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Evaluating the Returns to Variable Rate Nitrogen Application

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ABSTRACT

Potential benefits of variable rate nitrogen application are illustrated and information needs identified. Lower costs of precision farming services, higher crop prices, and greater divergence in yield response potentials across management zones reduce the spatial variability required for profitable variable rate application. Information needs include identification and measurement of management zones within a field and estimation of management zone yield response functions, crop and input prices, and the cost of precision farming services.

Key Words: *production economics, management zones, nitrogen, precision farming, spatial break-even variability proportions, spatial variability, variable rate application, yield response variability.*

Farmers in recent years have been applying inputs as if their fields were uniform in yield potential (National Research Council; Swinton and Lowenberg-DeBoer). Research has shown that agricultural fields are typically heterogenous with regard to the factors that determine crop growth (Carr *et al.*; Hannah, Harlan, and Lewis; Hibbard *et al.*; Malzer *et al.*; Sawyer; Spratt and McIver). Precision farming technologies provide farmers with the benefits of site-specific management, while giving them the advantages of mechanization (Swinton and Lowenberg-DeBoer). Some precision farming technologies produce site-specific information about a field, allowing farmers to separate it into smaller units or management zones, each of which is more uniform than the whole in potential yield response to a particular input. Farmers and agribusiness firms then can use other precision farming technologies and the management-zone information to prescribe and apply appropriate amounts of inputs to each management zone (National Research Council; Roberts, Kemper, and Christensen).

Precision farming has several potential economic benefits (Kitchen *et al.*; Koo and Williams; Sawyer; Swinton and Lowenberg-DeBoer; Watkins, Lu, and Huang; National Research Council; Roberts, Kemper, and Christensen). It can increase revenues by increasing crop yields above the yields achieved with a uniform level of input application. For example, precision application of fertilizer according to yield response potential across management zones can produce higher average yields than if a uniform rate were applied to all management zones. Precision farming also can reduce costs of production by reducing the level of input required to achieve a

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given yield. For example, precision placement of herbicides on weed-infested areas of a field may require less herbicide than if the label rate were applied uniformly across the entire field. Furthermore, precision farming can improve the management capabilities of farmers by giving them increased knowledge with which to make more informed management decisions about their fields. More informed decisions can provide increased net returns by helping farmers take advantage of more profitable alternatives.

The net economic benefit a farmer receives from variable rate input application is determined by variability in the factors within a field that influence crop yield (English, Roberts, and Mahajanashetti; Forcella; Hayes, Overton, and Price; Snyder). Two variability factors influence the economic viability of precision farming for a particular field. The first is the degree of spatial variability within the field, or the proportions of the field in each management zone, and the second is yield response variability among the management zones. If a field varied greatly among management zones with regard to yield response but one management zone encompassed almost all of the field, variable rate input application would be unprofitable. Similarly, if several management zones encompassed significant portions of the field but yield response to the input varied little across management zones, variable rate input application also would be unprofitable (English, Roberts, and Mahajanashetti).

Numerous private crop consulting firms and local cooperatives currently offer variable rate fertilizer application services to farmers for a fee (Lowenberg-DeBoer and Swinton; Swinton and Ahmad). The question of interest is whether the potential increase in revenue is sufficient to cover the cost of hiring those services. The objectives of this research were 1) to illustrate the potential economic benefits of using variable rate nitrogen services compared with the cost of hiring those services and 2) to illustrate the impacts of changes in input and output prices, field spatial variability, and yield response variability on potential net returns and potential use of custom-hired precision farming services. These objective are addressed by considering a theoretical model and a hypothetical case where fields consist of only two land types.

Theoretical Model

Assume that only two land types with different corn yield response functions for nitrogen fertilization exist in a particular geographic area and these land types define the management zones within a field. Further assume that fields contain these two land types in any proportion and fields with different land proportions are distributed uniformly across the geographic area. Let L and 1 − L represent the proportions of a field in low- and high-yield response lands, respectively. Low- and high-yield response lands are characterized by the yield response functions given in (1) and (2).

$$(1) \quad Y_l = Y_l(N_l)$$

$$(2) \quad Y_h = Y_h(N_h)$$

where Y is corn yield in bushels per acre, N is fertilizer nitrogen in pounds per acre, and l and h indicate low and high-yield response lands, respectively. Equations (1) and (2) are assumed to be concave.

