A MIXED INTEGER, NONLINEAR PROGRAMMING MODEL OF INNOVATIVE VARIABLE RATE PLANTING DATE WITH POLYMER SEED COATINGS

By

Carl R. Dillon
Scott A. Shearer
Thomas Mueller

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Carl Dillon is an associate professor, Department of Agricultural Economics, Scott A. Shearer an associate professor, Department of Biosystems and Agricultural Engineering and Thomas Mueller an assistant professor, Department of Agronomy, all at the University of Kentucky. The authors wish to acknowledge Murali Kanakasabai, Ph. D. student in the Department of Agricultural Economics at the University of Kentucky, for assistance in biophysical simulation work.

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ABSTRACT

The economic potential of innovative variable rate planting date for profitability and risk reduction is examined in a whole farm management setting. A mixed integer, quadratic programming model using a mean-variance (E-V) framework is used to represent the precision agriculture issues of varying planting date with novel polymer seed coatings.

Keywords: precision agriculture, mathematical programming, risk, variable rate technology

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INTRODUCTION

The innovation of precision agriculture has given producers an opportunity to enhance profitability. Touted for its substantial potential for improved production decision making through additional information and more detailed application, precision agriculture has seen more engineering and agronomic analysis than economic analysis. While precision agriculture cannot be globally proclaimed to be profitable or not, the excitement of the opportunities for precision agriculture do not preclude consideration of the costs of the technology. Ultimately the question of whether a producer is more profitable is central to the adoption of this technology. Additionally, an often overlooked component of precision agriculture is the impacts it has upon risk management.

One of the benefits of precision agriculture is the possibility of the reduction of some factors of production which in turn can reduce environmental risk, enhance profits and reduce the risks borne by the producer. Variable rate technology allows producers to precisely apply the optimal level of an input, altering the amount spatially so that every portion of the field is treated uniquely. Fertilizer and pesticide applications using such technology are often first to come to mind. Variable rate seeding is another option wherein the producer can alter both variety and population (i.e., seeding rate) spatially. This presents the possibility of enhanced profits and/or reduced risk over the use of field average recommendations.

The concept of variable rate planting date is not far fetched. Currently, at least one agribusiness firm is conducting a research and development program for a polymer coating which delays the exposure of the seed to soil. Spraying this polymer on seed will enable farmers to physically plant seed earlier than would otherwise be optimal. Thus, additional time from planting to germination can be provided through this innovative technology. Producers could use this technology in an otherwise traditional sense by having more acreage germinate at the perceived optimal time through the polymer coated seed being planted in earlier time periods assuming suitable field time, thus managing their limited machinery capacity. Additionally, planting dates could be altered spatially through the use of coated seeds for some soil types and the use of standard, uncoated seeds for other soil types. Variable rate planting from a single machinery operation would be possible with the successful development of this polymer coated seed.

Prior to its commercial release, technology can be valued. Estimation of the value of this polymer coated seed is the thrust of this study. Innovative technologies are often developed without adequate consideration of the willingness to pay of the consumer for the product in question. An economic analysis will be performed herein to provide insights regarding the value of a polymer coated seed to a representative Kentucky farmer as a case study. In so doing, the potential of both increased profitability and reduced production risk will be examined.

The purpose of this research project is to develop an economic model which permits the assessment of the potential of an innovative development project which will enable variable rate planting date through the use of polymer coated seeds. The specific objectives are to:

1) Develop procedures which permit the determination of economic performance of the variable rate planting date and current variable rate seeding (variety and population) to compare their relative and combined success for profit maximization and risk management, and

2) Ascertain the willingness to pay for the various technologies as influenced by risk aversion levels to yield variability and suitable field day variability.

BACKGROUND INFORMATION

Background information in the form of a review of literature can serve to establish a basic framework for the proposed study. Included in this will be a general discussion of the three areas of risk, precision agriculture technology and mathematical programming.

