Profitability of Variable Rate Phosphorus in a Two Crop Rotation

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Abstract

The purpose of this study is to examine the profitability of variable rate phosphorus application on rice and soybean production on fields comprised of up to four clay and silt loam soils in Arkansas County, Arkansas. The four chosen soils and Arkansas county represent traditional rice and soybean production areas in the state. Phosphorus (P) was chosen because: 1) farmers have recently been advised of the benefit of P applications on rice as well as soybeans 2) recommended P application rates vary greatly between clay and silt loam soils and across rice and soybeans and 3)the residual effects of P applications in a crop rotation affect the appropriateness of VRT.

A three phase simulation, regression and mathematical optimization analysis was conducted to determine, within a ten year planning horizon: 1) the conditions under which the profitability of variable rate P applications exceeded the profitability of uniform rate technology (URT) and 2) whether VRT profits over and above URT provided sufficient incentive for a producer to change from URT to VRT halfway through the ten year planning horizon.

While the study produced many interesting results, only one is discussed here. In general, results showed that the profitability of VRT was highly sensitive to the percentage of clay within a field. Often, even when VRT was found to be profitable on silt loam fields, switching from URT to VRT during a given 10 year planning horizon, was unadvisable as increased revenue from yields did not cover the costs of VRT hire.

Introduction

Arkansas is home to a diverse set of crops including rice, cotton, and soybean which rank first, fifth, and ninth, respectively in U.S. production (USDA, NASS, 1999). Rice and soybean are often grown in rotation. Today, some producers are attempting to manage nutrient requirements both across time and across variations in a field with variable rate technology (VRT). One such nutrient is phosphorus. In the past, phosphorus (P) applications were not generally recommended for rice because of flooded conditions and adequate initial levels of soil P (Beyrouty et al., 1991). Also, sufficient P was assumed to be applied to the soybean portion of the rotation. However, recent research has determined that applied P can be advantageous in rice production on alkaline silt loam soils (Wilson et al., 1999). Added P is still not recommended for clay soils. Adequate levels of P, based on recommended rates, can improve the chances of attaining optimal rice yields. Conversely, excess P in the soil may not directly affect production, but may indirectly decrease yields by causing micro nutrient imbalances. While there is evidence to suggest there is agronomic value to variable rate application of some nutrients, little or no information is available to farmers regarding the profitability of VRT nutrient management on rice or on crops grown in rotation together with rice.

The purpose of this study is to provide Arkansas agricultural producers with information regarding the profitability of variable rate P application on silt loam and clay fields commonly used in rice and soybean production. Simply put, this research was conducted to determine under what conditions variable rate P is economically viable for rice and soybean production in Arkansas.

Background

A review of the literature revealed that, to date, VRT is the most commonly examined of all precision agriculture technologies. VRT can be defined as varying the application rate of an input across a field as needed. In contrast, uniform rate technology (URT) applies a single rate of a product across a field. Many studies (Babcock and Pautsch, 1998; English et al, 1998, 1999; Lowenberg-DeBoer, 1998; Mahajanashetti et al., 1999; Prato and Kang, 1998; Roberts et al., 1998; Watkins et al., 1998) have examined the economic aspects of VRT. Several of the afore mentioned authors suggested that the value of VRT is linked to inherent differences within a field (i.e., textural and fertility variability and differences in water holding capacity). If the benefits of VRT are greater than all the costs associated with VRT, then the technology is valuable. However, VRT has been found to be profitable only when certain conditions exist. These conditions usually require a certain limited range of input cost to crop price ratios, a certain amount of variability within the quality of the soil in a field, or both.

Most VRT studies focused on monoculture crops such as cotton (Yu and Segarra, 1999) and corn (English et al., 1999, Lowenberg-DeBoer, 1998, Roberts et al., 1998). Many studies examined VRT nitrogen (English et al., 1998, 1999; Mahajanashetti et al., 1999; Roberts et al., 1998) while Yu and Segarra (1999) looked at P management. The focus of these studies typically was to examine the conditions which rendered variable rate nutrient application more profitable than uniform rate application. However, some studies also focused on the importance of environmental concerns (English et al., 1999; Prato and Kang, 1998).

