn 48-12STXRIB (Genuity Roundup/Genuity SmartStax Refugee-In-The-Bag) (Monsanto Company, St. Louis, MO) was planted at 32,000 seeds/acre in early May. Cultural (fertilization and pest control) practices followed local procedures. At physiological maturity (R6; Hanway, 1973), individual whole corn plants were cut at the soil surface with a knife and separated into the following tissue fractions; new leaves (ear leaf), old leaves (oldest necrotic leaf), stalk (plant stem stripped off all appendages excluding the roots), cob (without grain), and grain (manually husked from cob). A corn stalk chopper was simulated with the use a wood-chipper since South Dakota corn producers commonly use corn stalk choppers to pulverize corn stover biomass following harvest.

Partitioned stover was placed into leaching columns and replicated ten times. The experiment was a two-factorial plot design investigating the plant component (vegetative or reproductive structure) and rainfall increments (1, 3, 5, 7 inches). Various weights were utilized for material based on collection amounts. 20 g of new leaves, 20 g of old leaves, 57 g of shredded whole plant material, 30 g of stalk material, 20 g of cob material, and 30 g of kernels, and each were individually placed into leaching columns. Each column had diameter dimensions of 16.8 cm by 2.54 cm. A representative column can be seen in figure 3.1.

A plastic jug with four equidistant holes cut into the lid of the container was used to simulate rainfall under normal field conditions experiencing rainfall. During application process, particular care was used to best simulate rainfall upon biomass matter in a field setting. 563 cm^3 of Nanopure water was dripped onto each column to simulate 2.54 cm (1 inch) of rainfall. 7.62, 12.7, and 17.7 cm increments of rainfall were added in successive increments to represent 2-inches of increased rainfall. Finely-meshed cheesecloth material was placed into each column to filter biomass material from leachate, and clear plastic tubing ran from each column that carried the sieved leachate. Leachate was collected into pails and 125 mL cups took a representative sample from each pail.

The amount of K^+ removed in the leachate with successive rainfall increment was measured by the use of a Jenway model PFP7 industrial flame photometer (Bibby Scientific, Burlington, NJ). The procedure to measure exchangeable K^+ was through the NH_4OH method (Warnacke, 2012), but using Nanopure water instead of NH_4OH. Standard calibration solutions were created for 0, 1, 3, 5, 7, 9 ppm readings (Jenway PFP7 Flame Photometer Operator’s Manual). Samples were diluted with Nanopure filtered water to obtain values within machine accuracy. Dilutions were typically set to 1:8 (1 mL extract: 7 mL of Nanopure water) throughout the experiment. Each sample was analyzed/replicated on three separate occasions.

Figure 3.1. Plot design with an actual column used for analysis.

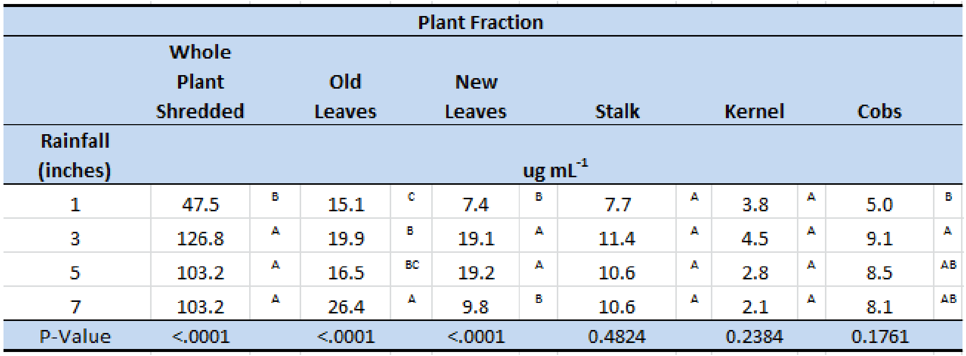
Potassium standards were analyzed between each sample until accurate values were obtained. Known standard stock solutions were analyzed every twenty samples. Machine drift was minimal over time. Polynomial equations quantified approximate K^+ readings from the flame photometer between standard runs in parts per million (PPM). R-squared values ranged from 0.96 to 1.00.

Statistical Analysis

PROC REG procedure of SAS 9.3 (SAS Institute, Inc., Cary, NC) was used to determine the impact of rainfall on the amount of K leached out of each plant partition at the a=0.05. The experiment contained ten replications of each plant fraction and four inch increments. Block and its interaction with all treatments were considered factors. Rainfall was considered a fixed factor.

RESULTS AND DISCUSSION

The tables and figures that follow outline the results of the K^+ leaching experiment. Results are reported as leachate per inch and not reported as accumulative amounts of leachate (Figure 3.2).



	Plant Fraction											
	Whole Plant Shredded		Old Leaves		New Leaves		Stalk		Kernel		Cobs	
Rainfall (inches)	ug mL^{-1}											
1	47.5	B	15.1	C	7.4	B	7.7	A	3.8	A	5.0	B
3	126.8	A	19.9	B	19.1	A	11.4	A	4.5	A	9.1	A
5	103.2	A	16.5	BC	19.2	A	10.6	A	2.8	A	8.5	AB
7	103.2	A	26.4	A	9.8	B	10.6	A	2.1	A	8.1	AB
P-Value	<.0001		<.0001		<.0001		0.4824		0.2384		0.1761	

Figure 3.2. K leachate expressed in ug/mL amongst corn biomass plant fractions across rainfall rates.

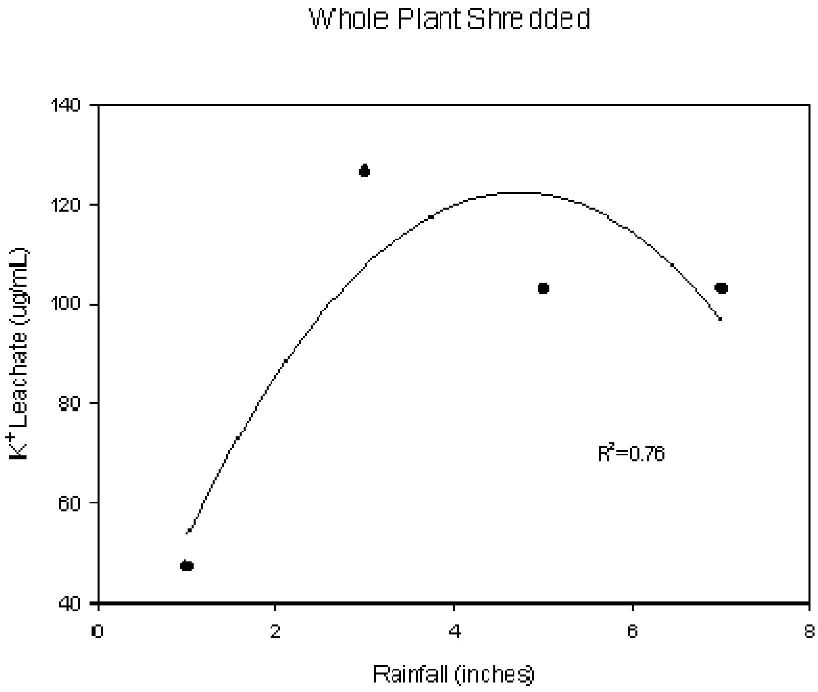


Figure 3.3. K leachate expressed in ug/mL amongst shredded corn biomass material across rainfall rates.

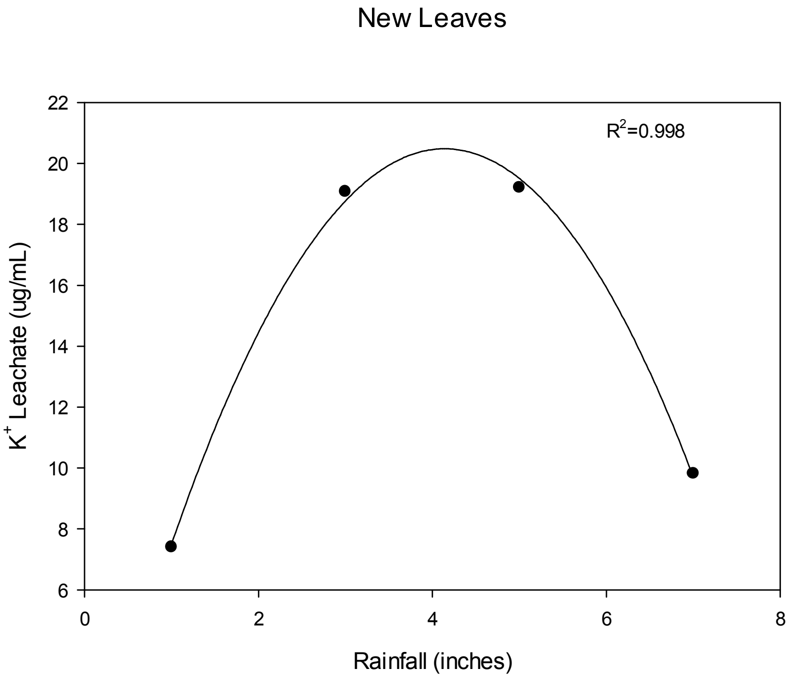


Figure 3.4. K leachate expressed in ug/mL amongst new leaves across rainfall rates.

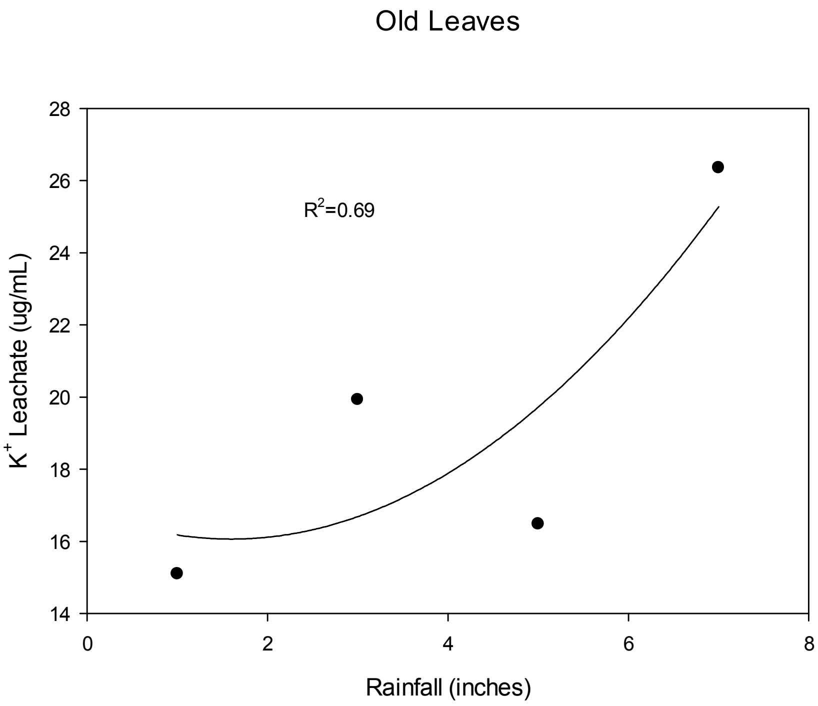

Old Leaves

Figure 3.5. K leachate expressed in ug/mL amongst old leaves across rainfall rates.

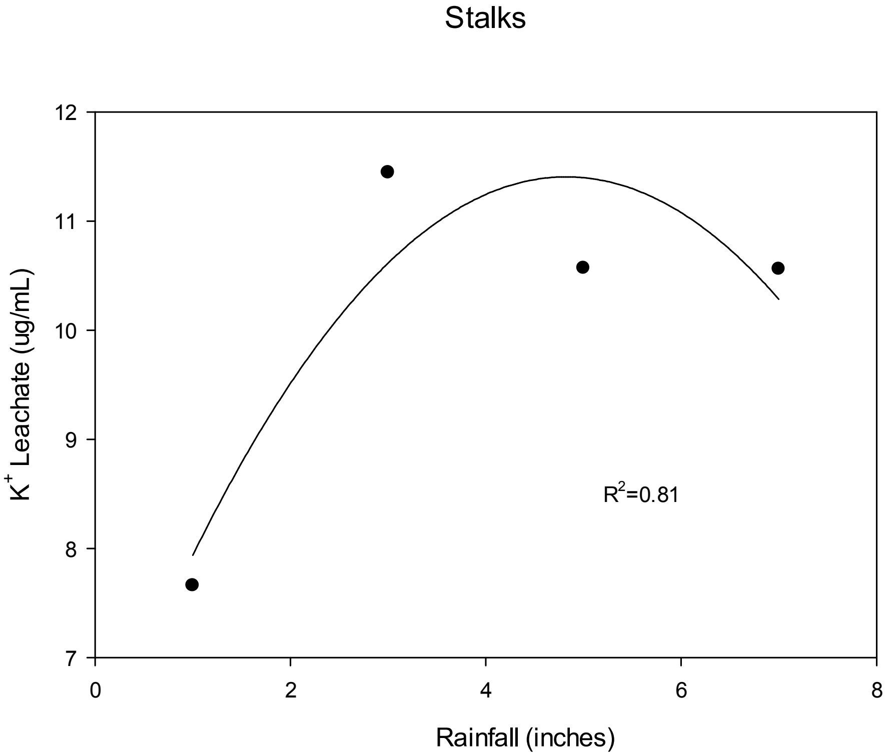

Stalks

Figure 3.6. K leachate expressed in ug/mL amongst corn stalks across rainfall rates.

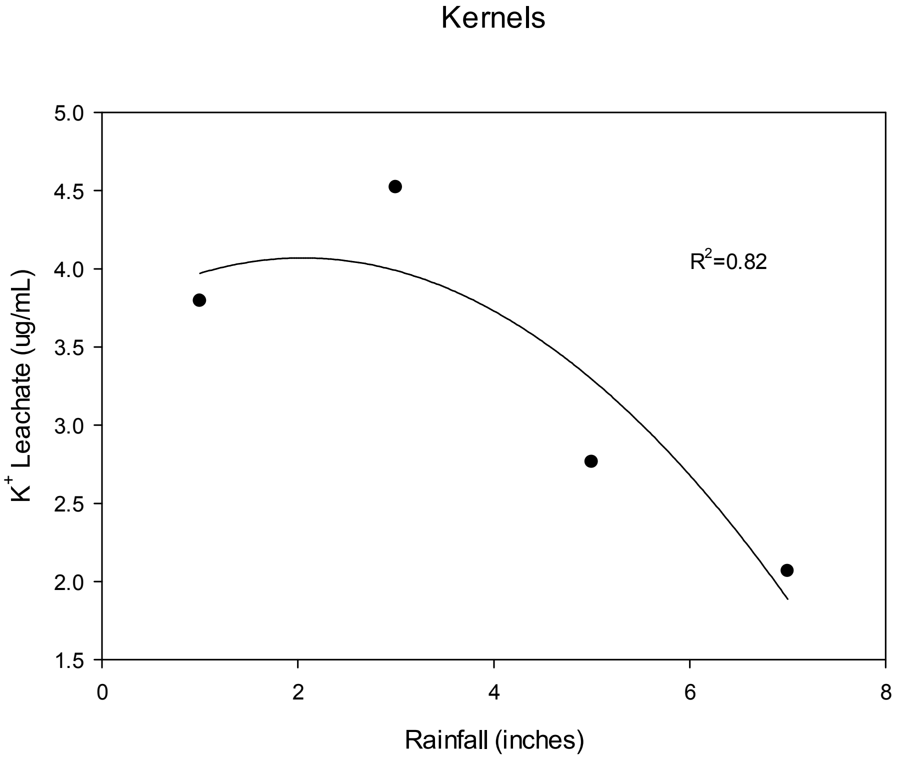


Figure 3.7. K leachate expressed in ug/mL amongst corn kernels across rainfall rates.

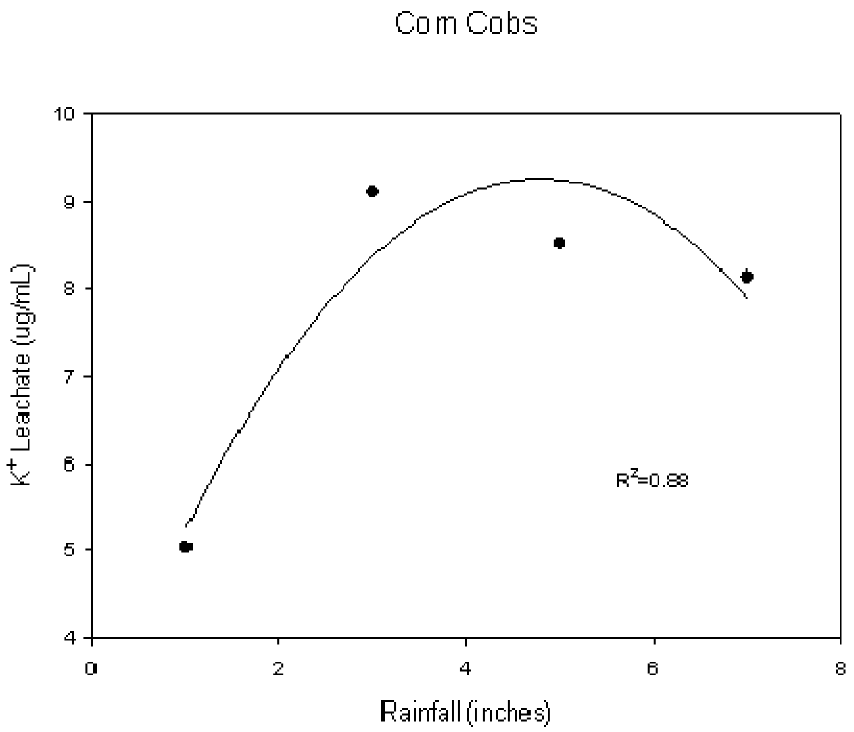
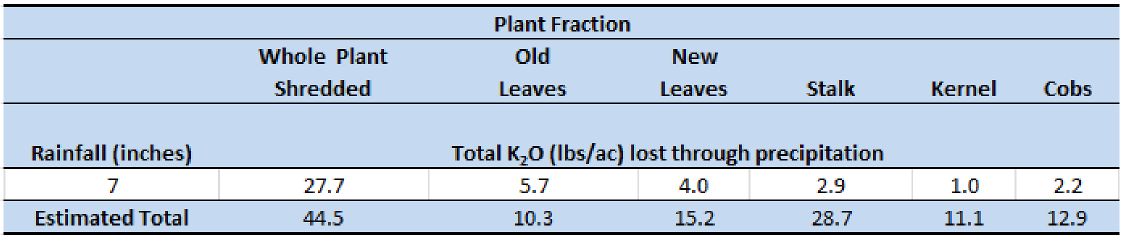


Figure 3.8. K leachate expressed in ug/mL amongst corn cobs across rainfall rates.



	Plant Fraction					
	Whole Plant Shredded	Old Leaves	New Leaves	Stalk	Kernel	Cobs
Rainfall (inches)	Total K_2O (lbs/ac) lost through precipitation					
7	27.7	5.7	4.0	2.9	1.0	2.2
Estimated Total	44.5	10.3	15.2	28.7	11.1	12.9

Figure 3.9. Total K_2O concentrations lost across plant biomass fractions with 7-inches of rainfall. Estimated total K_2O (lbs/acre) as reported from Ward Laboratories (Kerney, Nebraska).

In accordance with Figure 3.2, rainfall played an important role in K^+ leaching off of corn biomass fractionation. The whole plant shredded showed the greatest ability to displace K^+ with leachate values significantly rising from 47.5 to 126.8

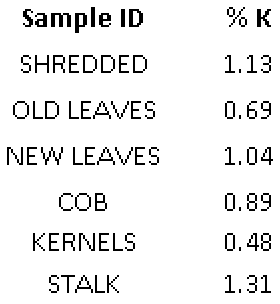
micrograms/millimeter following the application of 2 inches of rainfall (amounting to 3 inches of accumulated precipitation) (Figure 3.3). These differences were statistically significant at $P<0.0001$ (Figure 3.2). The applications of 2 inches to successively amount to 5 and 7 inches of rainfall did show an increase of total K^+ leachate, but instead displayed a negative rate of increase, stagnating at these rainfall amounts (Figure 3.3).

As expected, each fractionation was lower in K^+ leachate among all rainfall rates, but similar trends were seen across all treatments among rates of K^+ displacement. Since K^+ is mobile in the corn plant, more K^+ is expected in rapidly growing plant tissue. There was a trend for the old leaf fractionation to displace as much K^+ as in the newer leaf fractions (Figures 3.4 and 3.5), amassing 1.7 lbs K_20/acre more than the new leaves (Figure 3.9). This was opposite from expected as we assumed more K^+ would have leached out of the newer leaves. The stalk, kernel, and cob fractions each showed a similar leaching ability with the highest leaching ability occurring with the 3-inch total rainfall treatment (Figures 3.2, 3.6-3.8). K^+ leachate was lower in these fractions, which could be explained by surface area since these fractions represented a smaller total surface area take up of the column than did the much larger newer and old leaf fragments. Stalk and kernel leachate amounts were not significant at the 95% confidence interval (Figure 3.2). Graphically, trends for leaching capability of each fraction across rainfall increment are shown in Figures 3.3-3.8.

Figure 3.9 illustrates how much K_2O leached out of each fraction across the 7-inches of rainfall we simulated. International Plant Nutrition Institute estimates that 200 bushel per acre corn will remove 54 lbs K_2O (grain) and additional 220 lbs K_2O (stover concentration. Recall from Chapter 2 that the average K_2O application rate in South

Dakota is 29 pounds/acre. It is probable that the whole plant shredded treatment would represent what current South Dakota grain producers practice in fields. Assuming 0.27 lbs of K_2O are removed per bushel and the average South Dakota corn yield of 150 bushels/acre, 40.5 lbs of K_2O are required for corn production. It is probable that not only are South Dakota soils under-fertilized for production, but there may be a potential for that K^+ to be displaced from the soil for succeeding crop years. If offsite movement of K^+ is minimal and K^+ moves into the soil, the issue of K^+ leaching is minimized since it will become available for crop production and not negatively impacting environmental conditions. K^+ leaching will become an issue if offsite movement occurs, reducing the plant-available concentrations of K^+ and an increased environmental pollutant. Each plant fraction (old leaves, new leaves, stalk, kernel, and cob) does not equal the full whole plant shredded's amount of leached K_2O, so it can be reasoned that the final 9.9 lbs K_2O would have combined to be leached in the tassel and ear husk tissues. While not separately tested, each fraction was included in the whole plant shredded treatment.

To estimate total potassium held in each corn biomass treatment, Ward Laboratories (Kearney, Nebraska) tested each fraction for total K^+ concentration. Results of total K^+ concentration are provided in Table 3.9.



Sample ID	**% K**
SHREDDED	1.13
OLD LEAVES	0.69
NEW LEAVES	1.04
COB	0.89
KERNELS	0.48
STALK	1.31

Table 3.1. Total K^+ concentration in each biomass sample as reported from Ward Laboratories (Kearney, Nebraska).

To determine what percentage of K^+ leached out of the corn biomass material, we compared the relative percentages of K^+ leachate to total K^+ held in biomass material. Per inch of rainfall, we applied 563 cm^3 of rainfall, amassing a total of 3941 cm^3 across the seven inches. It is inconceivable to suggest that 3941 cm^3 successfully interacted and leached out of the column since some leachate either adsorbed to the plant material or simply did not filter through the drain plug and tubing into the collection pail. For our argument in considering total amounts of leachate, we assumed that all of this did leach. For each fractionation, we calculated an average K^+ leachate amount per inch. Total water leached was compared to the average K^+ leachate and equaled grams K^+. The calculated value was divided by grams used in each biomass fraction, equaling grams K/grams stover. This value indicated how much K^+ was leached across seven inches. The laboratory results from Ward Laboratories (Kearney, Nebraska) specified through microwave digestion K^+ concentrations in each sample. The amount of K^+ leached was compared to total K^+ concentration in each fraction to indicate what percent K^+ was leached out. Table 3.2 shows percentages of K^+ that was leached out of each appendage across the seven inches.

Sample ID	% of K^+ leached
Shredded	62.3
Old Leaves	55.6
New Leaves	26.3
Cob	17.0
Kernels	9.0
Stalk	10.1

Table 3.2. Relative percentages of K^+ leached out of corn biomass material.

In accordance with Table 3.2, the whole plant shredded material had the highest K^+ percentage leached out of the biomass material, suggesting that K^+ has a great ability to be leached across seven inches of rainfall. The new leaves leached a higher percentage than the older leaves, which is in agreement with the ability of K^+ to be translocated throughout the plant, reaching higher levels in the newer plant growth. The cob, kernel, and stalk fractions had the lowest degree of K^+ displacement. Successfully leaching K^+ out of these fractions is difficult, especially in a column study. In Table 3.1, new corn leaf tissues were estimated at 1.04%. Our results compare closely to Mallarino (2011) who only assessed corn plant tissues (not specifying age). At grain harvest time, K^+ concentration in corn leaf tissues was estimated at 1.0% (mid-October). While proportions of K^+ loss were minimal since residue was covered with snow, losses accelerated in March and into April to 0.6%. With 7 inches of rainfall in our experiment, we leached 26.3% of the K^+ held inside of the biomass material, or 0.766% K^+ remaining in tissue. Since meteorological data was not provided in Mallarino (2011), we cannot estimate how similar the leaching activities were in terms of accumulated precipitation.

CONCLUSION

While the majority of studies concerning K^+ leaching have been limited primarily to soil or below-ground studies, we tested the hypothesis of the above-ground ability for K^+ to leach out of corn biomass material with subsequent inches of rainfall with a column study. Each plant fraction experienced an increase in K^+ leaching with rainfall, usually leaching a maximum at or around 5 inches of accumulated rainfall. Rainfall rates were correlated with K^+ leaching, suggesting that K^+ displacement may be a factor of rainfall event instead of accumulated rainfall. We compared our leachate amounts to total K^+ and reasoned that the seven inches was able to remove a significant portion of plant K^+ concentrations. Future studies should continue to investigate the ability of K^+ to be leached out of corn biomass material and potential environmental detriments should offsite movement of K^+ occur.

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CHAPTER 4

UREA-N APPLICATIONS ON SOYBEAN [GLYCINE MAX] AT R3 GROWTH STAGE TO DETERMINE YIELD INCREASES UNDER INTENSIVE MANAGEMENT

Applying nitrogen to soybeans is not a common practice for South Dakota soybean growers. Soybeans are a legume crop, acquiring its nitrogen needs through a symbiotic association called fixation. Research has been conducted since the 1950's to study the impact of nitrogen fertilizer on increasing soybean yields (Lyons, 1952). Since nitrogen is an intrinsical component of proteins, nucleic acids, amino acids, and comprises a large portion of the photosynthetic machinery, legume crops such as soybeans have a large demand for nitrogen (Sinclair and Horie, 1989). Soybean growers are continually seeking to understand how intensive management programs can increase soybean yields.

Nitrogen is acquired through three main sources; biological nitrogen fixation from *Bradyrhizobium* species, soil residual nitrogen in the ammonium (NH_4^+) and nitrate (NO_3^-) forms, and from fertilizer supplying nitrogen (Murrell, 2012). These nitrogen sources are not equally proportioned for soybean uptake; 50-80% of nitrogen is supplied through nitrogen fixation (Salvagiotti, 2008). Under adverse conditions unfavorable for fixation, soil residual nitrogen has been reported to provide 40-75% of the crop's nitrogen supply (Sawyer, 2000). In situations where nitrogen fixation and soil residual nitrogen levels do not provide sufficient nitrogen needed to achieve maximum soybean yield, nitrogen fertilizer can serve as a means to provide additional nitrogen needed for the crop (Salvagiotti, 2009). The goal of nitrogen fertilization of soybeans is that the fertilizer will not substitute, but rather serve as a supplement for the nitrogen needed for the soybean crop. Hanway (1971) examined the soybean yield response by applying as much as 600 pounds N per acre and finding no significant yield response. He compared that treatment to soybeans that had been inoculated with *Bradyrhizobia* bacteria that was not supplemented with nitrogen (Hanway, 1971). Determining the correct amount, rate, timing, and placement is difficult.

Planting conditions in the Northern Great Plains can rapidly vary from year to year. These include soil moisture, temperature, soil organic matter content, and pH (Sorenson and Penas, 1978). If a soybean seed is sown into an environment not conducive for optimal germination and early vegetative growth, maximum nitrogen fixation and yield potential will not be attained. Nitrogen fixation may begin 14 days (Hardy, 1971), or even 28 days after planting (Clay, unpublished data). During this time, the crop must rely solely on soil residual nitrogen to supply its nitrogen needs, which can vary based upon texture, organic matter content, or residual nitrate levels. Soils having a particularly clayey texture with high organic matter content and high soil nitrate levels are less likely to exhibit a positive yield response to N fertilization than sandy soils with low organic matter content and low soil nitrate levels (Schmitt, 2001; Sawyer, 2000). Irrigation has proven to increase the probability of a yield response; Wesley showed an average yield gain of 6.9 bushels/acre to low N rates applied in Kansas (Wesley, 1998).

International Plant Nutrition Institute (IPNI) states that 4.72 pounds of nitrogen are required to produce 1 bushel of soybean grain (Murrell, 2012). A 55-bushel soybean crop will require 259.6 pounds of nitrogen. Soybean stover nitrogen content has been calculated to be 1.30 pounds N per 1 bushel soybean grain. A subsequent summation of

331.1 pounds of nitrogen are required (Iowa State University, 2007). The upper limit for nitrogen fixation has been suggested to be at 120 pounds per acre (Weber, 1966). Thus, to produce 55 bushel per acre soybeans, over 139 pounds of nitrogen must be made available by soil residual nitrogen content or fertilizer nitrogen applications. If the future goal is to produce 100 bushel/acre soybeans, 472 pounds of nitrogen will need to be supplied and made available to the crop. Careful nitrogen management must be accomplished since nitrogen is mobile in the soil and subject to leach, denitrify, or volatilize.

Early season applications of nitrogen decrease the *Bradyrhizobium* infection and nitrogen fixation (Schibbles, 1998). Beard (1971) reported a reduction in early nodulation numbers of soybean plots receiving a rate of 56 kg/ha of nitrogen. Mean yields of plots receiving 0, 56, 112, or 168 kg/ha of nitrogen did not differ significantly from either a vegetative, reproductive, or combination application. The current hypothesis is that late season (during the reproductive stages) nitrogen applications may increase soybean yields since the nitrogen fixation process reaches a conclusion at around R3 (Wesley, 1998). Barker and Sawyer (2001) tested the hypothesis that soil applied nitrogen fertilizer (in either urea or poly coated urea fertilizer form) could increase soybean yield when applied during the R2 (full bloom) to R3 (beginning pod formation) growth stages (Hanway, 1967). Results concluded that nitrogen fertilizer applications (regardless of placement, nitrogen treatment, or application rate) did not significantly increase soybean grain yields (Sawyer, 2000). Wingeyer (2014) assessed the application of urea across 0 and 60 kg N ha^{-1} treatments at the R1 (beginning flower) and R4 (full pod development) stages. He concluded that nitrogen applications during these stages did little to influence soybean grain yields, though grain yields varied from 4.24 and 3.39 Mg Ha^{-1} for the irrigated and non-irrigated treatments, suggesting water availability may help increase soybean grain yields with nitrogen (urea).

Salvagiotti (2009) showed that early season (vegetative stages) applications of a controlled-release nitrogen form can reduce the inhibition of nodule development. Timing of application is particularly important since too early of an application will diminish the contribution of biological nitrogen fixation. Current suggestions are to apply a controlled-release nitrogen source at the R3 growth stage. A deep-banded application of a controlled release nitrogen source is recommended, releasing nitrogen in such a way not to interfere with biological nitrogen fixation, but this method is not feasible for South Dakota growers during the R stages. Schmitt (2001) in Minnesota provided a similar test of urea sources (uncoated vs. poly coated) as Salvagiotti (2009), but they applied the nitrogen fertilizer at the R6 growth stage (full seed development). While the poly-coated urea resulted in greater nitrate concentrations at the R6 growth stage than the uncoated form, the in-season nitrogen fertilizer plots did not significantly yield greater than the control (no nitrogen) plots. It may be reasoned that nitrogen uptake and assimilation could have been limited or compromised at such a late period of soybean growth.

Little on-farm research has been conducted to examine if soybean yields can be increased with a late-season nitrogen application, particularly with encapsulated nitrogen (ESN), a slow-release source of nitrogen in the urea form. Much of the research available has been constrained to primarily plot work, generally measured in plots ranging in small relatively plot sizes with marginal spatial variability. We sought to determine how a controlled-release nitrogen form broadcasted during R3 to R4 (full pod development) could be implemented on farm trials to achieve high-yielding soybeans across a half-mile pass.

Objectives for this study included:

1.) Study the relationship between established plot research on soybean-nitrogen treatments and compare on-farm research conducted in South Dakota, USA
2.) Determine if ESN can increase soybean yields in South Dakota, USA
3.) Measure the soybean yield differences from varying row spacings across South Dakota, USA

MATERIALS AND METHODS

Site Locations

Numerous locations throughout east-central and southeastern South Dakota were part of the on-farm research examining nitrogen applications on soybeans. Fifteen fields in total were used. Figure 4.1 shows where across the area they took place (shown with flags).

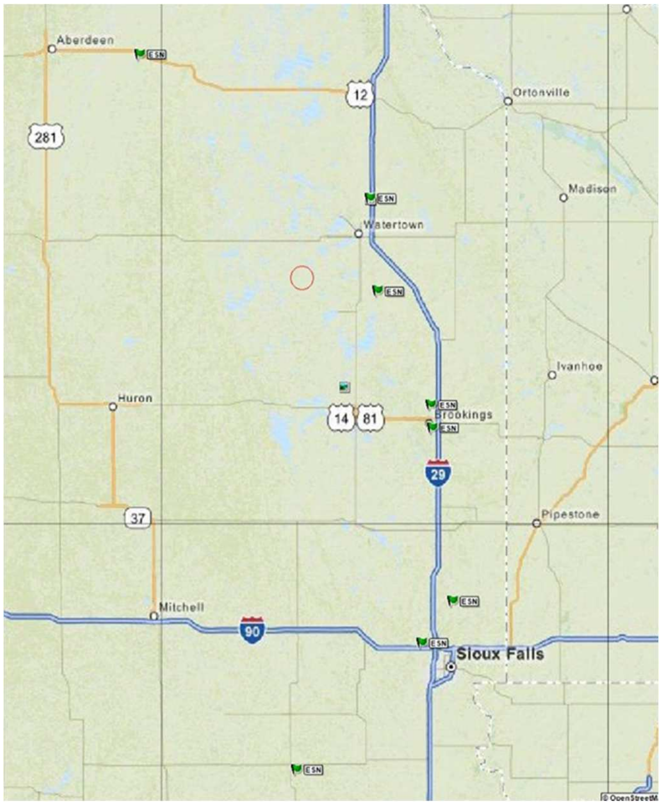


Figure 4.1. Map of east-central South Dakota indicating with red flags where on-farm ESN plots were conducted during 2014.

Site Specifications

Site characteristics and soil survey data can be found in Appendix D. On-farm cooperators needed to have a yield monitor where data could be archived and cleaned for statistical analysis. Individual producers applied 75 lbs N/acre of encapsulated nitrogen (46-0-0) or 163 lbs of product per acre during the R3 growth stage (July 20, 2014) (Hanway, 1967) with a topdress fertilizer application with a spinning-spreader. Each treatment was replicated 3-4 times per field and plot dimensions were typically 2,640 feet by 70 feet (4.24 acres). The experiment was a single-factorial arrangement, assessing only yield response by nitrogen application as part of a pilot program into nitrogen yield response in soybean crops. No other vegetative or reproductive parameters were analyzed in this project.

Agronomic management of fields followed local or historical practices according to grower desires. No fields received any form of nitrogen fertilizer prior to treatment addition. Fields were either tilled or notilled and product was not incorporated.

At physiological maturity (R8; Hanway, 1967), cooperating producers combined the entire plot area and field, archiving the yield monitor data with their combine's software. Yield monitor data was cleaned according to the protocols outlined in Chapter 5.

Landscape Positional Differences

Refer to Figure 2.5 for terminology used to identify landscape positions across treatment strips whenever possible.

Statistical Analysis

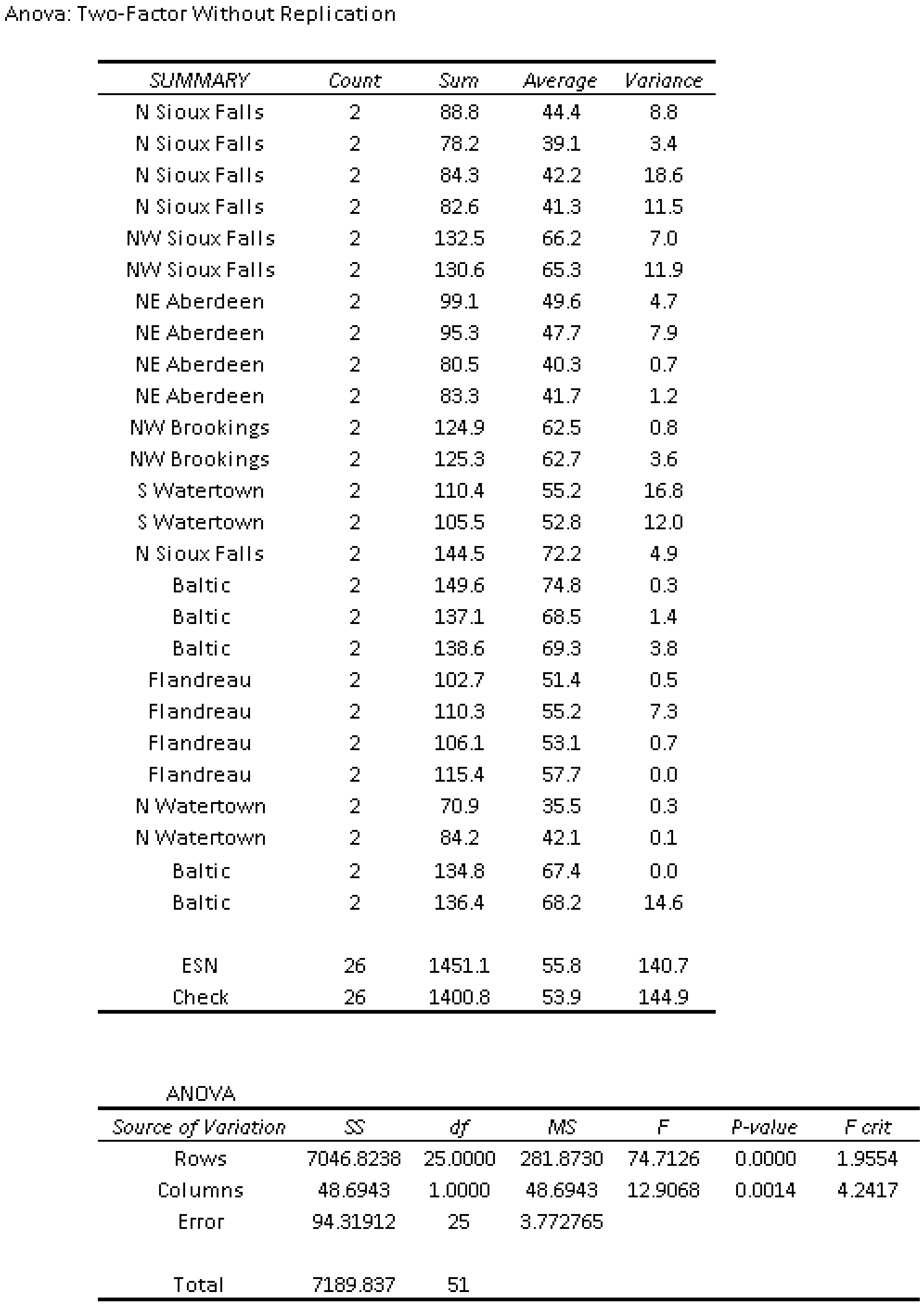
Surfer (Golden Software, Golden, Colorado) kriging was used to estimate the yield differences between the K^+ fertilization strips and the untreated strips at each site. Surfer kriging computer software (Golden Software, Golden, CO) was used for yield interpolation when needed. Microsoft Xcel (Microsoft Corporation, Redmond, Washington) was used for analysis of variance estimation for each sampling point between sampling periods.

RESULTS AND DISCUSSION

Table 4.1 provides plot averages for soybean yield across all site locations. Further analysis, including yield difference maps superimposed on LiDar imagery, can be found in Appendix D. Yield tables were separated via geographical locations across eastern South Dakota and can be found in Tables 4.1 and ANOVA results in Table 4.2.

Site	Rep	Location	ESN	Check	Yld Diff
Crooks	1	N Sioux Falls	46.5	42.3	4.2
	2	N Sioux Falls	40.4	37.8	2.6
	3	N Sioux Falls	45.2	39.1	6.1
	4	N Sioux Falls	43.7	38.9	4.8
Olaf	5	NW Sioux Falls	68.1	64.4	3.8
	6	NW Sioux Falls	67.8	62.9	4.9
Holler	7	NE Aberdeen	51.1	48.0	3.1
	8	NE Aberdeen	45.7	49.7	-4.0
	9	NE Aberdeen	40.9	39.7	1.2
	10	NE Aberdeen	40.9	42.5	-1.6
Converse	11	NW Brookings	63.1	61.8	1.3
	12	NW Brookings	64.0	61.3	2.7
Hoitsma	13	S Watertown	58.1	52.3	5.8
	14	S Watertown	55.2	50.3	4.9
Brian	15	N Sioux Falls	70.7	73.8	-3.1
	16	Baltic	74.4	75.2	-0.8
Tuffy West	17	Baltic	69.4	67.7	1.7
	18	Baltic	70.7	67.9	2.7
Downer	19	Flandreau	50.9	51.9	-1.0
	20	Flandreau	57.1	53.3	3.8
	21	Flandreau	53.7	52.4	1.2
	22	Flandreau	57.6	57.8	-0.1
Hendricks	23	N Watertown	35.9	35.1	0.8
	24	N Watertown	42.3	41.9	0.3
Tuffy East	25	Baltic	67.2	67.5	-0.3
	26	Baltic	70.9	65.5	5.4
AVERAGE YIELD			**55.8**	**53.9**	**1.9**

Table 4.1. Average side-by-side strip yield between ESN and check strips across site locations.



Anova: Two-Factor Without Replication

SUMMARY	Count	Sum	Average	Variance
N Sioux Falls	2	88.8	44.4	8.8
N Sioux Falls	2	78.2	39.1	3.4
N Sioux Falls	2	84.3	42.2	18.6
N Sioux Falls	2	82.6	41.3	11.5
NW Sioux Falls	2	132.5	66.2	7.0
NW Sioux Falls	2	130.6	65.3	11.9
NE Aberdeen	2	99.1	49.6	4.7
NE Aberdeen	2	95.3	47.7	7.9
NE Aberdeen	2	80.5	40.3	0.7
NE Aberdeen	2	83.3	41.7	1.2
NW Brookings	2	124.9	62.5	0.8
NW Brookings	2	125.3	62.7	3.6
S Watertown	2	110.4	55.2	16.8
S Watertown	2	105.5	52.8	12.0
N Sioux Falls	2	144.5	72.2	4.9
Baltic	2	149.6	74.8	0.3
Baltic	2	137.1	68.5	1.4
Baltic	2	138.6	69.3	3.8
Flandreau	2	102.7	51.4	0.5
Flandreau	2	110.3	55.2	7.3
Flandreau	2	106.1	53.1	0.7
Flandreau	2	115.4	57.7	0.0
N Watertown	2	70.9	35.5	0.3
N Watertown	2	84.2	42.1	0.1
Baltic	2	134.8	67.4	0.0
Baltic	2	136.4	68.2	14.6
ESN	26	1451.1	55.8	140.7
Check	26	1400.8	53.9	144.9

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	7046.8238	25.0000	281.8730	74.7126	0.0000	1.9554
Columns	48.6943	1.0000	48.6943	12.9068	0.0014	4.2417
Error	94.31912	25	3.772765			
Total	7189.837	51				

Table 4.2. Analysis of variance between ESN and check strips across all site locations.

Yield results varied by location among all fields analyzed. Table 4.1 indicates a summation of all strips across site locations. A total of 26 separate strips with ESN (75 lbs N/acre) and check (0 lbs N/acre) were analyzed in this study. The highest strip average gain from ESN application was 6.1 bushels/acre while the highest loss was 4.0 bushels/acre. Site-specific yield differences were generated, displayed in Appendix D, and discussed below. Overall, the yield advantage for ESN treatment was 1.9 bushels/acre, which was statistically significant at $P<0.0014$ level (Table 4.2). This is in accordance to recent research conducted with nitrogen on soybeans (Wingeyer, 2014) and similar research conducted with nitrogen available. These yield advantages were on par with other authors who only reported minimal gains to nitrogen fertilizer, regardless of product or placement. Some locations reported either no advantage or a yield reduction as a result of nitrogen fertilization (Table 4.1).

Subsequently, we report that across the half-mile treatment strip, we saw a wide degree of spatial variability of yield response to nitrogen application (Appendix D). This spatial analysis is lacking in the scientific literature and thus, we sought to understand in what topographical or landscape position may provide an advantage to nitrogen fertilization. Landscape position did play a role in yield response. In the toeslope/backslope and depressional areas across the strip, the difference between what was physically harvested versus the predicted values led credence to advantages of 10-20 bushels per acre (Appendix D). These topographical results are consistent with Figures 2.10-2.12 in which potassium fertilizer was analyzed We hypothesize that this may be the direct result to increased levels of available nitrogen in the transpirational stream for nitrogen uptake since this has been identified as the main source of nitrogen acquisition (Tsay et al, 2007). This theory would be in accordance with the work conducted by Wesley (1998) in Kansas. Our results support what Wingeyer (2014) illustrated that while there was not a significant yield response to urea application, mean yields were higher in the treatment areas. Future work should be focused on soybean genomics on which genes are responsible for nitrogen assimilation and uptake. Within the localities where we saw yield advantages to ESN application and negative yield gains, differential gene expression and manipulation needs to be performed.

