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Do Farmers Waste Fertilizer?

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1.0 Objectives and Background

Farmers in many jurisdictions apply nitrogen at levels that exceed crop nutrient needs, despite the apparent costs of over-application (Agriculture and Agri-food Canada, 2000). Recommendations that account for crop requirements and relative prices are publicly available to farmers from government extensions services, yet farmers tend to apply more than suggested. Sheriff (2005) argues that there are several reasons why farmers are apparently applying more fertilizer than a crop can use: (1) perception that the general recommendations are not appropriate for their individual situations (2) uncertainty about soil quality, nitrogen content and about weather, (3) effect of chemical fertilizer substitutes (i.e. manure) and complements (i.e. irrigation), and (4) hidden opportunity costs of farmer time and equipment.

Since over-application can lead to environmental damages, either the recommendations need to be modified to more accurately reflect individual site characteristics or farmers have to be better informed about the appropriateness of the agronomic advice and the consequences of applying more than the crop needs. In order to assess the empirical basis for differences in farmer perceptions of agronomic advice, this policy brief examines the differences in *ex-post* optimal and *ex-ante* recommended application rates of nitrogen to corn on 6 field trials over several years in southwestern Ontario. The results suggest farmers are not “wasting” fertilizer and that their over-application is a rational economic response.

2.0 Sources of Differences Between Farmer Rates and Agronomic Advice

2.1 Farmers Perception of Agronomic Advice

Farmers may apply more than the recommended rate of fertilizer if they feel the recommendations are too conservative for their individual situation. Over-application may result from differences in the perception of how a crop on an individual field actually responds to fertilizer. The relationship between fertilizer application and crop yield is generally represented by either a plateau or a polynomial function. Variations in the *ex post* optimal nitrogen rate (i.e. Maximum Economic Rate of Nitrogen or MERN) due to differences in the form of the assumed yield response function may explain the tendency for farmers to over-apply nitrogen if certain functional forms consistently suggest higher MERN levels than recommended.

Even if there is agreement on the functional form of the relationship between nitrogen application levels and corn yield, a farmer may feel this relationship holds for the average situation. A comparison of optimal N-rates across time for a given site would show whether the year-specific MERN tends to be higher than the recommended rate on average. However, being correct on average does not imply that over-application is unjustified. If the distribution of the differences between the *ex post* MERN and the *ex ante* recommended rates is either widely dispersed or skewed, farmers may be hesitant to apply the recommended amount. A wide distribution would suggest a low degree of confidence in the general recommendations while a non-symmetric distribution would indicate that the *ex post* optimal rates can be generally higher than the recommended rate even when the recommended rate is equal to the long term average *ex post* optimal rate.

2.2 Uncertainty

The range in the optimal rate between years (and locations) underlies the affect of weather and soil on the efficiency of nitrogen. For example, good weather can increase the impact of nitrogen since water is a complementary input to fertilizer while fertilizer may not by taken up by the crop in poor growing conditions. The inherent uncertainty about weather may induce even risk neutral farmers to apply more than the average if the expected gains from applying a bit more in the good years outweighs the expected cost of this extra nitrogen that is unused by the crop in the poor years.

Risk averse farmers are worried not only about average returns but also about the variability. Risk averse farmers would thus apply more than the recommended rate of fertilizer if the over-application reduced profit variability. In addition, the possibility of unfavourable weather not allowing for side-dress application may induce risk averse farmers to use pre-plant application, which increases nutrient losses and thus requires higher rates.

2.3 Other Reasons

The opportunity cost of farmer time and equipment at the time of fertilization in spring may be high. Given the time constraints at planting, it may be worthwhile to fertilize in the fall when the need for farmer time and equipment is lower if this covers the loss of nutrients due to an early fertilization. Similarly, high opportunity cost of transporting manure to distant fields can lead to manure being treated as a “waste product” and disposed in excess on nearby fields. In some instances manure may be the main source of excess nitrogen.

Finally, there is also a benefit to the farmer of having a good looking crop that results from an application rate higher than the one that maximizes profits. The intrinsic value to the farmer may be greater than the loss in profits and thus justify the higher application rate. The higher crop yields may also be important to the landlord whose field the farmer is growing the crop and with whom the farmer has to negotiate continued rental agreements.