Study Overview, Objectives and Assumptions

This study has built upon the research of English et al.(1999), Lowenberg-DeBoer (1998), Roberts et al. (1998), and Yu and Segarra (1999). Like Yu and Segarra (1999), this study focuses on the use of VRT in P application. However, while Yu and Segarra examined VRT on monoculture cotton production, this study examined the role of VRT on a two-crop rotation. As with English et al.(1999), Mahajanashetti et al.(1999), and Prato and Kang (1998), this study relies on data simulated by a biophysical model for the analysis. A 10 year planning horizon used by Yu and Segarra (1999) is applied. Similar to English et. al. (1999), Mahajanashetti (1998), and Roberts et. al (1999), this study used hypothetical field combinations of multiple soil series for analysis. Finally, like English et. al. (1999), Lowenberg-DeBoer (1999), Roberts et. al (1999), and Yu and Segarra (1999), prices of inputs and crops are varied to examine price effects on optimal P application rates and the profitability of VRT.

The objectives of this study are to:

- determine the relationship between yield and P on four soils commonly used to grow rice and soybeans in Arkansas
- evaluate the profitability of VRT of P on a rice and soybean rotation
- assess what conditions need to be present before VRT is profitable

Five assumptions are made to direct the study. First, producers are assumed to be price takers in both the input and output market. Second, soil combinations are such that only VRT can address soil differences at the field level. In some real world fields, variability can be treated by subdividing fields into smaller management units, as in Figure 1. However, in Eastern Arkansas, it may be more likely that soils are not separable in the fields (USDA, SCS, 1972). Instead the soils may be mixed as presented in Figure 2. Third, the producer applies constant rates of nitrogen on all soils. On a real farm, nitrogen rates may be adjusted for individual field and soil conditions. However, because P is the focus of this study, it is assumed that nitrogen use is fixed. Fourth, simulations are made to reflect potential conditions in Arkansas County, Arkansas. This area was chosen because the four selected soils are found in that county and it is one of the leading rice and soybean production areas in the state. Finally, technology is sufficient such that VRT applications are made accurately in a field.

Study Area

Based on ten year average production numbers, Arkansas County is one of the leading rice and soybean producing counties in the state. Four soils commonly found in rice and soybean fields in Arkansas County were chosen for this analysis: Calloway, Calhoun, Crowley, and Sharkey. Calloway, Calhoun, and Crowley are classified as silt loam soils while Sharkey is a clay soil. Agronomically, the three silt loam soils are considered similar in natural fertility and yield potential. They are low in organic matter and natural fertility while responding well to fertilizers and lime. It was expected that these three soils would have similar rice and soybean yields. The Sharkey clay soil is medium in organic matter and high in natural fertility. Under similar nitrogen management, Sharkey clay soils are expected to have lower rice yields than the silt loam soils. Sharkey is also expected to require less P than the silt loams, as currently the recommended P application to clay soils in Arkansas is zero. Applied P and yield are expected to be positively correlated on silt loam soils and negatively correlated on clay soils.

Development of a Theoretical Model of Production

Crop production is a function of many factors including weather, soil moisture, tillage, variety, pesticide, soil quality, and timing of practices. However, in this study a simplified model of production was chosen in order to focus on the profitability of variable rate P. In this simplified model, yield of a given crop is a function of soil P, applied P, and total available water. Total soil P available at the beginning of any period is a function of soil P, applied P, P runoff, and P uptake by the crop, all in the previous period. Phosphorus runoff in any given period is a function of soil P, applied P, total available water, and crop uptake of P, all in the current period. These generalized equations, which are assumed to include the same variables for both the rice and soybean equations, can be written as follows:

$$Yld_t = f(SP_t, AP_t, W_t) \quad (1)$$

$$SP_t = g(SP_{t-1}, AP_{t-1}, Runoff_{t-1}, UP_{t-1}) \quad (2)$$

$$Runoff_t = h(SP_t, AP_t, W_t, UP_t) \quad (3)$$

where: *Yld* is yield, *SP* is soil phosphorus, *AP* is applied phosphorus, *W* is total water, *Runoff* is runoff, *UP* is crop uptake of phosphorus, and *t* designates the time period. These equations will be used to estimate optimal P applications on individual soils and to assess under what conditions VRT is economically superior to uniform rate application.