Furthermore, let the field average yield response function be

$$(3) \quad Y_u = L[Y_l(N_u)] + (1 - L)[Y_h(N_u)]$$

where Y_u is a weighted average of the low- and high-yield response functions, with the weights being the proportions of the field in low- and high-yield response lands. For this function, nitrogen is applied to both the low- and high-yield response lands at the uniform rate of N_u.

Further, assume farmers in this geographic area are profit maximizers with knowledge of the yield response functions in (1), (2), and (3). Farmers using uniform rate technology will choose the uniform rate of nitrogen (N_u^*) that maximizes (4).

$$(4) \quad \pi_u = P_Y Y_u - P_N N_u$$

where π_u is the return above nitrogen cost per acre, P_Y is the corn price in dollars per bushels, and P_N is the nitrogen price in dollars per pound. Substituting N_u^* for N_u in (3) and (4) gives the following profit function for uniform rate technology (Nicholson):

$$(5) \quad \pi_u^* = f(L, P_Y, P_N).$$

This profit function relates the optimum return above nitrogen cost to corn and nitrogen prices and the proportion of the field in low-yield response land.

Now assume farmers fertilize using variable rate technology to maximize return above nitrogen cost on each land type. Return above nitrogen cost per acre (π_v) is

$$(6) \quad \pi_v = L[P_Y Y_l(N_l) - P_N N_l] + (1 - L)[P_Y Y_h(N_h) - P_N N_h].$$

The profit function for variable rate technology is determined by substituting the optimum levels of nitrogen for low- and high-yield response lands (N_l^* and N_h^*) into (6) to give

$$(7) \quad \pi_v^* = g(L, P_Y, P_N).$$

Finally, the optimum return to variable rate technology (π_{v-u}^*) is found by taking the difference between the profit function for variable rate technology (7) and the profit function for uniform rate technology (5) giving

$$(8) \quad \pi_{v-u}^* = r(L, P_Y, P_N).$$

For variable rate nitrogen technology to be economically beneficial to farmers, this return to variable rate technology must be greater than the increased cost of variable rate technology compared to uniform rate technology.

Equation (8) likely is concave as illustrated by the following example. If L = 0, the field has no spatial variability because the field is all high-yield response land and $\pi_{v-u}^* = 0$ because π_v^* equals π_u^*. As L becomes positive, π_v^* increases relative to π_u^* because the uniform rate is not the returns-maximizing rate for either land type, while the variable rates are the returns-maximizing rates for each land type. As L continues to increase, eventually π_{v-u}^* increases to a maximum and then declines until it again becomes zero when the field exhibits no spatial variability at L = 1.

Setting (8) equal to the additional cost of variable rate technology (VRC) and solving (9) for L gives the proportion of a field in low-yield response land that makes the return to variable rate technology equal to the added cost of variable rate technology:

$$(9) \quad \pi_{v-u}^* = r(L, P_Y, P_N) = VRC.$$

The concavity of (8) suggests that two levels of L exist for which farmers break even using variable rate technology. These levels of L are called *spatial break-even variability proportions* (SBVPs) (English, Roberts, and Mahajanashetti). They bound the range of L over which $\pi_{v-u}^* \geq VRC$. Farmers with fields having L within this range have an economic incentive to use custom hired variable rate nitrogen technology on their fields.

As the range of L bounded by the SBVPs widens, more fields in this geographic area likely will provide returns to variable rate technology that at least cover the additional cost, causing increased economic incentive to use custom hired variable rate technology in the area. Changes in P_Y and P_N likely will change the use of variable rate technology through their effects on (9) and, consequently, on the SBVPs. Furthermore, geographic areas with different parameters for (1) and (2) will have different SBVPs and farmers in those areas will have different economic incentives to use variable rate technology.

Simple Example

The theoretical model was applied to a simple case of nitrogen applied to a corn field that is assumed to be 50 percent low-yield response land (L = 0.5) and 50 percent high-yield response land. Assume (1) and (2) are quadratic corn yield response functions as follows

