Economic Analysis of Accuracy of N Application, April 13, 2006

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The value of N application accuracy is heavily determined by the underlying expected yield response function. The "flatter" the yield response function is near the economic optimal N rate, the less valuable is N application accuracy. That is because one can reduce N rates substantially without sacrificing a great deal of yield. In this research, we assumed the N response functions to be those discussed and reported in "Modifying Yield-Goal-Based Fertilizer Recommendations to Reflect Prices" available at www.agmanager.info and also presented at the 2006 Great Plains Soil Fertility Conference in Denver, Colorado. Besides being consistent with Kansas State's fertilizer recommendations, our response functions are known to be less-flat at the top than say the response functions underlying Iowa State University's web-based economic optimal N rate calculator for corn. Though it has not been ascertained as carefully, it also is likely that our response functions are less-flat than those used by the University of Nebraska in its N rate calculator. So, our analysis probably will show larger gains to N application accuracy than other research using flatter response functions.

Besides increased N, increased irrigation water also is needed in order to increase crop yields in irrigated crop production. Thus, relative to the non-irrigator with the same yield goal, the irrigator's economic optimal N rate will be reduced. In essence, the irrigator has to pay for two increased inputs in order to increase yields, N and water. This effect of reducing optimal N rate relative to the non-irrigator will result in being on a "steeper" portion of the response curve, which results in larger gains to N application accuracy. Thus, in subsequent work following the publication of the "Modifying Yield Goals ..." paper, Dhuyvetter, Dumler, and Kastens considered the impact of irrigation on crop yield in a limiting plateau fashion along with the impact on yield of N. This work has not yet been published and so readers will need to contact one of these three economists to get further information. But, some insight can be gained by examining the decision-tool spreadsheet, *KSU-CropBudgets2006.xls* available at www.agmanager.info. A modified form of this spreadsheet was used in this analysis.

This work depends on simulating N rates across injection knives given different levels of application accuracy. Important background information can be obtained from "Field evaluation of anhydrous ammonia manifold performance and variability," by Boyd, Hanna, Baker, and Colvin of Iowa State University (2002 ASAE Meetings paper number 021039). That study considered an NH3 applicator with 11 knives and reported application accuracy in terms of coefficient of variation (CV), which is the standard deviation of N rate across the 11 knives divided by the mean rate. Depending upon manifold type and configuration, the authors summarizing table reported application CV's ranging from 5.5% to 22.0% at an application rate of 75 lb N/acre. From that work, along with other observations uncovered in a web-based search, it appears that a 22% CV might adequately characterize a "low" application accuracy system, whereas "something less than 10%" might characterize a well-designed NH3 system. Finally, we will assume that a well-designed *pressure-increasing* NH3 system (not considered in the Iowa State study) might be associated with considerably lower CV's, say 3%.

In this present study we consider four measures of application accuracy, low (22% CV), medium

(8% CV), high (3% CV), and perfect (0% CV), with economic comparisons made between each measure of accuracy and a perfectly accurate one (i.e., comparisons with the 0% CV scenario).

In this economic analysis, like others before, we assume that a given crop plant will acquire its N from two application slots, which means that we compute a 2-knife average rate to determine the effective N rate used in the associated yield response function. Because of this 2-knife averaging, we work with 12 simulated knives rather than the odd-numbered 11 used in the actual Iowa State University study. For each "run" of our simulation, considering all possible 2-knife combinations gives us 12 measures of N rate and the 12 associated measures of yield (e.g., knife 1&2, 2&3, ... 12&12, 12&1).

For simulated variability in application given a CV (thus, a standard deviation of N rate), we work with normal score values rather than randomly drawn numbers from a standard normal statistical distribution. Normal scores are simply a reasonable approximation of the standard normal distribution given a selected sample size. For our 12-point situation, the rounded-to-2-decimals normal scores are 1.73, 1.15, 0.81, 0.55, 0.32, 0.10, along with their six negative counterparts. In this arrangement, the lowest and highest application knives will be 1.73 standard deviations above and below the targeted rate, and so on.

Though the normal score approach does prevent some N rate possibilities from occurring in our simulations (e.g., minus and positive infinity), many of the precluded ones likely are physically impossible and, even if possible, would occur with very low probabilities anyway. Moreover, this approach leads to a 12-point sample CV that is very close to the targeted one (e.g., 0.218 instead of 0.220). But, in our approach we also want to ensure random placement in the 12-point array of the 12 possible rates associated with the 12 normal score values. There would be 12!, or around 479 million unique orderings of the 12 rates considered. So, to reduce the scale of the problem, for a given targeted N rate, we consider only 10,000 random permutations (each permutation is considered a "run"). Using the normal score approach ensures that a) each run will have a 12-knife mean N rate exactly equal to the targeted N rate, and b) that the meaningful range of variation is covered in our analysis. We trust that using 10,000 runs will capture "enough" of the 479 million possibilities of orderings to ensure sufficient repeatability for our inferences.

