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# Value of Temperature-Activated Polymer-Coated Seed in the Northern Corn Belt

## David W. Archer and Russ W. Gesch

The value of an innovative seed technology is estimated in a discrete stochastic programming framework for a representative farm in the northern Corn Belt. Temperature-activated polymer-coated seed has the potential to increase net returns by increasing yields due to early planting and use of longer season varieties, as well as reducing yield loss due to delayed planting. A biophysical simulation model was used to estimate the impact of polymer-coated seed on corn and soybean yields and on field day availability for five planting periods, three crop varieties, and two tillage systems on two different soils under varying weather conditions.

*Key Words:* biophysical simulation, corn, mathematical programming, soybean

**JEL Classifications:** Q12, C61

A recent technological innovation has the potential to significantly change the timing of farmers' planting activities. A temperature-activated polymer seed coating has been developed that delays the exposure of seed to the soil until the soil reaches a specific temperature. When the soil reaches the critical temperature, the coating allows the seed to be exposed to the soil, and germination can occur. Polymer-coated seed has several potential uses. Dillon, Shearer, and Mueller investigated the value of polymer-coated seed in uniform whole-field and site-specific variable planting date applications for a representative Kentucky farm. They found that use of the technology would be limited for a risk-neutral producer in uniform whole-field applications, with much greater potential use and higher willingness-to-pay in site-specific variable planting date applications. The technology also could be used to improve planting options in double cropping systems. McCoy, Vyn, and West found that planting polymer-coated soybeans into standing wheat in late spring improved crop yields compared with seeding uncoated soybeans into standing wheat, making double cropping a viable alternative in traditional single crop areas. Perhaps the most widespread use of the technology, however, will be in early planting applications.

In early planting applications, polymer-coated seed has the potential to extend the planting window. A producer with limited labor or equipment could use the extended planting window to complete planting earlier, realizing higher yields by making full use of the available growing season and reducing potential yield losses due to delayed planting. Also, polymer-coated seed may allow produc-

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ers to plant longer season varieties, increasing potential yields. These factors are particularly important on the northern edge of the Corn Belt, where a short growing season leads to significant yield reduction when seeding is delayed beyond the optimum period and where cool, wet spring conditions often hinder seeding operations. Cool, wet spring conditions are also a significant barrier to the adoption of no tillage (NT) in the northern Corn Belt. The potential for polymer-coated seed to reduce this barrier has generated considerable interest (Grooms). Initial field research has shown that the polymer coating may allow corn and soybeans to be planted as much as 4 weeks early without a reduction in yield (Gesch et al.).

Prior to commercial release of the technology, it is useful to identify how it may be used, including its economic value to potential users, and impacts on cropping practices. The impact of this technology is illustrated with the case of a representative farm in the northern Corn Belt.

## Analytical Method

The benefits of using polymer-coated seed occur in the years when planting can begin early, reducing the risk of delayed planting. However, the opportunity for early planting can vary greatly from year to year with varying weather conditions. The stochastic nature of early planting opportunities leads to the formulation of production decisions in a discrete stochastic programming (DSP) model. A model was constructed for a representative farm in Stevens County, Minnesota. The farmer's objective was to maximize expected net returns given a production technology set and subject to uncertain weather conditions.

### *Crop Production*

Crop yields may be affected by weather conditions in the northern Corn Belt in several ways. Wet conditions in the spring may cause planting to be delayed, shortening the growing season and reducing crop yields. However, planting too early increases the risk of frost damage for early emerging crops, and prolonged cool, wet conditions after planting may cause seed to deteriorate in the soil. Temperature-activated polymer-coated seed may allow earlier planting while reducing the risk that seed will deteriorate in the soil and maximizing use of the growing season. However, if soil temperatures are warm early in the spring, polymer-coated seed may not protect against frost damage to early emerging crops.

To capture these effects, the Erosion/Productivity Impact Calculator (EPIC) biophysical simulation model (Sharpley and Williams) was used to estimate the impact of polymer-coated seed on corn and soybean yields under varying weather conditions. The EPIC simulations were run over a 51-year period using historical daily weather observations from the University of Minnesota West Central Research and Outreach Center. Missing weather observations were replaced using values generated by EPIC. The first year from each simulation was discarded to reduce the impact of initial conditions, leaving 50 years of observations for the analysis.

