# LARGE SCALE IMPLEMENTATION OF SENSOR BASED TECHNOLOGY USING THE GREENSEEKER$^{TM}$

By

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LARGE SCALE IMPLEMENTATION OF SENSOR

BASED TECHNOLOGY USING THE

GREENSEEKER™

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# CHAPTER I

## ABSTRACT

Nitrogen (N) fertilizer needs vary from year to year and field to field. Small grain producers are continuously looking for new techniques to improve their fertilizer use efficiency. Using the GreenSeeker™ Sensor and nitrogen (N) reference strips, crop response to N can be measured and yield potential can be predicted. This is done using the Sensor Based Nitrogen Rate Calculator (SBNRC), which uses Normalized Difference Vegetative Index (NDVI) readings taken from the reference strip and the farmer practice. Also, commercially available is the variable rate technology (VRT) that uses multiple GreenSeeker™ sensors mounted on a boom. This study was designed to evaluate the use of optical sensors for N rate determination in producer's fields. This study was important to do on a large scale rather than the traditional small plot research in an effort to show producers how precision agriculture works and how it can benefit them. Comparing the no topdress and what the producer typically applies topdress on winter wheat with the SBNRC recommended rate and the VRT rate was evaluated in this study. Also evaluated was the economics of using the SBNRC and the VRT technology and comparing it with the typical farmer practice (FP) and no topdress. In 2009 the SBNRC recommended 11 kg ha$^{-1}$ less N than the farmer practice and had an 8 kg ha$^{-1}$ increase in grain yield. The SBNRC had a gross return of \$509 ha$^{-1}$, \$15 ha$^{-1}$ more than the FP and \$66 ha$^{-1}$ more than the no topdress. In 2010 The SBNRC made 342 kg ha$^{-1}$ more grain than the no topdress, 88 kg ha$^{-1}$ more than the FP, and 243 kg ha$^{-1}$ more than the VRT. The SBNRC

had a gross return of \$10 $ha^{-1}$ more than the no topdress, \$44 ha-1 more than the FP, and \$30 $ha^{-1}$ more than the VRT.  This trial shows that on a large scale sensor based technology can benefit producers by increasing yield and increasing gross return.

# CHAPTER II

## INTRODUCTION

Research has shown that producers are more apt to adopt new technology that has been tested on large scale trials on the farm (Miller, 2006). This on farm research is important because it shows producers not only what technology is out there, but also that it has potential to work on their farm. Large scale research provides the opportunity for producers to evaluate their current methods of production and new technologies that could potentially be better. Teese (1977) points out that economic growth is the increase in useful knowledge and the extension of its application. Researchers must extend their products to producers in order for the new technology to become useful and expand. Information about this type of technology is available to the producers via farm field days and demonstration days; however, some farmers are reluctant to attend them. Many producers are not willing to change their operation because of family tradition. However, Miller (2006) stated that the producers that come to these events are receptive of the information being presented. Producers liked communicating with other producers to find out what has and has not been working for them. By doing research at a large scale on several producers fields, it presents an opportunity for researchers and producers to come together and share the technology that is available and show them what works and what doesn’t.  Performing this research on a large scale basis and in cooperation with different producers around the state is a great way to introduce the new technology that is available and present data to demonstrate how it can benefit them. This project will demonstrate how research is conducted on a large scale using equipment that is comparable to what producers are using in their operation.  If producers see how the technology works, they will be more interested in how it works and how it can benefit them in their own production systems. The technology that researchers are working on can be transferred to the producers so they can see the finished result. The obstacle faced by many researchers of transferring small plot data to a form that can be seen and utilized by producers can be overcome. By performing this large scale research in producers’ fields, those who see the benefits will be more apt to use this technology in their own production practices.

# CHAPTER III

## LITERATURE REVIEW

Nitrogen fertilizer is one of the largest expenses faced by producers, depending on the farm size and location (Biermacher et al., 2006). Nitrogen fertilizer accounts for 20 to 30% of the per hectare cash expenses (Biermacher et al., 2006). Worldwide, nitrogen use efficiency (NUE) is 33% (Raun and Johnson 1999). Scientists worldwide are striving to increase NUE through research. Through past research, it was found that a crop's need for N varies greatly from year to year; therefore, using the same rate year after year has the potential to be economically and/or environmentally disadvantageous (Biermacher et al., 2009). Additionally, the majority of fields are very diverse in soil type. One field may have several different soil types, which may impact crop demand for N. Nutrient availability is typically variable across each field (Washmon et al., 2002). Very seldom is a field completely homogenous or are two fields variable in the same pattern. Previous methods of N fertilizer application do not account for variability in the field or for the N needs of that crop in that specific year (Girma et al., 2007). Fluctuations in crop yields are not always a result of poor management, as some of this fluctuation can be attributed to the environment (Girma et al., 2007). The value of the precision system is sensitive to the price of UAN relative to the price of $NH_3$. When N is applied at a flat rate across the field, the resulting problem is poor nitrogen use

efficiency (Girma et al., 2006). Because available non-fertilizer N varies from year to year, the average N applied will be correct only 30% of the time. The N applied will be 22.5 kg N $ha^{-1}$ below what is required 37 % of the time and 22.5 to 90 kg N $ha^{-1}$ in excess of what is required 33% of the time. This is an average of 43 kg N $ha^{-1}$ (Girma et al., 2006). In Oklahoma, N recommendations are calculated using $N_{rec}$= Yield goal (kg $ha^{-1}$) x 0.033 (Zhang and Raun, 2006). The yield goal is based on that specific area's average yield for the past 5 years (Mullen et al., 2003). Raun et al. (2002) presents another method to estimate potential yield and N uptake using an active reflectance-sensor, the GreenSeeker™. This site-specific nitrogen fertilizer application system uses optical reflectance measurements of growing wheat plants to estimate N requirements using the Greenseeker™ sensor and a nitrogen reference strip. By using reference strips and the GreenSeeker™ sensor to estimate an N recommendation, a site specific N rate can be produced that is tailored for an individual field for that season (Raun et al., 1999).
The GreenSeeker™ utilizes spectral radiance measurements in red (671 nm) and NIR (780 nm) wavelengths and can help estimate N requirements utilizingthe normalized difference vegetative index or NDVI (Stone et al., 1995).

NDVI is calculated as:

$$NDVI = (NIR-Red/NIR+Red)$$

Where NIR and Red are near-infrared and red reflectance respectively, and NIR and Red are the near-infrared and red incident radiance (Mullen et al., 2003).

The NDVI index is then divided by the number of growing degree days greater than zero from planting to sensing to calculate INSEY or in-season estimate of yield (Lukina et al., 2001). Nitrogen fertilizer rate is then calculated by estimating the difference in N uptake from the N-Rich strip and farmer's practice, assuming NUE of 50 to 60% of the applied top-dress N.

The GreenSeeker™ sensor, along with supporting hardware and software provides the capability to variably apply N fertilizer (Solie et al., 2002). The GreenSeeker™ can capture the variability of a field and provide a recommendation of the appropriate amount of N fertilizer for that specific area. This technology is currently commercially available. Raun et al. (2002) concluded that using the optical sensor based algorithm that employs yield prediction and N responsiveness by location ($0.4m^2$ resolution) can increase yields and decrease environmental contamination due to excessive N fertilization. Raun et al. (2002) documented an increase in NUE of 15% when sensor based technology was utilized in trials.

Sensor based variable rate technology (sVRT) has potential as a solution to variable rate nitrogen fertilization (Stone et al., 1996). Sawyer (1994) stated there are a few things that could limit the use of map-based application of variable rate technology. The cost of sampling, mapping, equipment and labor needed to implement these technologies would limit the adoption and use of VRT. Sawyer (1994) also indicated that if producers are not convinced that this technology will increase their yields the following season, they will most likely not implement the technology. Sawyer (1994) indicated that this technology may not decrease input costs of the crop, which may concern producers of their ability to make a return on the investment. The goal of VRT is to avoid traditional costs, such as soil sampling, chemical analysis, data management, and recommendations, and to adjust the application rate based on sensor measurements of fertility as an applicator travels across the field (Sawyer, 1994). Stone (1995) demonstrated that using variable rate technology based on spectral index compared to the traditional flat rate N fertilizer applications could require less N fertilizer. He showed a savings between 32 and 57 kg N $ha^{-1}$ with the use of variable rate N applications.

Ioannidis (2005) states that there is concern that some research findings from small scale research plots may be false or misleading because the effects are smaller, the design of the experiment is more flexible than a large scale experiment, and there could be more than one research team working on the experiment, which may lead to inconsistencies in the experiment.

