Economic Evaluation of Fertilizer Reduction Incentive Programs for Rice Producers

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ABSTRACT

Producers are beginning to be provided the opportunity to participate in incentive programs to reduce application rates of fertilizer. This paper demonstrates three methods of arriving at a recommendation on program participation. Two methods employ commonly used production functions and economic optimization techniques. The economic evaluation of this decision is relatively difficult using these traditional methods. The third technique employs Monte Carlo simulation to include risk analysis in the program participation decision utilizing commonly available software. This method allows a greater level of information to be presented in a more straightforward manner to decision makers.

Introduction

Mississippi rice producers are being presented opportunities to participate in programs that provide incentives to reduce the amount of nitrogen fertilizer applied to their crops each year. Traditionally, the recommended economically optimal level of fertilizer applied to a crop is calculated analytically using an estimated yield response function along with fertilizer prices, fertilizer application costs, related harvest costs, and rice prices. These methods generate recommendations for optimal fertilizer application levels, but are not easily adapted to evaluate incentive programs for reduced application rates. In addition, these methods do not provide producers much information related to the risk associated with expected net returns above fertilizer and application costs at various levels of fertilizer application. Advances in widely available spreadsheet software now allow development of tools to aid producers in analyzing fertilizer application as a risky decision. This allows producers to make a more informed decision related to participation in fertilizer reduction incentive programs.

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This paper demonstrates three methods of arriving at a recommendation on program participation. Two methods employ commonly used production functions and economic optimization techniques. These methods were chosen to demonstrate how the problem could be approached using optimization techniques taking into account some of the drawbacks of these approaches with respect to analyzing results. The third technique employs Monte Carlo simulation to include risk analysis in the program participation decision.

The third method has not been applied in economic analysis of fertilizer reduction incentive programs, and has several advantages. The risk analysis utilizes empirical estimates of rice yield response at various levels of nitrogen fertilization along with Monte Carlo simulation to generate yield distributions. The yield distributions can be stored in a spreadsheet and distributed to decision makers, and then coupled with production economics decision theory to generate distributions of expected net returns above fertilizer and application costs. This method allows producers to examine the expected returns at the specified levels of fertilizer application, to compare the risk associated with reduced levels of fertilizer application to see if reduction in expected yield and fertilizer and application costs is offset by the cash incentives offered by a particular program.

Data and Methods

Yield data used in this paper were taken from a three-year study spanning the 2009 to 2011 crop years. This study was carried out in the Mississippi Delta at five locations with three replications per site per year. The yield data shown in Figure 1 was for Clearfield 111 (CL111), grown on silt loam soils with nitrogen rates of 0, 60, 90, 120, 150, 180, and 210 pounds per acre.

The baseline assumptions utilized to calculate the applied cost of nitrogen and the net price for rice are shown in Table 1. The market price for rice is assumed to be $6.50 per bushel. This price is adjusted for hauling and drying costs which are calculated on a green weight basis, with the original harvest moisture assumed to be 18 percent. These adjustments result in a net price for dry rice of $0.1256 per pound. Nitrogen prices are calculated using market prices for urea, which is assumed to contain 46 percent nitrogen. Including application costs of $7.00 per hundredweight, the applied nitrogen is calculated to be $0.67 per pound. The decision support aid developed for this study allows the producer to adjust any of these baseline parameters to fit their particular situation.

To demonstrate the traditional approach to the problem of making a recommendation with respect to program participation, the data were used to estimate two alternative fertilizer response functions. First, a quadratic functional form (Heady & Dillon, 1961) which allows for both declining and negative marginal productivity and a linear marginal product curve was estimated using classical sampling theory (Appendix I). Analysis of variance results indicated no location effects were present; however year effects were significant and are included in the model.

Second, a linear response stochastic plateau (LRP) function (Tembo, Brorsen, Epplin, and Tostao, 2008) was estimated using Bayesian methods (Brorsen, 2013). The LRP function incorporates von Liebig's "law of the minimum", and has two random effects, one which shifts the entire production function up or down based on annual conditions and the second which shifts only the additional yield potential from changes in nitrogen application (Appendix II).

For the third method in this study, empirical distributions were estimated for each nitrogen application rate with the Simetar program, a readily available add-in for Excel spreadsheets (Richardson, 2002). The estimated distributions were then simulated using Monte Carlo techniques with a Latin hypercube sampling method. The results from 500 draws for the seven estimated distributions are shown in Figure 2.

