LONG-TERM PROFITABILITY OF ANIMAL MANURE USING OPTIMAL NITROGEN APPLICATION RATE

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Abstracts: Dynamic optimization compared the NPV of manure and ammonium fertilizers on irrigated corn. Yield, soil residual nitrogen and pH functions were estimated from a six year experiment in Oklahoma. Results show that given prices of corn and nitrogen fertilizer, animal manures provide a higher NPV of return than ammonia fertilizer.

Key words: Animal Manure, Carryover, Optimal Application Rate

Introduction: There has been a significant increase in the production of livestock like swine and beef cattle from concentrated animal feeding operations (CAFOs) in the United States over the last two decades. As the structure of animal production is transforming to larger operations, the continuous localized accumulation and distribution of animal manure generated in the large CAFOs has been an important issue among interested parties such as farmers, animal operators, and regulatory agencies. For example, Innes (2000) argues that more than 25 percent of U.S surface contamination associated with agricultural activities was attributed to livestock by the U.S. Environmental Protection Agency (EPA).

Despite the large potential economic benefit of manure as a substitute for commercial fertilizer, manure can not only degrade the quality of our water, soil, and air resource but also can impose additional handling costs on farmers. Unlike commercial fertilizer, all nutrients in animal manure are not available for plant uptake due to insolubility of nutrients and the nitrogen content in the manure applied to the land is largely affected by not only the method of storage and application but also the timing of land disposal (Zhang, 2003). Furthermore, the ratios of nitrogen, phosphorous, and potassium in manure do not match the relative quantities required by plants, so there is a tendency for nutrients like phosphorous to be built up in the soil. In addition, much swine manure is collected, stored and applied as a liquid where most of the nitrogen is in the ammonium form. Thus, a significant portion of manure nitrogen has the potential to be lost to the atmosphere via volatilization during manure handling. Three environmental problems associated with animal manure are commonly discussed; potential phosphorous accumulation in the soil, nitrogen leaching from the soil, and nitrogen volatilization as ammonia (Carreira, 2004).

Previous studies on animal manure have mainly focused on the management decisions aimed to meet environmental regulations or use of animal manure as a substitute for commercial fertilizer. Nunez and McCann (2004) found that the awareness of other farmers using manure, off-farm income, location, transportation costs and the smell make a significant effect on farmers' willingness to use manure in the model. Norwood et al. (2005) estimated the average willingness to pay for dry manure by crop producers was $8.37 per ton when the value of fertilizer saved was $15 and $11.28 per ton when the value of fertilizer saved was $ 25 per acre. Carreira (2004) also compared the profitability of two irrigation systems (surface drip and center pivot sprinkler) using swine effluents with simulated EPIC data.

This paper estimates crop response and nutrient carryover functions for each source of fertilizer using multi-year experimental soil data with yield. Second, optimal steady state application rates for each source of fertilizer were examined in the optimization method in terms of relative profitability of animal manure. This paper provides an economic analysis of long-term data from an Oklahoma Panhandle research project involving applications of anhydrous ammonia, beef manure, and swine effluent to irrigated corn. The results compare the optimal management of nitrogen from anhydrous ammonia, beef manure, and swine effluent to maximize farmers' net income.

Model: We assume the farmer will maximize the net present value (NPV) of returns from irrigated continuous corn over some future period by applying nitrogen from either anhydrous ammonia (AA), beef manure (BM), or swine effluent (SE). Further assume total available nitrogen (TAN) to corn at a time is the sum of applied nitrogen and soil nitrate-nitrogen in the top 48 inches of the soil profile at the beginning of the crop year. Carryover functions are also estimated to describe the carryover of both residual nitrogen and soil pH to the next period. Fourth assume the prices of corn and other inputs are known over the planning horizon. Finally, once the corn response and carryover functions for each nitrogen fertilizer are known, a farmer can control the level of TAN by selecting the level of applied nitrogen and finally make a decision as to which source of nitrogen is the most profitable. Thus, with the presence of the nitrogen and soil pH carryover effect, the dynamic optimization is a useful approach to determine the optimal nitrogen application rules (Kennedy 1986, Thomas 2003).