In other sections of the treatment strip, we saw only incremental gains, if any advantage at all. The rationale for the minimal yield advantage (or disadvantage) may be related to untimely application of nitrogen to *Rhizobia* termination of nitrogen fixation and subsequent senescence. Since growing conditions were dry following ESN application, subsoil moisture may have been limited in various site locations, comprising the extent to which urea hydrolysis would occur. It can be assumed, as a corollary, that less nitrogen was available for plant uptake based upon landscape position (summit). Soybean planting and (as a result) growth stage varied across the state in 2014 as a result of a later and wetter spring than what southeast South Dakota producers are accustomed to. Urea held in an encapsulated nitrogen form requires time for the polymer-coating to be broken down and for hydrolysis to take place. If yield advantages were to occur on what was believed to be the optimal growth stage to apply nitrogen fertilizer to soybeans, the availability of nitrogen to the crop must have been made available soon following application and not later than expected. A wide range of growth stage or days following germination have been reported, as well as determining *Rhizobia* senescence or final nitrogen fixation period.

Correlation Analysis

For fields where whole strip soybean yield data was provided, we wished to assess how average yield in areas across the strips related to yield differences generated from Surfer 11.0 (Golden Company, Golden, CO). If soybean yield potential was low, it was reasoned that ESN application may result in incremental yield advantages. Likewise, if soybean grain yields were already high, ESN application may not have resulted in yield advantages across the treatment strip. Correlation between average yield from the O lbs N/acre strip and the 150 lbs N/acre strip were averaged and related to the strip yield differences to understand if yield environment played a role in ESN yield increases. Results are displayed in Figures 4.2-4.4.

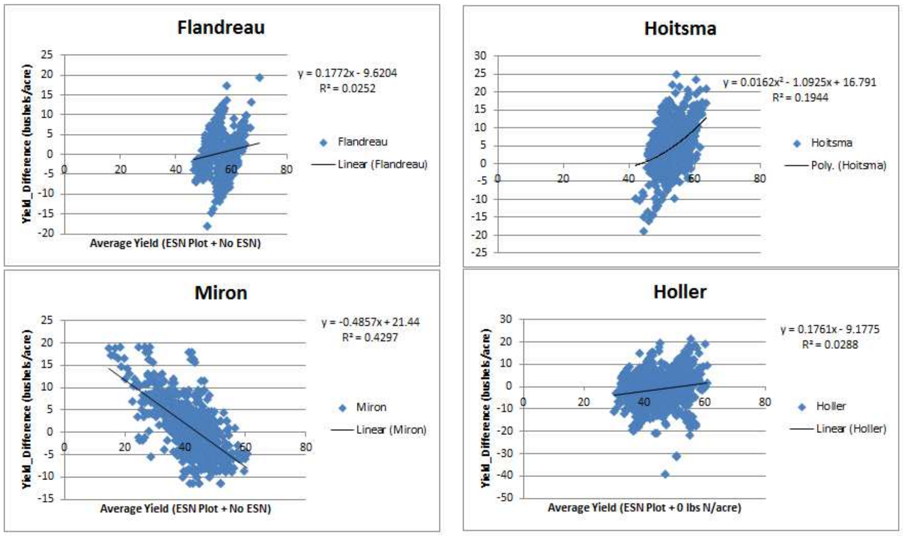


Figure 4.2. Average Yield (ESN + No ESN) (bushels/acre) across treatment strips reflected across yield differences (bushels/acre) recorded between soybean yield monitor data and residual yield data generated from Surfer 11.0. Positive yield differences indicate an ESN-associated yield advantage across treatment strip; negative differences indicate a yield deterrent from ESN application.

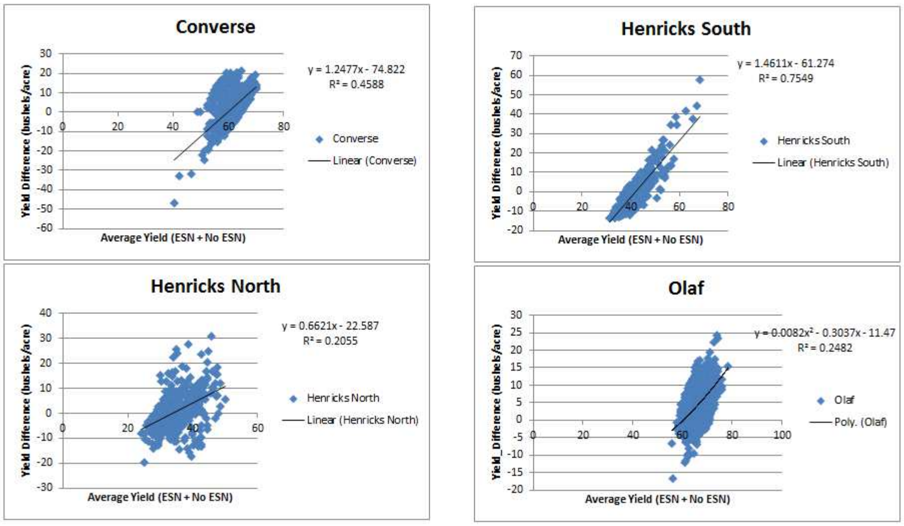


Figure 4.3. Average Yield (ESN + No ESN) (bushels/acre) across treatment strips reflected across yield differences (bushels/acre) recorded between soybean yield monitor data and residual yield data generated from Surfer 11.0. Positive yield differences indicate an ESN-associated yield advantage across treatment strip; negative differences indicate a yield deterrent from ESN application.

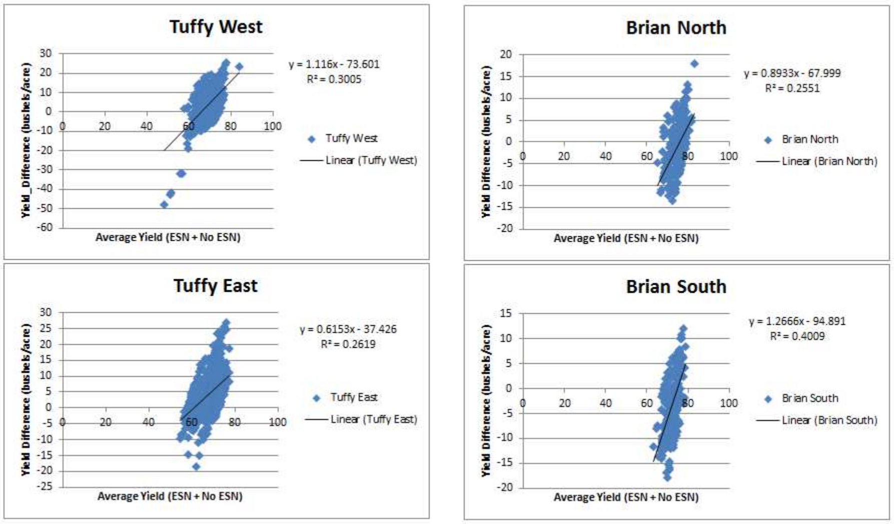


Figure 4.4. Average Yield (ESN + No ESN) (bushels/acre) across treatment strips reflected across yield differences (bushels/acre) recorded between soybean yield monitor data and residual yield data generated from Surfer 11.0. Positive yield differences

indicate an ESN-associated yield advantage across treatment strip; negative differences indicate a yield deterrent from ESN application.

A total of twelve fields were identified for correlation analysis. In 11 of the 12 fields, an increase in average yield between treatment strip (ESN) and untreated strip (No ESN) resulted in yield advantages associated from ESN application. In higher yielding areas across the strip, not only were incremental yields attained, but substantial increases (>10 bushels/acre) occurred. Along the treatment strip, where the yields were the highest, the greatest yield advantage from ESN application occurred. It can be argued that ESN applications may be beneficial in high-yielding environments versus lower or stressed environments. Conversely, in the lower yielding areas of the ESN treatment strip, ESN-associated yield decreases did occur, sometimes on the magnitude of 10-20 bushels per acre. We attempted to decipher why in fact these yield increases or decreases occurred, reasoning that they may be related to topographical position across the strip, or if an additional nitrogen supply in a high yielding environment played a role in increasing yields.

Economics to Consider

Producers need to carefully weigh income and expenses when considering ESN fertilization on soybeans, especially in the face of difficult financial circumstances. If the cost per pound of nitrogen is $0.50, applying 75 lbs N acre in the ESN form in the 46-0-0 (N-P-K) form will require $35 per acre. Application costs can vary based upon machinery and labor manpower, and it can be argued that capital costs of owning a spreader will need to be ascertained. A producer can decide to have a fertilizer retailer apply the product. Typically, costs of application can range from $4-7 per acre. It is reasonable to assume a cooperator may have $40-45 per acre invested in ESN fertilization on soybeans if application rates followed what we used in our study. If a producer owns a spinning spreader, capital and depreciation needs to be configured.

Incomes must be carefully calculated to estimate expected returns to ESN fertilization. A composite average of 1-2 bushels per acre advantage to ESN fertilization at a cash market price of $9 per bushel would return $9-18 to the producer. Under these circumstances, it would be unprofitable to apply ESN on soybeans and would not be a recommended best management practice. Since we observed a magnitude of spatial variability with ESN yield response, in some portions of the treatment strip where we observed 10-20 bushel increase linked to ESN fertilization (toeslope/backslope and depressional areas), a grower would reap a benefit of $90-180 per acre in these topographical areas (Figures 4.2-4.4). As the correlation analysis indicated, economic benefits may occur in higher yielding situations. Likewise, in some flat, level terrain areas of the treatment strips, we also encountered yield reductions to the ESN fertilization.

Future Work

Researchers need to continue to analyze under what topographical and geographical areas producers can expect to see advantages to ESN fertilization since we saw spatial variability in yield responses. Focus should also be paid on determining why we received yield reductions, incremental yield gains, or substantial yield increases tied to ESN fertilization. We hypothesized to what we consider to be the underlying causes to these yield responses. Figuring out the *Rhizobia* nitrogen fixation process and what soil environmental conditions influence the fixation period (when infection initiates, how conditions affect rates of nitrogen fixation, and specifying when *Rhizobia* terminate fixation) needs to continue. Under landscape positions where yield gains took place, work should be devoted as a rate-study project to determine optimum rates of nitrogen fertilization since our work was confined as a pilot program with a universal rate for ESN fertilization that did not change across site locations. It appears that this management practice is only cost effective at specific sites in the fields. Understanding how soybean genomics that may have resulted in yield gains needs to be better understood.

Yield responses to nitrogen fertilization can vary based upon soil organic matter and nitrate-N levels. In this first year, we did not quantify either. It will be helpful going forward to illustrate that since such correlations have been hypothesized in the literature.

CONCLUSION

Our work with supplementing soybeans with nitrogen fertilization in the ESN form provided interesting yield results. We observed only incremental gains across a composite strip, but discovered substantial gains across varying landscape positions on half mile strips in South Dakota, USA. Going forward, we need to study the interactions between yield advantages and topographical location and explain under what conditions soybeans can be adequately fertilized with nitrogen so as to increase yields towards the heralded 100-bushel landmark towards the middle portions of the 21st century.

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Appendix A

CHAPTER 1

EFFECTS OF CORN (Zea Mays L.) STOVER REMOVAL ON SOIL TEST K LEVELS IN CONTINUOUS CORN UNDER VARYING MANAGEMENT PRACTICES

INTRODUCTION

SAS Code

Code used for assessing soil test values found below in Appendix A.1.

```
data test;
input Plot Block Tr08$      Tr12$  water$ nrate$  till$    res$ ppm08 ppm12 kbal;
cards;

102  1   NT    NTR  DRY  0n   notill  remove313   320   7
102  1   NT    NTR  DRY  0n   notill  remove280   314   34
401  2   NT    NTR  DRY  0n   notill  remove418   324   -94
401  2   NT    NTR  DRY  0n   notill  remove316   375   59
503  3   NT    NTR  DRY  0n   notill  remove349   279   -70
503  3   NT    NTR  DRY  0n   notill  remove343   304   -39
802  4   NT    NTR  DRY  0n   notill  remove287   305   18
802  4   NT    NTR  DRY  0n   notill  remove275   323   48
102  1   NTM   NTM  DRY  0n   notill  retain  313   298   -15
102  1   NTM   NTM  DRY  0n   notill  retain  280   313   33
401  2   NTM   NTM  DRY  0n   notill  retain  316   246   -70
401  2   NTM   NTM  DRY  0n   notill  retain  418   349   -69
503  3   NTM   NTM  DRY  0n   notill  retain  343   277   -66
503  3   NTM   NTM  DRY  0n   notill  retain  349   349   0
802  4   NTM   NTM  DRY  0n   notill  retain  287   309   22
802  4   NTM   NTM  DRY  0n   notill  retain  275   397   123
102  1   REM   R    DRY  0n   till    remove325   257   -68
102  1   REM   R    DRY  0n   till    remove247   339   92
401  2   REM   R    DRY  0n   till    remove297   337   40
401  2   REM   R    DRY  0n   till    remove305   404   99
503  3   REM   R    DRY  0n   till    remove286   320   34
503  3   REM   R    DRY  0n   till    remove308   349   41
802  4   REM   R    DRY  0n   till    remove432   303   -129
802  4   REM   R    DRY  0n   till    remove254   362   108
102  1   MAIN  M    DRY  0n   till    retain  355   308   -46
```

102	1	MAIN	M	DRY	0n	till	retain	242	305	63
401	2	MAIN	M	DRY	0n	till	retain	267	131	-136
401	2	MAIN	M	DRY	0n	till	retain	367	351	-16
503	3	MAIN	M	DRY	0n	till	retain	374	310	-64
503	3	MAIN	M	DRY	0n	till	retain	331	351	20
802	4	MAIN	M	DRY	0n	till	retain	408	319	-89
802	4	MAIN	M	DRY	0n	till	retain	186	291	105
202	1	NT	NTR	WET	0n	notill	remove	365	274	-91
202	1	NT	NTR	WET	0n	notill	remove	287	319	32
301	2	NT	NTR	WET	0n	notill	remove	337	316	-20
301	2	NT	NTR	WET	0n	notill	remove	272	311	40
603	3	NT	NTR	WET	0n	notill	remove	396	327	-70
603	3	NT	NTR	WET	0n	notill	remove	357	385	28
702	4	NT	NTR	WET	0n	notill	remove	378	336	-41
702	4	NT	NTR	WET	0n	notill	remove	295	307	12
202	1	NTM	NTM	WET	0n	notill	retain	365	262	-103
202	1	NTM	NTM	WET	0n	notill	retain	287	316	29
301	2	NTM	NTM	WET	0n	notill	retain	337	257	-80
301	2	NTM	NTM	WET	0n	notill	retain	272	288	16
603	3	NTM	NTM	WET	0n	notill	retain	396	268	-129
603	3	NTM	NTM	WET	0n	notill	retain	357	324	-32
702	4	NTM	NTM	WET	0n	notill	retain	378	254	-124
702	4	NTM	NTM	WET	0n	notill	retain	295	270	-25
202	1	REM	R	WET	0n	till	remove	245	190	-55
202	1	REM	R	WET	0n	till	remove	289	362	73
301	2	REM	R	WET	0n	till	remove	306	304	-2
301	2	REM	R	WET	0n	till	remove	163	277	114
603	3	REM	R	WET	0n	till	remove	409	399	-10
603	3	REM	R	WET	0n	till	remove	323	444	121
702	4	REM	R	WET	0n	till	remove	320	287	-33
702	4	REM	R	WET	0n	till	remove	312	312	0
202	1	MAIN	M	WET	0n	till	retain	247	303	57
202	1	MAIN	M	WET	0n	till	retain	209	315	106
301	2	MAIN	M	WET	0n	till	retain	283	254	-29
301	2	MAIN	M	WET	0n	till	retain	318	391	73
603	3	MAIN	M	WET	0n	till	retain	389	322	-67
603	3	MAIN	M	WET	0n	till	retain	389	331	-58
702	4	MAIN	M	WET	0n	till	retain	427	331	-96
702	4	MAIN	M	WET	0n	till	retain	274	369	94
101	1	NT	NTR	DRY	150n	notill	remove	269	179	-90
101	1	NT	NTR	DRY	150n	notill	remove	199	289	90
403	2	NT	NTR	DRY	150n	notill	remove	346	266	-80
403	2	NT	NTR	DRY	150n	notill	remove	324	261	-63
502	3	NT	NTR	DRY	150n	notill	remove	320	185	-135
502	3	NT	NTR	DRY	150n	notill	remove	324	321	-3
801	4	NT	NTR	DRY	150n	notill	remove	335	187	-148

801	4	NT	NTR	DRY	150n	notill	remove	308	244	-64
101	1	NTM	NTM	DRY	150n	notill	retain	177	293	116
101	1	NTM	NTM	DRY	150n	notill	retain	199	329	130
403	2	NTM	NTM	DRY	150n	notill	retain	193	223	30
403	2	NTM	NTM	DRY	150n	notill	retain	324	261	.
503	3	NTM	NTM	DRY	150n	notill	retain	324	309	-15
503	3	NTM	NTM	DRY	150n	notill	retain	118	198	80
801	4	NTM	NTM	DRY	150n	notill	retain	308	293	-15
801	4	NTM	NTM	DRY	150n	notill	retain	262	252	-10
101	1	REM	R	DRY	150n	till	remove	304	192	-112
101	1	REM	R	DRY	150n	till	remove	287	340	53
403	2	REM	R	DRY	150n	till	remove	344	330	-14
403	2	REM	R	DRY	150n	till	remove	172	356	184
502	3	REM	R	DRY	150n	till	remove	225	201	-24
502	3	REM	R	DRY	150n	till	remove	265	335	70
801	4	REM	R	DRY	150n	till	remove	343	372	29
801	4	REM	R	DRY	150n	till	remove	156	208	52
101	1	MAIN	M	DRY	150n	till	retain	319	319	0
101	1	MAIN	M	DRY	150n	till	retain	299	331	32
403	2	MAIN	M	DRY	150n	till	retain	358	251	-107
403	2	MAIN	M	DRY	150n	till	retain	231	301	71
502	3	MAIN	M	DRY	150n	till	retain	339	346	7
502	3	MAIN	M	DRY	150n	till	retain	346	363	17
801	4	MAIN	M	DRY	150n	till	retain	317	329	12
801	4	MAIN	M	DRY	150n	till	retain	258	341	83
201	1	NT	NTR	WET	150n	notill	remove	325	184	-141
201	1	NT	NTR	WET	150n	notill	remove	310	204	.
303	2	NT	NTR	WET	150n	notill	remove	332	197	-136
303	2	NT	NTR	WET	150n	notill	remove	347	292	-55
602	3	NT	NTR	WET	150n	notill	remove	360	313	-47
602	3	NT	NTR	WET	150n	notill	remove	343	333	-10
701	4	NT	NTR	WET	150n	notill	remove	348	251	-97
701	4	NT	NTR	WET	150n	notill	remove	324	382	58
201	1	NTM	NTM	WET	150n	notill	retain	325	165	-161
201	1	NTM	NTM	WET	150n	notill	retain	310	204	-105
303	2	NTM	NTM	WET	150n	notill	retain	332	342	9
303	2	NTM	NTM	WET	150n	notill	retain	347	392	45
602	3	NTM	NTM	WET	150n	notill	retain	360	249	-111
602	3	NTM	NTM	WET	150n	notill	retain	343	309	-34
701	4	NTM	NTM	WET	150n	notill	retain	348	332	-17
701	4	NTM	NTM	WET	150n	notill	retain	324	314	-10
201	1	R	R	WET	150n	till	remove	297	311	15
201	1	R	R	WET	150n	till	remove	.	178	.
303	2	R	R	WET	150n	till	remove	341	248	-93
303	2	R	R	WET	150n	till	remove	298	315	17
602	3	R	R	WET	150n	till	remove	361	303	-58

602	3	R	R	WET	150n	till	remove	363	309	-54
701	4	R	R	WET	150n	till	remove	192	191	-1
701	4	R	R	WET	150n	till	remove	298	359	62
201	1	MAIN	M	WET	150n	till	retain	301	302	1
201	1	MAIN	M	WET	150n	till	retain	.	193	.
303	2	MAIN	M	WET	150n	till	retain	290	293	2
303	2	MAIN	M	WET	150n	till	retain	187	338	152
602	3	MAIN	M	WET	150n	till	retain	346	391	45
602	3	MAIN	M	WET	150n	till	retain	232	374	142
701	4	MAIN	M	WET	150n	till	retain	337	329	-8
701	4	MAIN	M	WET	150n	till	retain	299	333	34
103	1	NT	NTR	DRY	75n	notill	remove	303	278	-25
103	1	NT	NTR	DRY	75n	notill	remove	386	364	-22
402	2	NT	NTR	DRY	75n	notill	remove	264	162	-101
402	2	NT	NTR	DRY	75n	notill	remove	292	251	-40
501	3	NT	NTR	DRY	75n	notill	remove	298	262	-37
501	3	NT	NTR	DRY	75n	notill	remove	240	344	104
803	4	NT	NTR	DRY	75n	notill	remove	306	277	-29
803	4	NT	NTR	DRY	75n	notill	remove	323	295	-28
103	1	NT	NTM	DRY	75n	notill	retain	386	382	-4
103	1	NT	NTM	DRY	75n	notill	retain	303	350	47
402	2	NT	NTM	DRY	75n	notill	retain	264	299	35
402	2	NT	NTM	DRY	75n	notill	retain	292	358	66
501	3	NT	NTM	DRY	75n	notill	retain	298	279	-19
501	3	NT	NTM	DRY	75n	notill	retain	240	256	16
803	4	NT	NTM	DRY	75n	notill	retain	323	280	-43
803	4	NT	NTM	DRY	75n	notill	retain	306	345	39
103	1	REM	R	DRY	75n	till	remove	250	253	3
103	1	REM	R	DRY	75n	till	remove	259	278	19
402	2	REM	R	DRY	75n	till	remove	254	180	-74
402	2	REM	R	DRY	75n	till	remove	272	261	-11
501	3	REM	R	DRY	75n	till	remove	238	225	-13
501	3	REM	R	DRY	75n	till	remove	212	337	126
803	4	REM	R	DRY	75n	till	remove	360	249	-112
803	4	REM	R	DRY	75n	till	remove	.	345	.
103	1	MAIN	M	DRY	75n	till	retain	292	284	-8
103	1	MAIN	M	DRY	75n	till	retain	269	362	93
402	2	MAIN	M	DRY	75n	till	retain	320	317	-3
402	2	MAIN	M	DRY	75n	till	retain	271	275	4
501	3	MAIN	M	DRY	75n	till	retain	236	254	18
501	3	MAIN	M	DRY	75n	till	retain	225	268	43
803	4	MAIN	M	DRY	75n	till	retain	275	232	-42
803	4	MAIN	M	DRY	75n	till	retain	185	238	54
203	1	NT	NTR	WET	75n	notill	remove	426	245	-181
203	1	NT	NTR	WET	75n	notill	remove	274	249	-24
302	2	NT	NTR	WET	75n	notill	remove	276	253	-23

```
302     2       NT      NTR     WET     75n     notill  remove256       246     -10
601     3       NT      NTR     WET     75n     notill  remove280       265     -15
601     3       NT      NTR     WET     75n     notill  remove329       325     -4
703     4       NT      NTR     WET     75n     notill  remove340       251     -89
703     4       NT      NTR     WET     75n     notill  remove273       268     -5
203     1       NTM     NTM     WET     75n     notill  retain  426     233     .
203     1       NTM     NTM     WET     75n     notill  retain  274     266     -8
302     2       NTM     NTM     WET     75n     notill  retain  256     248     -8
302     2       NTM     NTM     WET     75n     notill  retain  276     345     69
601     3       NTM     NTM     WET     75n     notill  retain  329     250     -79
601     3       NTM     NTM     WET     75n     notill  retain  280     257     -22
703     4       NTM     NTM     WET     75n     notill  retain  340     259     -81
703     4       NTM     NTM     WET     75n     notill  retain  273     272     -1
203     1       REM     R       WET     75n     till    remove300       255     -45
203     1       REM     R       WET     75n     till    remove.         309     .
302     2       REM     R       WET     75n     till    remove297       237     -60
302     2       REM     R       WET     75n     till    remove215       260     45
601     3       REM     R       WET     75n     till    remove255       295     40
601     3       REM     R       WET     75n     till    remove186       262     76
703     4       REM     R       WET     75n     till    remove360       316     -44
703     4       REM     R       WET     75n     till    remove212       238     26
203     1       M       M       WET     75n     till    retain  242     276     34
203     1       M       M       WET     75n     till    retain  245     328     83
302     2       MAIN M          WET     75n     till    retain  246     250     4
302     2       MAIN M          WET     75n     till    retain  264     364     100
601     3       MAIN M          WET     75n     till    retain  325     231     -94
601     3       MAIN M          WET     75n     till    retain  340     269     -71
703     4       MAIN M          WET     75n     till    retain  371     296     -75
703     4       MAIN M          WET     75n     till    retain  272     229     -43


run;*/quit;

proc glm data=test;
 title rate water till res (water main plot, nrate subplot, split plot) proc glm linear model;
class nrate water till res block;
model ppm12 = nrate water till res
                nrate*water nrate*till nrate*res
                water*till water*res
                till*res
                water*nrate*till
                water*nrate*till*res
                block block*water block*nrate block*till block*res
                block*water*nrate block*water*nrate*till;
random block block*water block*nrate block*till block*res block*water*nrate
block*water*nrate*till;
```

```
test h=water e=block*water;
test h=nrate e=block*nrate*water;
test h=nrate*water e=block*nrate*water;
test h=till  e=block*nrate*water*till;
test h=nrate*till e=block*nrate*water*till;
test h=water*till e=block*nrate*water*till;
test h=water*nrate*till e=block*nrate*water*till;
/*lsmeans nrate/ pdiff;
lsmeans water/pdiff; */
means nrate/lsd;
means nrate*res/lsd;
means water/lsd;
means water*res/lsd;
means till/lsd;
means res/lsd;
means nrate*water/lsd;
means nrate*till/lsd;
means water*till/lsd;
means till*res/lsd;
means nrate*water*till/lsd;
run;
        quit;
```

SAS code used for assessing corn grain yields between years provided below in Appendix A.2.

```
data test;
input Plot Block Tr08$      Tr12$  water$ nrate$  till$    res$ ppm08 ppm12 kbal;
cards;

102   1     NTR   NTR   DRY   0n    notill  remove127.7  107.3  -20.4
401   2     NTR   NTR   DRY   0n    notill  remove97.1   73.5   -23.6
503   3     NTR   NTR   DRY   0n    notill  remove132.2  110.4  -21.9
802   4     NTR   NTR   DRY   0n    notill  remove94.7   88.3   -6.4
102   1     NTR   NTM   DRY   0n    notill  retain  127.7  106.2  -21.5
401   2     NTR   NTM   DRY   0n    notill  retain  97.1   94.6   -2.6
503   3     NTR   NTM   DRY   0n    notill  retain  132.2  105.7  -26.5
802   4     NTR   NTM   DRY   0n    notill  retain  94.7   105.3  10.5
102   1     R     R     DRY   0n    tilled  remove135.8  104.4  -31.4
401   2     R     R     DRY   0n    tilled  remove102.6  93.7   -8.8
503   3     R     R     DRY   0n    tilled  remove156.4  100.2  -56.2
802   4     R     R     DRY   0n    tilled  remove101.0  99.9   -1.1
102   1     MAIN MAIN DRY   0n    tilled  retain  97.2   112.5  15.3
401   2     MAIN MAIN DRY   0n    tilled  retain  88.9   116.4  27.5
```

503	3	MAIN	MAIN	DRY	0n	tilled	retain	135.8	126.2	-9.6
802	4	MAIN	MAIN	DRY	0n	tilled	retain	104.8	111.2	6.3
202	1	NTR	NTR	WET	0n	notill	remove	150.0	145.8	-4.3
301	2	NTR	NTR	WET	0n	notill	remove	144.6	136.7	-7.8
603	3	NTR	NTR	WET	0n	notill	remove	161.3	139.3	-22.0
702	4	NTR	NTR	WET	0n	notill	remove	144.3	133.5	-10.8
202	1	NTR	NTM	WET	0n	notill	retain	150.0	137.4	-12.6
301	2	NTR	NTM	WET	0n	notill	retain	144.6	137.2	-7.4
603	3	NTR	NTM	WET	0n	notill	retain	161.3	141.4	-19.9
702	4	NTR	NTM	WET	0n	notill	retain	144.3	144.7	0.4
202	1	R	R	WET	0n	tilled	remove	173.1	132.6	-40.5
301	2	R	R	WET	0n	tilled	remove	166.1	145.4	-20.7
603	3	R	R	WET	0n	tilled	remove	152.0	115.0	-37.0
702	4	R	R	WET	0n	tilled	remove	161.0	118.1	-42.9
202	1	MAIN	MAIN	WET	0n	tilled	retain	170.3	159.5	-10.8
301	2	MAIN	MAIN	WET	0n	tilled	retain	103.1	116.8	13.7
603	3	MAIN	MAIN	WET	0n	tilled	retain	142.1	139.3	-2.9
702	4	MAIN	MAIN	WET	0n	tilled	retain	134.4	145.7	11.3
101	1	NTR	NTR	DRY	150n	notill	remove	19.1	140.5	121.5
403	2	NTR	NTR	DRY	150n	notill	remove	187.0	184.0	-3.0
502	3	NTR	NTR	DRY	150n	notill	remove	183.2	147.7	-35.5
801	4	NTR	NTR	DRY	150n	notill	remove	166.7	149.6	-17.1
101	1	NTR	NTM	DRY	150n	notill	retain	19.1	134.9	115.8
403	2	NTR	NTM	DRY	150n	notill	retain	187.0	159.4	-27.6
502	3	NTR	NTM	DRY	150n	notill	retain	183.2	138.2	-44.9
801	4	NTR	NTM	DRY	150n	notill	retain	166.7	159.6	-7.1
101	1	R	R	DRY	150n	tilled	remove	173.4	120.4	-53.0
403	2	R	R	DRY	150n	tilled	remove	174.4	180.7	6.3
502	3	R	R	DRY	150n	tilled	remove	213.0	151.5	-61.5
801	4	R	R	DRY	150n	tilled	remove	179.2	154.3	-24.9
101	1	MAIN	MAIN	DRY	150n	tilled	retain	165.2	169.5	4.2
403	2	MAIN	MAIN	DRY	150n	tilled	retain	184.3	162.9	-21.3
502	3	MAIN	MAIN	DRY	150n	tilled	retain	181.8	161.5	-20.3
801	4	MAIN	MAIN	DRY	150n	tilled	retain	182.7	157.5	-25.2
201	1	NTR	NTR	WET	150n	notill	remove	227.1	159.6	-67.5
303	2	NTR	NTR	WET	150n	notill	remove	236.5	195.3	-41.3
602	3	NTR	NTR	WET	150n	notill	remove	219.7	190.4	-29.3
701	4	NTR	NTR	WET	150n	notill	remove	235.2	161.6	-73.7
201	1	NTR	NTM	WET	150n	notill	retain	227.1	171.0	-56.0
303	2	NTR	NTM	WET	150n	notill	retain	236.5	178.6	-57.9
602	3	NTR	NTM	WET	150n	notill	retain	219.7	194.4	-25.3
701	4	NTR	NTM	WET	150n	notill	retain	235.2	173.1	-62.1
201	1	R	R	WET	150n	tilled	remove	249.6	146.3	-103.3
303	2	R	R	WET	150n	tilled	remove	229.4	168.0	-61.4
602	3	R	R	WET	150n	tilled	remove	223.0	150.8	-72.2
701	4	R	R	WET	150n	tilled	remove	205.6	149.4	-56.2

```
201     1       MAIN MAIN WET   150n    tilled  retain   202.3  179.9  -22.3
303     2       MAIN MAIN WET   150n    tilled  retain   200.1  181.5  -18.6
602     3       MAIN MAIN WET   150n    tilled  retain   227.2  177.2  -50.0
701     4       MAIN MAIN WET   150n    tilled  retain   222.5  186.4  -36.0
103     1       NTR  NTR  DRY   75n     notill  remove190.6  148.2  -42.4
402     2       NTR  NTR  DRY   75n     notill  remove136.9  129.7  -7.2
501     3       NTR  NTR  DRY   75n     notill  remove143.8  131.7  -12.1
803     4       NTR  NTR  DRY   75n     notill  remove160.6  141.5  -19.1
103     1       NTR  NTM  DRY   75n     notill  retain   190.6  148.6  -42.0
402     2       NTR  NTM  DRY   75n     notill  retain   136.9  162.8  25.9
501     3       NTR  NTM  DRY   75n     notill  retain   143.8  140.5  -3.3
803     4       NTR  NTM  DRY   75n     notill  retain   160.6  141.6  -18.9
103     1       R    R    DRY   75n     tilled  remove186.3  144.3  -42.0
402     2       R    R    DRY   75n     tilled  remove161.2  146.4  -14.9
501     3       R    R    DRY   75n     tilled  remove164.1  144.4  -19.7
803     4       R    R    DRY   75n     tilled  remove179.3  127.1  -52.2
103     1       MAIN MAIN DRY   75n     tilled  retain   167.8  111.5  -56.4
402     2       MAIN MAIN DRY   75n     tilled  retain   170.7  152.9  -17.8
501     3       MAIN MAIN DRY   75n     tilled  retain   169.8  124.3  -45.5
803     4       MAIN MAIN DRY   75n     tilled  retain   166.5  137.3  -29.2
203     1       NTR  NTR  WET   75n     notill  remove222.2  195.5  -26.7
302     2       NTR  NTR  WET   75n     notill  remove197.4  160.8  -36.6
601     3       NTR  NTR  WET   75n     notill  remove203.9  160.1  -43.8
703     4       NTR  NTR  WET   75n     notill  remove209.1  191.9  -17.2
203     1       NTR  NTM  WET   75n     notill  retain   222.2  179.4  -42.8
302     2       NTR  NTM  WET   75n     notill  retain   197.4  155.1  -42.4
601     3       NTR  NTM  WET   75n     notill  retain   203.9  201.7  -2.2
703     4       NTR  NTM  WET   75n     notill  retain   209.1  184.1  -24.9
203     1       R    R    WET   75n     tilled  remove202.0  150.7  -51.2
302     2       R    R    WET   75n     tilled  remove214.3  155.1  -59.3
601     3       R    R    WET   75n     tilled  remove214.1  142.7  -71.3
703     4       R    R    WET   75n     tilled  remove228.4  163.5  -64.9
203     1       MAIN MAIN WET   75n     tilled  retain   201.4  171.0  -30.5
302     2       MAIN MAIN WET   75n     tilled  retain   219.3  165.6  -53.7
601     3       MAIN MAIN WET   75n     tilled  retain   189.5  177.6  -11.9
703     4       MAIN MAIN WET   75n     tilled  retain   220.6  182.1  -38.5


run;*/
;
run ;

proc glm data=test;
 title rate water till res (watere main plot, nrate subplot, split plot) proc glm linear model;
class nrate water till res block;
```

```
model ppm12 = nrate water till res
                  nrate*water nrate*till nrate*res
                  water*till water*res
                  till*res
                  water*nrate*till
                  water*nrate*till*res
                  block block*water block*nrate block*till block*res
                  block*water*nrate block*water*nrate*till;
random block block*water block*nrate block*till block*res block*water*nrate
block*water*nrate*till;
test h=water e=block*water;
test h=nrate e=block*nrate*water;
test h=nrate*water e=block*nrate*water;
test h=till  e=block*nrate*water*till;
test h=nrate*till e=block*nrate*water*till;
test h=water*till e=block*nrate*water*till;
test h=water*nrate*till e=block*nrate*water*till;
/*lsmeans nrate/ pdiff;
lsmeans water/pdiff; */
means nrate/lsd;
means nrate*res/lsd;
means water/lsd;
means water*res/lsd;
means till/lsd;
means res/lsd;
means nrate*water/lsd;
means nrate*till/lsd;
means water*till/lsd;
means till*res/lsd;
means nrate*water*till/lsd;
run;
```

Appendix B

CHAPTER 2

SOYBEAN Glycine max(L) Merrill) YIELD RESPONSE WITH K^+ FERTILIZATION FOLLOWING CONSECUTIVE YEARS OF CORN (Zea mays L.) STOVER REMOVAL IN SOUTH DAKOTA, USA

Introduction

Meteorological Data

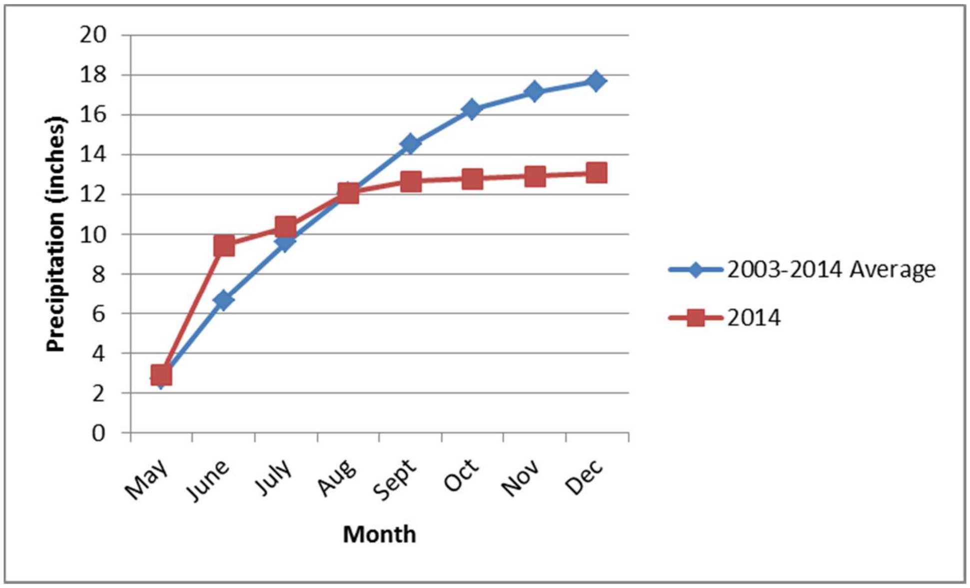


Figure B.1. 11-year average and 2014 growing season precipitation (inches) at Eggleston, Hand County, and Beadle County sites.

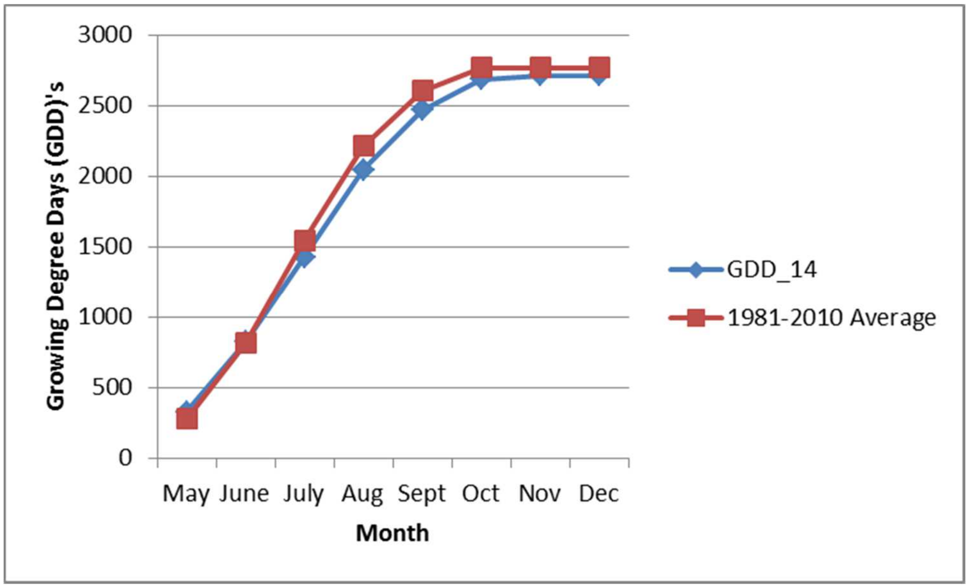


Figure B.2. 11-year average and 2014 growing degree day accumulations (GDD)(degrees C) at Eggleston, Hand County, and Beadle County sites.

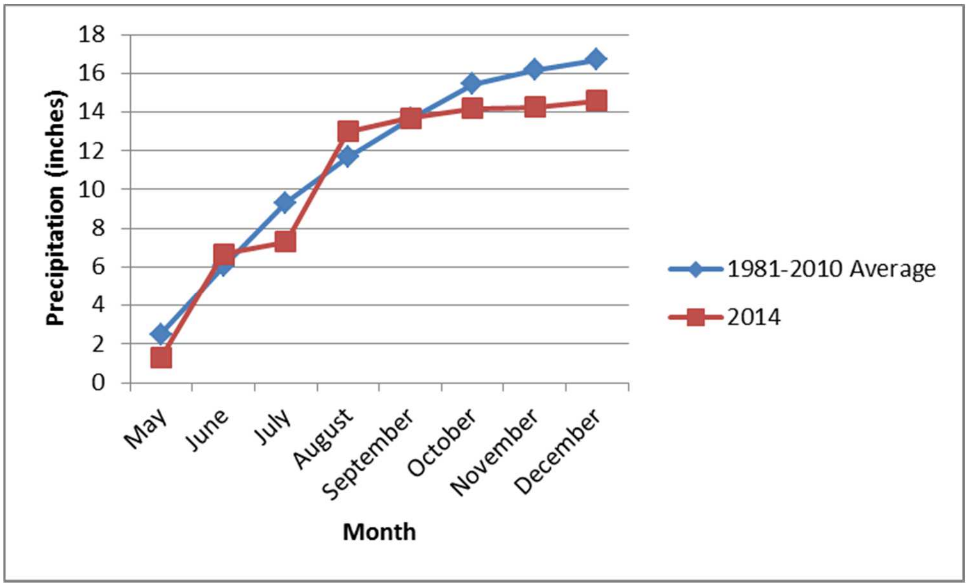


Figure B.3. 30-year average and 2014 growing season precipitation (inches) for Roscoe site.

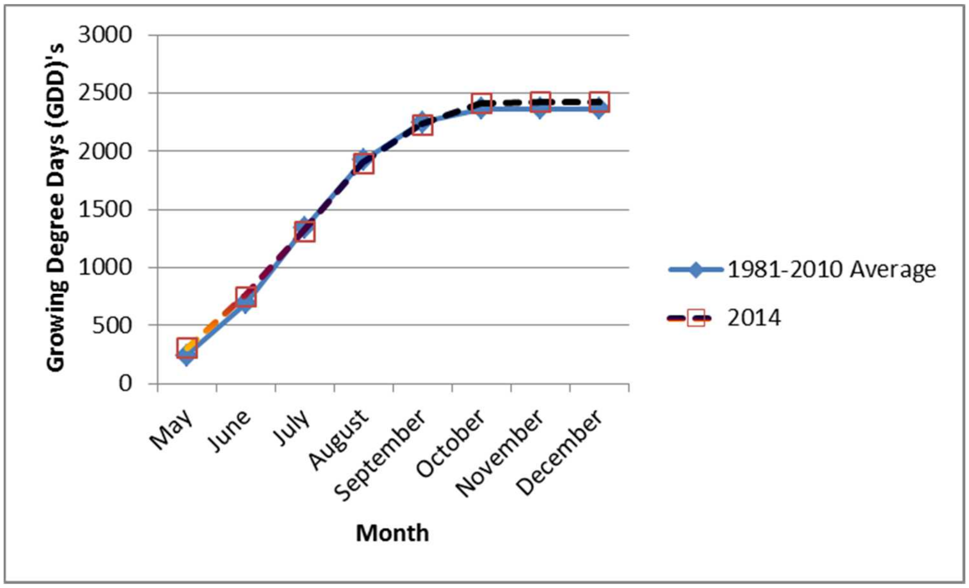


Figure B.4. 30-year average and 2014 growing degree day accumulations (GDD)(degrees C) at Roscoe site.

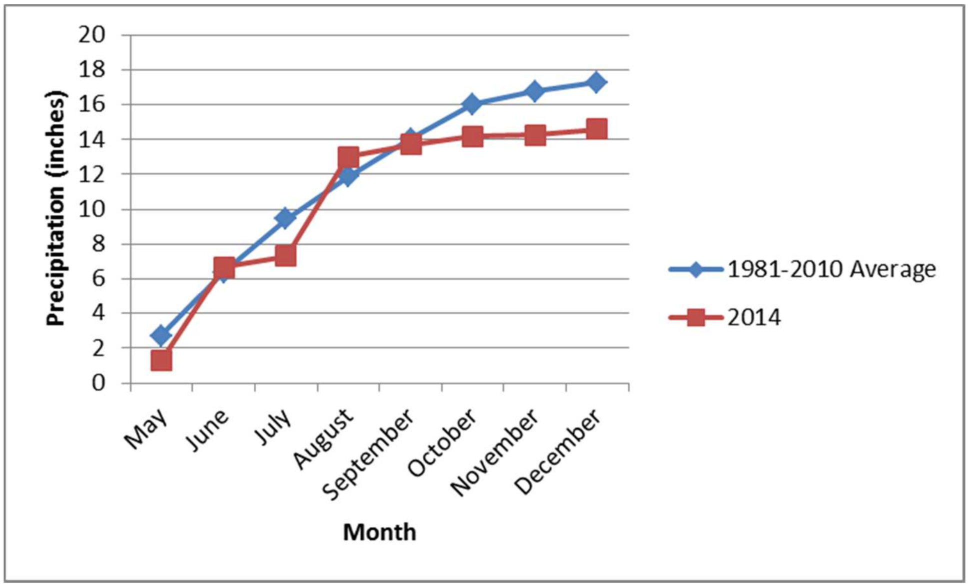


Figure B.5. 30-year average and 2014 growing season precipitation (inches) for Bath site.

