VALIDATION OF NITROGEN CALIBRATION STRIP TECHNOLOGY FOR PRESCRIBING ACCURATE TOPDRESS NITROGEN FERTILIZER

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VALIDATION OF NITROGEN CALIBRATION

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NITROGEN FERTILIZER

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TABLE OF CONTENTS

Section	Page
Abstract	1
I. Introduction	2
II. Objective	7
III. Materials and Methods	7
IV. Results and Discussion	11
Nitrogen Rate Recommendation Using NCS and N-rich strips	11
Grain Yield	12
Marginal Revenue	13
Nitrogen Use Efficiency	14
V. Conclusions	15
VI. References	16
VII. Appendix	27

LIST OF TABLES

Table Page

1a. Application dates for nitrogen calibration strip experiment for the nine sites in Oklahoma, 2004-2005 18

1b. Application dates for nitrogen calibration strip experiment for the eleven sites in Oklahoma, 2005-2006 18

2a. Total N Applied for nine sites in Oklahoma (kg ha^{-1}), 2004-2005 19

2b. Total N applied for nitrogen calibration strip experiment conducted at eleven sites across Oklahoma (kg ha^{-1}), 2005-2006. 20

3a. Winter wheat grain yield means (kg ha^{-1}) for nitrogen calibration strip experiment conducted at nine sites across Oklahoma, 2004-2005. 21

3b. Winter wheat grain yield means (kg ha^{-1}) for nitrogen calibration strip experiment conducted at eleven sites across Oklahoma, 2005-2006. 22

4a. Marginal revenue estimated using price of wheat and N applied for nine sites in Oklahoma, 2004-2005 23

4b. Marginal revenue based on price of wheat and N applied for eleven sites in Oklahoma, 2005-2006 24

5a. Winter wheat NUE (%) from grain and fertilizer data at ten sites across Oklahoma, 2004-2005 25

5b. Winter wheat percent nitrogen use efficiency (NUE) for nitrogen calibration strip experiment conducted at eleven sites across Oklahoma, 2005-2006.. 26

Validation of Nitrogen Calibration Strip Technology for Prescribing Accurate Topdress Nitrogen Fertilizer

Abstract

Making midseason nitrogen (N) recommendations for many crops have not been perfected and many recommendations once used have become out dated. Since the introduction of synthetic fertilizers inaccurate fertilizer rates have been applied due to failure to recognize temporal variability. The nitrogen calibration strip (NCS) technology is one method in which a producer can manage temporal variability by determining N response in-season and making the suitable topdress N application. This study evaluated the use of early-season N fertilizer strips (45, 90, and 135 kg N ha^{-1}) to visually interpret N response mid-season and apply a field-based topdress N application compared to that determined using the Sensor Based Nitrogen Rate Calculator (SBNRC). The SBNRC measures in-season N responsiveness, and estimated yield potential using a GreenSeeker™ hand-held optical reflectance sensor. In both years that this study was conducted temporal, variability had a large role and there was a wide range in grain yield among locations. No significant difference among treatments was found at many of the sites indicating that N levels were adequate to carry the crop to maturity. The SBNRC recommendations had a higher return marginal revenue than the NCS method of determining N needs based on visual appearances. Both SBNRC and the NCS

prescribed less fertilizer than traditional flat rates. These methods also resulted in improved nitrogen use efficiency (NUE) versus conventional practices.

I. Introduction

Since the introduction of synthetic fertilizers, crop yields have increased and continue to increase as technology and information on applications advance. As early as 1957, foliar application of urea solutions at rates from 11 to 56 kg N ha^{-1} at flowering were shown to increase wheat grain protein by as much as 4.4% (Finney et al., 1957). A question which every agricultural producer is faced with is how much fertilizer should be applied and when is the best time to apply the fertilizer to maximize yield (Dinnes et al., 2002). Natural gas prices continue to rise, causing N fertilizer prices to increase, and applying the correct topdress N rate in winter wheat production is becoming more important. New and Improved methods of determining midseason N recommendations are needed to avoid the over application of fertilizer.

Improvement of NUE is one of the major soil nutrient management issues for agricultural researchers today. The current NUE for cereal crop production is estimated to be near 33% indicating that much of the applied fertilizer N is not used by the plants (Raun and Johnson, 1999). To most producers and researchers a 33% NUE should be very alarming number when the price of N is about 74 cents per kilogram. According to Raun and Johnson (1999) a 1% increase in the efficiency of N use for cereal production worldwide would lead to about $235 million savings in cost of fertilizer (1999 prices). This shows that small improvements in the NUE of cereal grains can lead to big savings for the future. According to the Food and Agriculture Organization of the United Nations (FAO) 85 million Mt of N fertilizers was used in 2002 worldwide (FAO, 2004). This quantity was more than double that used in 1970 (32 million Mt), and resulted in increased grain yields, but NUE remained low.

In general, N deficiencies can be easily detected early in the growing season leaving ample time to correct the deficiency without damaging crop yield. The easily-observed symptoms of N deficiencies are chlorotic leaf tips and leaf margins due to a drop in chlorophyll content. Nitrogen is translocated from older to new leaves to sustain growth; therefore cholorosis is first seen in the oldest more mature leaves, and last in the upper, actively-growing leaves. The loss of the older leaves will result in poor plant growth and yield reduction. Generally growth is slowed, stunted and burning of the leaf tips and margins is evident (Agriculture, Food and Rural Development, 2004). According to Plank (1999) the critical level of N in plant tissue is around 3 percent. For several crops, when the N level in leaves drops below 3%, N deficiency symptoms appear and grain yield and quality decline. When N deficiency symptoms occur, some type of damage has been inflicted. There are some exceptions to the 3% threshold, which are young plants when the critical level may be 4% or more, and for leguminous plants, such as soybean, peanut, alfalfa, etc., where the critical N percentage is 3 to 4% (Plank, 1999).

The presence of these obvious symptoms in a field enables the producer to reduce the preplant fertilization program and apply topdress (split application) N based on the intensity of the symptoms. Yet, this requires the development of a simple technology in which different rates of N are visually evaluated to help estimate the amount of N fertilizer to apply to a field.

Split application of fertilizer, when properly used, is one way of improving NUE. Splitting application of N fertilizer between preplant and spring topdress was often the most cost effective and environmentally sound approach to N management (Southern and Central Great Plains, 1995). Over the past years anhydrous ammonia has been the cheapest form of fertilizer, but with natural gas prices on the rise, all forms of fertilizer are costing farmers more, making split applications of fertilizer an important procedure in every operation. Nitrogen rates and timing of applications are key management factors for making good wheat yields, and therefore, rates should be based on soil potential, cultivar, realistic yield goal, previous crop and residual N (Harris, 2000). The fertilization of winter wheat can be extended across a wide window of times. Since anhydrous ammonia has been the cheapest form of fertilizer, many producers have put on all or most of the needed N prior to planting, but this can have serious effects (Weisz and Heiniger, 2004), which include winter kill, diseases, weak immunity, and environmental pollution. Preplant N is important to promote fall tillering (Weisz and Heiniger, 2004). However, some of the same effects can occur when excessive amounts of fertilizer are applied in the spring such as lodging and reduction in milling properties, but splitting the applications will help support tillering (prepant N) and a spring topdress application will ensure adequate yield (Lee, 1996).

