Profitability of Conventional vs. Variable Rate Nitrogen Application in Wheat Production

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Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Orlando, FL, February 6-9, 2010

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Abstract

A variable rate nitrogen applicator based on optical reflectance measurements was developed to increase profits in wheat production by reducing the cost of production or by increasing grain yield. This paper determines if yields and profits from the variable rate treatments are significantly different from the conventional treatments.

Keywords profitability – variable rate application – optical reflectance sensing - wheat

Introduction

In Oklahoma, USA, nitrogen (N) is a crucial nutrient in wheat (*Triticum aestivum*) production, and can account for approximately 15-25% of production cost (Biermacher et al. 2006; Oklahoma State University Extension Service 2009). Various systems have been developed to increase N use efficiency (NUE) by determining the precise level of N the crop needs in a given year. The intention is to increase expected net returns by reducing the excess N that is applied in a given year and by increasing yield in years when the crop has a high yield response to N.

There are two primary methods for precision N application (Lambert and Lowenberg-DeBoer 2000). The first method uses frequent soil tests from several areas in a fields as well as GIS mapping data (Carr et. al 1991; Swinton and Lowenberg-DeBoer 1998; Koch et al. 2004). The second uses optical reflectance measurements based on the crop's vegetation level to estimate N requirements (Alchanatis et al. 2005; Ehlert et al. 2004; Raun et al. 2002, 2005). There is no overwhelming evidence that the soil sampling and sensing methods increase profits enough in wheat production to recover the upfront capital cost for the technologies (Anselin et al. 2004; Lambert and Lowenberg-DeBoer 2000; Bernsten et al. 2006; Biermacher et al. 2009). However, sensing is thought to be a more likely economically viable system than the soil sampling because soil sampling for N is both expensive and inaccurate.

Biermacher et al. (2009) analyzed the economic feasibility of using real-time on-the-go optical reflectance measurements (ORM) to apply N fertilizer in wheat production. This specific system used an N fertilizer optimization algorithm (NFOA) developed by Raun et al. (2002). The data in Biermacher's study spans from 2002 to 2004. During this time period, the NFOA estimated the optimal N level from sensors spaced approximately 0.66 meters (m) apart. The system used real time data to apply N at seven variable rate levels. Results from Biermacher et al. (2009) show that using this precision applicator did not increase mean yields or mean net returns compared to pre-determined uniform applications of N (i.e., conventional treatment).

In 2005, modifications were made to the experiment trials as well as the NFOA used in Biermacher et al. (2009). The sensing grid was expanded from 0.66 m apart to 3.3 m apart, cutting the cost of the previous applicator by $35,000. Second, the real time sensing was lagged to apply N levels based on wheat data sensed seconds before. That is, the amount of N applied to a plant was determined from a sensor reading that occurred several feet behind the area it is currently applying N. This removes precision from the machine, but also decreases the cost of the machine. Third, three variable rate levels were used to apply N instead of the seven levels on the previous applicator. Fourth, several variable rate sensor readings were taken at each location and the sensed quantities of N were averaged across a field. The average sensing rate at each location was applied uniformly creating two uniform rate treatments (URT). The variable rate treatments (VRT) use the real-time on-the-go data to apply varying levels of N across a field. Finally and most importantly, the NFOA was modified every year to improve predictions of N needs.

There are two objectives of this research: (1) to determine if yields from the ORM treatments are statistically different from the conventional treatments (i.e., pre-determined amounts of uniform N) yield; and (2) to determine if the net returns from the modified ORM treatments are statistically different from the net returns from the conventional treatments. The results provide Oklahoma wheat producers with valuable economic information for maximizing expected profits.

Theory

The ORM treatments (i.e., VRT and URT) require producers to apply a non-yield-limiting amount of N in late summer/early fall to a narrow strip, which is called the N rich strip (NRS). Wheat is then planted in the fall. In late winter, the NFOA uses normalized difference vegetation index (NDVI) from the wheat in the NRS and the wheat in the field to calculate the amount of N needed for the wheat to reach its potential maximum yield (i.e., plateau) (Raun et al. 2002, 2005; Solie et al. 2002). Finally, a liquid fertilizer applicator equipped with optical reflectance sensors as well as a GPS system is used to apply the level of N estimated by NFOA. The NFOA algorithm seeks to apply the correct amount of N required for the crop to reach its yield plateau. However, Tembo et al. (2008) demonstrate that given current prices when the variance of the expected plateau is considered the economically optimal amount N is more than the level the NFOA determines to apply.