The risk analysis was developed by storing the simulation results for each nitrogen rate in a spreadsheet decision support aid that is designed to calculate net returns above hauling, drying, checkoff, nitrogen and nitrogen application costs for each of the 500 random draws. After calculating the net returns for each nitrogen level for each draw, the application rates with the lowest net return and the highest net return were identified for each draw[1]. The decision aid presents the results as percentages in colored bar segments for each of the seven nitrogen application rates. Red indicates the percentage of the 500 draws that a particular nitrogen application rate had the lowest net return, yellow indicates the percentage of the 500 draws that a particular nitrogen application had neither the lowest or the highest net return, and the green portion of the bar indicates the percentage of the time that the particular nitrogen application rate had the highest net return.

While this method does not optimize the rate of nitrogen application, it provides valuable information to a decision-maker as to the risk related to each of the specified levels of nitrogen application. In addition, this method allows for subsidies to be added below the level specified in the program, which recalculates the returns net of the subsidy and presents the change in percentages of lowest and highest net returns in a straightforward, easy to interpret format.

Data related to the incentive program is for the 2013 Conservation Innovation Grant-Greenhouse Gas Project available to Mississippi rice producers through the Environmental Quality Incentives Program (USDA-NRCS, 2013). This is a voluntary program that provides financial and technical assistance to rice producers to field test and demonstrate specific conservation practices which reduce greenhouse gas emissions from rice fields. This program included a $40 per acre incentive to cap nitrogen utilization at 125 pounds per acre under the programs approved nutrient management practices, which serves as the baseline incentive payment in this study.

Results and Discussion

As shown in Figures 1 and 2, yield variability decreases in this data set as fertilizer rates increase. While the literature related to the use of fertilizer in non-irrigated crop production sometimes notes that yield variability increases with fertilization rates, fertilization of rice grown with irrigation in this case has the opposite effect. The coefficient of variation for yields from the 0 nitrogen application rate was 33.4 percent, and declined to a low of 6.2 percent for the 210 pounds of nitrogen application rate. This reduction in variability from increasing rates of fertilizer application over the range in this data supports taking risk into account when making fertilization decisions, which is of interest to producers who are offered a choice of reducing nitrogen rates in exchange for a cash incentive.

Analysis of variance results showed no location effect, with significant year effects as can be seen in Figure 1. As a result, the quadratic function was estimated with year effects included, and parameter estimates are shown in Appendix I. All of the parameter estimates had the theoretically expected sign, and are statistically significant. The parameter estimate for the 2010 crop year indicates that expected yields would be 1,599 pounds less than in 2009, and the parameter estimate for the 2011 crop here indicates that yields for that year would be 2,270 pounds less than 2009. These parameter estimates are used to adjust the expected returns for the results shown in Table 3. Based on the parameter estimates for the quadratic function the profit maximizing level of nitrogen is shown in Equation 1.

$$(1) \quad N^{*} = (41.835 {*} P_y - P_x)/(0.172 {*} P_y)$$

where:

N^* = optimal level of nitrogen in pounds per acre,

P_y = price of rice net of hauling, drying and check-off costs in dollars per pound,

P_x = price of nitrogen per pound including application cost.

The optimal nitrogen fertilizer rates derived from the quadratic production function for selected rice and nitrogen prices are shown in Table 2. Most of the recommended rates are at or above the maximum nitrogen application rates used in the study, but compare closely to the 200 pounds of nitrogen per acre currently recommended in Mississippi State University planning budgets (MSU, 2012).

Net returns above harvesting, and marketing and fertilization costs for each selected rice and fertilizer combination were calculated and subtracted from the calculated net return above harvesting, marketing, and fertilization costs at 125 pounds of nitrogen plus the $40 per acre subsidy. These results are shown in Table 3, and indicate that the $40 per acre subsidy is inadequate to offset the loss in net revenue due to lower production that results from the reduced nitrogen fertilization rates. Estimated losses per acre range from $31.82 per acre for low rice price and high nitrogen price combinations to a high of $65.62 per acre for low nitrogen prices and high rice prices. Based on these results, subsidies would have to range from a minimum of approximately $70 per acre to a high of $105 per acre to attract participation in the program.

Next, the LRP production function was estimated and optimal fertilizer recommendations calculated. The Bayesian estimated parameters for the LRP function are shown in Appendix II. Equation 2 represents the nitrogen rate that results in the highest average expected profit from sampling n number of times from the distribution of simulated values. To obtain the nitrogen rate that maximizes expected profit for the LRP function it is necessary to use Monte Carlo integration (Brorsen, 2013) to approximate the integral of the expected profit function (Equation 2). The vector $\tilde{\theta}$ contains the parameter estimates from Appendix II along with P_y and P_x.

$$(2) \qquad max_{N\geq 0}\left(\frac{1}{n}\right)\sum_{i=1}^{n} E\pi\left(N|\tilde{\theta}_i\right)$$

Optimization of the LRP function was carried out in SAS using PROC NLP (Brorsen, 2013), with the optimal nitrogen rates shown in Table 4. The optimal rates recommended by the LRP function are approximately 40 pounds per acre less than the recommendations derived using the quadratic function and approximately 30 pounds per acre less than the current MSU recommendations.