Data Simulation and Manipulation

The Environmental Policy Integrated Climate, or EPIC, model was developed to evaluate crop production, soil erosion, water quality aspects, environmental concerns, ramifications of management practice changes, and responses to other changes (Mitchell et al., 1995). Rice and soybean production practices in the model (such as tillage, planting, spraying, irrigating, and harvesting) were chosen to reflect actual field practices (Windham, 1999a and 1999b). A 1:1 rice-soybean rotation which is representative of Arkansas County (Norman, 1999) was followed. Applications of all inputs, except P, were held constant on all simulations. Simulation runs were generated on the four soils under 13 fertilizer rates. Phosphorus levels were varied from zero to 96 pounds per acre on each crop. This wide range was used in an attempt to capture the impact of P on crop yields. Three general management strategies were followed: 1) varying the P rates over both the rice and soybean crop production periods, 2)recommended P rates were placed on soybean but rates varied on rice and 3) recommended P rates were placed on rice but rates varied on soybean. A total of 37 treatments were replicated across the four soils, producing 148 total treatments. As a result, 4,440 annual observations were recorded over the 30-year period, 2,220 annual observations each for rice and soybean.

EPIC simulated yields were compared to actual farm yields reported in Arkansas County, Arkansas. EPIC soybean yield ranges of 18 to 46 bushels per acre were similar to those reported for irrigated soybean (AASS, 1999). On the other hand, simulated rice yields of 85 to 125 bushels per acre were slightly lower than typically found in Arkansas County (AASS, 1999). It is likely that the range in the nutrient application rates (which included too little and too much nutrients) could have affected the observed yields and made these suboptimal.

Econometric Estimation of a Theoretical Model of Production

EPIC generated panel data for over 200 variables, each for 30 years. A fixed effects model was chosen to estimate the desired relationships within these equations. All equations were tested and corrected for any failures associated with panel data (Hsaio,1999) The theoretical yield equations were estimated using the variables listed in equation 1. In equations 2 and 3, yield served as a better proxy for P uptake by the plant than the EPIC P uptake variable. Equations 4 through 6 show the final functional form of the estimated model:

$$Yld_t = f(C, SP_t, AP_t, W_t, SP_t^2, AP_t^2, W_t^2) \tag{4}$$

adj R^2: Rice = 0.64 Soybean = 0.70

$$SP_t = g(C, SP_{t-1}, AP_{t-1}, Runoff_{t-1}, Yld_{t-1}) \tag{5}$$

adj R^2: Rice = 0.87 Soybean = 0.89

$$Runoff_t = h(C, SP_t, AP_t, W_t, Yld_t) \tag{6}$$

adj R^2: Rice = 0.71 Soybean = 0.82

where: *C* is an intercept term and other variables are defined as above. As expected, the yield, soil P and runoff equations were a function of the same variables when estimated for rice and for soybean. Yield equations were estimated in the quadratic form as is often associated with rice and soybean yield response to available P (Norman, 1999). The soil P and P runoff equations were estimated in the linear functional form as expected based on previous research (Daniel, 1999). Many of the coefficients were significant at the 99 percent confidence level. The signs and magnitudes of all coefficients were as expected[1].

Impacts of Alternative P Applications in an Optimization Framework

Once estimated, the regression equations were placed into the General Algebraic Modeling System, or GAMS, (Brooke et al., 1998) a mathematical optimization program, to ultimately determine the profitability of VRT on fields with combinations of different soils. However, before profitability questions could be addressed on fields comprised of multiple soils, relationships between P rates, yields, and net revenue on individual soils were determined in two scenarios.