Yields were simulated for each crop with weekly planting dates ranging from April 3 to May 22 for corn (8 weeks) and from April 3 to June 5 for soybeans (10 weeks). EPIC adjusts planting dates from year to year by checking soil temperatures beginning on the specified planting date and initiating planting when the soil temperature reaches a specified minimum. For this analysis the soil temperature minimums were 50°F (10°C) for corn and 54°F (12°C) for soybeans. This mimics the behavior of seed with a polymer coating that becomes permeable at 50°F for corn and 54°F for soybeans. The EPIC model does not, however, model deterioration of seed in the soil prior to germination and the resulting yield loss. To capture this effect, it was assumed that seed deterioration would be significant enough that planting before the "normal" planting dates of April 29 for corn and May 13 for soybeans would be precluded for uncoated seed. After the normal planting dates, it was assumed that no seed deterioration would occur and yields for coated and uncoated seed would be identical. This assumption could overestimate the relative value of seed com-

**Table 1.** Expected Corn Yields from EPIC Simulation by Soil, Tillage, and Maturity

| | Conventional Tillage | | | No-Till | | |
|---|---|---|---|---|---|---|
| Planting Period | Early | Normal | Late | Early | Normal | Late |
| | bushels/acre | | | | | |
| Aastad soil | | | | | | |
| March 31–April 13 | 148.7 | 153.5 | 154.0 | 134.1 | 137.8 | 136.6 |
| April 14–April 28 | 149.1 | 153.7 | 154.0 | 134.3 | 138.3 | 137.3 |
| April 29–May 12 | 148.7 | 152.3 | 151.1 | 133.8 | 137.4 | 135.6 |
| May 13–May 26 | 144.4 | 144.7 | 140.5 | 130.3 | 131.1 | 127.1 |
| May 27–June 9 | 133.5 | 128.9 | 119.6 | 120.5 | 116.2 | 107.6 |
| Parnell soil | | | | | | |
| March 31–April 13 | 140.8 | 143.7 | 142.8 | 125.7 | 127.9 | 126.2 |
| April 14–April 28 | 141.2 | 144.0 | 143.0 | 125.8 | 128.4 | 127.0 |
| April 29–May 12 | 140.7 | 142.4 | 140.1 | 125.2 | 127.6 | 125.6 |
| May 13–May 26 | 135.9 | 134.9 | 130.2 | 122.3 | 122.7 | 118.7 |
| May 27–June 9 | 124.4 | 119.3 | 110.4 | 113.4 | 108.8 | 100.6 |

pared with uncoated seed, since it limits some of the planting flexibility available with uncoated seed prior to normal planting dates. However, after the normal planting dates, this assumption ignores some of the yield loss that could occur from seed deterioration of uncoated seed, which would tend to underestimate the benefits of polymer-coated seed.

Yields were simulated for three different maturity classes for each crop denoted early, normal, and late. Yields were also simulated under two different tillage systems, conventional tillage (CT) and NT, and for two different soil types, Aastad clay loam and Parnell silty clay loam. Weekly crop yields were averaged for each of five 2-week periods to reduce the number of stages included in the DSP model to a tractable level. The five planting periods used in the DSP model were March 31–April 13, April 14–28, April 29–May 12, May 13–26, and May 27–June 9.

Expected corn and soybean yields from the EPIC simulations are shown in Tables 1 and 2. Expected yields were generally highest when planting 2 weeks early for corn and 4 weeks early for soybeans. However, expected

**Table 2.** Expected Soybean Yields from EPIC Simulation by Soil, Tillage, and Maturity

| | Conventional Tillage | | | No-Till | | |
|---|---|---|---|---|---|---|
| Planting Period | Early | Normal | Late | Early | Normal | Late |
| | bushels/acre | | | | | |
| Aastad soil | | | | | | |
| March 31–April 13 | 44.1 | 45.8 | 45.7 | 39.9 | 41.6 | 41.4 |
| April 14–April 28 | 44.3 | 45.9 | 45.7 | 39.9 | 41.6 | 41.4 |
| April 29–May 12 | 44.2 | 45.6 | 45.4 | 39.9 | 41.6 | 41.3 |
| May 13–May 26 | 43.3 | 44.2 | 43.1 | 39.3 | 40.5 | 39.6 |
| May 27–June 9 | 41.3 | 40.6 | 37.7 | 37.8 | 37.6 | 34.9 |
| Parnell soil | | | | | | |
| March 31–April 13 | 40.6 | 41.4 | 40.7 | 36.5 | 37.3 | 36.1 |
| April 14–April 28 | 40.8 | 41.6 | 40.8 | 36.6 | 37.3 | 36.1 |
| April 29–May 12 | 40.8 | 41.5 | 40.8 | 36.6 | 37.3 | 36.1 |
| May 13–May 26 | 39.8 | 40.0 | 38.8 | 36.0 | 36.6 | 35.0 |
| May 27–June 9 | 37.6 | 36.7 | 33.9 | 34.9 | 34.4 | 31.7 |

