Benefits of Reducing Nutrient Variation in Fertilizer Mixes

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Abstract: *This article examines nutrient deficiencies (below guaranteed levels) in major blended commercial fertilizers and their economic impact on net revenues of Texas farmers. Violations by fertilizer manufacturers in meeting specific labeled nutrient levels were more than offset in economic value by excesses in other nutrients and by production of blends that contained more than the required levels of all nutrients. The study concluded that economic losses to Texas farmers would likely be associated with requiring nutrient levels to be more tightly distributed around the guaranteed or labeled nutrient levels.*

Key Words and Phrases: *Benefits, Distribution, Fertilizer, Nutrient deficiencies.*

Fertilizer is produced either by chemically combining various elements (referred to as homogeneous blend) or physically mixing certain chemical blends to obtain a fertilizer with a different set of element (nutrient) percentages. The resulting nutrient proportions in individual samples of the homogeneous blends are generally equal to the proportions of elements or nutrients used in creating the fertilizer; thus, there is negligible error from mixing, settling and spreading (Wells *et al.*; Karnok). Conversely, the proportions of nutrients in the physically-mixed fertilizers ("blended" fertilizers) are subject to variation in the proportions of ingredient elements due to particle segregation, especially when particle sizes differ (Hoffmeister; Karnok). This variation has been attributed primarily to the inability of current blending and spreading technology to distribute the elements evenly.

This variation in fertilizer composition could have direct economic implications for the farmer since nutrient levels can occasionally vary more than 50 percent from guaranteed (required) levels. Fertilizer often significantly influences yield, so there may be induced variation in levels of crop production. Gross receipts are subsequently affected. Furthermore, if the fertilizer producer "skimps" on the quantities of the ingredient elements vis-a-vis the guaranteed levels, the likelihood of obtaining a deficient blend increases. Moderate impacts upon net revenue of individual farms may have significant aggregate effects.

New technology is now available to reduce the segregation problem in the blended fertilizers. Regulations in several states, including Texas, have been proposed to require fertilizer plants to reduce sample variation in nutrient composition. However, implementation of the new technology to reduce sample variation would require substantial capital outlays for some plants.

This study was conducted in response to regulatory concerns about the economic effects on farmers from wide variations in nutrient composition of some blended fertilizers. Its purpose is to estimate the value of the new technology to fertilizer users. Specific objectives are to: 1) examine the variation in Texas net farm income due to using bulk fertilizer blends which are subject to particle segregation, 2) estimate the value of the new technology to farmers from reducing the total variation in nutrient composition of selected fertilizer blends, and 3) estimate the distribution of net returns under alternative levels of variation in nutrient levels.

The remainder of this paper is organized as follows. The methods used to conduct the analysis are identified first. They are followed, in turn, by a discussion of the data, empirical results and conclusions.

Method of Analysis

Economic returns from agricultural production decisions are highly uncertain. The uncertainty is due not only to variations in nutrient composition of blended fertilizers used, but also to variations in crop response to fertilizer (caused in large part by random and unpredictable weather) and to uncertainties in market crop prices when most inputs are committed to production. Because of these uncertainties, our analysis examines changes that reductions in fertilizer nutrient variation have on the distribution of net farm income rather than just mean net farm income.

To accomplish the objectives of the study, the most commonly purchased bulk blends and their respective sales regions in the state are identified. Production response equations to fertilizer nutrients are acquired or estimated for each major crop in six Texas regions. Parameters of probability density functions that describe crop prices and nutrient compositions in bulk blends are estimated. Representative net revenue distributions are computed for major crops in each region. The regional crop net revenue distributions are aggregated to obtain estimates of the distribution of aggregate statewide net income and its sensitivity to variation in fertilizer nutrient composition.

To account for different agroclimatic conditions among the heterogeneous regions and for different nutrient responses by individual crops under such conditions, we first conduct the analysis for each major crop and region and then aggregate the results to derive statewide inferences. The reader is cautioned that to do so requires that one work with very thin data series for some crops and districts. An alternative would be to conduct the entire analysis using state-level data. Although some individual relationships estimated as part of this analysis may be suspect because of data limitations, it is our judgment that the overall inferences are likely to be more reliable than that from the alternative approach that ignores geographic variation.