The conventional treatments require farmers to apply a pre-determined amount of N prior to planting in the fall or in late winter that does not vary by field or year. This imprecise approach commonly results in farmer's applying more N in a given year than is needed to reach the yield plateau. The reason producers do this is that yield loss from limited levels of N will typically reduce net returns more than applying excess N (Roberts 2009). This encourages farmers to apply more N than necessary, resulting in lower net returns than could be achieved under accurate information (i.e., knowledge of the correct amount of N to apply).

The expected profit maximization framework that assumes producers are risk neutral is applied in this analysis. That is, the adoption of the ORM treatments will occur when the expected net return of the ORM treatments are greater than the expected net return of the conventional treatments. Any gains in net returns from using ORM are expected to be mostly due to reduced N cost, but can also result from yield gains in years when yield has a high response to top-dress. Net return gains from the ORM treatments must overcome the upfront capital investment of the ORM sensors and the NRS for technology adoption to occur.

Material and Methods

Data

The data consisted of yields and amounts of N applied from 10 treatment trials spanning from 2005-2009. The experimental plots were located near Altus, Lahoma, Perkins, Lake Carl Blackwell (LCB), Hennessey, Tipton, and Covington, Oklahoma, USA. These plots have been part of a long-term experiment focused on precision N application. The trials were continuous meaning that the same treatment was used on the same plot every year. These plots were 6.0 m long by 3.99 m wide which is smaller than actual fields meaning there is likely less spatial variability than in an actual farmer's field. Thus, the benefits from the VRT might be under estimated in this data than in actual farmer's field.

The treatments are as listed, with the first number representing the kg ha^{-1} pre-plant N and the last number representing the kg ha^{-1} top-dress N: 0/0, 0/45, 0/90, 45/45, 45/0, 90/0, 0/VRT, 45/VRT, 0/URT, and 45/URT. GreenSeeker ™ Hand-held NTech Industries Inc sensors were used to determine N amounts for the VRT and URT treatments at each location. Rainfall and soil characteristics for each location are summarized in Tables 1 and 2.

The prices of N and wheat were obtained from United States Department of Agricultural (USDA) National Agricultural Statistic Service (NASS). Four-year average prices of wheat and N were used to estimate expected net returns. The price of wheat was \$0.12, \$0.13, \$0.18, and \$0.23 kg^{-1} for 2004, 2005, 2006, and 2007, respectively, resulting in an average price of \$0.16 kg^{-1} for wheat (USDA 2008a) (Table 1).

Anhydrous ammonia (NH_3) (82% N) and ammonium nitrate (AN) (33.5%) were the pre-plant sources of N, and urea and ammonium nitrate (UAN) (28%) was the top-dress N source. NH_3 was reported by NASS as \$0.45, \$0.50, \$0.65, and \$0.66 kg^{-1} for 2004, 2005, 2006, and 2007, respectively, resulting in an average price of \$0.56 kg^{-1} (USDA 2008b). AN was reported by NASS as \$0.87, \$0.98, \$1.12, and \$1.24 kg^{-1} for 2004, 2005, 2006, and 2007, respectively, resulting in an average price of \$1.05 kg^{-1} (USDA 2008b). UAN was reported by NASS as \$0.73, \$0.90, \$0.93, and \$1.15 kg^{-1} for 2004, 2005, 2006, and 2007, respectively, resulting in an average price of \$0.93 kg^{-1} (USDA 2008b) (Table 1). The cost of one kg of N from AN is 1.87 times more than the cost of one kg of N from NH_3. One kg of N from UAN costs 1.66 times more than one kg of N from NH_3. The per-unit cost advantage of NH_3 explains why it is common practice to use NH_3 in this region.

The custom N application rates estimated by the Oklahoma Cooperative Extension Service are used for the application cost of NH_3, AN, and UAN. The custom rates are estimated every other year by surveying farmers and custom applicators across Oklahoma, USA. The average application cost for NH_3, AN, and UAN is \$24.57, \$9.18, and \$9.60 ha^{-1} (Doye et al. 2006; Doye and Sahs 2008) (Table 2).