Risk

The importance of risk management in agriculture decision-making has been well established (e.g. - Anderson, Dillon and Hardaker; Hardaker, Huirne and Anderson; Robison and Barry). Risk may be categorized into many different types and sources: production, price or marketing, institutional, human or personal and financial (Hardaker, Hurine and Anderson). Additionally, there are many individual types of risk within each of these major categories as well as many opportunities for managing these individual types of risk. Consequently, these issues will be briefly examined.

Production risk is frequently associated with fluctuating yields as a result of changes in weather. Crop yield variability, however, can result from several different causes including weather conditions, weeds, insects, disease and soil fertility. Furthermore, farmers have the ability to manage production risk through techniques beyond crop mix diversification. While several examples of crop mix as a means of reducing risk can be found (e.g.- Dillon, Mjelde and McCarl; Misra and Spurlock; Teague and Lee; Apland, Barnes and Justus) a wide variety of production practices for risk reduction have been researched: planting date (e.g.-Larson et al.; Larson and Mapp; Dillon, Mjelde and McCarl), variety selection (e.g.-Traxler et al.; Dillon; Grisley), plant population (e.g.-Larson et al.; Sweeney, Granade and Burton; Polito and Voss), irrigation (e.g.-Boggess and Ritchie; Boggess and Amerling; Harris and Mapp), pest management (e.g. Hurd; Szmedra, Wetzstein and McClendon), tillage technique (e.g.-Epplin and Al-Sakkaf; Krause and Black; Williams et al.), nutrient management (e.g.-Mjelde et al.; Pingali et al.), weed management (e.g.-Donald and Prato; Olson and Eidman; Zacharias and Grube) and stubble management (e.g.-Oriade, Dillon and Keisling).

Precision Agriculture Technology

The economic feasibility of precision agriculture is a common underlying question of producers considering its adoption. There are numerous studies regarding the economic issues in the area of precision agriculture. However, as is common with new technologies, many of the studies, they are broad based and display a substantial number of philosophical discussions. General philosophical discussions have ranged from historically descriptive (e.g.- Lowenberg-DeBoer; Sonka and Coaldrake) to examining the research opportunities and challenges of the future (e.g.-Weiss). Lowenberg-DeBoer and Swinton conducted a review of the economics of precision agriculture, finding that economic feasibility is dependent upon several factors including many components of the underlying economic, agronomic and engineering environment. Precision agriculture has been shown to be profitable, not profitable or inconclusive with mixed results, depending on the crop, inputs and conditions.

In addition to these general precision agriculture economic studies, the specific area of variable rate technology is worthy of examination. Variable rate technology research has included analyses of such components as nitrogen management (e.g., Thrikawala et al.; Babcock and Pautsch), lime application (e.g., Bongiovanni and Lowenberg-DeBoer) and spatial break-even variability assessment (English, Roberts and Mahajanashetti). Incorporation of risk management potential is not prevalent in the variable rate technology literature. While many of these economic analyses have examined anecdotal situations, risk with respect to the uncertainties due to variability in weather seemingly has yet to be considered. Development of a framework for investigating risk in precision agriculture systems will allow comparisons of different management scenarios such as variable rate seeding and early planting dates management to be made.

This study expands the related research by Dillon, Mueller and Shearer which examines the economics of variable rate planting date and seeding rate. While this paper is methodologically similar and borrows from this seminal piece, the study at hand incorporates suitable field day risk, evaluation of willingness to pay for each crop and focuses on a different location while including double -cropped wheat and soybeans. Dillon, Mueller and Shearer demonstrate the general increased willingness to pay for polymer coated seeds as yield risk aversion increases for the circumstances of that analysis. Furthermore, the greater value of the polymer coated seed under variable rate technology is displayed.

Mathematical Programming

Mathematical programming, as a constrained optimization technique, has not been utilized extensively in economic analysis of either the profitability or risk management potential of precision agriculture technologies. For the study at hand, consideration of mean-variance risk programming models and mixed integer programming models are relevant.