yields tended to decrease for the earliest planting periods due to the increased incidence of frost damage. Expected yields decreased for delayed plantings, decreasing more rapidly for later maturity varieties than for early maturity varieties. Although highest yields occurred under CT, yields also tended to decrease more rapidly with delayed planting than under NT. Similarly, expected yields were higher on Aastad soils than on Parnell soils, but they also tended to decrease more rapidly with delayed planting.

### *Field Day Estimation*

EPIC-simulated soil moisture and temperature values were also used to estimate the impact of varying weather conditions on field day availability. A modified version of the procedure described by Dillon, Mjelde, and McCarl was used to determine field day availability. The criteria used to identify a nonworking day were (1) if it rained 0.15 inches (0.38 cm) or more on a given day, that day was not considered a field day; (2) if soil moisture in the top 3.9 inches (10 cm) was greater than 80% of available water capacity for CT or greater than 90% of available water capacity for NT, that day was not considered a field day; and (3) if soil temperature was at or below 32°F (0°C) at any depth, that day was not considered a field day. A higher available water capacity threshold was used for NT than for CT to take into account the effect of better soil structure in the undisturbed soil under NT, which would allow field traffic in wetter conditions.

In general, there tended to be fewer available field days for the Parnell soil than for the Aastad soil due to the greater water-holding capacity of the Parnell soil. Also, there tended to be fewer available field days under NT than under CT due to slower drying under NT. Consequently, the least limiting field conditions occurred on the Aastad soil under CT, and the most limiting field conditions occurred on the Parnell soil under NT.

The total number of field days available in each 2-week planting period was treated as stochastic in the DSP model. In order to reduce the "curse of dimensionality" problem in the DSP model, it was determined that the distributions would be approximated by a two-point estimate using Gaussian quadrature (GQ). With five planting periods, this would lead to $2^5 = 32$ states of nature in the model.

The distribution of available field days differed for the corn and soybean simulations, so the GQ estimates for each crop would provide different estimates of the states of nature. These could not be handled simultaneously in the DSP model. It was decided to use the distribution from the corn simulations only, which generally had the most limiting field day availability. Field day distributions also differed depending on tillage system and soil type. However, the tillage system decision is generally a longer term decision made for the entire farm, so only one tillage distribution would be used for making within-season cropping decisions. Also, assuming both soil types occurred in all fields, only the most limiting soil type would be relevant in determining field day availability.

As Etyang et al. indicate, the distribution of available field days in one period may be related to the realized number of field days in previous periods. To allow for this possibility, the number of available field days in each period was regressed, recursively, by ordinary least squares starting with the number of field days in the preceding period, then the number of field days in each of the two preceding periods, descending to period 1. The regressions in which all of the coefficients were significant were selected as the "best" models. Results for the significant regressions are given in Table 3. The number of field days available in period 5 ($D_5$) was not related to the number of field days in any previous period for any tillage system or soil type. The number of field days in period 4 ($D_4$) was not related to the number of field days in any previous periods for CT on either soil type, and the number of field days in period 3 ($D_3$) was not related to the number of field days in any previous periods for CT on an Aastad soil. The number of available field days in most other periods showed a positive significant relationship with the previous period, indicating a tendency for conditions to persist. The results agree with