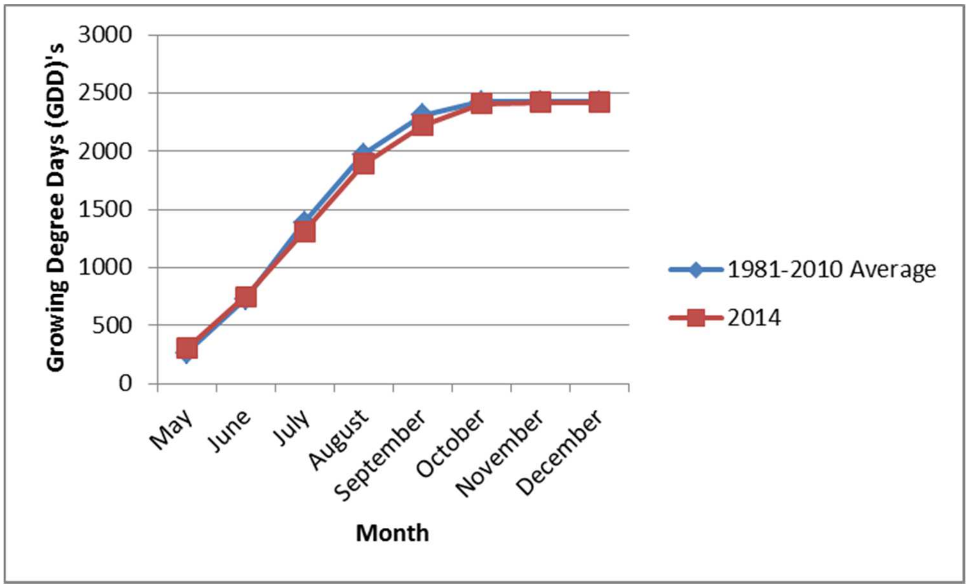


Figure B.6. 30-year average and 2014 growing degree day accumulations (GDD)(degrees C) at Bath site.

Due to their close proximity between site locations (within 20 miles of each field), a single precipitation and temperature chart was displayed for the ‘Eggleston,’ ‘Hand County,’ and ‘Beadle County’ farms. Early season precipitation was above the 11-year average for these sites with May 2014 rainfall as 0.16 inches above the average. Rainfall increased 6.54 inches in June 2014, which was 2.77 inches above the normal average. During the critical months for vegetative and reproductive growth, precipitation leveled off with the average, 0.04 inches above for August 2014. As harvest commenced, the region fell dramatically behind the 11-year average of 17.66 inches with only receiving a total of 13.06 inches of rainfall during the year (Figure B.3). A twelve year average was computed instead of a 30-year average for these locations since irregular and possible inaccurate data was presented from the nearest weather stations that computed 30-year averages for each location. Instead, data that was highly consistent with other locations and deemed reliable was found in a 12-year average. The Bath and Roscoe site locations received rainfall on par with the 30-year average, though conditions were drier during the June-early July months, but late season rainfalls during the reproductive stages of soybean development (Figure B.3 and B.5).

Growing degree days are calculated in soybean production to estimate plant growth stage. At the Hand, Beadle, and Eggleston locations, growing degree days consistently followed a similar trend toward the 30-year average for growing degree day accumulation (Figure 3.11). Sentiment that was used to compute the 12-year average as determined above was used again in a similar capacity. A similar trend was noted at the Bath and Roscoe locations (Figures 3.5 and 3.7). Since growing degree days are a function of high and low temperatures, it can be assumed that temperatures accurately reflected the 30-year average. While increases in temperature may signify higher rates of plant growth and development, a failure to accumulate rainfall will diminish plant productivity. When rainfall is too abundant, delayed soybean productivity can occur as a result of

Site Characteristics

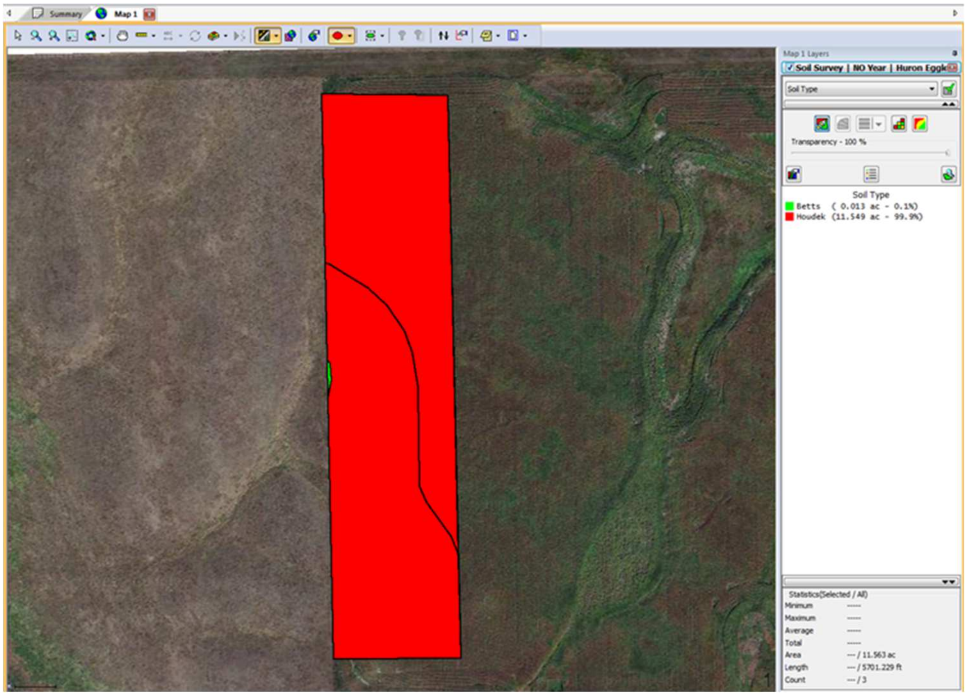
The first was located in Beadle County, South Dakota, near Eggleston, SD, called the ‘Eggleston’ farm. The field is located at 44.294807, -98.503139. The dominant soil types are Betts stony loam with 6-40% slope (0.01 acres), Houdek-Ethan loams with 6-9% slopes (6.062 acres), and Houdek-Prosper loams with 1-6% slopes (5.5 acres) (Figure 3.1). The crop productivity index ratings ranged from 55-84 for the plot area. The previous crop was corn and had an extensive history of corn stover of at least three consecutive years. The crop sown in 2014 was soybeans following the broadcast application of 250 lbs K/acre on May 1st. Soil sampling occurred on June 4, 2014 during the V1 (Hanway, 1963) growth stage (Figure 3.2). Crop harvest took place in early October 2014. Soil samples were taken every 100-feet outside of the plot following application where no K^+ drift had occurred in order to estimate approximate K^+ soil concentrations before application occurred. Laboratory analysis followed the ammonium acetate extraction method to estimate exchangeable K^+.

The second field analyzed was also in Beadle County, South Dakota, near Wosley, SD, named 'Beadle' farm. The field is located at 44.525778, -98.769420. The dominant soil types are Houdek loam with undulating slopes (1.3 acres), Houdek-Prosper loams with 0-2% slope (9.1 acres), and Tetonka silt loam (1.8 acres). Soil classification map is provided in Figure 3.4. The field has a crop productivity index of 57 to 88. The field had an extensive history of corn stover removal and the previous crop was corn. The crop sown in 2014 was soybeans following the broadcast application of 250 lbs K/acre on May 1st. Crop harvest took place in early October 2014. Soil sampling occurred on June 4, 2014 during the V1 (Hanway, 1963) growth stage. The field was left no-till. Initial soil samples were taken during the V2 growth stage to quantify early season soil test K values. Extraction followed similar protocols as with other fields. Results of the sampling are provided in Figure 3.5.

A third site location was in Hand County, SD, near Wosley, SD, named 'Hand' farm. The site is located at 44.631559, -98.155530. The dominant soil types were Carthage fine sandy loam with 0-2% slopes (1.8 acres), Carthage-Blendon fine sandy loams with 0-2% slopes (3.3 acres), Hand-Bonilla loams with 0-3% slopes (1.6 acres), and Hoven silt loam (0.7 acres) (Figure 3.7). Crop productivity index ratings ranged from

15 to 85. The field previously had corn sown, and an extensive history of stover removal had taken place. The crop sown in 2014 was soybeans following the broadcast application of 250 lbs K/acre on May 1st. Soil sampling occurred on June 4, 2014 during the V1 (Hanway, 1963) growth stage. Crop harvest took place in early October 2014. Initial spring soil samples were taken during the V2 (Hanway, 1973) growth stage along the parameter of the plot to quantify early season soil test K values.

A fourth field was located near Bath, South Dakota, in Brown County, named 'Bath' farm. The site location was 45.556258, -98.304250. The predominant soil type is a Great Bend-Beotia silt loam with 0 to 2 percent slope encompassing the entire plot area (Figure 3.9). The crop productivity index for the treatment area is 95. The field was no-tilled and had an extensive history of corn stover removal. Corn was the previous crop and soybeans were the main crop in 2014. The crop sown in 2014 was soybeans following the broadcast application of 250 lbs K/acre on May 1st. Crop harvest took place in early October 2014. Soil sampling occurred on June 4, 2014 during the V1 (Hanway, 1963) growth stage. Croplan 1400 soybeans were planted at 155,000 seeds/acre. Initial soil test K values were estimated by sampling outside of the plot area (Figure 3.10) and extracted through the ammonium acetate method. Results of soil sampling are shown in Figure 3.11. A fifth farm was conducted near Roscoe, South Dakota, in Edmunds County called the 'Roscoe' field. The field is located at 45.415, -99.6776 and has a crop productivity index that ranges from 47 to 83 across the treatment area. The dominant soil types are Lehr loam with 0-2% (1.31 acres), Lehr loam with 2-6 percent slopes (0.53 acres), Vida-Zahl loams with 6-9% slopes (0.27 acres), Williams-Bowbells loams with 3-6% slopes (1.80 acres). Asgrow (Monsanto Company, St. Louis, MO, USA) 1431 soybeans were planted at 180,000 seeds per acre following the broadcast application of 250 lbs K/acre on May 1st, 2014. Crop harvest took place in early October 2014. Soil sampling occurred on June 4, 2014 during the V1 (Hanway, 1963) growth stage (Figure 3.2).

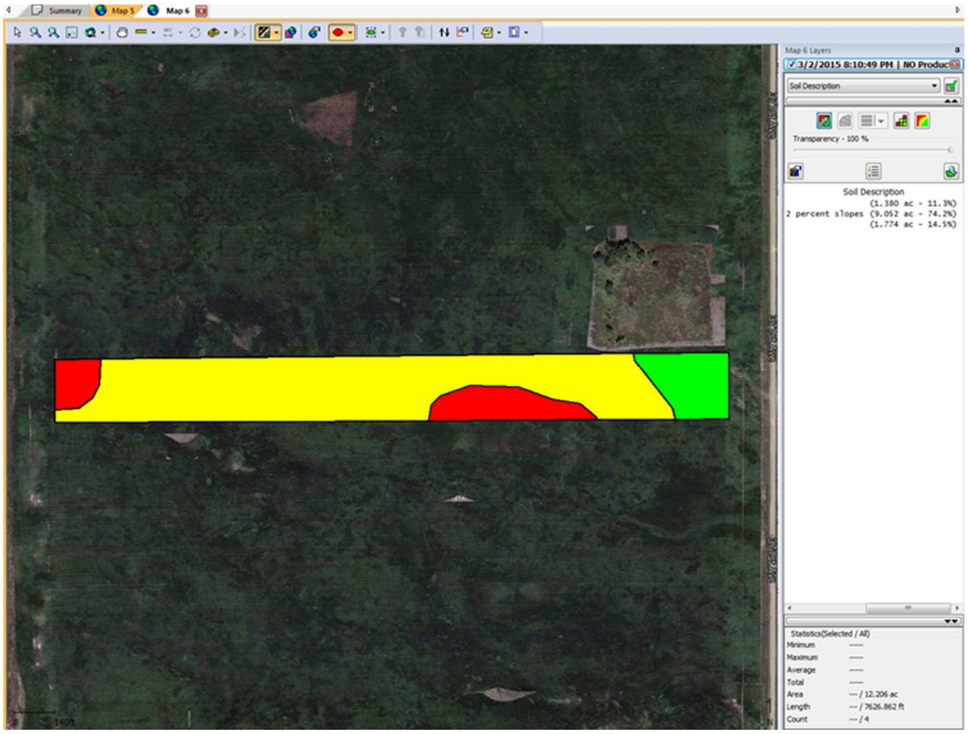


Soil Type

Soil Type
🟩 Betts (0.013 ac - 0.1%)
🟥 Houdek (11.549 ac - 99.9%)

Statistics(Selected / All)	
Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 11.563 ac
Length	--- / 5701.229 ft
Count	--- / 3

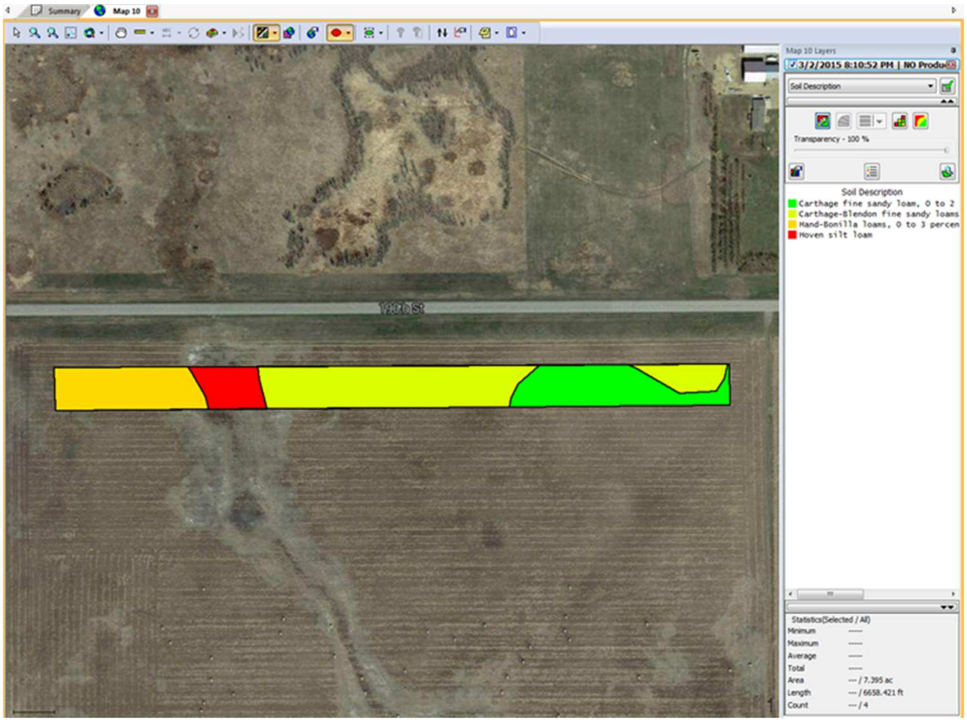
Figure B.8. Soil type and classification map derived from Web Soil Survey for ‘Eggleston’ farm



Soil Description
(1.380 ac - 11.3%)
2 percent slopes (9.052 ac - 74.2%)
(1.774 ac - 14.5%)

Statistics(Selected / All)
Minimum ------
Maximum ------
Average ------
Total ------
Area --- / 12.206 ac
Length --- / 7626.862 ft
Count --- / 4

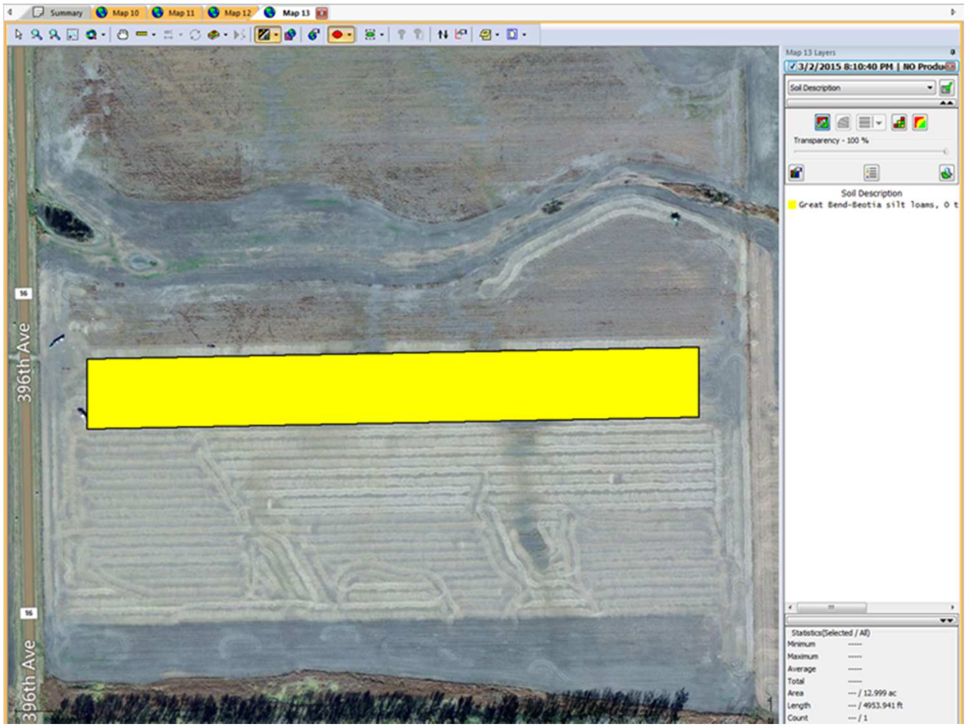
Figure B.9. Soil type and classification map derived from Web Soil Survey for ‘Hand’ farm



Soil Description
🟩 Carthage fine sandy loam, 0 to 2
🟨 Carthage-Blendon fine sandy loams
🟨 Hand-Bonilla loams, 0 to 3 percen
🟥 Hoven silt loam

Statistics(Selected / All)
Minimum ------
Maximum ------
Average ------
Total ------
Area --- / 7.395 ac
Length --- / 6658.421 ft
Count --- / 4

Figure B.10. Soil type and classification map derived from Web Soil Survey for ‘Beadle’ farm



✓ 3/2/2015 8:10:40 PM | NO Produ

Soil Description

Transparency - 100 %

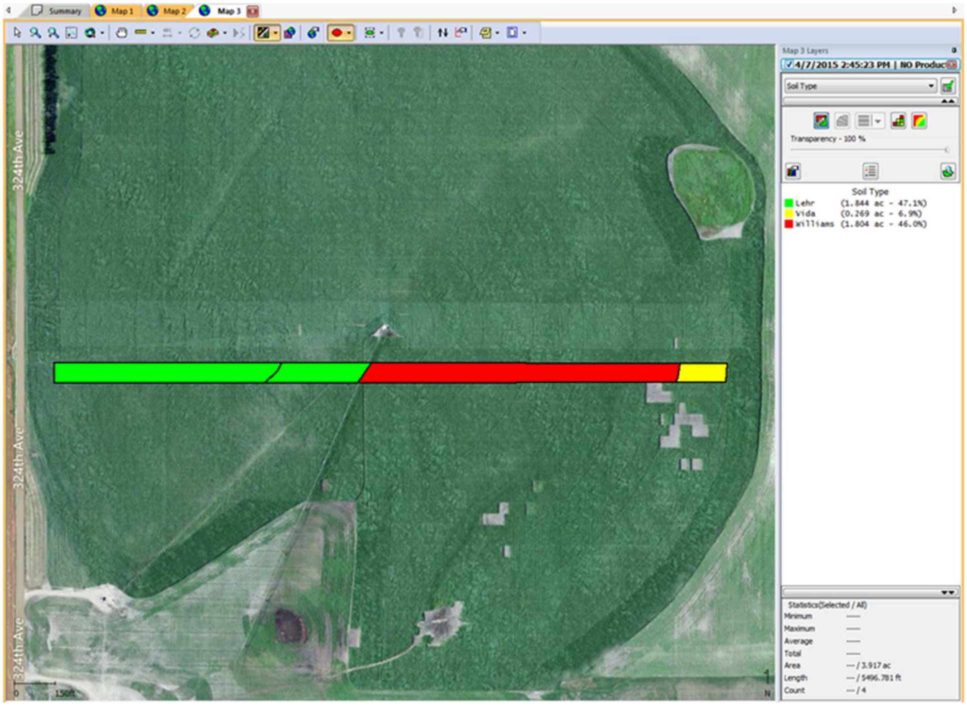
Soil Description

🟨 Great Bend-Beotia silt loams, 0 t

Statistics(Selected / All)

Minimum	------
Maximum	------
Average	------
Total	------
Area	--- / 12.999 ac
Length	--- / 4953.941 ft
Count	--- / 1

Figure B.11. Soil type and classification map derived from Web Soil Survey for ‘Bath’ farm.



Map 3 Layers

☑ 4/7/2015 2:45:23 PM | NO Produc

Soil Type

Transparency - 100 %

Soil Type

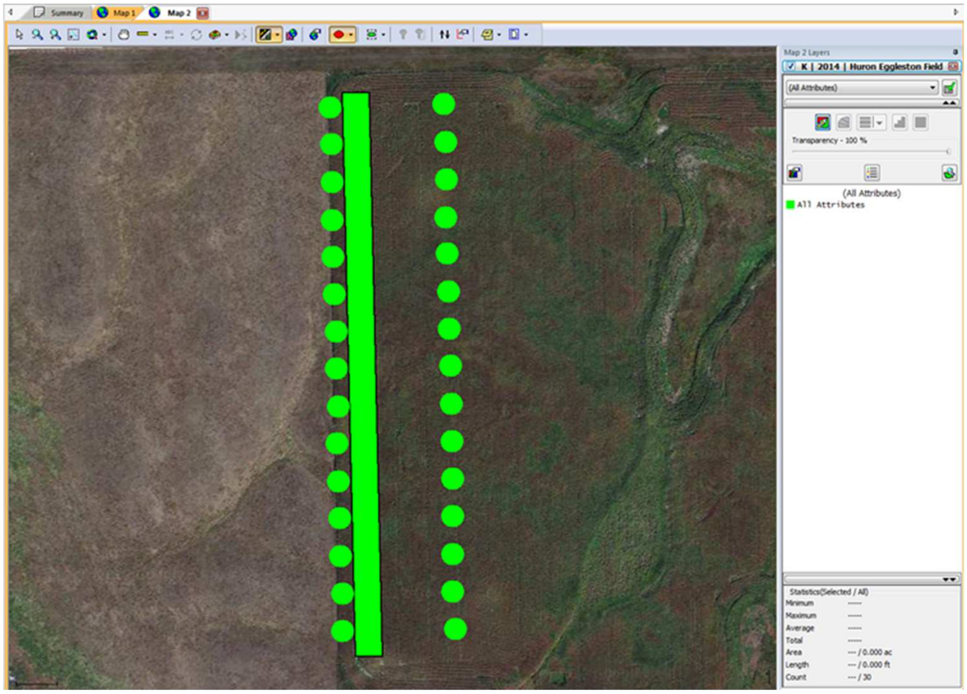
🟩	Lehr	(1.844 ac - 47.1%)
🟨	Vida	(0.269 ac - 6.9%)
🟥	Williams	(1.804 ac - 46.0%)

Statistics(Selected / All)

Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 3.917 ac
Length	--- / 5496.781 ft
Count	--- / 4

Figure B.12. Soil type and classification map derived from Web Soil Survey for 'Roscoe' farm

Early Season Soil Sampling Points



Map 2 Layers

☑ K | 2014 | Huron Eggleston Field

(All Attributes)

Transparency - 100 %

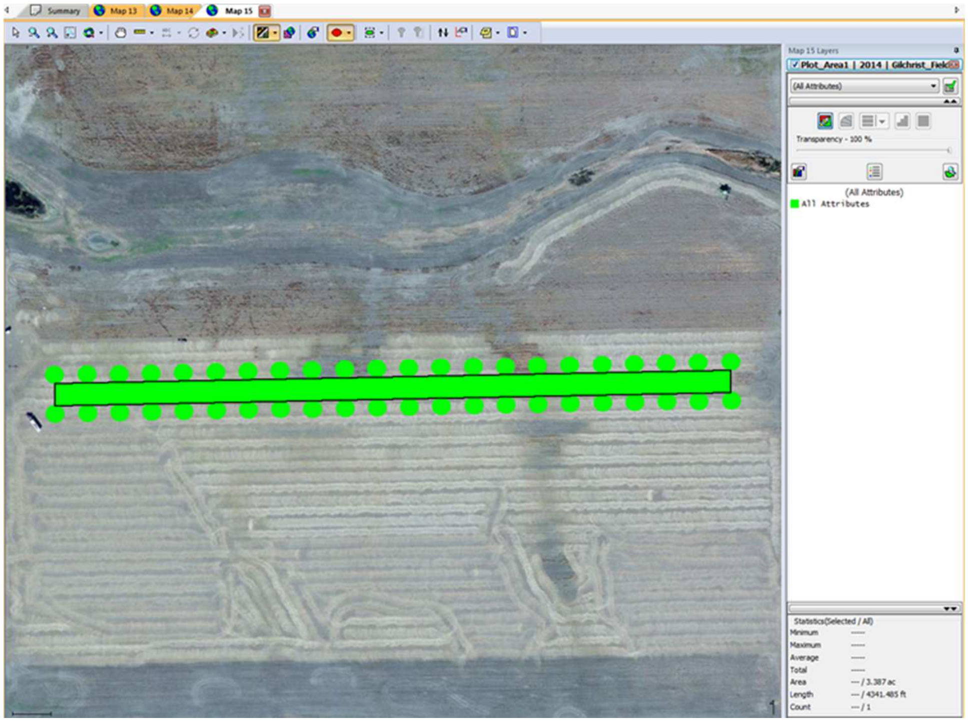
(All Attributes)

🟩 All Attributes

Statistics(Selected / All)

Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 0.000 ac
Length	--- / 0.000 ft
Count	--- / 30

Figure B.13. Map layout of “Eggleston’ farm depicting the plot area in green polygon with initial soil sampling points taken following emergence (June 4, 2014).



☑ Plot_Area1 | 2014 | Gilchrist_Fiel

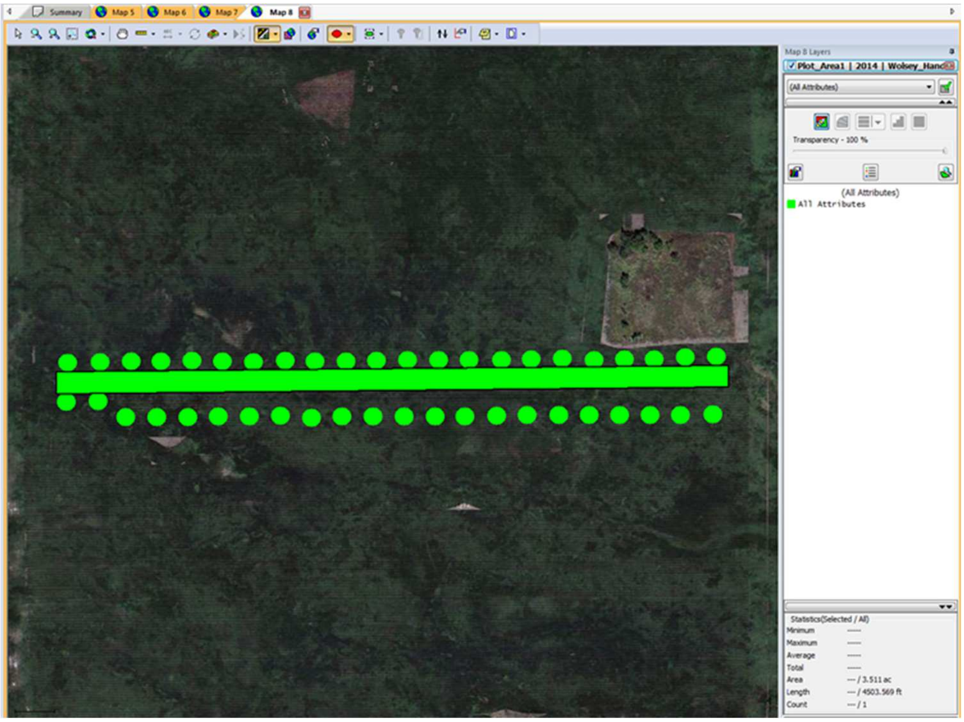
(All Attributes)

Transparency - 100 %

Statistics(Selected / All)

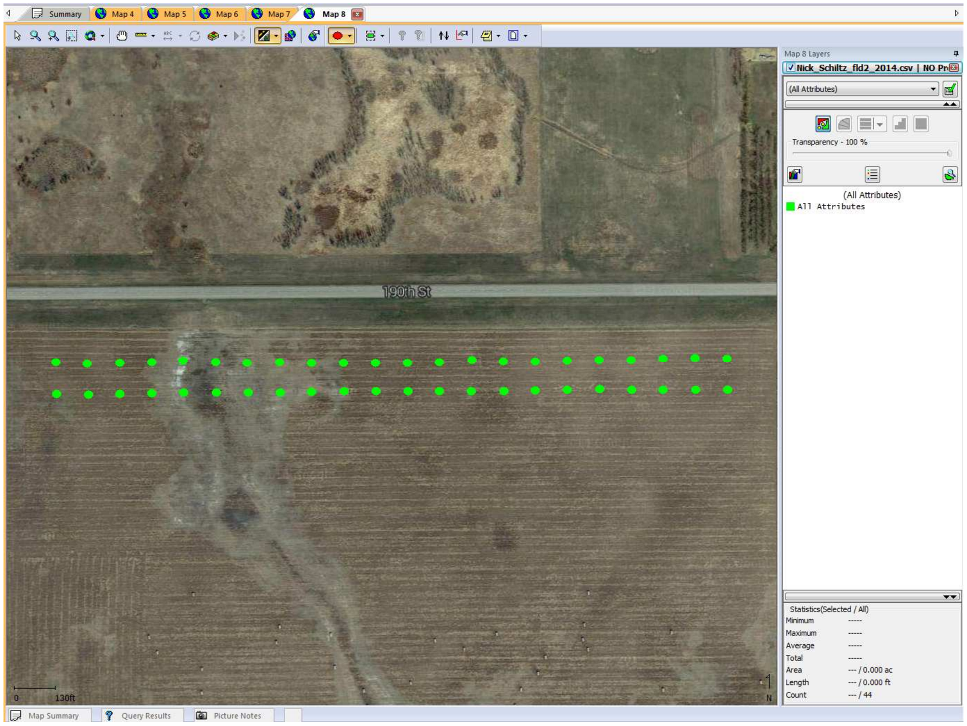
Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 3.387 ac
Length	--- / 4341.485 ft
Count	--- / 1

Figure B.14. Map layout of ‘Bath’ farm depicting the plot area in green polygon with initial soil sampling points taken following emergence (June 5, 2014).



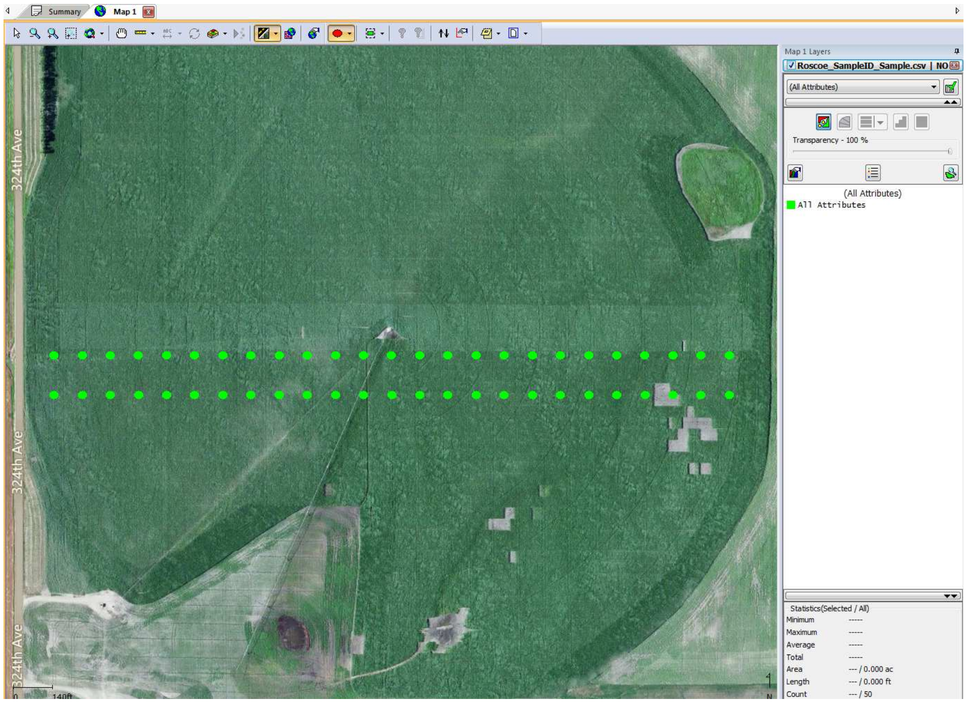
Statistics(Selected / All)
Minimum -----
Maximum -----
Average -----
Total -----
Area --- / 3.511 ac
Length --- / 4503.569 ft
Count --- / 1

Figure B.15. Map layout of ‘Hand’ farm depicting the plot area in green polygon with initial soil sampling points taken following emergence (June 4, 2014).



Statistics(Selected / All)
Minimum -----
Maximum -----
Average -----
Total -----
Area --- / 0.000 ac
Length --- / 0.000 ft
Count --- / 44

Figure B.16. Map layout of ‘Beadle’ farm with initial soil sampling points taken following emergence (June 4, 2014).



Roscoe_SampleID_Sample.csv | NO

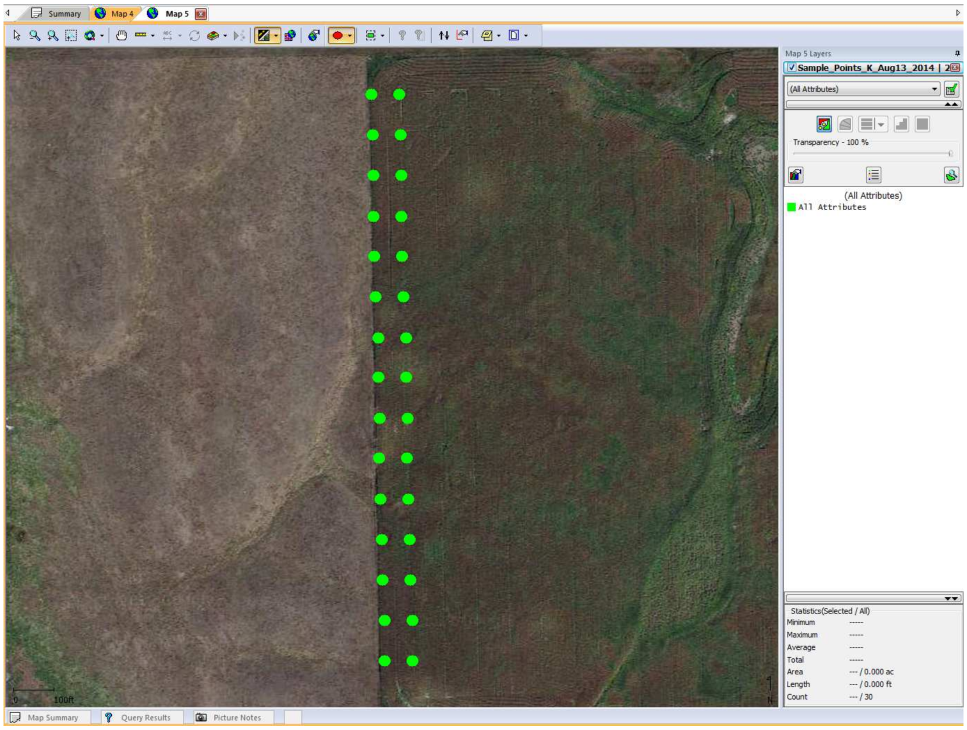
Transparency - 100 %

Statistics(Selected / All)

Minimum -----
Maximum -----
Average -----
Total -----
Area --- / 0.000 ac
Length --- / 0.000 ft
Count --- / 50

Figure B.17. Map layout of ‘Roscoe’ farm with initial soil sampling points taken following emergence (June 4, 2014).

Late Season Soil Sampling Points



☑ Sample_Points_K_Aug13_2014 | 2

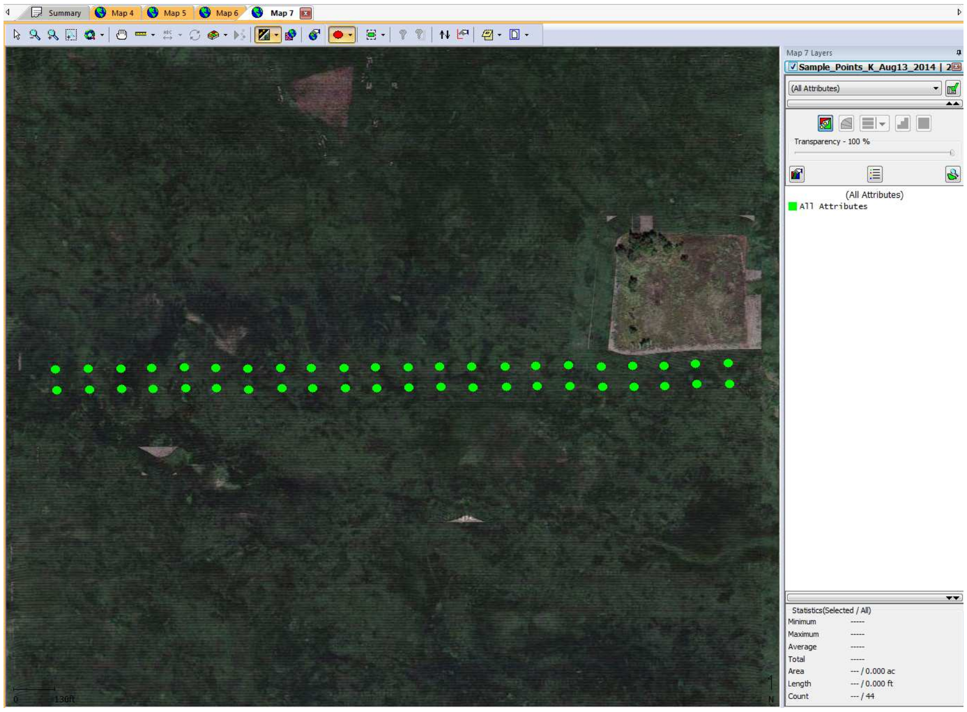
(All Attributes)

🟩 All Attributes

Statistics(Selected / All)

Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 0.000 ac
Length	--- / 0.000 ft
Count	--- / 30

Figure B.18. Soil sampling points used at ‘Eggleston’ field for the end of season soil sampling points (August 16, 2014).



☑ Sample_Points_K_Aug13_2014 | 2

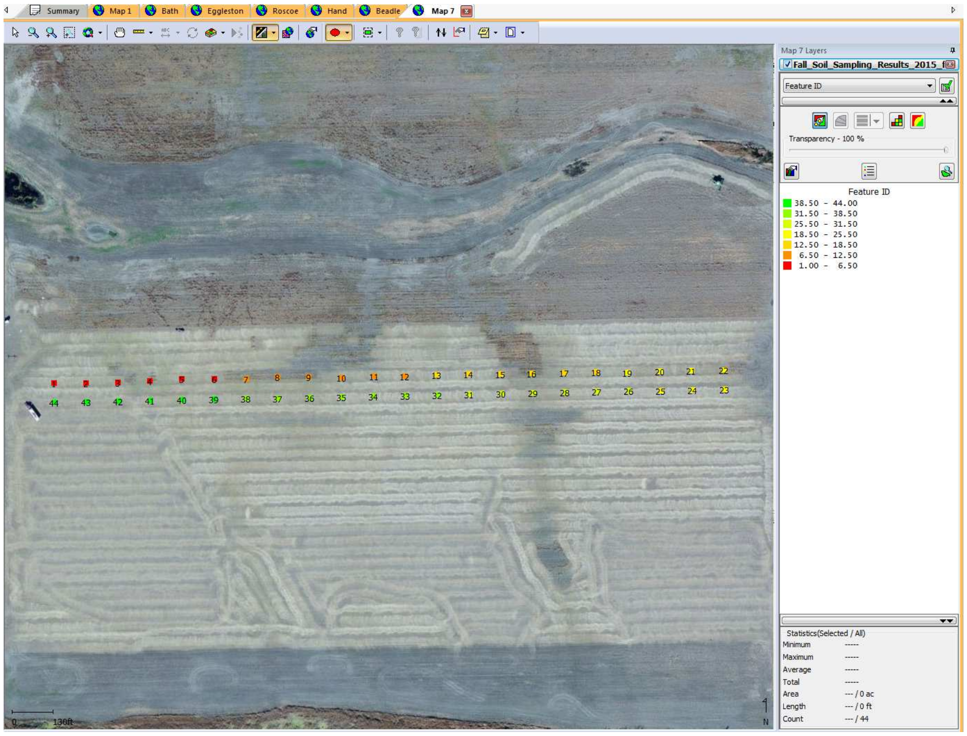
(All Attributes)

🟩 All Attributes

Statistics(Selected / All)

Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 0.000 ac
Length	--- / 0.000 ft
Count	--- / 44

Figure B.19. Soil sampling points used at ‘Hand’ field for the end of season soil sampling points (August 16, 2014).



Map 7 Layers

☑ Fall_Soil_Sampling_Results_2015_f

Feature ID

Transparency - 100 %

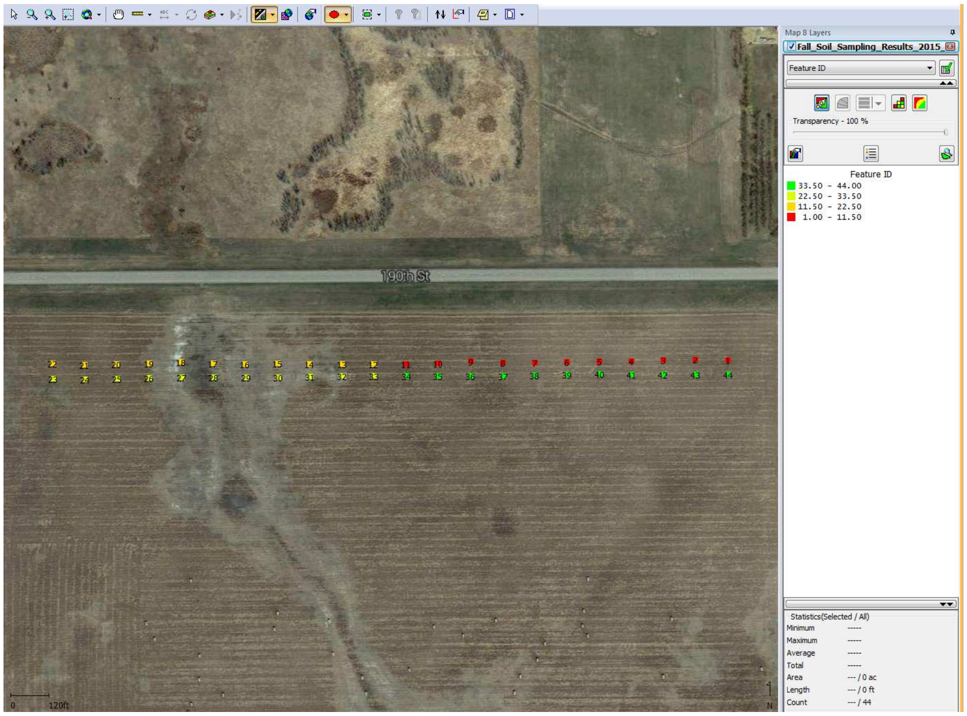
Feature ID

🟩	38.50 - 44.00
🟩	31.50 - 38.50
🟨	25.50 - 31.50
🟨	18.50 - 25.50
🟨	12.50 - 18.50
🟧	6.50 - 12.50
🟥	1.00 - 6.50

Statistics(Selected / All)

Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 44

Figure B.20. Soil sampling points used at ‘Bath’ field for the end of season soil sampling points (April 14, 2015).



Map 8 Layers

☑ Fall_Soil_Sampling_Results_2015_

Feature ID

Transparency - 100 %

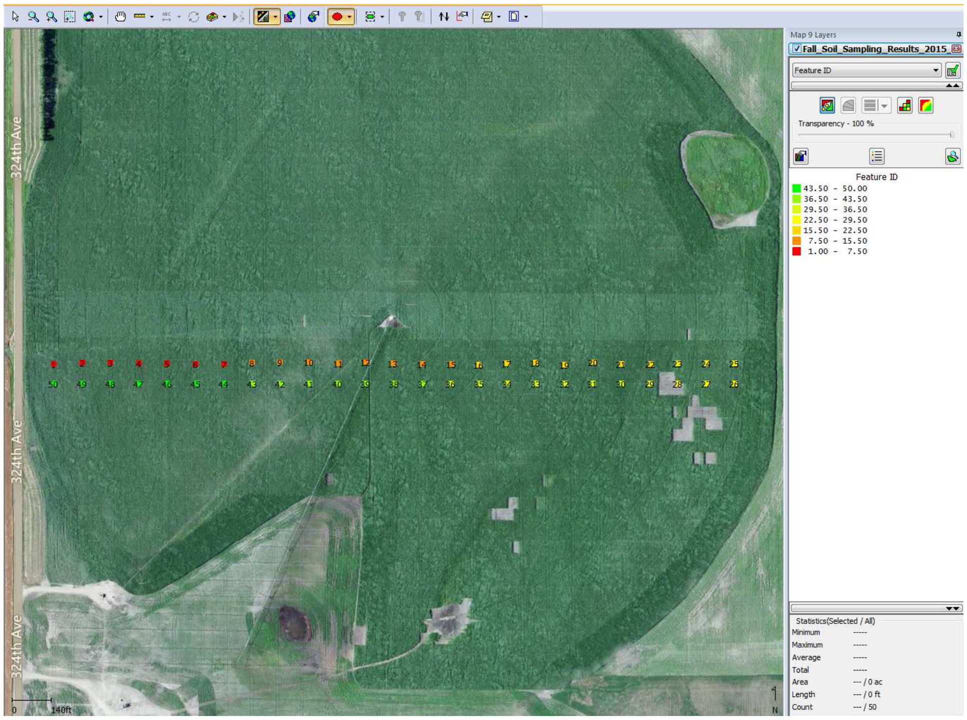
Feature ID

🟩	33.50 - 44.00
🟨	22.50 - 33.50
🟧	11.50 - 22.50
🟥	1.00 - 11.50

Statistics(Selected / All)

Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 44

Figure B.21. Soil sampling points used at 'Beadle' field for the end of season soil sampling points (April 14, 2015).