The application of N fertilizer helps the yield of many crops but the question that still remains is how much fertilizer should be applied in each field? According to Johnson et al. (2000) 33 kg N for every 1000 kg of wheat grain yield that the farmer expects to produce is required. This rule of thumb has been used for years and it has worked reasonably well. But if soil samples are not taken on a regular basis, available N might be overlooked. This old rule of thumb has been a good basis for N recommendations for the last several years. But research from Lahoma, OK over a 30 year period has shown that 60 % of the time 33 kg N per every 1000 kg would have been wrong by more than 10 % (Johnson and Raun 2003).

Voss (1998) suggested that the greatest improvement in fertilizer recommendations in many states was the development of the nitrate soil test. This still holds true, but this is an estimate at a particular time not taking into account any N acquired during the growing season or the changes in yield potential due to environmental factors occurring after planting. Since then, there has also been extensive research on the prediction of N needs based on plant health through chlorophyll meters, optical reflectance sensors, and aerial photography. All of which could help to accurately predict N fertilization based on plant health. The use of leaf color as a guide for effectively determining N needs has been shown to be highly effective for mid-season N management and to avoid over application of N in rice and wheat (Singh et al., 2002). Systems have been developed to determine midseason N fertilizer topdress recommendations, but the demand still exists for a simple system that cereal grain producers can use to quickly estimate required N topdress rates. NCS, a method of applying preplant N strips of several rates, either preplant or soon after planting was found useful in providing visual interpretation of winter wheat N demand and improved determination of topdress N rate (Raun et al., 2004). These authors reported that the method accounted for N mineralization and atmospheric N deposition from planting to mid-season fertilization. The farmer can then determine a topdress fertilizer rate to apply on his or her field based on treatments applied preplant or soon after the stand was established.

The purpose of N rich strips is very similar to the NCS since they are both used for predicting topdress N rates. According to Raun et al. (2005) the maximum wheat yields vary greatly from year-to-year, and the amount of N that the environment delivers (essentially for free) changes even more. Predicting topdress rates changes with time, location, weather and the current practices of the farmer, which has a big impact on the amount of N needed.

Identifying a specific yield potential does not translate directly to an N recommendation. Therefore determining the extent to which the crop will respond to additional N is equally important (Raun et al., 2004). Using the Handheld sensor, NDVI (normalized difference vegetative index) readings are collected from an N rich strip and the farmer practice to determine the benefit of additional N (Raun et al., 2004). From the NDVI readings, RI (Response Index) can be calculated by dividing average NDVI from a non-N limiting strip (created in each field by fertilizing a strip at a rate where N would not be limiting throughout the season) by the average NDVI in a parallel strip that is representative of the N availability across the field as affected by N fertilizer applied by the farmer (Raun, 2002).

II. Objective

The objectives of this study were to compare the use of preplant nitrogen calibration strips and sensor based nitrogen rate calculator to conventional methods for determining mid-season fertilizer N rates.

III. Materials and Methods

Experimental sites were established in the fall of 2004 and 2005 in both farmer fields and research stations across Oklahoma. Nine and eleven sites were selected in the crop year of 2004-2005 and 2005-2006, respectively, to validate NCS and evaluate N-rich strips. The NCS consisted of three preplant fertilizer treatments (45, 90, 135 kg ha^{-1}) applied in strips. Each strip was 2.3 m wide by 18.3 m long and fertilizer treatments were parallel and adjacent so that the visual differences between rates would be easily noticed. The strips were applied preplant or soon after emergence so that there would adequate time for response. The NCS treatments were replicated twice at each site. Between each of the two replicates a space of 14 m was left for a check and additional treatments.

These additional treatments consisted of a check (no N applied), 50 and 100 kg N ha^{-1} flat rates, a rate based on the visual observations of the NCS, and finally a rate determined by the sensor based N calculator (SBNRC) found at (http://www.nue.okstate.edu). The amount of N applied based on the NCS was identified by visually comparing the lowest rate at which no visual differences existed between it and the highest rate. The experimental design of both treatment sets was a randomized complete block. The actual plot size of each of the additional treatments was 3.05 by 6.1 m. These treatments were intended to be a topdress application of fertilizer applied around February and March when the wheat was at the Zadoks 31 (first node detectable) growth stage.

In 2004-2005 an all terrain vehicle (ATV) four-wheeler and a Kawasaki Mule equipped with a special spray attachment was used to apply the NCS and the N-rich strips. The sprayer attachment consisted of a 12-volt pump capable of delivering 18.2 liter per minute to a set of booms. Two sets of booms were installed so that three rates of fertilizer could be applied. Both booms were mounted on the rear of the ATV one in front of the other boom. The front booms have a set of three nozzles that were calibrated to deliver 45 kg N ha^{-1}. Directly behind the first set of nozzles is another boom, which was calibrated to deliver 90 kg N ha^{-1}. Combined, these booms were capable of delivering 135 kg N ha^{-1} for the strip application.

For the second year (2005-2006) another applicator was designed and used to apply the strips. The only thing that was changed was the overall width of the strips from 2.3m to 4.3m. The change was implemented on the Kawasaki Mule. This sprayer was composed of a 50 gallon tank mounted on a skid that was purchased from Wylie manufacturing company (Lubbock, Texas). A seven roller Hydro pump, powered by a 5.5 HP 4-stroke Honda engine, was used to deliver UAN to 28 Remcor solenoid valves. The solenoid valves were mounted in clusters of four resulting in seven sets of valves mounted on 0.61 m centers across a three section 4.3 m boom. Each solenoid valve was equipped with a wide angle flat spray tip from Teejet®. The nozzles were sized for an operating pressure of 275.8 kPa and also corresponding rates of 0.1, 0.2, 0.4 and 3.1 liters per minute. The solenoid valves were controlled by a programmable logic controller (PLC) set for the desired nozzles, interval, and distance. To monitor the speed and distance a Dickey-John Radar was mounted on the front of the applicator. The PLC, which controls the applicator was mounted on front close to the operator controls so that the LCD display screen could be monitored for speed and rates that were manually selected by selecting specific nozzle combinations for a desired rate.