Sensing was done with hand-held sensors on a sensing grid of 3.3 m. Equipping an applicator with optical reflectance sensors spaced at 3.3 m costs \$25,000. This cost is significantly lower than the previous applicator, which cost \$60,000. An 8% annual interest rate is assumed as well as a useful life of five years for the ORM sensors. Thus the annual cost to own and operate a sprayer equipped with ORM sensors is \$6,000. A premium of \$2.00 per hour above the normal hourly wage to operate a sprayer is assumed. That is, the hourly wage for operating the sprayer with ORM sensors is \$12 per hour instead of \$10 h^{-1} for operating a sprayer without sensors. The machine is assumed to travel at 24 km per hour with a field efficiency of 70% (ASABE 2006). A 10 h work day is assumed with the possibility of using the sprayer 15 days a year. The total cost for the modified precision applicator is estimated at \$1.55 ha^{-1}, which is approximately half the cost of the precision applicator estimated in Biermacher et al. (2009) (Table 2).[1]

Cost of the NRS was determined by the size of the field, and the dimensions of the fertilizer applicator. The NRS was the length of the field by the width of the fertilizer spray boom. The spray boom was 19.82 m in width, and the field was assumed to be a square 64.7 ha. This results in the NRS covering approximately 2.5% of the field. The non-yield-limiting amount of N applied to the NRS is 135 kg ha^{-1}. Since two ORM treatments (45/VRT and 45/URT) have already received 45 kg ha^{-1} pre-plant, only an additional 90 kg ha^{-1} is applied to the NRS. The total cost of the NRS for the treatments that apply zero pre-plant is \$2.23 ha^{-1} and for the treatments that apply 45 kg ha^{-1} pre-plant is \$1.85 ha^{-1} (Table 2). Table 1 and 2 consolidates the data discussed in this section.

Methods

The analysis is performed by using a mixed model to estimate and test the fixed effects of treatment on yield and net returns. Random effects are included for site year. The equation to estimate the effects of treatment on yields is

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[1] National Resource Conservation Service Environmental Quality Incentive Program provides an incentive for adopting the ORM system. The subsidy is not included in this analysis because it is only available for a small number of counties in Oklahoma (USDA 2008c). The 2008 maximum available payment is \$21,446.40. It is capped at 64.7 ha and can be paid out over a one, two, or three year time period.

$$Y_{tli} = \alpha + \sum_{n=1}^{10} \beta_n X_{ni} + u_{tl} + \varepsilon_{tli} \tag{1}$$

where Y_{tli} is the yield in the *t*th time period, at the *l*th location, and on the *i*th plot; α is the yield intercept; X_{ni} is an indicator variable for N treatment; β_n is yield responses to the N treatment; $u_{tl} \sim N(0, \sigma_u^2)$ is the site-year random effect; and $\varepsilon_{tli} \sim N(0, \sigma_\varepsilon^2)$ is the random error term. The null hypothesis is there is no difference in expected yields across the 10 N treatments.

To analyze economic feasibility, partial budgets are commonly used (Thrikawala et al. 1999; Koch et al. 2004; Mooney et al. 2009). Developing and using a budget is straightforward; however, Bullock and Bullock (2000) and Koch et al. (2004) argue that many studies do not include all of the necessary costs to estimate net returns. Biermacher et al. (2009) designed and implemented a partial budget that captures the expected net returns for the ORM treatments. The partial budgets used in Biermacher et al. (2009) are modified by excluding the cost of applying top-dress N to the NRS, in addition to updating the budgets for the lower-cost applicator and recent prices. The NRS already had enough N for the wheat to reach the yield plateau. Therefore, the cost of top-dress N under the ORM treatment excludes the NRS and focused on the remaining portion of the field. Also, the ORM treatments in this analysis has a lower capital cost than the previous applicator because it uses fewer sensors. These two modifications reduce the cost of precision technology relative to Biermacher et al. (2009), but still capture the necessary costs. Mathematically, expected net returns are calculated as follows:

$$E[NR_i] = pE[Y_i] - r_i E[N_i] - E[AC_i] - ORM_i \tag{2}$$

where NR_i is net returns for the i th system; p is wheat price, Y_i is yield; r_i is the cost of N and N_i is the quantity of N applied; AC_i is the application costs; and ORM_i represents the cost of optical reflectance sensing technology including the NRS. Expected net returns are estimated using two models. The first assumes that pre-plant N is NH_3 and the second assumes that pre-plant N is AN. NH_3 has a cost advantage relative to AN. A liquid solution of UAN is the top-dress source of N.