Animal manure as a nitrogen fertilizer is different from a commercial fertilizer in that organic nitrogen in the manure must mineralize before it is available to plants. Secondly animal manure is a mixed fertilizer which contains several nutrients among which nitrogen and phosphorous are the most important. One concern with the use of animal manure is its nitrogen content. The decision problem for a farmer choosing a nitrogen fertilizer to get the highest NPV per hectare over a planning horizon can be written as:

$$
\begin{aligned}
(1)\quad & \max_{s,\ NA_t^s} NPV = \sum_{t=1}^{T} \delta^{t-1} \mathrm{E}(p \cdot \mathrm{Y}_t^s - r_s \cdot NA_t^s - TVC) \\
\text{s.t}\quad & Y_t^s = Y_t^s(TAN_t^s, pH_t^s), \\
& TAN_t^s = NA_t^s + SN_t^s, \\
& SN_{t+1}^s = g_t^s(NA_t^s,\ SN_t^s), \\
& pH_{t+1}^s = q_t^s(pH_t^s,\ NA_t^s), \\
& NA_t^s,\ SN_t^s,\ TAN_t^s \geq 0 \text{ for all } t, \\
& s{=}1 \textit{ for AA, 2 for BM and 3 for SE,}
\end{aligned}
$$

where *s* is the choice of nitrogen fertilizer, NPV is the present value of returns (\$ ha^{-1}) from corn production over the period, t is the year of the planning horizon, p is the price of corn (\$ kg^{-1}), r_s is the price (\$ kg^{-1}) of type *s* nitrogen fertilizer, Y_t^s is the corn yield function with respect to TAN and soil pH level under type *s* nitrogen fertilizer, TVC is total variable cost (\$ ha^{-1}) of all inputs except fertilizer, NA_t^s is the amount (kg ha^{-1}) of type *s* nitrogen fertilizer in year t, SN_t^s is the soil nitrate-nitrogen level (kg ha^{-1}) in year t under type s nitrogen fertilizer, $g_t^s(\cdot)$ and $q_t^s(\cdot)$ are a nitrogen and soil pH carryover function, respectively, under type s nitrogen fertilizer in year t, and δ is the discount factor.

The functional form for corn yield is assumed to be a quadratic function (see Table 1) of TAN with a random year effect, thus

$$(2)\quad Y_{it}^s = \alpha^s + \beta^s TAN_{it}^s + \rho^s (TAN_{it}^s)^2 + \kappa^s pH_{it}^s + u_t^s + \varepsilon_{it}^s$$

where Y_{it}^s is a corn yield i th observation at year t, α^s, β^s, ρ^s and κ^s are the parameters to be estimated, TAN_{it}^s is the total available nitrogen of i th observation in year t, pH_{it}^s is the soil pH level of i th observation at year t, u_t^s is random year effects, $u_t^s \sim N\left(0,\ \sigma_{u^s}^2\right)$, and ε_{it}^s is an error term, $\varepsilon_{it}^s \sim N\left(0,\ \sigma_{\varepsilon^s}^2\right)$.

The nitrogen carry-over function is defined as

$$(3)\quad SN_{i\,t+1}^{\,s} = \gamma^s + \phi^s (NA_{it}^s + SN_{it}^s) + \varphi_{i\,t+1}^s$$

$$\text{s.t.}\qquad \varphi_{i\ t+1}^s \sim N(0,\sigma_{\varphi^s}^2),$$

where γ^s, ϕ^s, π^s, and μ^s are parameters to be estimated, and $\varphi_{i\,t+1}^s$ is an error term. Stoecker and Onken (1989) showed that the effect of soil nitrogen on yield is statistically different from that of applied nitrogen. However, in this study soil nitrogen is based on measurements to the top 6 inches in depth and TAN is used because of the multicollinearity between soil nitrogen and applied nitrogen.