Aggregate Net Farm Income. The aggregate net farm income (*NR*) associated with the use of fertilizer blends is described as:

$$NR = \sum_i \sum_j A_{ij}[PC_{ij} g^{ij}(N_{ij}, P_{ij}, K_{ij}) - TC_{ij}], \tag{1}$$

where A_{ij} is the total acreage devoted to crop i in region j; PC_{ij} denotes the unit price of the i^{th} crop in the j^{th} region; $g^{ij}(N_{ij}, P_{ij}, K_{ij})$ is the i^{th} crop's respective production response (estimated yield) for the j^{th} region to the nutrient levels of Nitrogen (N_{ij}), phosphorus (P_{ij}), and potassium (K_{ij}); and TC_{ij} represents the total cost per acre (assumed to be locally constant in the relevant range of production) for the i^{th} crop in the j^{th} region (Texas Agricultural Extension Service). The nutrient N_{ij} was computed as:

$$N_{ij} = \sum_k Prop_{jk} N_{ijk}, \tag{2}$$

where $Prop_{jk}$ is the proportion of the k^{th} blend to the total usage of the various blends for region j ($\sum_k Prop_{jk} = 1$), and the summation extends over all blend indices. The nutrients P_{ij} and K_{ij} are computed analogously. The quantities N_{ijk}, P_{ijk} and K_{ijk} were determined by using the quantity of the blend that satisfies the minimum requirement of nitrogen as provided by the Extension Service crop budgets. To maintain generality, government subsidies were not included in the analysis.

Monte Carlo Analysis. A Monte Carlo analysis of statewide net returns was conducted, with nutrient levels and crop prices drawn randomly. The purpose of the analysis was to provide an economic basis for evaluating benefits to farmers from regulations requiring fertilizer manufacturers to reduce variation in fertilizer mixes. These regulations would necessitate use of new technology. To accomplish this objective, the distributions of crop prices and nutrient levels must be described.

Because inferences from this study were to be based on several aspects of the statistical distribution of aggregate net returns rather than on the mean value only, it was necessary to assess this distribution. In principle, once the distributions of each of the prices and nutrient levels are identified, the analytical (or exact) distribution of the net returns (being a function of prices and nutrient levels) can be obtained by convolution methods (Mood, Graybill and Boes). However, because the aggregate net return is a complex function of prices and nutrient levels, Monte Carlo methods were used instead to assess this distribution.

Although the Monte Carlo approach has many uses and forms, a single Monte Carlo iteration in the context of this study involved randomly generating for each i, j, a crop price (PC) and also for each k, a realization of nutrients N, P and K. Each of these four random variables was generated from its own distribution using methods discussed in Kennedy and Gentle. Then the corresponding value for aggregate net returns was computed as given in (1). Repeating such iterations many times produces many values of aggregate net returns (representing a set of randomly generated values from the statistical distribution on net returns). From these values, the desired statistics (e.g., minimum, maximum, median, mean, and standard deviation) can be computed. As the number of Monte Carlo iterations increases, these statistics tend to converge to the actual parameters, or functions of parameters, that are being estimated. Thus, the Monte Carlo approach can be seen as a practical alternative to obtaining the exact distribution on aggregate net returns. Because of the mathematical convenience of this method and the availability of inexpensive computing power, the Monte Carlo approach has been widely used in all scientific and engineering disciplines in lieu of more complex analytical methods.

For simplicity, it was assumed that prices of each crop are described by the triangular probability density function,

$$f(PC) = \begin{cases} 2(PC-L)/(H-L)(M-L), & if \;\; L<PC\leq M, \\ 2(H-PC)/(H-L)(H-M), & if \;\; M<PC<H, \end{cases} \tag{3}$$

where L is the lowest, M is the most likely (mode) and H is the highest observed prices attained by the random price variable, PC. The parameters L and H were specified as the minimum and maximum values, respectively, of the crop's sample price series. The sample mode was used as an estimate for M (Kennedy and Gentle).

