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Paper Title:

Integrating Economic and Environmental Considerations Into The Fertilization Decision Process

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03-market structure	17-law	31-policy
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A van Kuelen fertilizer response model that empirically integrates economic, agronomic and environmental considerations was applied to an analysis of nitrogen fertilization of corn in the Coastal Plains. The results suggest that the previous emphasis in the literature on "optimal carryover rates" and "fertilizing the soil" are inconsistent with both economic and environmental goals.

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INTEGRATING ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS INTO THE FERTILIZATION DECISION PROCESS

ABSTRACT

A van Kuelen fertilizer response model that empirically integrates economic, agronomic and environmental considerations was applied to an analysis of nitrogen fertilization of corn in the Coastal Plains. The results suggest that the previous emphasis in the literature on "optimal carryover rates" and "fertilizing the soil" are inconsistent with both economic and environmental goals.

INTEGRATING ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS INTO THE FERTILIZATION DECISION PROCESS.

Currently in the U.S. there is growing concern that modern agricultural practices, that heavily rely on chemical input use, may create undesirable side effects. Specifically, it has become increasingly clear over the past two decades that nitrate losses from agricultural land have the potential to contaminate ground and surface water. According to the 1990 EPA National Pesticide Survey, nitrates are present above the analytical detection level in fifty-two percent of community water sources, and fifty-seven percent of rural domestic wells.

Given the sheer quantity of nitrogen fertilizer used in crop production, and its limited availability, excessive nitrate losses also threaten agriculture sustainability. The economics of crop production can also be improved by reducing nitrate losses. Given that fertilizer cost is an important component of the total production cost, excessive nitrate losses can negatively affect farm profitability.

Historically, production scientists have made fertilizer recommendations to agricultural producers on the basis of building and maintaining an optimal fertility stock in the soil in order to achieve a maximum, or plateau yield, under any weather conditions (Lanzer et al., 1987). That is, it was recommended to fertilize the soil. The reason for this approach can be found in von Liebig's Law of the Minimum which states that the yield of a crop is limited by the nutrient present at the lowest level below its minimum required for maximum yield. Notwithstanding the agronomists and soil scientists traditional goal of maximizing crop yield, agricultural economists have long argued that fertilization recommendations should not be made without considering the input-output cost relationships (Redman and Allen, 1954). Another concept well established in the literature is fertility carryover. According to a 1981 study by Lanzer and Paris, carryover fertilizer "is like money in the bank and is part of the fertilizer economics". There is no doubt that carryover fertilizer is part of the economics of agricultural production, yet it is also clear that in many situations, this left over fertilizer may leach or runoff before the next crop can utilize it, thus potentially endangering the water supply.

Hallberg (1987) cites empirical evidence documenting this potential problem. He references recent studies that indicate that nitrogen recovery from agronomic crops is seldom more than 70 percent and generally is closer to 50 percent of the nitrogen fertilizer applied; moreover, he also indicates that in areas where nitrogen fertilizer is used, nitrate concentrations in groundwater can increase from three-fold to sixty-fold.

Despite the great amount of research undertaken by agricultural scientists on nutrient response, to date, neither agricultural economists, nor agronomists or soil scientists have adequately incorporated environmental considerations in the fertilization recommendation process. The purpose of this study then is to develop a conceptual fertilizer response model that can be used to evaluate different fertilization strategies according to economic, agronomic, and environmental considerations.

Conceptual Framework and Methodology.

Van Keulen Response Model.

The yield of a crop is generally represented as a function of fertilizer applied; nonetheless, van Keulen (1986) following de Wit (1953) suggests, that to obtain a yield response, the fertilizer applied to the soil must be taken up and used by the growing crop. This approach allows for the study of the relationship between fertilizer applied to the soil and the fertilizer actually used by the plant. By separating the biological process of fertilizer uptake from the managerial process of fertilizer application, it is believed that the von Keulen approach will provide better information on the economic and environmental aspects of the fertilization problem (van Keulen and Wolf, 1986). The use of the van Keulen response model requires the estimation of functional relationships between yield and nitrogen uptake and between nitrogen uptake and nitrogen applied. Although several mathematical forms could be used to describe these relationships, the extensive work done in the fertilizer response field, and a need to maintain consistency with several agronomic principles, suggests that perhaps the most appropriate functional forms are of the Mitsherlich-Spillman type. In general, the yield nitrogen uptake function can described by:

$$Y = B+M(1-e^{-fU})$$

where Y is total grain yield, M is the asymptotic maximum yield obtainable by the nitrogen taken up U, B is an intercept shifter reflecting the fact that some nutrient uptake will occur without any associated grain yield, and (f) is the relative efficiency of yield per unit of nitrogen uptake. In similar fashion the uptake-application relationship can be represented as:

$$U = Z+W(1-e^{-kA})$$

where U is the total nitrogen uptake, W is the asymptotic maximum uptake from the nitrogen applied (A) and the available nitrogen from a particular soil (Z), and (k) is a relative efficiency measure. That is, (k) is the fraction of (A) recovered by the crop at low levels of fertilizer applications.

Graphical representation of the van Keulen nitrogen response model is presented in figure 1. Quadrant I depicts the relationship between crop yield and the nitrogen uptake. With increasing uptake of nitrogen, the curve will start to show diminishing returns. Eventually, the yield-uptake curve will reach a plateau maximum when nitrogen will no longer be the limiting factor. The curvature of this function is affected by the efficiency (f) with which the nitrogen is taken up by the crop. The greater the absolute value of (f), the greater the marginal efficiency of nitrogen uptake. This efficiency measure is primarily a function of the biological characteristics of the crop.

Quadrant II depicts the uptake-application relationship. The intercept of this curve represents the level of nitrogen that the crop has available from the soil prior to any fertilization. This value is affected by the mineral composition of the soil, and its organic matter components. Also, temperature and water availability will influence the value of the intercept. The curvature of this function is reflected in the efficiency measure k. The greater in absolute terms k is, the greater is the fraction of nitrogen fertilizer recovered by the crop from the soil. The magnitude of k is affected by the type of fertilizer used, method and timing of application, water availability, and cultivar.

Quadrant IV represents the classical relationship between yield and fertilizer application. The intercept value will depend on the level of the utilizable nitrogen present in the soil. The slope is again a measure of efficiency, it indicates the contribution to total yield of the last unit of nitrogen applied. This curve can be obtained by eliminating the uptake variable from the other two curves (van Keulen and Wolf, 1986).

Crop Profitability and Nitrogen Usage.

Given the van Keulen type of response model and assuming perfect competition in the input and output markets, the optimal nitrogen fertilizer usage level is given by the maximization of the following net returns (NR) function:

$$NR = P_c Y(U(A)) - P_n A$$

where, P_c is the current price of corn, Y(U(A)) is the yield of corn expressed as a function of nitrogen taken up U, which is in turn a function of the nitrogen applied A, and P_n is the current price of nitrogen fertilizer inclusive of the variable cost of application. The optimal level of nitrogen fertilizer is obtained by solving the following first order condition:

$$\partial NR/\partial A = P_c(\partial Y/\partial U)(\partial U/\partial A) - P_n = 0$$

or

$$(\partial Y/\partial U)(\partial U/\partial A) = P_n/P_c$$

Clearly the optimal choice of nitrogen application under profit maximization will be affected by the current price ratio, and will not necessarily result in yield maximization.

Environmental Considerations and Their Effects on Optimal Nitrogen Usage.

Binger and Hoffman (1988), state that externalities will arise when the action of an agent directly impacts the utility and/or the profit of another agent. When crop production activities result in the degradation of water quality, the consumers of the polluted waters, without doubt, experience a reduction in utility. On this account it seems appropriate to analyze the fertilization problem within an economic framework that can account for the negative externality created by the excessive use of fertilizer.

For the purpose of illustration, multimarket effects can be eliminated by assuming fixed input prices for the industry. Then the net returns function for the firm can be modified as follows to account for the social cost of pollution:

$$NR = P_c Y(U(A)) - P_n A - P_s S$$

where P_s is the social cost of nitrogen losses, and

$$S = (A + CI) - (U + CO)$$

is the quantity of nitrogen lost from the soil. A is the nitrogen applied this season, CI is the nitrogen residual from the previous growing season, U is nitrogen uptake, and CO is the nitrogen carryover to the next growing season. Assuming that carryover is in steady state, (i.e. CI - CO = 0), the first order conditions for net returns maximization then become:

$$\partial NR/\partial A = P_c(\partial Y/\partial U)(\partial U/\partial A) - P_n - P_s(1-\partial U/\partial A) = 0$$

or

$$(\partial Y/\partial U)(\partial U/\partial A) = (P_n + P_s(1-\partial U/\partial A))/P_c$$