Wollenhaupt (1994) found that for a producer to apply variable rate technology based on field mapping could potentially be strenuous on the producer because the need for comprehensive field mapping based on soil tests. These soil tests would need to be analyzed by a lab, imposing a large management load on the producer.

Multiple methods of predicting yield have been tested, not just using the GreenSeeker ™. Scharf et al., (2006) found that collecting twenty to thirty readings in each plot using a chlorophyll meter to predict yield in all stages of corn (V5 to R5) showed that 22 of the 24 models found a high significance between economic optimal N rate and yield. Scharf (2001) collected soil mineral N measurements at planting and side dress time in corn, used a chlorophyll meter as well as tissue N to try to find an optimum N rate. The study found that using tissue N measurements and the chlorophyll meter were more correlated to optimum N rate than the soil measurements. Roberts et al. (2010) found that using reflectance sensors in corn has the potential to benefit the environment. This study found that using the reflectance sensors can benefit the environment by reducing the amount of N fertilizer that is being applied. He stated that many producers use an insurance N application to protect them against yield loss due to under-fertilizing. This could indicate that producers are over fertilizing their fields with excess N to protect them. In this study, it was found that N savings ranged from 10 to 50 kg N $ha^{-1}$, when all sites were combined.

# CHAPTER IV

## OBJECTIVE

The objective of this project was to evaluate the sensor based N management approaches in winter wheat on producer fields and compare them with what individual producers are currently doing.

# CHAPTER V

# MATERIALS AND METHODS

In the fall of 2008 and 2009, 13 and 9 trials, respectively, were established. For each production season locations were selected across the state. Fields and locations were selected after sowing to ensure sites with good stand establishment. Preplant N fertilization and sowing were performed by the producer on a field scale. Each trial consisted of 4 treatments arranged in a randomized complete block design (RCBD), replicated 3 times. Plot size ranged from 20 m x 133.33 m to 10 m x 66.67 m depending on location and situation (Figure 1).

The first treatment was used as the check and consisted of no top-dress application with the only nitrogen applied as “producer” pre-plant. The second treatment was the same N rate the producer was going to apply topdress to that specific field for that specific year. The third treatment was the (Sensor Based Nitrogen Rate Calculator) SBNRC uniform flat rate. The SBNRC rate is determined by averaging NDVI readings collected from the N-Rich Strip and the farmer practice (farmer’s pre-plant N rate). For the fourth treatment a RT-200 sensor based variable rate applicator was used. The RT-200 was equipped with a Recon hand held with RT Commander program, version 1.3.8 DSD installed. In the program, the no topdress reference NDVI value was typed in, along with the N-Rich strip NDVI value. Next the crop algorithm “w Wheat Dry v 1.4 Okstate” was selected. A value of 50 percent was then entered in for NUE. For each location, there was a different value for GDD’s. This value was GDD’s where GDD’s were above zero from planting date to sensing date.

A small tractor with an N-rich strip N-ramp applicator was taken to each site and 3 sets of N-strips and N-ramps were applied on both sides of the trials. The applicator was a 3 point mounted sprayer with a 4 m boom. The left 2 m of the boom applied a flat rate of N. This was used as the N rich strip. The right 2 m of the boom applied an N Ramp. The N ramp starts out at a high rate of UAN (approximately 179.2-201.6 kg $ha^{-1}$) and incrementally decreases the amount of N every 6.66 m all the way down to 0 kg N $ha^{-1}$. The N ramps were not used in calculating the recommended rate, but as a visual tool for the producers. The strips were applied over the top of the producer’s pre-plant fertilizer application. Table 1 lists the locations for both 2008-2009 harvested sites, NDVI of the the no topdress reference strips, GDD’s where GDD’s were above zero from planting to sensing, observed yield, and predicted yield.

An applicator built by engineers at Oklahoma State University was used to apply all treatments including the RT-200 variable rate. The applicator is equipped with a 10 m boom with 4 GreenSeeker™ sensors mounted across the boom. A light bar equipped with GPS was utilized in the applicator to minimize overlap and gaps and maintain accuracy. While applying top-dress, the applicator records NDVI readings for the area that was top-dressed. The N-Rich and 0-N areas next to each other were sensed using a handheld sensor and were averaged together for the SBNRC.

In the fall of 2008 13 site experiments were established in Ottawa County, Garfield County, Barber County Kansas, Canadian County, Kiowa County, and Woodward County. Eight of these trials were harvested. Five locations were lost due to drought, late freeze, head scab, or miscommunication. In the fall of 2009 nine site experiments were established in Barber County Kansas, Canadian County, Harmon County, and Kiowa County. Two trials were lost due to miscommunication. At each of these sites a 15 cm soil sample was collected prior to planting. Approximately 20 cores were taken over the entire trial. Table 2 lists the predominated soil types for each location in both years.

The producer harvested the middle of each plot with the same equipment that was being used in the rest of the field. At the end of each plot the combine unloaded the grain that was collected from that plot into a weigh wagon. The calibrated weigh wagon weighs grain in 10 lb increments. A sub-sample of each plot was collected for grain nitrogen content and grain moisture content. Statistical analysis was performed using SAS (SAS, 2003), using proc glm and duncan's multiple range test with an alpha level of 0.10. Gross return was evaluated in SAS using $5.00 per bushel of grain and $.50 per pound of N. This was then converted into kg $ha^{-1}$ of grain and kg N $ha^{-1}$. This was done using SAS with the following formula: gross return = (((yield/1.12/60))*5.00-(Nrate*.5)) *2.471.

# CHAPTER VI

# RESULTS

In the 2008-2009 growing season there was a range of weather conditions that swept through the state of Oklahoma. Through the winter it was dry and mild for most of the state. Rain showers during the spring led to higher than normal yield potential for many producers. In 2009, eight of the fourteen trials were harvested and yield was recorded. Of the five lost sites, four were due to inclement weather and two due to miscommunication with the producer. At the Woodward site, fertilizer was applied over the trial, and at the Ottawa 4 site the field was harvested by the producer before any trial data could be collected. The winter of 2008-2009 was very dry at several locations. The 3 sites in Hobart were lost due to drought, as only 1.93 cm of rain fell from Nov 1 2008 to Feb 28 2009. On May 7 2009 temperatures at the El Reno Mesonet (http://agweather.mesonet.org) recorded a daily low of -6.83 degree C. Because of this the Canadian County site 3, located in a river bottom, suffered substantial freeze damage and was not harvestable.

In 2009, a malfunction occurred in the variable rate applicator. The VRT treatment #4 was not properly applied; therefore, only results from treatments 1, 2, and 3 will be discussed. It should be noted that the malfunction in no way effected the application of the flat rates.

The results of 2009 are listed in Table 3. Table 4 lists the 2009 percent N concentration in the grain taken at harvest. Table 5 lists the N rate for each treatment at each location for 2009.

**Site 1. Ottawa Co. OK 2009.**

Site 1 was a no-till field following corn. At this location, 2.24 Mg $ha^{-1}$ of poultry litter was applied prior to sowing. Due to environmental conditions the wheat was sown relatively late with reduced stand establishment. Both yield and economical return responded numerically to top-dress N at this site. There was a significant difference, 10 kg $ha^{-1}$ in grain yield between the SBNRC and the no topdress treatments. No statistical significance was identified for gross return. At this location there was a significant amount of Fusarium head blight (*Fusarium graminearum)* present at harvest. This, coupled with the potential delayed mineralization of the applied litter and dry cool winter with a warm wet late spring, may have resulted in the over estimation of N needs.

Grain N concentration analysis at this location identified a significant increase in percent N concentration of the SBNRC above the no-topdress; however, there was no significant difference between SBNRC and FP or FP and No-topdress (Table 4). The range of NDVI taken from the handheld sensor for the no N reference was from .52-.61 with a standard deviation of .05. The N-rich strip NDVI ranged from .61-.71 with a standard deviation of 0.02 (Table 6).

**Site 2. Ottawa Co. OK 2009.**

At site 2, the wheat was planted after sunflowers. It was observed that there was a heavy residue layer left after the sunflower harvest, and a minimum tillage application was initiated before planting wheat. Applied N increased both yield and gross return. There was a significant difference across all treatments when analyzing grain yield. The SBNRC which applied 15 kg $ha^{-1}$ more was significantly higher than the FP and the no topdress treatments. There was however no statistical significance among treatments when analyzing gross return. Analysis of grain N concentration at this site showed no significant differences among treatments (Table 4).