The nutrient level for the k^{th} blend in the j^{th} region was assumed to be distributed as Gaussian normal, $N(\mu_{jk}, \sigma_{jk}^2)$. The sample means and variances of the nutrients for each blend and region were used as estimates of the respective means and variances (Box and Muller).[1] In those activities involving use of chemical blends, the random nutrients from the blended fertilizers were added to the deterministic quantities associated with the other fertilization methods in order to obtain total nutrient levels. Also, in cases in which no blend data were available, the means were set to the guaranteed levels.

One hundred random deviates of net revenue were generated and sample means and standard deviations were tabulated. An empirical distribution function was then obtained. These sets of information were derived under six alternative assumptions regarding the parameters of the fertilizer distributions. The first alternative was based on the current fertilizer means and standard deviations (described subsequently in the Data section). In the second through sixth alternatives, the means were the guaranteed levels while the standard deviations were 5.0 percent, 2.5 percent, 1.0 percent, 0.5 percent, and 0.25 percent, respectively, of the guaranteed levels. These standard deviations were chosen to represent investigational allowance limits for nutrient composition at two standard deviations below the guaranteed level. Since the nutrient levels are assumed to be distributed normally, the investigational allowance limit represents the 95 percent confidence interval.

Fertilizer Response Functions. Where available, previously estimated fertilizer response functions for the various regions were used in the analysis. The crop response functions in the remaining regions were estimated as part of this study. Experimental data from field plots were used. The data generally included multi-year replications. In most cases in which estimation of response functions was necessary, there were few response data points (in one case only 12). Hence, the nonlinear power function was chosen for the functional form due to its parsimony of parameters and its curvilinear surface. Using this functional form, the observed response, Y_i, was expected to be described as:

$$Y_i = \alpha N_i^{\beta} P_i^{\gamma} K_i^{\delta} + e_i, \qquad (4)$$

where N, P and K are nitrogen, phosphorus and potassium, respectively, the subscript i denotes the i^{th} observation, and the errors, e_i, are normal and independently and identically distributed for all i. All other variables were held constant in each experimental design. The parameter estimates α, β, and γ were obtained via the Davidon-Fletcher-Powell (second-order) nonlinear least-squares algorithm implemented by the SHAZAM statistical package (White). The parameter δ was not estimated because of little variability in K in each sample.

Data

Quantities of the major physically-mixed fertilizers sold in Texas in 1986-1987 are reported in Table 1. Each type of fertilizer is expressed in percentage of nitrogen (or nitrogen compound), phosphorus (or phosphoric compound), and potassium (or potassium compound). Primary usage of these blends occurred in Extension Districts 4, 5, 8, 10, 11 and 14 (see Figure 1). Sample data for each district and blend were obtained from reports of the Office of the Texas State Chemist. The sample means, standard deviations, and the 1986 sales of each blend and proportions of total district usage (on a weight basis) are shown in Table 2a and Table 2b.[2] Attention will be restricted to their use on major crops in each district.

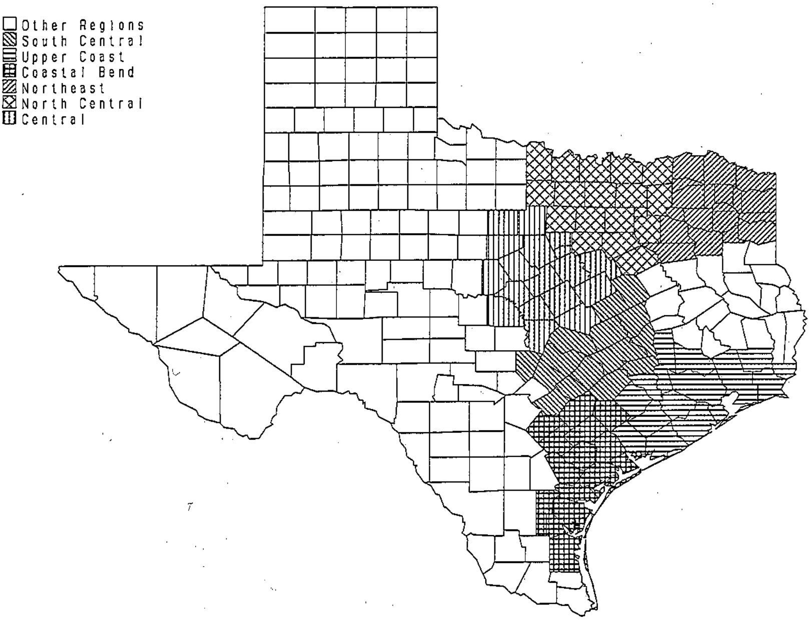
Major crops produced in the six districts and examined in this analysis are corn, wheat, grain sorghum, cotton and rice. Production of these crops in this area in 1986-1987 was 5.1 million acres (Texas Department of Agriculture, 1987a; 1987b).[3]