$$(10) \quad Y_l = 15 + 0.5N_l - 0.0016N_l^2$$

$$(11) \quad Y_h = 25 + 1.2N_h - 0.003N_h^2.$$

Given these hypothetical concave response

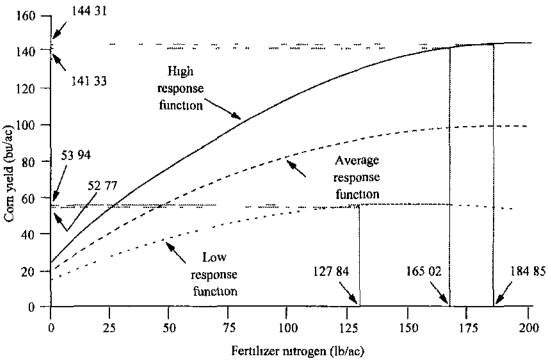

Figure 1. Hypothetical corn yield with 50 percent low-response land

functions, the uniform rate response function is

$$(12)\quad Y_u = 20 + 0.85N_u - 0.0023N_u^2.$$

Returns above nitrogen cost per acre for both uniform and variable rate technologies were determined assuming the 1986–95 average nitrogen and corn prices of \$0.22 per pound of nitrogen (range \$0.17 to \$0.30) and \$2.42 per bushel of corn (range \$1.65 to \$3.50) (Tennessee Department of Agriculture). The additional cost to farmers of using variable rate nitrogen technology was obtained by contacting two farmers' cooperatives in West Tennessee (Names of stores are withheld to prevent disclosure.). Both were asked to provide an estimate of the amount per acre they would charge farmers to create a variable rate nitrogen application map using soil survey maps of the field, a site visit to the field, and discussions with the farmer. Charges for this service were reported between \$0.50 and \$1.00 per acre. Both cooperatives reported a charge for variable rate application of about \$2.00 per acre more than the charge for uniform rate application. Hence, the total additional charge for variable rate services above uniform rate services was between \$2.50 and \$3.00 per acre.

Figure 1 depicts the assumed yield response functions for the two land types and for the field average. For any level of nitrogen, the marginal physical product of the low-yield response land is lower than for the high-yield response land.

Uniform Rate Technology

Assuming uniform rate technology, the rate of nitrogen that maximizes return above nitrogen cost is determined from (12) to be 165 pounds of nitrogen per acre (Figure 1). This rate is applied to both high- and low-yield response lands using uniform rate application technology. With 165 pounds of nitrogen applied, the high-response land yields 141 bushels of corn per acre and the low-response land yields only 54 bushels per acre.

Table 1 presents returns above nitrogen costs per acre for each land type when uniform rate technology is used. Return above nitrogen cost for the high-response land is \$305.71 per acre, while return above nitrogen cost for the low-response land is only \$94.23 per acre.

The typical farmer would probably know that yield and return above nitrogen cost are lower on the low-response land, but without the information attainable through precision farming technology, the extent of the lower yield and return may not be apparent. Low-yield and return on the low-response land would be masked if the farmer used less precise information associated with the field average yield of 98 bushels per acre and the average return above nitrogen cost of \$199.97 per acre.

Variable Rate Technology

Figure 1 shows the amounts of fertilizer nitrogen required to maximize return above nitrogen cost for each land type. The high-response land receives 20 pounds per acre more nitrogen (185) and the low-response land receives 37 pounds per acre less nitrogen (128) than when uniform rate technology is used (165). Yield on the high-response land increases by 3 bushels to 144 bushel per acre, while yield on the low-response land decreases by only 1 bushel to 53 bushels per acre. Yield on the high-response land increases more than yield decreases on the low-response land because of

Table 1. Return Above Nitrogen Costs for High- and Low-yield Response Lands and Field Average Return Above Nitrogen Cost, Yield, and Nitrogen Rate Using Uniform Rate Technology, 50 Percent Low-response Land, 1986–95 Mean Nitrogen and Corn Prices

	Per acre
High-response land	
Gross return	$342.02 = $2.42/bu × 141.33 bu/ac
Nitrogen cost	36.31 = $0.22/lb × 165.02 lb/ac
Return above nitrogen cost	$305.71
Low-response land	
Gross return	$130.54 = $2.42/bu × 53.94 bu/ac
Nitrogen cost	36.31 = $0.22/lb × 165.02 lb/ac
Return above nitrogen cost	$94.23
Field average return above nitrogen cost	$199.97 = ($305.72 + $94.24)/2
Field average yield	97.63 = (141.33 + 53.94)/2
Field average nitrogen use	165.02

differences in the marginal physical products of nitrogen.

Table 2 shows returns above nitrogen costs per acre for the two land classes and for the average of the entire field when variable rate technology is used. Return per acre is $308.56 for the high-response land and $99.58 for the low-response land. Field average yield is now 99 bushels per acre, up one bushel per acre from the uniformly rate situation, and average nitrogen use is now 156 pounds per acre, down 9 pounds per acre from the uniform rate. Average return above nitrogen cost per acre is $204.07, which is $4.10 per acre more than when uniform rate technology is used.