Map 9 Layers

☑ Fall_Soil_Sampling_Results_2015_

Feature ID

Transparency - 100 %

Feature ID

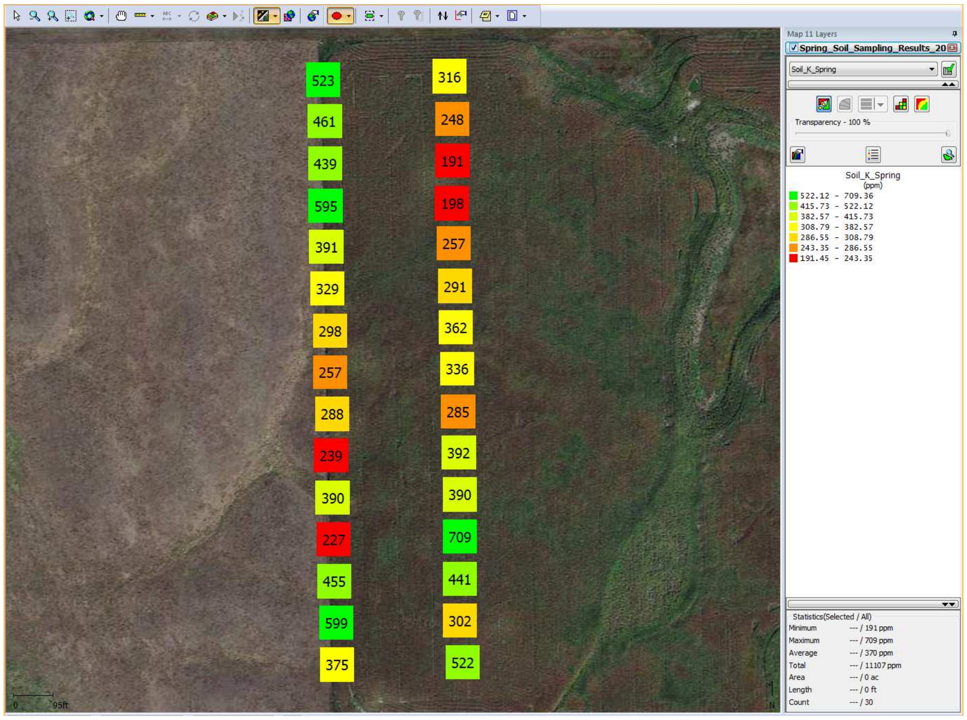
🟩	43.50 - 50.00
🟩	36.50 - 43.50
🟨	29.50 - 36.50
🟨	22.50 - 29.50
🟧	15.50 - 22.50
🟧	7.50 - 15.50
🟥	1.00 - 7.50

Statistics(Selected / All)

Minimum	-----
Maximum	-----
Average	-----
Total	-----
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 50

Figure B.22. Soil sampling points used at ‘Roscoe’ field for the end of season soil sampling points (April 14, 2015).

Spring Soil Test K Results



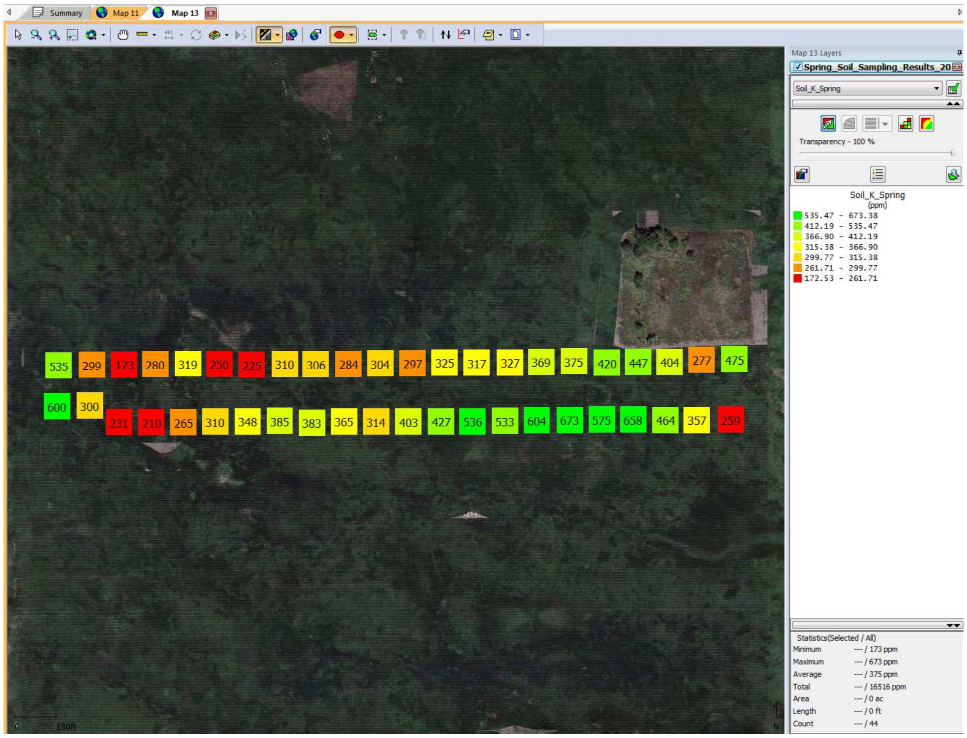
Soil_K_Spring
(ppm)

🟩	522.12 - 709.36
🟩	415.73 - 522.12
🟨	382.57 - 415.73
🟨	308.79 - 382.57
🟨	286.55 - 308.79
🟧	243.35 - 286.55
🟥	191.45 - 243.35

Statistics(Selected / All)

Minimum	--- / 191 ppm
Maximum	--- / 709 ppm
Average	--- / 370 ppm
Total	--- / 11107 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 30

Figure B.23. Graphical representation of approximate spring soil test K levels at V2 leaf stage in ‘Eggleston’ farm near Eggleston, SD.



Map 13 Layers

☑ Spring_Soil_Sampling_Results_20

Soil_K_Spring

Transparency - 100 %

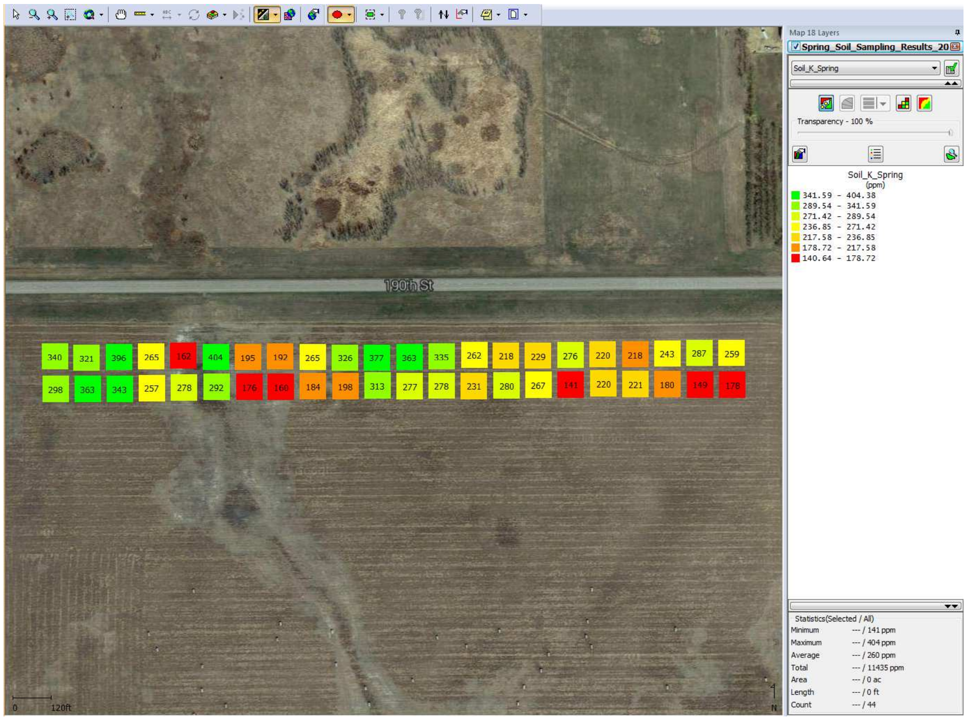
Soil_K_Spring
(ppm)

🟩	535.47 - 673.38
🟩	412.19 - 535.47
🟨	366.90 - 412.19
🟨	315.38 - 366.90
🟨	299.77 - 315.38
🟧	261.71 - 299.77
🟥	172.53 - 261.71

Statistics(Selected / All)

Minimum	--- / 173 ppm
Maximum	--- / 673 ppm
Average	--- / 375 ppm
Total	--- / 16516 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 44

Figure B.24. Graphical representation of approximate spring soil test K levels at V2 leaf stage in ‘Hand’ farm near Wosley, SD.



Map 18 Layers

☑ Spring_Soil_Sampling_Results_20

Soil_K_Spring

Transparency - 100 %

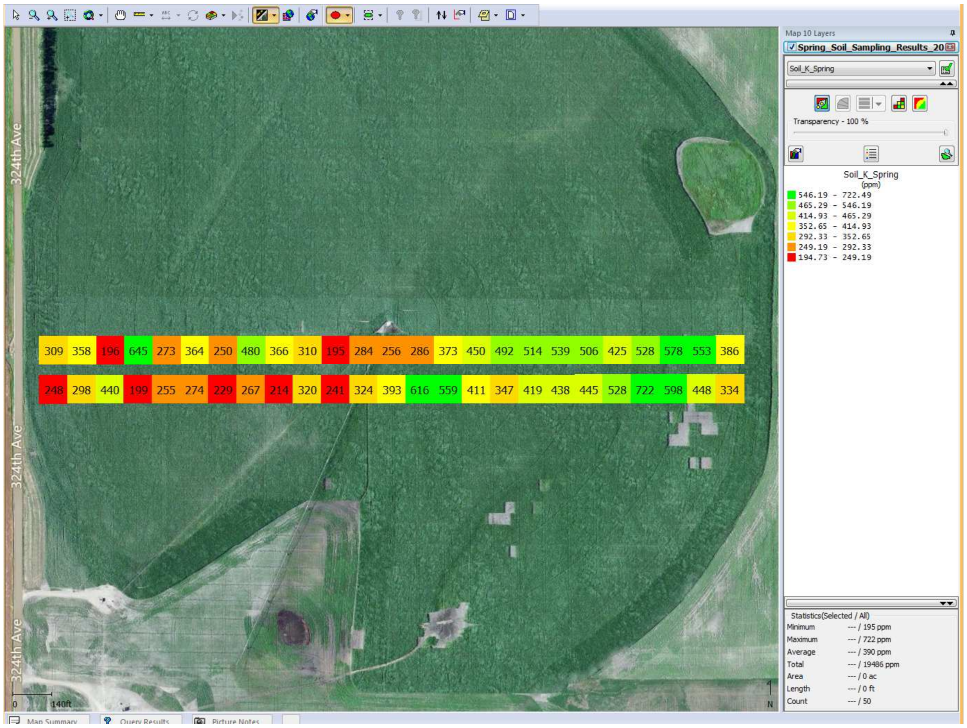
Soil_K_Spring
(ppm)

🟩	341.59 - 404.38
🟩	289.54 - 341.59
🟨	271.42 - 289.54
🟨	236.85 - 271.42
🟨	217.58 - 236.85
🟧	178.72 - 217.58
🟥	140.64 - 178.72

Statistics(Selected / All)

Minimum	--- / 141 ppm
Maximum	--- / 404 ppm
Average	--- / 260 ppm
Total	--- / 11435 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 44

Figure B.25. Graphical representation of approximate spring soil test K levels at V2 leaf stage in ‘Beadle’ farm near Wosley, SD.



309	358	196	645	273	364	250	480	366	310	195	284	256	286	373	450	492	514	539	506	425	528	578	553	386
248	298	440	199	255	274	229	267	214	320	241	324	393	616	559	411	347	419	438	445	528	722	598	448	334

Map 10 Layers

☑ Spring_Soil_Sampling_Results_20

Soil_K_Spring

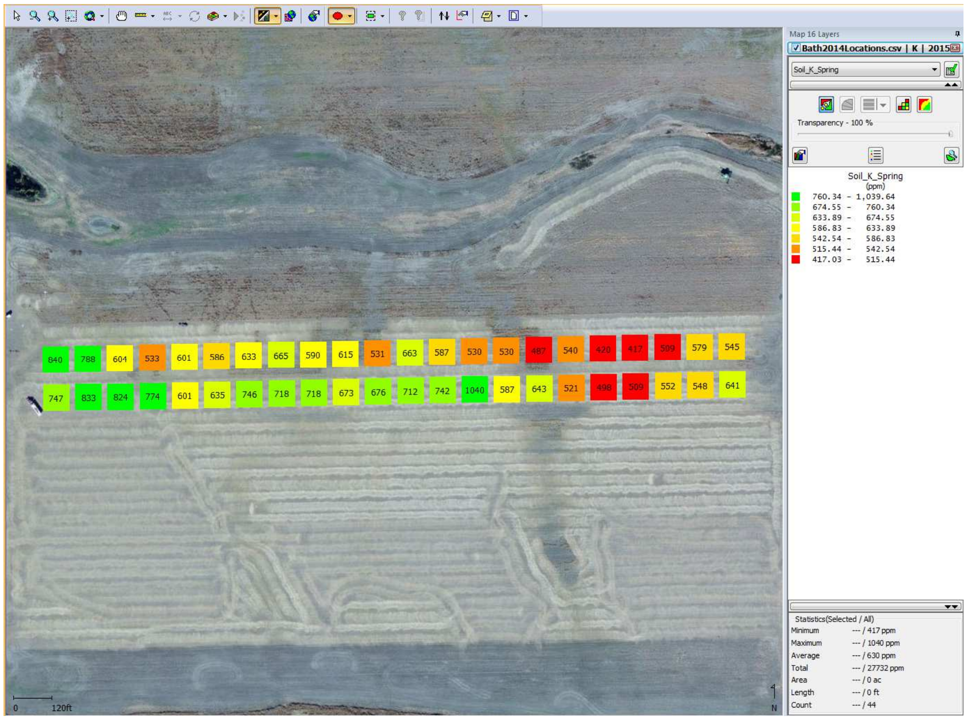
Transparency - 100 %

Soil_K_Spring
(ppm)

🟩 546.19 - 722.49
🟩 465.29 - 546.19
🟨 414.93 - 465.29
🟨 352.65 - 414.93
🟨 292.33 - 352.65
🟧 249.19 - 292.33
🟥 194.73 - 249.19

Statistics(Selected / All)	
Minimum	--- / 195 ppm
Maximum	--- / 722 ppm
Average	--- / 390 ppm
Total	--- / 19486 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 50

Figure B.26. Graphical representation of approximate spring soil test K levels at V2 leaf stage in ‘Roscoe’ farm near Roscoe, SD.



☑ Bath2014Locations.csv | K | 2015

Soil_K_Spring

Transparency - 100 %

Soil_K_Spring
(ppm)

🟩	760.34 - 1,039.64
🟩	674.55 - 760.34
🟨	633.89 - 674.55
🟨	586.83 - 633.89
🟨	542.54 - 586.83
🟧	515.44 - 542.54
🟥	417.03 - 515.44

Statistics(Selected / All)

Minimum	--- / 417 ppm
Maximum	--- / 1040 ppm
Average	--- / 630 ppm
Total	--- / 27732 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 44

Figure B.27. Graphical representation of approximate spring soil test K levels at V2 leaf stage in ‘Bath farm near Bath, SD.

Early season soil sampling results at ‘Eggleston’ farm revealed exceptionally high levels of exchangeable K. The plot average tested at 370 parts per million (ppm) with some localities reaching in excess of 500 ppm along the southern portions of the plot. The lowest regions tested at 198-226 parts per million of exchangeable K, still suggesting a plethora of plant-available potassium for uptake (Figure 3.3).

The ‘Beadle’ County farm had the lowest exchangeable K levels as the plot average was 260 parts per million, only climbing to over 400 parts per million in certain localities, and only decreasing to 141-170 parts per million nearest the eastward end rows (Figure 3.9).

The ‘Hand’ farm achieved exchangeable potassium levels on a plot average of 375 parts per million. Values increased in areas nearest the farm site of 554 parts per million, but decreased to 263 parts per million on the western portions of plot (Figure 3.6). The explanation for the highest soil test K values along the farm site is the possibility of repeated manure applications onto soil locations surrounding the farm.

The 'Bath' farm tested, on average, exchangeable K values that surpassed 600 parts per million, reaching 630 parts per million, the highest for exchangeable K that which we studied. The highest K levels were recorded across the western half of the field of 650-735 parts per million. The lowest values were 487-519 parts per million along the eastern part of the field. Astonishingly, the highest recorded potassium reading was 1040 ppm.

The 'Roscoe' field followed a similar trend with soil test K levels among the other fields we analyzed. The minimum soil PPM reading was 195 and the highest was 722 ppm, averaging 390 ppm K. The field had a pivot irrigation system, and soil test K levels varied considerably from 174 ppm to 333 ppm K within 128 feet along the western area of the plot that was irrigated. The eastern plot area of the strip did not vary in K levels as considerably.

Initial soil sampling supports Fixen et al (2010) who proposed the average soil test K values in South Dakota of 247 ppm K. No field tested lower than an average of 260 ppm K. However, certain locations in fields tested below 247 and even reached depths of 140 ppm K, suggesting possible soybean yield responses to K fertilization.

Interpolated Spring Soil Test K Results

The 'Beadle' County farm had the lowest exchangeable K levels of all locations with the plot average of 258 parts per million with a standard deviation of 91 ppm K.

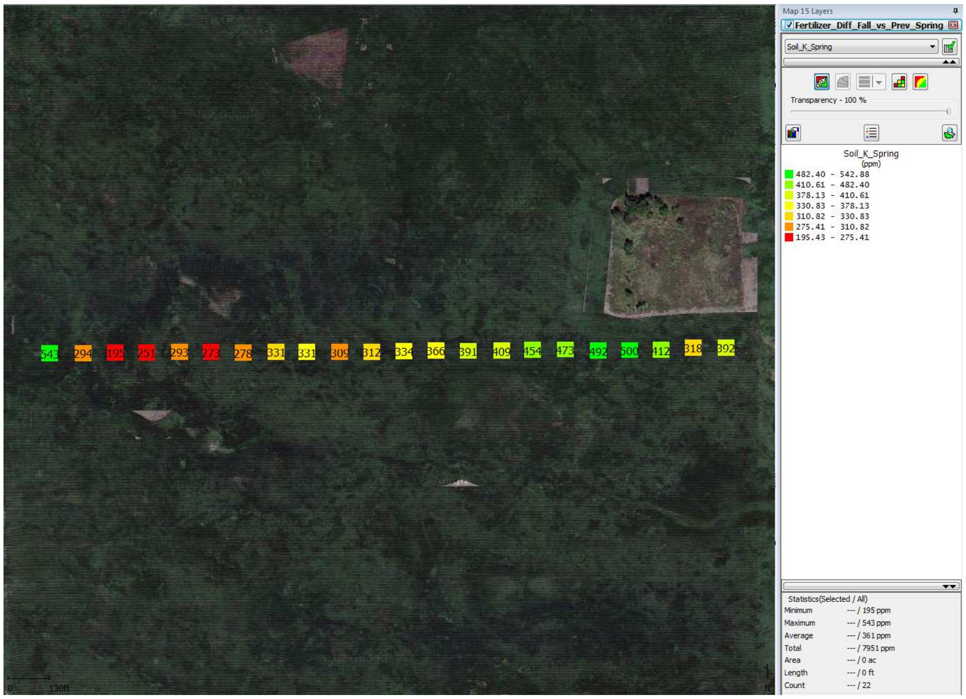
Certain elevation and landscape positions varied with soil K levels. The Hand soil types with 0-3% elevation tested between 231-364 ppm K while similar soil types with a 0-2% grade tested between 174 to 336 ppm K. Drainage class characteristics showed a similar trend between K differences as did the elevation classes.

The 'Hand' farm achieved exchangeable potassium levels on a plot average of 361 parts per million with a standard deviation of 88 ppm K. Values increased in areas nearest the farm site of 454-500 parts per million K, but decreased to 195-294 parts per million on the western portions of plot (Figure 3.6). No differences in drainage class or elevation occurred along the strip. The explanation for the highest soil test K values along the farm site is the possibility of repeated manure applications onto soil locations surrounding the farm.

The 'Eggleston' farm tested, on average, exchangeable K values that surpassed 393 ppm soil test K values with a standard deviation of 79 ppm K. The minimum soil test K value was 288 ppm K and the highest value was 504 ppm. While the northern sampling points did not vary considerably, the middle plot sampling points did vary, with values near 288-420 ppm K within 200 feet of points. This may be due to differences in elevation since STK levels were lower in the shoulder and summit regions (8% grade) of the strip than with lower (4%) grade in the flat regions.

The 'Roscoe' field followed a similar trend with soil test K levels among the other fields we analyzed. The minimum soil test K value was 231 ppm and the maximum value was 620 ppm. On average, the plot tested at 391 ppm K. Approximately half way across the strip (1258 feet), a pivot irrigation system is installed and used. On the first 1258 feet of the field, the soil test values ranged from 231-330 ppm, but on the second 1258 feet of the treatment plot, the values soared from 432-620 ppm K. Elevation did not vary across the strip, but STK levels were consistently higher (445-620 ppm K) in the well-drained soils than in the 'somewhat excessively' wet drainage class (231-409 ppm K).

The 'Bath' field had an average K-fertilization strip soil test K levels of 629 ppm and a standard deviation of 91 ppm K, climbing to 805 ppm in some locations and dipping down to 460 ppm K. The lowest soil test K levels were recorded across the eastern portion of the field (similar to values received on the 0 lbs K_2O/acre strip. Likewise, highest values (680-800 ppm K) were seen on the western stretches of the plot. In many cases, there were similar trends and values between K-strip soil test K values and sampling points outside of the treatment plot. Drainage and elevation did not appear to affect soil test K levels as neither deviated from 'well' or '1%,' respectively.



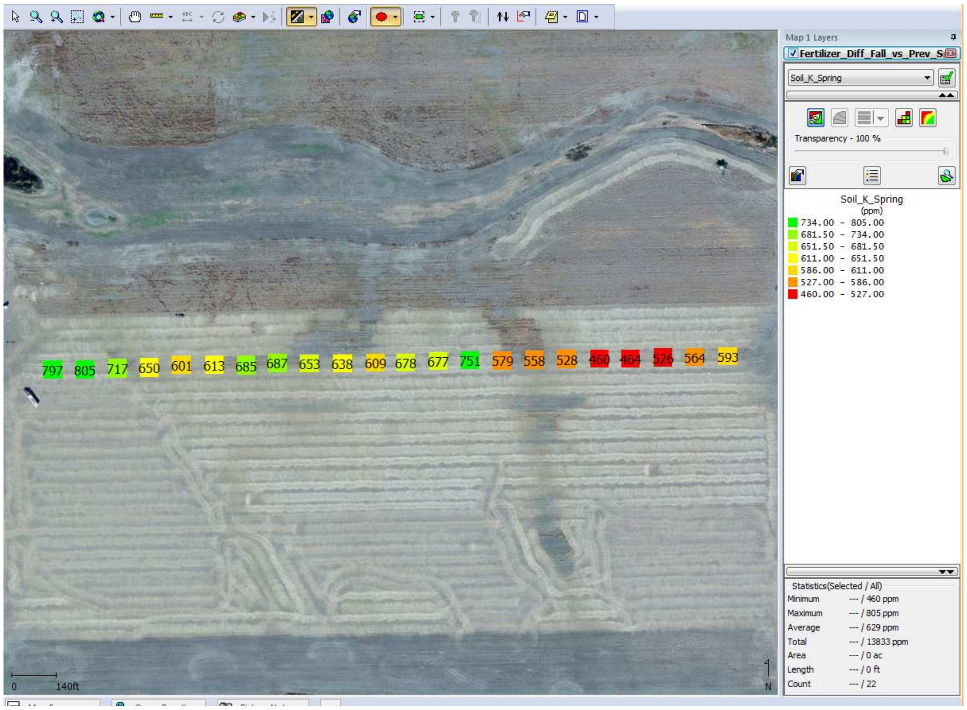
Soil_K_Spring

Soil_K_Spring
(ppm)

🟩 482.40 - 542.88
🟩 410.61 - 482.40
🟨 378.13 - 410.61
🟨 330.83 - 378.13
🟨 310.82 - 330.83
🟧 275.41 - 310.82
🟥 195.43 - 275.41

Statistics(Selected / All)	
Minimum	--- / 195 ppm
Maximum	--- / 543 ppm
Average	--- / 361 ppm
Total	--- / 7951 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 22

Figure B.28. Graphical representation of approximate interpolated spring soil test K levels at ‘Hand’ farm near Wosley, SD, on June 4, 2015.

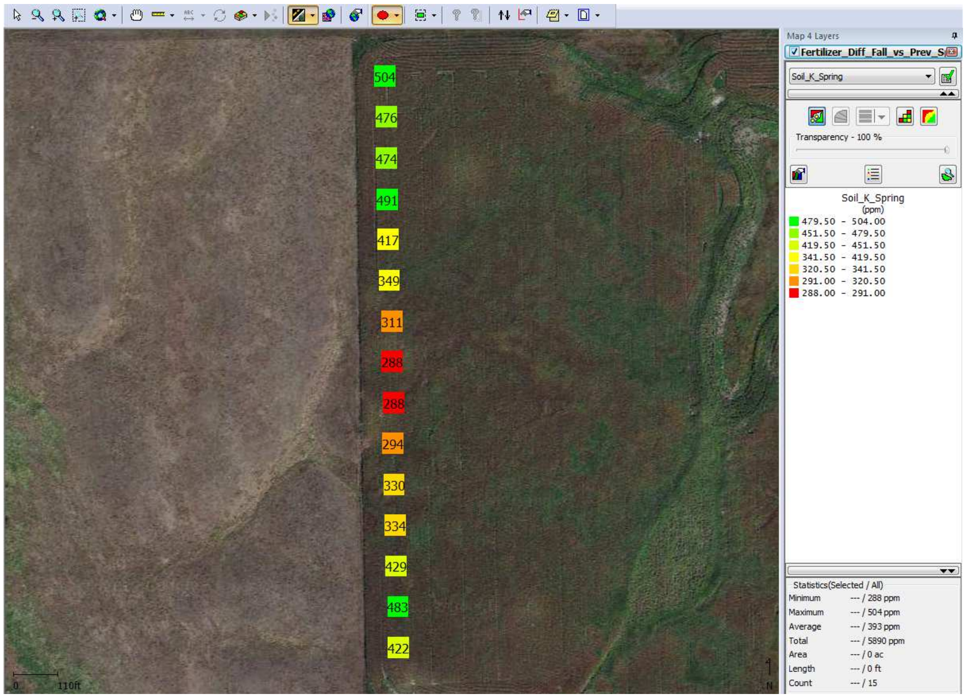


Soil_K_Spring
(ppm)

🟩 734.00 - 805.00
🟩 681.50 - 734.00
🟨 651.50 - 681.50
🟨 611.00 - 651.50
🟨 586.00 - 611.00
🟧 527.00 - 586.00
🟥 460.00 - 527.00

Statistics(Selected / All)	
Minimum	--- / 460 ppm
Maximum	--- / 805 ppm
Average	--- / 629 ppm
Total	--- / 13833 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 22

Figure B.29. Graphical representation of approximate interpolated spring soil test K levels at ‘Bath’ farm near Bath, SD, on June 5, 2015.



Map 4 Layers

☑ Fertilizer_Diff_Fall_vs_Prev_S

Soil_K_Spring

Transparency - 100 %

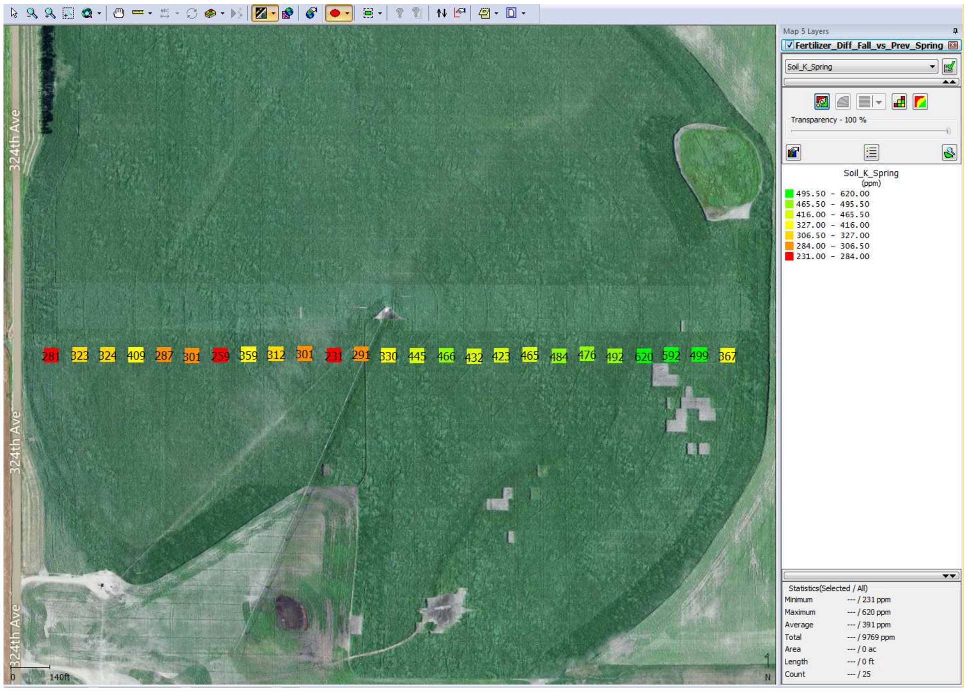
Soil_K_Spring
(ppm)

🟩 479.50 - 504.00
🟩 451.50 - 479.50
🟨 419.50 - 451.50
🟨 341.50 - 419.50
🟨 320.50 - 341.50
🟧 291.00 - 320.50
🟥 288.00 - 291.00

Statistics(Selected / All)

Minimum	--- / 288 ppm
Maximum	--- / 504 ppm
Average	--- / 393 ppm
Total	--- / 5890 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 15

Figure B.30. Graphical representation of approximate interpolated spring soil test K levels at 'Eggleston' farm near Eggleston, SD, on June 4, 2015.



Map 5 Layers

☑ Fertilizer_Diff_Fall_vs_Prev_Spring

Soil_K_Spring

Transparency - 100 %

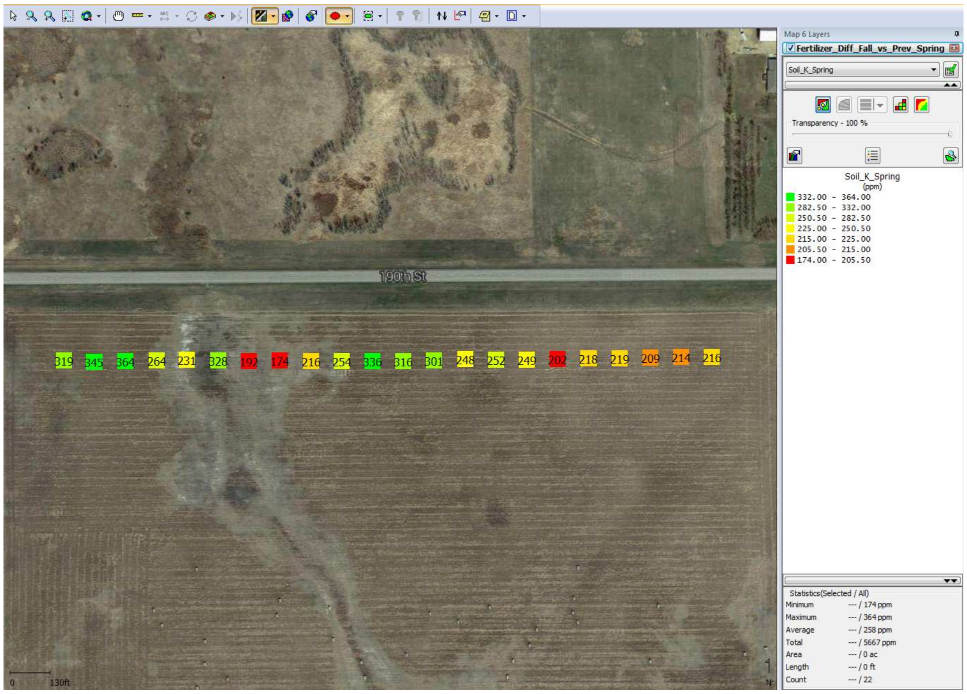
Soil_K_Spring
(ppm)

🟩 495.50 - 620.00
🟩 465.50 - 495.50
🟨 416.00 - 465.50
🟨 327.00 - 416.00
🟨 306.50 - 327.00
🟧 284.00 - 306.50
🟥 231.00 - 284.00

Statistics(Selected / All)

Minimum	--- / 231 ppm
Maximum	--- / 620 ppm
Average	--- / 391 ppm
Total	--- / 9769 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 25

Figure B.31. Graphical representation of approximate interpolated spring soil test K levels at ‘Roscoe’ farm near Bath, SD, on June 4, 2015.



Map 6 Layers

☑ Fertilizer_Diff_Fall_vs_Prev_Spring

Soil_K_Spring

Transparency - 100 %

Soil_K_Spring
(ppm)

🟩 332.00 - 364.00
🟩 282.50 - 332.00
🟨 250.50 - 282.50
🟨 225.00 - 250.50
🟧 215.00 - 225.00
🟧 205.50 - 215.00
🟥 174.00 - 205.50

Statistics(Selected / All)	
Minimum	--- / 174 ppm
Maximum	--- / 364 ppm
Average	--- / 258 ppm
Total	--- / 5667 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 22

Figure B.32. Graphical representation of approximate interpolated spring soil test K levels at Beadle farm near Wosley, SD, on June 4, 2015.

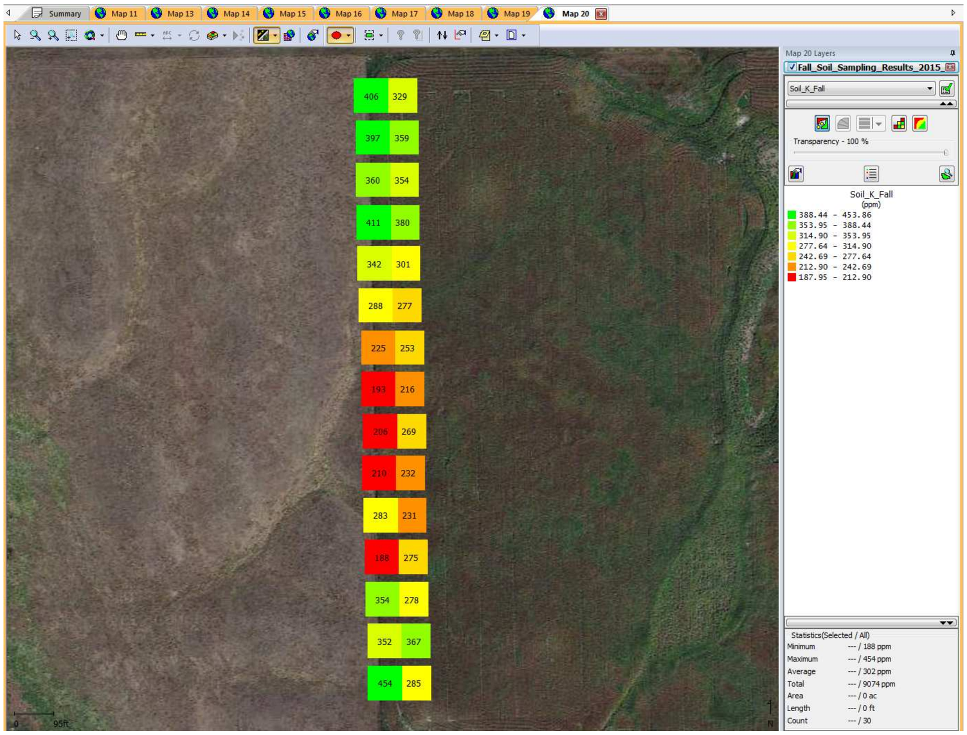
Fall Soil Test K Levels

Final soil sampling results at ‘Eggleston’ farm revealed exceptionally high levels of exchangeable K. The plot average tested at 302 parts per million (ppm) with some localities reaching in excess of 400 ppm along the southern portions of the plot. The lowest regions tested at 188-230 parts per million of exchangeable K, still suggesting a plethora of plant-available potassium for uptake (Figure 3.3). K values were similar to those seen in the spring since only 155 lbs K_2O/acre was applied and not the intended application rate.

The ‘Beadle’ County farm had the lowest exchangeable K levels as the plot average was 481 parts per million, only climbing to over 530 parts per million in certain localities. The lowest values for the strip were recorded at 336 ppm (Figure 3.9).

The ‘Hand’ farm achieved exchangeable potassium levels on a plot average of 513 parts per million. Values increased in areas nearest the farm site of 471-644 parts per million, but decreased to 263 parts per million on the western portions of plot (Figure 3.6). The explanation for the highest soil test K values along the farm site is the possibility of repeated manure applications onto soil locations surrounding the farm.

The ‘Roscoe’ farm tested, on average, exchangeable K values that surpassed 779 ppm along the potassium treatment strip. The lowest values were recorded along the eastern portions of the field, approaching 600-650 ppm K. Highest values were 993 ppm K. The ‘Roscoe’ field followed a similar trend with soil test K levels among the other fields we analyzed. The minimum soil PPM reading was 364 and the highest was 906 ppm, averaging 573 ppm K. A similar trend for K variability noted from the spring was seen the fall as soil test K levels varied considerably from 364 to 572 ppm K within 128 feet along the western area of the plot that was irrigated. The eastern plot area of the strip did not vary K levels as considerably, similar to spring.



☑ Fall_Soil_Sampling_Results_2015_

Soil_K_Fall

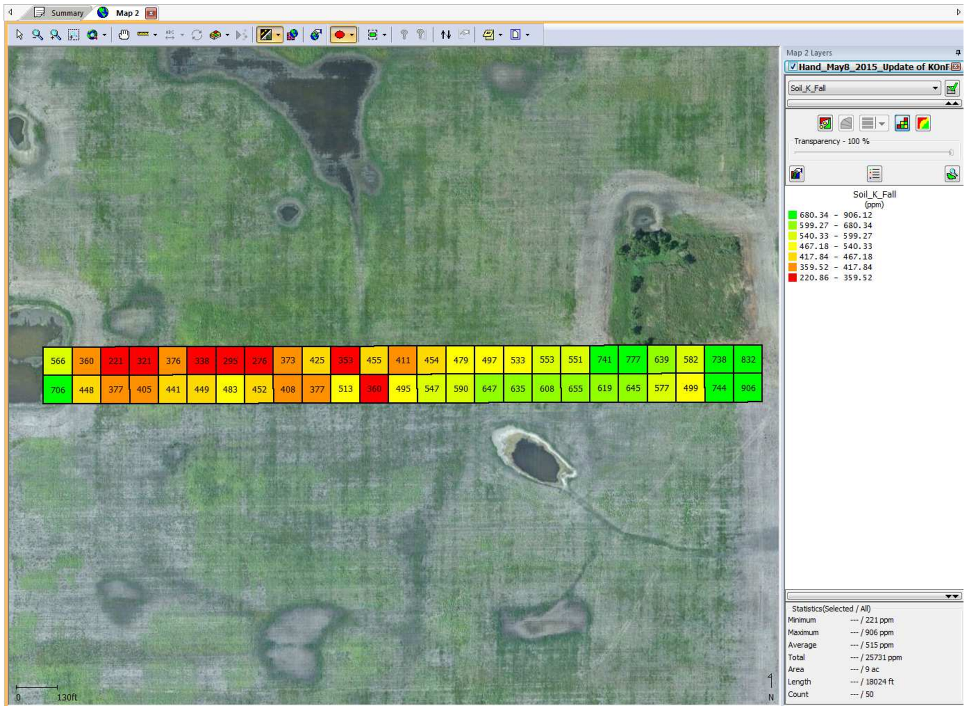
Transparency - 100 %

Soil_K_Fall
(ppm)
🟩 388.44 - 453.86
🟩 353.95 - 388.44
🟨 314.90 - 353.95
🟨 277.64 - 314.90
🟨 242.69 - 277.64
🟧 212.90 - 242.69
🟥 187.95 - 212.90

Statistics(Selected / All)

Minimum	--- / 188 ppm
Maximum	--- / 454 ppm
Average	--- / 302 ppm
Total	--- / 9074 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 30

Figure B.33. Graphical representation of approximate fall soil test K levels at R5 growth stage in ‘Eggleston’ farm near Eggleston, SD on August 16, 2014.



☑ Hand_May8_2015_Update of KOnF

Soil_K_Fall

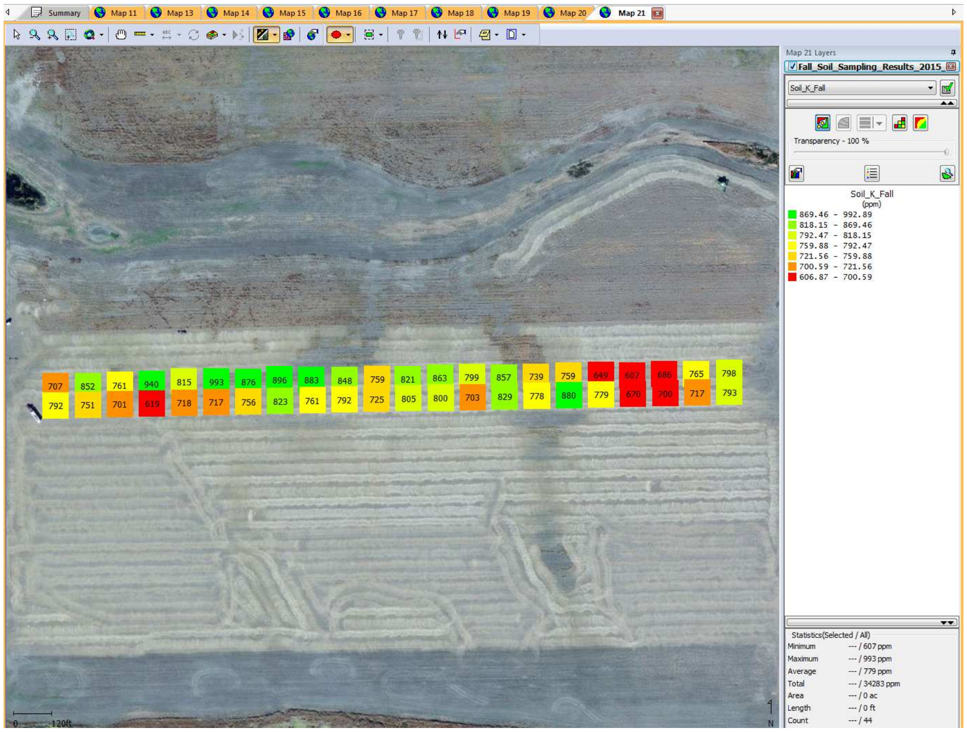
Transparency - 100 %

Soil_K_Fall
(ppm)
🟩 680.34 - 906.12
🟩 599.27 - 680.34
🟨 540.33 - 599.27
🟨 467.18 - 540.33
🟨 417.84 - 467.18
🟧 359.52 - 417.84
🟥 220.86 - 359.52

Statistics(Selected / All)

Minimum	--- / 221 ppm
Maximum	--- / 906 ppm
Average	--- / 515 ppm
Total	--- / 25731 ppm
Area	--- / 9 ac
Length	--- / 18024 ft
Count	--- / 50

Figure B.34. Graphical representation of approximate fall soil test K levels at R5 growth stage in 'Hand' farm near Wosley, SD on August 16, 2014.