Table 1.
Fertilizer Blends Examined in Analysis

Fertilizer Type[a]	Quantity Sold in Texas[b]
N-P-K Percent	Tons
10-20-10	14,830
13-13-13	62,431
15-05-10	19,945
15-15-15	25,714
17-17-17	48,991
21-08-17	39,724

[a]Each type of fertilizer is expressed in percentage of nitrogen (N), phosphorus (P), and potassium (K).
[b]Total bulk and packaged.
Source: Office of the Texas State Chemist.

Figure 1.
Texas Agricultural Extension Districts, 1987



For the net returns analysis, eleven years of prices (1975-1985) at a particular selling date and location within the state were inflated to February, 1987, equivalents to remove inflationary effects and to be consistent with other data used. Prices were inflated by means of the producers' price index for total finished goods (U.S. Department of Labor). The maximum, minimum and mode values of each sample price distribution are reported in Table 3.

Fertilizer response functions previously estimated for some of the crops in three districts are reported in Table 4. Reported functions were based upon "typical" levels of input use. Production inputs not listed in Table 4

Table 2a.

Sample Statistics of Different Types of Fertilizer Used in Texas by District, 1986-87

District	Blend 10-20-10 Percent				Blend 13-13-13 Percent				Blend 15-05-15 Percent			
	N	*P*	*K*	Sales	*N*	*P*	*K*	Sales	*N*	*P*	*K*	Sales
	- - - *percentage*[a] - - -			*tons*[b]	- - - *percentage*[a] - - -			*tons*[b]	- - - *percentage*[a] - - -			*tons*[b]
4	9.78 (0.89)	18.91 (1.49)	10.16 (0.93)	3,900 (23.06)	13.01 (0.60)	13.08 (0.60)	12.92 (0.46)	1,932 (11.43)	14.84 (0.86)	5.93 (0.79)	9.85 (1.04)	1,935 (11.44)
5	9.95 (1.02)	18.46 (1.62)	10.23 (1.53)	3,288 (5.89)	12.81 (0.32)	12.73 (0.78)	12.30 (0.99)	6,600 (11.82)	na	na	na	1,186 (2.12)
8	10.27 (1.40)	19.67 (1.38)	9.70 (2.54)	920 (9.07)	13.04 (0.76)	13.07 (0.53)	13.14 (0.97)	3,308 (32.63)	15.29 (0.65)	4.52 (0.66)	8.98 (1.56)	1,059 (10.44)
10	9.98 (1.19)	19.01 (2.19)	10.05 (1.45)	2,432 (10.92)	13.14 (0.68)	12.67 (1.48)	12.54 (1.33)	9,204 (41.29)	14.73 (0.52)	5.51 (1.27)	9.64 (0.06)	826 (3.70)
11	10.18 (0.28)	19.90 (0.32)	11.66 (1.30)	211 (1.57)	12.90 (0.59)	12.87 (1.14)	12.84 (1.15)	9,773 (72.63)	15.33 (0.37)	4.99 (0.63)	9.76 (0.94)	920 (6.38)
14	9.93 (0.29)	20.70 (0.67)	10.71 (1.24)	435 (8.29)	12.87 (0.46)	12.92 (0.83)	12.79 (0.39)	3,946 (75.16)	na	na	na	222 (4.23)

[a] Mean percentage of nutrient composition in a district based on sampling 100-lb. bags, and the standard deviation is shown below in the parenthesis.
[b] Total quantity sold in a district with proportion of district sales shown in the parenthesis.
[c] Not available.

Source: Office of the Texas State Chemist.