**Site 3. Ottawa Co. OK 2009.**

Site 3 was no-till wheat planted after soybeans. It was sown late (November) directly after soybean harvest. Due to environmental and planting conditions, the stand was fair with little growth throughout the winter. There was a response to N for both yield and gross revenue. For yield, there was a statistical significance across all treatments at this site. The FP, which applied 50 more kg $ha^{-1}$ had significantly higher yield than the SBNRC and the no topdress treatment. The SBNRC was significantly higher than the no topdress treatment. The no topdress treatment was statistically lower than the FP and the SBNRC treatments when analyzing gross return. The range of NDVI recorded with the handheld sensor from the no N reference ranged from .31-.37 with a standard deviation of .02. The N-rich strip had an NDVI range from .38-.44 and had a standard deviation of 0.02 (Table 6).

**Site 4. Barber Co. Kiowa, KS 2009.**

This location is a continuous conventional till wheat field. The field is traditionally grazed with stocker cattle through the winter. For the past 3-4 years, it has had yields near

4700 kg ha$^{-1}$ grain.  In 2008-2009 growing season, there was little response to topdress N. It was identified for yield the FP treatment was statistically higher than the FP and the SBNRC treatments when 67 and 27 kg N ha$^{-1}$ was applied respectively.  Statistically there was no significant difference when analyzing gross return at this site.  Grain N concentration analysis at this site showed no significant differences among the treatments (Table 4)

NDVI recorded with the handheld sensor on the no N reference ranged from .557-.698 with a standard deviation of .06 while the N-rich strip ranged from .655-.728 with a standard deviation of 0.02 (Table 6).

**Site 5.  Barber Co. Kiowa, KS 2009.**

Four years ago, this site was broken out of alfalfa production and placed into continuous cultivated wheat production. This field has produced wheat yields approaching 6050 kg ha$^{-1}$. Numerically, there was a response to N between the SBNRC and no topdress treatments.  Statistically there was no significant difference when analyzing grain yield. In this case, the SBNRC applied 59 kg N ha$^{-1}$ less per hectare. The FP treatment was statistically lower than the no topdress and the SBNRC treatments when analyzing gross return.  Grain N concentration analysis from this site showed no significant differences among treatments (Table 4).

Ranges of NDVI recorded with the handheld sensor for the no N reference ranged from .527-.599 with a standard deviation of .03. The N-rich strip ranged from .578-.674 with a standard deviation of .04 (Table 6)

**Site 6. Barber Co. Kiowa, KS 2009.**

This site is a continuous conventional till wheat site with a broken pattern of hay grazer production. Yields for this site are typical for the region, usually around 3400 kg $ha^{-1}$. There was a response to N for both yield and gross return. There was a significant difference among all treatments when analyzing grain yield. The FP was significantly higher than the SBNRC with an application rate of 24 kg N $ha^{-1}$ more. It was identified that there was a statistical significance between the no topdress and the FP treatments when analyzing gross return. Analysis of grain N concentration at this site found the FP to be higher than the SBNRC and the no topdress treatments. (Table 4).

The range of NDVI readings from the handheld sensor for the no N reference ranged from .544-.622 with a standard deviation of .03. The N-rich strip ranged from .653-.745 with a standard deviation of .03 (Table 6).

**Site 7. Canadian Co. El Reno, OK 2009.**

This site is a continuous conventional till wheat production site. Numerically, there was a response to N for both yield and gross return. There was a significant difference among all treatments when analyzing grain yield at this site. The yield of the SBNRC was increased with an additional 21 kg N $ha^{-1}$ above the FP. The SBNRC had a significantly higher gross return than the FP and the no topdress treatments. N concentration analysis at this site found no significant differences among treatments (Table 4).

NDVI recorded with the handheld sensor on the no N reference ranged from .441-.592 with a standard deviation of .08. The N-rich strip ranged from .621-.658 with a standard deviation of .02 (Table 6).

**Site 8. Canadian Co. El Reno, OK 2009.**

This site is a continuous conventional till wheat site. This site had fair stand throughout the season. There was a significant response to N for both yield and gross return. There was a significant difference among all treatments when analyzing grain yield at this location. The no topdress treatment was significantly lower than the FP and SBNRC treatments when analyzing gross return. The SBNRC increased N by 35 kg ha $^{-1}$ above the FP and resulted in a yield increase of 390 kg ha$^{-1}$ of grain. Grain N concentration analysis found a significant difference in %N in the SBNRC treatment. There was no significant difference between FP and no topdress N concentration (Table 4).

The range of NDVI recorded by the handheld sensor ranged from .442-.462 with a standard deviation of .01 on the no N reference. On the N-rich strip, NDVI ranged from .481-.569 with a standard deviation of .05 (Table 6).

Over all sites harvested in 2009, the average FP N rate was 56 kg N ha$^{-1}$. The SBNRC recommended an average N rate of 45 kg N ha$^{-1}$. The FP yielded an average of 3061 kg ha$^{-1}$ of grain. The SBNRC treatment yielded an average of 3069 kg ha$^{-1}$ of grain. Over all sites, the SBNRC recommended 11 kg N ha$^{-1}$ less than the FP and increased grain yield by 8 kg ha$^{-1}$. The SBNRC had a gross return of \$509 ha$^{-1}$, \$15 ha$^{-1}$ more than the FP and \$66 ha$^{-1}$ more than the no topdress.

**2010**

In the 2009-2010 crop season, some areas had a growing season capable of producing above average yields. In other regions, moisture was below average throughout the winter months and produced a less than average wheat crop. Kiowa Kansas received 10.9 cm less rain than the 30 year average, potentially leading to less than average wheat yields. In SW Oklahoma, rainfall totals were not greater compared to the 30 year average for the area, but timely distribution of precipitation potentially led to above average yields for the Hollis area. (http://agweather.mesonet.org). Of the nine sites established, 8 were harvested. At the Hollis 3 site the producer used a custom harvesting company, and the operator did not recognize the trial in the field and it was harvested with the rest of the field.

The results of 2010 are listed in table 7. Table 8 lists the N rate for each treatment at each location in 2010.

**Site 1. Harmon Co Hollis OK 2010**

This site is a conventional till, bedded and irrigated wheat site. It was broken out from alfalfa the previous spring. The producer applied 112 kg $ha^{-1}$ of ammonium polyphosphate (APP) (10-34-0). The FP was based on a yield goal of 5376 kg $ha^{-1}$. At sensing soil test N was 25 kg N $ha^{-1}$ (Table 9).

At this location there was no yield response to N. At this location the SBNRC and VRT rates were 153 and 159 kg N $ha^{-1}$ less than the FP respectively. The FP treatment had a significantly lower gross return than all other treatments at this location. The range of NDVI readings collected by the RT 200 from across this site ranged from .637 to .838 with a standard deviation of .03 and a CV of .08. (Figure 2) Hand held sensor NDVI readings for the no N reference ranged from .754 to .855 with a standard deviation of .03. The N-rich strip had NDVI readings ranging from .823 to .888 with a standard deviation of .03. (Table 10) Grain N concentration analysis identified the FP treatment had a significantly higher N concentration percentage than the no topdress, SBNRC, and VRT treatments. There was no significant difference between the no topdress, SBNRC, and the VRT treatments. (Table 11)

**Site 2. Kiowa Co. Hobart, OK 2010**

This site is a continuous no-till wheat field. The producer applied 67.2 kg $ha^{-1}$ of DAP preplant. At sensing soil test N was 20 kg N $ha^{-1}$ (Table 9)

There was a response to N at this location. The FP and the SBNRC treatments were not statistically significant when analyzing grain yield. The SBNRC applied 12 kg $ha^{-1}$ less than the FP treatment. The no topdress and the VRT were not significantly different. The VRT applied 31 and 19 kg N $ha^{-1}$ less than the FP and the SBNRC respectively. when analyzing grain yield. However the FP and SBNRC were statistically significant from the no topdress and the VRT treatments. There was no significance among all treatments when analyzing gross return. This site had a range of NDVI readings collected by the RT 200 from across the site from .12 to .695 with a standard deviation of .05 and a CV of .15 (Figure 2). Handheld readings for the no topdress reference strip ranged from .349 to .439 with a standard deviation of .04. The N-rich strip had NDVI readings from .495 to .535 with a standard deviation of .02 (Table 10). When analyzing grain N concentration, it was identified that there was no statistical significance between all the treatments at this site. (Table 11)

**Site 3. Kiowa Co. Hobart, OK 2010**

This site is a continuous no-till wheat field. The producer applied 67.2 kg $ha^{-1}$ of DAP preplant. At sensing soil test N was 21 kg N $ha^{-1}$ (Table 9).

One problem that was encountered at this site was the range of NDVI readings and the application rate that was applied on the VRT treatment. The applicator is programmed to not apply N when the RT-200 system reads an NDVI reading less than .25. At this site, there was a substantial amount of readings that were below .25 (Figure 4); therefore, no fertilizer N was applied 56% of the treatment area. It is hypothesized that this is the reason the VRT treatment did not receive as much fertilizer N as the SBNRC treatment. This particular site had heavy residue and small wheat at the time of fertilizing.