Clearly, for any positive value of P_s, the optimal choice of nitrogen input will be lower when the social cost of nitrate losses is incorporated in the decision process. Under this framework different strategies can be ranked according to the underlying decision maker preferences. For instance, if the decision maker is concerned only with profit maximization, and the external cost of fertilizer applications is not internalized, that is $P_s = 0$ for the producer, different fertilizer strategies can be ranked by the classical profit maximizing model. On the other hand, in situations where the environmental concern of society is strong enough to override the classical production objective of profit maximization, this type of framework could help in determining an appropriate manner to internalize the social cost of excessive fertilizer usage into the cost of production.

The difficulty of accounting for externalities in empirical studies clearly lies in the nearly impossible task of estimating a proxy for the social cost of externalities. Nonetheless, empirically it is possible to assess nitrate losses arising from different managerial practices.

Empirically Assessing Nitrogen Losses.

The van Keulen fertilizer response model also has the advantage of providing a first level approximation of the potential nitrate loss from the soil. Referring to figure 1, the index of potential nitrate loss (PNL) can be expressed mathematically as:

$$PNL = (CI + A) - U$$

where CI is the nitrogen carryover from the previous growing season including the nitrogen inherent to the particular soil (this term is the intercept of the uptake-application curve), A is again the quantity of nitrogen applied, and U is the nitrogen taken up by the crop. Reducing PNL implies reducing the difference between (CI + A) and U, that is moving toward management practices that achieve a nutrient balance.

Government Limitations on Nitrate Losses and Their Effect on Profitability.

Referring to quadrant II, in figure 1, a 45° line extending from the origin (a) can be used to represent the concept of nutrient balance. On that line all the nitrogen applied is taken up by the crop. The uptake-application curve crosses (a) at only one point (h), at lower levels of fertilizer applications, the nitrogen applied is not sufficient to sustain the crop growth, and the soil inherent and carryover nitrogen starts to be depleted. On the other hand, at higher levels of fertilizer applications, additional nitrogen applications contribute less and less to the crop's growth; hence, nitrogen is increasingly being mineralized, and/or is increasingly being lost from the soil. Now consider a government policy aimed to reduce nitrogen losses. Under this framework, a policy could be implemented that requires growers to achieve nutrient balance. This policy would in effect limit fertilizer applications to h. If h is less than the optimal level of application for net returns maximization, the nutrient balance requirement will result in a lower yield and a decrease in revenue.

Procedures.

In an effort to obtain appropriate data for the specification of the yield uptake and the application uptake functions for nitrogen, the crop simulation model CERES-Maize was used. The Crop Environment Resource Synthesis Model, was developed by the joint effort of several scientists of the ARS branch of the USDA in Temple, Texas. This computer model "simulates the effects of weather, soil water, genotype, and nitrogen dynamics in the soil and crop, on the crop growth and yield" (Jagtap et al., 1988). Also, as the authors state, the nitrogen dynamics sub-model in CERES-Maize is capable of computing nitrogen uptake, leaching, nitrification, denitrification and mineralization.

The computer model was calibrated using F.M. Rhoads 1985 experimental nitrogen response data for corn in Quincy, Florida, by matching soil type, cultivar, and weather and then comparing the yields reported in the experiments with the ones generated by the model. After calibration, the model was used to examine how corn yield response to nitrogen varies given changes in initial soil fertility (5ppm, 20ppm, and 40ppm of elemental N), level of nitrogen application (0, 50, 100, 150, 200, 300 kg./ha.), timing of applications (one application, four applications), and water availability (irrigated or non-irrigated). Each of the combinations was simulated over 30 years (1959-1980) of weather data. The resulting data on corn yield and nitrogen uptake, together with the nitrogen application level, was used to generate summary functions for yield as a function of nitrogen uptake (Y(U)), and for nitrogen uptake as a function of nitrogen applied (U(A)). Non-linear regression procedures were used to fit summary functions to the data.

Results.

Technical Relationships.

Preliminary results for corn grown in soil with an initial level of 20ppm of elemental nitrogen are presented in figure 1. Quadrant II depicts the functions summarizing the relationship between nitrogen applied and nitrogen taken up for irrigated corn. The intercepts, for single nitrogen application, and for four equal applications, have the value of 24 kg/ha and 22 kg/ha respectively. These values represent the nitrogen available to the crop solely from the soil under irrigated conditions. The efficiency measure for the single nitrogen application is k_1 = -.0075, while in the four applications case k_4 = -.00833, indicating that nitrogen applied in 4 equal applications is more efficiently taken up by the crop.