Table 2b.

Sample Statistics of Different Types of Fertilizer Used in Texas by District, 1986-87

District	Blend 15-15-15 Percent				Blend 17-17-17 Percent				Blend 21-08-17 Percent			
	N	*P*	*K*	Sales	*N*	*P*	*K*	Sales	*N*	*P*	*K*	Sales
	- - - *percentage*[a] - - -			*tons*[b]	- - - *percentage*[a] - - -			*tons*[b]	- - - *percentage*[a] - - -			*tons*[b]
4	14.98 (0.42)	14.31 (0.32)	14.57 (0.57)	2,858 (16.90)	17.07 (1.00)	17.58 (1.78)	16.22 (1.63)	6,205 (36.70)	na	na	na	79 (0.45)
5	15.28 (1.10)	14.73 (0.77)	13.76 (1.45)	5,656 (10.13)	17.04 (1.41)	17.76 (1.29)	17.14 (1.40)	21,257 (38.10)	20.44 (1.14)	8.79 (0.78)	17.62 (2.01)	17,805 (31.92)
8	14.08 (0.64)	14.86 (2.22)	15.94 (1.75)	3,485 (34.37)	na	na	na	1,367 (13.48)	na	na	na	na
10	14.25 (0.56)	14.74 (1.62)	16.47 (1.95)	1,969 (8.84)	17.27 (0.75)	16.25 (1.02)	17.35 (1.18)	6,460 (28.99)	na	na	na	1,392 (6.24)
11	14.86 (0.53)	13.80 (2.41)	15.39 (1.50)	2,402 (17.84)	na	na	na	152 (1.12)	na	na	na	na
14	na	na	na	290 (5.52)	na	na	na	174 (3.31)	na	na	na	183 (3.48)

[a] Mean percentage of nutrient composition in a district based on sampling 100-lb. bags, and the standard deviation is shown below in the parenthesis.
[b] Total quantity sold in a district with proportion of district sales shown in the parenthesis.
[c] Not available.

Source: Office of the Texas State Chemist.

Table 3.
Parameter Estimates for District Crop Price Distributions

Crop[a]	District	Parameters[b] *L*	*M*	*H*	Market/ Selling Date[c]
Corn	4, 8 & 10	2.65	3.32	5.75	NC/September
	11 & 14	2.68	3.64	5.44	NC/August
Wheat	All	3.59	4.14	6.80	HP/July
Grain Sorghum	4, 5, 8 & 10	1.70	2.91	3.75	DA/October
	11 & 14	1.67	2.88	3.97	CB/September
Cotton	4, 5, 8 & 10	48.45	82.64	102.61	DA/December
	11 & 14	48.97	69.84	103.86	DA/November
Rice	11	8.72	9.36	11.75	HM/August

[a]Corn, wheat, and grain sorghum prices are expressed in \$/bu; price of rice is in \$/cwt; cotton price is in ¢/lb.
[b]*L*, *M*, and *H*, respectively, represent lowest, mode, and highest parameters in the triangular probability density function.
[c]The markets are defined as: north of the Canadian River (NC), Houston Port (HP), Dallas (DA), Coastal Bend (CB), and Houston Mill (HM).

(e.g., labor) were held constant. Data used to estimate additional response functions via (4) came from Experiment Station field trials (Laws; Laws and Simpson; Turner).

Empirical Results

Parameter estimates, descriptive terms, and data sources for the crop fertilizer response functions estimated as part of this study are shown in Table 5. These parameters were estimated using equation 4.

Equation 1 estimates of aggregate net farm revenue in the combined six districts are reported for each alternative in Table 6. In making our estimates we found that each alternative results in negative net farm returns in these districts.[4] Crop prices over the ten-year period were insufficient in many districts to cover all costs of production and provide a competitive return on investment. In the following discussion, an increase in net returns really means a decrease in losses. A decrease in net returns refers to an increase in losses.