The first year (2004-2005), wheat was harvested by hand, removing an area of 1 m^2 from the center of each plot at physiological maturity (Zadoks 91). Following harvest, samples were threshed using a mechanical plot thresher. In 2005-2006, wheat was harvested using a Massey 8XP test plot combine. The main reason for the change in harvest method was to reduce variability within the plots that occurred during hand harvesting and to get a representative yield estimate. Wheat grain weight was measured, sub-samples were taken from the grain samples, dried in a forced-air oven at 66^{o}C, and ground to pass a 140 mesh sieve (100 µm). From the ground sub-samples, total N was determined using a Carlo Erba 1500 dry combustion analyzer using the method developed by Schepers et al. (1989). Using percent N concentration in the grain, total N uptake was determined as the product of N concentration in the grain and yield.

NUE was calculated using the difference method where N uptake of the check (0-N) is subtracted from the treated plot and then divided by the N rate applied. Marginal revenue was determined based on two factors; wheat price ($0.17 USD) and price of fertilizer ($0. 84USD). The fertilizer rate multiplied by the cost was subtracted from the grain yield multiplied with grain price to determine marginal revenue.

Nitrogen rate recommendations were determined using two approaches. The first employed the NCS by choosing the lowest N rate where no visual differences were observed between it and the highest rate. The second employed the Sensor Based Nitrogen Rate Calculator or SBNRC (http://www.soiltesting.okstate.edu/SBNRC/SBNRC.php). This method first estimates early season (Zadoks 25-31, Chang, 1974) yield potential from both the farmer practice (YP0) and the N rich strip by dividing NDVI readings collected using the GreenSeeker™ hand held sensor, and dividing this reading by the number of days from planting to sensing where Growing Degree Days (GDD)= ((Tmin + Tmax)/2 – 4.4C) > 0. For winter wheat, the latter essentially eliminates those days where growth was not possible. Independent of the biomass produced per day, the estimated responsiveness of the crop to fertilizer N or response index (RI)(Mullen et al. 2003; Johnson et al. 2003) is determined as the ratio of NDVI in the N Rich Strip, and NDVI in the farmer practice. The yield potential possible if N were applied (YPN) is determined by multiplying the yield potential of the farmer practice (YP0) times the response index. Using the estimated yield potentials from the farmer practice and that possible if N were to be applied (YPN), estimated N uptake from each is determined by multiplying the respective YP value in kg ha^{-1} by the average percent N encountered in wheat grain (2.35% for this region). The difference in projected N uptake (YPN and YP0) is then divided by an efficiency factor of 0.60 to determine the appropriate topdress N rate to apply to achieve the estimated YPN. The factor of 0.6 is used because 60 percent N use efficiency is considered to be an optimum for mid season N applications, however this can change depending on region and/or crop. For both the SBNRC and NCS, sensor readings, and/or visual interpretation, respectively took place between Zadoks wheat growth stages 25 (main stem and 5 tillers visible) and 31 (first node visible). Detailed equations are presented in Raun (2006). These values are used to accurately predict both the yield and the need for additional N managing temporal variability.

The data from this experiment were fitted to an additive Analysis of Variance (ANOVA) model. Fisher's test statistic was used to test difference in treatments. Then protected Least Significant Difference (LSD) was used to separate treatment means. Data analysis was preformed in SAS (SAS, 2001) using General Linear model (GLM) procedures.

IV. Results and Discussion

Nitrogen Rate Recommendation Using NCS and N-rich strips

Tables 2a and 2b illustrate the wide range of rates prescribed and evaluated in 2004-2005 and 2005-2006 crop years. With on-farm research there are a wide range of management practices and production history at each site which subsequently affects treatment response. Additionally, each farmer managed his farm his own way, thus applying either preplant or topdress N rates and were recorded evaluated versus the NCS and SBNRC. The SBNRC recommended the lowest N rate at 65% of the sites while at 15% of sites, the NCS recommended the lowest rate. In 2004-2005 at five sites (Bessie, Enid, Perkins N, Perkins S, and Stillwater) the SBNRC recommended 30 kg N ha^{-1} or less. In 2005-2006, at seven sites (Enid, Hennessey, Hennessey Hladik Farm, Hydro, Lake Carl Blackwell, Lahoma, and Perkins) the SBNRC recommended 7-104 kg N ha^{-1} with 87% of these sites recommending 26 kg N ha^{-1} or less. In 2004-2005 the NCS recommended the lowest rate at two sites (Ames and Austin) and in 2005-2006 at one site (Bessie, 36 kg N ha^{-1}). At some sites farmers applied a higher preplant N rate than what was needed. At those sites the application of topdress fertilizer was excessive and did not result in any yield benefit. In general, where farmers applied excessive preplant N using the NCS and SBNRC approches, no fertilizer was recommended.

Grain Yield

One of the main objectives of this experiment was to reduce the amount of fertilizer used by prescribing more accurate mid season fertilizer N without reducing yields. From both years that this experiment was conducted a wide range in grain yields were observed (Tables 3a and3b). Analysis of variance followed by mean separation using protected least significant difference (LSD), at 5% critical significance levels in both years showed that nearly half the sites did not show significant yield differences. One reason for this was because adequate amounts of residual N was present since the check plot performed as well as most of the topdress and preplant treatments at several of the sites. Statistically, SBNRC and NCS methods of determining midseason N rates did not yield less than the other topdress treatments at 4-sites (Ames, Austin, Enid, Perkins S and Stillwater) in 2004-2005. The SBNRC recommended 57 and 30 kg N ha^{-1} at Hennessey and Stillwater based on yield potential (Table 2a). The Hennessey site had higher yields than at Stillwater which the SBNRC predicted while prescribing the optimum in-season N rate. At Perkins, the SBNRC did not prescribe any fertilizer because the calculator predicted the yield potential of that site to be low and the response index near 1.0. In 2005-2006 at seven sites (Bessie, Carrier, Drummond, Efaw, Hennessey, Hydro and Perkins), the SBNRC and NCS treatments did yield as much as other topdress treatments. At Hydro the SBNRC with only 7 kg ha^{-1} and the 50 kg N ha^{-1} topdress treatments resulted in equal yields but both nearly 300 kg ha^{-1} more than the check.

Marginal Revenue

Averaged over all sites, the 45 and 90 kg N ha^{-1} preplant rates resulted in slightly higher profit. The 45 kg N ha^{-1} topdress rate resulted in the highest profit in 2004-2005. When analyzing profit based on wheat price and price of N fertilizer the SBNRC method resulted in highest profit at Perkins S in 2004-2005. Averaged over all sites in 2005-2006 the profit obtained using the SBNRC was US$ 4 per hectare less than the no fertilizer check but much higher than the other treatments. It is important to note that the 2005-2006 season was characterized by low moisture for most of the sites and as a result lower yields and a decreased demand for fertilizer N. In addition the SBNRC treatment which relies on the estimated responsiveness using the response index did prove to detect this lack in demand to N. The reasonably high profit obtained by SBNRC treatment was thus due to no fertilizer N recommended at some of the sites also in part because predicted yield was low due to the moisture deficit. Unlike 2004-2005, preplant N rates did not result in high profit because the fertilizer applied did not translate into profit. At locations such as Drummond, Lake Carl Blackwell and Lahoma which had relatively better moisture, profit was higher for the 45 and 90 kg N ha^{-1} preplant rates.