In quadrant I the relationship between yield and nitrogen uptake is presented. The intercept with the uptake axis of the summary function for the single nitrogen application is 7.5 kg/ha, while for the function representing four nitrogen applications the intercept is 7.37 kg/ha. These values reflect an uptake threshold before any grain yield can be expected. The parameter (f), the efficiency, with which the crop takes up nitrogen from the soil, are f_1 = -.0165 and f_4 = .-0158.

Quadrant IV depicts the classical relationship between yield and fertilizer application when the quantity of nitrogen applied is split in four applications. This curve is constructed by eliminating the uptake variable from the other two curves. The intercept with the yield axis represent the grain yield possible with no nitrogen application.

Profitability and Environmental Considerations.

Without economic or environmental considerations, the typical producer will apply as much nitrogen as necessary to obtain the highest yield possible. The yield application function becomes asymptotic around 300 kg N/ha. When the nitrogen application is split four times, at 300 kg N/ha, total simulated grain yield was 12,820 kg/ha . Referring back to the application uptake summary function, this level of nitrogen application results in an uptake of 244 kg N/ha, which implies that 56 kg N/ha are left in the soil. This clearly poses a potential environmental hazard to Florida's water resources. The greater the difference between the nitrogen applied and the nitrogen taken up by the crop, the greater the potential for environmental damage.

Introducing current prices into the decision process of input applications, it is possible to observe the effects of profitability on optimal nitrogen usage. At an approximate price of $ .25 per kilogram of nitrogen, including custom application costs, and with average price for corn at approximately $ .093 per kilogram, the first order condition for returns maximization results in an optimal level of nitrogen application of 197 kg N/ha. At this application level, nitrogen uptake is 209 kg N/ha, and the total yield is 12,661 kg/ha. The optimal choice of nitrogen input under returns maximization results in net returns of 1,128 $/ha compared to a net returns of 1,117 $/ha with the level of nitrogen application associated with yield maximization. If the price of corn changes to .12 $ per kilogram, the optimal level of nitrogen application becomes 215 kg N/ha, and total returns are 1471 $/ha.

Government Regulations and Crop Profitability.

It is not hard to imagine greater government involvement in environmental issues in the coming years. As argued previously, the government could impose a limit on the amount of the nitrogen fertilizer that could potentially be lost from the soil. An interesting comparison is to look how the optimal choice of nitrogen input varies from the application level needed to maintain a nutrient balance.

Again, from figure 1 quadrant II, the interception of the 45° line and the application uptake curve (point h) represents the concept of nutrient balance. At point (h) total uptake equals total application of 228 kg N/ha (See figure 1). At this application rate the total yield is 12,734 kg/ha, nitrogen uptake equals nitrogen applied, and total returns are 1,127 $/ha. In this particular case, the nutrient balance and the maximum net returns levels of nitrogen application are essentially the same. However, in general, particularly with lower carryover and/or higher output prices, the net returns maximizing level of nitrogen application will exceed the nutrient balance level of application.

Conclusions.

This paper uses a van Keulen fertilizer response model to provide a framework for empirically integrating economic, agronomic and environmental considerations into fertilizer application decisions. This methodology explicitly separates the managerial fertilizer application process from the biological uptake process. This separation focuses attention on fertilizer management (e.g. rate, timing, placement, form) as a means of maintaining yields while reducing fertilizer application, provides a first-order approximation of potential fertilizer loss and allows for more indepth analysis of the economics and environmental impacts of fertilizer application. The van Keulen approach was applied to an analysis of nitrogen fertilization of corn in the Coastal Plains region of North Florida.

The results suggest that the previous emphasis in the literature on "optimal carryover rates" and "fertilizing the soil" are inconsistent with both economic and environmental goals. From an environmental perspective, the optimal carryover of applied fertilizer from one season to the next is clearly zero since residual nitrogen can potentially leach into groundwater or runoff into surface waters. Likewise, from an economic perspective, carryover fertilizer or "money in the bank" in essence has a negative interest rate. Furthermore, modern soil testing and tissue testing techniques allow farmers to determine the crop's fertilizer needs at or after planting and fertilizer can be applied in readily available forms. Thus, by waiting the farmer can determine the crop's fertilizer needs and determine the optimal level of fertilizer to apply based on current crop conditions and price expectations. In essence, the focus shifts to "fertilizing the plant" rather than "the soil" and application decisions are based on up-to-date information.