The soil pH carry-over effect is defined as

$$(4)\quad \ln\left(\frac{pH_{i\,t+1}^s}{pH_{it}^s}\right) = z^s NA_{it}^s + \varpi_{i\,t+1}^s$$

where z^s is a parameter to be estimated, and $\varpi_{i\,t+1}^s$ is an error term, $\varpi_{i\,t+1}^s \sim N\left(0,\ \sigma_{\varpi^s}^2\right)$.

Data: In order to determine long-term profitability of the animal manure relative to a commercial fertilizer, we used the experimental data from the Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, OK (36°35 N, 101°37 W, and elevation 992 m). Mean annual precipitation and temperature at the station are 435 mm and 13.2 °C, respectively. The predominant soil series at this site is a Richfield clay loam (fine, smectitic, mesic, Aridic Argiustoll) on 0-2% slopes.

The experiment has been repeated each year since 1995 using a randomized complete block design with three replicates in order to determine the effects of annual applications of AA, BM, and SE on crop yield and soil properties. Corn (*Zea mays* L.) was planted annually, under conventional tillage methods and was irrigated under a center pivot system using LEPA nozzles. The experimental design called for application of BM, SE, and AA to provide 0, 56, 168, and 504 kg N $ha^{-1}yr^{-1}$; beginning in 1995 and has been repeated annually to the same plots. The 0 N rates were used as a control. AA was soil injected in Feb.-Mar. of each year; while BM was applied and incorporated prior to annual planting, and SE was surface applied at approximately the 6-leaf (V6) growth stage of corn.

Soil samples to a depth of 48 inches were obtained in the spring of each year prior to treatment application from 4.6 m by 9 m treatment plots. The animal waste samples were collected and stored at 4˚C until analysis was preformed. Swine effluent samples were collected from a commercial nursery lagoon and BM used was obtained from a feedlot; the same facilities were used each year for BM and SE, respectfully. The annual quantities of beef manure applied were 4, 12, 27 Mg ha^{-1} for 56, 168 and 504 kg N ha^{-1} respectively. The respective quantities of swine effluent applied were 73, 176, 527 m^3 ha^{-1} for 56, 168, and 504 kg N ha^{-1}.

The experimental data provided the corn yield, soil nitrate and phosphorous, and soil pH level over the period. Table 1 shows the mean crop yield at different application rates. The corn yield increased with the intended N application rate until 168 kg ha^{-1} but decreased when the intended application rate reached 504 kg ha^{-1}. Soil residual nitrogen and phosphorous levels are found in Figure 1. The phosphorus accumulation in plots treated with manure is noticed although phosphorous is not considered in this study because it is not significant in the yield, where the average soil phosphate level in the BM plots has increased from about 102 kg ha^{-1} in 1995 to about 400 kg ha^{-1} in 2003.

Changes in the soil pH level over the period are shown in Figure 2. For the AA plots, the soil pH level treated with the low application rates (56 and 168 kg ha^{-1}) remained nearly constant while the soil pH level with the high rate (504 kg ha^{-1}) decreased from 7.8 to 6.6 over the experimental period. The soil pH level under BM and SE plots remained constant over the same period regardless of the nitrogen application rates.

However, the actual amount of nitrogen applied fluctuated considerably from the intended amount as shown in Table 2. The eight year average in Table 2 shows the actual application rate of nitrogen in the BM treatment plots was higher while actual nitrogen application rates in the SE treatment plots were less than the intended rate. The actual N values were used in the analysis.