<u>Nitrogen Use Efficiency</u>

Overall the best NUE was recorded with SBNRC treatments. This is likely because the SBNRC manages temporal variability and prescribes N based on crop need and potential yield leading to improved efficiency. Initially Raun et al. (2001) designed this strategy to increase NUE beyond the 33% world average (Raun and Johnson, 1999) to a maximum possible. Studies conducted at Oklahoma State University found NUE increased 15% using the SBNRC in wheat (Raun et al., 2002). The NCS treatment had > 33% NUE at many of the sites in 2005-2006 (Table 5a). In both years for a few locations NUE was not calculated because no N was recommended by the SBNRC and NCS treatments (denoted by NA). Combined over sites and years, the SBNRC treatments resulted in the higher NUE. A closer look at the effect of topdress N treatments on NUE revealed that the SBNRC treatment resulted in higher NUE than the other topdress N rates (Figure 1). This occurred because the SBNRC resulted in more precise N recommendations than what could be detected and concluded from blanket topdress rates.

V. Conclusions

From the results obtained in this experiment temporal variability was a major factor. The use of the NCS technology helps decrease the impact of temporal variability from field to field. Many of the sites showed no increase in yield due to added topdress N. The use of preplant NCS provided a good indicator of the amount of N to apply when inspecting response visually. However, this method requires more preplant N rates than just the three evaluated here. For many of the trials that were conducted in farmer fields adequate amounts of N were applied preplant to carry the wheat crop through to maturity, largely because many farmers in this region have over applied N and as a result N responsiveness was small.

The use of the NCS as an indicator of midseason N needs was a good reference guide, and the cost to implement this type of program was considered to be inexpensive relative to what could be gained. Once the NCS are applied producers can visually track whether a response is likely or unlikely as the season progresses. However, it should be noted that if visual differences between the farmer practice and the NCS are detectable, it is preferable to correct N deficiencies early in the season, before yield potential can be reduced. More defined and precise N interpretations can be made from those same strips using the Greenseeker™ sensor and the use of the SBNRC, which ultimately has the capability to pick up more differences than what can be observed visually.

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Table 1a. Application dates for nitrogen calibration strip experiment for the nine sites in Oklahoma, 2004-2005

Procedure:	Ames	Austin	Bessie	Enid	Hennessey	Marshall	Perkins N	Perkins S	Stillwater
	------------------------------				Date				------------------------------
Planting	9/24/04	9/25/04	10/05/04	10/20/04	10/25/04	9/24/04	10/18/04	10/18/04	10/21/04
Strip Fertilization	10/20/04	12/04/04	10/25/04	12/8/04	12/15/04	12/15/04	11/30/04	11/30/04	12/15/04
Midseason Fertilization	3/04/05	3/04/05	3/03/05	3/7/05	3/04/05	3/04/05	3/10/05	3/10/05	3/10/05
Harvest	6/03/05	6/03/05	6/02/05	6/03/05	6/06/05	6/03/05	6/07/05	6/07/06	6/07/06
Variety	Jaggaline	OK 102	Jagger	Cutter	Cutter	Jagger	Jagger	Jagger	2174

Table 1b. Application dates for nitrogen calibration strip experiment for the eleven sites in Oklahoma, 2005-2006

Procedure:	Bessie	Carrier	Drum	Efaw	Enid	Henn1	Henn2	Hydro	LCB	Lahoma	Perkins
	------------------------------					Date					------------------------------
Planting	10/18/05	10/04/05	9/21/05	10/11/05	10/22/05	10/17/05	10/17/05	10/20/05	10/19/05	10/14/05	10/10/05
Strip Fertilization	10/18/05	10/28/05	10/22/05	11/02/05	11/01/05	10/21/05	10/21/05	10/18/05	11/02/05	10/2805	11/02/05
Midseason Fertilization	3/14/06	3/15/06	3/21/06	3/16/06	3/17/06	3/17/06	3/17/06	3/14/06	3/17/06	3/15/06	3/16/06
Harvest	5/26/05	6/05/06	6/06/06	6/14/06	6/05/06	6/06/06	6/05/06	5/26/06	6/01/06	6/07/06	5/30/06
Variety	Jagger	OK101	2174	Enduran	2174	Overly	Overly	2174	Jagger	Overly	Jagger

Locations: LCB (Lake Carl Blackwell), Hen1 (Hennessey), Hen 2 (Hennessey Hladik farms), Drum (Drummond)

Table 2a. Total N Applied for nine sites in Oklahoma (kg ha^{-1}), 2004-2005

Trt	N rate	Ames	Austin	Bessie	Enid	Hennessey	Marshall	Perkins N	Perkins S	Stillwater	Average
		------------------------------(kg ha^{-1})------------------------------									
1	101 (TD)	111	202	111	109	101	213	101	101	101	127
2	SBNRC[†] (TD)	30	105	40	8	57	112	0	0	30	43
3	NCS[†] (TD)	10	101	55	53	90	202	45	45	90	77
4	50 (TD)	60	151	60	58	50	162	50	50	50	77
5	0	10	101	10	8	0	112	0	0	0	2.7
6	45 (Pre)	54	146	46	53	45	157	45	45	45	71
7	90 (Pre)	99	190	100	97	90	202	90	90	90	116
8	134 (Pre)	144	235	144	142	134	246	134	134	134	160

† Sensor based N rates (kg ha^{-1}).
‡ Nitrogen calibration strip
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.

Table 2b . Total N applied for nitrogen calibration strip experiment conducted at eleven sites across Oklahoma (kg ha^{-1}), 2005-2006.

Trt	N rate	Bessie	Carrier	Drum	Efaw	Enid	Hen1	Hen2	Hydro	LCB	Lahoma	Perkins
		--(kg ha^{-1})--										
1	101 (TD)	17	177	151	101	101	101	193	101	101	101	101
2	SBNRC † (TD)	40	96	63	12	26	21	104	7	13	20	20
3	NCS‡(TD)	36	121	95	45	45	45	92	0	45	90	90
4	50 (TD)	86	126	100	50	50	50	142	50	50	50	50
5	0	36	76	50	0	0	0	92	0	0	0	0
6	45 (Pre)	81	121	95	45	45	45	137	45	45	45	45
7	90 (Pre)	125	16	140	90	90	90	181	90	90	90	90
8	134 (Pre)	170	210	184	134	134	134	226	134	134	134	134

Locations: LCB (Lake Carl Blackwell), Hen1 (Hennessey), Hen 2 (Hennessey Hladik farms), Drum (Drummond).
Trt denotes Treatment number.
† Sensor based N rates (kg ha^{-1}).
‡ Nitrogen calibration strip
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.
Numbers in parenthesis denote preplant fertilizer (kg ha^{-1}) applied by farmers at each site. This amount has been added to the amounts applied.