The optimization for the LRP function was rerun for each rice and fertilizer price combination with nitrogen rates constrained to a maximum of 125 pounds per acre. The differences between the values of the objective functions for the optimal and constrained values were calculated and adjusted for the subsidy, and these results are shown in Table 5. As would be expected with a considerably lower optimal level of nitrogen recommendations, the net returns from program participation are higher than the net returns using the quadratic function recommendation. As shown in Table 5, the net returns from participating in the program are positive for all combinations of rice and nitrogen prices except for the high rice price-low nitrogen price combination.

Given that the selection of the functional form of the yield response function has provided two significantly different answers to the participation question, the risk analysis approach was applied. The risk analysis results for the base case can be seen in Figure 3. The decision chart presents the percentage of the time each application rate has the greatest (green), lowest (red), and neither the highest or lowest (yellow) net return above harvest, marketing, and fertilization costs for each fertilization rate. In addition, the expected value of the net return is calculated and presented in the X axis label. As shown in Figure 3, the 120 pound rate has an expected return of $1,114 per acre, the 180 pound rate of $1,177 per acre, and the 210 pound rate has an expected return of $1,158 per acre. The 180 pound rate had the highest net return for 71.6 percent of the draws, with the 210 pound rate having the highest net return for 23 percent of the draws. Rates above 180 pounds per acre generated the lowest returns 0.6 percent of the time. These results would be more in line with current MSU recommendations of 200 pounds of nitrogen per acre than the LRP recommendations.

While this technique does not generate an optimal result, it does allow a producer to see that 94.6% of the time the highest net returns are generated at fertilization rates at or above 180 pounds of nitrogen per acre, and that the expected returns for the higher nitrogen rates are more than $40 per acre greater than the 120 pound rate, which is the rate nearest the capped rate of 125 pounds.

The decision support aid also generates a net return after subsidy, which is shown in Figure 4. The addition of the $40 per acre subsidy at nitrogen rates below 120 pounds per acre changes expected maximum returns at the 120 pound level from a 2.4 to 42.8 percent, with the rates above 180 pounds per acre dropping from 94.6 to 54.6 percent. It should be noted, that the rates above 120 pounds per acre generated the lowest return 10.8 percent of the time, while the 120 pound rate generated the lowest net return zero percent of the time. Based on this analysis, it is unlikely that producers would participate in the program as the highest expected net returns are still at the levels of 180 pounds and above.

The decision support aid can be used to evaluate varying levels of incentive payments. As shown in Figure 5, if per acre incentive payments were increased to $70 per acre the 120 pound application rate would result in the highest net returns over 50 percent of the time, with the highest expected value of any of the application rates.

This method can be adapted for other crops by a straightforward process. The decision support aid is developed to allow the user to enter data on crop and fertilizer prices directly, and generate all the expected return distributions. For any crop of interest, the user needs only to estimate the empirical yield distributions for alternative nitrogen rates for that crop and insert those into the decision support aid template.

Conclusion

This paper demonstrates how risk analysis can be of use in approaching the decisions producers face with analyzing fertilizer reduction incentive programs. Analysis for this particular variety, CL111, on this particular soil type indicates that current subsidy levels are likely too low to attract widespread participation in the study area.

The risk analysis technique developed and presented in this paper has the advantage of being easily adapted to different soil types and varieties when compared to conventional methods of developing yield response functions and coupling that with economic decision theory. This method also allows a greater level of information to be presented in a more straightforward manner to decision makers. While this example case involves rice production, this method can be easily adapted to any crop.

Endnote

[1] The random yields were simulated so that each fertilizer application rate probability distribution was sampled using the same risk or deviate, therefore the same weather effects were experienced by all seven distributions and the yield differences were due only to the nitrogen effects.