Defining Two Scenarios

Two types of optimization scenarios were run for each soil. The objective of each scenario was to maximize net revenue over a ten year planning horizon, subject to conditions put forth in each scenario. This study varied rice prices, soybean prices, P prices, and the discount rates (using current and five year low, high and average numbers) to create a total of 36 price/discount rate combinations. All 36 price combinations were applied to all four soils, creating 144 optimization runs. Crop yield, applied P, and net revenue values were calculated for each optimization. The two types of scenarios were as follows:

Scenario One: Maximize net revenue by choosing the most appropriate P application rates for rice and soybean for the 10-year planning horizon (*optimal P rates*)

Scenario Two: Maximize net revenue when P application rates are fixed at uniform rates across all soils for the 10-year planning horizon (*uniform P rates*)

A ten year planning horizon was chosen for two reasons. First, a planning horizon that was long enough to observe any trends in phosphorus carryover between rice and soybean production

[1] Details regarding the coefficients estimated for each of the 24 equations (3 equations for 2 crops on 4 soils) is available from the authors.

years was desired. Second, it has been suggested in the literature that at least 4 to 5 years of data was needed before a farmer could choose to switch from uniform rate to variable rate so a planning horizon was desired that would capture the economic returns to gathering this information and allowing for a change in management strategy.

Scenario One - Optimal Phosphorus Application Rates

Table 1 presents the phosphorus rates, yields and dollar amounts that maximized revenues in scenario one. As expected for silt loam soils, the optimal P rate on Calloway and Crowley soils were similar. Unexpectedly, optimal P rates for rice were much higher on Calhoun soils. This may be the result of a problem within the simulation of the data, but Norman (1999) stated that these rates were still within normal ranges. P rates on the Sharkey soils for rice and soybean were two and nine pounds per acre, respectively. Although rates of zero were expected, this too is within a normal range (Norman, 1999). As expected the yields on the silt loam soils are higher than those on the Sharkey clay soil.

Surprisingly, optimal P application rates were insensitive to price or discount rate ranges. *NPV,* defined as the discounted sum of net returns over direct costs of production over the ten year horizon, varied with price ratios but were consistently positive or consistently negative across scenarios, only magnitudes differed. Given the narrow variability in these price ratios over the past five years, results were insensitive to changes and therefore only results using current (1999) numbers (rice $3.85/bu; soybean $6.50/bu; phosphorus $0.25/lb; 8 percent discount rate) are reported here.

Scenario Two - Uniform Rate Technology Rates

Simulations were run using three different uniform rates, which for simplicity can be abbreviated as *U1*, *U2*, and *U3*. U1 represents a uniform P rate appropriate on a Calloway or Crowley silt loam soil. U2 represents the uniform P rate appropriate on a Calhoun silt loam soil.

U3 represents the uniform P rate appropriate on a Sharkey soil. Clearly a farmer would choose to spread P at the uniform rate appropriate for his soil. However, as will be shown later most fields are not comprised of one soil alone. Therefore, the effect of sub-optimal P application rates needed to be noted.

Table 2 shows how fixing P to non-optimal application rates impacts yields and NPVs. Soils associated with a given uniform rate have yields and NPV that were very similar to those produced under the optimal P application rate. However, yields and NPV on silt loam soils were most negatively impacted when U3 was utilized because applied P was too low. Similarly, compared to the optimal P rate application, yields and NPV on the Sharkey clay fell dramatically under U1 and U2 rate applications because P applications were too high.

Identifying the Impacts of VRT on Intra Field Variation

Once the relationships between P application rates, yields, and NPV were established for the four soils individually, this study proceeded to examine P applications on fields comprised of more than one soil to test the profitability of variable rate P applications. The analysis was conducted in four steps. First, a series of 139 hypothetical fields was created consisting of one, two, three, and all four soils.[2] Second, appropriate VRT costs were added to production costs to differentiate between uniform rate net returns (NPV_{URT}) and variable rate net returns (NPV_{VRT}) per acre. Based on a survey of representatives from the agricultural suppliers in Arkansas, a custom rate of $4.00 per acre was used in the analysis (Griffin, 1999).

Third, three expectations were formulated based on the findings of other studies noted in the literature review, the econometric estimation of the theoretical model and the characteristics of the four Arkansas soils chosen for the study. First, given the similar physical and chemical

[2] See authors for details

characteristics of the silt loam soils, it was expected that VRT would not be profitable on silt loam soils alone. Second, given the differences in the characteristics of clay and silt loam soils it was expected that the level of Sharkey clay in the field would determine the degree of VRT profitability. Finally, it was expected that the difference between NPV_{VRT} and NPV_{URT} would be sensitive to input/output price ratios.