Table 3a. Winter wheat grain yield means (kg ha^{-1}) for nitrogen calibration strip experiment conducted at nine sites across Oklahoma, 2004-2005.

Trt	N rate	Ames	Austin	Bessie	Enid	Hennessey	Marshall	Perkins N	Perkins S	Stillwater	Average
		--------------------	--------------------	--------------------	--------------------	(kg /ha)	--------------------	--------------------	--------------------	--------------------	
1	101 (topdress)	4240	3640	4425	3227	2550	1620	1905	2995	1600	2911
2	SBNRC† (TD)	3990	3330	3275	3050	2900	1365	1470	2890	1525	2644
3	NCS‡ (TD)	4045	3370	2985	3300	3450	1655	1745	3015	1550	2791
4	50 (topdress)	4460	3345	3995	3200	3025	1510	1660	2875	1325	2822
5	0	3950	3635	2550	2925	2650	1385	1570	2475	1150	2477
6	45 (Pre)	3750	4025	3625	3550	3725	1700	1520	2355	1800	2894
7	90 (Pre)	3925	3870	5025	3300	3150	2200	1790	2485	2025	3086
8	134 (Pre)	4035	3865	4155	3050	3350	2310	1535	2740	2025	3007
SED		495	421	556	337	651	203	258	253	243	

† Sensor based N rates (kg ha^{-1}). Rates were 0 at Marshall, Perkins N, Perkins S and Enid; 5 at Austin; 20 at Ames; 30 at 222 and Bessie; 57 at Hennessey.
‡ Nitrogen calibration strip
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.
€ Farmer rates were 0 kg N ha^{-1} except at Marshall (56 kg N ha^{-1}) and Enid (45 kg N ha^{-1}).
SED is standard error of the difference between two equally replicated means

Table 3b. Winter wheat grain yield means (kg ha^{-1}) for nitrogen calibration strip experiment conducted at eleven sites across Oklahoma, 2005-2006.

Trt	N rate	Bessie	Carrier	Drum	Efaw	Enid	Henn1	Henn2	Hydro	LCB	Lahoma	Perkins	Average
		---(kg ha^{-1})--											
1	101 (TD)	2207	3995	2957	3412	3350	3712	5141	3478	4546	2782	2106	3426
2	SBNRC† (TD)	2214	3860	2922	3283	2980	3481	4892	3610	3318	3583	1956	3281
3	NCS‡ (TD)	1673	3869	3008	3101	1801	3352	5533	3312	4049	3832	2139	3243
4	50 (TD)	2111	3747	3076	3243	3240	3366	5157	3636	4113	3728	2152	3415
5	0	2555	3949	2825	2981	3222	3331	5648	3485	3406	2445	1740	3235
6	45 (Pre)	2433	3717	3485	2851	3866	2176	5455	3497	4056	3553	1773	3351
7	90 (Pre)	2353	3823	3306	3041	3779	2544	5759	3341	4423	3998	1639	3455
8	134 (Pre)	2571	3861	3321	3403	3912	2145	5992	3589	4391	4249	1602	3549
	SED	413	277	147	335	621	235	257	383	404	492	166	

Trt denotes Treatment number.
† Sensor based N rates (kg ha^{-1}).
‡ Nitrogen calibration strip
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.
SED standard error of the difference between two equally replicated means

Table 4a. Marginal revenue estimated using price of wheat and N applied for nine sites in Oklahoma, 2004-2005

Trt	N rate	Ames	Austin	Bessie	Enid	Hennessey	Marshall	Perkins N	Perkins S	Stillwater	Average
						($/ha)					
1	101 (TD)	463.68	334.74	486.79	338.47	258.55	75.79	177.99	314.13	139.89	287.76
2	SBNRC† (TD)	480.41	353.31	385.12	376.31	328.24	103.88	183.60	360.96	172.49	304.96
3	NCS ‡(TD)	499.27	360.97	340.24	380.89	377.62	86.82	191.31	349.93	140.31	303.10
4	50 (TD)	521.13	327.87	463.06	365.07	347.85	92.02	177.36	329.11	135.52	306.62
5	0	487.41	394.07	312.55	360.69	330.99	106.38	196.09	309.13	143.64	293.50
6	45 (Pre)	435.79	416.13	425.53	412.11	438.61	119.08	163.21	267.50	198.18	319.53
7	90 (Pre)	431.00	370.13	568.39	354.25	340.15	154.89	170.29	257.09	199.64	316.28
8	134 (Pre)	418.10	342.87	433.08	296.38	338.49	141.98	111.79	262.30	172.99	279.77

† Sensor based N rates (kg ha^{-1}).
‡ Nitrogen calibration strip
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.

Table 4b. Marginal revenue based on price of wheat and N applied for eleven sites in Oklahoma, 2005-2006

Trt	N rate	Bessie	Carrier	Drum	Efaw	Enid	Henn1	Henn2	Hydro	LCB	Lahoma	Perkins	Average
		---------------	---------------	---------------	---------------	---------------	($/ha)	---------------	---------------	---------------			
1	101 (TD)	283	571	406	529	493	583	764	541	733	416	295	510
2	SBNRC† (TD)	365	614	473	580	489	608	793	644	586	628	335	556
3	NCS‡ (TD)	271	595	462	520	261	566	918	596	691	614	310	528
4	50 (TD)	308	568	469	541	515	563	809	612	698	628	345	551
5	0	430	647	466	536	554	599	939	627	613	440	313	560
6	45 (Pre)	370	568	548	475	632	354	867	592	692	602	282	544
7	90 (Pre)	318	549	478	472	579	383	884	526	721	645	220	525
8	134 (Pre)	320	519	443	500	565	273	888	533	678	652	176	504

Locations: LCB (Lake Carl Blackwell), Hen1 (Hennessey), Hen 2 (Hennessey Hladik farms), Drum (Drummond)
† Sensor based N rates (kg ha^{-1}).
‡Nitrogen calibration strip
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.