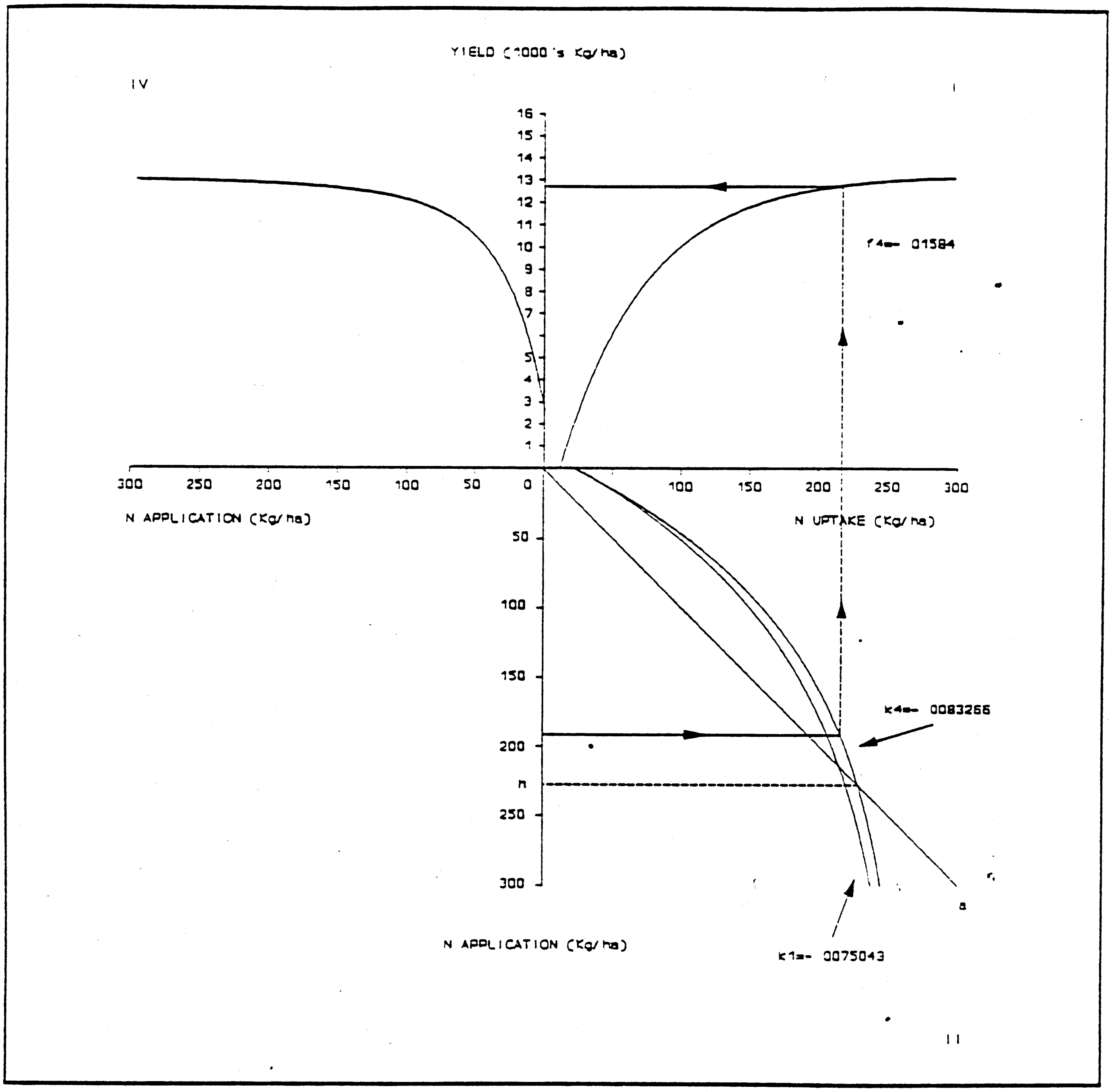

Figure 1. Van Keulen diagram for irrigated corn grown on soil with initial elemental nitrogen content of 20ppm.

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