The net returns equation is similar to equation (2) with the only change being that the dependent variable is net returns:

$$NR_{tli} = \alpha + \sum_{n=1}^{10} \beta_n X_{ni} + u_{tl} + \varepsilon_{tli} \qquad (3)$$

where NR_{tli} is the net returns for time period t, location l, and plot i. The null hypothesis is there is no difference in expected yields across the 10 N treatments. If the nulls are rejected, a Tukey-Kramer test is used to assess the statistical significance of paired comparisons. The parameters in equations (1) and (3) are estimated using proc MIXED in SAS (SAS Institute Inc. 2004).

Extending Biermacher et al. (2009), the Likelihood Ratio (LR) test was used to test for heteroskedasticity in the treatment residuals. The null hypothesis of the LR test is that the residuals are homoskedastic, with the alternative hypothesis stating that the residuals are heteroskedastic. The null is rejected if the LR statistic is greater than the X^2 critical value at the 0.05% level ($X^2_{9,\,0.05} = 16.92$). The null was not rejected at the 0.05% level for yields so no correction needed to be made for heteroskedasticity in treatments.

The LR test was also used to test for heteroskedasticity in the year residuals. In 2007 and 2009 a freeze severely damaged the wheat crop and in 2008 heavy fall rains allowed for record level yields in one location. These weather condition result in high variation of yields in three out of the five years data analyzed in this paper. The null hypothesis of the LR test is that year residuals are homoskedastic, with alternative stating that the residuals are heteroskedastic. The LR statistic was 134.4; therefore, the null hypothesis was rejected at the 0.05 level ($X^2_{4,\,0.05}$ = 9.49), and proper corrections were made to the data.

Similarly, net returns were tested for heteroskedasticity by treatment and year. The null hypotheses that the treatment and year residuals are homoskedastic were not rejected at the 0.05 level.

Results

Yields

The yield data across locations, years and treatments are summarized in Table 3. High variation of yields across the locations, treatments and years are apparent in the table. The maximum yield is 4810 kg ha^{-1}, at Lahoma in 2008, and the lowest yield is 37 kg ha^{-1}, at LCB in 2009 (Table 3). On average the 0/90 treatment produces the largest yields with the 45/45 treatment a close second. Yields were lowest when zero N is applied.

For the ORM treatments, the 45/VRT treatment produced the largest yield on average. Yields from the split treatments (i.e., 45/VRT and 45/URT) were larger than the top-dress treatments (i.e., 0/VRT and 0/URT). On average, the split treatments applied more N than the top-dress treatments, which might explain the split treatments outperforming the top-dress treatments. Relative to the conventional treatments, the 45/VRT treatment produced the third highest yields on average, outperforming the 90/0 treatment.

The null hypothesis that yields for the 10 treatments were not different from each other was rejected at the 0.001 level. The Tukey-Kramer tests indicated several interesting differences between the treatments at the 0.05 level. The nine treatments that applied N were better than the treatment that applied zero N. The 45/45 treatment produced a larger yield than the 45/0 treatment, and the 0/90 treatment had a larger yield than the 0/45, 45/0, 0/URT, 0/VRT, and the 90/0 treatment. The 45/VRT, and 45/URT treatments were not found to be different from the 0/90, 45/45, and 90/0 treatments.

The 0/90 treatment produced higher yields that the 90/0 treatment, indicating that during this time period top-dress had a higher yield response than pre-plant N. This is a different result from Biermacher et al. (2009), who found that pre-plant N had a higher average yield response than top-dress N on these same sites. Heavy rains in the fall of 2008 resulted in pre-plant N being leached and also creating large potential yields. This is most noticeable at Lahoma which received 229 mm of rain in September and October, and had a top-dress response that produced record yields for this area. Concluding that top-dress had a higher NUE than pre-plant from 2005-2009 and pre-plant had a higher NUE than top-dress from 2002-2004 in the same locations, warrants a further investigation into the marginal product of pre-plant, top-dress, and VRT N.

Net Returns

Table 4 gives net returns when NH_3 is the pre-plant N source. The highest net returns are \$699 ha^{-1} at Lahoma in 2008, and the lowest are -\$168 ha^{-1} at LCB in 2009. On average, the 0/90 treatment had the highest net returns and the 0/0 treatment has the lowest (Table 4). The 0/URT treatments ranked fourth relative to all the treatments. No conclusion was made whether the VRT or URT produced the highest net returns since VRT is the most profitable for the split treatment and the URT is the most profitable for the top-dress treatment (Table 4). The split treatments requires producers to apply N twice in a given year which increases the cost of production. On average the split treatments had higher yields for the ORM treatments, but the yield gains from the second application must exceed the cost of second application.