Table 5a. Winter wheat NUE (%) from grain and fertilizer data at ten sites across Oklahoma, 2004-2005

Trt	N rate	Ames	Austin	Bessie	Enid	Hennessey	Marshall	Perkins N	Perkins S	Stillwater	Average
		--(% NUE)--									
1	101 (TD)	7	8	54	16	8	7	14	18	14	16
2	SBNRC† (TD)	0	17	54	NA	12	NA	NA	NA	100	37
3	NCS‡ (TD)	NA	NA	78	25	34	20	6	9	40	30
4	50 (TD)	5	15	67	23	11	17	16	17	11	20
6	45 (Pre)	0	40	35	30	27	9	1	4	27	19
7	90 (Pre)	5	15	63	19	16	18	8	7	24	19
8	134 (Pre)	2	9	35	11	18	12	4	13	20	14
	SED	2.7	24.9	27.8	18.5	17	9.5	8.2	12.9	11.3	

† Sensor based N rates (kg ha^{-1}).
‡ Nitrogen calibration strip
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.
NA denotes no fertilizer N applied
SED standard error of the difference between two equally replicated means

Table 5b. Winter wheat percent nitrogen use efficiency (NUE) for nitrogen calibration strip experiment conducted at eleven sites across Oklahoma, 2005-2006.

Trt	N rate	Bessie	Carrier	Drum	Efaw	Enid	Henn1	Henn2	Hydro	LCB	Lahoma	Perkins	Average
		--------------------	--------------------	--------------------	--------------------	--------------------	(% NUE)	--------------------	--------------------	--------------------	--------------------		
1	101 (TD)	4	8	14	22	19	19	10	28	40	28	26	22
2	SBNRC[†] (TD)	0	6	12	87	0	50	0	58	11	100	48	37
3	NCS[†] (TD)	NA	7	15	17	37	9	NA	0	NA	73	28	24
4	50 (TD)	4	3	15	24	22	19	8	47	45	71	46	31
6	45 (Pre)	2	8	23	5	42	0	15	40	56	58	26	29
7	90 (Pre)	1	6	19	10	32	0	23	19	41	54	8	22
8	134 (Pre)	3	5	17	15	35	0	22	18	33	52	7	20
	SED	2.6	5.8	7.7	12.6	32.1	19.1	12	30.1	28.7	16.2	13.4	

Locations: LCB (Lake Carl Blackwell), Hen1 (Hennessey), Hen 2 (Hennessey Hladik farms), Drum (Drummond)
[†] Sensor based N rates (kg ha^{-1}).
TD denotes topdress N applied as UAN.
Pre denotes preplant N applied as UAN.
NA denotes no fertilizer N applied.
SED standard error of the difference between two equally replicated means

VII. Appendix

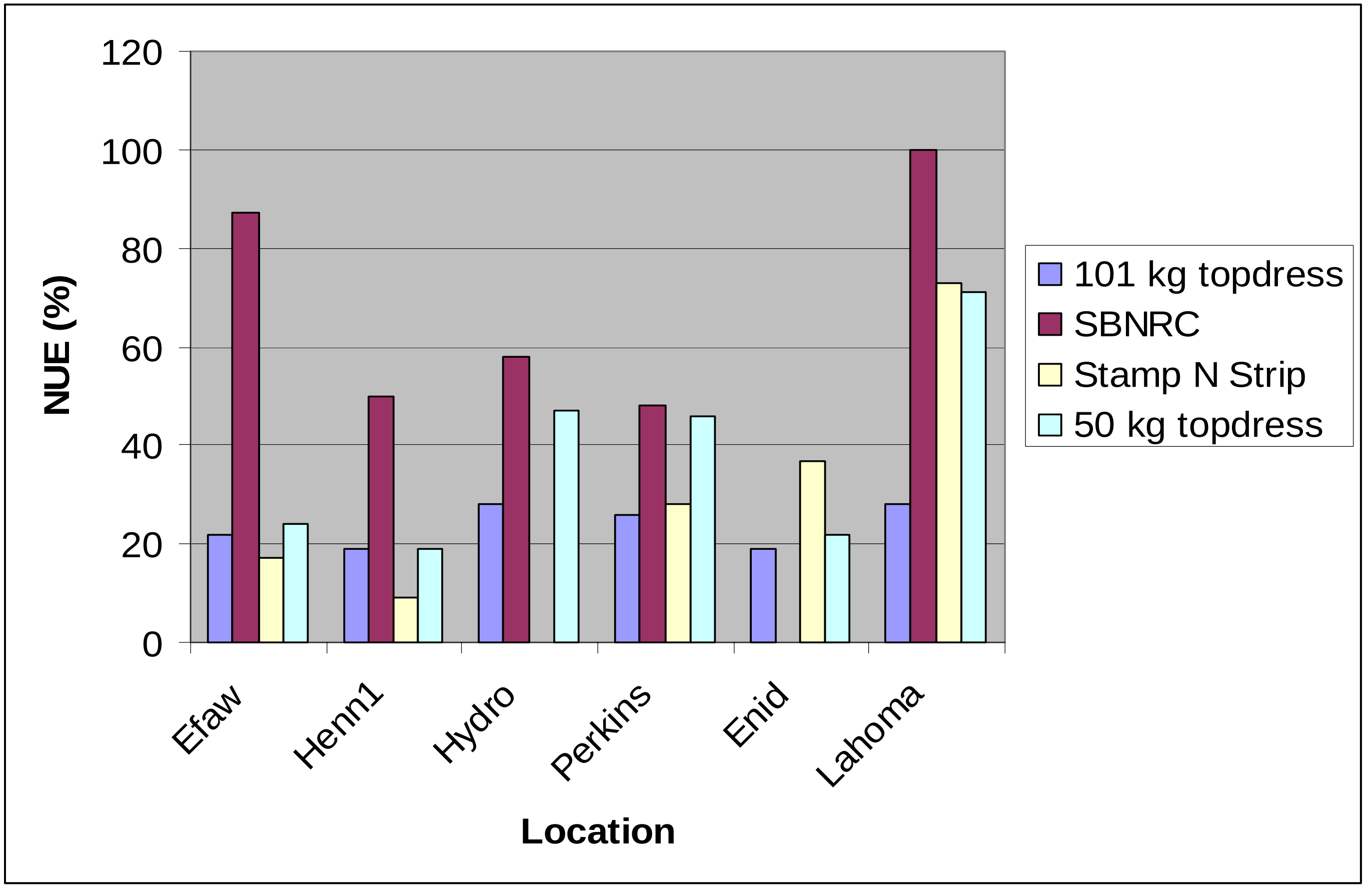

Figure 1. Winter wheat percent nitrogen use efficiency (NUE) for nitrogen calibration strip experiment, 2005-2006.