Return to Variable Rate Technology

Referring to equation (8), this $4.10 per acre return to variable rate technology equals the return above nitrogen cost per acre using variable rate technology ($204.07) minus the return above nitrogen cost per acre using uniform rate technology ($199.97). A portion of the return to variable rate technology comes from the one-bushel increase in yield times the price of corn ($2.20 per acre) and another portion comes from the nine-pound-per-acre reduction in nitrogen use times the price of nitrogen ($1.90 per acre). This $4.10 per acre must be greater than the cost of custom hired

Table 2. Return Above Nitrogen Costs for High- and Low-yield Response Lands and Field Average Return Above Nitrogen Cost, Yield, and Nitrogen Rate Using Variable Rate Technology, 50 Percent Low-response Land, 1986–95 Mean Nitrogen and Corn Prices

	Per acre
High-response land	
Gross return	$349.23 = $2.42/bu × 144.31 bu/ac
Nitrogen cost	40.67 = $0.22/lb × 184.85 lb N/ac
Return above nitrogen cost	$308.56
Low-response land	
Gross return	$127.70 = $2.42/bu × 52.77 bu/ac
Nitrogen cost	28.12 = $0.22/lb × 127.84 lb/ac
Return above nitrogen cost	$99.58
Field average return above nitrogen cost	$204.07 = ($308.56 + $99.58)/2
Field Average yield	98.54 = (144.31 + 52.77)/2
Field average nitrogen use	156.35 = (184.85 + 127.84)/2

Table 3. Nitrogen and Corn Price Sensitivity Analysis for 50 Percent Low-response Land

Nitrogen/corn price ratio[a] ($/lb)/($/bu)	Optimal return above nitrogen cost for variable rate technology ($/ac)	Optimal return above nitrogen cost for uniform rate technology ($/ac)	Difference in returns above nitrogen costs ($/ac)
0.17/1.65	37.13	34.16	2.97
0.22/1.65	29.64	23.20	3.44
0.30/1.65	18.41	14.16	4.25
0.17/2.42	113.10	109.42	3.68
0.22/2.42	105.16	101.06	4.10
0.30/2.42	92.97	88.14	4.83
0.17/3.50	246.43	242.82	3.61
0.22/3.50	211.92	206.81	5.11
0.30/3.50	199.09	193.31	5.78

[a] Source *Tennessee Agriculture, 1990–1997* (Tennessee Department of Agriculture)

variable rate nitrogen services for variable rate technology to be economically beneficial to farmers.

The question that now must be addressed by the farmer is whether $4.10 per acre is enough to cover the fee required by firms providing precision farming services. With L equal to 0.5, the farmer of this field would increase net return between $1.10 per acre ($4.10 − $3.00) and $1.60 per acre ($4.10 − $2.50) by contracting for variable rate nitrogen services.

Sensitivity Analysis

The information presented in Table 3 suggests that for this field the return to variable rate technology increases as the price of nitrogen increases and as the price of corn increases. The highest return to variable rate technology of $5.78 per acre occurs when nitrogen and corn prices are both at their 10-year highs, while the lowest return of $2.97 per acre is provided when prices are at their 10-year lows. Thus, if 10-year low prices prevailed and the cost of variable rate nitrogen application were $3.00 per acre, the worst that could happen to the farmer of this field would be to come within $0.03 per acre of breaking even ($2.97 − $3.00). Alternatively, if 10-year high prices prevailed and the cost of variable rate services were $2.50 per acre, the best that could happen would be to increase net return by $3.28 per acre ($5.78 − $2.50).

Table 4 shows the SBVPs for various corn and nitrogen prices and costs of services. The minimum SBVP and the maximum SBVP define the range of L over which hiring variable rate nitrogen services is profitable. For example, if 10-year high prices prevailed ($0.30/$3.50) and the cost of variable rate services were $2.50 per acre, hiring the services would be profitable if the field were within the range of 16 to 91 percent low-response land. For fields in which L lies outside this range, for example L equals 10 or 95 percent, farmers would not find the economic benefit of variable rate technology worth the $2.50-per-acre cost.