The null hypothesis of no difference in net returns across the 10 N treatments was not rejected at the 0.05 level. The 0/90 treatment had the highest net returns on average, even though, NH_3 had an average relative cost advantage to UAN. In contrast, Biermacher et al. (2009) found that the 45/0 treatment had the highest net returns on average when NH_3 was the pre-planted, and that the cost advantage of NH_3 over UAN resulted in higher net returns for the 90/0 treatment than the 0/90 treatment.

Table 5 shows net returns when AN is used as pre-plant N. The 0/90 treatment produced the largest average net returns (Table 5). For the ORM treatments, the top-dress treatments have higher average net returns than the split treatments, which differ from the NH_3 results. Relative to the conventional treatments, the 0/URT ranked third in average net returns, being outperformed by the 0/45 and 0/90 treatments (Table 5). Interestingly, the 45/0 treatment has higher net returns than the 90/0 treatment, which suggests that the marginal value product of N from AN is exceeded by the marginal factor cost when applying 90 kg ha^{-1} (Table 5).

Similar to the NH_3 net returns, the null hypothesis was not rejected at the 0.05% level. The 0/90 treatment had the largest net returns and AN net returns were, on average, lower than net returns for NH_3 due to the per-unit cost advantage of NH_3 over AN.[2]

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[2] The fragility of the results was tested by removing Altus, Perkins, and 2008 Lahoma from the data and re-estimated the models. Altus is located in western Oklahoma and is marginal wheat land, Perkins has poor N

Sensitivity Analysis

Table 6 summarizes how sensitive expected net returns were to the change in N and wheat prices. The highest and the lowest price for NH_3, AN, UAN and wheat were selected from the data and expected net returns were estimated under a high and low scenario. The base levels of net returns were provided for comparison purposes. For NH_3, the 0/90 treatment produces the highest average net returns for the three scenarios; the results were not sensitive to the price of NH_3. The results for AN did not drastically change under the high and low price scenarios. The 0/90 treatment still had the highest average net returns, although under the low price scenario the 45/VRT surpasses the 0/VRT in net returns. For the UAN scenarios, NH_3 was assumed as the pre-plant source of N. The 0/90 treatment had the highest average net returns for both scenarios; however, when the price on UAN reaches \$0.73 kg^{-1} the 0/URT produces the largest net returns among ORM treatments. Under the high and low wheat price scenarios, net returns were highest for the 0/90 treatment, which was identical to base level results.

Conclusions

Predicting the exact amount of N to apply for wheat to reach its plateau is difficult with temporal and spatial variability. Yields from the ORM treatments were not statistically different from the conventional treatment, but averaged smaller yields than the 0/90 and 45/45 treatments. The lower yields with the ORM treatments suggest applying additional N could improve the precision system. Future research should consider Bayesian decision theory to determine the

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responses due to its soil characteristics, and 2008 Lahoma were record high yields. Removing these observations data did not change the conclusions.

optimal level of N instead of the current approach that implicitly assumes the plateau is estimated without error.

Net return results found no statistical difference between the treatments, and the 0/90 treatment had the highest net returns on average. The sensitivity analysis demonstrates that conclusions were not sensitive to changes in prices.

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Table 1. Summary of the average N, and wheat prices (\$ per kg^{-1}) from 2004-2007

Years	NH_3	AN	UAN	Wheat
2004	\$ 0.45	\$ 0.87	\$ 0.73	\$ 0.12
2005	\$ 0.50	\$ 0.98	\$ 0.90	\$ 0.13
2006	\$ 0.65	\$ 1.12	\$ 0.93	\$ 0.18
2007	\$ 0.66	\$ 1.24	\$ 1.15	\$ 0.23
Average	\$ 0.56	\$ 1.05	\$ 0.93	\$ 0.16

Source: USDA (2008a) and (2008b)

Table 2. Summary of the application and technology costs (\$ per ha^{-1})

	NH_3	AN	UAN	technology
Application[a]	\$ 24.57	\$ 9.18	\$ 9.60	
ORM sensors[b]				\$ 1.55
NRS[b]				
0/VRT & 0/URT				\$ 1.85
45/VRT & 45/URT				\$ 2.23

[a] Source: Doye et al. (2006); Doye and Sahs (2008)
[b] Source: ASABE (2006)

Table 3. Yields and nitrogen (N) quantities applied by the ORM system (in kg ha^{-1}) across all treatments, locations and years