Appendix I

The quadratic model used in this study is shown in the following equation along with its parameter estimates.

$$yit = \beta_0 + \beta_1 {*} n_{it} + \beta_2 {*} n^2_{it} + \beta_3 {*} \mathit{yr2010} + \beta_4 {*} \mathit{yr2011} + \varepsilon_{it}$$

where:

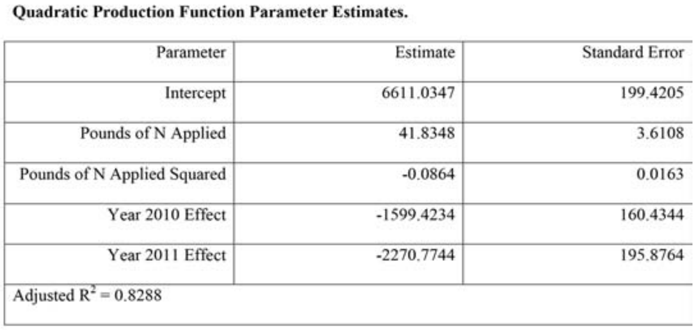
y_{it} = dry weight yield of CL111 rice in pounds per acre in *i*th plot at time *t*,

n_{it} = pounds of nitrogen per acre applied to the *i*th plot at time *t*,

yr2010 = 1 if *t* is 2010, 0 otherwise,

yr2011 = 1 if *t* is 2011, 0 otherwise,

ε_{it} = random error term.



Quadratic Production Function Parameter Estimates.

Parameter	Estimate	Standard Error
Intercept	6611.0347	199.4205
Pounds of N Applied	41.8348	3.6108
Pounds of N Applied Squared	-0.0864	0.0163
Year 2010 Effect	-1599.4234	160.4344
Year 2011 Effect	-2270.7744	195.8764
Adjusted R^2 = 0.8288		

Appendix II

The LRP model used in this study is shown in the following equation along with its parameter estimates.

$$y_{it} = \min(\beta_0 + \beta_1 n_{it}, \mu_m + \gamma_t) + \varepsilon_{it} + u_t$$

where:

y_{it} = dry weight yield of CL111 rice in pounds per acre in ith plot at time t,

n_{it} = pounds of nitrogen per acre applied to the ith plot at time t,

ε_{it} = random error term,

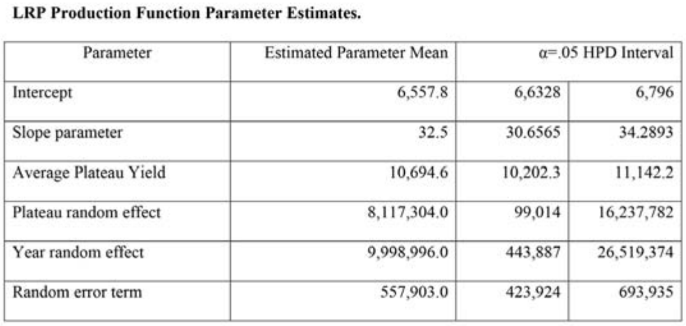
γ_t = plateau random effect,

u_t = year random effect,

μ_m = average plateau yield,

β_0 = intercept parameter,

β_1 = slope parameter.



LRP Production Function Parameter Estimates.

Parameter	Estimated Parameter Mean	α=.05 HPD Interval	
Intercept	6,557.8	6,6328	6,796
Slope parameter	32.5	30.6565	34.2893
Average Plateau Yield	10,694.6	10,202.3	11,142.2
Plateau random effect	8,117,304.0	99,014	16,237,782
Year random effect	9,998,996.0	443,887	26,519,374
Random error term	557,903.0	423,924	693,935

The highest posterior density (HPD) intervals show the upper and lower bounds of the region that has a 95 percent chance of holding the true parameter.

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Table 1. Baseline Assumptions

Item	Value
Rice Price - Dry ($/bushel)	$ 6.50
Moisture %	18.0%
Drying - ($/bushel)	$ 0.45
Hauling - ($/bushel)	$ 0.30
Checkoff - ($/bushel)	$ 0.03
Shrink % to 16% Base	1.50%
Urea Price $/ton	$ 550.00
Application Cost $/cwt.	$ 7.00
Dry Net Rice Price $/pound	$ 0.1256
Applied N Cost $/pound	$ 0.67

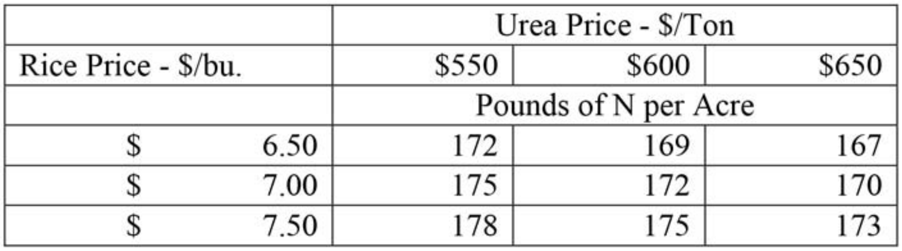
Table 2. Optimal Nitrogen Fertilization Rates in Pounds per Acre at Selected Prices of Rice and Urea from the Quadratic Function