Map 21 Layers

☑ Fall_Soil_Sampling_Results_2015_

Soil_K_Fall

Transparency - 100 %

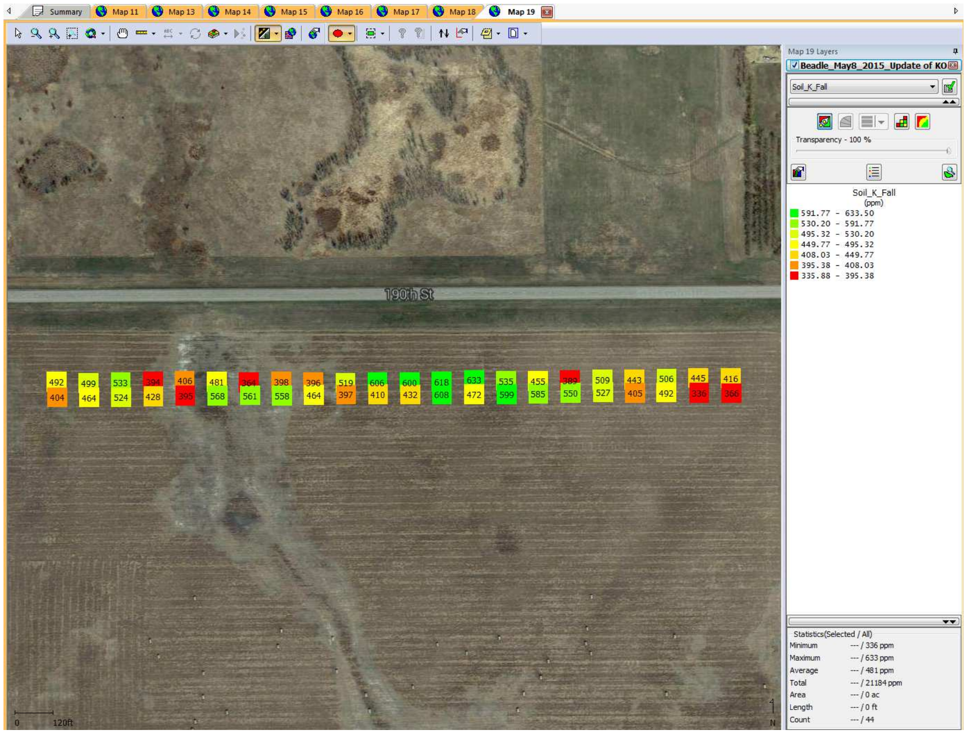
Soil_K_Fall
(ppm)

🟩	869.46 - 992.89
🟩	818.15 - 869.46
🟨	792.47 - 818.15
🟨	759.88 - 792.47
🟨	721.56 - 759.88
🟧	700.59 - 721.56
🟥	606.87 - 700.59

Statistics(Selected / All)

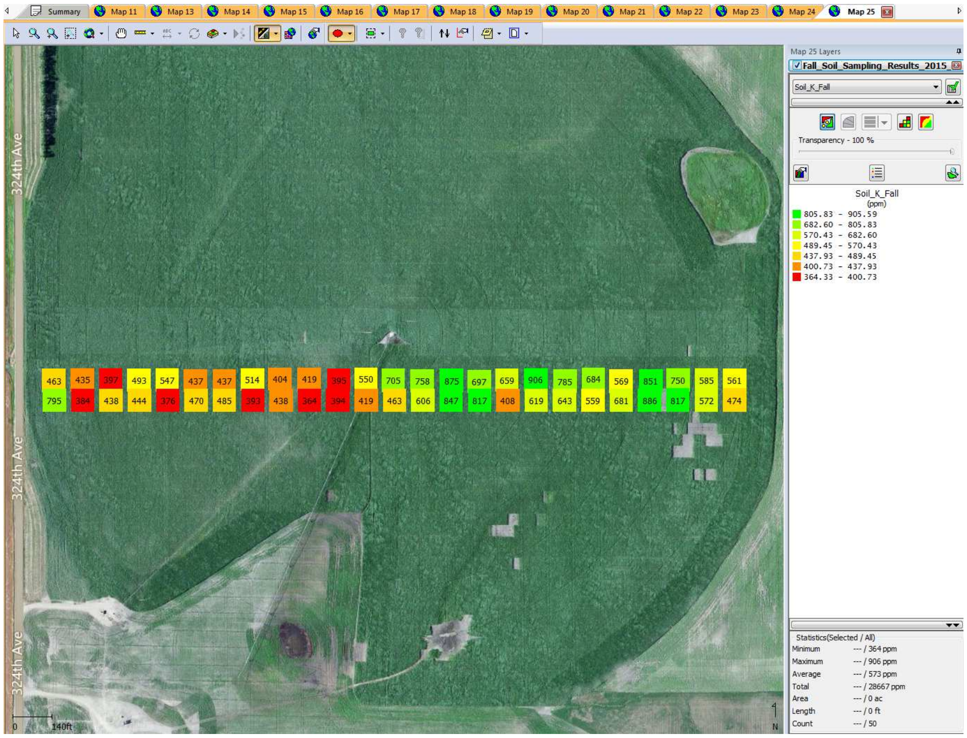
Minimum	--- / 607 ppm
Maximum	--- / 993 ppm
Average	--- / 779 ppm
Total	--- / 34283 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 44

Figure B.35. Graphical representation of approximate fall soil test K levels at 'Bath' farm near Bath, SD, on April 14, 2015.



Statistics(Selected / All)
Minimum --- / 336 ppm
Maximum --- / 633 ppm
Average --- / 481 ppm
Total --- / 21184 ppm
Area --- / 0 ac
Length --- / 0 ft
Count --- / 44

Figure B.36. Graphical representation of approximate fall soil test K levels in ‘Beadle’ farm near Wosley, SD, on April 14, 2015.



Statistics(Selected / All)
Minimum --- / 364 ppm
Maximum --- / 906 ppm
Average --- / 573 ppm
Total --- / 28667 ppm
Area --- / 0 ac
Length --- / 0 ft
Count --- / 50

Figure B.37. Graphical representation of approximate fall soil test K levels in 'Roscoe' farm near Roscoe, SD, on April 14, 2015.

2014 In-seasonal Soil Test K Differences Along K-Applied Strip

The 'Bath' field had an average soil test difference of 175 ppm, outlining that spring potash fertilizer dramatically increased soil test K levels. At the very maximum, spatial points attained values near 380 ppm, but also saw some localities experiencing a negative result at a high of -90 ppm. The negative differences were recorded on the first 300 feet of the fertilization strip while positive differences occurred throughout the center and eastern portions of the field.

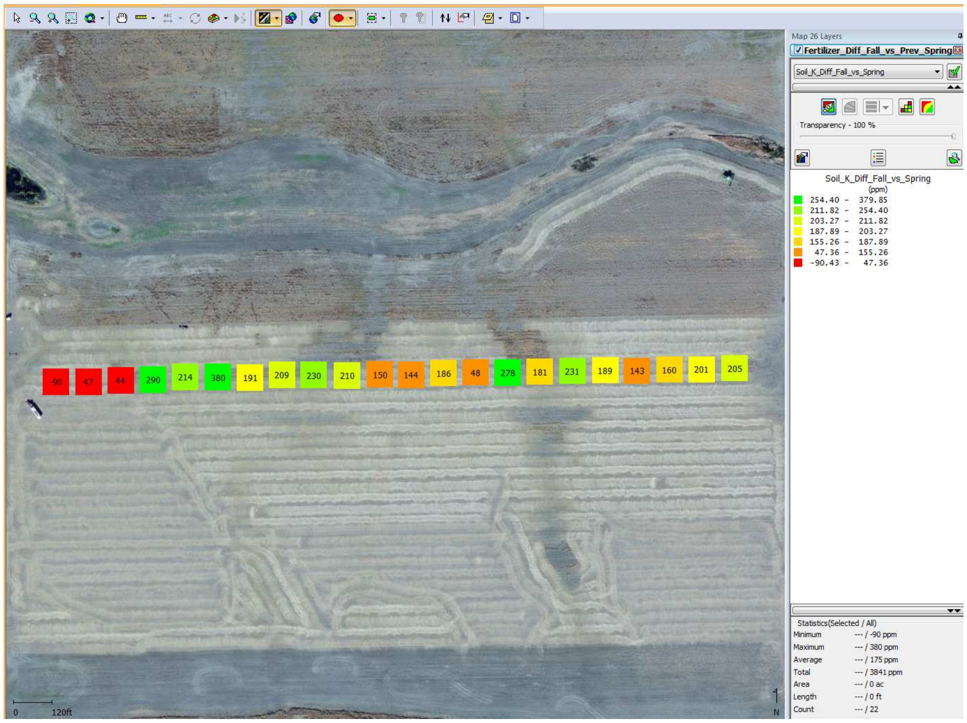
The 'Eggleston' field had the lowest gains from potash fertilizer, experiencing losses (negative differences) throughout every sampling point across the strip. The lowest negative difference was -19 ppm while the highest loss occurred at -175 ppm, averaging across the strip at -99 ppm. The losses were equally spatially placed across the strip and can be attributed to miscommunication since only 250 lbs 0-0-62 per acre was applied (155 lbs K_2O/acre).

The 'Roscoe' field gained appreciable soil test K levels as the average gain attributed to K fertilization was 204 ppm. The range of gain varied from 73 to 441 ppm. Gains occurred all across the strip.

The 'Hand' farm received soil test K increases of 181 ppm across the field. Maximum gains were 514 ppm and minimally gained 7 ppm. While the highest soil tests were initially recorded along the farm site nearest the field, soil K increases only increased linearly with the field average.

The ‘Beadle’ county farm had the highest rate of increase contributed to K fertilization as the strip increased by 226 ppm per acre. Minimally, the increases were 130 ppm, and increased maximally to 385 ppm.

With 250 lbs K_2O per acre applied, it is reasoned that soil test K levels could potentially have risen 20.83 ppm K per acre. Across all fields, each K fertilization achieved gains of close to 100 ppm K (where 250 lbs K_20 per acre was applied).



☑ Fertilizer_Diff_Fall_vs_Prev_Spring

Soil_K_Diff_Fall_vs_Spring

Transparency - 100 %

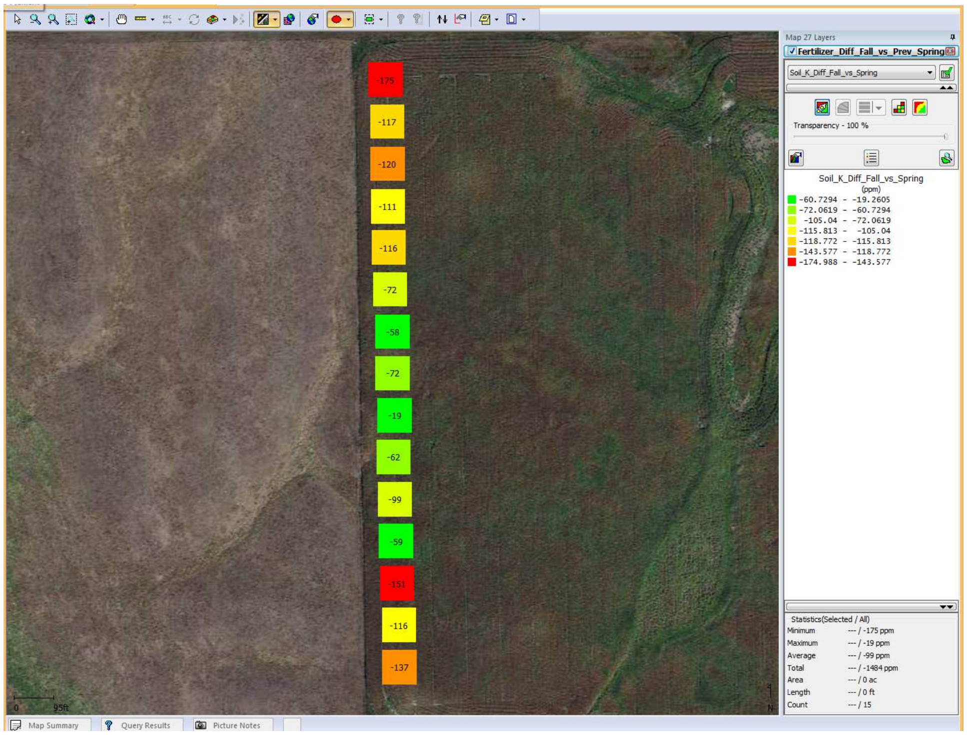
Soil_K_Diff_Fall_vs_Spring
(ppm)

🟩 254.40 - 379.85
🟩 211.82 - 254.40
🟨 203.27 - 211.82
🟨 187.89 - 203.27
🟧 155.26 - 187.89
🟧 47.36 - 155.26
🟥 -90.43 - 47.36

Statistics(Selected / All)

Minimum	--- / -90 ppm
Maximum	--- / 380 ppm
Average	--- / 175 ppm
Total	--- / 3841 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 22

Figure B.38. Graphical representation of soil test K differences between fall 2014 and spring 2014 at ‘Bath’ farm near Bath, SD.



☑ Fertilizer_Diff_Fall_vs_Prev_Spring

Soil_K_Diff_Fall_vs_Spring

Transparency - 100 %

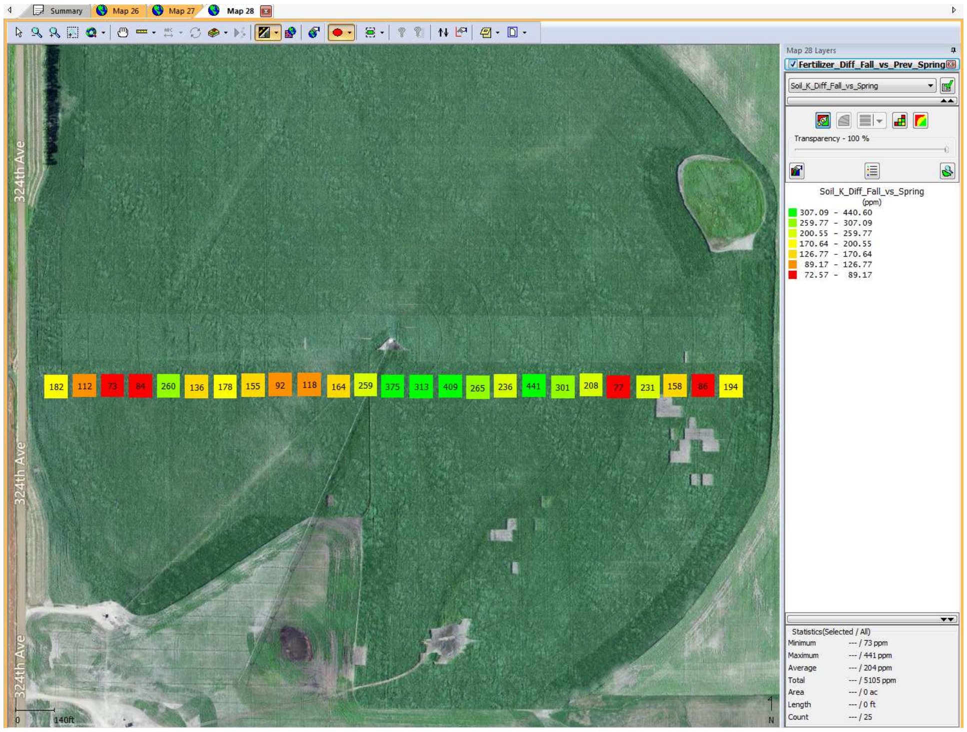
Soil_K_Diff_Fall_vs_Spring
(ppm)

🟩	-60.7294 - -19.2605
🟩	-72.0619 - -60.7294
🟨	-105.04 - -72.0619
🟨	-115.813 - -105.04
🟨	-118.772 - -115.813
🟧	-143.577 - -118.772
🟥	-174.988 - -143.577

Statistics(Selected / All)

Minimum	--- / -175 ppm
Maximum	--- / -19 ppm
Average	--- / -99 ppm
Total	--- / -1484 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 15

Figure B.39. Graphical representation of soil test K differences between fall 2014 and spring 2014 at ‘Eggleston’ farm near Eggleston, SD.



☑ Fertilizer_Diff_Fall_vs_Prev_Spring

Soil_K_Diff_Fall_vs_Spring

Transparency - 100 %

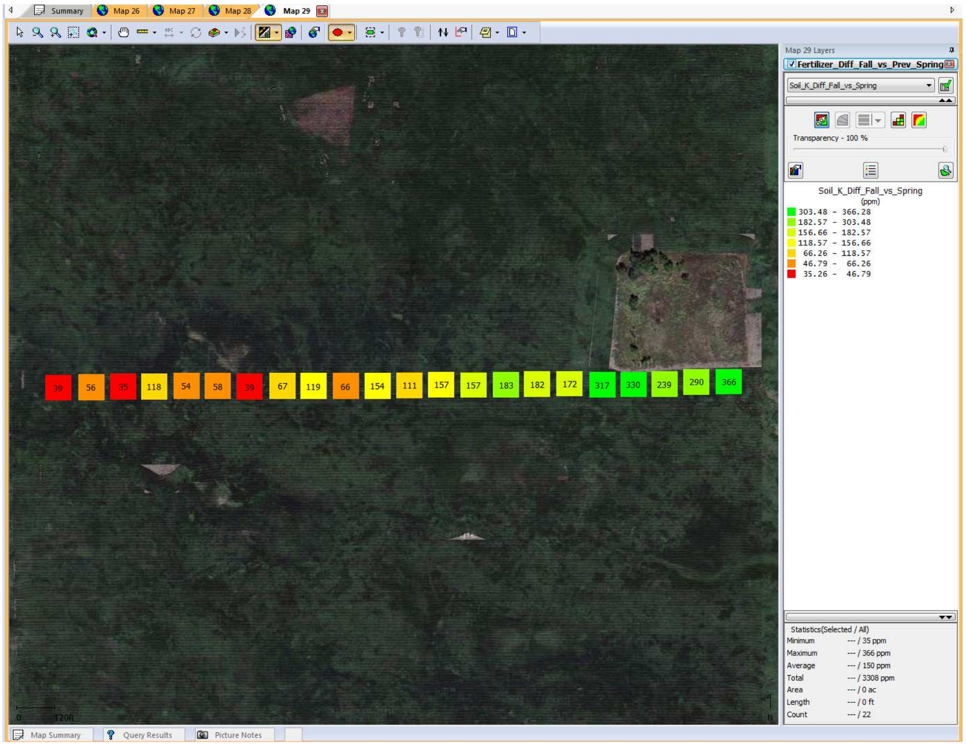
Soil_K_Diff_Fall_vs_Spring
(ppm)

🟩	307.09 - 440.60
🟩	259.77 - 307.09
🟨	200.55 - 259.77
🟨	170.64 - 200.55
🟨	126.77 - 170.64
🟧	89.17 - 126.77
🟥	72.57 - 89.17

Statistics(Selected / All)

Minimum	--- / 73 ppm
Maximum	--- / 441 ppm
Average	--- / 204 ppm
Total	--- / 5105 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 25

Figure B.40. Graphical representation of soil test K differences between fall 2014 and spring 2014 at ‘Roscoe’ farm near Roscoe, SD.



☑ Fertilizer_Diff_Fall_vs_Prev_Spring

Soil_K_Diff_Fall_vs_Spring

Transparency - 100 %

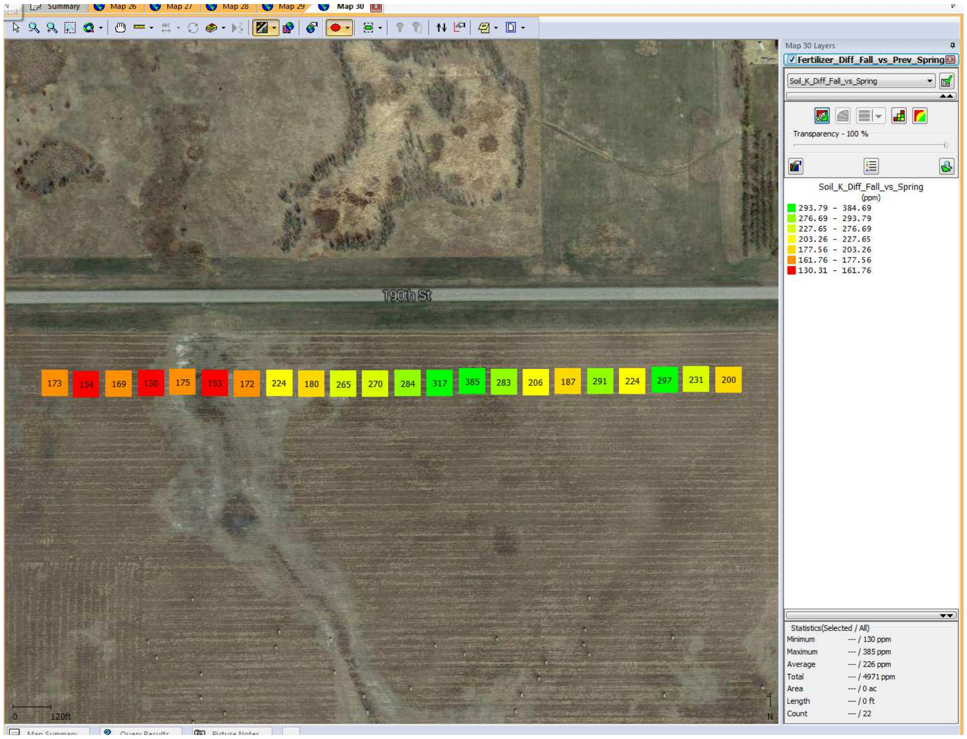
Soil_K_Diff_Fall_vs_Spring (ppm)

🟩	303.48 - 366.28
🟩	182.57 - 303.48
🟨	156.66 - 182.57
🟨	118.57 - 156.66
🟨	66.26 - 118.57
🟧	46.79 - 66.26
🟥	35.26 - 46.79

Statistics(Selected / All)

Minimum	--- / 35 ppm
Maximum	--- / 366 ppm
Average	--- / 150 ppm
Total	--- / 3308 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 22

Figure B.41. Graphical representation of soil test K differences between fall 2014 and spring 2014 at ‘Hand’ farm near Wosley, SD.



☑ Fertilizer_Diff_Fall_vs_Prev_Spring

Soil_K_Diff_Fall_vs_Spring

Soil_K_Diff_Fall_vs_Spring
(ppm)

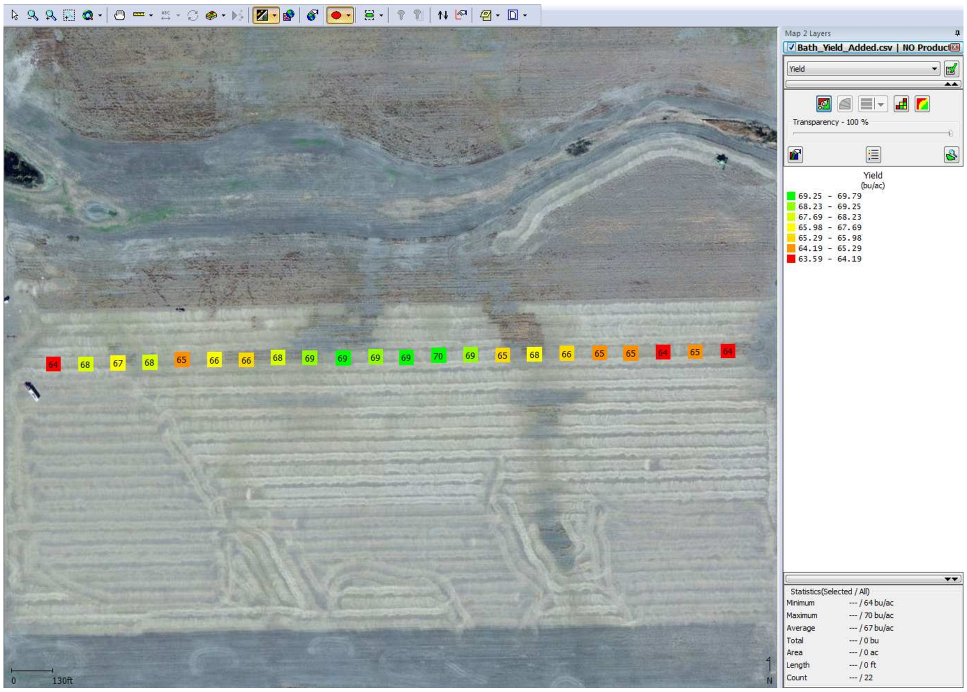
🟩	293.79 - 384.69
🟩	276.69 - 293.79
🟨	227.65 - 276.69
🟨	203.26 - 227.65
🟨	177.56 - 203.26
🟧	161.76 - 177.56
🟥	130.31 - 161.76

Statistics(Selected / All)

Minimum	--- / 130 ppm
Maximum	--- / 385 ppm
Average	--- / 226 ppm
Total	--- / 4971 ppm
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 22

Figure B.42. Graphical representation of soil test K differences between fall 2014 and spring 2014 at ‘Beadle’ farm near Wosley, SD.

.2014 Yield Monitor Data



☑ Bath_Yield_Added.csv | NO Product

Yield

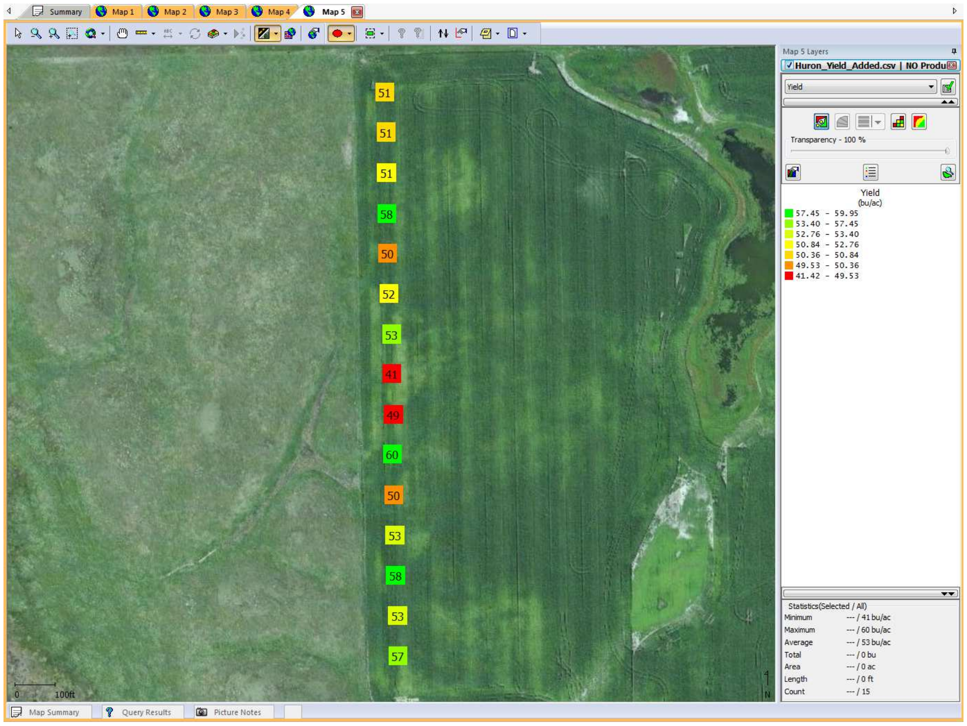
Transparency - 100 %

Yield
(bu/ac)

- 🟩 69.25 - 69.79
- 🟩 68.23 - 69.25
- 🟨 67.69 - 68.23
- 🟨 65.98 - 67.69
- 🟨 65.29 - 65.98
- 🟧 64.19 - 65.29
- 🟥 63.59 - 64.19

Statistics(Selected / All)	
Minimum	--- / 64 bu/ac
Maximum	--- / 70 bu/ac
Average	--- / 67 bu/ac
Total	--- / 0 bu
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 22

Figure B.43. Yield monitor data overlaid on fall soil sampling points for ‘Bath’ farm near Bath, SD, for 2014 growing season inside the K-applied strip



Statistics(Selected / All)

Minimum	--- / 41 bu/ac
Maximum	--- / 60 bu/ac
Average	--- / 53 bu/ac
Total	--- / 0 bu
Area	--- / 0 ac
Length	--- / 0 ft
Count	--- / 15

Figure B.44. Yield monitor data overlaid on fall soil sampling points for ‘Eggleston’ farm near Eggleston, SD, for 2014 growing season inside the K-applied strip

2014 Soybean Yield Difference Maps

The generated yield difference maps are graphically displayed below.

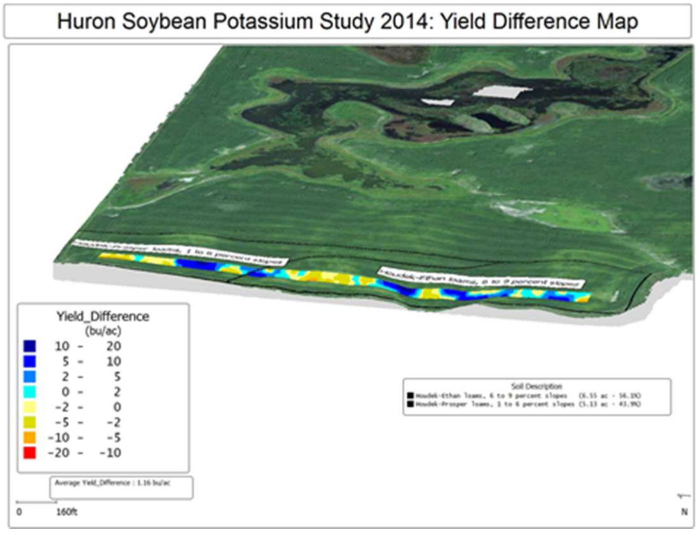


Figure B.45. Yield difference map for ‘Eggleston’ farm superimposed on a soil type map/topographic map.

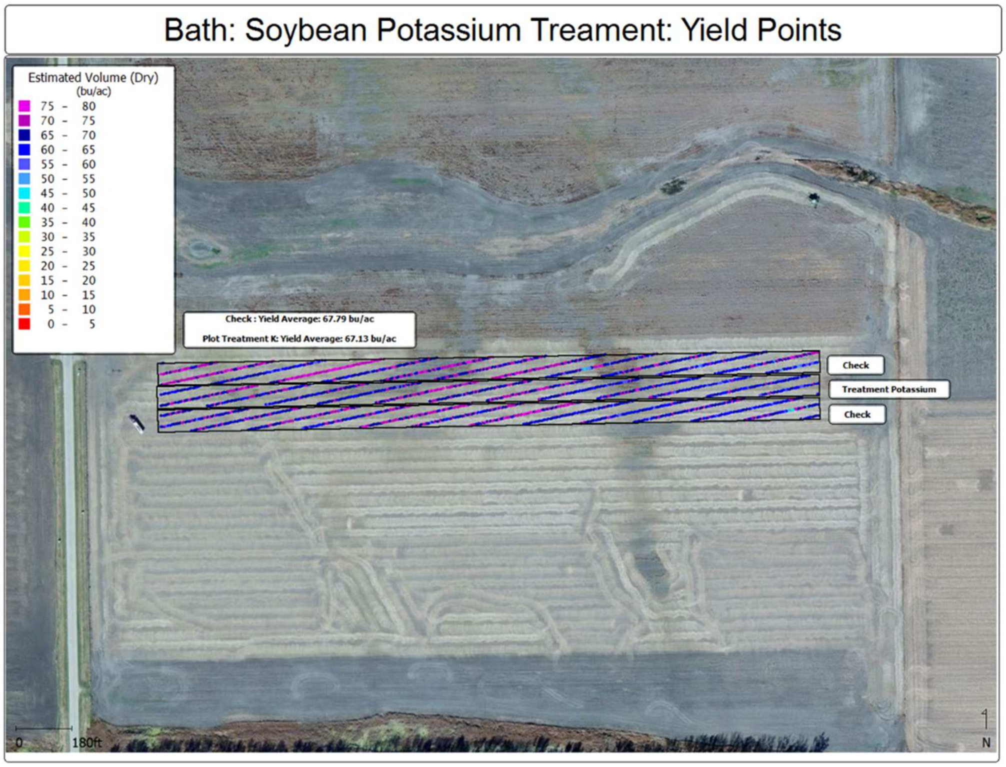


Figure B.46. Cleaned yield monitor collected from 2014 harvest for ‘Roscoe’ farm

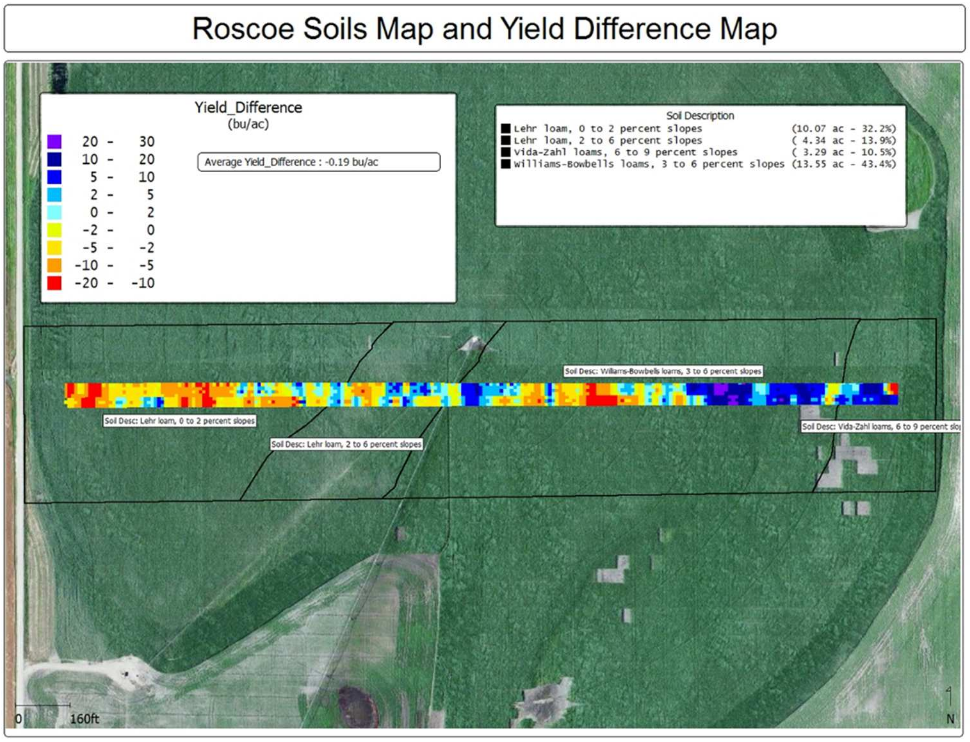
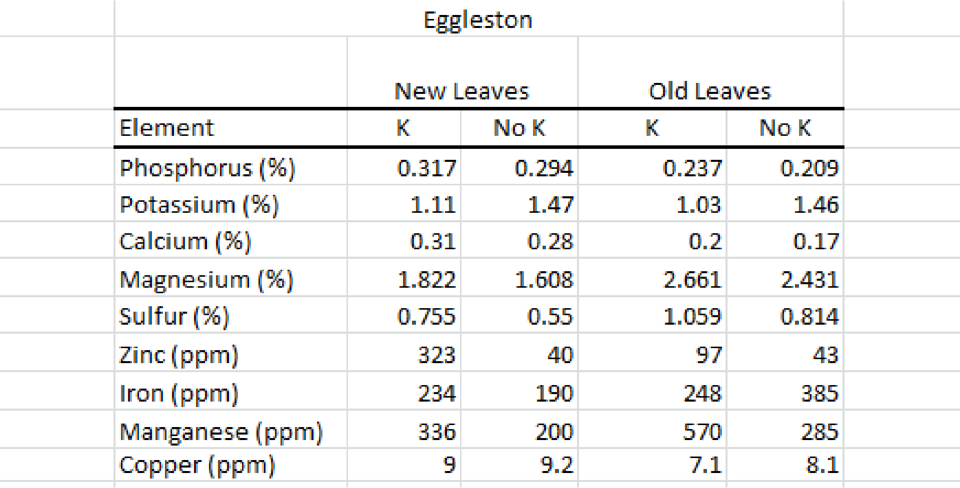


Figure B.47. Yield difference map (Chapter 6) superimposed on a soil type map for ‘Roscoe’ farm.

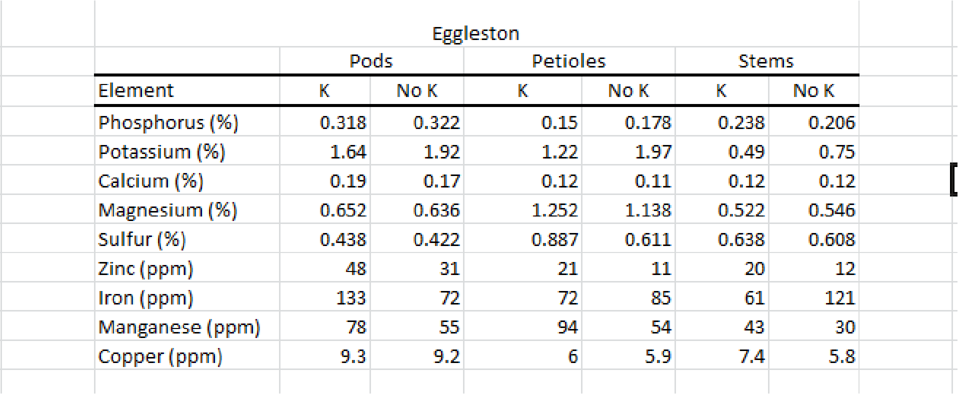
2014 Tissue Sampling Nutrient Results

Leaf tissue concentrations of various macronutrient and micronutrients are graphically displayed below.



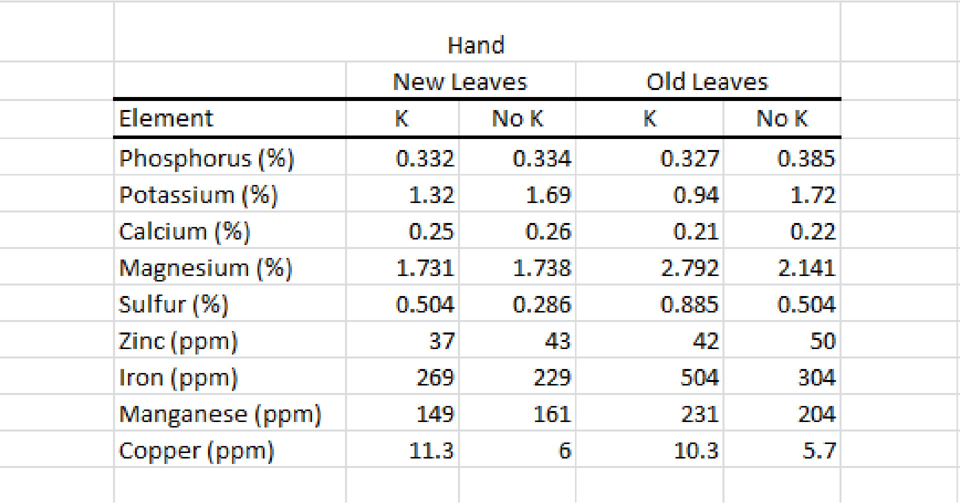
Eggleston				
	New Leaves		Old Leaves	
Element	K	No K	K	No K
Phosphorus (%)	0.317	0.294	0.237	0.209
Potassium (%)	1.11	1.47	1.03	1.46
Calcium (%)	0.31	0.28	0.2	0.17
Magnesium (%)	1.822	1.608	2.661	2.431
Sulfur (%)	0.755	0.55	1.059	0.814
Zinc (ppm)	323	40	97	43
Iron (ppm)	234	190	248	385
Manganese (ppm)	336	200	570	285
Copper (ppm)	9	9.2	7.1	8.1

Figure B.48. In-season tissue sampling (R6 growth stage; newest trifoliates and oldest trifoliates) of soybean plants between K^+ fertilization strip and control strip at ‘Eggleston’ Farm.



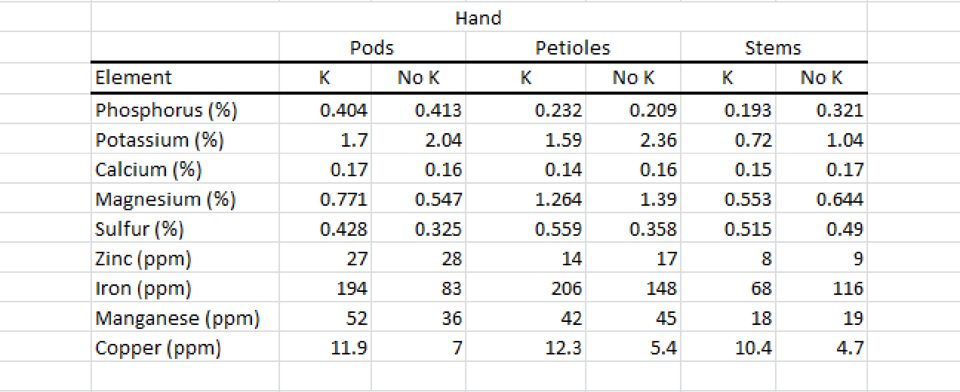
Eggleston						
	Pods		Petioles		Stems	
Element	K	No K	K	No K	K	No K
Phosphorus (%)	0.318	0.322	0.15	0.178	0.238	0.206
Potassium (%)	1.64	1.92	1.22	1.97	0.49	0.75
Calcium (%)	0.19	0.17	0.12	0.11	0.12	0.12
Magnesium (%)	0.652	0.636	1.252	1.138	0.522	0.546
Sulfur (%)	0.438	0.422	0.887	0.611	0.638	0.608
Zinc (ppm)	48	31	21	11	20	12
Iron (ppm)	133	72	72	85	61	121
Manganese (ppm)	78	55	94	54	43	30
Copper (ppm)	9.3	9.2	6	5.9	7.4	5.8

Figure B.49. In-season tissue sampling (R6 growth stage; pods, petioles, and stems) of soybean plants between K^+ fertilization strip and control strip at ‘Eggleston’ Farm.



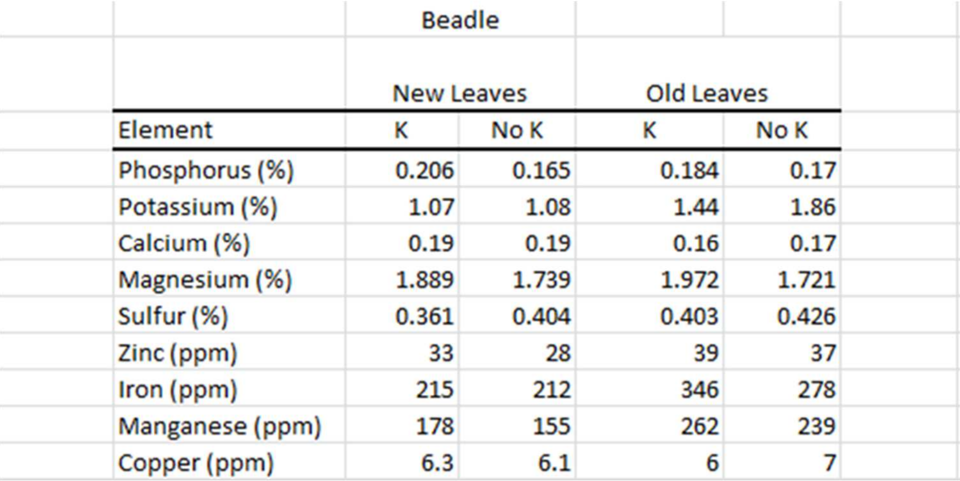
Hand				
	New Leaves		Old Leaves	
Element	K	No K	K	No K
Phosphorus (%)	0.332	0.334	0.327	0.385
Potassium (%)	1.32	1.69	0.94	1.72
Calcium (%)	0.25	0.26	0.21	0.22
Magnesium (%)	1.731	1.738	2.792	2.141
Sulfur (%)	0.504	0.286	0.885	0.504
Zinc (ppm)	37	43	42	50
Iron (ppm)	269	229	504	304
Manganese (ppm)	149	161	231	204
Copper (ppm)	11.3	6	10.3	5.7

Figure B.50. In-season tissue sampling (R6 growth stage; newest trifoliate and oldest trifoliate) of soybean plants between K^+ fertilization strip and control strip at ‘Hand’ Farm.



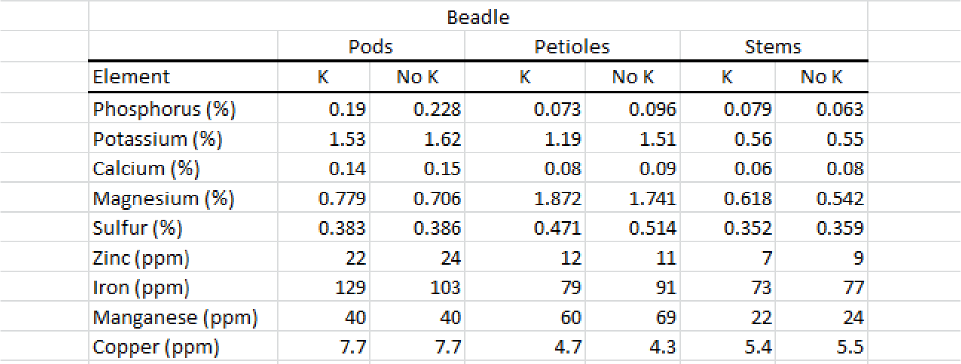
Hand						
	Pods		Petioles		Stems	
Element	K	No K	K	No K	K	No K
Phosphorus (%)	0.404	0.413	0.232	0.209	0.193	0.321
Potassium (%)	1.7	2.04	1.59	2.36	0.72	1.04
Calcium (%)	0.17	0.16	0.14	0.16	0.15	0.17
Magnesium (%)	0.771	0.547	1.264	1.39	0.553	0.644
Sulfur (%)	0.428	0.325	0.559	0.358	0.515	0.49
Zinc (ppm)	27	28	14	17	8	9
Iron (ppm)	194	83	206	148	68	116
Manganese (ppm)	52	36	42	45	18	19
Copper (ppm)	11.9	7	12.3	5.4	10.4	4.7

Figure B.51. In-season tissue sampling (R6 growth stage; pods, petioles, and stems) of soybean plants between K^+ fertilization strip and control strip at ‘Hand’ Farm.