Year	Treatment	Altus	N	Lahoma	N	LCB	N	Perkins	N	Hennessey	N	Covington	N	Tipton	N	Average	N
Avg.	0/0	2,469		1,531		1,763		1,078		2,911		856		1,022		1,631[a]	
Avg.	0/45	2,967		2,388		2,047		1,328		3,347		1,354		1,725		2,141[a]	
Avg.	0/90	3,084		3,330		2,285		1,579		3,589		1,587		2,300		2,511	
Avg.	45/45	2,791		3,350		2,103		1,419		3,672		1,400		2,515		2,424	
Avg.	45/0	2,706		2,241		2,013		1,322		3,584		1,236		1,594		2,054[a]	
Avg.	90/0	2,774		2,998		2,073		1,648		3,457		1,294		1,714		2,228	
Avg.	0/VRT	2,845	54	2,661	77	1,780	30	1,080	33	3,369	96	1,254	38	1,897	39	2,127[a]	52
Avg.	45/VRT	2,883	32	2,927	35	1,811	16	1,150	13	3,772	49	1,264	19	2,368	33	2,311[a]	28
Avg.	0/URT	2,822	49	2,729	69	1,764	27	1,243	35	3,630	86	1,093	27	1,689	42	2,139	49
Avg.	45/URT	2,780	25	2,910	39	1,700	17	1,312	15	3,621	29	1,240	10	2,306	33	2,267	24

Note: Yields were not available for every location from 2005-2009. All available yields included in the analysis and are shown in the table

[a] Significant at the 95% level

Table 4. Net returns (in \$ ha^{-1}) with NH_3 as pre-plant N across all treatments, locations and years

Year	Treatment	Altus	Lahoma	LCB	Perkins	Hennessey	Covington	Tipton	Average
Average	0/0	406	231	290	163	479	141	168	268
Average	0/45	437	336	276	146	500	172	233	300
Average	0/90	415	454	265	139	498	168	286	318
Average	45/45	358	433	227	102	503	129	313	295
Average	45/0	395	289	272	146	540	153	212	287
Average	90/0	381	393	248	162	494	138	207	289
Average	0/VRT	410	356	250	135	455	159	264	290
Average	45/VRT	385	389	210	116	516	130	299	292
Average	0/URT	399	374	250	160	507	143	228	294
Average	45/URT	364	383	191	141	509	134	289	287

Note: Yield data were not available for every location from 2005-2009. All available data were included in the analysis

Table 5. Net returns (in \$ ha^{-1}) with AN as pre-plant N across all treatments, locations and years

Year	Treatment	Altus	Lahoma	LCB	Perkins	Hennessey	Covington	Tipton	Average
Average	0/0	406	231	290	163	479	141	168	268
Average	0/45	437	336	276	146	500	172	233	301
Average	0/90	415	454	265	139	498	168	286	320
Average	45/45	352	427	220	96	497	123	306	291
Average	45/0	389	282	266	139	533	147	206	282
Average	90/0	353	364	219	133	465	109	178	263
Average	0/VRT	410	356	250	135	455	159	264	290
Average	45/VRT	379	383	203	110	509	124	293	287
Average	0/URT	404	374	239	155	507	143	228	293
Average	45/URT	358	377	184	145	502	128	283	283

Note: Yield data were not available for every location from 2005-2009. All available data were included in the analysis

Table 6. Sensitivity analysis of average net returns (in \$ ha^{-1}) for a change in N and wheat prices across the treatments

	Price	0/0	0/45	0/90	45/45	45/0	90/0	0/VRT	45/VRT	0/URT	45/URT
NH_3											
High	\$0.66	268	300	318	293	284	284	290	289	294	284
Base	\$0.56	268	300	318	295	287	289	290	292	294	287
Low	\$0.45	268	300	318	298	300	305	290	295	294	290
AN											
High	\$1.24	268	300	318	286	279	272	290	283	294	279
Base	\$1.05	268	300	318	295	287	289	290	292	294	287
Low	\$0.87	268	300	318	303	295	305	290	299	294	295
UAN[a]											
High	\$1.15	268	294	307	289	287	289	284	289	288	283
Base	\$0.93	268	300	318	295	287	289	290	292	294	287
Low	\$0.73	268	305	328	300	287	289	295	295	299	290
Wheat Price[a]											
High	\$0.23	334	385	417	387	366	379	374	379	379	373
Base	\$0.16	268	300	318	295	287	289	290	292	294	287
Low	\$0.12	223	243	251	232	233	228	231	232	236	228

Note: These are the average net returns for across treatments, years, and locations

[a] NH_3 is assumed to be the pre-plant source on N