	Urea Price - $/Ton		
Rice Price - $/bu.	$550	$600	$650
	Pounds of N per Acre		
$ 6.50	211	209	206
$ 7.00	214	211	209
$ 7.50	216	214	212

Table 3. Net Change in Returns above Harvest, Marketing and Fertilization Costs per Acre When Capping Nitrogen Fertilization Rates at 125 Pounds per Acre Versus Quadratic Function Recommended Rate Including Subsidy

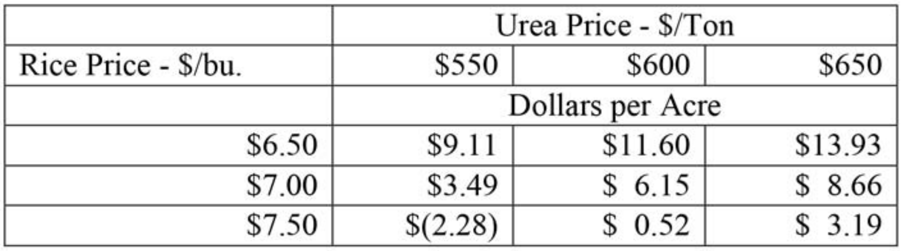
	Urea Price - $/Ton		
Rice Price - $/bu.	$550	$600	$650
	Dollars per Acre		
$ 6.50	$(40.93)	$(36.19)	$(31.82)
$ 7.00	$(53.22)	$(48.50)	$(43.74)
$ 7.50	$(65.62)	$(60.80)	$(56.03)

Table 4. Optimal Nitrogen Fertilization Rates in Pounds per Acre at Selected Prices for Rice and Urea from the LRP Function



	Urea Price - $/Ton		
Rice Price - $/bu.	$550	$600	$650
	Pounds of N per Acre		
$ 6.50	172	169	167
$ 7.00	175	172	170
$ 7.50	178	175	173

Table 5. Net Change in Returns above Harvest, Marketing and Fertilization Costs per Acre with Various Rice and Urea Prices When Capping Nitrogen Fertilization Rates at 125 Pounds per Acre Versus LRP Function Recommended Rate Including Subsidy



	Urea Price - $/Ton		
Rice Price - $/bu.	$550	$600	$650
	Dollars per Acre		
$6.50	$9.11	$11.60	$13.93
$7.00	$3.49	$ 6.15	$ 8.66
$7.50	$(2.28)	$ 0.52	$ 3.19