When analyzing grain yield, it was identified the no topdress was significantly lower than the other treatments. Also the yield of the VRT was significantly lower than the FP and SBNRC treatments. No significant differences in yield of the FP and SBNRC was observed where the SBNRC applied 18 kg N $ha^{-1}$ more. When analyzing gross return, it was identified that the VRT and the no topdress treatments had a significantly lower values than the FP and the SBNRC treatments, which had no significant difference. The range of NDVI readings collected by the RT 200 from across this site was from .173 to .634 with a standard deviation of .05 and a CV of .19. (Figure 2). Handheld readings from the no N reference ranged from .326 to .407 with a standard deviation of .03. The N-rich strip had a range of readings from .48 to .583 with a standard deviation of .04 (Table 10).

Grain N concentration analysis at this location identified no significant difference among all the treatments. (Table 11)

**Site 4. Canadian Co. El Reno, OK 2010**

This site is a no-till wheat after corn field. The producer applied 16.2 kg N $ha^{-1}$ preplant. At the time of sensing the soil test N was 65 kg N $ha^{-1}$ (Table 9).

When analyzing grain yield, it was identified that the VRT applied 13 and 10 kg N $ha^{-1}$ less than the FP and the SBNRC respectively. The VRT was significantly higher than the no topdress treatment. There was no statistical significance among all treatments at this site when analyzing gross return. The range of NDVI readings collected by the RT 200 from across this site was from .207 to .661 with a standard deviation of .06 and a CV of .12. (Figure 3) Handheld readings taken from the no N reference ranged from .514 to .585 with a standard deviation of .03. Readings from the N-rich strip ranged from .551 to .629 with a standard deviation of .03 (Table 10).

When analyzing grain N concentration at this site, it was identified there was no significant difference between the VRT and SBNRC treatments. Also there was no significant difference between the SBNRC and FP treatments. No significant difference between the FP and no topdress treatments was identified. There was a significant difference between the VRT, FP, and no topdress treatments. Also there was a significant difference between the SBNRC and the no topdress treatment. (Table 11)

**Site 5. Canadian Co. El Reno, OK 2010**

This site is a continuous till wheat field. The producer applied 7.84 kg N $ha^{-1}$ preplant. At the time of sensing soil test N was 67 kg N $ha^{-1}$ (Table 9).

There was no statistical significance across all treatments when analyzing grain yield at this location. At this site the SBNRC applied 9 and 16 kg N ha $^{-}$1 more than the FP and VRT treatments respectively. Also there was no significant difference among all treatments when analyzing gross return. The range of NDVI readings collected by the RT 200 from across this site was from .572 to .893 with a standard deviation of .07 and a CV of .09 (Figure 3). Handheld readings taken from the no N reference ranged from .717 to .847 with a standard deviation of .06. The N-rich strip readings ranged from .878 to .922 with a standard deviation of .02 (Table 10). Grain N concentration analysis at this site identified the SBNRC had a significantly higher N concentration than the rest of the treatments. There was no significant difference between the no topdress, FP, and the VRT treatments. (Table 11)

**Site 6. Barber Co Ks. Kiowa, KS 2010**

This site is a continuous till wheat field. The producer applied 50.4 kg N $ha^{-1}$ of DAP preplant. At the time of sensing soil test N was 45 kg N $ha^{-1}$ (Table 9).

The FP treatment yield was statistically lower than the other treatments with 43 kg N $ha^{-1}$ more was applied to this treatment. When analyzing gross return it was identified the FP was statistically lower than the other treatments. Also there was a significant difference with the no topdress treatment compared to the other treatments. The range of NDVI collected by the RT-200 over the entire site ranged from .394 to .682 with a standard deviation of .05 and a CV of .10 (Figure 3). Handheld readings from the no N reference ranged from .524 to .644 with a standard deviation of .04. The N-rich strip had a range from .55 to .654 with a standard deviation of .04 (Table 10). When evaluating grain N concentration at this site it was identified that there was no significant difference between the FP, SBNRC, and the VRT treatments. Also there was no significant difference between the SBNRC, VRT, and the no topdress treatments. There was a significant difference between the FP and the no topdress treatments. (Table 11)

**Site 7. Barber Co Ks. Kiowa, KS 2010**

This site is a continuous till wheat field. The producer applied 50.4 kg N ha$^{-1}$ of DAP preplant. At the time of sensing soil test N was 67 kg N ha$^{-1}$ (Table 9).

When analyzing grain yield it was identified there was no significance between the SBNRC and the VRT treatments, which applied 15 and 12 kg N ha $^{-1}$ respectively. Also there was no significant difference between the no topdress and the FP treatments, which had an N rate of 0 and 56 kg N ha $^{-1}$ respectively. There was however a significant difference between the no topdress and FP treatments compared to the SBNRC and VRT treatments. When analyzing gross return, it was identified that the no topdress was significantly higher when compared to the other treatments. It should be noted that the no topdress and the FP treatments out yielded the SBNRC and the VRT treatments. This is likely due to the very low yields of the SBNRC and the VRT treatments of the second rep which were positioned next to each other. The range of NDVI collected from the RT-200 over the entire site ranged from .339 to .779 with a standard deviation of .07 and a CV of .13 (Figure 3). Handheld sensor readings from the no N reference ranged from .636 to .732 with a standard deviation of .06. The N-rich strip readings ranged from .676 to .743 with a standard deviation of .04 (Table 10). Grain N concentration analysis identified the FP treatment had a significantly higher grain N percentage than the other treatments. There was no significant difference between the VRT, SBNRC, and the no topdress treatments. (Table 11)

In 2010 the average yield for the no topdress treatment over all 8 harvested sites was 3513 kg ha$^{-1}$ of grain. This treatment had an average N rate of 75 kg N ha$^{-1}$ and a gross return of \$646 ha$^{-1}$. The FP treatment had an average yield of 3768 kg ha$^{-1}$ of grain with a gross return of \$612 ha$^{-1}$. The SBNRC treatment applied 40 kg N ha $^{-1}$ and had an average yield of 3856 kg ha$^{-1}$ of grain and had a gross return of \$656 ha$^{-1}$. Average yield for the VRT treatment was 3613 kg ha$^{-1}$ with a gross return of \$626 ha$^{-1}$ with an application average rate of 26 kg N ha $^{-1}$. Over all sites, the SBNRC treatment made 342 kg ha$^{-1}$ more grain than the no topdress treatment, 88 kg ha$^{-1}$ more grain than the FP, with 35 kg N ha$^{-1}$ less, and 243 kg ha$^{-1}$ more grain than the VRT treatment with the SBNRC applying 14 kg N ha$^{-1}$ more. Economically, the SBNRC treatment had a gross return of \$10 ha$^{-1}$ more than the no topdress treatment, \$44 ha$^{-1}$ more than the FP treatment and \$30 ha$^{-1}$ more than the VRT treatment. Compared to the FP treatment the VRT treatment had 156 kg ha$^{-1}$ less grain but made \$14 ha$^{-1}$ more than the FP treatment.

# CHAPTER VII

# CONCLUSION

Over all sites harvested in 2009 and 2010 the SBNRC treatment applied 22 kg N $ha^{-1}$ less than the FP treatment over 2 years and 14 kg N $ha^{-1}$ more than the VRT in 2010 resulting in higher yields than the no topdress, FP, and VRT treatments. Also the SBNRC treatment had higher gross return than all the other treatments. The two year average of N rate for the FP and SBNRC was 65 and 43 kg N $ha^{-1}$ with an increase in yield by 6 kg $ha^{-1}$ for the SBNRC treatment. These trials demonstrate that using the N-rich strip and the GreenSeeker™ sensor has the potential to save money by putting less N down while maintaining yields. It can also benefit producers by putting more N down when it is needed and increasing yields. Using the N-rich strip gives the producer a reference, a visual aid, to go by in deciding whether to apply topdress or not to apply topdress. It is an easy yes or no solution to topdressing winter wheat. When using the SBNRC approach, it can give you a recommended rate for that specific field for that specific year. In some years the strip may not be very visible, showing that there is not a need for as much topdress N. Some years the strip is visible, thus an application of topdress N is needed. In 2009 there were some problems with the RT-200 variable rate application, but those were fixed for the 2010 topdressing season. The VRT did not yield as high as the SBNRC and FP treatments; however, its gross return was greater than the no topdress.

These trials indicate that the VRT could have a place and can be beneficial to producers when it is used. It is hypothesized that even with these large scale trials, not all the variability throughout the field was caught; however, by doing these trials at a large scale we gained a better understanding on how the VRT will perform on producer's fields. The VRT worked best on the site with a relatively wide distribution of NDVI across the site. Excluding the no-till sites where the VRT did not work as well, the next to worst site had a relatively low distribution size. More data needs to be collected and analyzed in order to gain a better understanding of how this system works and how it can be applied.