3.0 Assessing the Reasons for Over-Application using Nitrogen Field Trials

3.1 Data and Methods

Seven randomized complete block nitrogen trials, conducted in five counties in southwestern Ontario, Haldinand-Norfolk, Elgin, Middlesex, Kent, and Essex, were selected from the dataset used in Janovicek *et al*. (2004). The experiments were conducted between 1989 and 2001 with the time period overlapping in six experiments from 1990 to 1992. Two of the experiments contained multi-year data (i.e. 9 and 6 years). Corn heat units within the experimental area ranged from 3000 to 3400. There was also some heterogeneity in terms of soil texture, which included sand, loamy sand, sandy loam, loam, and clay loam. Fields in all seven experiments were planted in corn in the previous year and there were no cover crops. A moldboard plow was used in the fall of the previous year in five of the experiments and mulch-tillage in the other two trials. Each site had 5 or 6 application rates of anhydrous ammonia (six sites) or urea-ammonium-nitrate (one site) between 0 and 262 kg N per hectare. Yield was recorded for each rate. There were 8 replications per treatment in one experiment and 4 in the other six experiments.

The application rates and yield levels were used to estimate a yield response for 4 commonly-used functional forms: (1) a linear function with a plateau; (2) a quadratic function; (3) a quadratic function with a plateau; and (4) the Mitscherlich production function. The *ex post* profit maximizing nitrogen rate (MERN) was calculated for each site and each year under the four alternative functional forms using current prices. The MERN values for each site by year and functional form were also compared to the rate that would have been recommended for the location by extension personnel. The *ex ante* recommended N-rate is calculated by using The Ontario Nitrogen Calculator, which is an online read-only Excel spreadsheet with pre-entered formulae that take into account general growing conditions on a farm, such as corn heat units, previous crop, soil texture, as well as corn and nitrogen prices (OMAFRA, 2006). A quadratic-plateau functional form is assumed as the underlying relationship between nitrogen and corn yield for OMAFRA nitrogen recommendations.

3.2 Farmers Perception of Agronomic Advice

None of the functional forms produced MERN values consistently higher than the recommended rate. The *ex post* MERN estimated with a quadratic-plateau, which is the underlying response model in the recommendation, was higher than the recommend rate on half of the 6 sites but lower on the other half. Even with the quadratic function that generated the highest MERN on average, the *ex ante* recommendations were higher than the MERN on 2 of the 6 sites. Thus, differences in the underlying relationship between nitrogen rate and corn yield is not a reason for over-application.

The spatial variation in MERN values is expected, and the recommended rates do vary by site depending on yield potential. The differences between the recommended and MERN were correlated with the yield potential to determine if the basis for the recommendation should be adjusted. The correlations tend to be positive, which suggests that the recommended rates are lower than the *ex post* MERN on lower yielding sites. While the average difference between the recommended and MERN values is not large, the range in differences across sites is significant. The range in differences averages 215 kg/ha in 1990 and 114 kg/ha in 1991. The skewness of the distribution is negative and given that the recommended rate is higher than the *ex post* MERN for many of the situations in those two years, the result is due to a few large differences. If the recommended rate is lower than the *ex post* MERN in a given year, it tends to be much lower.

Approximately half of the years result in the recommended rate being higher than the *ex post* MERN values across functional forms with the exception of the quadratic. However, in those other years when the recommended rate is lower than the MERN, it is much lower since there is potential for large yields in good growing conditions with sufficient nitrogen that is not adequately captured by the recommendations based on average yield potential.