Figure 1. CL111 Yields on Silt Loam Soils at Alternative Nitrogen Rates

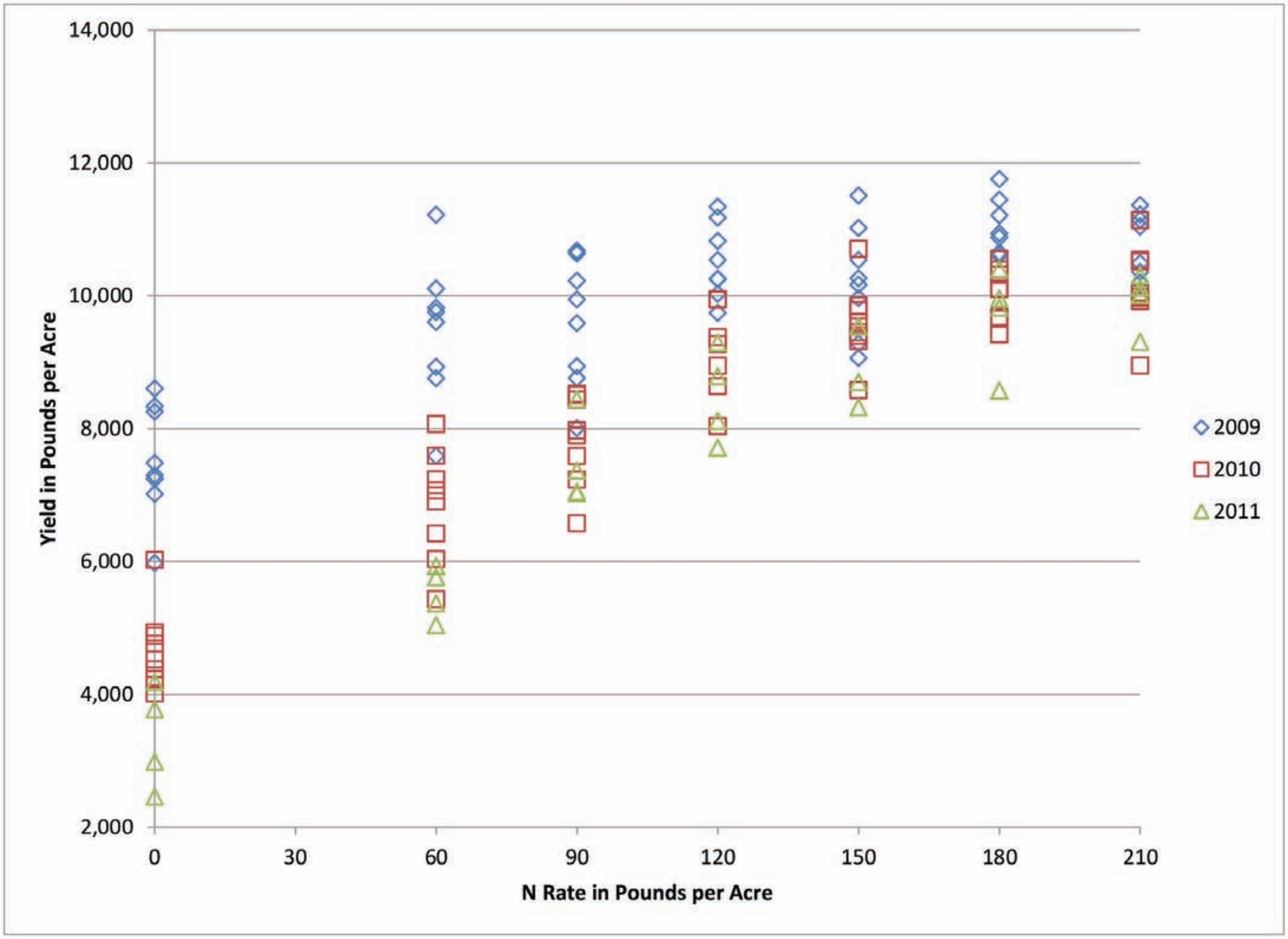


Figure 2. Cumulative Distribution Functions of Simulated CL111 Yields at Alternative Nitrogen Rates on Silt Loam Soils