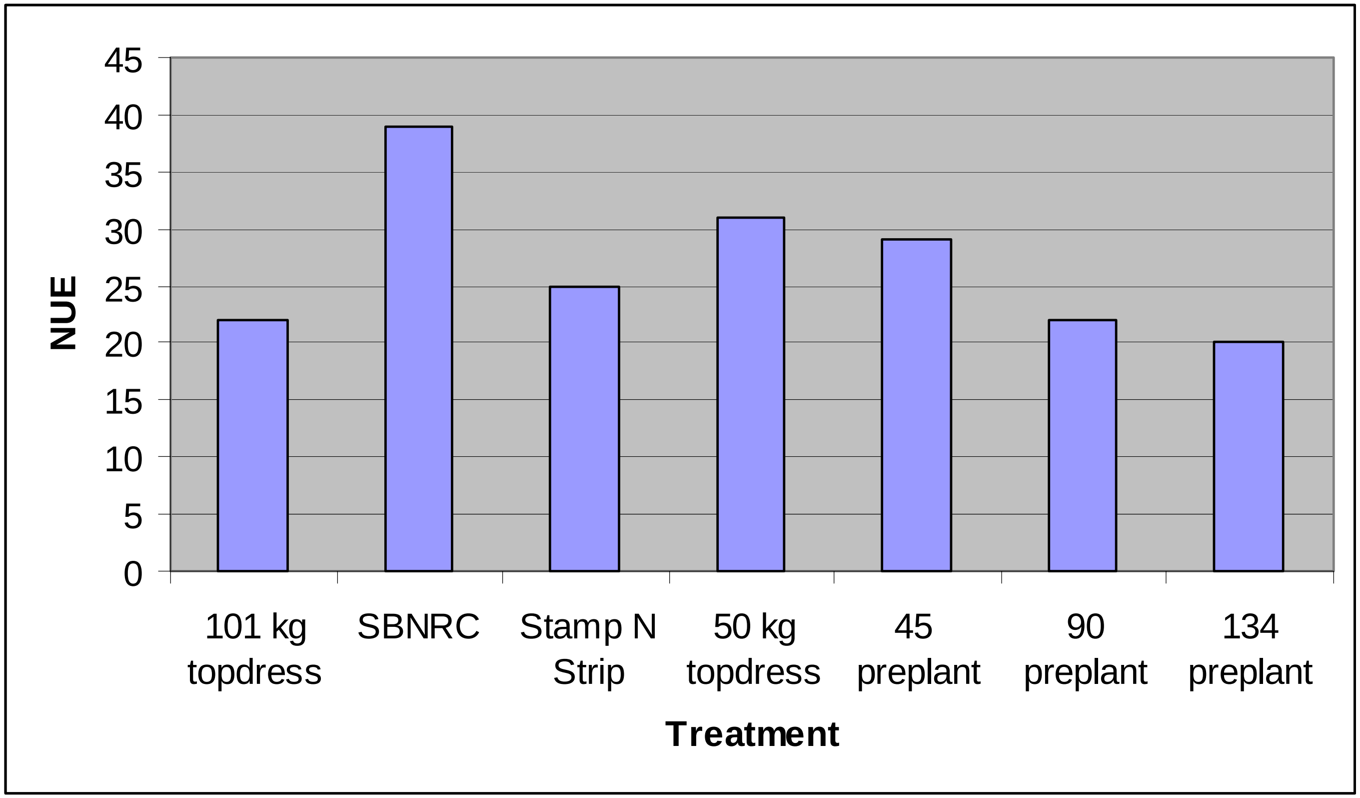

Figure 2. Average nitrogen use efficiency for the nitrogen calibration strip experiment for all eleven sites in Oklahoma, 2005-2006

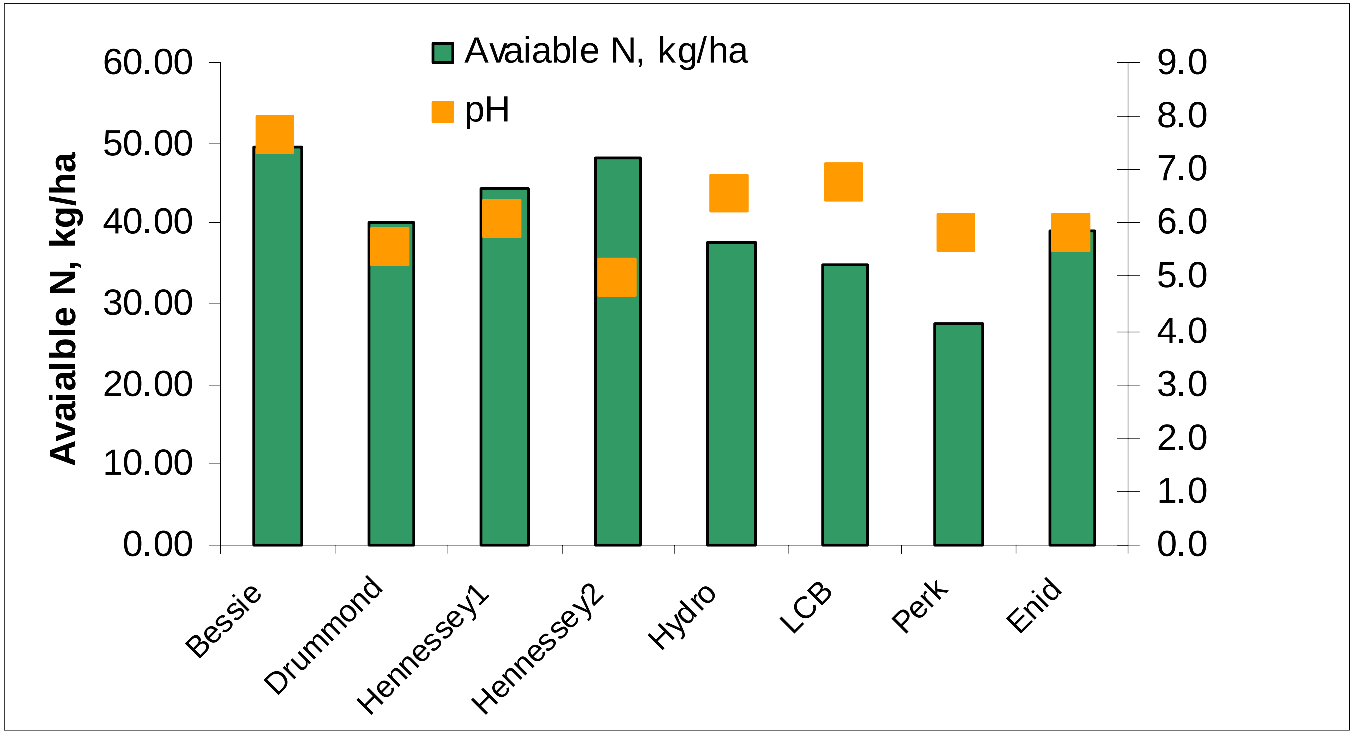

Figure 3. Initial total available N (NO3-N and NH4_N) for soil samples collected prior to preplant N application at different sites, Oklahoma, Fall 2005.

Figure 4. Applicator used to apply Nitrogen Calibration Strips in 2004-5005.