Fourth, a comparison of the net revenue from using VRT versus a uniform rate was made for each field. Finally the economic benefit of switching from URT to VRT within a fixed planning horizon was considered. This last step is explained below.

Comparison of VRT to URT on Silt Loam Soil Fields Only

Results showed that VRT could be superior to URT under two conditions. First, as shown in Table 3, VRT was superior to U1 when Calloway and/or Crowley made up between 50 and about 75 percent of the field. As more and more Calloway and/or Crowley were present in the field, the difference between VRT and U1 narrowed. Once Calloway and/or Crowley made up 76 percent of the field, VRT was no longer more profitable than U1. Second, VRT was superior to U2 when a field consisted of between 50 and 60 percent Calhoun. As more Calhoun enters the field, VRT becomes less attractive compared to U2. Generally speaking VRT was not desirable if the field was comprised of only one soil and only rarely desirable in a field comprised of three silt loam soils.

Comparison of VRT to URT on Silt Loam-Clay Fields

Clay soils introduced a greater degree of variability to the field suggesting that VRT might be appropriate. VRT was superior to URT in these mixed fields when the amount of Sharkey was greater than two percent and less than 98 percent as seen by some examples in the shaded sections of Table 4. As expected, returns to VRT were greater on fields of clay and silt loam combinations. Unexpectedly however, gains could be over $200 per acre when the fields was nearly evenly split between clay and silt loam. These large returns to VRT can be explained as follows. Given the broad differences in nutrient requirements between the clay and silt loam fields, applications of rates desired for one soil type could have devastating effects on yields and thus net revenue of other soil types. When the clay rate was applied to silt loam soils, yield decreased more than when other silt loam application rates were applied. However, when a silt loam rate was applied to Sharkey clay, yields decreased dramatically. Thus there was much to be gained by applying the proper P rate to each portion of the field.

Switching from URT to VRT within the Planning Horizon

The above discussion described the conditions that need to exist for VRT to be superior to URT. These results are summarized in Table 5. Suppose a farmer applying a uniform rate in his fields discovers during the first half of the planning horizon that net return to VRT could be greater than net return to URT. (That is, his fields meet one of the conditions described in Table 5). Analysis was conducted to determine how much the farmer stood to gain by switching from URT to VRT for the second half (starting in the sixth year) of the planning horizon. These results are summarized in Table 6.

In general it was found that on fields of silt loam soils only, switching from a uniform rate to the VRT rate half way through the planning horizon resulted in 10 year NPV difference of $0.50 to roughly $5.00 lower than those earned with URT for the full planning horizon. These results, while initially counterintuitive, can be explained as follows. The initial returns to VRT were calculated assuming immediate response of yields to proper fertilize rates. However, if fields have been over or under fertilized, yields are not likely to reach optimal levels the first year of appropriate nutrient application. Switching from URT to VRT in year six does increase yields for years six through 10 over those yields under URT. However, these gains in yield for the final five years of production were not sufficient to offset the added costs of VRT incurred in those years. Therefore, in these cases switching from URT to VRT is not recommended.

When the Sharkey clay soil was added to the field mix, switching from URT to VRT in mid horizon often became attractive. As shown in Table 6 a farmer stood to gain anywhere from $0.50 an acre to $330 acre by switching mid horizon. This result occurred because yields - particularly those on Sharkey clay - recovered sufficiently to provide an added revenue that was greater than the costs of VRT. For example, in one case, Sharkey rice yields were reduced from 121 bushels per acre to 49 when a U2 rate was applied. When phosphorus use is corrected on Sharkey soil, input costs fall - due to a large reduction in phosphorus use - and net return increase - due to a large increase in yields. This lead to larger increases in NPV differences than observed for silt loam soils only.

Summary and Conclusions

This paper describes some of the results of an empirical study of the profitability of VRT of P on a rice and soybean rotation. These results can be summarized as follows. First, VRT is only superior to a URT when sufficient variation exists within a field. Cases of sufficient variation include:

- when Calloway and/or Crowley make up between 50 and 75 percent of the field (VRT is superior to a U1 rate),
- when Calhoun composes between 50 and 60 percent of the field, (VRT is superior to a U2 rate), and
- when the proportion of Sharkey is between three and 97 percent of the field, (VRT is superior to the appropriate use of U1, U2, and U3 rates).