# CHAPTER VII

# DISCUSSION

It is important to note that the SBNRC methodology resulted in increased gross return versus the farmer practice in 13 of 16 trials ($5.00/bu, 0.50/lb N). Also relevant was noting that the 0-N check had greater profit than the SBNRC in 7/16 trials. While this is noteworthy, it really isn't a viable comparison since farmers are unlikely to apply 0-N preplant. This is an important research need in the treatment structure as it properly allows for the evaluation of N response. But, it is not a viable option that farmers would chose. That the 0-N check plot did so well is a testament to the fact that many farmers have over applied N, and as a result, enough residual N was present to produce near maximum yields.

Hindsight analysis would suggest that possibly less N could have been applied for the SBNRC treatment. In retrospect, how did the SBNRC do so well in recognizing that in many cases, decreased N applied was in order? The SBNRC works off of recognizing increased or decreased yield potential. These results also substantiate the fact that the SBNRC recommended less N at many sites where farmer N rates were excessive. How did it know? As described in methods, the SBNRC is a predictive tool. Combining predicted yield potential and N responsiveness, this tool can more accurately determine mid-season fertilizer N rates than other methods that are currently in use. As such, this approach should be considered more by farmers who are guessing when making their mid-season N recommendations, without the use of an N Rich Strip and sensor based yield potential prediction.

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Table 1. Location, NDVI of the no topdress reference, GDD's where GDD's were greater than zero from planting to sensing, observed grain yield at harvest, and predicted yield at time of sensing.

| 2009 | | | | |
|---|---|---|---|---|
| Location | NDVI | GDD's | Observed Yield | Predicted yield |
| 1 | 0.57 | 73 | 1224 | 4428 |
| 2 | . | . | . | . |
| 3 | 0.34 | 53 | 1268 | 3091 |
| 4 | 0.62 | 101 | 2889 | 2876 |
| 5 | 0.58 | 97 | 3948 | 2762 |
| 6 | 0.58 | 98 | 3711 | 2722 |
| 7 | 0.53 | 87 | 1590 | 2843 |
| 8 | 0.46 | 77 | 2056 | 2762 |
| 2010 | | | | |
| 1 | 0.453 | 103 | 3100 | 3763 |
| 2 | 0.77 | 103 | 4076 | 4906 |
| 3 | 0.323 | 71 | 1985 | 3763 |
| 4 | 0.277 | 72 | 1415 | 3965 |
| 5 | 0.431 | 61 | 5881 | 6586 |
| 6 | 0.783 | 90 | 4220 | 6922 |
| 7 | 0.54 | 92 | 3145 | 3091 |
| 8 | 0.584 | 89 | 3871 | 4368 |

Table 2. Predominated soil types of each trial in both years.

| | Predominate Soil types |
|---|---|
| | 2009 |
| Site 1 | Parsons silt loam-Parsons, Fine, Mixed, Active, Thermic Mollic Albaqualfs |
| Site 2 | Taloka silt loam-Taloka, Fine, Mixed, Active, Thermic Mollic Albaqualfs |
| Site 3 | Taloka silt loam-Taloka, Fine, Mixed, Active, Thermic Mollic Albaqualfs |
| Site 4 | Grant silt loam-Grant fine, silty, mixed Superactive, Thermic udic Argiustioll |
| Site 5 | Dale silt loam- Dale fine silty mixed Superactive Thermic Pachic Haplustoll |
| Site 6 | Pond Creek silt loam-Pond Creek fine silty Mixed Superactive Thermic Pachic Argiustoll |
| Site 7 | Dale silt loam- Dale fine silty mixed Superactive Thermic Pachic Haplustoll |
| Site 8 | Bethany-Bethany fine, mixed, Superactive, Thermic pachic Paleustoll |
| | 2010 |
| Site 1 | Westill clay- Westill, Fine, Mixed, Active, Thermic Vertic Argiustoll |
| Site 2 | Apermont silt loam-Aspermont, fine-silty, Mixed, Active, Thermic Typic Calciustepts |
| Site 3 | Hollister silty clay- Hollister, Fine, Smectitic, Thermic Typic Haplusterts |
| Site 4 | Hollister silty clay- Hollister, Fine, Smectitic, Thermic Typic Haplusterts |
| Site 5 | Dale silt loam- Dale fine silty mixed Superactive Thermic Pachic Haplustoll |
| Site 6 | Reniach very fine silt loam- Coarse-silty, Mixed, Superactive, Thermic Pachic Haplustoll |
| Site 7 | Grant silt loam-Grant fine, silty, mixed Superactive, Thermic udic Argiustioll |
| Site 8 | Pond Creek silt loam-Pond Creek fine silty Mixed Superactive Thermic Pachic Argiustoll |

Table 3. Effect of topdress N application methods on wheat grain yield in 2008-2009 growing season. Means within a row for each site followed by the same letter are not significantly different at the 0.10 probability level.

| | Yield kg ha-1 | | | %N in Grain | | | Gross Return % ha-1 | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | No Topdress | FP | SBNRC | No Topdress | FP | SBNRC | No Topdress | FP | SBNRC |
| 1 | 1224 b | 1581 ba | 1747 a | 2.05 b | 2.09 ab | 2.12 a | 225 a | 237 a | 255 a |
| 2 | 2567 c | 3553 b | 3664 a | 2.27 a | 2.37 a | 2.4 a | 472 b | 604 a | 605 a |
| 3 | 1268 c | 2651 a | 2231 b | . | . | . | 233 b | 372 a | 356 a |
| 4 | 2889 b | 3492 a | 2981 b | 1.82 a | 2.05 a | 1.87 a | 531 a | 559 a | 515 a |
| 5 | 3948 a | 3948 a | 4082 a | 2.49 a | 2.53 a | 2.55 a | 726 a | 643 b | 741 a |
| 6 | 3711 c | 4467 a | 4151 b | 1.84 b | 2.05 a | 1.9 b | 682 b | 739 a | 710 ab |
| 7 | 1590 c | 1967 b | 2482 a | 1.73 a | 1.78 a | 1.79 a | 292 b | 316 b | 375 a |
| 8 | 2056 c | 2826 b | 3216 a | 1.75 b | 1.8 b | 1.95 a | 378 b | 481 a | 510 a |
| Averages | 2407 | 2727 | 3082 | 1.99 | 2.10 | 2.08 | 442 | 494 | 510 |

Table 4. N rate application for all treatments at each location in 2009.

| | No Topdress | Farmer Practice | SBNRC |
|---|---|---|---|
| Location | Nrate | Nrate | Nrate |
| Site 1 | 0 | 44 | 54 |
| Site 2 | 0 | 40 | 55 |
| Site 3 | 0 | 94 | 44 |
| Site 4 | 0 | 67 | 27 |
| Site 5 | 0 | 67 | 8 |
| Site 6 | 0 | 67 | 43 |
| Site 7 | 0 | 37 | 66 |
| Site 8 | 0 | 31 | 66 |
| **Averages** | **0** | **56** | **45** |

Table 5. Readings taken from the handheld sensor of the no N reference and the N-rich strip taken at time of application in 2009.

| | Site 1 | | Site 3 | | Site 4 | | Site 5 | | Site 6 | | Site 7 | | Site 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich |
| | 0.573 | 0.667 | 0.343 | 0.408 | 0.58 | 0.695 | 0.527 | 0.639 | 0.589 | 0.691 | 0.441 | 0.658 | 0.461 | 0.569 |
| | 0.612 | 0.711 | 0.345 | 0.421 | 0.593 | 0.701 | 0.588 | 0.578 | 0.577 | 0.687 | 0.571 | 0.625 | 0.442 | 0.486 |
| | 0.522 | 0.609 | 0.367 | 0.439 | 0.609 | 0.699 | 0.599 | 0.595 | 0.549 | 0.678 | 0.592 | 0.621 | 0.462 | 0.481 |
| | | | 0.314 | 0.403 | 0.688 | 0.655 | 0.59 | 0.674 | 0.588 | 0.693 | | | | |
| | | | 0.331 | 0.434 | 0.698 | 0.692 | | | 0.622 | 0.745 | | | | |
| | | | 0.312 | 0.38 | 0.557 | 0.728 | | | 0.6 | 0.694 | | | | |
| | | | | | | | | | 0.56 | 0.689 | | | | |
| | | | | | | | | | 0.544 | 0.653 | | | | |
| Average | 0.57 | 0.66 | 0.34 | 0.41 | 0.62 | 0.70 | 0.58 | 0.62 | 0.58 | 0.69 | 0.53 | 0.63 | 0.46 | 0.51 |
| STDEV | 0.05 | 0.05 | 0.02 | 0.02 | 0.06 | 0.02 | 0.03 | 0.04 | 0.03 | 0.03 | 0.08 | 0.02 | 0.01 | 0.05 |
| CV | 0.08 | 0.08 | 0.06 | 0.05 | 0.09 | 0.03 | 0.06 | 0.07 | 0.05 | 0.04 | 0.15 | 0.03 | 0.02 | 0.10 |
| Median | 0.57 | 0.67 | 0.34 | 0.41 | 0.60 | 0.70 | 0.59 | 0.62 | 0.58 | 0.69 | 0.57 | 0.63 | 0.46 | 0.49 |