Six years of production data were available to estimate the corn response function for each fertilizer treatment, but the year 2000 yield data was eliminated because of significant hail damage. The average market price from 1996 to 2005 (NASS, 2006) of corn in Oklahoma was

\$0.09 kg^{-1}. The average national price of AA for the same period was \$0.30 kg^{-1} (ERS, 2006). The cost of nitrogen in beef manure derived from custom hauling rates assuming 5.4 kilogram of available nitrogen per ton was \$0.26 kg^{-1} (Wiederholt, 2005). The market value of nitrogen in the swine effluent is assumed to be \$0.15 kg^{-1} (Carreira). TVC, operating costs for all variable inputs other than fertilizer (corn seed, pesticide, crop insurance, labor, fuel, etc), were assumed to be \$282.42 ha^{-1} (OSU Enterprise Budget). Finally, the manure sampling cost (\$30 ha^{-1}) incurs every year assuming that the hydrometer method is adopted (Baker, 1996).

Estimation Results: The corn response function to TAN and soil pH for each nitrogen fertilizer was estimated using the PROC NLMIXED in SAS. The statistic method of the estimation was the maximum likelihood method which asymptotically assumes the normal distribution. The functional form used this study is a quadratic with the assumption of no heteroskedasticity. In equation 2, the intercept and coefficient for TAN squared $(TAN_{it}^{s})^{2}$ are expected to be negative while coefficients for TAN (TAN_{it}^{s}) and soil pH level (pH_{it}^{s}) are expected to be positive. The sign of the coefficient of the squared TAN is expected to be negative to ensure the concavity of a crop response function. The estimated parameters in the crop response function for three nitrogen fertilizers are shown in Tables 3. Figure 3 shows the implied functions for each fertilizer with different levels of TAN.

The likelihood ratio test was employed to test whether an intercept and slopes of the crop response function under BM and SE were different from those under AA. We failed to reject the null hypothesis that the crop response function for BM is equal to that for AA at the ten percent confidence level. However, the null hypothesis that the crop response function for SE is equal to that for AA at the same confidence level. This indicates the intercept and parameters in the SE response function are statistically different from those in the AA response function.

All estimated parameters in the response function for three nitrogen fertilizer functions show the expected signs. Parameter estimates for the intercept, a squared TAN, and soil pH level for all three nitrogen fertilizers were significantly different than zero at five percent significant level. The intercept and coefficients of both a squared TAN and a soil pH level for BM and SE were significantly different from those for the AA function. However, we failed to reject the null hypothesis that a coefficient of TAN for BM and SE was equal to those in the AA function.

The nitrogen carryover function for each fertilizer was also estimated using the maximum likelihood method in the PROC NLMIXED in SAS. The estimated parameters are reported in Tables 4. Positive signs for an intercept and a lag of total available nitrogen were expected in the nitrogen carryover function for all three fertilizers. The likelihood ratio test was used to examine the null hypothesis that the nitrogen carryover function for BM and SE are equal to that for AA. The null hypothesis was rejected at the 5 percent confidence level for both BM and SE. This indicates that the nitrogen carryover with BM and SE was significantly different from nitrogen carryover with AA. Expected signs for variables in the carryover function for three nitrogen fertilizer were obtained and all parameter estimates of the carryover function excluding the intercept for AA were significantly different from zero at the five percent confidence level.

The soil pH carryover function for each fertilizer was estimated using the maximum likelihood method in the PROC MIXED in SAS. The estimated parameters are found in Table 5. The negative sign for lagged applied nitrogen for AA and the positive signs for BM and SE were also expected based on the experimental data (See Figure 2). The likelihood test also showed that the coefficients for lagged applied nitrogen for the manure were significantly different from that for AA at the five percent confidence level. This indicates that the soil pH level is differently affected by the source of nitrogen. Expected signs for the lagged applied nitrogen for all fertilizer were also obtained. Only the coefficient for AA was significant at the five percent confidence level.

Results from the Dynamic Optimization: The annual optimal solutions for application rate, soil residual nitrogen, yield and soil pH level were solved in terms of each source of nitrogen using the Microsoft Excel Solver with additional assumption of a) a twenty-year planning horizon; b) five percent discount rate; c) the same initial level of nitrate-nitrogen residual for all plots (141 kg ha^{-1}); d) no uncertainty regarding nutrients in the manure and e) the same initial soil pH levels for AA, BM, and SE (7.75).