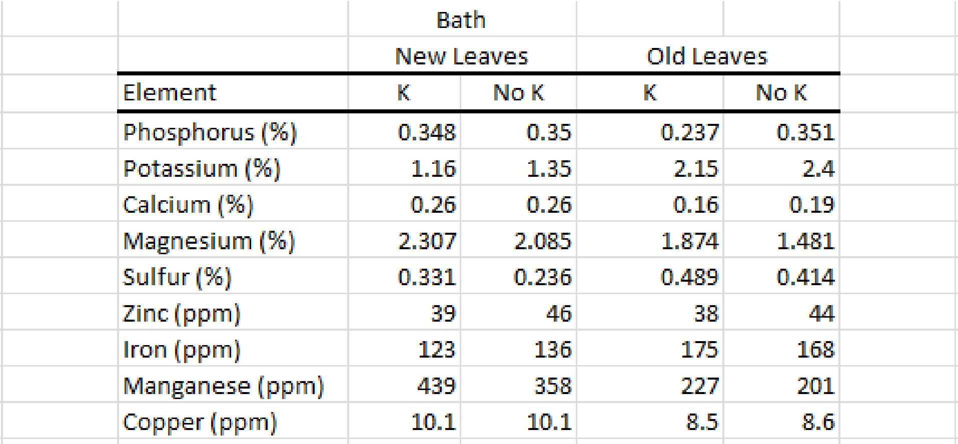
	Beadle			
	New Leaves		Old Leaves	
Element	K	No K	K	No K
Phosphorus (%)	0.206	0.165	0.184	0.17
Potassium (%)	1.07	1.08	1.44	1.86
Calcium (%)	0.19	0.19	0.16	0.17
Magnesium (%)	1.889	1.739	1.972	1.721
Sulfur (%)	0.361	0.404	0.403	0.426
Zinc (ppm)	33	28	39	37
Iron (ppm)	215	212	346	278
Manganese (ppm)	178	155	262	239
Copper (ppm)	6.3	6.1	6	7

Figure B.52. In-season tissue sampling (newest trifoliates and oldest trifoliates) of soybean plants between K^+ fertilization strip and control strip at 'Beadl'e Farm.



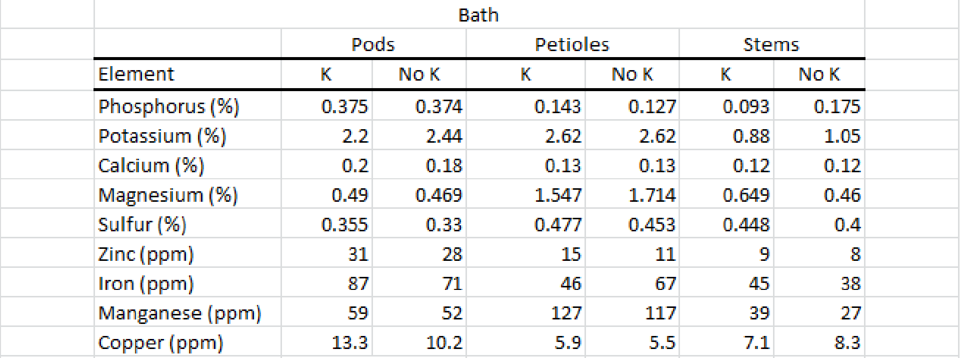
	Beadle					
	Pods		Petioles		Stems	
Element	K	No K	K	No K	K	No K
Phosphorus (%)	0.19	0.228	0.073	0.096	0.079	0.063
Potassium (%)	1.53	1.62	1.19	1.51	0.56	0.55
Calcium (%)	0.14	0.15	0.08	0.09	0.06	0.08
Magnesium (%)	0.779	0.706	1.872	1.741	0.618	0.542
Sulfur (%)	0.383	0.386	0.471	0.514	0.352	0.359
Zinc (ppm)	22	24	12	11	7	9
Iron (ppm)	129	103	79	91	73	77
Manganese (ppm)	40	40	60	69	22	24
Copper (ppm)	7.7	7.7	4.7	4.3	5.4	5.5

Figure B.53. In-season tissue sampling (R6 growth stage; pods, petioles, and stems) of soybean plants between K^+ fertilization strip and control strip at 'Beadle' Farm.



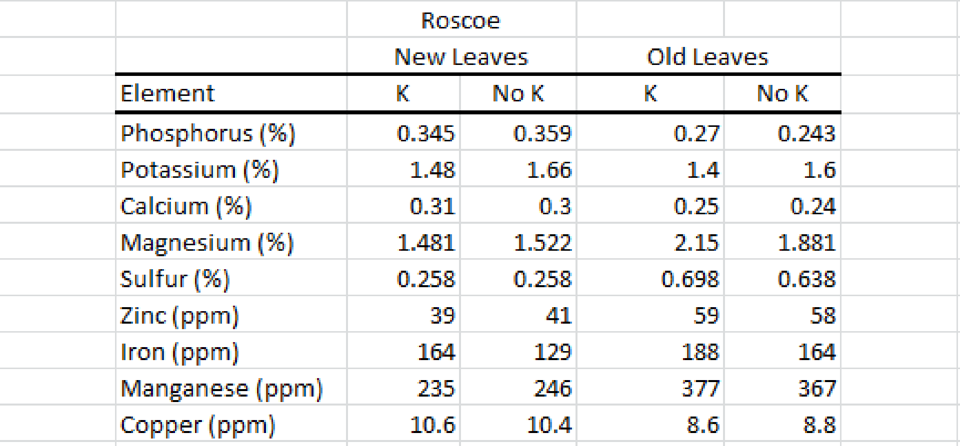
	Bath			
	New Leaves		Old Leaves	
Element	K	No K	K	No K
Phosphorus (%)	0.348	0.35	0.237	0.351
Potassium (%)	1.16	1.35	2.15	2.4
Calcium (%)	0.26	0.26	0.16	0.19
Magnesium (%)	2.307	2.085	1.874	1.481
Sulfur (%)	0.331	0.236	0.489	0.414
Zinc (ppm)	39	46	38	44
Iron (ppm)	123	136	175	168
Manganese (ppm)	439	358	227	201
Copper (ppm)	10.1	10.1	8.5	8.6

Figure B.54. In-season tissue sampling (newest trifoliates and oldest trifoliates) of soybean plants between K^+ fertilization strip and control strip at 'Bath' Farm.



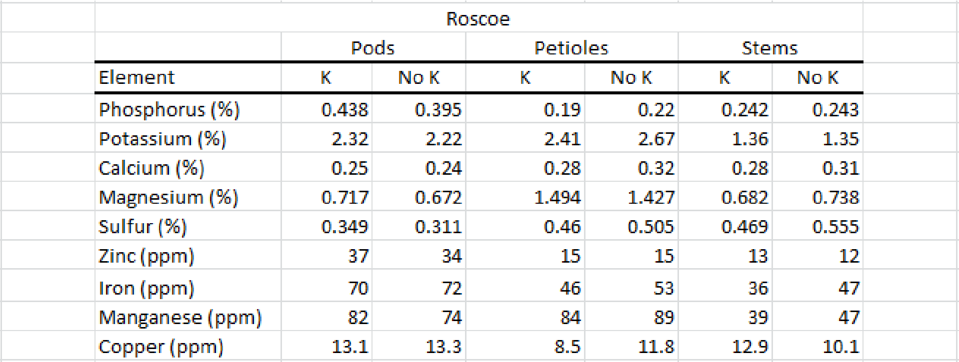
	Bath					
	Pods		Petioles		Stems	
Element	K	No K	K	No K	K	No K
Phosphorus (%)	0.375	0.374	0.143	0.127	0.093	0.175
Potassium (%)	2.2	2.44	2.62	2.62	0.88	1.05
Calcium (%)	0.2	0.18	0.13	0.13	0.12	0.12
Magnesium (%)	0.49	0.469	1.547	1.714	0.649	0.46
Sulfur (%)	0.355	0.33	0.477	0.453	0.448	0.4
Zinc (ppm)	31	28	15	11	9	8
Iron (ppm)	87	71	46	67	45	38
Manganese (ppm)	59	52	127	117	39	27
Copper (ppm)	13.3	10.2	5.9	5.5	7.1	8.3

Figure B.55. In-season tissue sampling (R6 growth stage; pods, petioles, and stems) of soybean plants between K^+ fertilization strip and control strip at 'Bath' Farm.



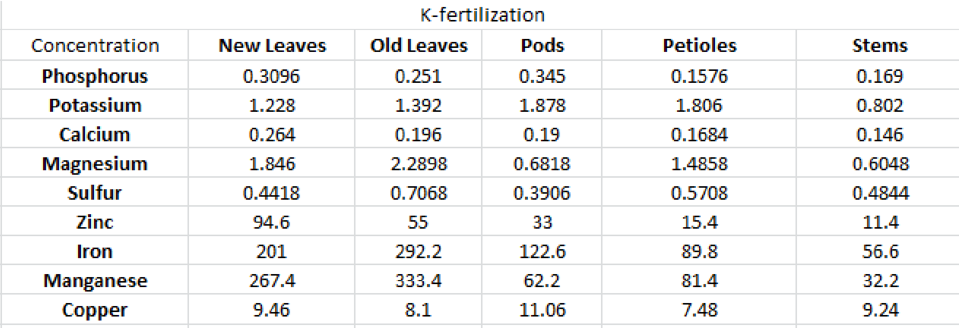
	Roscoe			
	New Leaves		Old Leaves	
Element	K	No K	K	No K
Phosphorus (%)	0.345	0.359	0.27	0.243
Potassium (%)	1.48	1.66	1.4	1.6
Calcium (%)	0.31	0.3	0.25	0.24
Magnesium (%)	1.481	1.522	2.15	1.881
Sulfur (%)	0.258	0.258	0.698	0.638
Zinc (ppm)	39	41	59	58
Iron (ppm)	164	129	188	164
Manganese (ppm)	235	246	377	367
Copper (ppm)	10.6	10.4	8.6	8.8

Figure B.56. In-season tissue sampling (newest trifoliates and oldest trifoliates) of soybean plants between K^+ fertilization strip and control strip at 'Roscoe' Farm.



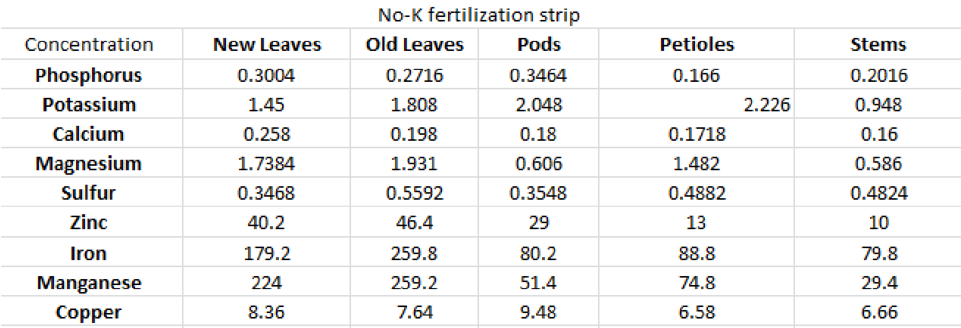
	Roscoe					
	Pods		Petioles		Stems	
Element	K	No K	K	No K	K	No K
Phosphorus (%)	0.438	0.395	0.19	0.22	0.242	0.243
Potassium (%)	2.32	2.22	2.41	2.67	1.36	1.35
Calcium (%)	0.25	0.24	0.28	0.32	0.28	0.31
Magnesium (%)	0.717	0.672	1.494	1.427	0.682	0.738
Sulfur (%)	0.349	0.311	0.46	0.505	0.469	0.555
Zinc (ppm)	37	34	15	15	13	12
Iron (ppm)	70	72	46	53	36	47
Manganese (ppm)	82	74	84	89	39	47
Copper (ppm)	13.1	13.3	8.5	11.8	12.9	10.1

Figure B.57. In-season tissue sampling (R6 growth stage; pods, petioles, and stems) of soybean plants between K^+ fertilization strip and control strip at 'Bath' Farm.



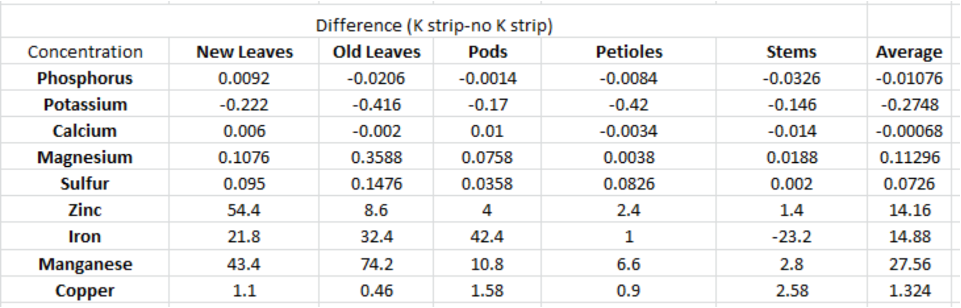
	K-fertilization				
Concentration	**New Leaves**	**Old Leaves**	**Pods**	**Petioles**	**Stems**
Phosphorus	0.3096	0.251	0.345	0.1576	0.169
Potassium	1.228	1.392	1.878	1.806	0.802
Calcium	0.264	0.196	0.19	0.1684	0.146
Magnesium	1.846	2.2898	0.6818	1.4858	0.6048
Sulfur	0.4418	0.7068	0.3906	0.5708	0.4844
Zinc	94.6	55	33	15.4	11.4
Iron	201	292.2	122.6	89.8	56.6
Manganese	267.4	333.4	62.2	81.4	32.2
Copper	9.46	8.1	11.06	7.48	9.24

Figure B.58. Average In-season tissue sampling results from K-fertilization strip.



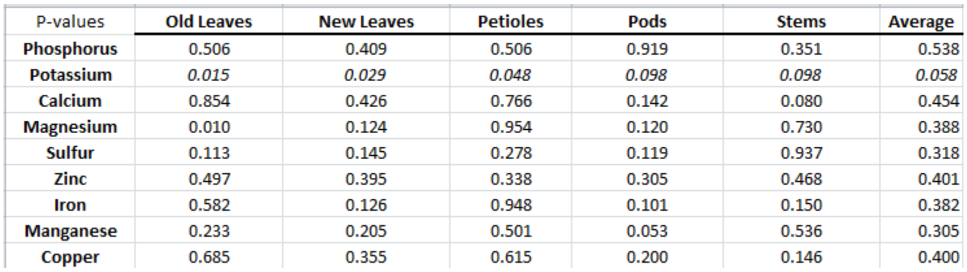
	No-K fertilization strip				
Concentration	**New Leaves**	**Old Leaves**	**Pods**	**Petioles**	**Stems**
Phosphorus	0.3004	0.2716	0.3464	0.166	0.2016
Potassium	1.45	1.808	2.048	2.226	0.948
Calcium	0.258	0.198	0.18	0.1718	0.16
Magnesium	1.7384	1.931	0.606	1.482	0.586
Sulfur	0.3468	0.5592	0.3548	0.4882	0.4824
Zinc	40.2	46.4	29	13	10
Iron	179.2	259.8	80.2	88.8	79.8
Manganese	224	259.2	51.4	74.8	29.4
Copper	8.36	7.64	9.48	6.58	6.66

Figure B.59. Average In-season tissue sampling results from No-K fertilization strip.



	Difference (K strip-no K strip)					
Concentration	**New Leaves**	**Old Leaves**	**Pods**	**Petioles**	**Stems**	**Average**
Phosphorus	0.0092	-0.0206	-0.0014	-0.0084	-0.0326	-0.01076
Potassium	-0.222	-0.416	-0.17	-0.42	-0.146	-0.2748
Calcium	0.006	-0.002	0.01	-0.0034	-0.014	-0.00068
Magnesium	0.1076	0.3588	0.0758	0.0038	0.0188	0.11296
Sulfur	0.095	0.1476	0.0358	0.0826	0.002	0.0726
Zinc	54.4	8.6	4	2.4	1.4	14.16
Iron	21.8	32.4	42.4	1	-23.2	14.88
Manganese	43.4	74.2	10.8	6.6	2.8	27.56
Copper	1.1	0.46	1.58	0.9	2.58	1.324

Figure B.60. Tissue sampling results showing difference between K-fertilization strip and No-K fertilization strip.

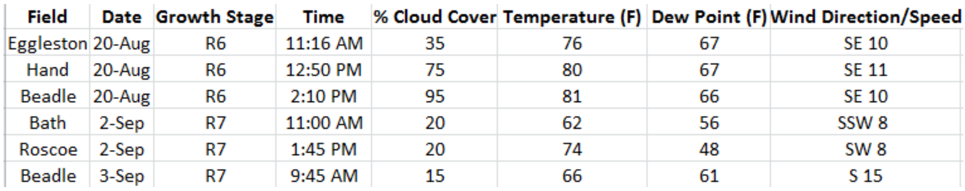


P-values	**Old Leaves**	**New Leaves**	**Petioles**	**Pods**	**Stems**	**Average**
Phosphorus	0.506	0.409	0.506	0.919	0.351	0.538
Potassium	*0.015*	*0.029*	*0.048*	*0.098*	*0.098*	*0.058*
Calcium	0.854	0.426	0.766	0.142	0.080	0.454
Magnesium	0.010	0.124	0.954	0.120	0.730	0.388
Sulfur	0.113	0.145	0.278	0.119	0.937	0.318
Zinc	0.497	0.395	0.338	0.305	0.468	0.401
Iron	0.582	0.126	0.948	0.101	0.150	0.382
Manganese	0.233	0.205	0.501	0.053	0.536	0.305
Copper	0.685	0.355	0.615	0.200	0.146	0.400

Figure B.61. P-values determined for in-season tissue sampling results compared between K and No K fertilization strips.

Stomatal Conductance

Table B.1 illustrates weather conditions experienced during sampling time for stomatal conductance.



Field	**Date**	**Growth Stage**	**Time**	**% Cloud Cover**	**Temperature (F)**	**Dew Point (F)**	**Wind Direction/Speed**
Eggleston	20-Aug	R6	11:16 AM	35	76	67	SE 10
Hand	20-Aug	R6	12:50 PM	75	80	67	SE 11
Beadle	20-Aug	R6	2:10 PM	95	81	66	SE 10
Bath	2-Sep	R7	11:00 AM	20	62	56	SSW 8
Roscoe	2-Sep	R7	1:45 PM	20	74	48	SW 8
Beadle	3-Sep	R7	9:45 AM	15	66	61	S 15

Table B.7. Weather conditions at each site location for leaf porometer use

APPENDIX C

CHAPTER 3

ON-FARM RESEARCH USING ESN TO DETERMINE YIELD INCREASES UNDER INTENSIVE MANAGEMENT

SAS code used for statistical procedures

```
libname stovrem "C:\nickschiltz";
PROC IMPORT
           OUT=K_leaching (keep= Structure ug_mL Rain)
         DATAFILE="C:\nickschiltz\K_Leaching_Experiment"
           DBMS=Excel Replace;
         SHEET="SAS";
         GETNAMES=YES;
         MIXED=NO;
         SCANTEXT=YES;
         USEDATE=YES;
         SCANTIME=YES;
run;
/*
proc sql;
create table stovrem.k_bal_wo0N as
select plot, block, irrigate, nrate, tillage, residue, y_bal
from stovrem.y_bal where nrate in ('150n','75n', '0n');
*/
proc print data=K_leaching;
 Title 'K_Leaching_Study';

 Proc Mixed data =K_Leaching;
 class Structure ug_mL Rain ;
 model ug_mL = Structure|Rain/DDFM=SATTERTH;
 random Structure*Rain;
 lsmeans Structure|Rain/pdiff;
 ods output diffs=ppp lsmeans=mmm;
 run;
 %include 'C:\nickschiltz\PDMIX800.SAS';
 %pdmix800(PPP,MMM,alpha=.05,sort=yes);
quit;
```

APPENDIX D

CHAPTER 4

ON-FARM RESEARCH USING ESN TO DETERMINE YIELD INCREASES UNDER INTENSIVE MANAGEMENT

Site Characteristics

Only fields that which available data exists on site characteristics are provided below. The first field analyzed was named the ‘Hoitsma’ farm. The farm is located at 44.72189,-96.89995. The dominant soil types were Vienna-Brookings complex with 0-2 percent slopes that had a crop productivity index of 89. A Vienna-Brookings complex with 1 to 6 percent slopes was also included that had a crop productivity of 83.

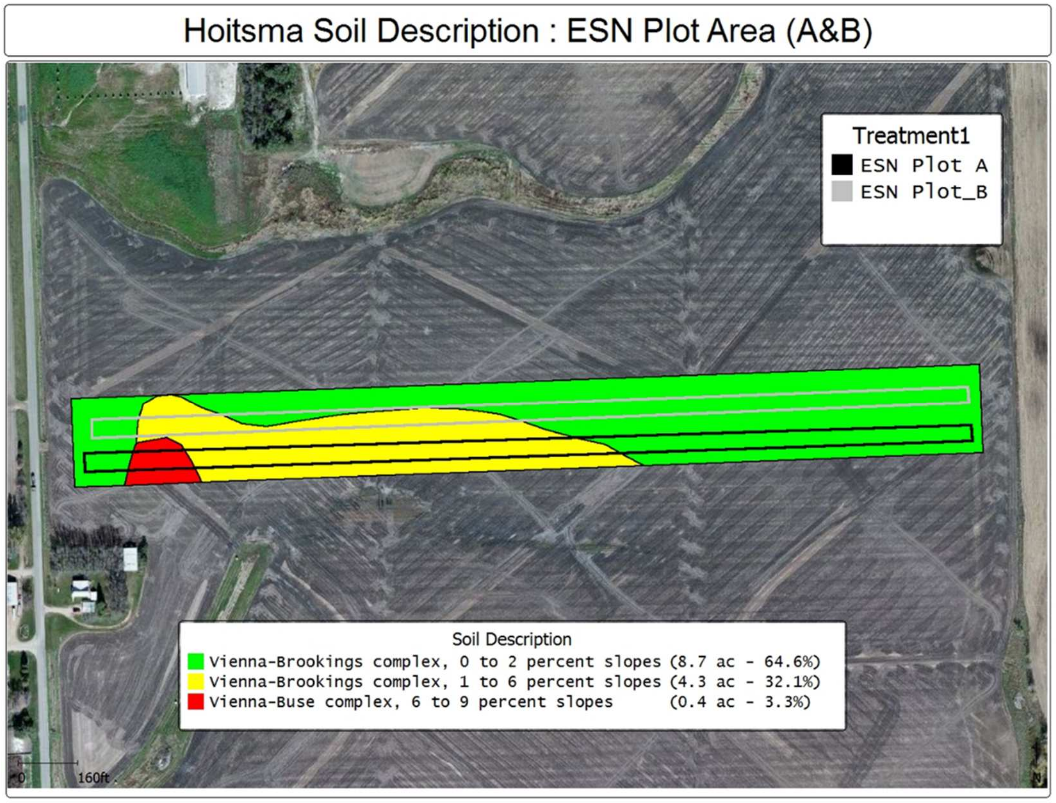


Figure D.1. Treatment plots superimposed on a soil type map generated from Web Soil Survey data of 'Hoitsma' farm.

The second field was named the 'Crooks' farm, located at 43.62294, -96.836067. The plot area contained a cadre of soil types with a wide range of vegetative productivity classes. These included a Crofton-Nora complex with 9 to 15 percent slopes (vegetative index of 52), Moody-Nora complex with 2 to 6 percent slopes (vegetative index of 88), Nora-Crofton complex with 6 to 9 percent slopes (vegetative index of 68), Trent silty clay loam with 1 to 3 percent slopes (vegetative index of 98), and a Whitewood silty clay loam with 0 to 2 percent slopes (vegetative index of 84). Soil type maps and landscape positions were also created for the Crooks farm shown below.

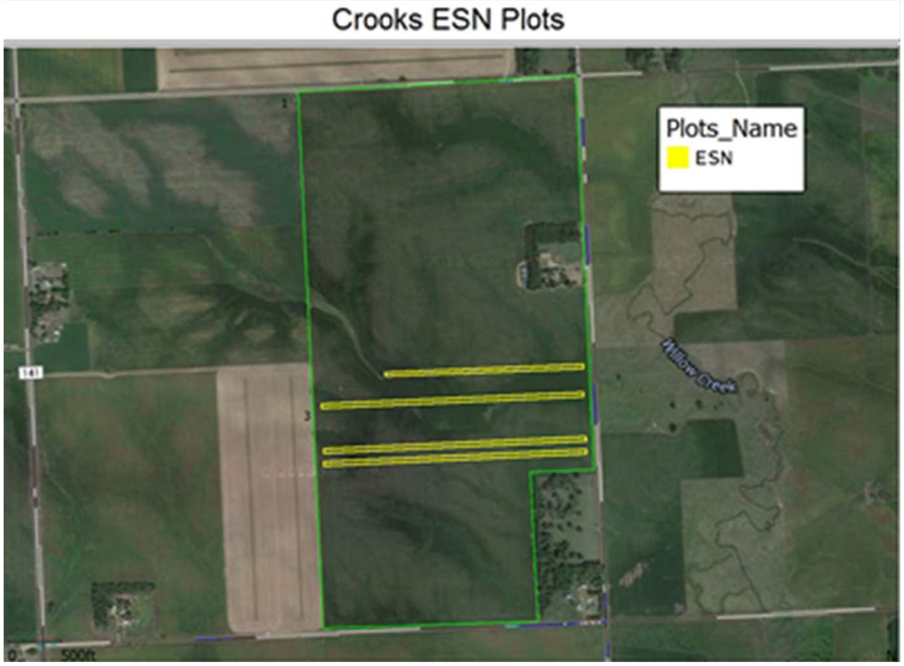


Figure D.2. ESN strips outlined across an aerial image of producer field of 'Crooks' farm.

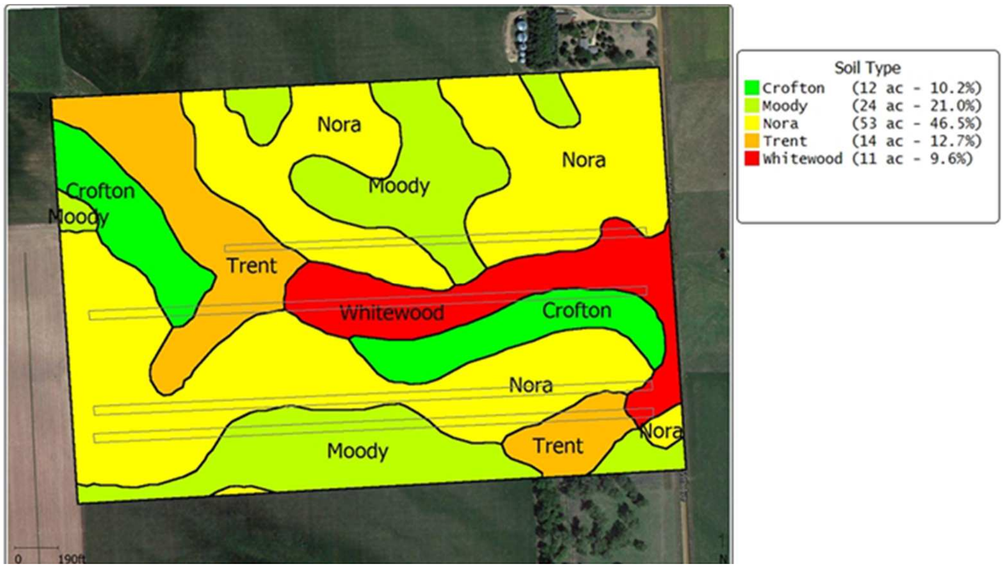


Figure D.3. ESN strips superimposed on a soil type map generated from Web Soil Survey data of ‘Crooks’ farm.

Crooks ESN Plots: Elevation Map

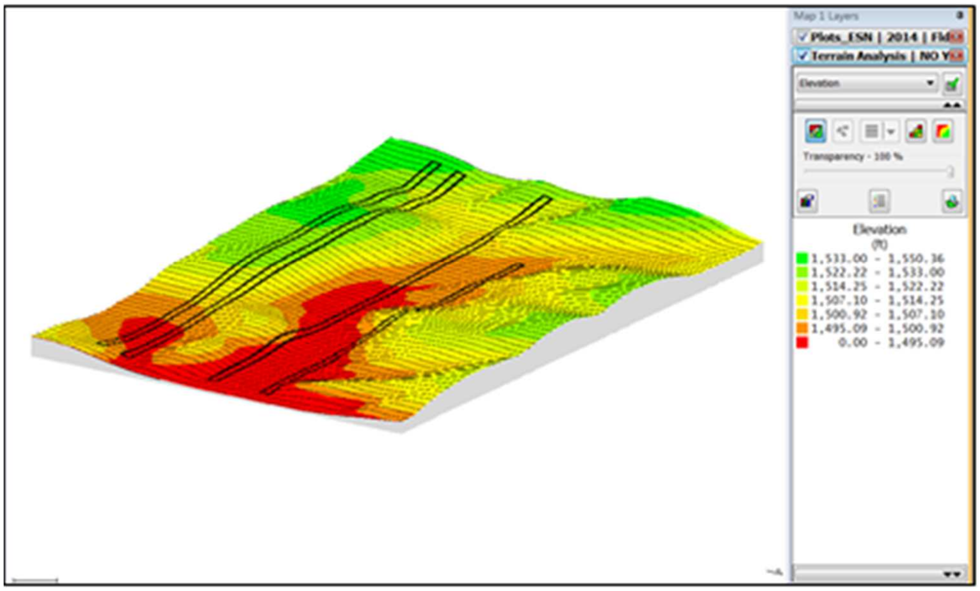


Figure D.4. ESN strips displayed across elevation using LiDar imagery of ‘Crooks’ farm.

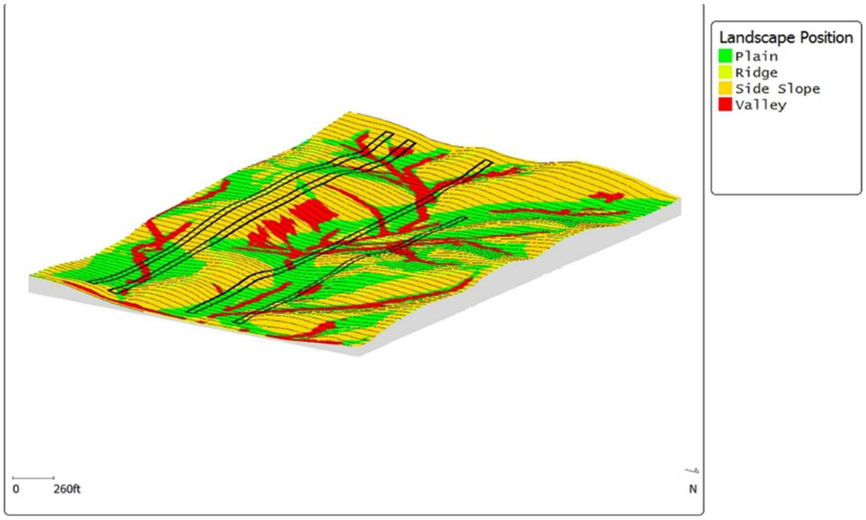


Figure D.5. ESN strips shown across landscape position obtained from Web Soil Survey data of ‘Crooks’ farm.

The third field was named the ‘Converse farm.’ It is located at 44.42414, -97.180776. The dominant soil types were a Poinsett-Buse-Waubay complex with 1 to 6 percent slopes (vegetative index of 81), Poinsett-Buse-Waubay complex with 2 to 9 percent slopes (vegetative index of 71), Poinsett-Waubay silty clay loams with 1 to 6 percent slopes (vegetative index of 89), and Waubay-Badger silty clay loams (vegetative index of 90). Treatment areas (shown below) reflect where different nitrogen rates were applied. Each of the maps was superimposed on a wide range of imagery, including soil classification and elevation, also provided below.

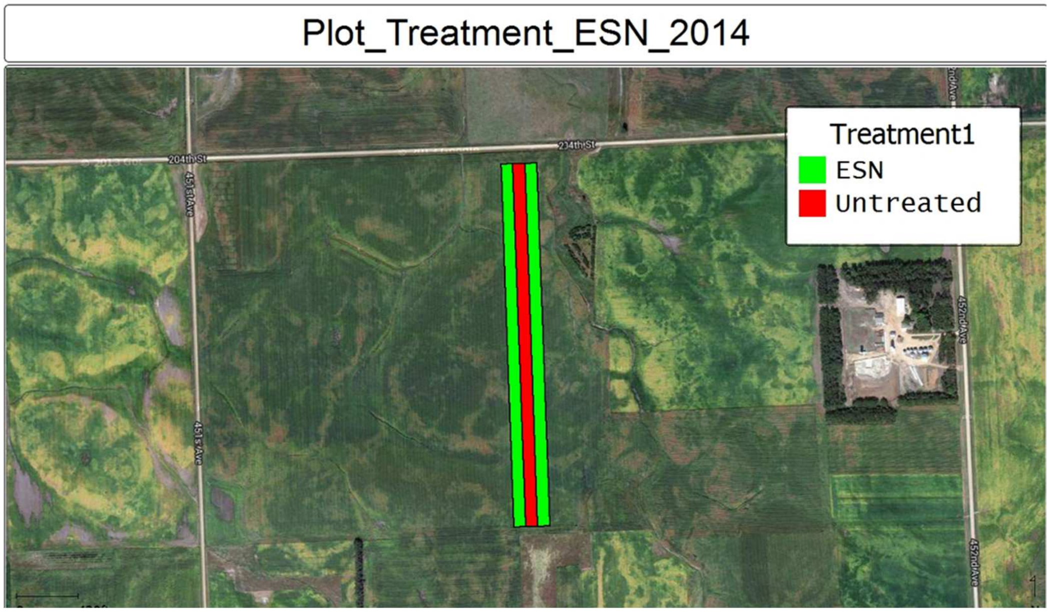


Figure D.6. Map outlining treatment plot areas and strips used for analysis of 'Converse' farm.

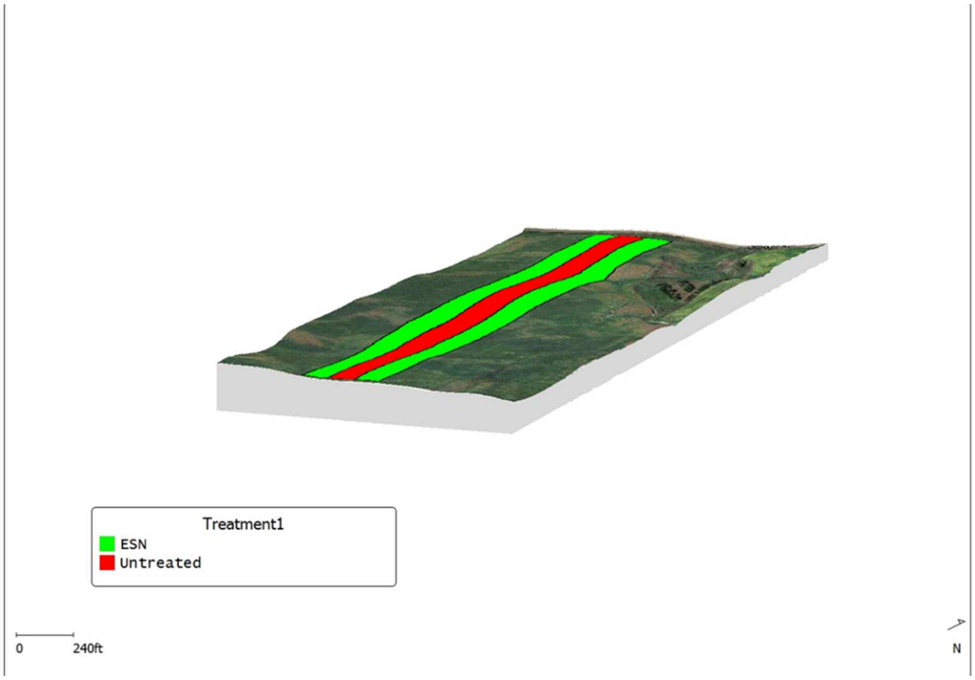


Figure D.7. Plot treatment strips superimposed on LiDar data showing elevation differences of 'Converse' farm.

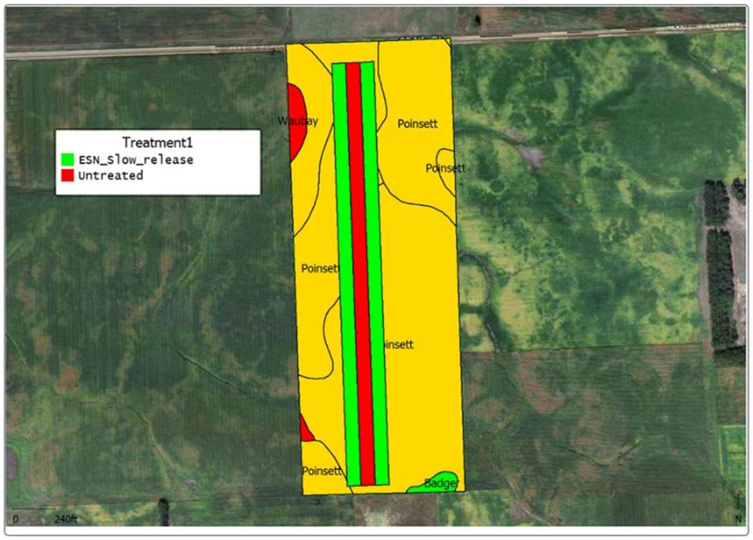


Figure D.8. Plot treatment strips displayed across soil classification data obtained from Web Soil Survey of ‘Converse’ farm.

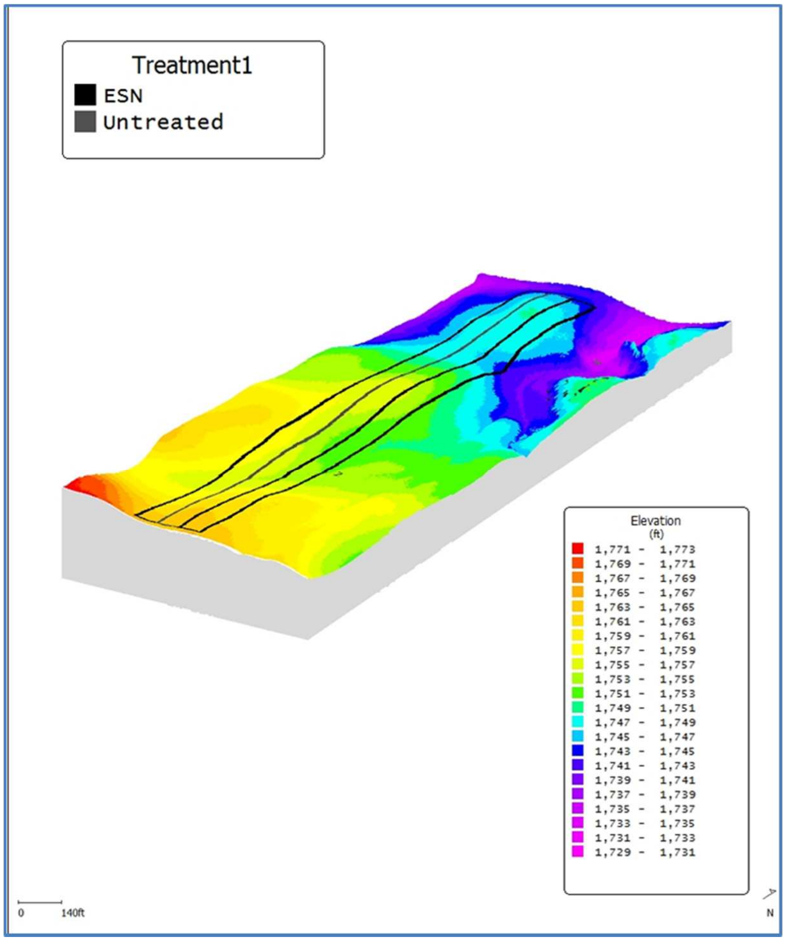


Figure D.9. ESN and control strips superimposed on elevation map derived from LiDar imagery of ‘Converse’ farm.

Four fields were analyzed through a cooperation with on-farm producers through Hefty Seed Brand Company (Baltic, South Dakota). The first of four fields was termed the ‘Brian’ field and is located at 43.72595,-96.687486. The second of four fields was the ‘Tuffy East’ farm that is located at 43.75838, -96.692517. The third of four fields was the ‘Tuffy West’ farm and is located at 43.76023, -96.706059. The final of four fields was the ‘Olaf’ farm that is located at 43.7532, -96.677143.

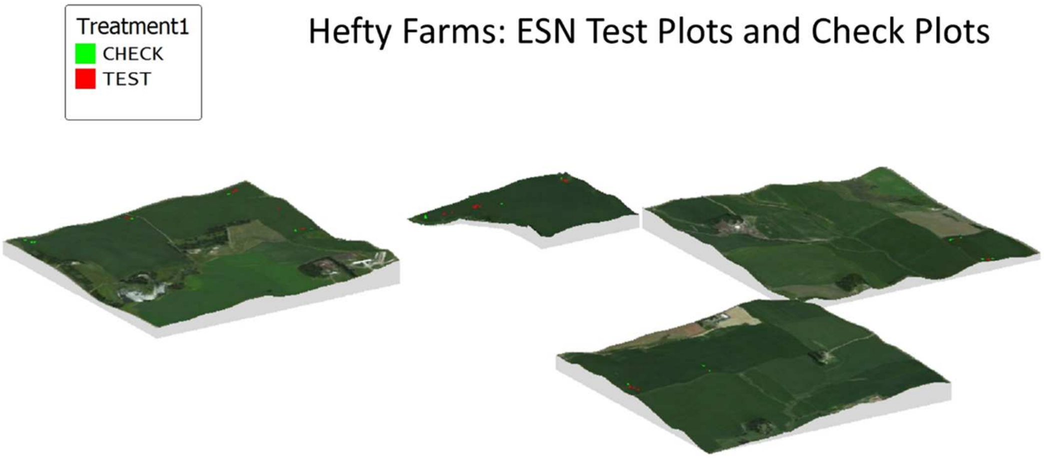


Figure D.10. Collection of ESN on-farm research farms utilized through Hefty Seed Brand. ESN strips shown in red and check strips in green.

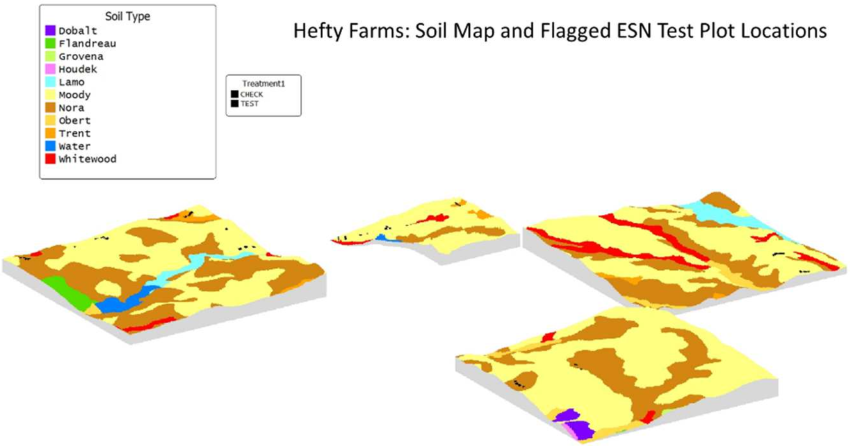


Figure D.11. Hefty Seed Brand producer fields showing strip treatment areas superimposed across soil type maps.

The eighth field analyzed was the 'Flandreau East' field and is located at 44.72189, -96.685256.

Figure D.12. Unmanned Aerial Image obtained on September 2, 2014, with the use of an unmanned aerial image of 'Flandreau East Field.' Obtained courtesy of cooperator.

The ninth field analyzed was the 'Hendricks' field that is located at 45.00711, -97.070413.

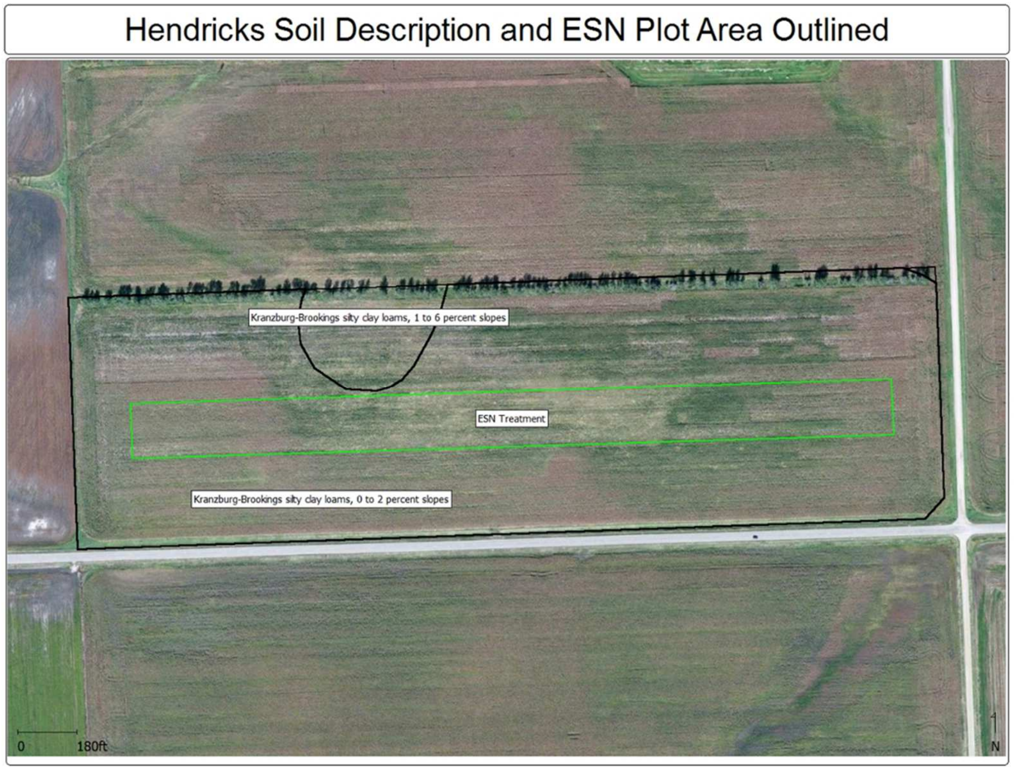


Figure D.13. Soil description of 'Hendricks' farm obtained for Web Soil Survey encompassing the ESN treatment plot area.