Table 6. Effect of topdress N application methods on wheat grain yield, percent N in the grain, and gross return in 2009-2010 growing season. Means within a row for each site followed by the same letter are not significantly different at the 0.10 probability level.

| | Yield kg ha-1 | | | | %N in Grain | | | | Gross Return $ ha-1 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | No Topdress | FP | SBNRC | VRT | No Topdress | FP | SBNRC | VRT | No Topdress | FP | SBNRC | VRT |
| 1 | 4076 a | 4209 a | 4194 a | 4056 a | 2.32 b | 2.66 a | 2.42 b | 2.29 b | 749 a | 553 b | 739 a | 721 a |
| 2 | 1985 b | 2626 a | 2679 a | 2215 b | 2.24 a | 2.19 a | 2.18 a | 2.21 a | 365 a | 400 a | 425 a | 363 a |
| 3 | 1416 c | 2708 a | 2822 a | 1614 b | 2.16 a | 2.14 a | 2.13 a | 2.08 a | 260 b | 415 a | 419 a | 257 b |
| 4 | 5881 b | 6124 ab | 6143 ab | 6279 a | 2.36 c | 2.38 bc | 2.47 ab | 2.5 a | 1081 a | 1057 a | 1083 a | 1120 a |
| 5 | 4220 a | 4390 a | 4492 a | 4288 a | 1.9 b | 1.91 b | 2.08 a | 1.94 b | 776 a | 752 a | 759 a | 741 a |
| 6 | 3145 a | 3035 b | 3122 a | 3134 a | 2.51 b | 2.64 a | 2.57 ab | 2.56 ab | 578 a | 489 c | 558 b | 560 b |
| 7 | 3871 a | 3953 a | 3611 b | 3580 b | 2.11 b | 2.45 a | 2.19 b | 2.26 b | 712 a | 658 b | 645 b | 643 b |
| Averages | 3513 | 3864 | 3866 | 3595 | 2.23 | 2.34 | 2.29 | 2.26 | 646 | 618 | 661 | 629 |

Table 7. N rate application for all treatments at each location in 2010.

| Location | No Topdress | Farmer Practice | SBNRC | VRT |
|---|---|---|---|---|
| Site 1 | 0 | 179 | 26 | 20 |
| Site 2 | 0 | 67 | 55 | 36 |
| Site 3 | 0 | 67 | 81 | 32 |
| Site 4 | 0 | 56 | 38 | 28 |
| Site 5 | 0 | 45 | 54 | 38 |
| Site 6 | 0 | 56 | 13 | 13 |
| Site 7 | 0 | 56 | 15 | 12 |
| **Averages** | **0** | **75** | **40** | **26** |

Table 8. Soil tests taken at time of sensing over all sites in 2010. Approximately 20 cores were taken over the entire trial area.

| Location | Surface N03 (ppm) | P (ppm) | K (ppm) | pH |
|---|---|---|---|---|
| Site 2 | 11 | 29.5 | 335.5 | 7.5 |
| Site 3 | 9 | 8.5 | 337.5 | 7.6 |
| Site 4 | 9.5 | 22 | 371.5 | 7.5 |
| Site 5 | 29 | 19 | 102 | 5.8 |
| Site 6 | 30 | 38 | 189.5 | 6.6 |
| Site 7 | 20 | 18.5 | 190 | 8.0 |
| Site 8 | 30 | 15 | 176.5 | 7.7 |

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Table 9. Readings taken from the handheld sensor of the no N reference and the N-rich strip taken at time of application in 2010.

| | Site 1 | | Site 2 | | Site 3 | | Site 4 | | Site 5 | | Site 6 | | Site 7 | | Site 8 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich | No topdress | N-Rich |
| | 0.585 | 0.745 | 0.807 | 0.873 | 0.439 | 0.502 | 0.407 | 0.583 | 0.585 | 0.564 | 0.836 | 0.914 | 0.597 | 0.592 | 0.636 | 0.676 |
| | 0.657 | 0.771 | 0.791 | 0.823 | 0.422 | 0.535 | 0.38 | 0.545 | 0.575 | 0.56 | 0.847 | 0.922 | 0.548 | 0.565 | 0.636 | 0.683 |
| | 0.711 | 0.793 | 0.754 | 0.844 | 0.431 | 0.534 | 0.37 | 0.535 | 0.547 | 0.551 | 0.717 | 0.878 | 0.524 | 0.55 | 0.732 | 0.743 |
| | 0.548 | 0.74 | 0.855 | 0.877 | 0.405 | 0.522 | 0.326 | 0.48 | 0.532 | 0.576 | 0.833 | 0.893 | 0.644 | 0.654 | . | . |
| | 0.525 | 0.72 | 0.83 | 0.883 | 0.373 | 0.517 | 0.336 | 0.503 | 0.563 | 0.629 | . | . | 0.583 | 0.609 | . | . |
| | 0.523 | 0.702 | 0.8 | 0.888 | 0.349 | 0.495 | 0.381 | 0.57 | 0.514 | 0.588 | . | . | 0.576 | 0.59 | . | . |
| Average | 0.59 | 0.75 | 0.81 | 0.86 | 0.40 | 0.52 | 0.37 | 0.54 | 0.55 | 0.58 | 0.81 | 0.90 | 0.58 | 0.59 | 0.67 | 0.70 |
| STDEV | 0.08 | 0.03 | 0.03 | 0.03 | 0.04 | 0.02 | 0.03 | 0.04 | 0.03 | 0.03 | 0.06 | 0.02 | 0.04 | 0.04 | 0.06 | 0.04 |
| CV | 0.130 | 0.044 | 0.043 | 0.030 | 0.088 | 0.032 | 0.083 | 0.073 | 0.049 | 0.049 | 0.076 | 0.022 | 0.072 | 0.061 | 0.083 | 0.053 |
| Median | 0.57 | 0.74 | 0.80 | 0.88 | 0.41 | 0.52 | 0.38 | 0.54 | 0.56 | 0.57 | 0.83 | 0.90 | 0.58 | 0.59 | 0.64 | 0.68 |

| Treatment | |
|---|---|
| 1 | No Top-dress N |
| 2 | Typical Farmer Practice |
| 3 | SBNRC Uniform Rate |
| 4 | RT-200 Variable Rate |