The average optimal values and NPV of a 20-Year Planning Horizon for each fertilizer are reported in Table 6. Given prices of corn ($0.09/kg) and nitrogen fertilizer ($0.30, 0.26, and 0.15 for AA, BM, and SE, respectively), SE generated the highest NPV of return for a 20-year period. AA has the lowest average application rate and yield and BM has the highest application rate. AA has the highest average soil residual nitrogen and SE has the lowest. The lower application rate and yield for AA than expected can be explained by the pH decline due to the continuous application of ammonia fertilizer. Compared to the initial value, the average optimal soil pH for AA declined while that for BM and SE increased. Despite the economic benefits of the manure, higher values of application rates when manure is used could have negative environmental consequences in the long run.

Conclusion: Estimated parameters in the crop response and nitrogen and soil pH carryover function were used in the optimization program to obtain annual optimal solutions for each nitrogen fertilizer. Results showed that the organic nitrogen fertilizer provide higher NPV of return for a 20-year planning horizon than the commercial fertilizer.

However, some caution should be taken in interpreting results. Nitrogen application optimal rules derived here are only applicable to a limited circumstance and should be evaluated on a field-by-field basis in that ; a) the availability of animal manure should be considered due to relatively high hauling costs of manure; b) nutrients values in animal manure are highly affected by forms of manure, kind of ration, manure handling method, and moisture contents; c) the further consideration of the phosphorous accumulation in the field is needed when the decision on the application of manure is made in order to prevent environmental problems like runoff.

More farmers have considered animal manure as a viable alternative to a commercial fertilizer as the price of commercial fertilizer has continued to go up for recent years. Results in this paper support the economic feasibility of animal manure within the dynamic optimization structure but better nutrients management in animal manure is necessary to improve the substitutability of animal manure. Further research is necessary to address three important issues; phosphorous accumulation under the manure application, and uncertainty regarding nutrients in the manure. In addition, it is important to evaluate the effects of both nitrate losses and costs for manure analysis on the profitability of manure relative to commercial fertilizer.

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Table 1. Mean of Corn Yield (kg / ha)

Applied Nitrogen	Source AA	 BM	 SE
0	6,401	5,160	6,292
56	7,393	7,280	7,711
168	7,509	9,412	8,875
504	6,054	7,413	7,851

Table 2. Eight Year Average of Actual Applied Nitrogen with BM and SE (kg/ha/year)

Intended Rate	Source (Standard errors in brackets) BM	 SE
56	75 (17.86)	47 (18.46)
168	224 (53.65)	141 (55.26)
504	671 (160.95)	423 (166.15)

Table 3. Parameter Estimates of Corn Response Function for Three Nitrogen Fertilizers (kg/ha/year)

	Regression Coefficient Estimates (Standard errors in brackets) AA	 BM	 SE
Intercept (α^s)	-10,516 (6.01)	-12,726 (7.05)	-3,509 (7.43)
TAN (β^s)	4.64 (1.09)	7.33 (1.96)	9.30 (3.10)
TAN Squared (ρ^s)	-0.003 (0.00)	-0.008 (0.00)	-0.015 (0.00)
Soil pH (κ^s)	2,135 (49.62)	2,403 (57.03)	1,304 (61.62)
Variance of a Random Year Effect ($\sigma^2_{u^s}$)	470,836 (0.003)	561,698 (0.0002)	517,439 (0.0004)
Variance of an Error Term ($\sigma^2_{\varepsilon^s}$)	1,330,029 (0.01)	1,420,023 (0.02)	1,544,913 (0.04)

Note:all parameters are significant at the 5 % level. *N*=60 for AA, BM, and SE, respectively.