On silt loam fields, returns to VRT were small, on average less than $10.00 per acre. However However on fields containing both silt loam and clay soils, average gains were higher at $30 per acre.

Secondly, if a farmer is attempting to maximize net profit during a planning horizon, it does not always make sense to switch from URT to VRT, even if sufficient variation in a field exists. Optimal yield response to appropriate P rates is not immediate. Therefore, a farmer must be sure that annual yield gains will be larger than VRT before implementing this change in production management. These results show that switching is likely not desirable in fields of silt loam soils alone, but that "late" adoption in fields of both clay and silt loam soils may be worthwhile.

While this paper gives some indication of the potential profitability of variable rate phosphorus in rice and soybean rotations. It is still unclear how many farmers are likely to adopt the technology. Soil scientists at the University of Arkansas are employing other precision farming technologies, such as geographic information systems and global positioning systems to better understand the soil composition of the cropland in Arkansas county and other counties within the state. This information will then let us know how many fields meet this adoption criteria. Secondly, adoption is likely to be greatly affected by relative return and farm size. Farmers earning relatively small returns to precision farming on small acreages are not likely to adopt the technology as quickly as those farmers with large acreages who stand to gain larger overall returns.

This research concludes the first step in the investigation of VRT P applications in Arkansas. Research is currently underway to study how different rice/soybean rotations affect nutrient carryover and thus the applicability of VRT on an annual basis.

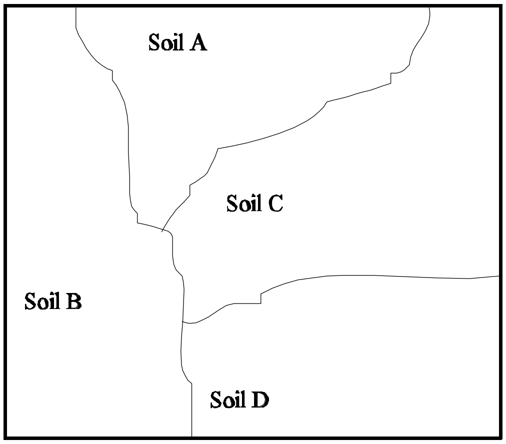

Figure 1 Separable Soils

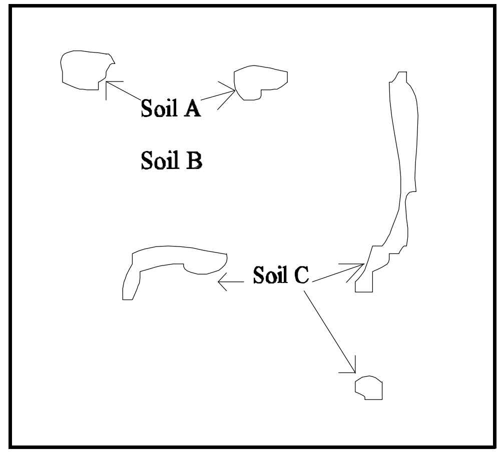

Figure 2 Inseparable Soils

Table 1 Optimal Phosphorus Rates and Associated Yields and Net Revenue

Crop	Rice		Soybean		Rotation
Soil	P (lbs/ac)	Avg Ann Yield (bu/ac)	P (lbs/ac)	Avg Ann Yield (bu/ac)	10 Yr NVP ($/ac)
Calloway	47	134	36	35	1421
Calhoun	60	132	36	35	1352
Crowley	45	123	33	38	1182
Sharkey	2	121	9	30	887

Table 2 Yields and NPV Under Optimal Rate and Uniform Rate Scenarios

Soil	U1			U2			U3		
	Rice (bu/ac)	Soy (bu/ac)	NPV ($)	Rice (bu/ac)	Soy (bu/ac)	NPV ($)	Rice (bu/ac)	Soy (bu/ac)	NPV ($)
Calloway	134	35	1418.88	127	34	1375.14	94	29	371.66
Calhoun	128	33	1260.49	132	35	1351.77	85	20	85.56
Crowley	122	36	1172.14	117	34	1112.18	88	30	308.99
Sharkey	57	10	-339.34	49	9	-497.64	121	30	886.69

[a] Shaded table cells indicate the optimal or appropriate uniform application rate is applied to a given soil.