The use of mean-variance or E-V (expected value-variance) analysis as a risk modeling method is common in the literature. Boisvert and McCarl list 39 studies which use this technique. However, integration of a nonlinear programming model such as the quadratic programming technique of the mean-variance analysis with mixed integer programming models is not prevalent in the literature. Integer programming applications investigating risk management issues include Held and Helmer, Kaiser and Apland, Lambert and McCarl and Leatham and Baker.

ANALYTICAL PROCEDURE

The analytical procedure including both the theoretical and methodological framework for the study at hand embodies the decision-making environment facing the representative Henderson County grain producer in Kentucky. The farmer's assumed goal is to maximize expected utility which is represented in a mean-variance framework. The producer's decisions are determined by economics which in turn are driven by the underlying production function. Consequently, the discussion of the analytical procedure will focus on two issues: the crop production models and the economic model.

The Crop Production Models

The producer selects from corn, soybeans and wheat and the four enterprises of corn, full season soybeans, wheat and double-cropped soybeans with wheat. Crops were produced no-till under dryland conditions. A wide range of planting dates for all the crops were incorporated into the analysis as reflected in Kentucky Agricultural Statistics. However, in order to investigate the trends towards earlier planting dates and the potential of variable rate planting date, the ranges were moved earlier by one to two weeks. Additionally, alternative plant populations and maturity classes were examined for corn and soybean. Variable rate planting is allowed on only corn and full season soybeans for this study given the narrow window of completing double cropped enterprise activities and the question of delayed germination impact on feasibility to this system. Expert opinion of agricultural producers, Kentucky Cooperative Extension Service Specialists and others were sought in determination of the agronomic experimental design.

Corn planting took place in weekly intervals from March 29 through May 24 for nine planting dates. Corn included early, medium and late maturity classes as well as low, medium and high plant populations of 20,000; 24,000 and 28,000 plants per acre respectively. Corn yields are simulated using the CORNF model by Stapper and Arkin.

Soybean planting dates were in nine weekly intervals from April 26 through June 21. Three general, overall representative varieties of maturity group III, IV and V (MG III, MG IV, MG V) soybean were included. Additionally, six plant and row spacing combinations were incorporated for alternative plant population alternatives. These included soybean row spacing of nine inches (with two and three plants per foot), nineteen inch rows (with four and six plants per foot) and thirty inch rows (with six and nine plants per foot). The SOYGRO (Wilkerson et al.) model was used to simulate soybean yields.

The wheat planting dates were ranged from September 27 to November 22 in nine weekly intervals. Wheat was drilled with a single cultivar and plant population assumed. While wheat is almost always double-cropped with some other crop, often soybean, the option of single crop wheat was simulated. When wheat is double-cropped, it is assumed to be double-cropped with soybean which is planted ten days after wheat harvest. The double-cropped soybean plant and row spacing as well as maturity groups parallel those utilized for the full season soybean experimental design. The CERES model (Ritchie and Otter) model was utilized for simulating wheat yields and was integrated with the SOYGRO model for the simulation of double-cropped wheat and soybean. This allows the consideration of soil moisture impacts to be duly reflected in generating yield estimations.

The biophysical simulation models relied upon daily weather data from Henderson for 1978 through 1999 which, because of the overlap of winter wheat, provided twenty one seasons of estimated yield data. The exception on weather data was the need for solar radiation which required the use of Evansville, Indiana as a location. Extensive validation of yield responses to varying management practices was not possible because of insufficient data, which is the reason the biophysical simulation models are used. However, some validation was performed by reliance upon previous studies validation of all models concerned as well as comparison of overall yield levels and responsiveness of yields to alterations and to production practices. This entailed examination of Kentucky Agricultural Statistics for various years, comparison to Ohio Valley region of Kentucky Farm Business Management Association results (Morgan; Gibson) and discussions with experts. Overall, the yield responses seem to be quite reasonable.