Table 4.
District Nitrogen Response Function Coefficients from Other Sources

		Estimated Coefficients[a]		
Crop	District	Constant	N	N^2
Grain Sorghum	5	4,506.35	36.51	-0.17
	11 & 14	2,031.00	22.40	-0.13
Wheat	5	2,287.82	42.08	-0.34
Corn	11 & 14	2,022.00	38.90	-0.23
Cotton	5	1,310.00	0.29	[b]
	11	500.00	0.02	0.05[c]

[a]The coefficients are obtained from the quadratic function: $Y = \theta_0 + \theta_1 N + \theta_2 N^2$, where Y is yield; N is nitrogen; and the θs are the parameters to be estimated. All the variables are measured in lbs./acre. No asymptotic t-statistics are reported because of the small number of observations.

[b]Not estimated due to small variation in sample.

[c]The positive sign on this estimated parameter implies that the marginal product for cotton in District 11 increases as more nitrogen is applied. Although it is unlikely that this finding would be valid over a wide range of nitrogen levels, no arbitrary adjustments were made in this estimated equation for purposes of the analysis.

Source: Personal communications. Parameter estimates for grain sorghum, wheat and cotton in District 5 were obtained from Hons. Estimates for grain sorghum and corn in Districts 11 and 14, and cotton in District 11 were obtained from Matocha.

Focusing first on alternatives 2-6, the sample mean and median net returns remain nearly constant as investigational allowance limits are decreased from 10 percent to 0.5 percent. Negligible increases in annual net farm income from major crops in these regions resulted from decreasing the limits from 10 to 0.5 percent. None of the increases in mean net returns, individually or collectively, is statistically significant at the 5 percent level. In fact, the change in mean net returns among these alternatives is less than 1 sample standard deviation of any alternative. The impact on median net returns is greater but still negligible; the change is significant only when the sample standard deviation for alternative 6 is considered as the reference.

Important changes, however, are noted in the minimum and maximum sample net returns and in the standard deviation. As the investigational allowance limits are reduced, the total dispersion and standard deviation of sample net returns decrease approximately in proportion to the limit.

Table 5.
District Response Function Coefficient Obtained from Estimation

Crop	District	Estimated Coefficients[a] Constant	N	P	R^2
Grain Sorghum	4, 8 & 10	4,318.13	0.0560	0.0089	0.91
Wheat	4, 8 & 10	16.65	0.0323	0.0720	0.96
Cotton	4, 8 & 10	708.93	0.2249	-0.2296[b]	0.94
Rice	11	2,103.78	0.2377	[c]	0.42

[a]The coefficients are obtained from the power function: $Y_i = \alpha N_i^{\beta} P_i^{\gamma} K_i^{\delta}$, where Y is yield; N, P, and K are nitrogen, phosphorus, and potassium, respectively; and α, β, γ, and δ are parameters to be estimated. All the variables are measured in lbs./acre. The parameter δ was not estimated because little variability in K was observed in any sample. No asymptotic t-statistics are reported because of the small number of observations.

[b]The negative sign on this estimated parameter implies that the marginal product of phosphorous for cotton production in these districts is negative. Although unlikely to be valid over a wide range of phosphorous levels, no arbitrary adjustments were made in this estimated equation for the analysis.

[c]Little variation in P was observed in this sample, so the parameter was not estimated.

Source: Parameter estimates for grain sorghum and wheat were obtained from Laws and Simpson. Estimates for cotton were obtained from Laws, and rice from Turner.

Changes in the distribution are substantial and imply that the chance of a very low total net return is less with the lowest limit than with the highest. Just as the dispersion of total net returns to farming in these districts decreases markedly with the investigational allowance, so would the dispersion of net returns to individual farms decrease.

Now we will turn our attention to alternative 1 which is based on the nutrient content and dispersion of an actual sample of fertilizer analyses taken in 1986-1987 rather than on a mean equal to guaranteed level with a specified investigational allowance limit. Two important findings are apparent from these results:

1. The sample mean of net returns in alternative 1 is higher than in any of the other alternatives. This occurs because the weighted sample mean of fertilizer nutrient levels exceeded the guaranteed levels in districts that are major contributors to total crop production.