Table 3 Returns to VRTover URT on Fields of Silt Loam Soils

Field Combination (percent)			NPV_{VRT} - NPV_{U1} (dollars per acre)	NPV_{VRT} - NPV_{U2} (dollars per acre)
Calloway	Calhoun	Crowley		
60	20	20	-5.29	N/A[a]
40	20	40	-3.63	N/A
20	20	60	-1.98	N/A
50	25	25	-0.41	N/A
20	60	20	N/A	-3.62
20	80	0	N/A	-17.68
0	80	20	N/A	-12.78
0	60	40	N/A	1.28[b]
0	50	50	23.96	8.30
25	50	25	21.89	2.18
50	50	0	19.82	-3.95
20	40	40	14.21	N/A
40	40	20	12.56	N/A
60	40	0	10.90	N/A
25	25	50	1.66	N/A

[a] N/A is not applicable because these net revenue would result only from applications of an inappropriate uniform rate which a farmer would normally not use.
[b] Shaded areas highlight positive returns to VRT

Table 4 Returns to VRT over URT on Fields of Silt Loam and Clay Soils

Field Combinations (percent)				Net Returns to VRT (dollars per acre)		
Calloway	Calhoun	Crowley	Sharkey	NPV_{VRT} - NPV_{U1}	NPV_{VRT} - NPV_{U2}	NPV_{VRT} - NPV_{U3}
99	0	0	1	-12.55	N/A[a]	N/A
0	99	0	1	N/A	-13.00	N/A
0	0	99	1	-4.35	N/A	N/A
98	0	0	2	-0.31	N/A	N/A
0	0	98	2	7.80	N/A	N/A
0	98	0	2	N/A	0.85	N/A
0	0	97	3	19.96[b]	N/A	N/A
0	97	0	3	N/A	14.69	N/A
97	0	0	3	11.93	N/A	N/A
0	0	95	5	44.27	N/A	N/A
0	95	0	5	N/A	42.38	N/A
95	0	0	5	36.41	N/A	N/A
20	20	40	20	241.16	N/A	N/A
40	20	20	20	239.51	N/A	N/A
20	40	20	20	257.35	273.24	N/A
20	20	20	40	484.30	N/A	610.95
5	0	0	95	N/A	N/A	25.62
0	0	5	95	N/A	N/A	16.83
0	5	0	95	N/A	N/A	36.47
1	1	1	97	N/A	N/A	5.05
0	3	0	97	N/A	N/A	11.15
2	0	0	98	N/A	N/A	-5.85
0	0	2	98	N/A	N/A	-9.37
0	2	0	98	N/A	N/A	-1.52
1	0	0	99	N/A	N/A	-16.35
0	0	1	99	N/A	N/A	-18.11
0	1	0	99	N/A	N/A	-14.18
0	0	0	100	N/A	N/A	-26.84

[a] N/A is not applicable because these net return would result only from applications of an inappropriate uniform rate which a farmer would normally not use.
[b] Shaded areas highlight positive returns to VRT

Table 5 Conditions Where VRT is Superior to URT

Soils in the Field	When VRT is Superior to URT
Any 1 soil	Never
Calloway and Crowley	Never
Calhoun and any combination of Calloway and/or Crowley	Superior to U1 when Calloway/Crowley is between 50 and 75 percent of field
Calhoun and any combination of Calloway and/or Crowley	Superior to U2 when Calhoun is between 50 and 60 percent of field
Sharkey and any silt loam soil combination	Superior to U1, U2, and U3 when amount of Sharkey in the field is between 3 and 97 percent

Table 6 NPV of Switching from URT to VRT

Soils in the Field	NPV Under Late Adoption
Calhoun and any combination of Calloway and/or Crowley	Negative
Sharkey and Crowley	$2.93 to $277.52 per acre
Sharkey and Calloway	$1.00 to $330.02 per acre
All four soils	$0.50 to $240.00 per acre

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