The Economic Model

The case study production decision model is formulated as a mathematical programming model wherein a producer attempts to maximize the risk adjusted net returns above specified costs (including all variable costs and relevant fixed costs). This captures the underlying economic theoretical framework of shifting the production possibility curve (with commodity produced by time period representing the alternative outputs) inherent to the issue of polymer coated seed adoption. Land charges, property taxes and returns to management and overhead labor were excluded. The enterprises were incorporated as decision variables in the model. Constraints include land, suitable field days by week, rotational constraints and variable rate feasibility constraints. A mixed integer nonlinear model is required.

A combined quadratic and integer programming model was employed within a expected value-variance (E-V) framework to incorporate profit and risk considerations. The sufficiency conditions under which the use of E-V is consistent with expected utility theory include one of the following: (1) normal distribution (Freund), (2) if the distributions of net returns associated with the decision variable differ only by location and scale (Meyer) or (3) if the utility can be approximated by a quadratic function (Markowitz). The specification of the E-V model is:

$$MAX\ \overline{Y} - \Phi\sigma^2{}_y$$

subject to:

$$(1)\quad \sum_E \sum_V \sum_P \sum_S X_{E,V,P,S,ST} \leq ACRE_{ST} \qquad \forall ST$$

$$(2)\quad \sum_E \sum_V \sum_P \sum_S \sum_{ST} LAB_{E,S,WK} X_{E,V,P,S,ST} \leq FLDDAY_{WK} \qquad \forall WK$$

$$(3)\quad \sum_E \sum_V \sum_P \sum_S \sum_{ST} EXPYLD_{C,E,V,P,S,ST,YR} X_{E,V,P,S,ST} - SALES_{C,YR} = 0 \qquad \forall\ C,YR$$

$$(4)\quad \sum_E \sum_V \sum_P \sum_S \sum_{ST} REQ_{I,P*} X_{E,V,P,S,ST} - PURCH_I = 0 \qquad \forall I$$

$$(5)\quad \sum_I IP_I PURCH_I - \sum_C \underset{C}{P} * SALES_{C,YR} + Y_{YR} = 0 \qquad \forall\ YR$$

$$(6)\quad \sum_{YR} \frac{1}{N} Y_{YR} - \overline{Y} = 0$$

$$(7)\quad \sum_E \sum_V \sum_P \sum_S ROTATE_{R,E} X_{E,V,P,S,ST} \leq 0.5 * ACRE_{ST} \qquad \forall\ R,ST$$

$$(8)\quad \sum_P \sum_{ST} X_{E,V,P,S,ST} - M * INT_{V,S} \leq 0 \qquad \forall V,S$$

$$(9)\quad \sum_V INT_{V,S} \leq 2 \qquad \forall S$$

where

activities include:

$\overline{Y}$ = expected net returns above variable cost (mean across years)

Y_{YR} = net returns above variable cost by year (net returns)

$X_{E.V,P,S,ST}$ = production of enterprise E of variety V with a plant population P under sowing date S in acres on soil type ST

$SALES_{C,YR}$ = bushels of crop C, sold by year

$PURCH_{I}$ = purchases of input I

$INT_{v,s}$ = binary integer decision variables

constraints include:

(1) Land resource limitation
(2) Labor resource limitations by week
(3) Sales balance by crop and year
(4) Input purchases by input
(5) Profit balance by year
(6) Expected profit balance
(7) Rotation limitations
(8) Logical condition limitations
(9) Integer variable limitations of two seed bins

coefficients include:

Φ = Pratt risk-aversion coefficient
M = A large number (Big M)
P_{C} = Price of crop C in dollars per bushel
IP_{I} = Price of input I
$EXPYLD_{C,E,V,P,S,YR}$ = Expected yield of crop C for enterprise E of variety V planted in population P planted on sowing date S in bushels per acre for year YR
$REQ_{I,P}$ = Requirement of input I for production in row and plant spacing P in units per acre
$LAB_{E,S,WK}$ = Labor requirements for production of enterprise E planted on sowing date S in week WK in hours per acre
$FLDDAY_{WK}$ = Available field days per week at varying levels of certainty
$ROTATE_{R,E}$ = Rotation categorization matrix by enterprise E to include corn if R=1 and soybean if R=2

indices include:

C = Crop
E = Enterprise
V = Variety (MG III, IV and V for soybeans or EARLY, MEDIUM and LATE for corn)
P = Plant population
S = Sowing date
I = Input
WK = Week
YR = Year
R = Rotation category

The objective function maximizes the certainty equivalent of net returns which is net returns above variable costs (hereafter referred to as simply net returns) less the product of Pratt risk-aversion function coefficient and the variance of net returns (σ^2_y). The Pratt risk-aversion function coefficient is a measure of a hypothetical producer's aversion to risk. This coefficient is calculated using the method described by McCarl and Bessler, wherein a producer is said to maximize the lower limit from a confidence interval of normally distributed net returns. The resultant general formula for calculating the risk aversion parameter is:

$$\Phi = 2Z_{\alpha} / S_y$$

where Φ = risk-aversion coefficient, Z_{α}= the standardized normal Z value of α level of significance and S_y= the relevant standard deviation the risk-neutral profit maximizing base case for each.

The data required to specify the production decision model are: 1) available land by soil type, 2) available field days, 3) labor requirements, 4) input requirements and prices, 5) crop prices and 6) yields. The hypothetical farm is assumed to be a commercial size grain operation with 1500 acres. This is derived by rounding the average number of acres owned for an Ohio Valley grain farm of 1495 up to 1500 (Ibendahl, Morgan and Heisterberg). Proportions of soil type then are assumed at 50% each for base case runs and at 90% each under a sensitivity analysis discussed later.

A suitable field days simulation model was used to estimate the number of days suitable for fieldwork. This model relies upon historical weather data and soil water simulation under a modified procedure discussed by Dillon, Mjelde and McCarl. As the most restrictive soil type, a deep silt loam was used for this purpose. A 50% likelihood of a given number of days suitable for fieldwork occurring in any particular week was then specified as the base case labor constraint. Available field time is calculated by multiplying the average number of workable field days per week by 12 working hours per day for 2.56 persons (an average number of laborers on a Kentucky grain farm, see Morgan). The weekly number of days the tractor could work was calculated using a field days criteria function. The criteria used to identify a nonworking day are: 1) if it rained three consecutive days, the third day along with the following day is not considered a field day, 2) if the soil moisture of the top 3.9 inches (10cm) is 80 percent or greater of water storage capacity on a given day, then that day is not considered a field day, and 3) if it rained 0.15 inches (0.38 cm) or more on a given day, then that day is not considered a field day. The soil moisture portion of the biophysical model is used to derive soil moisture. The vector of the field days available appeared as the weekly right-hand side values in the mathematical programming model; the average weekly days available for Henderson was 6.29 with a standard deviation of 1.88.

The chance-constrained formulation of the uncertain right-hand side of days suitable for fieldwork used herein is the well known technique developed by Charnes and Cooper. Some applications of the technique to agriculture are seen in the literature (e.g.- Boisvert and Jensen; Danok et al.) and the technique is much simpler to use than stochastic programming with recourse (Etyang et al.). Consequently, the labor constraints are, in general mathematical programming notation:

$$P\left(\sum_j a_{ij} X_j \leq b_i\right) \geq \alpha$$

This in turn may be reduced to:

$$\Sigma\, a_{ij} X_j \leq b_{i,\alpha}$$

where $b_{i,\alpha}$ is the b_i associated with a probability α of occurring. This more general form is used because the days per week suitable for fieldwork is not normally distributed based upon

Kolmogorov-Smirnov statistics. Consequently, the normally distributed $\overline{b_i}$ - $Z_\alpha \sigma_{bi}$ was not used but rather actual sample distribution calculations for α including 50, 75 and 90 percent likely.

The labor requirements per week, input prices and input requirements per acre were taken from representative Tennessee no-till enterprise budgets (Gerloff and Maxey). Labor requirements were adjusted to weekly data and shifted by planting date. Statistical computation of simulated harvest dates allowed for adjustment of harvest time by maturity class. The 1995-1999 Kentucky average season prices for each crop were used with \$2.64/bu for corn, \$6.89/bu for soybean and \$3.16/bu for wheat (Kentucky Agricultural Statistics 1998-1999). A hauling charge of \$0.15/bu was subtracted in each case.