Table 4. Parameter Estimates of Soil Nitrogen Carryover Function for Three Nitrogen Fertilizers (kg/ha/year)

	Regression Coefficient Estimates (Standard errors in brackets)		
	AA	BM	SE
Intercept (γ^s)	44.84	48.66[a]	43.98[a]
	(41.63)	(8.78)	(8.49)
Lag of TAN (ϕ^s)	0.28[a]	0.034[a]	0.04[a]
	(0.05)	(0.01)	(0.01)
Variance of an Error Term ($\sigma^2_{\varphi^s}$)	56,519[a]	1,830[a]	1,478[a]
	(10,179)	(374)	(302)

[a] denotes significance at the 5 % level. *N*=60, 48, and 48 for AA, BM, and SE, respectively

Table 5. Parameter Estimates of Soil pH Carryover Function for Three Nitrogen Fertilizers

	Regression Coefficient Estimates (Standard errors in brackets)		
	AA	BM	SE
Lag of Applied Nitrogen (z^s)	-0.00004[a]	0.000003	0.000011
	(0.00002)	(0.00001)	(0.00001)

[a] denotes significance at the 5 % level. *N*=12 for AA, BM, and SE, respectively

Table 6. Average of Optimal Application Rate, Soil Residual Nitrogen ,Yield, and Soil pH for the 20 Periods, and NPV of a 20-Year Planning Horizon for Three Nitrogen Fertilizers

	Source		
	AA	BM	SE
Application Rate (kg/ha/year)	110	232	227
Soil Residual Nitrogen kg/ha)	74	63	60
Yield (kg/ha/year)	6,441	7,500	8,304
Soil pH	7.6	7.8	8.9
NPV of a 20- year Planning Horizon ($/ha)	3,609	3,751	4,949