Table 6.
Statistics for Net Farm Revenue in Six Districts for Alternative Tolerance Limits

		Sample Statistics				
Alternative	Tolerance Limit[a]	Mean	Median	Standard Deviation	Minimum	Maximum
	- % -	*million dollars*				
1	Current	-69.16	-69.19	0.74	-70.88	-67.01
2	10.0	-70.90	-71.01	1.20	-73.30	-68.75
3	5.0	-70.88	-70.90	0.61	-72.06	-69.79
4	2.0	-70.87	-70.89	0.24	-71.34	-70.43
5	1.0	-70.87	-70.88	0.12	-71.10	-70.65
6	0.5	-70.87	-70.87	0.06	-70.98	-70.76

[a]The investigational allowance limit is expressed as 2 standard deviations under each alternative.

2. The standard deviation of net returns is only a little higher than at the 5 percent investigational allowance limit (alternative 3), and the range of net returns is less than at the 10 percent limit (alternative 2).

Since current regulations produce a dispersion statistically similar to that of alternative 3, and if it can be assumed that fertilizer manufacturers will not change the average of fertilizer nutrient content relative to the guaranteed level, the effect of reducing the investigational allowance limit to 1/10 its current level would be similar to the changes noted between alternatives 3 and 6. The mean of total net farm income in these districts would increase about $10,000 annually, and the minimum (2.5 percent) would increase about $1.1 million (as evident from the differences between alternatives 3 and 6). However, if the manufacturers were also to reduce mean fertilizer nutrient content (from the current situation) to the guaranteed level in response to a change in the investigational allowance limit, the mean of total net farm income would decrease $1.7 million with a $100,000 decrease in the minimum level (2.5 percent), i.e., the differences between alternatives 1 and 6.

Conclusions

Based on the available data, we found little support for the assertions that the segregation problem has resulted in consistent shortcomings by the manufacturers in fulfilling the guaranteed nutrient levels in the six blends examined. Although some nutrient shortages have occurred with individual batches, the sample statistics from the blend data and the distribution results indicate that violations were more than offset by excesses in other nutrients and by other samples in which guaranteed levels were exceeded.

A possible solution to the dispersion problem is to tighten the investigational allowance limits as reflected between alternatives 3 and 6, wherein the maximum deviations from guarantee change from 5 percent to 0.5 percent of guarantee. The violating firms would be required to adopt new blending technologies that would mitigate the particle segregation problem. However, consistent with findings from recent agronomic studies (e.g., Wells *et al.*), the potential gain to farmers appears small. It is particularly small in comparison to the possible farm loss if manufacturers were to improve the reliability of the blends and reduce the average nutrient content to the guaranteed level. Even if there were no reduction in average nutrient levels, the potential gains to farmers are so small they would not offset heavy investments in new equipment by fertilizer plants.

An important limitation of this study was the inability to invoke asymptotic (large sample) properties of the fertilizer composition sample statistics. There were less than eight sample points per blend in some districts, and in few districts did the number of sample points exceed 14. Assumptions, such as uniformity of producer production functions, cost structures, and proportion of blends used on individual farms in a district, also limited our ability to accurately interpret the estimates of total net revenues from the analysis. Since agricultural activities such as pasture and hay production and nonagricultural uses of fertilizer were not considered, the analysis underestimates by an unknown amount the total effect of reducing the investigational allowance. However, it is believed that the underestimation is relatively small. Thus, based on this analysis, we do not recommend requiring fertilizer manufacturers to invest in new technology to reduce nutrient variation in fertilizer mixes.

Notes

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1. All variability in nutrients is attributed to the degree of quality control imposed by fertilizer manufacturers rather than imputing some of the variability to sampling and chemical analysis methods. The variability due to sampling and analysis procedures is thought to be small. This assumption causes the blend variabilities reported in this paper to be upper bound estimates of the true variability due to particle segregation.

2. The nutrient data reported in Tables 2a and 2b are based on sampling fertilizer bags, mainly 100 pounds each. Therefore, the analytical results reported in this paper presume that economic relevance to producers is based on variability among bags.

3. Another important crop, hay, was not included in the analysis because a significant portion of its use is as an on-farm feed. Hay's indirect contribution to activities such as beef cattle and dairy production is difficult to estimate.

4. The reader should note that these figures do not include government program payments, which could be sufficient to render positive net returns and enable operations to continue in the long run.

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