RESULTS AND DISCUSSION

Results focus on the willingness to pay for the polymer coated seed technology as influenced by risk aversion levels to yield variability and suitable field day variability. Furthermore, analysis is conducted for the economic potential of this technology when used under two production management systems: traditional field average application and variable rate application of seeding rate and variety assuming a two seed bin per row planter. A maximum willingness to pay is estimated by examining the optimal objective function value of the unconstrained scenario and an economic experiment disallowing the use of the polymer coated seed. Objective function value differences attributable to the seed technology are allocated to each crop assuming an average 50 pound per acre soybean seed requirement and a 0.25 bag/acre corn seed requirement. A field average condition is modeled by requiring production practices to remain the same across soil types whereas the variable rate technology permits alteration across soil types when relevant (i.e., actual planting time cannot be varied but the polymer coated seed allows for delay in germination).

The maximum willingness to pay and acreage levels for the polymer coated seed technology are displayed for the traditional field average production system in Table 1 and the variable rate technology system in Table 2. Different risk attitude results for yield and suitable field day risk are presented. The results demonstrate the complicated interactions and dynamics involved in the analysis. Under field average conditions, the use of polymer coated seed in corn was virtually nonexistent with no and medium risk aversion to suitable field days under risk neutrality toward yield risk being an exception. The medium suitable field day risk and 90% risk aversion level to yield risk was the other exception. Soybean production demonstrated a much greater use of the technology for the conditions analyzed. The increase of risk aversion to suitable field day availability generally resulted in increased use of the polymer coated seed as might be expected but this trend was not globally present across all yield risk aversion levels indicating the complexity of the decision. Unlike the findings of Dillon, Mueller and Shearer which shows a generally increased willingness to pay for a Shelby county, Kentucky producer under greater yield risk aversion, no specific trends exist for yield risk aversion for the conditions analyzed in this study. The entirely risk neutral producer adopted no polymer coated seeds while initial yield risk aversion led to a willingness to pay of 2.16 cents per pound for soybean seed and $4.31 per bag of corn seed. At extremely high suitable field day risk aversion, the willingness to pay for polymer coated soybean seed ranges from 16.59 cents per pound to as high as 65.13 cents per pound. Also note that despite the fact that as much as 61% of soybean acreage may be planted using the new seed technology, almost no increase in producer welfare leads to a willingness to pay of zero for polymer coated soybean seed under some circumstances.

There is generally a greater willingness to pay for the new seed technology under variable rate technology as might be anticipated (Table 2). This is especially true for corn where a marked improvement in the adoption of the technology is evident. This is a dramatic shift from only three risk attitude combinations resulting in adoption under field average to almost every risk attitude combination resulting in polymer coated seed usage. Under risk neutrality, the maximum willingness to pay for polymer coated corn (soybean) seed ranged from \$21.10 to \$37.13 per bag (10.55 to 18.57 cents per pound) across suitable field day risk aversion. The production environment modeled demonstrates a generally declining willingness to pay as yield risk aversion increases unlike the findings of Dillon, Mueller and Shearer. This could be due to the underlying production environment and weather condition differences. Trend differences in the northern United States versus the southern United States might be a possibility here and merit further investigation.

Sensitivity analysis of changes in the results of polymer coated seed technology adoption under variable rate precision agriculture production systems to alteration in crop prices was conducted. Specifically, an increase and a decrease in all three crop prices amounting to 25% was modeled and the new optimal solution studied. The results are presented in Tables 3 and 4 for crop price decreases and increases respectively. The adoption of polymer coated seed was virtually eliminated for corn production with the reduced output prices. Only the yield risk neutral displayed adoption at 24 to 27% of the corn acreage and a willingness to pay of \$15.65 and \$17.17 per bag for no and medium suitable field day risk averse producers respectively. While the maximum willingness to pay decreased for the yield risk neutral scenario for soybean seed, it increased for soybean seed under all yield risk averse scenarios coupled with no or medium suitable field day risk aversion. Extreme risk aversion to suitable field day availability demonstrated mixed results.