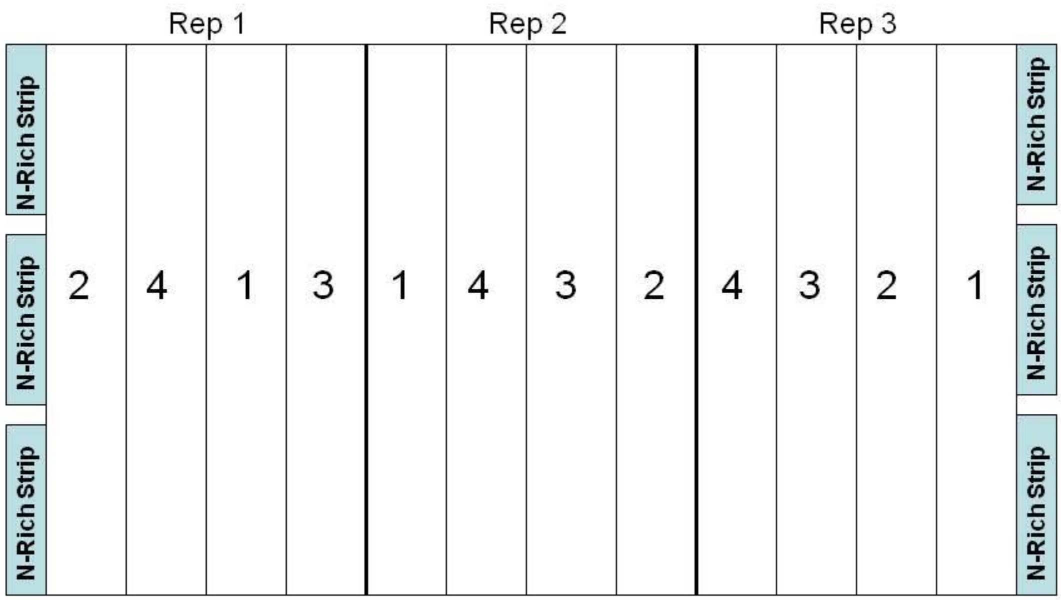


Figure 1. Treatment structure implemented at all sites in both years

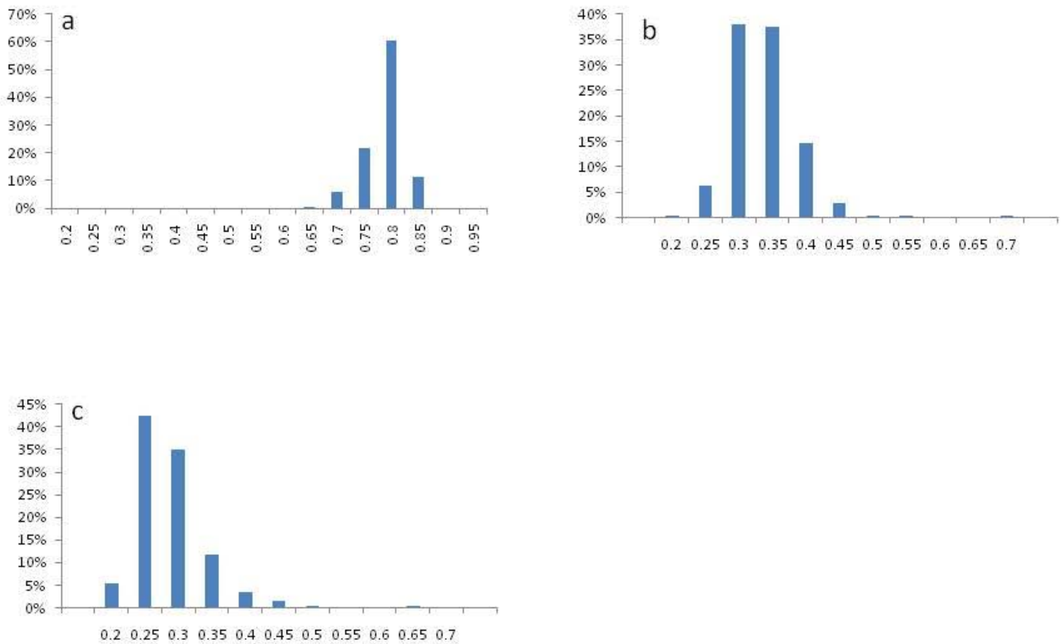


Figure 2. Histograms of NDVI taken from the RT-200 VRT system at time of topdress. The X axis is NDVI, and Y axis is the number of readings. (a) Harmon Co site 1, (b)Hobart site 2, and(c) Hobart site 3, 2010.

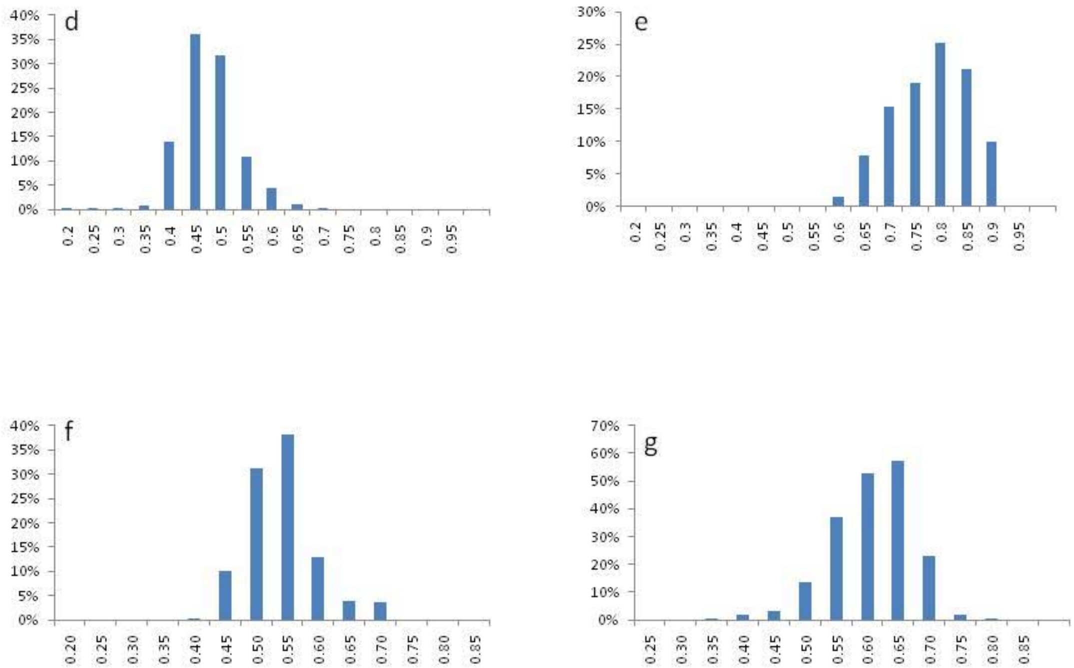


Figure 3. Histograms of NDVI taken from the RT-200 VRT system at time of topdress. The X axis is NDVI and the Y axis is number of readings. (d) El Reno site 5, (e) El Reno site 6, (f) Kiowa, KS, site 7, and (g) Kiowa, KS, site 8 2010.

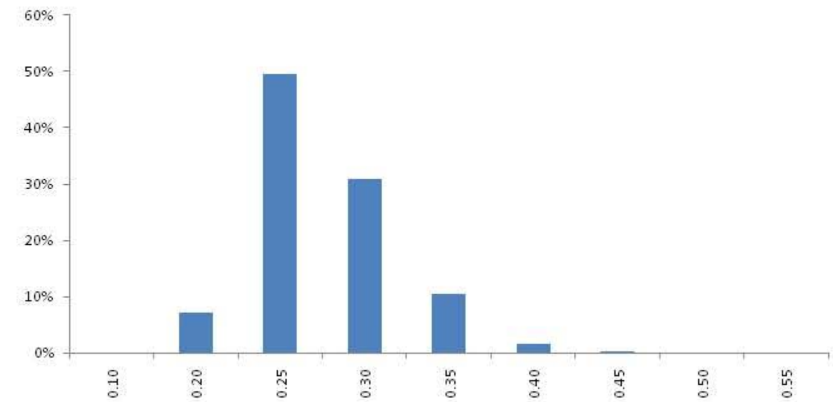


Figure 4. Histogram of NDVI readings collected with the RT-200 from treatment 4 at the Hobart site 3.

# APPENDICES

| | Yield kg ha-1 | |
|---|---|---|
| Source of variation | df | Mean squares |
| **Site 1 2009** | | |
| Rep | 2 | 152630 |
| Treatment | 2 | 214790 |
| Error | 4 | 81551 |
| **Site 2 2009** | | |
| Rep | 2 | 9494 |
| Treatment | 2 | 1092866 |
| Error | 4 | 2297 |
| **Site 3 2009** | | |
| Rep | 2 | 79448 |
| Treatment | 2 | 1508048 |
| Error | 4 | 10011 |
| **Site 4 2009** | | |
| Rep | 2 | 7302 |
| Treatment | 2 | 316550 |
| Error | 4 | 39126 |
| **Site 5 2009** | | |
| Rep | 2 | 207747 |
| Treatment | 2 | 17778 |
| Error | 4 | 7012 |
| **Site 6 2009** | | |
| Rep | 2 | 78599 |
| Treatment | 2 | 432853 |
| Error | 4 | 11343 |
| **Site 7 2009** | | |
| Rep | 2 | 272272 |
| Treatment | 2 | 601555 |
| Error | 4 | 22843 |
| **Site 8 2009** | | |
| Rep | 2 | 6574 |
| Treatment | 2 | 1044657 |
| Error | 4 | 21406 |

Figure A1. Analysis of Variance for wheat grain yield as influenced by topdress application methods at 5 sites in Oklahoma and 3 sites in Kansas, 2009.