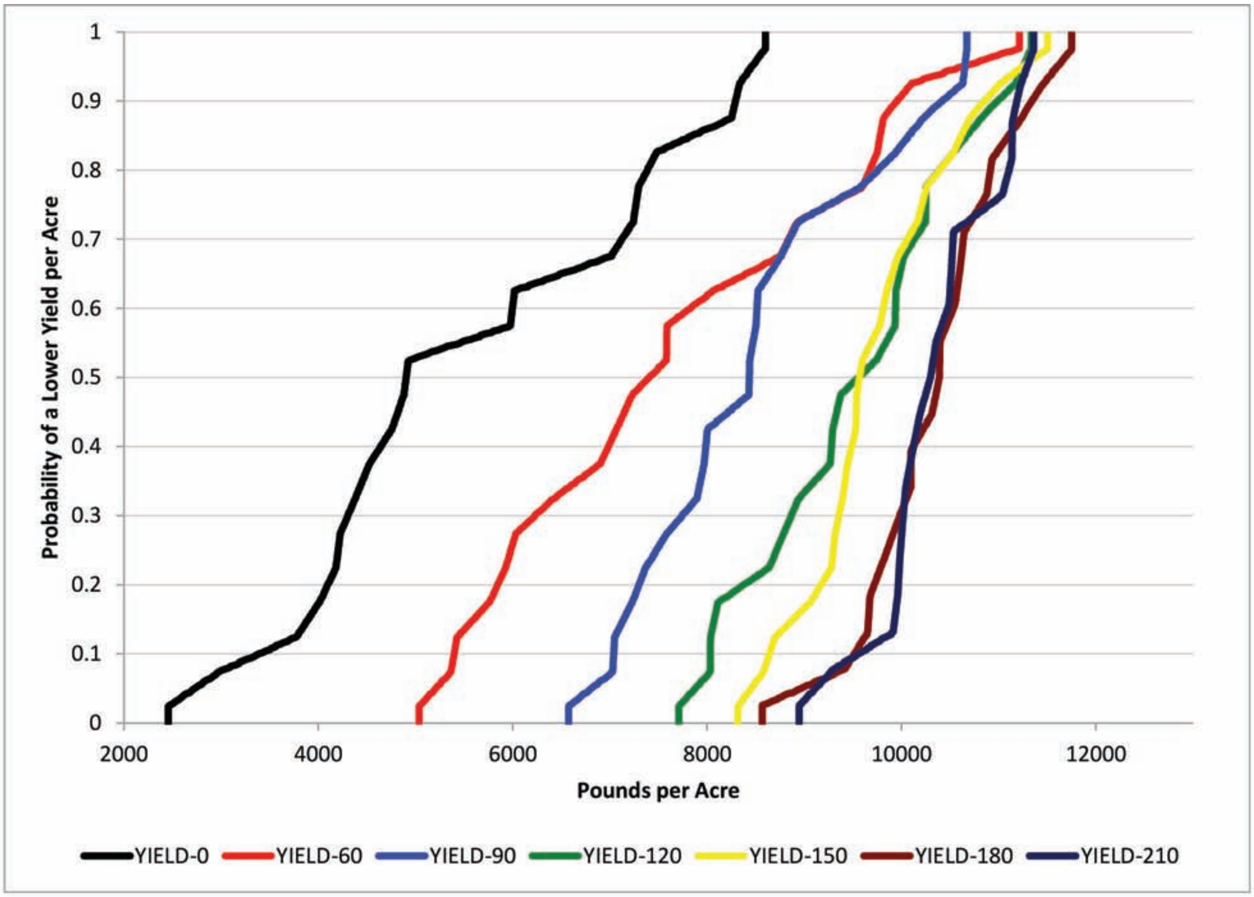


Figure 3. Risk Analysis for Returns Above Selected Harvest and Fertilization Costs

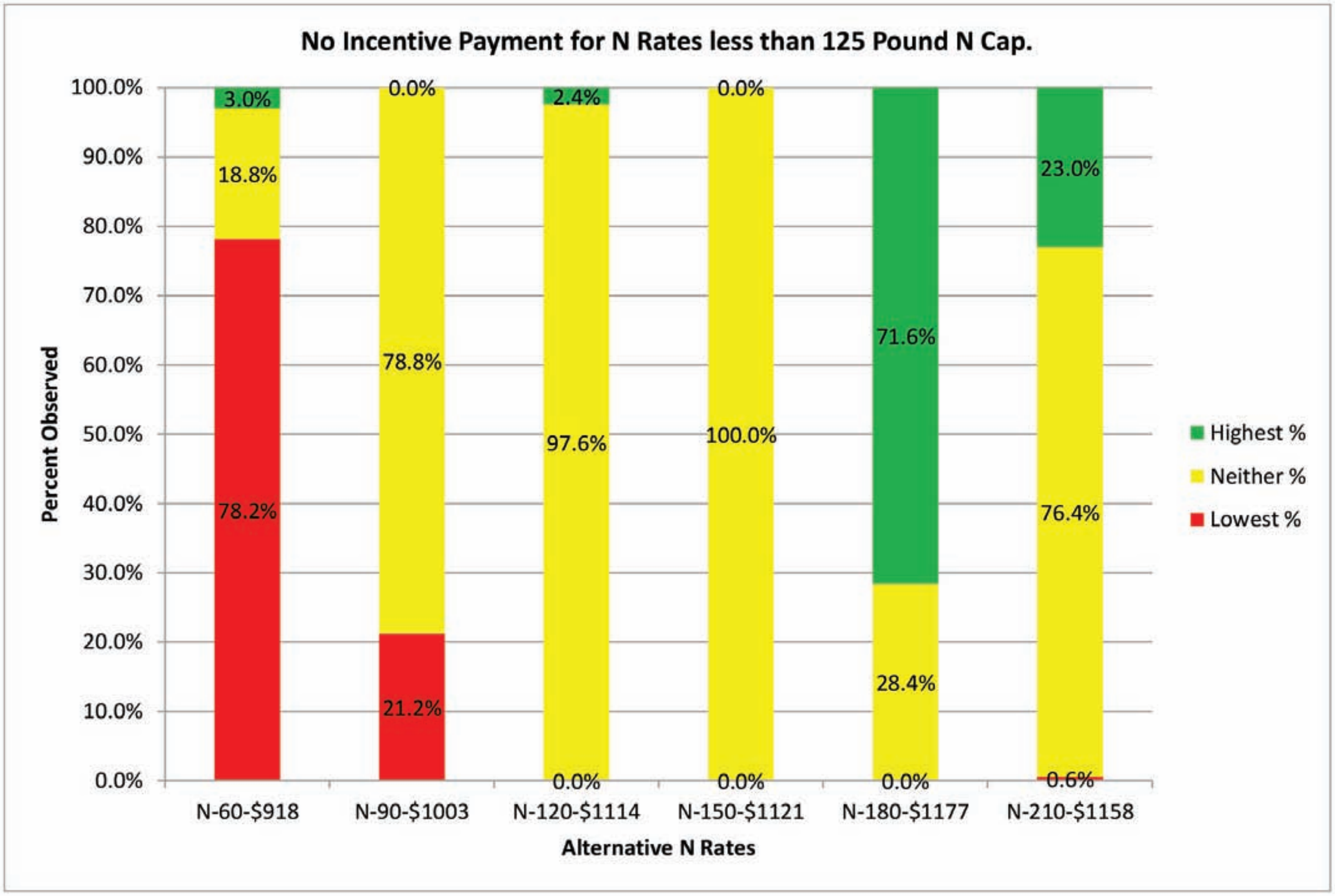


Figure 4. Risk Analysis for Returns Above Selected Harvest and Fertilization Costs Including $40 Incentive for Rates Less Than 125 Pounds per acre