Increases in crop prices lead to higher levels of adoption of polymer coated seed technology in corn (Table 4) of up to 50% of acreage. Adoption rates and the maximum willingness to pay were equal or greater for corn seed under very yield risk and suitable field day risk combination examined. Trends of the impact of increased crop prices on soybean seed adoption rates and willingness to pay were not as obvious with mixed results offered by the model solutions. It is possible that the interactions of competing for scarce resources may lead to one crop driving the derived demand for polymer coated seed and the second most profitable crop possessing a need for the technology only as remaining suitable field day resources dictate. Further investigation of this supposition is needed.

SUMMARY AND CONCLUSIONS

Although not currently available commercially, scientists are developing chemical coatings on seed which will delay germination and thereby allow variable rate planting date. Investigation of this potential variable rate planting date technology is conducted in this study to assist in determining the economic potential prior to its complete development.

Economists need to be proactive in providing feasibility assessments in the development of new technology. Detailed economic assessment of the benefits of potential technological developments can assist in shaping the direction of strategic plans regarding resources allocated to research and development of such technology. Greater willingness to pay for the new seed technology is evident for variable rate precision agriculture than under traditional field average production systems. Greater aversion to suitable field day risk generally leads to a greater adoption of the polymer coated seed and a greater willingness to pay. Unlike a previous study, increased yield risk aversion did not generally give rise to increased willingness to pay indicating the complexity of the decisions to adopt this novel delayed germination technology.

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Table 1. Maximum Producer Willingness to Pay for and Percentage Acres in Polymer Coated Seed under Traditional Field Average

	Corn			Soybean		
Yield Risk Aversion	Suitable Field Day Risk Aversion* None	Medium	High	Suitable Field Day Risk Aversion* None	Medium	High
	Willingness to Pay ($/bag)			Willingness to Pay (cents/lb)		
50%	0.00	2.33	0.00	0.00	0.00	16.59
55%	4.31	9.15	0.00	2.16	4.58	31.21
60%	0.00	0.00	0.00	5.43	3.67	53.27
65%	0.00	0.00	0.00	6.53	0.57	57.57
70%	0.00	0.00	0.00	4.21	0.15	59.27
75%	0.00	0.00	0.00	0.00	0.00	58.32
80%	0.00	0.00	0.00	0.00	0.00	58.32
85%	0.00	0.00	0.00	0.00	0.00	65.13
90%	0.00	0.00	0.00	0.00	0.00	60.27
	Acreage (%)			Acreage (%)		
50%	0	6	0	0	0	28
55%	0	13	0	20	20	28
60%	0	0	0	18	27	28
65%	0	0	0	5	61	39
70%	0	0	0	2	61	41
75%	0	0	0	0	61	41
80%	0	0	0	0	61	41
85%	0	0	0	0	61	41
90%	0	0	0	0	54	41

*The yield risk level represents the certainty of receiving or exceeding a maximized lower level confidence limit on net returns. Assuming a normal distribution of net returns, a 50 percent certainty exists at risk neutrality that the actual net returns will be at or higher than the expected net returns. With risk aversion, a higher percentage of certainty in net returns is required; therefore, a certainty parameter larger than 50 percent is necessary. McCarl and Bessler provided details. The suitable field day risk aversion represents the likelihood of completing machinery operations by week with 50%, 75% and 90% likelihood for no, medium or high risk aversion respectively.