Site Yield Monitor/Yield Difference Maps of Treatment Strips

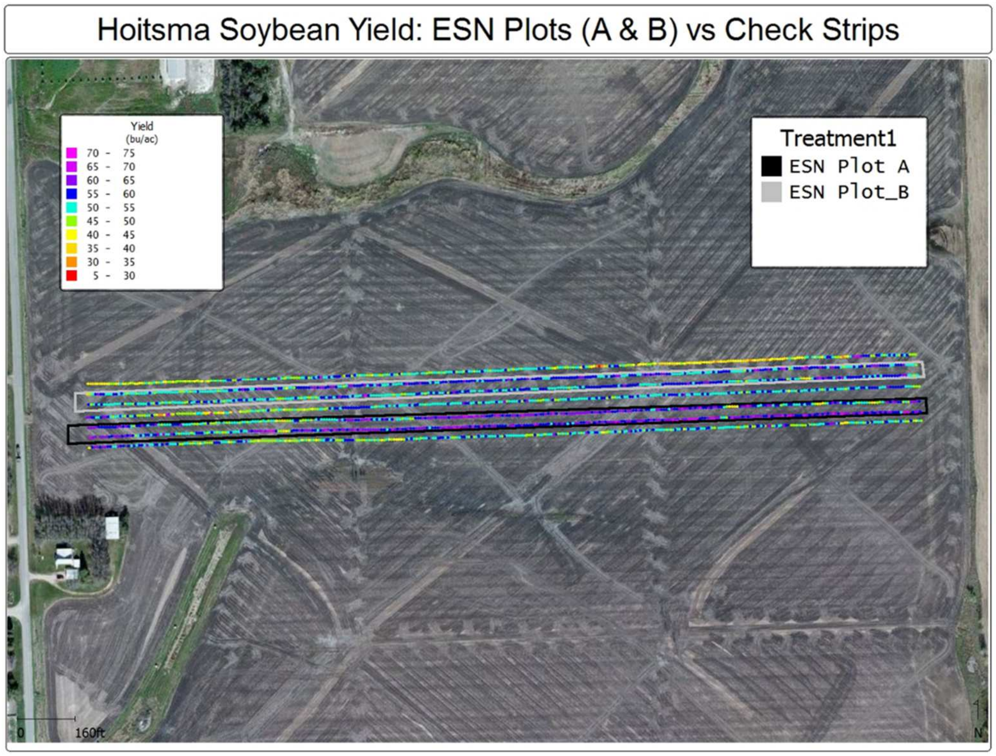

Hoitsma Soybean Yield: ESN Plots (A & B) vs Check Strips

Figure D.14. Cleaned soybean yield data of ‘Hoitsma’ farm showing ESN plot spatial yield in grey/black boxes with nearest control strip on both sides of plot yield data.

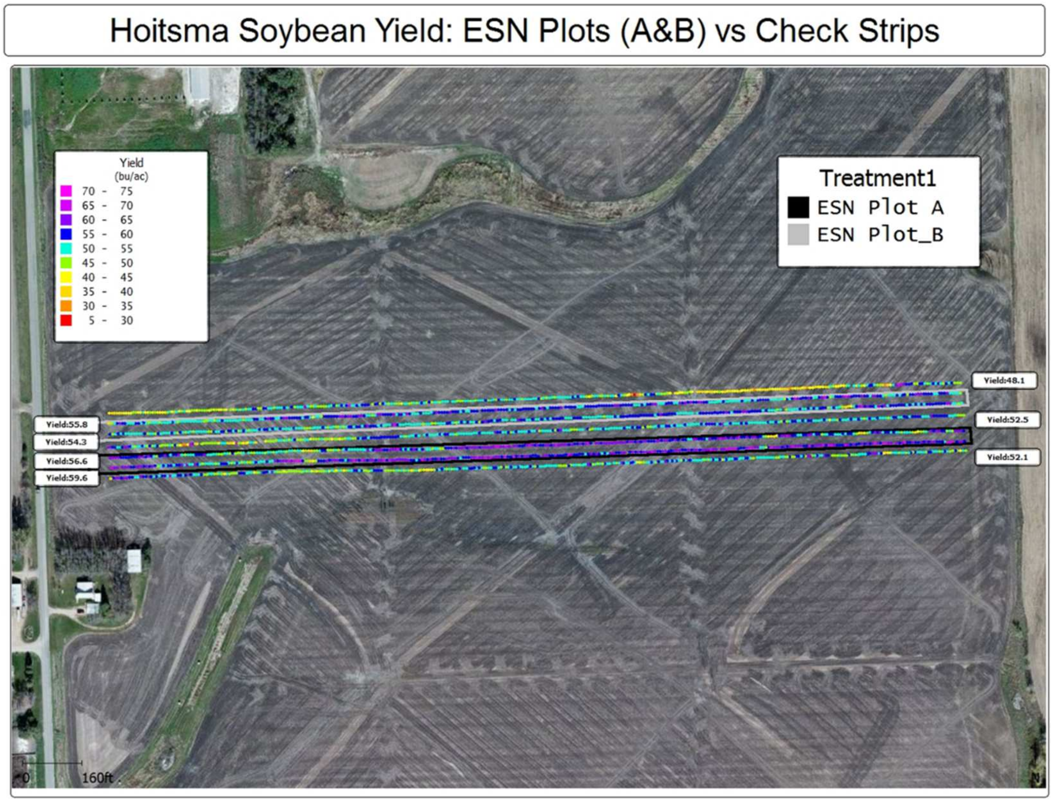

Hoitsma Soybean Yield: ESN Plots (A&B) vs Check Strips

Figure D.15. Cleaned soybean yield data of 'Hoitsma' farm showing ESN plot spatial yield in grey/black boxes with nearest control strip on both sides of plot yield data. Swaths labeled according to strip treatments.

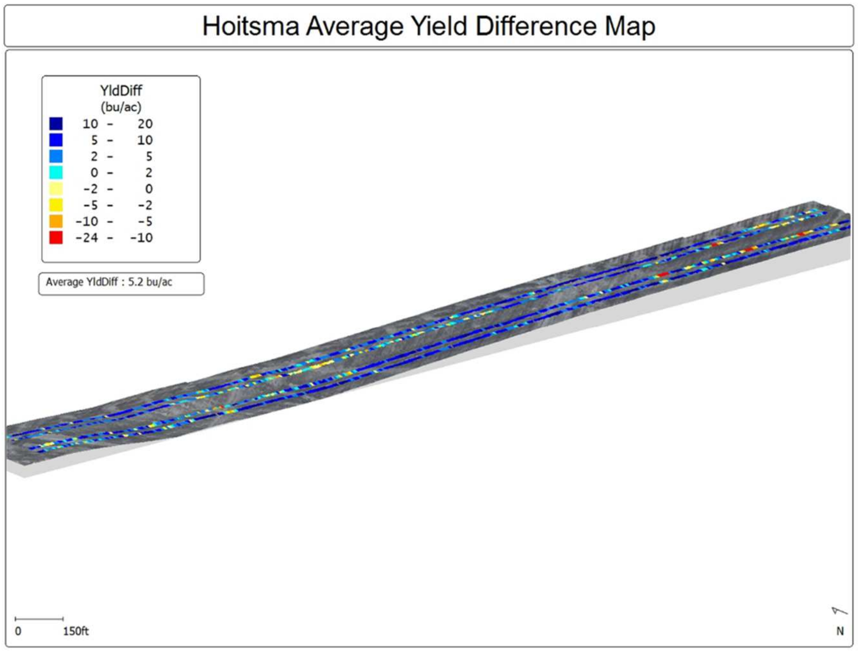

Hoitsma Average Yield Difference Map

Figure D.16. Yield difference map (Chapter 6) superimposed on an elevation map for ‘Hoitsma’ farm generated from LiDar imagery.

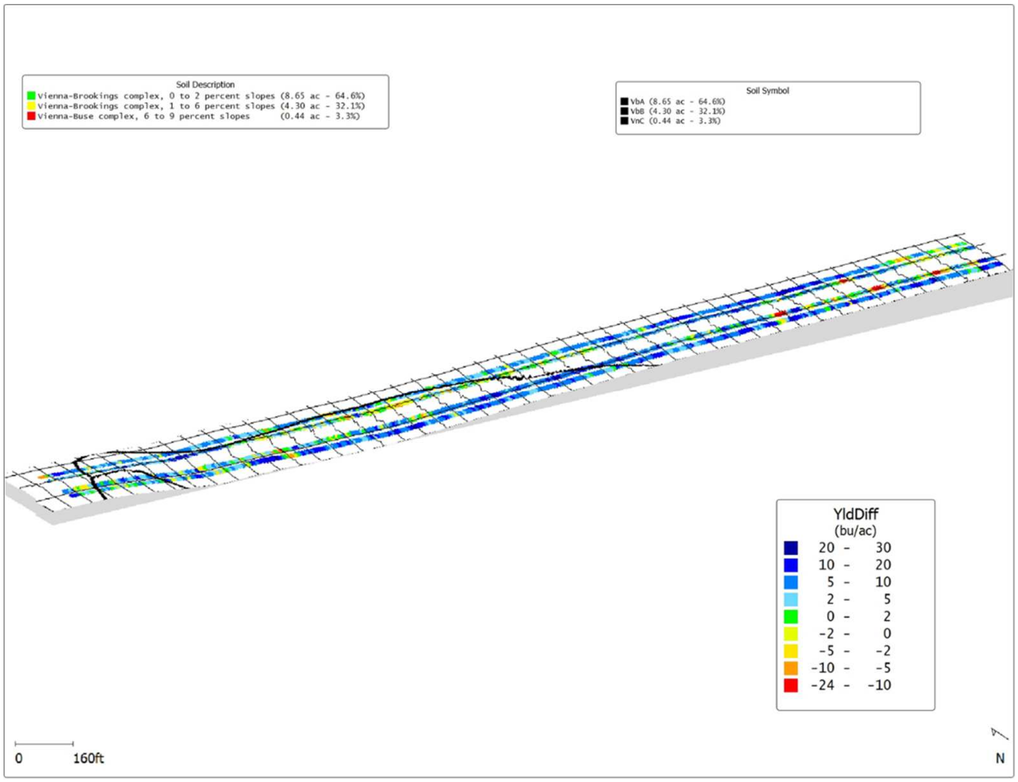
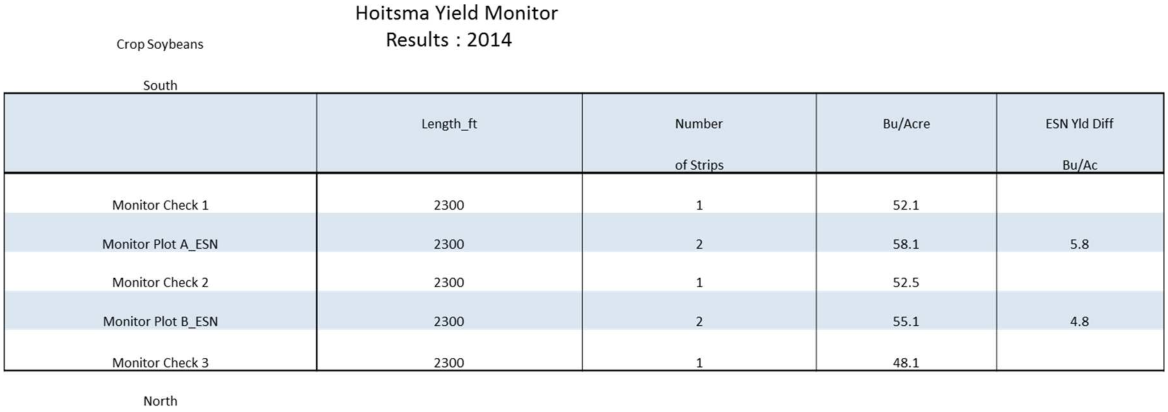


Figure D.17. Yield difference map (Chapter 6) superimposed on a soil type map for ‘Hoitsma’ farm.



Hoitsma Yield Monitor
Results : 2014

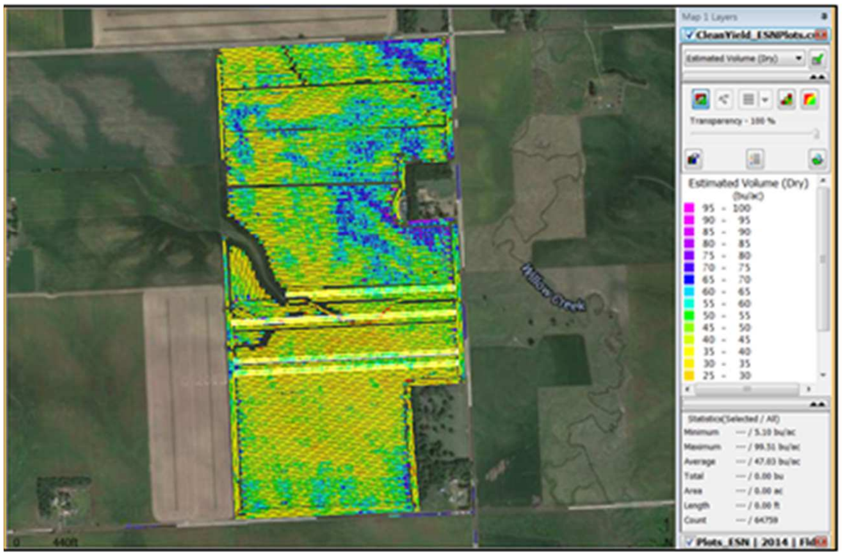
Crop Soybeans

South

	Length_ft	Number of Strips	Bu/Acre	ESN Yld Diff Bu/Ac
Monitor Check 1	2300	1	52.1	
Monitor Plot A_ESN	2300	2	58.1	5.8
Monitor Check 2	2300	1	52.5	
Monitor Plot B_ESN	2300	2	55.1	4.8
Monitor Check 3	2300	1	48.1	

North

Figure D.18. Tabular arrangement specifying number of treatment strips identification with estimated yield and yield differences associated to ESN fertilization (expansion of Figures)


Crooks ESN Plots 2014

Statistics(Selected / All)

Minimum	--- / 5.10 bu/ac
Maximum	--- / 99.31 bu/ac
Average	--- / 47.03 bu/ac
Total	--- / 0.00 bu
Area	--- / 0.00 ac
Length	--- / 0.00 ft
Count	--- / 64759

Figure D.19. Cleaned yield monitor data from 'Crooks' farm illustrating whole-yield grain yield with ESN treatment plot area superimposed.

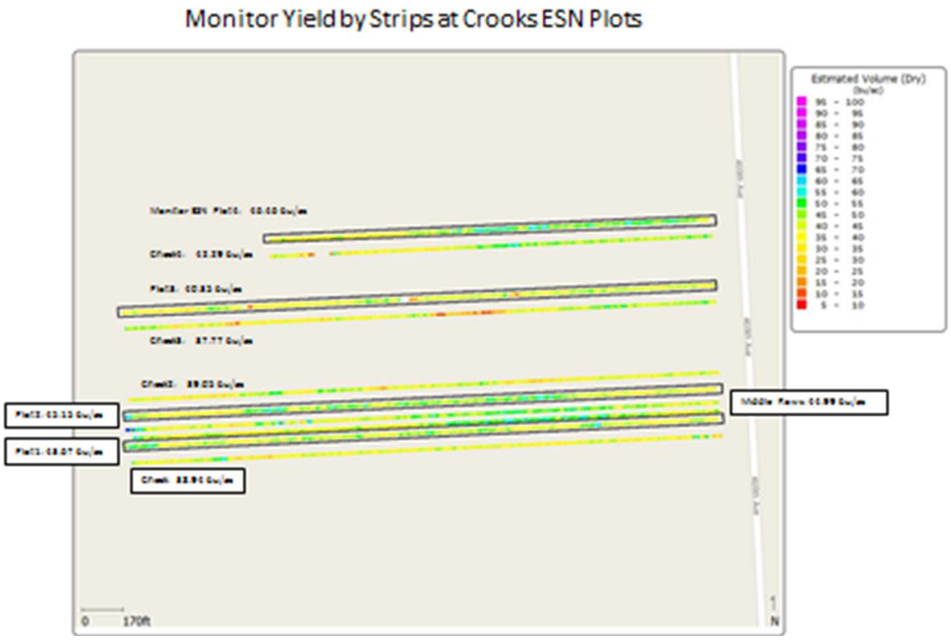


Figure D.20. Cleaned yield monitor data illustrating yield across ESN plot and check areas at 'Crooks' farm.

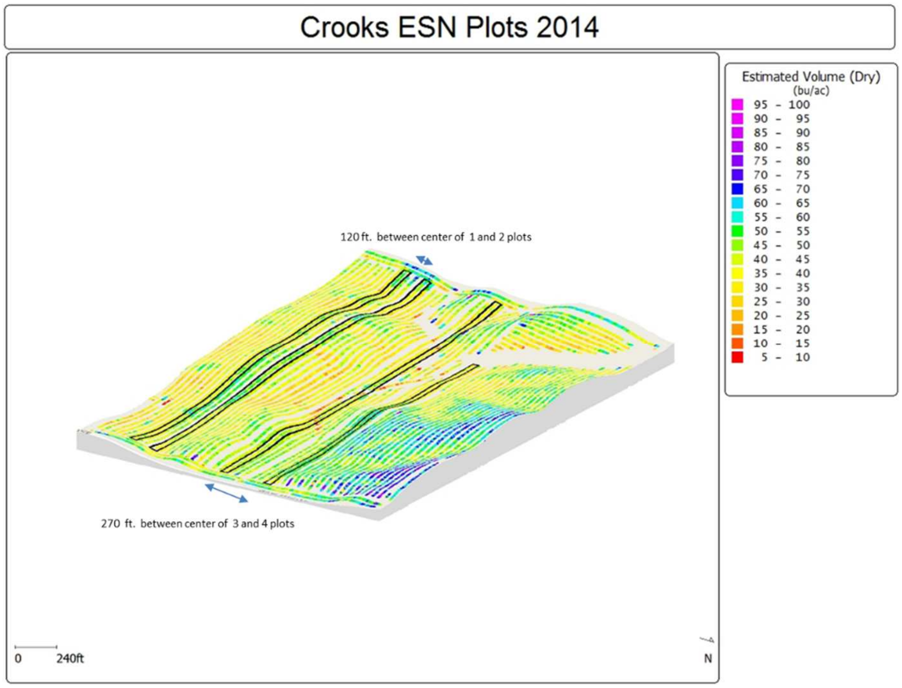


Figure D.21. Estimated dry grain yield of 'Crooks' farm superimposed on soil topography map generated from LiDar imagery.

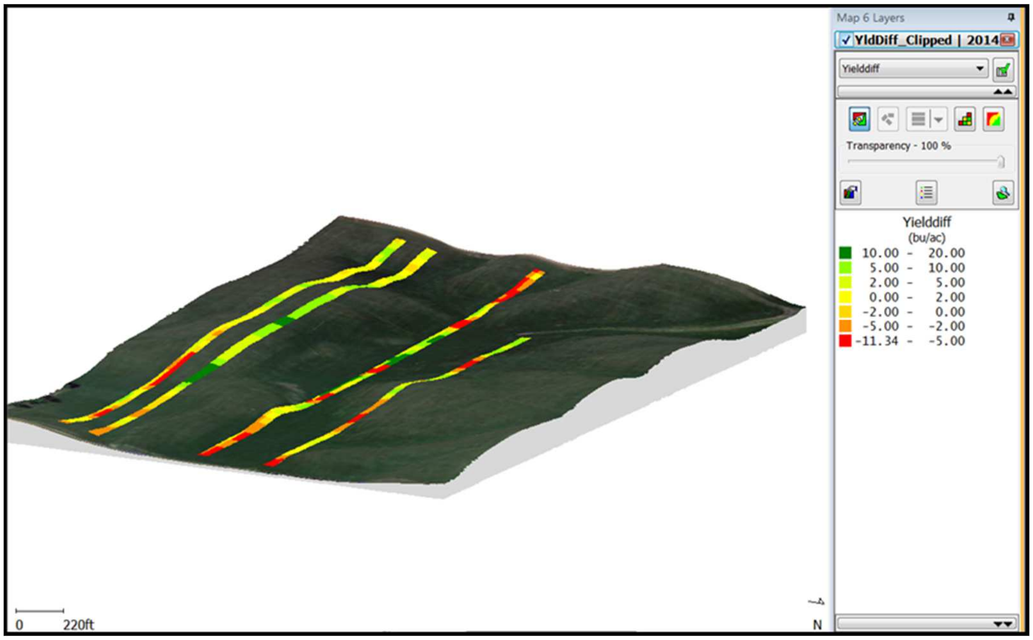


Figure D.22. Yield difference map (Chapter 6) created for ‘Crooks’ farm for ESN treatment strips minus interpolated yield.

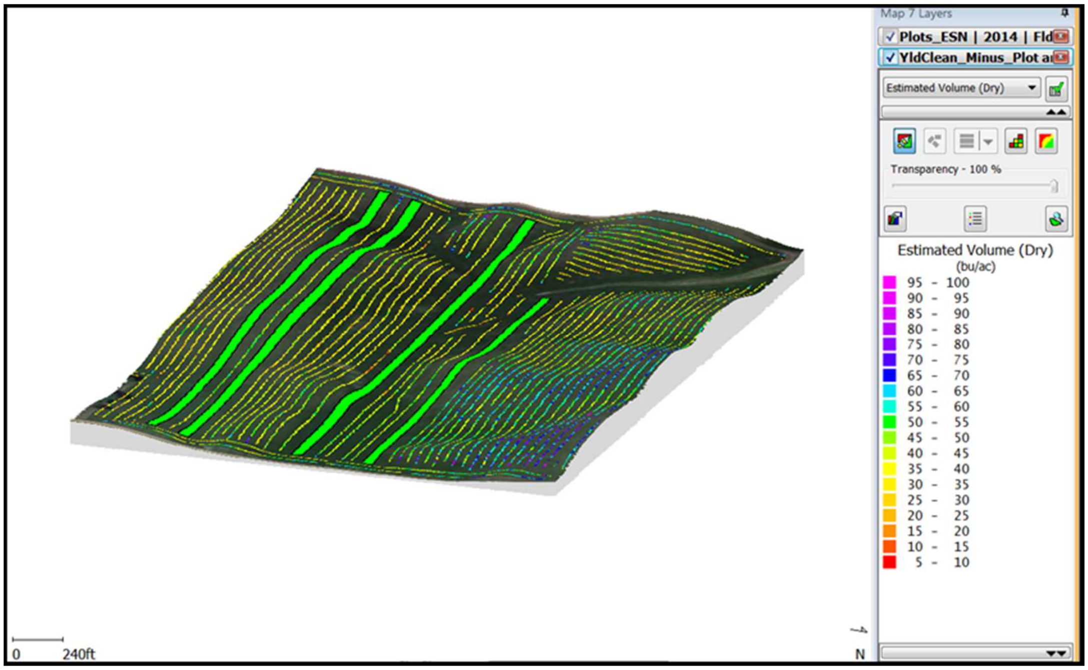
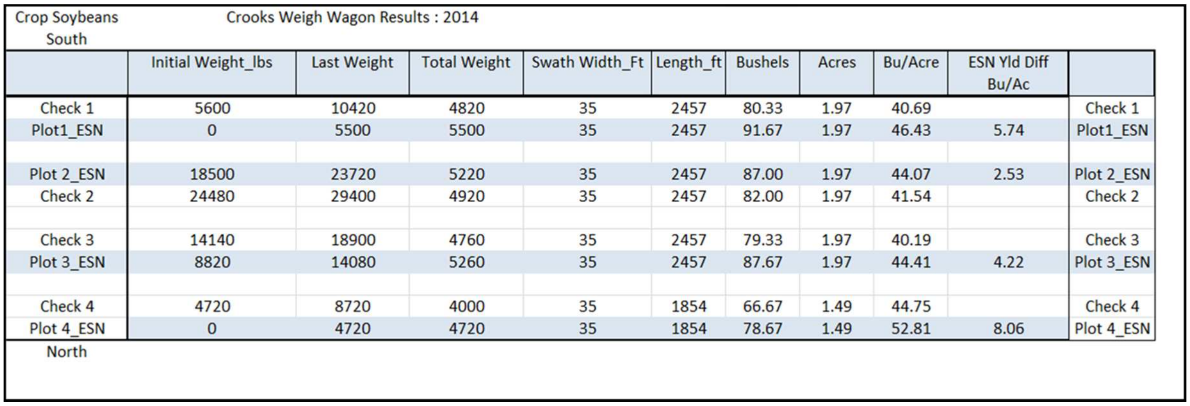


Figure D.23. Yield difference map (Chapter 6) created for ‘Crooks’ farm with ESN treatment strips showing interpolated yield.



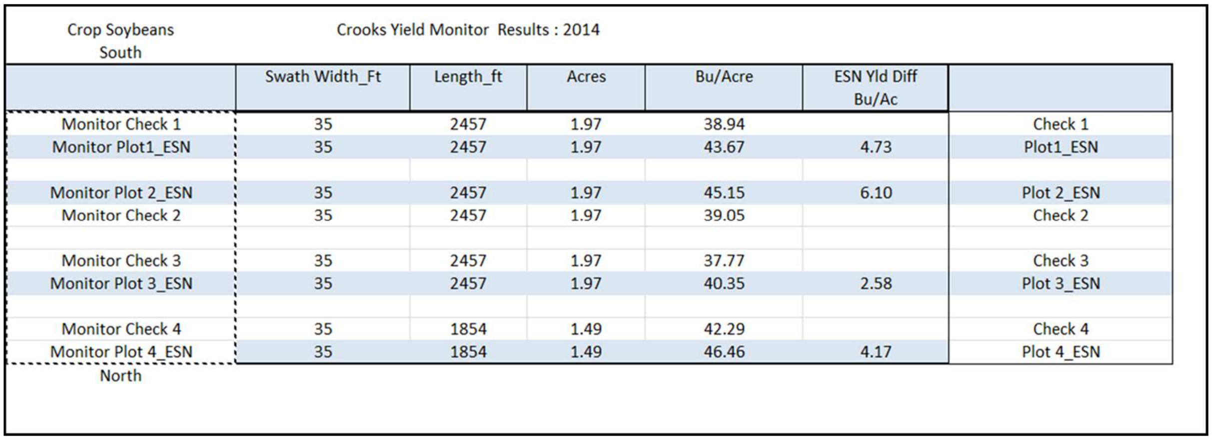
Crop Soybeans
South

Crooks Weigh Wagon Results : 2014

	Initial Weight_lbs	Last Weight	Total Weight	Swath Width_Ft	Length_ft	Bushels	Acres	Bu/Acre	ESN Yld Diff Bu/Ac	
Check 1	5600	10420	4820	35	2457	80.33	1.97	40.69		Check 1
Plot1_ESN	0	5500	5500	35	2457	91.67	1.97	46.43	5.74	Plot1_ESN
Plot 2_ESN	18500	23720	5220	35	2457	87.00	1.97	44.07	2.53	Plot 2_ESN
Check 2	24480	29400	4920	35	2457	82.00	1.97	41.54		Check 2
Check 3	14140	18900	4760	35	2457	79.33	1.97	40.19		Check 3
Plot 3_ESN	8820	14080	5260	35	2457	87.67	1.97	44.41	4.22	Plot 3_ESN
Check 4	4720	8720	4000	35	1854	66.67	1.49	44.75		Check 4
Plot 4_ESN	0	4720	4720	35	1854	78.67	1.49	52.81	8.06	Plot 4_ESN

North

Figure D.24. Tabular arrangement for weigh wagon results for 'Crooks' farm displaying yield across ESN and control strips. Yield differences also shown.



Crop Soybeans
South

Crooks Yield Monitor Results : 2014

	Swath Width_Ft	Length_ft	Acres	Bu/Acre	ESN Yld Diff Bu/Ac	
Monitor Check 1	35	2457	1.97	38.94		Check 1
Monitor Plot1_ESN	35	2457	1.97	43.67	4.73	Plot1_ESN
Monitor Plot 2_ESN	35	2457	1.97	45.15	6.10	Plot 2_ESN
Monitor Check 2	35	2457	1.97	39.05		Check 2
Monitor Check 3	35	2457	1.97	37.77		Check 3
Monitor Plot 3_ESN	35	2457	1.97	40.35	2.58	Plot 3_ESN
Monitor Check 4	35	1854	1.49	42.29		Check 4
Monitor Plot 4_ESN	35	1854	1.49	46.46	4.17	Plot 4_ESN

North

Figure D.25. Tabular arrangement for cleaned yield monitor results of ESN and control strips for 'Crooks' farm along with yield differences.

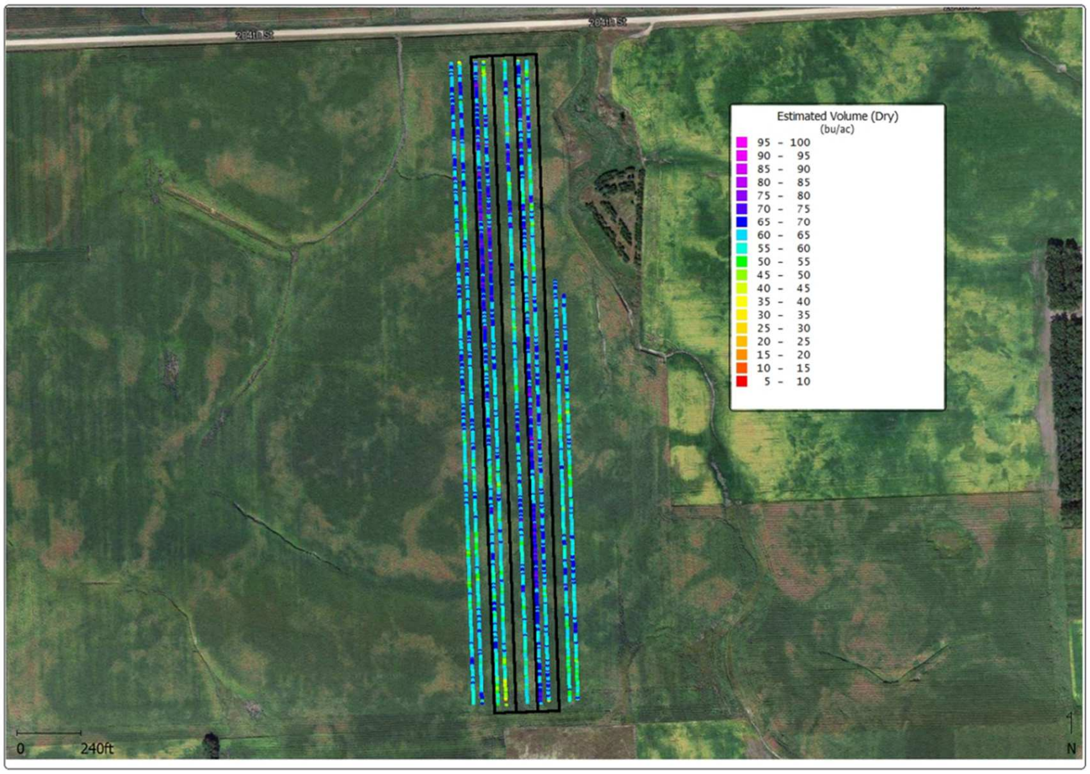
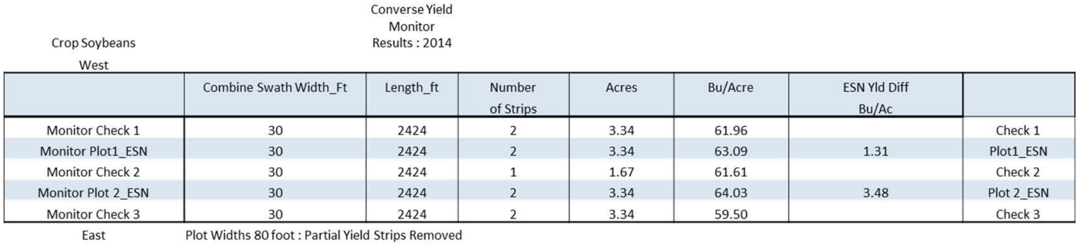


Figure D.26. Cleaned yield monitor for ‘Converse’ farm for ESN strips and control strips.


Converse Yield Monitor Results : 2014

Crop Soybeans

West

	Combine Swath Width_Ft	Length_ft	Number of Strips	Acres	Bu/Acre	ESN Yld Diff Bu/Ac	
Monitor Check 1	30	2424	2	3.34	61.96		Check 1
Monitor Plot1_ESN	30	2424	2	3.34	63.09	1.31	Plot1_ESN
Monitor Check 2	30	2424	1	1.67	61.61		Check 2
Monitor Plot 2_ESN	30	2424	2	3.34	64.03	3.48	Plot 2_ESN
Monitor Check 3	30	2424	2	3.34	59.50		Check 3

East

Plot Widths 80 foot : Partial Yield Strips Removed

Figure D.27. Tabular arrangement of Figure showing yield across ESN strips and control strips with yield difference maps.

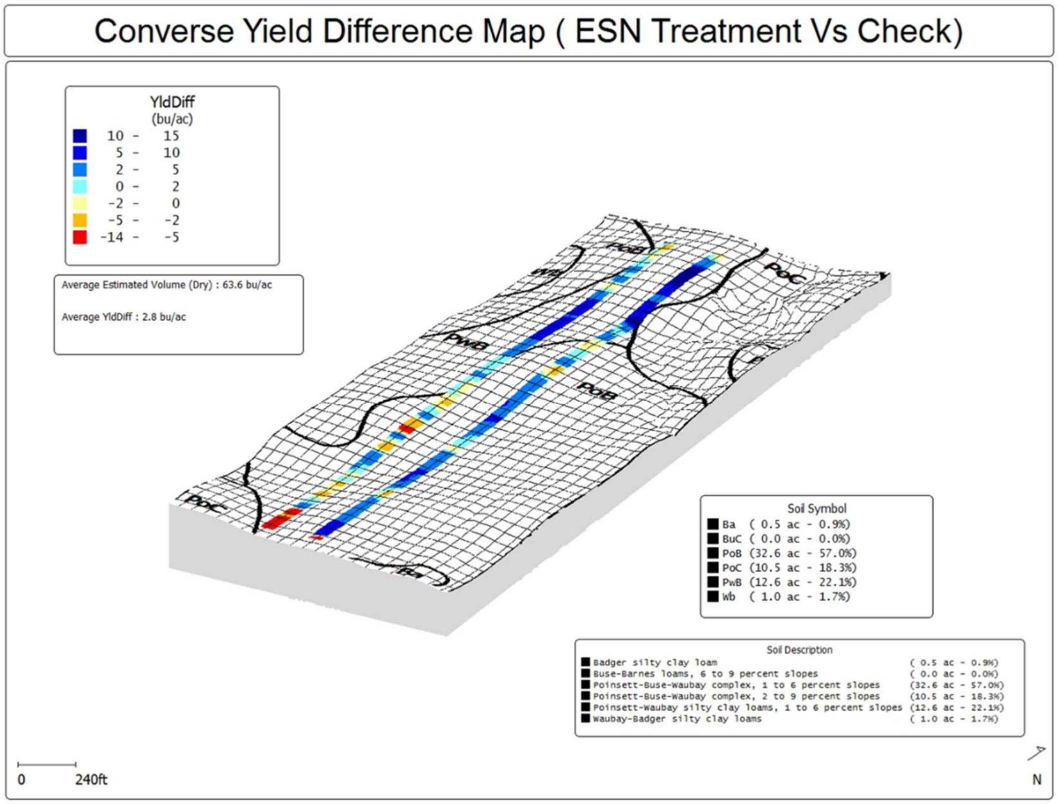
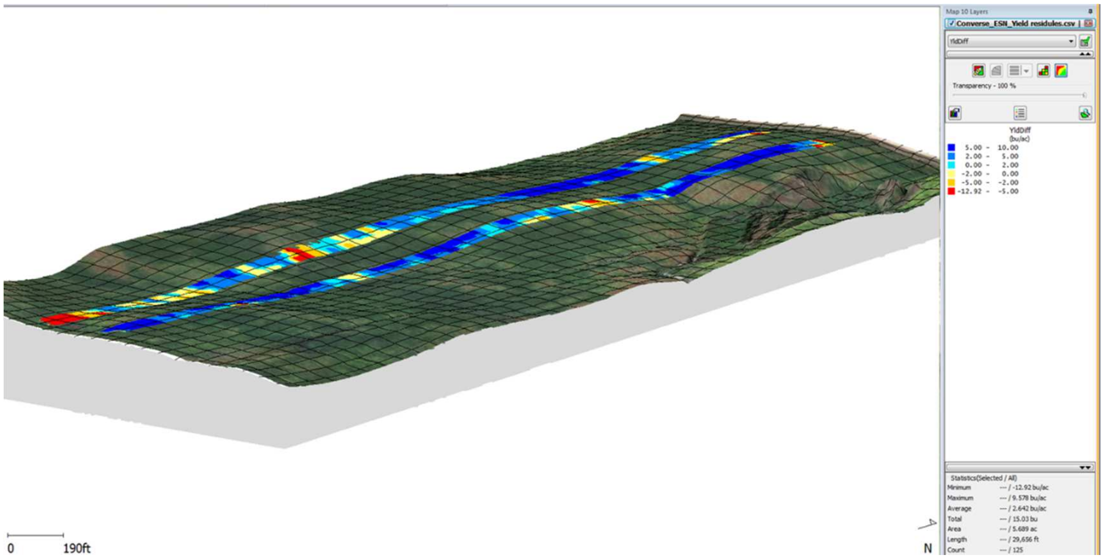


Figure D.28. Yield difference map (Chapter 6) superimposed on an elevation/soil type map for ‘Converse’ farm generated from LiDar imagery



Statistics(Selected / All)
Minimum --- / -12.92 bu/ac
Maximum --- / 9.578 bu/ac
Average --- / 2.642 bu/ac
Total --- / 15.03 bu
Area --- / 5.689 ac
Length --- / 29,656 ft
Count --- / 125

Figure D.29. Yield difference map (Chapter 6) superimposed on a soil topographic map for ‘Converse’ farm generated from LiDar imagery

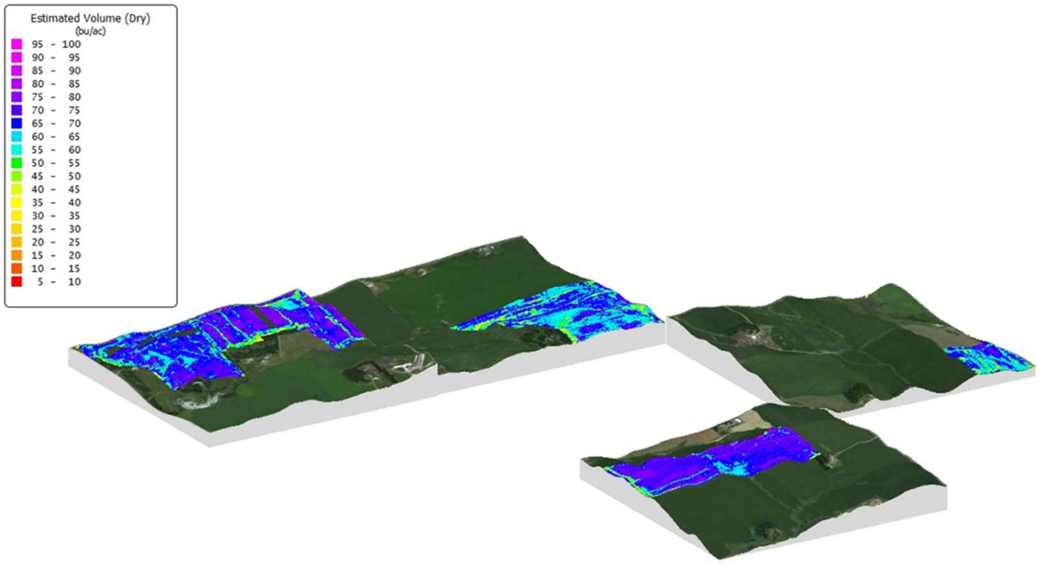


Figure D.30. Estimated dry soybean yield production from Hefty Seed Brand collection of fields with particular attention paid to ESN treatment areas across all three fields.

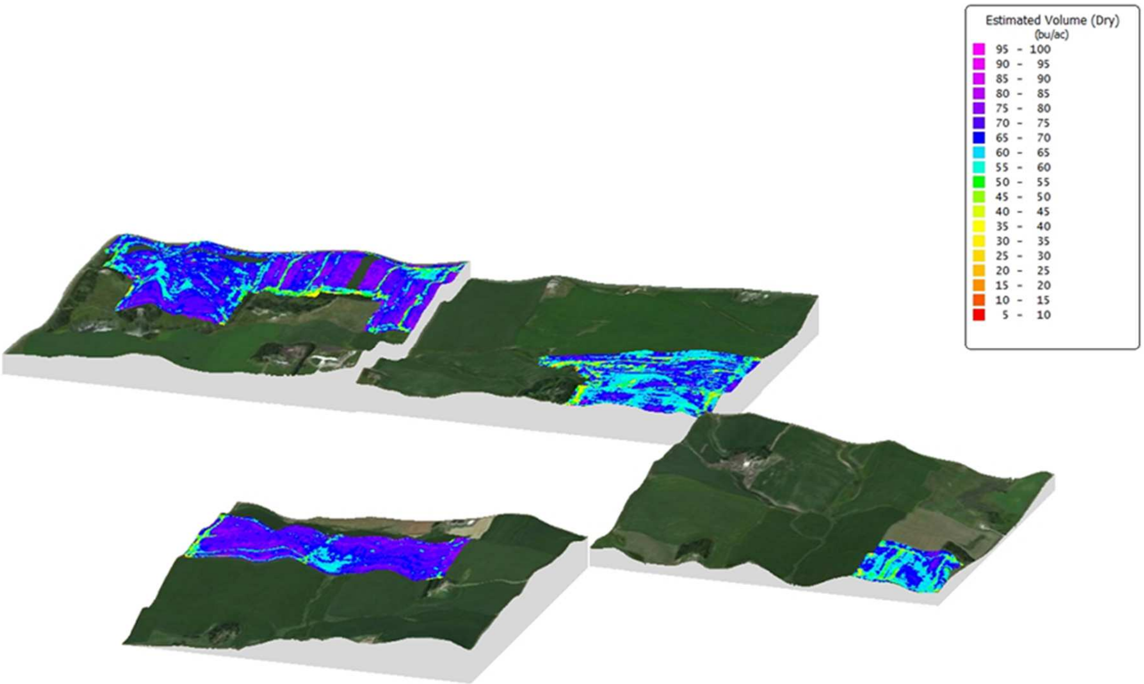


Figure D.31. Estimated dry soybean yield production from Hefty Seed Brand Collection of fields with particular attention paid to ESN treatment areas across all three fields.

Brian Field: Yield Monitor Averages for ESN and Check Strips: Yield Average=73.87 bu/ac

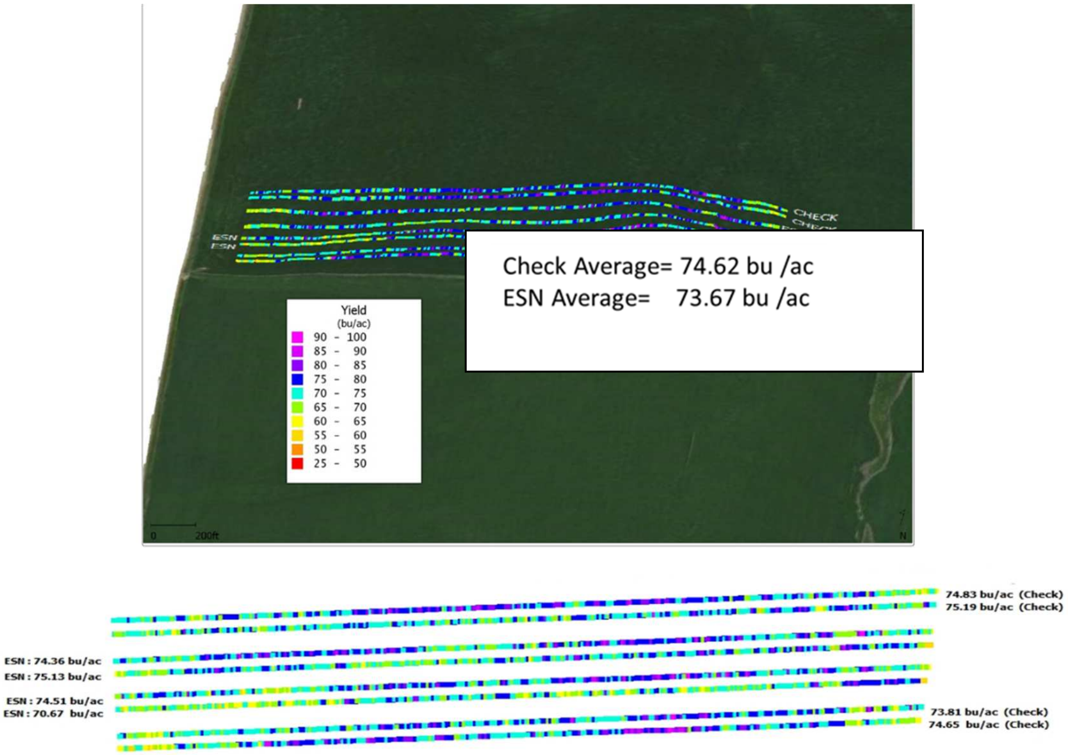


Figure D.32. Estimated dry soybean grain yield of ESN treatment and control strips of 'Brian' field superimposed on a soil topography map obtained from LiDar imagery.