Figure 5. Applicator used to apply Nitrogen Calibration Strips in 2005-2006

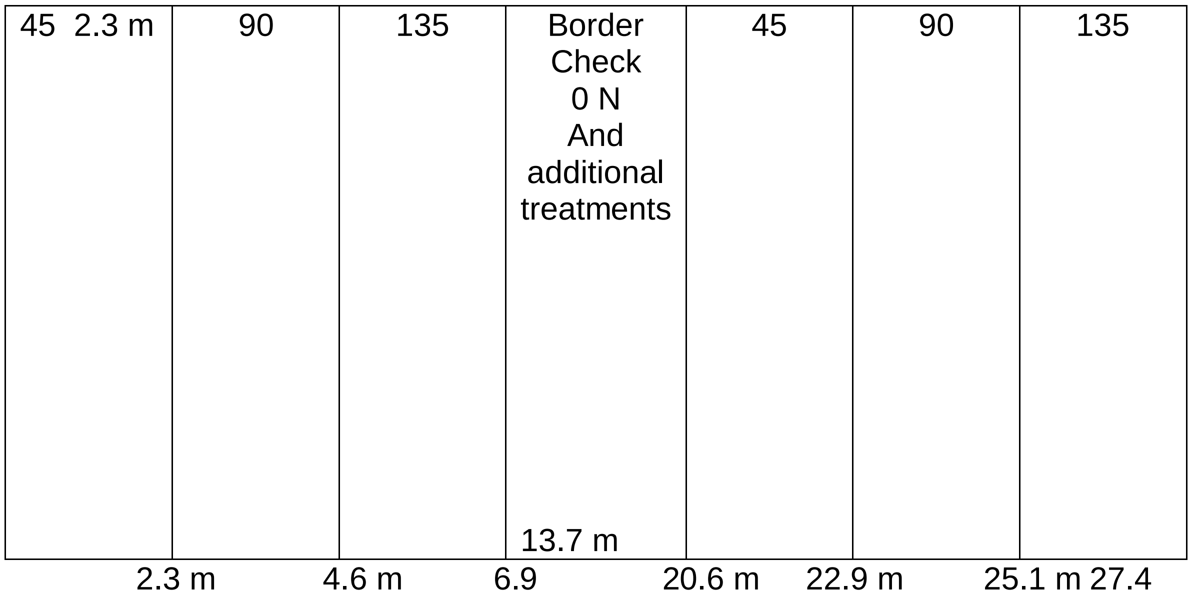

Figure 6. Strip Procedure for Fall Applications

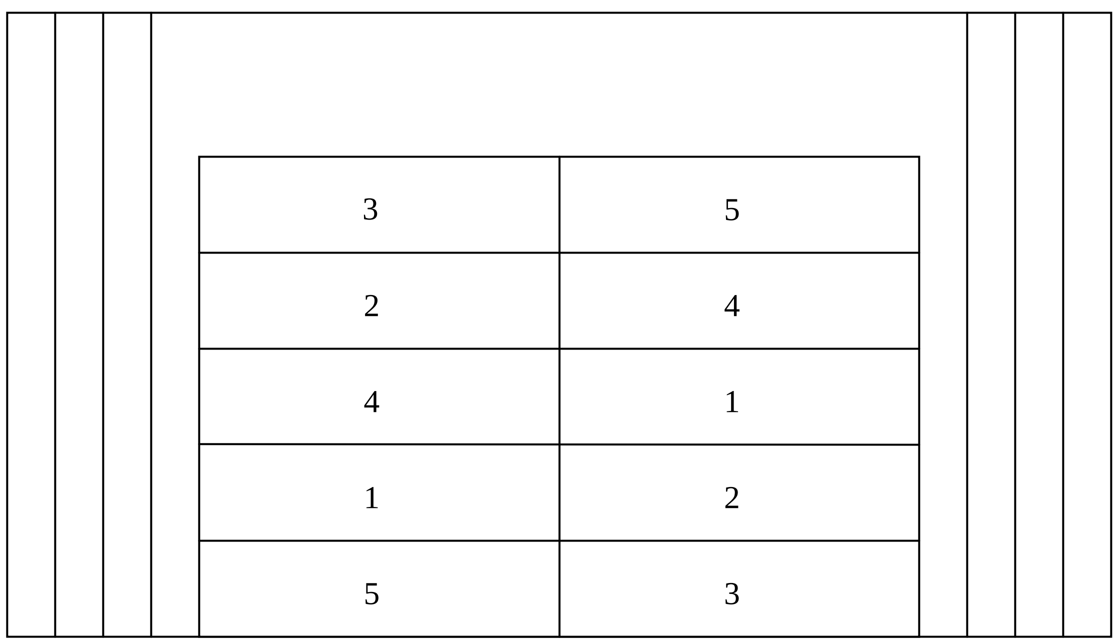

Figure 7. Treatment Structure of the nitrogen calibration strip validation experiment. Where #1 to #5 refers to N rates of 101 kg N ha^{-1}, sensor based N rate, nitrogen calibration strip N rate, 50.4 kg N ha^{-1}, and a check (0 N kg ha^{-1}).

Vita

Clinton Joseph Mack

Candidate for the Degree of

Masters of Science

Thesis: VALIDATION OF NITROGEN CALIBRATION STRIP TECHNOLOGY FOR PRESCRIBING ACCURATE TOPDRESS NITROGEN FERTILIZER

Major Field: Plant and Soil Sciences

Biographical:

Education: Graduated from Drummond High School, Drummond, Oklahoma in May 1999; receiving Bachelor of Science degree in Plant and Soil Sciences from Oklahoma State University Stillwater, Oklahoma 2004. Completed the requirements for Masters of Science degree with a major in Plant and Soil Science at Oklahoma State University in December, 2006.

Experience: Raised on a farm near Drummond, Oklahoma; employed as a farm hand during the summer; employed by Oklahoma State University, Department of Plant and Soil Sciences, as an undergraduate and graduate research assistant; Oklahoma State University, Department of Plant and Soil Sciences, 2002- present.

Professional Memberships: ASA

Name: Clinton J. Mack Date of Degree: December, 2006

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: VALIDAITON OF NITROGEN CALIBRATION STRIP TECHNOLOGY FOR PRESCRIBING ACCURATE TOPDRESS NITROGEN FERTILIZER

Pages in Study: 32 Candidate for the Degree of Masters of Science

Major Field: Plant and Soil Science

Scope and Method of Study: The purpose of this study was to determine a method of determining Nitrogen rate recommendations midseason by the use of preplant N strips (called the nitrogen calibration strips) by using both visual observations and optical sensor measurements.

Findings and Conclusions: From the results obtained in this experiment from a two year period temporal variability was a major factor. Many of the sites may have shown no significant difference from the added topdress treatments therefore added N would have not had a significant increase in yield. The use of preplant NCS is a good indicator of the amount of N to apply although when making a visual indication of how much N should be applied requires more preplant N rates than just three rates. From many of the trails that were conducted in farmer fields there was adequate amounts of N put on preplant to carry the wheat crop through maturity.

ADVISER'S APPROVAL: _____________ Dr. William Raun________________