Table 2. Maximum Producer Willingness to Pay for and Percentage Acres in Polymer Coated Seed under Variable Rate Technology

Yield Risk Aversion	Corn Suitable Field Day Risk Aversion* None	Medium	High	Soybean Suitable Field Day Risk Aversion* None	Medium	High
	Willingness to Pay ($/bag)			Willingness to Pay (cents/lb)		
50%	21.10	23.16	37.13	10.55	11.58	18.57
55%	12.57	11.91	46.88	6.29	5.95	23.44
60%	7.35	7.46	0.00	3.67	3.73	37.62
65%	8.08	8.22	0.00	4.04	4.11	44.99
70%	9.49	9.49	63.33	4.75	4.75	31.67
75%	9.81	9.81	76.01	4.90	4.90	38.01
80%	9.62	9.62	0.00	4.81	4.81	60.36
85%	0.83	0.74	0.00	0.42	0.37	66.48
90%	0.09	0.00	0.00	0.05	0.00	59.06
	Acreage (%)			Acreage (%)		
50%	27	24	12	28	28	25
55%	50	50	12	28	28	25
60%	50	50	0	16	15	28
65%	50	50	0	8	7	35
70%	46	46	23	4	4	41
75%	25	25	16	3	3	41
80%	12	12	0	1	1	41
85%	5	4	0	55	59	40
90%	1	0	0	36	40	45

* See footnote of Table 1.

Table 3. Maximum Producer Willingness to Pay for and Percentage Acres in Polymer Coated Seed under Variable Rate Technology and 25% Crop Price Decreases

	Corn			Soybean		
Yield Risk	Suitable Field Day Risk Aversion*			Suitable Field Day Risk Aversion*		
Aversion	None	Medium	High	None	Medium	High
	Willingness to Pay ($/bag)			Willingness to Pay (cents/lb)		
50%	15.65	17.17	0.00	7.83	8.59	16.56
55%	0.00	0.00	0.00	10.03	10.03	26.55
60%	0.00	0.00	0.00	7.89	7.89	29.51
65%	0.00	0.00	0.00	7.82	7.82	32.64
70%	0.00	0.00	0.00	7.69	7.69	35.93
75%	0.00	0.00	0.00	7.44	7.44	39.51
80%	0.00	0.00	0.00	6.92	6.92	43.47
85%	0.00	0.00	0.00	4.88	4.88	45.85
90%	0.00	0.00	0.00	1.38	1.38	42.75
	Acreage (%)			Acreage (%)		
50%	27	24	0	28	28	51
55%	0	0	0	28	28	41
60%	0	0	0	27	27	41
65%	0	0	0	16	16	41
70%	0	0	0	11	11	41
75%	0	0	0	7	7	41
80%	0	0	0	5	5	41
85%	0	0	0	3	3	41
90%	0	0	0	1	1	41

* See footnote of Table 1.

Table 4. Maximum Producer Willingness to Pay for and Percentage Acres in Polymer Coated Seed under Variable Rate Technology and 25% Crop Price Increases

	Corn			Soybean		
Yield Risk	Suitable Field Day Risk Aversion*			Suitable Field Day Risk Aversion*		
Aversion	None	Medium	High	None	Medium	High
	Willingness to Pay ($/bag)			Willingness to Pay (cents/lb)		
50%	9.18	26.16	46.92	4.59	13.08	23.46
55%	13.48	13.07	61.37	0.00	6.54	30.68
60%	9.39	9.60	0.00	4.70	4.80	62.20
65%	11.68	11.71	77.40	5.84	5.85	38.70
70%	14.18	14.19	69.83	0.00	0.00	34.91
75%	8.74	9.44	79.86	4.37	4.72	39.93
80%	11.24	11.15	85.65	5.62	5.58	42.82
85%	12.28	13.58	93.09	6.14	6.79	46.54
90%	11.63	13.49	84.54	5.81	6.74	42.27
	Acreage (%)				Acreage (%)	
50%	45	24	12	0	28	25
55%	50	50	12	27	27	25
60%	50	50	0	11	11	23
65%	50	50	18	4	4	28
70%	50	50	26	0	0	45
75%	45	44	26	36	40	52
80%	36	35	26	18	25	53
85%	25	24	15	13	15	53
90%	15	15	6	8	11	53

* See footnote of Table 1.