With wider ranges in SBVPs, more fields within this geographic area likely would meet the spatial variability requirements for variable rate technology to be profitable. Consequently, farmers would have an economic incentive to increase their acreage under variable rate application contracts. The ranges of the SBVPs presented in Table 4 widen as the cost of variable rate nitrogen services decreases from $3.00 to $2.50 per acre and as the nitrogen price increases. The ranges also widen as the corn price increases, except when the nitrogen price is at its 10-year low. When the nitrogen price is $0.17 per pound and the variable rate application cost is $2.50 per acre, the range of SBVPs widens as the corn price increases from $1.65 per bushel (42) to its mean of $2.42 per bushel (58), but narrows when the

Table 4. Break-Even Percentages of Low-response Land for Various Nitrogen and Corn Price Combinations for Costs of Variable Rate Nitrogen Services of $2.50/ac and $3.00/ac

Nitrogen/corn price ratios ($/lb)/($/bu)	Cost of variable rate nitrogen services					
	$2.50/ac			$3.00/ac		
	Minimum	Maximum	Range[b]	Minimum	Maximum	Range[b]
0.17/1.65	35	77	42	52	64	12
0.22/1.65	29	82	53	38	76	38
0.30/1.65	22	87	65	28	83	55
0.17/2.42	26	84	58	34	79	45
0.22/2.42	23	86	63	29	82	53
0.30/2.42	19	89	70	24	86	62
0.17/3.50	27	83	56	35	78	43
0.22/3.50	18	90	72	22	87	65
0.30/3.50	16	91	75	19	89	70

[a] Source: *Tennessee Agriculture, 1990–1997* (Tennessee Department of Agriculture).
[b] Maximum minus Minimum.

corn price increases to its high of $3.50 per bushel (56). A similar pattern holds when the cost of variable rate application services is $3.00 per acre, except the ranges are narrower.

Table 5 presents sensitivity analysis results for 5-percent increases and decreases in the low-response function parameters, other things constant. Results show that the ranges of SBVPs narrow with increases in the linear parameter (b). For example, when the cost of services is $2.50 per acre and the linear parameter increases from its original level of 0.5 to 0.525, the range of SBVPs narrows from 63 to 44, which is a 30-percent decrease in the range. Alternatively, a decrease in the parameter value to 0.475 widens the range to 73, which is a 16-percent increase in the range. Five-percent increases (decreases) in the qua-

Table 5. Sensitivity Analysis for Break-Even Percentages of Low-response Land When Yield Response Function Parameters for Low-response Land Increase or Decrease by 5 Percent, for Mean Nitrogen and Corn Prices and Costs of Variable Rate Nitrogen Services of $2.50/ac and $3.00/ac

Parameter value[a]	Cost of variable rate nitrogen services					
	$2.50/ac			$3.00/ac		
	Minimum	Maximum	Range[b]	Minimum	Maximum	Range[b]
	Percent					
Linear parameter (b), low-response land						
0.525 (5% increase)	34	78	44	47	67	20
0.5 (original value)	23	86	63	29	82	53
0.475 (5% decrease)	17	90	73	21	88	67
Quadratic parameter (c), low-response land						
0.00168 (5% increase)	17	90	73	21	87	66
0.0016 (original value)	23	86	63	29	82	53
0.00152 (5% decrease)	34	79	45	46	69	23

[a] Nitrogen and corn prices are at their 1986-95 means of $0.22/lb and $2.42/bushel. Other parameters for both low and high-response lands are assumed to be constant at their original levels.
[b] Maximum minus Minimum.

Table 6. Yield Response Function Parameters that Cause Return to Variable Rate Nitrogen Application to Be Less Than or Equal to the Cost of Variable Rate Nitrogen Services Regardless of the Percentage of Low-response Land for High, Mean, and Low Nitrogen and Corn Prices and Costs of Variable Rate Nitrogen Services of $2.50/ac and $3.00/ac

Parameter and price level	Original parameter level	Cost of variable rate nitrogen services			
		$2.50/ac		$3.00/ac	
		Estimate	Percent change	Estimate	Percent change
High-response land b					
Low prices	1.2	1.167	−2.8	1.197	−0.3
Mean prices	1.2	1.122	−6.5	1.147	−4.4
High prices	1.2	1.082	−9.8	1.102	−8.2
High-response land c					
Low prices	0.003	0.00310	3.3	0.00301	0.3
Mean prices	0.003	0.00324	8.0	0.00316	5.3
High prices	0.003	0.00337	12.3	0.00330	10.0
Low-response land b					
Low prices	0.5	0.518	3.6	0.502	0.4
Mean prices	0.5	0.542	8.4	0.528	5.6
High prices	0.5	0.563	12.6	0.552	10.4
Low-response land c					
Low prices	0.0016	0.00154	−3.8	0.00159	−0.6
Mean prices	0.0016	0.00146	−8.8	0.00151	−5.6
High prices	0.0016	0.00140	−12.5	0.00143	−10.6