**Table 3.** Regression of Available Field Days on Previous Period(s) Available Field Days

| $D_i$ Available Field Days in Period $i$ | Conventional Tillage Intercept | Conventional Tillage $D_{i-1}$ Coefficient | Conventional Tillage $D_{i-2}$ Coefficient | No-Till Intercept | No-Till $D_{i-1}$ Coefficient |
|---|---|---|---|---|---|
| Aastad soil | | | | | |
| $D_2$ | 2.393 | 0.745 | | 2.060 | 0.619 |
| $D_3$ | | | | 3.464 | 0.525 |
| $D_4$ | | | | 6.711 | 0.314 |
| Parnell soil | | | | | |
| $D_2$ | 1.399 | 0.729 | | 1.111 | 0.638 |
| $D_3$ | 5.648 | 0.680 | −0.449 | 2.151 | 0.649 |
| $D_4$ | | | | 4.195 | 0.533 |

the perception that available field days are more persistent early in the season when temperatures are cool and soils take longer to dry. Also, the results agree with the perception that available field days are more persistent under NT than under CT because higher crop residue amounts on the soil surface under NT slow soil drying. The results for period 3 ($D_3$) under CT and on a Parnell soil were unusual in that the coefficients for the previous two periods were both significant and the coefficient on the two-period lagged coefficient was negative. This would indicate that conditions generally persist for a period, but tend to reverse within two periods. It is not intuitively clear why this might be the case.

The GQ estimates of available field days are given in Table 4. For periods where the number of available field days were not related to available field days in previous periods, the procedure outlined by Preckel and DeVuyst was used to estimate 2-point GQ distributions. Initially, the first three sample moments of available field days were calculated from the observations generated by the EPIC simulations. Second, the following system of equations was solved for $c_0$ and $c_1$:

$$(1) \qquad c_0 + c_1E(X) = -E(X^2)$$
$$c_0E(X) + c_1(X^2) = -E(X^3),$$

where $E(X)$, $E(X^2)$, and $E(X^3)$ are the sample moments. Third, the quadratic equation

$$(2) \qquad X^2 + c_1X + c_0 = 0$$

was solved for roots $X_1$ and $X_2$, the two point-estimates of available field days. Finally, the system

$$(3) \qquad p_1 + p_2 = 1$$
$$p_1X_1 + p_2X_2 = E(X)$$

was solved for $p_1$ and $p_2$, the probability estimates for each point-estimate.

For periods where the number of available field days depended on available field days in previous periods, the procedure was modified following Etyang et al. to generate 2-point estimates based on the sample moments of the regression residuals. These points were then used in the regression equation along with the number of field days in the previous period to obtain estimates of the field days in the current period. For example, the number of days available in period 2 on an Aastad soil under CT depends on the number of days available in the previous period. Suppose the realization in period 1 was point 2, so there were 11.07 days available for field work. If the realization in period 2 was point 1, then the number of field days available in period 2 would be $D_2 = 2.393 + 0.745 \times 11.07 - 2.80 = 7.84$.

In 25% of the cases, the 2-point GQ estimation procedure produced negative estimates of available field days for one of the points. To obtain 2-point estimates that were feasible while retaining as much information on the observed distribution as possible, it was necessary to relax the condition that the 2-point distribution exactly matches the first three mo-

**Table 4.** Two-Point Gaussian Quadrature (GQ) Estimates of Field Day Availability

| | Point 1 | | | Point 2 | | |
|---|---|---|---|---|---|---|
| | Probability | Days | Residual[b] | Probability | Days | Residual |
| Aastad soil | | | | | | |
| CT | | | | | | |
| Period 1 | 0.73 | 0.55 | | 0.27 | 11.07 | |
| Period 2[a] | 0.60 | | −2.80 | 0.40 | | 4.28 |
| Period 3 | 0.33 | 7.22 | | 0.67 | 12.28 | |
| Period 4 | 0.45 | 4.75 | | 0.55 | 11.95 | |
| Period 5 | 0.26 | 4.81 | | 0.74 | 12.19 | |
| NT | | | | | | |
| Period 1 | 0.77 | 0.44 | | 0.23 | 11.40 | |
| Period 2[a] | 0.60 | | −2.33 | 0.40 | | 3.56 |
| Period 3 | 0.59 | | −3.10 | 0.41 | | 4.49 |
| Period 4 | 0.43 | | −3.89 | 0.57 | | 2.92 |
| Period 5 | 0.36 | 5.76 | | 0.64 | 12.10 | |
| Parnell Soil | | | | | | |
| CT | | | | | | |
| Period 1 | 0.80 | 0.24 | | 0.20 | 11.75 | |
| Period 2[a] | 0.80 | | −1.57 | 0.20 | | 6.22 |
| Period 3 | 0.49 | | −4.12 | 0.51 | | 3.88 |
| Period 4 | 0.38 | 4.55 | | 0.62 | 11.89 | |
| Period 5 | 0.33 | 5.48 | | 0.67 | 12.27 | |
| NT | | | | | | |
| Period 1 | 0.83 | 0.33 | | 0.17 | 11.66 | |
| Period 2[a] | 0.80 | | −1.32 | 0.20 | | 5.42 |
| Period 3[a] | 0.76 | | −2.15 | 0.24 | | 6.79 |
| Period 4 | 0.57 | | −3.31 | 0.43 | | 4.38 |
| Period 5 | 0.46 | 3.40 | | 0.54 | 11.41 | |

Note: CT is conventional tillage; NT is no-till.