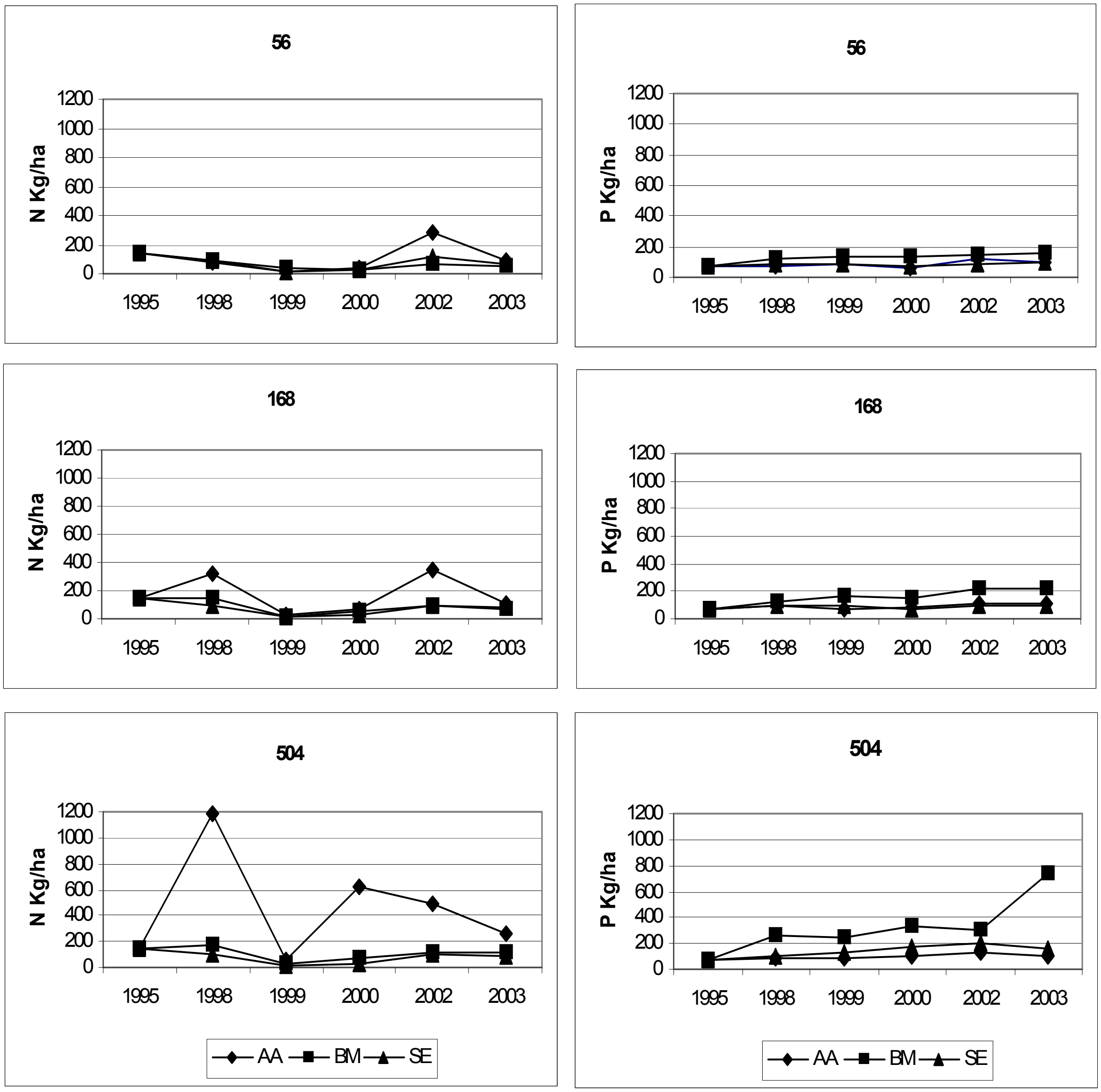


Figure 1. Soil Residual Nitrogen and Phosphorous Level of Top 6 inch over the Experimental Periods at the Different Nitrogen Application Rates