Though our spreadsheet framework can consider numerous combinations of prices and various crops we will confine our comparison to dryland wheat with a yield goal of 45 bu/acre and irrigated corn with a yield goal of 225 bu/acre. We consider long run crop prices of \$3.20/bu for wheat and \$2.35 for corn, but adjust those prices for a marginal cost of harvesting of \$0.28/bu. We consider a fertilizer N price of \$0.25 per lb of N (\$400/T for NH3). For irrigation, we consider a 300 foot deep well operating at 20 psi and a \$8.50/mcf price of natural gas, which leads to an irrigation pumping cost of \$6.06 per acre-inch of water applied. Also, for this irrigated situation we assume 18 inches of annual rainfall. Finally, we consider soil test N (0-24 inches) to be 30 lb/acre and soil organic matter to be 1.8 percent at the 0-6 inch depth.

Results

Table 1 reports the application accuracy information for dryland wheat and table 2 for irrigated corn. Clearly, from this analysis, the benefits of improved N application accuracy are not large for wheat but are considerably higher for irrigated corn. As an example, consider a manager changing from a well-managed (i.e., medium accuracy) NH3 delivery system to a pressure-increasing system (i.e., high accuracy) in the case of irrigated corn. Our study suggests that the annual benefit of that change is $1.91/acre, which is from the difference between $437.49/acre revenue associated with the high accuracy system and $435.59/acre revenue associated with the medium accuracy. Thus, in this case, one would have $1.91/acre to amortize the additional investment for making such a system change. For dryland wheat, the comparable amount to pay off the investment would be only $0.07/acre.

Extensions to analysis

Practical experience can lead to farmers making better (more profitable) decisions over time around “problems” such as low accuracy of N application. Typically, we would expect higher application rates in such cases in order to alleviate visibly N-deficient areas of the field such as striping due to application problems. However, this direction of adjustment is not a foregone conclusion, especially when one considers irrigation and different prices of fertilizer N. In this case, we simulated adjustments to the recommended fertilizer and irrigation rates to see how much additional profit could be acquired given known inaccuracy of application. However, we do not report the results for two reasons. First, the direction of change (whether one should apply more or less water or more or less fertilizer) to increase profits could not easily be generalized to meaningful rules of thumb. Second, the gains from this simulation represented only a small part of the difference in profits across the different application accuracies.

Another point of interest is the following. In historically well-fertilized fields, especially with no-till, fertilizer trials often reveal that large differences in fertilizer rates might be associated with negligible differences in crop yield. This likely is because of the large capacity of the soil to mineralize N during the growing season in such situations. But, if that is true, then it likely also is true that our analysis is over-stating the differences in profit associated with different N application accuracies. That is, random variations of application will average out over years and the capacity of soils to mineralize N will hence smooth through the problem.

One caveat to this study is that it made no attempt to consider the possibility that alternative delivery systems for NH3, especially pressure-reducing vs. pressure-increasing, might be associated with different relative efficiencies in terms of placing the NH3 into the soil without excessive losses due to point-of-soil-contact vaporization.

Conclusion

This research assesses the economic benefit associated with selected improvements in N application accuracy. The decision to purchase an N delivery system should be based on weighing the annualized cost of the competing investments against such annual benefits. Moreover, consideration should be given to crop type, potential vaporization losses, and the possibility that the capacity of soils to smooth through N application problems may further reduce the benefits to improving application accuracy from those reported here.

Table 1. Comparison of N application accuracy for dryland wheat

	12-knife application rate coefficient of variation (CV)			
	0.00	0.03	0.08	0.22
yield goal, bu/acre	45	45	45	45
crop price adj for harvest, $/bu	$2.92	$2.92	$2.92	$2.92
fertilizer N price, $/lb	$0.25	$0.25	$0.25	$0.25
soil test N, lb N per acre	30	30	30	30
soil organic matter, percent	1.8	1.8	1.8	1.8
fertilizer N rate, lb/acre	56.90	56.90	56.90	56.90
fertilizer N cost, $/acre	$14.22	$14.22	$14.22	$14.22
	economic differences across application accuracies			
crop yield, bu/acre	44.43	44.43	44.40	44.23
yield revenue, $/acre	$129.74	$129.73	$129.66	$129.14
difference from 0% CV, $/acre	------	-$0.01	-$0.08	-$0.60

Table 2. Comparison of N application accuracy for irrigated corn

	12-knife application rate coefficient of variation (CV)			
	0.00	0.03	0.08	0.22
yield goal, bu/acre	225	225	225	225
crop price adj for harvest, $/bu	$2.07	$2.07	$2.07	$2.07
fertilizer N price, $/lb	$0.25	$0.25	$0.25	$0.25
irrigation cost, $/acre-inch	$6.06	$6.06	$6.06	$6.06
annual rainfall, inches	18	18	18	18
soil test N, lb N per acre	30	30	30	30
soil organic matter, percent	1.8	1.8	1.8	1.8
irrigation water, inches	14.8	14.8	14.8	14.8
fertilizer N rate, lb/acre	229.94	229.94	229.94	229.94
irrigation cost, $/acre	$89.69	$89.69	$89.69	$89.69
fertilizer N cost, $/acre	$57.49	$57.49	$57.49	$57.49
	economic differences across application accuracies			
crop yield, bu/acre	211.86	211.35	210.43	207.43
yield revenue, $/acre	$438.55	$437.49	$435.59	$429.37
difference from 0% CV, $/acre	------	-$1.06	-$2.97	-$9.18