| Gross Return $ ha-1 | | |
|---|---|---|
| Source of variation | df | Mean squares |
| **Site 1 2009** | | |
| Rep | 2 | 5159 |
| Treatment | 2 | 667 |
| Error | 4 | 2757 |
| **Site 2 2009** | | |
| Rep | 2 | 321 |
| Treatment | 2 | 17613 |
| Error | 4 | 78 |
| **Site 3 2009** | | |
| Rep | 2 | 2686 |
| Treatment | 2 | 17179 |
| Error | 4 | 338 |
| **Site 4 2009** | | |
| Rep | 2 | 247 |
| Treatment | 2 | 1514 |
| Error | 4 | 1323 |
| **Site 5 2009** | | |
| Rep | 2 | 7022 |
| Treatment | 2 | 8277 |
| Error | 4 | 237 |
| **Site 6 2009** | | |
| Rep | 2 | 2657 |
| Treatment | 2 | 2375 |
| Error | 4 | 383 |
| **Site 7 2009** | | |
| Rep | 2 | 9203 |
| Treatment | 2 | 5412 |
| Error | 4 | 772 |
| **Site 8 2009** | | |
| Rep | 2 | 222 |
| Treatment | 2 | 14399 |
| Error | 4 | 724 |

Figure A2. Analysis of Variance for gross return as influenced by topdress application methods at 5 sites in Oklahoma and 3 sites in Kansas, 2009.

| %N in Grain | | |
|---|---|---|
| Source of variation | df | Mean squares |
| **Site 1 2009** | | |
| Rep | 2 | 0.004 |
| Treatment | 2 | 0.003 |
| Error | 4 | 0.0003 |
| **Site 2 2009** | | |
| Rep | 2 | 0.005 |
| Treatment | 2 | 0.014 |
| Error | 4 | 0.006 |
| **Site 3 2009** | | |
| Rep | . | . |
| Treatment | . | . |
| Error | . | . |
| **Site 4 2009** | | |
| Rep | 2 | 0.006 |
| Treatment | 2 | 0.05 |
| Error | 4 | 0.01 |
| **Site 5 2009** | | |
| Rep | 2 | 0.03 |
| Treatment | 2 | 0.004 |
| Error | 4 | 0.02 |
| **Site 6 2009** | | |
| Rep | 2 | 0.002 |
| Treatment | 2 | 0.04 |
| Error | 4 | 0.002 |
| **Site 7 2009** | | |
| Rep | 2 | 0.02 |
| Treatment | 2 | 0.003 |
| Error | 4 | 0.005 |
| **Site 8 2009** | | |
| Rep | 2 | 0.002 |
| Treatment | 2 | 0.03 |
| Error | 4 | 0.003 |

Figure A3. Analysis of Variance for percent N in the grain as influenced by topdress application methods at 5 sites in Oklahoma and 3 sites in Kansas, 2009.

| Yield kg ha-1 | | |
|---|---|---|
| Source of variation | df | Mean squares |
| **Site 1 2010** | | |
| Rep | 2 | 2868 |
| Treatment | 3 | 18675 |
| Error | 6 | 10357 |
| **Site 2 2010** | | |
| Rep | 2 | 177083 |
| Treatment | 3 | 332850 |
| Error | 6 | 60606 |
| **Site 3 2010** | | |
| Rep | 2 | 29685 |
| Treatment | 3 | 1589055 |
| Error | 6 | 10055 |
| **Site 4 2010** | | |
| Rep | 2 | 372459 |
| Treatment | 3 | 82004 |
| Error | 6 | 55716 |
| **Site 5 2010** | | |
| Rep | 2 | 115422 |
| Treatment | 3 | 42568 |
| Error | 6 | 49496 |
| **Site 6 2010** | | |
| Rep | 2 | 25224 |
| Treatment | 3 | 7574 |
| Error | 6 | 1564 |
| **Site 7 2010** | | |
| Rep | 2 | 733632 |
| Treatment | 3 | 90818 |
| Error | 5 | 19181 |

Figure A4. Analysis of Variance for wheat grain yield in the grain as influenced by topdress application methods at 5 sites in Oklahoma and 2 sites in Kansas, 2010.

| Gross Return $ ha-1 | | |
|---|---|---|
| Source of variation | df | Mean squares |
| **Site 1 2010** | | |
| Rep | 2 | 97 |
| Treatment | 3 | 25752 |
| Error | 6 | 350 |
| **Site 2 2010** | | |
| Rep | 2 | 5986 |
| Treatment | 3 | 2649 |
| Error | 6 | 2049 |
| **Site 3 2010** | | |
| Rep | 2 | 1003 |
| Treatment | 3 | 25036 |
| Error | 6 | 340 |
| **Site 4 2010** | | |
| Rep | 2 | 12590 |
| Treatment | 3 | 2027 |
| Error | 6 | 1883 |
| **Site 5 2010** | | |
| Rep | 2 | 3902 |
| Treatment | 3 | 631 |
| Error | 6 | 1673 |
| **Site 6 2010** | | |
| Rep | 2 | 853 |
| Treatment | 3 | 4653 |
| Error | 6 | 53 |
| **Site 7 2010** | | |
| Rep | 2 | 24908 |
| Treatment | 3 | 3041 |
| Error | 5 | 648 |

Figure A5. Analysis of Variance for gross return as influenced by topdress application methods at 5 sites in Oklahoma and 2 sites in Kansas, 2010.

| %N in Grain | | |
|---|---|---|
| Source of variation | df | Mean squares |
| **Site 1 2010** | | |
| Rep | 2 | 0.05 |
| Treatment | 3 | 0.08 |
| Error | 6 | 0.01 |
| **Site 2 2010** | | |
| Rep | 2 | 0.002 |
| Treatment | 3 | 0.002 |
| Error | 6 | 0.005 |
| **Site 3 2010** | | |
| Rep | 2 | 0.002 |
| Treatment | 3 | 0.003 |
| Error | 6 | 0.003 |
| **Site 4 2010** | | |
| Rep | 2 | 0.005 |
| Treatment | 3 | 0.01 |
| Error | 6 | 0.003 |
| **Site 5 2010** | | |
| Rep | 2 | 0.003 |
| Treatment | 3 | 0.02 |
| Error | 6 | 0.004 |
| **Site 6 2010** | | |
| Rep | 2 | 0.002 |
| Treatment | 3 | 0.009 |
| Error | 6 | 0.002 |
| **Site 7 2010** | | |
| Rep | 2 | 0.006 |
| Treatment | 3 | 0.05 |
| Error | 5 | 0.009 |

Figure A6. Analysis of Variance percent N in the grain as influenced by topdress application methods at 5 sites in Oklahoma and 2 sites in Kansas, 2010.

VITA

Jerry L. May

Candidate for the Degree of

Master of Science

Thesis: LARGE SCALE IMPLEMENTATION OF SENSOR BASED TECHNOLOGY USING THE GREENSEEKER$^{TM}$

Major Field: Plant and Soil Science/Soil Fertility

Biographical:

Education:

Completed the requirements for the Master of Science in Plant and Soil Science/Soil Fertility at Oklahoma State University, Stillwater, Oklahoma in July, 2010.

Completed the requirements for the Bachelor of Science in Plant and Soil Science/Agronomy at Oklahoma State University ,Stillwater, Oklahoma in 2008.

Experience: Experiences have given me a foundation that is applicable in soil science and fertility: including soil description and land suitability, no-till and conventional till crop production, variable nitrogen application, yield prediction using optical sensors, and extending research products to producers via large scale research.

Professional Memberships:

American Society of Agronomy. 2009-Present
Soil Science Society of America. 2009-Present
Crop Science Society of America. 2009-Present

Name: Jerry L. May Date of Degree: July, 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: LARGE SCALE IMPLEMENTATION OF SENSOR BASED TECHNOLOGY USING THE GREENSEEKER™

Pages in Study: 52 Candidate for the Degree of Master of Science

Major Field: Plant and Soil Science/Soil Fertility

Scope and Method of Study:

The goal of this project was to compare what the producer's typical practice was against what the GreenSeeker™ predicts. This project also compared those two with the variable nitrogen rate RT-200 system. This study was designed to evaluate the use of optical sensors for N rate determination in producer's fields. Also evaluated was the economics of using the SBNRC and the VRT technology and comparing it with the typical farmer practice (FP) and no topdress.

Findings and Conclusions:

In 2009 the SBNRC recommended 11 kg $ha^{-1}$ less N than the farmer practice and had an 8 kg $ha^{-1}$ increase in grain yield. The SBNRC had a gross return of \$509 $ha^{-1}$, \$15 $ha^{-1}$ more than the FP and \$66 $ha^{-1}$ more than the no topdress. In 2010 The SBNRC made 342 kg $ha^{-1}$ more grain than the no topdress, 88 kg $ha^{-1}$ more than the FP, and 243 kg $ha^{-1}$ more than the VRT. The SBNRC had a gross return of \$10 $ha^{-1}$ more than the no topdress, \$44 ha-1 more than the FP, and \$30 $ha^{-1}$ more than the VRT. This trial shows that on a large scale sensor based technology can benefit producers by increasing yield and increasing gross return.

ADVISER'S APPROVAL: Dr. Brian Arnall