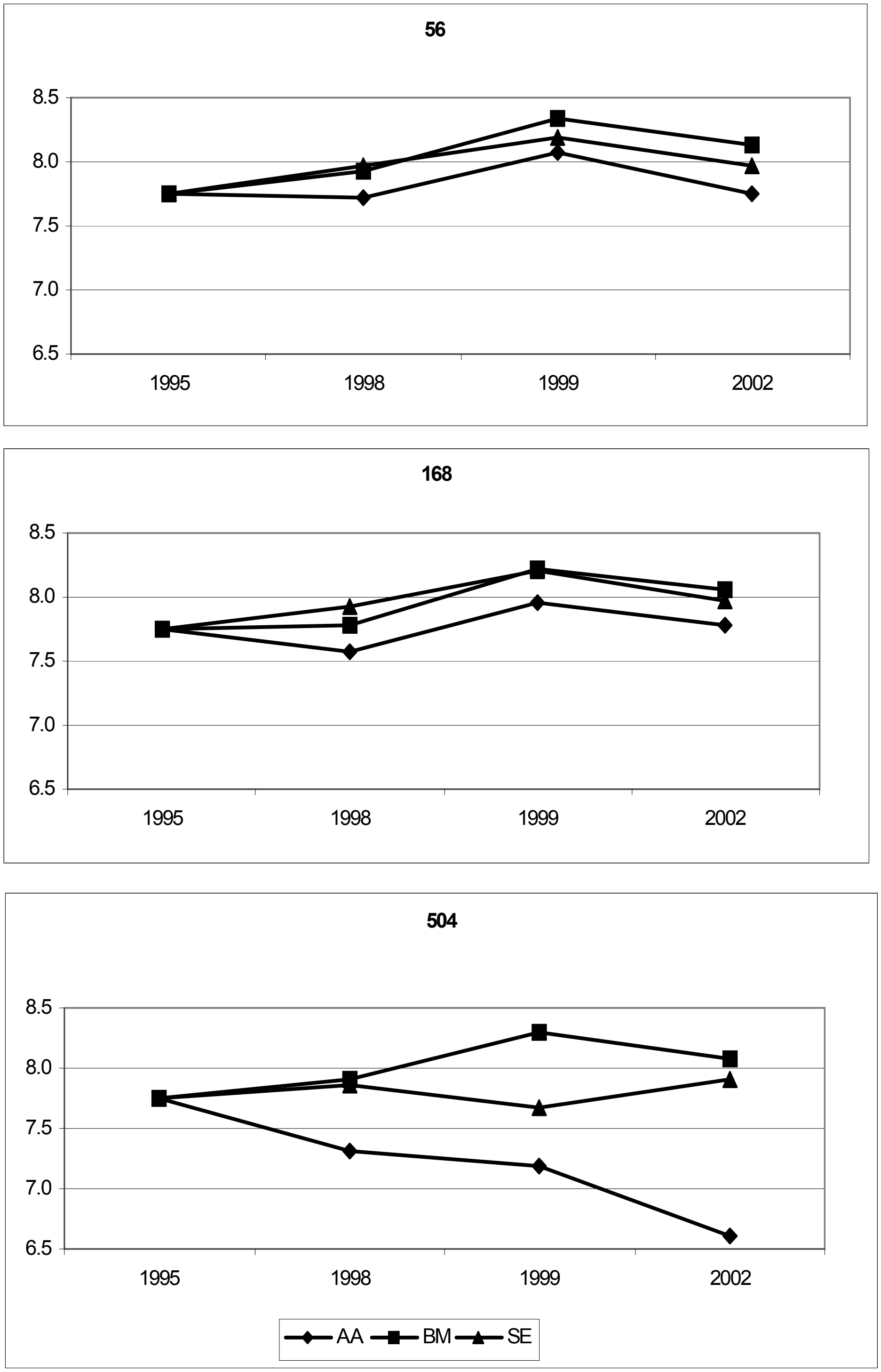
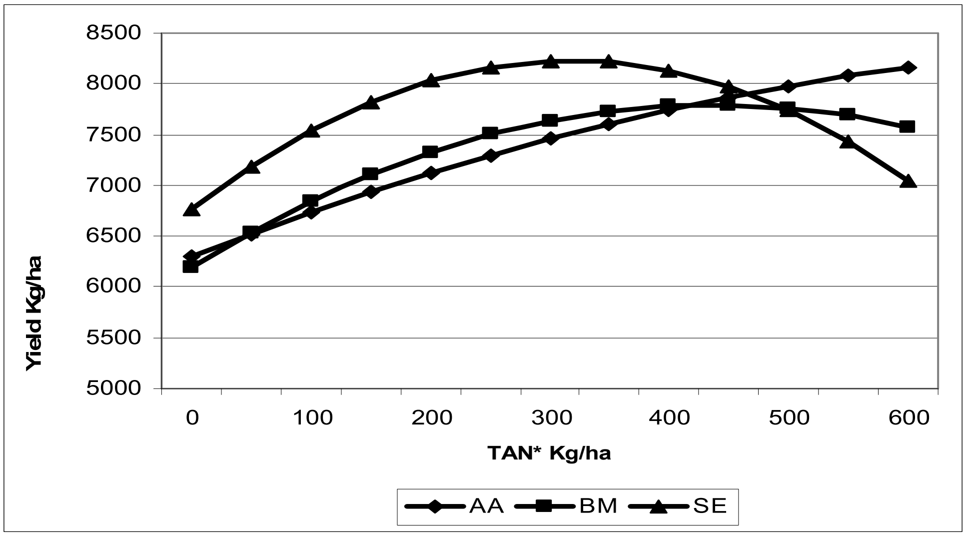


Figure 2. Soil pH Level of Top 6 inch over the Experimental Periods at the Different Nitrogen Application Rates



* denotes total available nitrogen.

Figure 3. Implied Crop Response Functions for Three Fertilizers with a Different Total Available Nitrogen at 7.86 Soil pH level