[a] Estimated using linear programming model to match first two moments instead of GQ.

[b] For field day estimates that depend on previous period available field days, GQ estimates are realizations of the regression residual that are used to calculate available field days with the regression equation.

ments of the sample. A simple optimization model was constructed to provide a 2-point estimate that exactly matched the first two moments of the original distribution and minimized the absolute deviation from the third moment while requiring the estimated number of field days to be nonnegative. The model is given in the Appendix.

### *Economic Model*

The representative farm was assumed to grow corn and soybeans in rotation, with 50% of the acres in corn and 50% of the acres in soybeans in any 1 year. The farm was assumed to have 625 acres (253 ha.) of cropland, which is the average size for cropland farms in Stevens County, Minnesota (USDA-NASS). Two tillage scenarios were considered, one in which the entire farm utilized CT and one in which the entire farm utilized NT. The model was run separately for each tillage scenario.

The economic model was formulated as a whole-farm discrete stochastic programming (Cocks) optimization model. The DSP model was chosen over the chance-constrained programming model (Charnes and Cooper) utilized by Dillon, Shearer, and Mueller because the effect of low probability events (i.e., available field days early in the season) on farm planting decisions was critical in this analysis. Following Etyang et al., the farmer was assumed to choose planting activities based on the realization of available days in the current period plus the knowledge of the distributions, but not the realizations, of available days in future periods. The farmer's objective was to maximize expected net returns given by

$$(4)\quad \text{Max} \sum_{p}\sum_{n}\sum_{c}\sum_{s}\sum_{m} \text{PROB}_{p,n} \times (\text{PRICE}_{c}\text{YIELD}_{p,c,s,m} - \text{COST}_{p,c,s,m})X_{p,n,c,s,m}$$

subject to field day availability constraint

$$(5)\quad \sum_{c}\sum_{s}\sum_{m} (\text{PREP}_{p,n}\text{PREPLAB} + X_{p,n,c,s,m}\text{LAB}) \leq \text{FLDDAY}_{p,n} \quad \forall\ p,\ n;$$

time path soil constraint

$$(6)\quad \sum_{p}\sum_{m} X_{p,n,c,s,m} - \text{SOILAC}_{c,s} \leq 0 \quad \forall\ c,\ s,\ n;$$

field preparation constraints

$$(7)\quad \sum_{i=1}^{p} \text{PREP}_{p,n} - \sum_{i=1}^{p}\sum_{c}\sum_{s}\sum_{m} X_{i,n,c,s,m} \geq 0 \quad \forall\ n; \quad p = 1, 2, \ldots, 5;$$

soil constraints

$$(8)\quad \sum_{c} \text{SOILAC}_{c,s} \leq \text{SOILLIM}_{s} \quad \forall\ s; \quad \text{and}$$

rotation constraints

$$(9)\quad \text{SOILAC}_{1,s} = \text{SOILAC}_{2,s} \quad \forall\ s,$$

where

$X_{p,n,c,s,m}$ = acres production in period $p$ and state $n$ of crop $c$ on soil type $s$ crop maturity rating $m$;
$\text{PREP}_{p,n}$ = acres of field preparation in period $p$ and state $n$;
$\text{SOILAC}_{c,s}$ = total acres of production of crop $c$ on soil type $s$;
$\text{SOILLIM}_{s}$ = total acres land of soil type $s$ available for crop production;
$\text{FLDDAY}_{p,n}$ = number of field days available in period $p$ and state $n$;
$\text{PROB}_{p,n}$ = probability of state $n$ in period $p$;
$\text{PRICE}_{c}$ = price per bushel of crop $c$;
$\text{YIELD}_{p,c,s,m}$ = expected yield of crop $c$ planted in period $p$ on soil type $s$ with crop maturity rating $m$;
$\text{COST}_{p,c,s,m}$ = per acre cost of production for crop $c$ planted in period $p$ on soil type $s$ with crop maturity rating $m$;
PREPLAB = days labor required per acre for field preparation work; and
LAB = days labor required per acre for planting.