Olaf Field: Yield Monitor Averages for ESN and Check Strips: Yield Average= 66.24 bu/ac

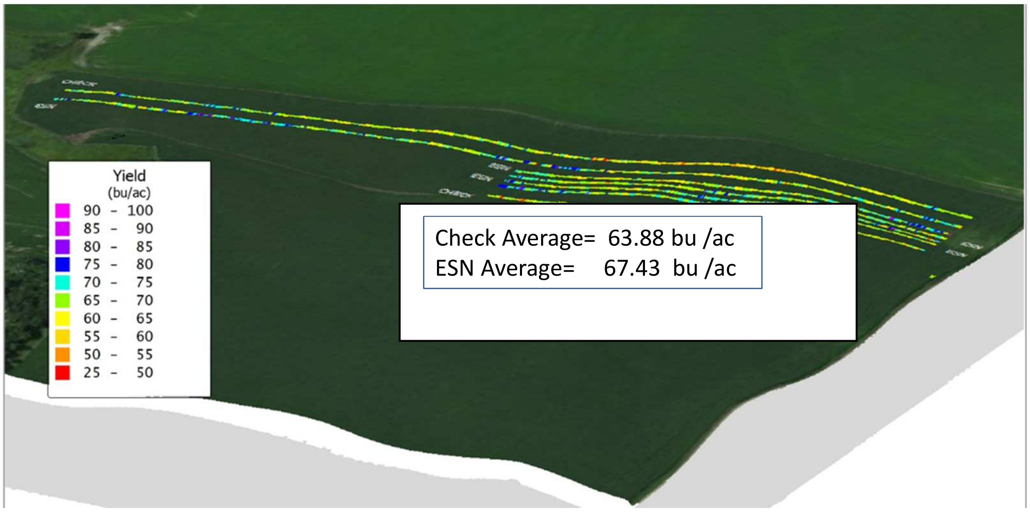
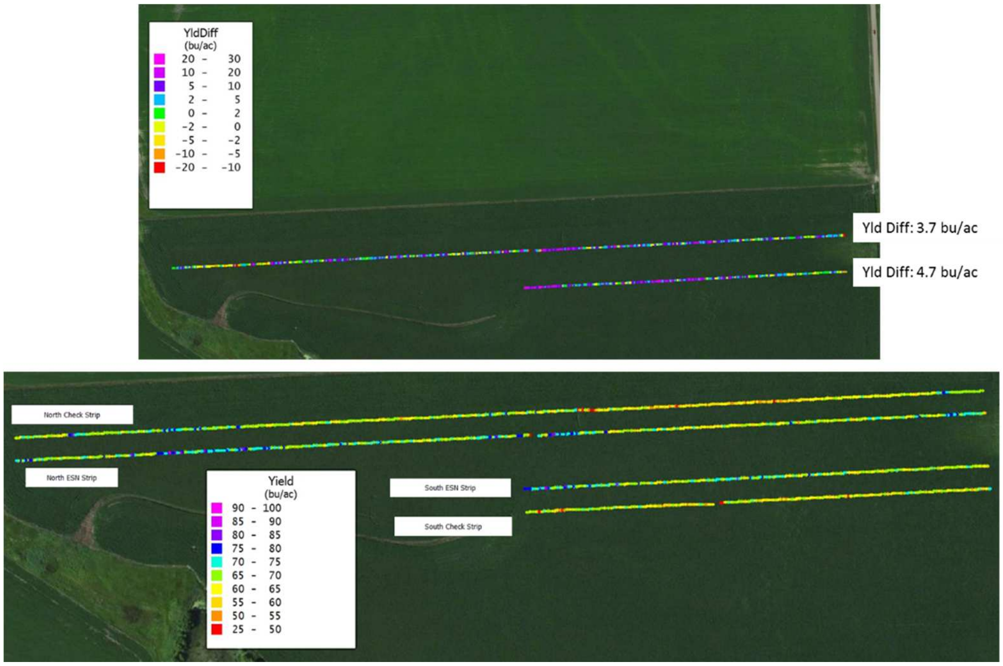
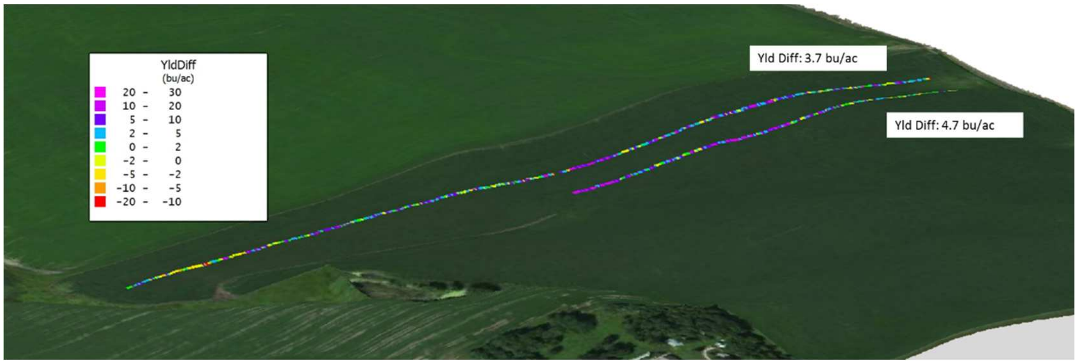


Figure D.33. Estimated dry soybean grain yield of ESN treatment and control strips of ‘Olaf’ field superimposed on a soil topography map obtained from LiDar imagery.



Olaf Field: Yield Difference Map : ESN vs Check Strips: North Strips and South Strips

Figure D.34. Yield difference map (Chapter 6) for ‘Olaf’ farm generated for North and South ESN and control strips.



Olaf Field: Yield Difference 3D Map : ESN vs Check Strips: North Strips and South Strips

Figure D.35. Yield difference map (Chapter 6) superimposed on an soil topographic map for north and south ESN and check yield strips 'Olaf' farm generated from LiDar imagery

Tuffy East Field: Yield Monitor Averages for ESN and Check Strips: Yield Average= 69.09 bu/ac

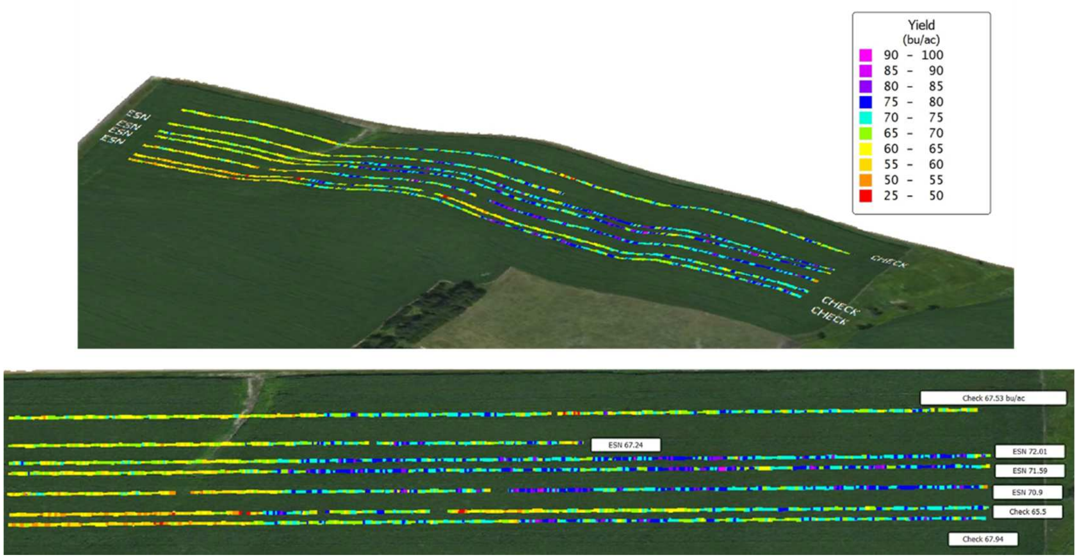


Figure D.36. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for 'Tuffy East' farm.

Tuffy-East Field: Yield Difference 3D Map : ESN vs Check: West Strips and East Strips

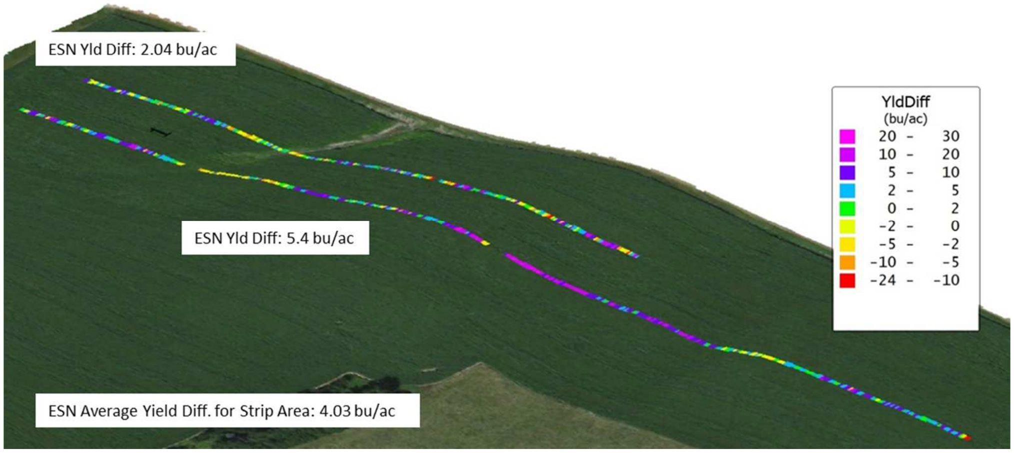


Figure D.37. Yield difference map (Chapter 6) superimposed on an soil topographic map for 'Tuffy-East' farm generated from LiDar imagery

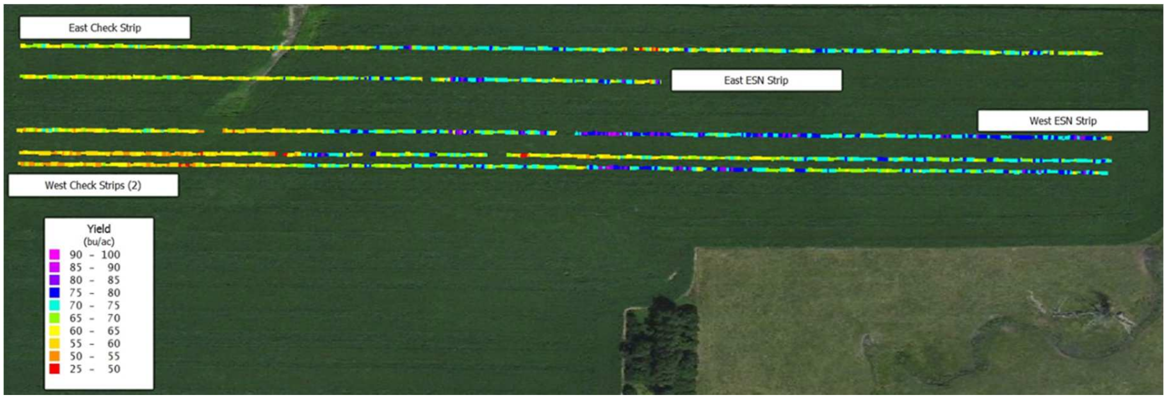


Figure D.38. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for west and east strips at 'Tuffy East' farm.

Tuffy West Field: Yield Monitor Averages for ESN and Check Strips: Yield Average= 69.65 bu/ac

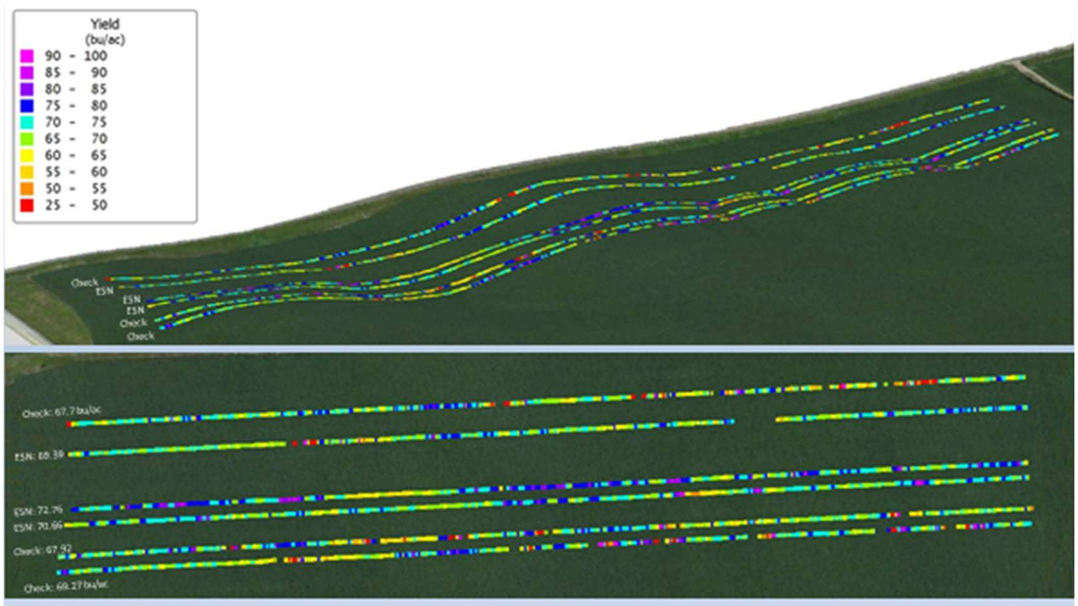


Figure D.39. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for west and east strips at 'Tuffy East' farm.

Tuffy-West Field: Yield Difference 3D Map : ESN vs Check: North Strips and West Strips

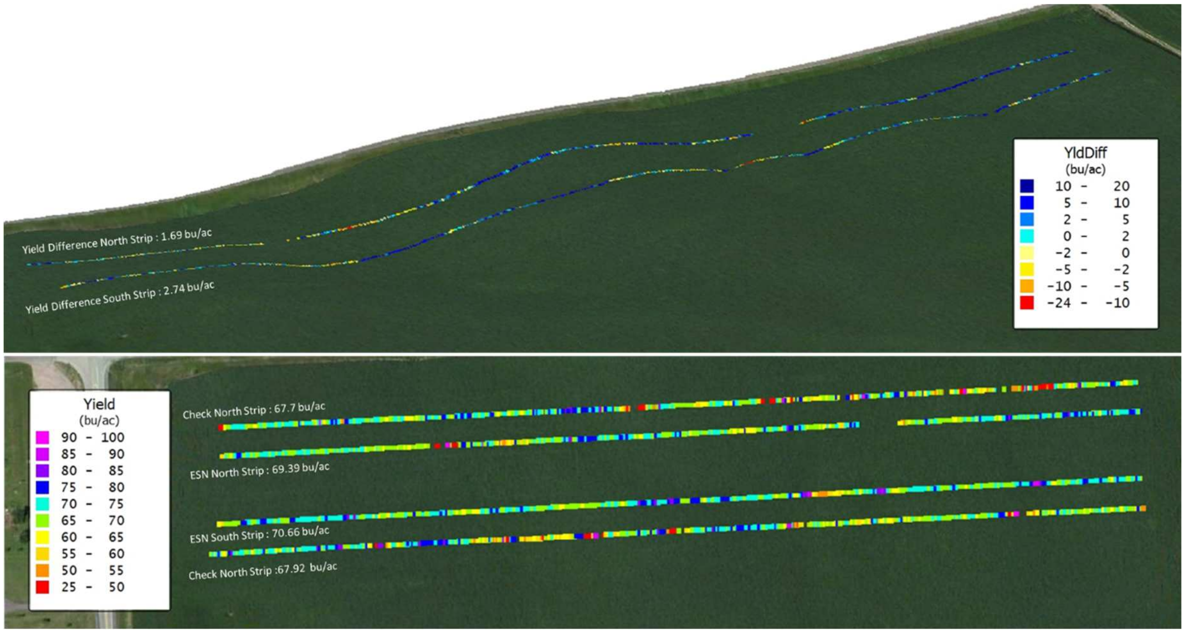


Figure D.40. Yield difference map (Chapter 6) superimposed on an soil topographic map for 'Tuffy-East' farm generated from LiDar imagery

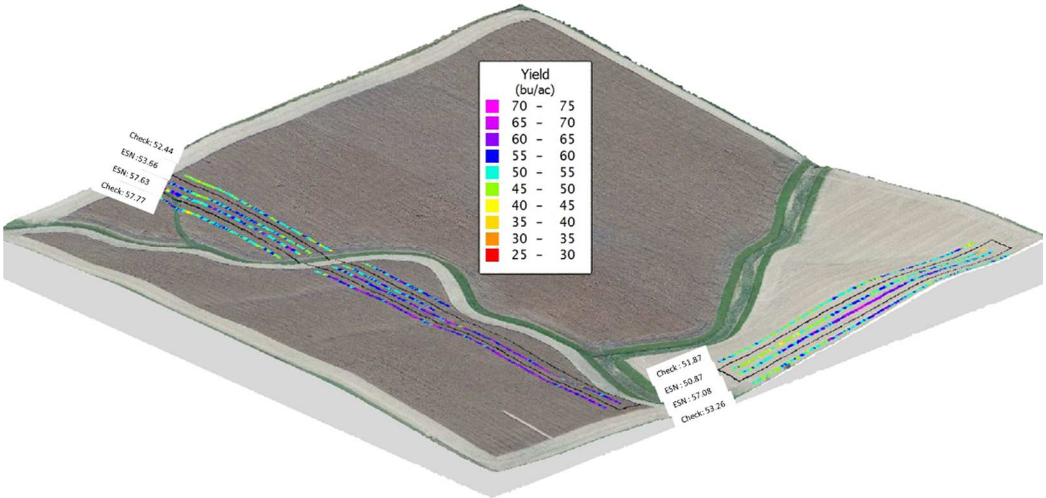

Flandreau Field: Yield Monitor Averages for ESN and Check Strips: Yield Average= 54.93 bu/ac

Figure D.41. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for west and east strips at 'Flandreau' farm

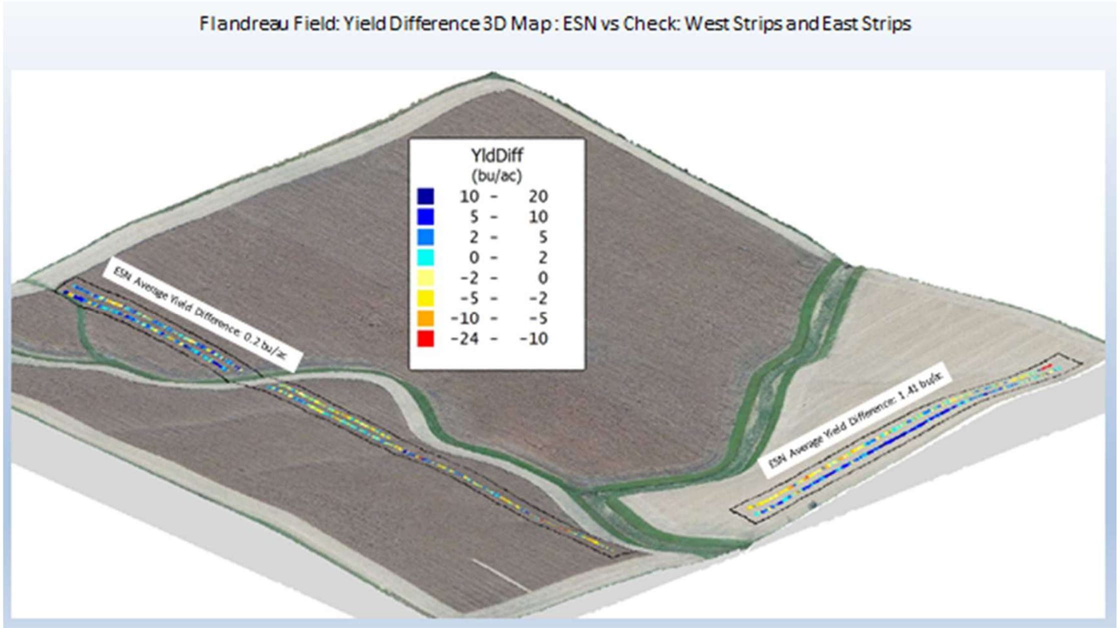


Figure D.42. Yield difference map (Chapter 6) superimposed on an soil topographic map for 'Flandreau' farm generated from LiDar imagery

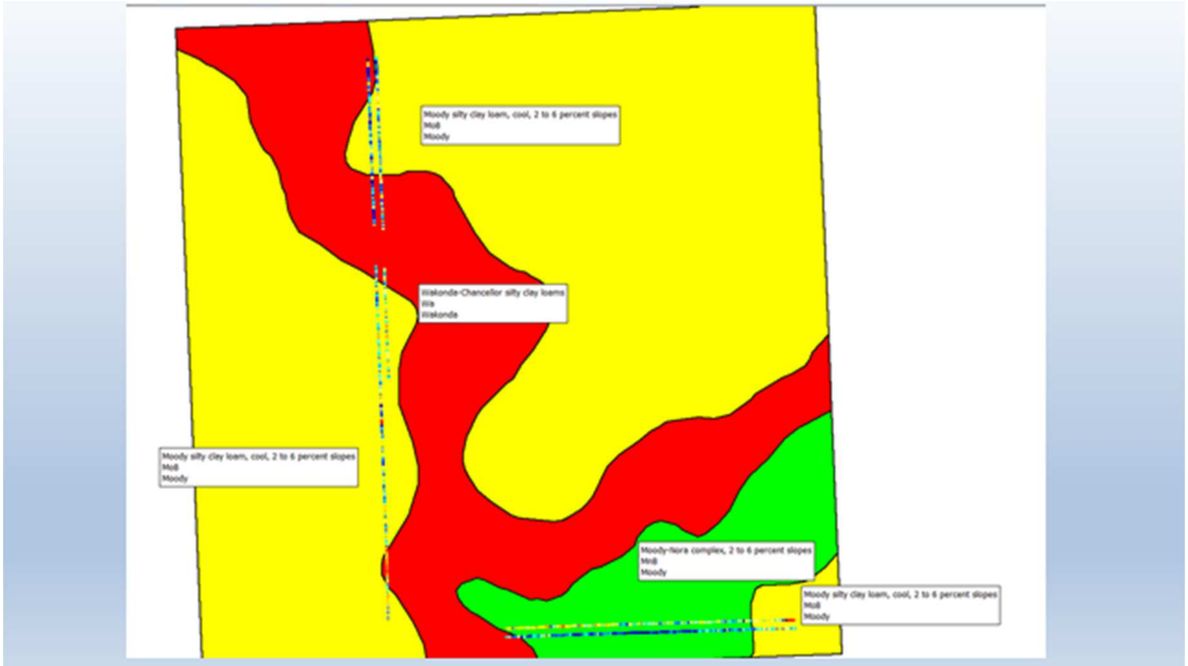


Figure D.43. Yield difference map (Chapter 6) superimposed on an soil topographic map for 'Flandreau' farm generated from LiDar imagery

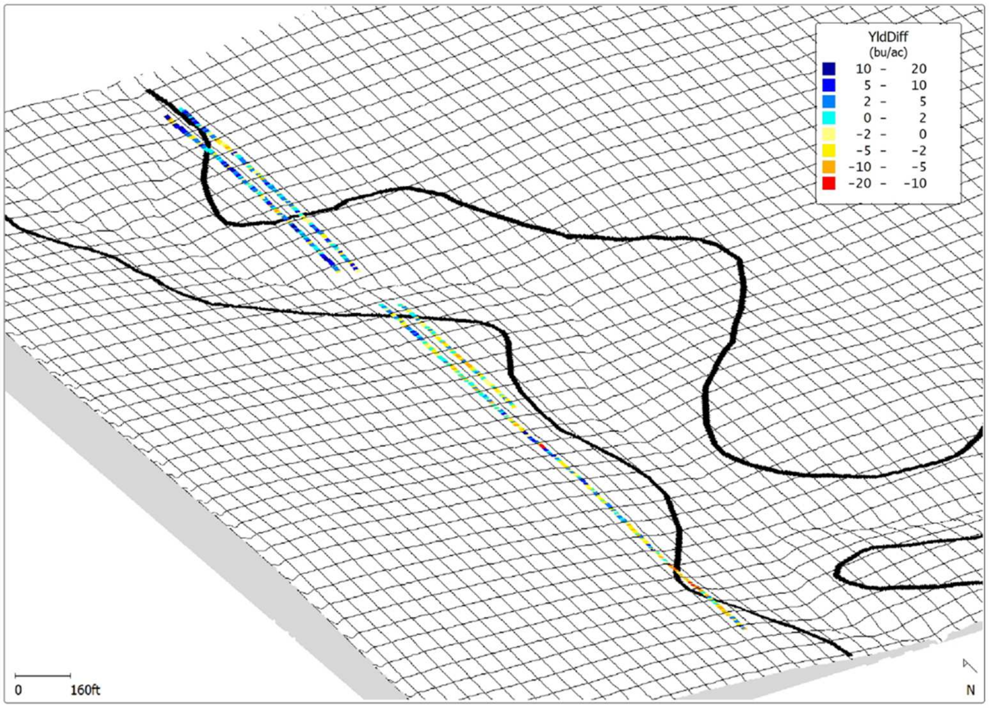


Figure D.44. Yield difference map (Chapter 6) superimposed on an soil topographic map for ‘Tuffy-East’ farm generated from LiDar imagery

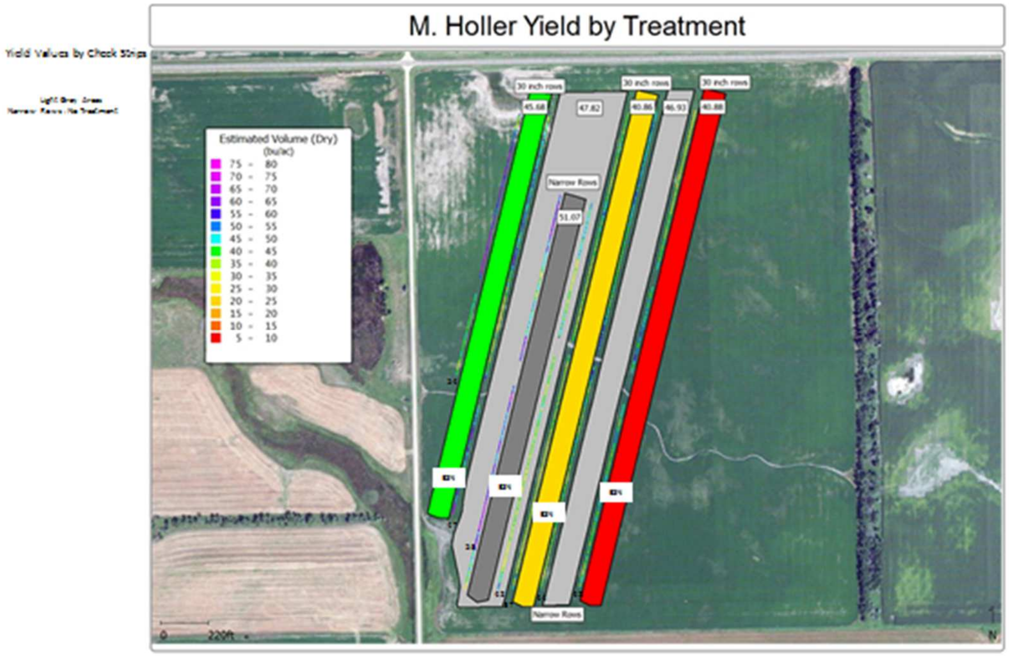


Figure D.45. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for west and east strips at ‘Holler’ farm. On-farm cooperator also tested out various row spacings around the ESN plots, so data is presented with both treatments.

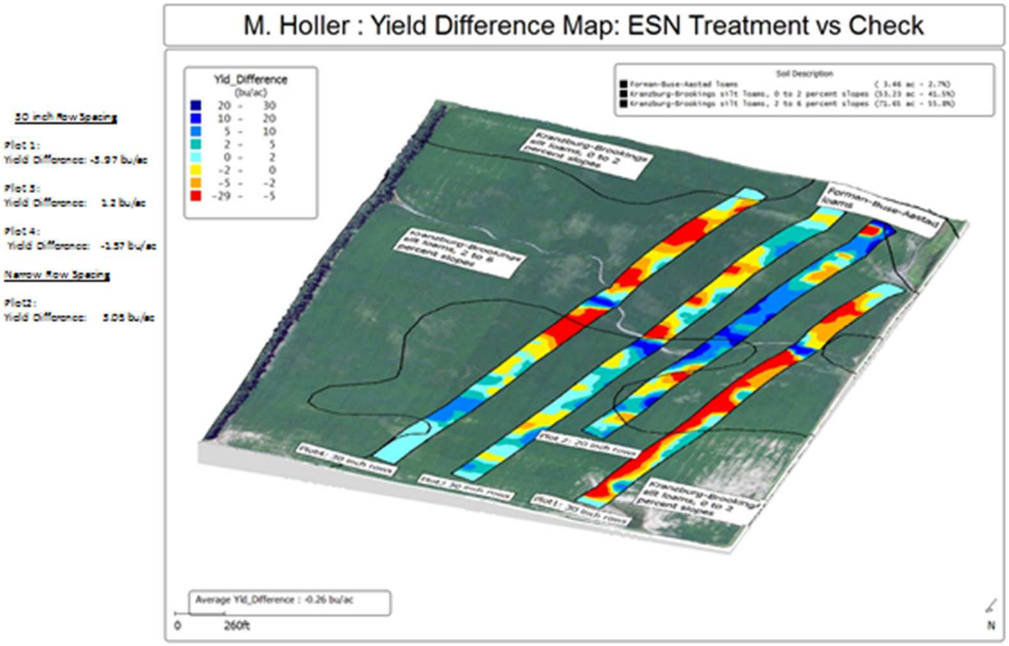


Figure D.46. Yield difference map (Chapter 6) superimposed on an soil topographic map for ‘Holler’ farm generated from LiDar imagery.

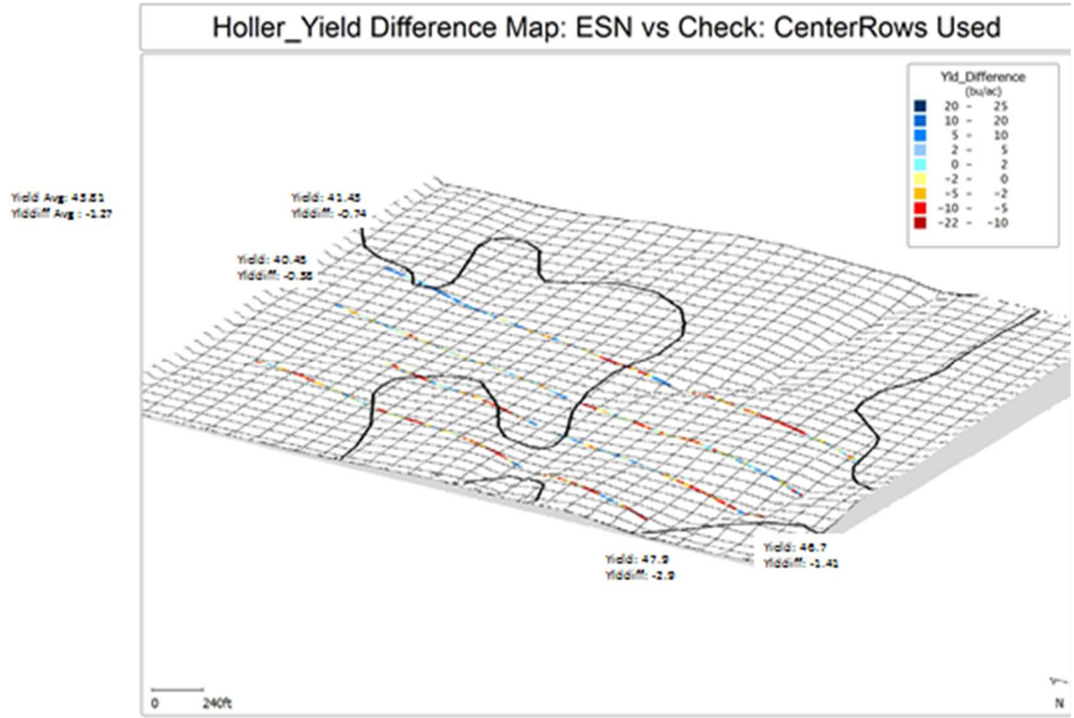


Figure D.47. Yield difference map (Chapter 6) superimposed on an soil topographic map for ‘Tuffy-East’ farm generated from LiDar imagery.

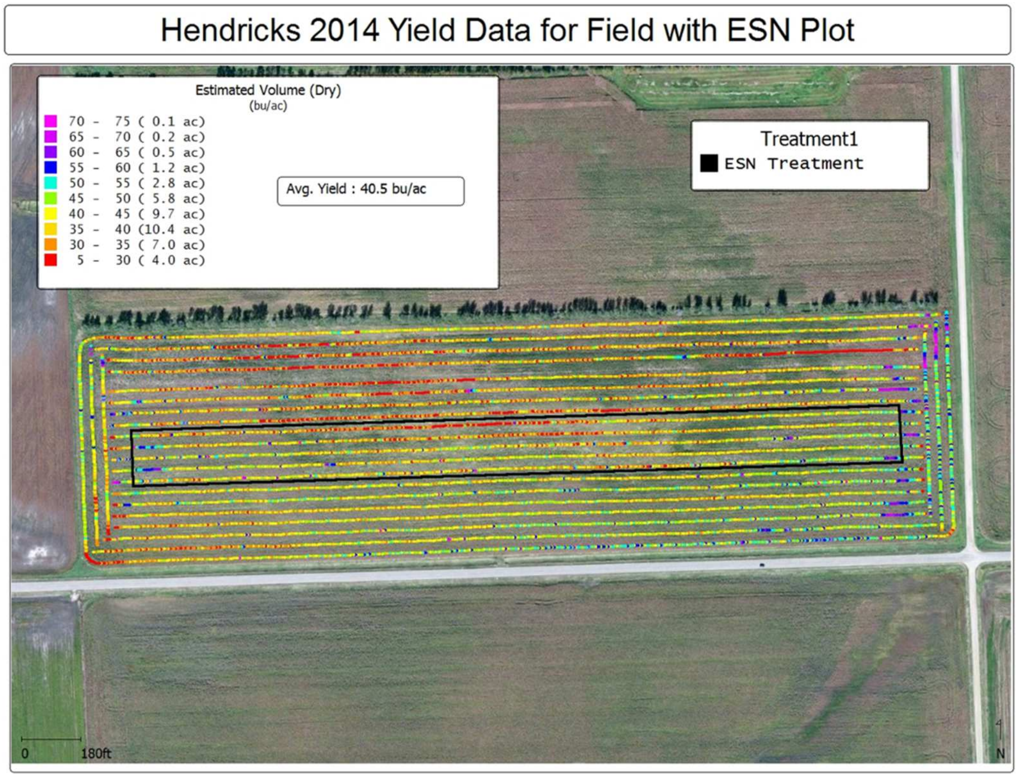


Figure D.48. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for west and east strips at ‘Hendricks’ farm.

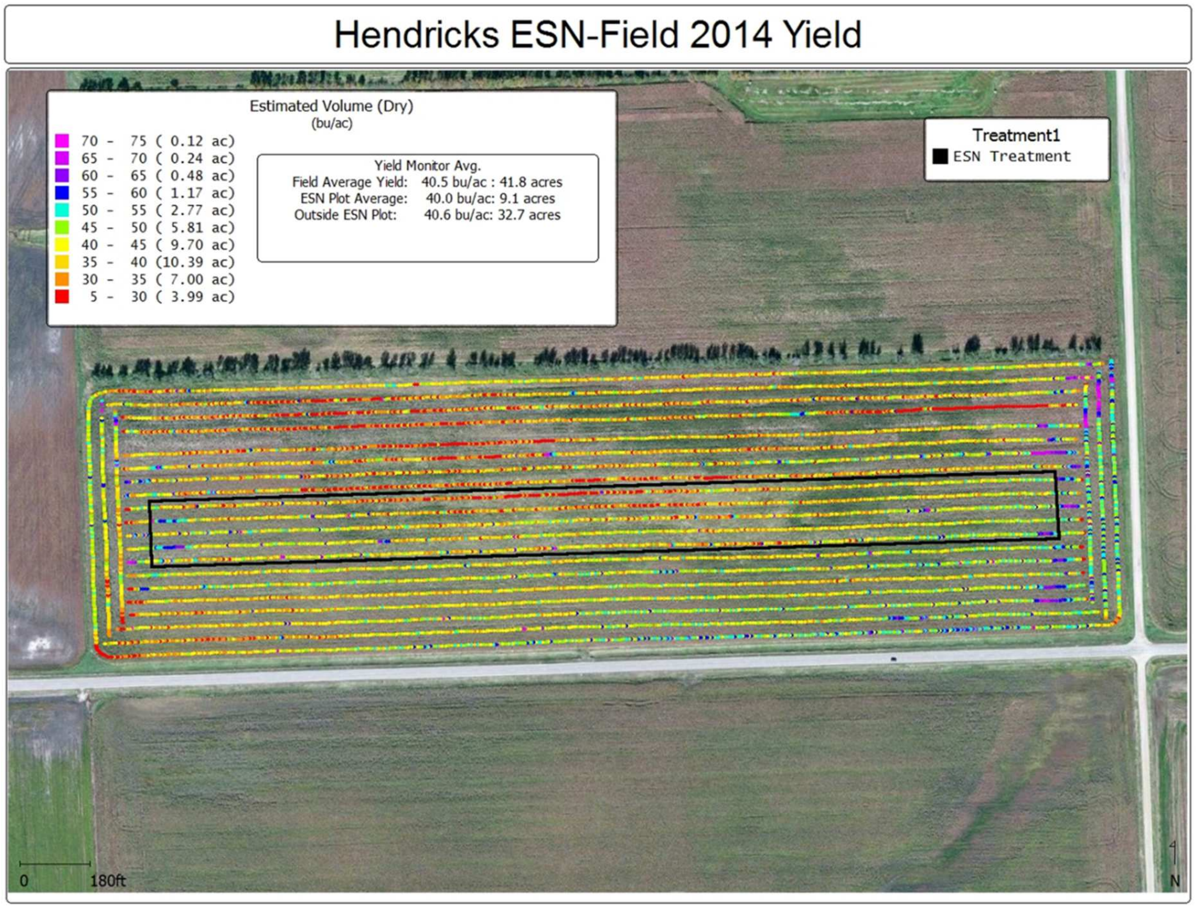


Figure D.49. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for west and east strips at ‘Hendricks’ farm**.**

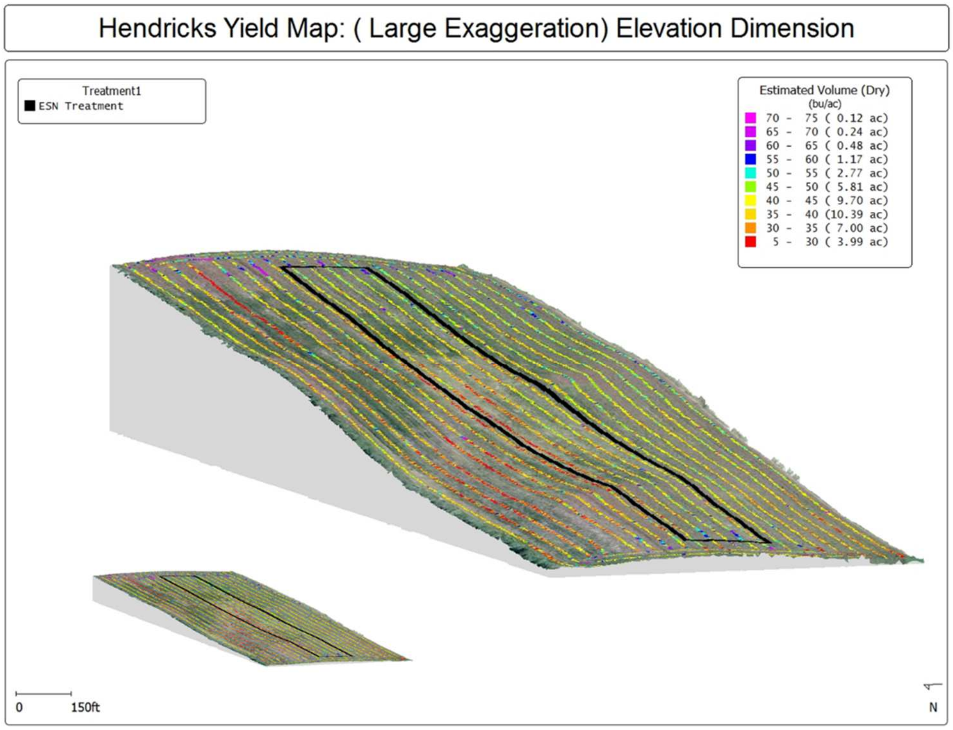


Figure D.50. Yield difference map (Chapter 6) superimposed on an soil topographic map for 'Holler' farm generated from LiDar imagery.

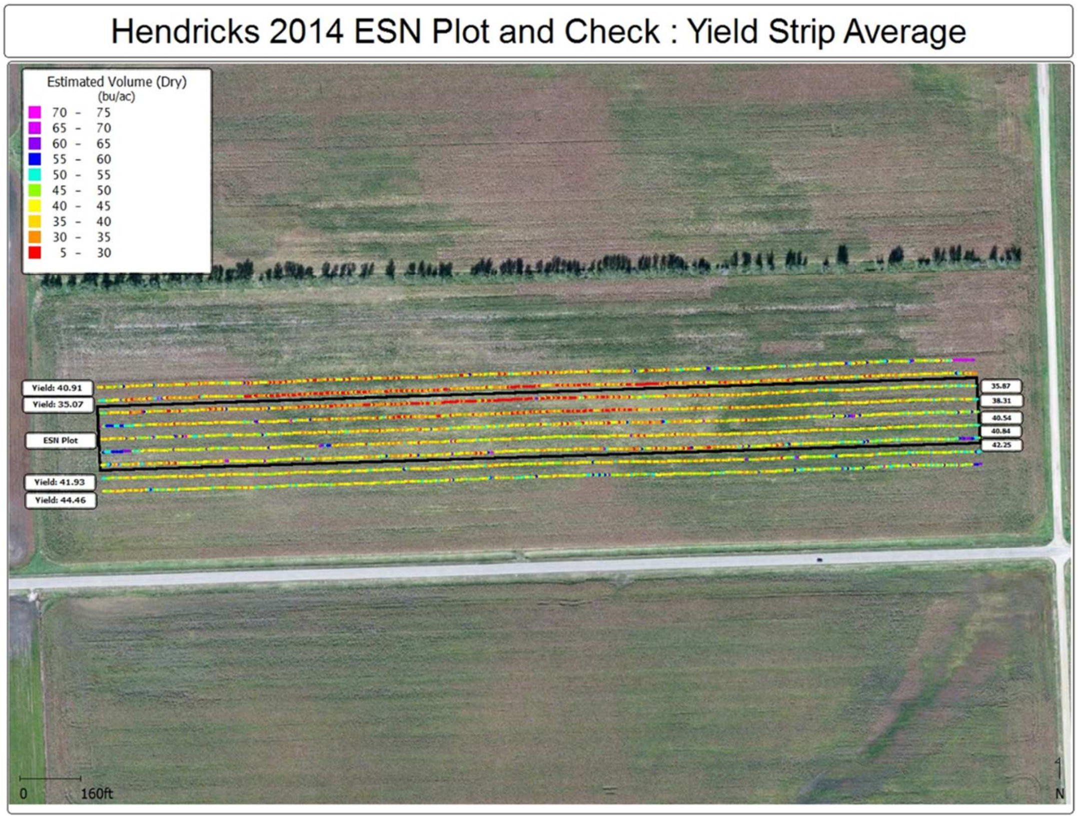


Figure D.51. Estimated dry soybean grain yield for ESN and control strips superimposed on soil topographic map generated from LiDar imagery for west and east strips at 'Hendricks' farm.

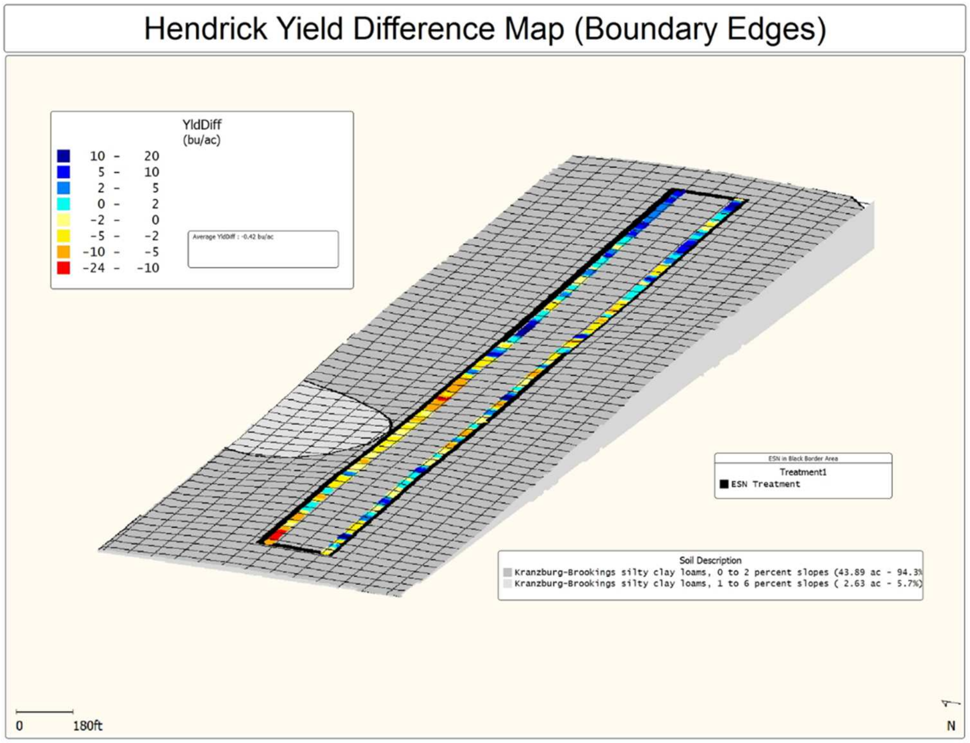


Figure D.52. Yield difference map (Chapter 6) superimposed on a soil topographic map for ‘Tuffy-East’ farm generated from LiDar imagery