dratic parameter (c) have similar effects as 5-percent decreases (increases) in the linear parameter (b). Furthermore, changes in the high-response function parameters have opposite effects on the range of SBVPs as changes in the parameters of the low-response function. These results occur because of the way changes in the parameters cause the marginal physical products of nitrogen for the two land types to converge or diverge. The concavity of (8) causes the range of SBVPs to be more sensitive to convergence than to divergence in the marginal physical products of the two response functions. In summary, these results suggest that the larger the divergence of the marginal physical products, the greater the likelihood that variable rate nitrogen technology will be profitable on a particular field. Furthermore, given two geographic areas with similar characteristics, farmers within the area with the more divergent marginal physical products would have more fields falling within the SBVP range, giving them an economic incentive to contract a larger portion of their acreage for variable rate nitrogen services than farmers in the other area with less divergent marginal physical products.

Table 6 contains further sensitivity analysis of the response function parameters. The results show the parameter levels required to make the return to variable rate technology equal to the cost of hiring the services at the optimum L, other things constant. The optimum L, where return to variable rate nitrogen technology is maximized, is around 58 percent. At the parameter levels indicated in Table 6, only one SBVP exists at the optimum L and an L does not exist for which variable rate technology provides a positive net return. Therefore, farmers in this geographic area would have no economic incentive to use variable rate technology regardless of the L in their fields.

The results in Table 6 indicate that the profitability of variable rate technology is more sensitive to changes in the response function parameters when lower nitrogen and corn prices prevail and when the cost of services is higher. For example, when nitrogen and corn prices are at their 10-year lows and the cost of services is $3.00 per acre, the linear parameter for the high-response function would have to decline by only 0.3 percent before a positive net return to variable rate technology would not exist in this geographic area. This result contrasts with a required 9.8-percent reduction in that parameter when prices are at their 10-year highs and the cost of services is $2.50 per acre. At these high prices and this low cost of services, the linear parameter for the low-response function (0.563) would have to be more than 53 percent lower than the original linear parameter for the high-response function (1.2) for variable rate nitrogen technology to be profitable between some range of SBVPs. For low prices and a $3.00-per-acre cost of services, the linear parameter of the low-response function (0.502) would have to be more than 58 percent lower than the linear parameter of the high-response function (1.2). The allowable changes in the response function parameters range from −0.3 percent for the high-response linear parameter assuming low prices and a $3.00-per-acre cost of services to 12.6 percent for the low-response function linear parameter assuming high prices and a $2.50-per-acre cost of services. These results emphasize the sensitivity of the return to variable rate nitrogen technology to differences in the marginal physical products of the yield response functions.

Conclusions

The example in this paper was presented to theoretically demonstrate the potential benefits and costs to farmers of using precision farming services rather than to economically justify their use. The actual benefits can only be determined on a field-by-field basis because they depend on the particular characteristics of each field. Nevertheless, this example has demonstrated that precision farming potentially can help farmers increase returns by increasing average yield and reducing input use. From a theoretical perspective, this example suggests that economic incentives for farmers to use variable rate technology increase (decrease) as prices of both the input and output increase (decrease), as the cost of services decreases (increases), and as the marginal physical products of the two land types diverge (converge). These results were shown to be fairly robust over a 10-year historical range of nitrogen and corn prices and over wide ranges of spatial variability for two land types within a hypothetical geographic area. However, the results were highly sensitive to the amount of yield response variability among management zones, suggesting that the marginal physical product of the low-response land must be substantially lower than the marginal physical product of the high-response land, and that yield response functions must be estimated accurately. Whether these results are robust for a variety of actual field conditions with two or more land types remains a topic for future research.

The example in this paper allows identification of the types of information needed to make informed input application decisions and to fully utilize variable rate application technology in an economically optimal fashion. To employ variable rate input application optimally from an economic standpoint, management zones must be identified and measured, yield-input response functions for these management zones must be estimated, and expected prices for the input and output must be identified. Furthermore, the cost of the variable rate technology must be incorporated into the analysis. Although not addressed explicitly in this analysis, the impacts on the return to variable rate technology emanating from residual or carry-over input levels also should be evaluated.

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