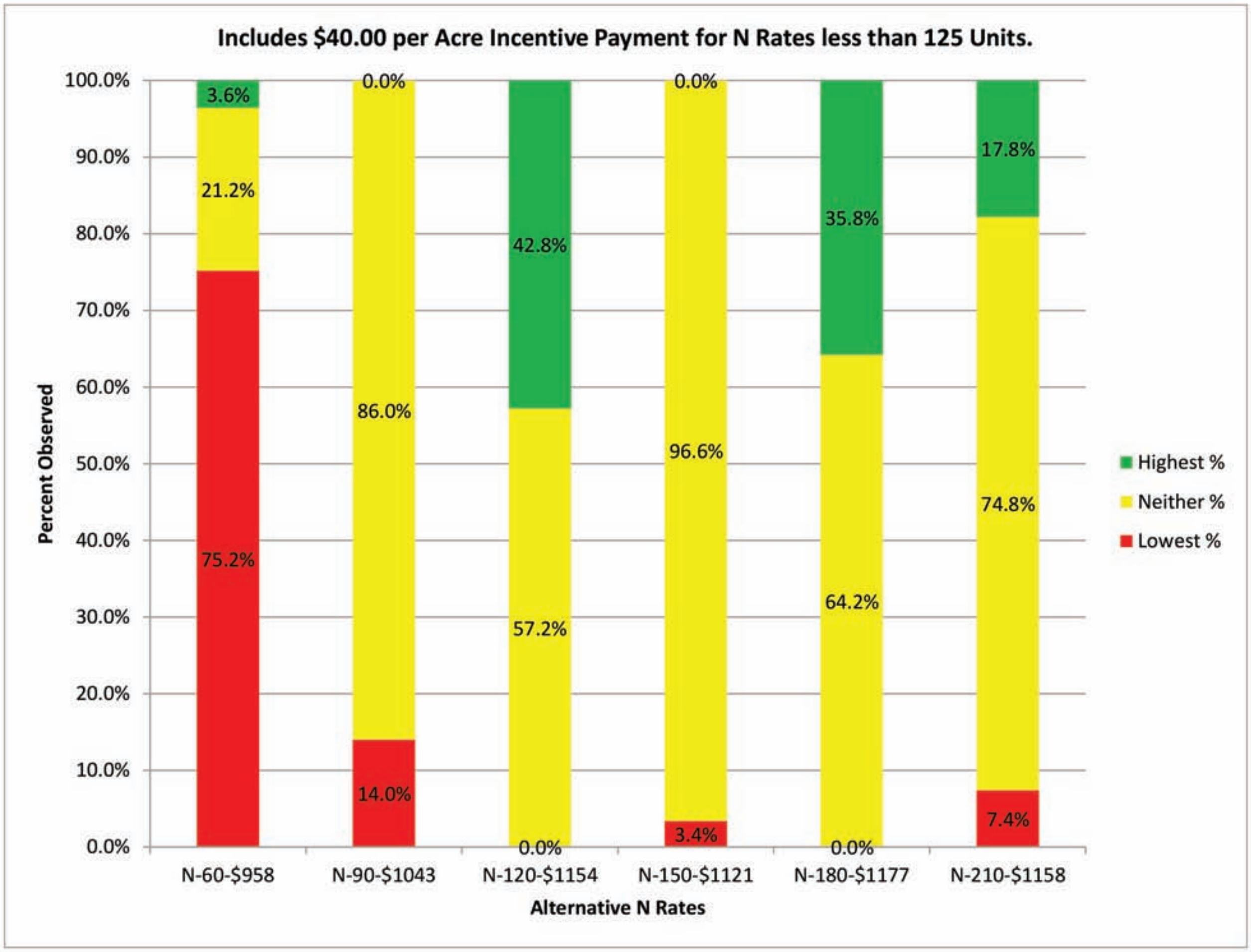


Figure 5. Risk Analysis for Returns Above Selected Harvest and Fertilization Costs Including $70 Incentive for Rates Less Than 125 Pounds per acre