The temporal variation in MERN has two implications on why farmers may not apply the recommended rate. First, is the extremely large variation in the *ex post* MERN across seasons, particularly for less productive sites. While the recommended rate may be close to the MERN on average, the large variability could erode a farmer's trust in a single nitrogen recommendation value, and induce them to follow their own judgment. Second, is the symmetry of the distribution of MERN relative to the recommended rate. A symmetric distribution would imply that the years in which optimal N-rate is above the recommended rate is equal to the number of years for which the optimal rate is lower than the recommended rate. The skewness parameter is generally negative; implying that the recommended rate is more likely to be greater than the *ex post* MERN. However, it still may be beneficial to apply more than recommended if the profit gains in those years when the *ex post* MERN is higher than recommended overweigh the cost of wasted nitrogen in the other years when the MERN is lower. This especially applies to risk-neutral farmers, who are indifferent to the higher probability of losing profit as long as the gain in those few years is large enough to offset the losses. The profitability of such a strategy is examined in the next section

Across all sites and years, the reduction in profit from following the recommended rate instead of applying the *ex post* optimal rate was approximately $50/ha. The reduction is slightly less on average if more than the recommended rate is applied suggesting that there may be a payoff to applying more for the good years. The difference between the MERN and recommended rate is less than $10/ha on approximately one-third of the trials. The largest differences in profit between the MERN and recommended occur when the recommended is lower than the *ex post* optimal as opposed to being too high. This under-application in good years tends to be associated with the less productive sites but also happens on the highest yielding site. The reductions in profit when the recommended is above the *ex post* MERN on 3 of the 6 sites are not as great as from under-application on the other 3 sites.

The average range of nitrogen rates below and above MERN for each site and year resulting in less than a $25/ha reduction in the maximum profit associated with the MERN is approximately 50kg/ha with the values fairly consistent within a given functional form. The amount is approximately one-third of the recommended rate across all sites. The result confirms a relatively flat payoff to soil testing and the low value of obtaining additional information, suggested by Pannell (2006).

3.3 Uncertainty

The effect of risk was examined using data on yield response to nitrogen from one site over 8 years and two different models: (1) certainty equivalent model and (2) risk-value model. The advantage of the risk value model is that it can account for non-normality in the distribution of profit and the reference point for measuring profit variability can be different from the average profit. The risk analysis based on the certainty equivalent model confirmed findings of Just and Pope (1979), Love and Buccola (1991), and Nelson and Preckel (1989) that additional nitrogen increases variance of profit and thus risk-averse farmers should apply less rather than more nitrogen than the average. However, risk neutral farmers using a plateau yield response would be justified to apply more than the average because the gain in profit in good years overweighs the cost of wasted nitrogen in bad years.

The risk analysis based on the risk value model produced results generally consistent with the certainty equivalent model. It only produced different results when the farmer's reference profit was much higher than the average.

4.0 Policy Implications

The results of our analysis suggest that farmers are not "wasting" fertilizer by applying more than the recommended rate. The difference is not due to farmers assuming their land is more responsive to nitrogen than the average (the Lake Wobeygon condition where everyone is above average). Instead, the over-application is due to uncertainty. There was a high degree of variability in optimal nitrogen rates, especially across years, due to differences in weather. The variability may cause farmers to have less confidence in a single, constant recommendation as suggested by Janovicek (2005) and Sheriff (2005). More importantly is that the benefits of over-application in the good years are greater than the costs of excess fertilizer in the poor years. The expected benefits and expected costs are not symmetric so it pays for risk neutral farmers to apply a little extra just in case. Uncertainty may also be a reason for over-application for a farmer concerned about risk if risk deals with the probability of low yields. While applying more nitrogen reduced the likelihood of poor yields, it does increase the variability of profits so does not reduce risk from a traditional economic definition.

The analysis also found that a relatively flat payoff functions to nitrogen, which suggests a low payoff to variable rate application technology. However, there does appear to be significant value to forecasting the likelihood of weather events during the growing season so that nitrogen rates can be adjusted accordingly. The flat payoff function also suggests that the other potential values from over-application such as the amenity value of a good-looking crop and the opportunity costs of time may justify the costs of applying more fertilizer than the recommended rate.

Even though the results of this study suggest there are private net benefits to a farmer from over-applying fertilizer, there are potential environmental consequences not accounted for by the farmer. For example, Gray *et al*. (2005) suggest relatively high total market and non-market benefits of voluntary Environmental Farm Plans. Thus, focusing on potential negative environmental consequences of nitrogen over-application, rather than lost profits, may be a more effective policy for reducing nitrogen use.

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