Indices denote

$p$ = time period (1–5);
$n$ = state of nature (1–32);
$c$ = crop (corn, soybeans);
$s$ = soil type (Aastad, Parnell); and
$m$ = crop maturity rating (early, normal, late).

Labor for field preparation and planting activities was limited by field day availability in periods 1–5 assuming 12 hours of labor could be used for field work for every available field day. Field preparation labor estimates accounted for the labor need for spring tillage operations in the CT scenario, and no field preparation labor was required for the NT scenario. It was assumed that land not planted by the end of the fifth period would incur no production costs and would generate no income. This could potentially cause the costs of extreme planting delays and, consequently, the value of polymer-coated seed to be overestimated. No limits on available labor were imposed for any field activities after planting since it was assumed that polymer-coated seed would have no effect on the producer's ability to complete field activities later in the season, including harvest. However, polymer-coated seed could potentially affect crop drying costs due to differences in crop moisture at harvest. Differ-

**Table 5.** Whole Farm Expected Net Returns with No Polymer-coated Seed, and Changes in Whole Farm Expected Net Returns with the Introduction of Polymer-coated Seed

| | | Change from No Polymer Seed Case | | |
|---|---|---|---|---|
| Soil Type and Tillage System | No Polymer Seed ($) | Polymer Corn Seed Only ($) | Polymer Soybean Seed Only ($) | Polymer Corn and Soybean Seed ($) |
| 100% Aastad CT | 73,353 | 634 | 2,952 | 3,562 |
| 100% Parnell CT | 61,149 | 447 | 1,792 | 2,237 |
| 50% Aastad/50% Parnell CT | 66,610 | 456 | 1,937 | 2,389 |
| 100% Aastad NT | 65,231 | 530 | 1,441 | 1,817 |
| 100% Parnell NT | 50,573 | 773 | 1,053 | 1,377 |
| 50% Aastad/50% Parnell NT | 55,331 | 866 | 1,270 | 1,600 |

Note: CT is conventional tillage; NT is no-till.

ences in drying costs were not included in this analysis. Since planting delays generally lead to higher crop drying costs, omitting drying costs from this analysis may cause the value of polymer-coated seed to be underestimated.

Costs of production were estimated using the functions in EPIC with equipment cost parameters based on Minnesota Extension Service cost estimates (Lazarus). No land, overhead, or management costs were included, assuming none of these would change with the availability of polymer-coated seed. Crop prices were fixed at $1.98 per bushel for corn and $5.69 per bushel for soybeans, reflecting the average of the higher of the market year average costs from 1996 to 2000 for Minnesota (USDA-NASS) or the commodity loan rate for Stevens County, Minnesota.

Three different scenarios for soil types were considered: (1) 100% Aastad soil, (2) 100% Parnell soil, and (3) 50% Aastad and 50% Parnell soil. For the third scenario, costs and yield were specific to soil type, whereas field day availability depended on the Parnell soil, which was the most limiting soil type.

The value of polymer-coated seed was estimated by running four different scenarios: (1) no polymer-coated seed available, (2) polymer-coated seed available for corn only, (3) polymer-coated seed available for soybeans only, and (4) polymer-coated seed available for both corn and soybeans.

The difference in net returns between the scenario where polymer-coated seed was not available (scenario 1) and the scenarios where polymer-coated seed was available (scenarios 2, 3, and 4) were used to estimate the value of polymer-coated seed and to indicate the effect of polymer-coated seed on crop production practices. Prices for polymer-coated seed were the same as for regular seed, so the expected value of polymer-coated seed in this analysis represented the additional amount producers would be willing to pay over the cost of regular seed.

## Results and Discussion

Whole-farm expected net returns for the baseline case of no polymer-coated seed and changes in whole-farm expected net returns from the baseline for each of the other scenarios are given in Table 5. Highest expected net returns occurred on the Aastad soil under CT for each of the polymer seed scenarios. The largest increase in net returns with polymer-coated seed also occurred on the Aastad soil under CT where expected net returns increased $3,562 or 4.0% with the introduction of both corn and soybean polymer-coated seed. A large part of this increase occurred when soybean polymer-coated seed was introduced alone, with an increase of $2,942 over the no-polymer case. The lowest expected net returns occurred on the Parnell soil under NT. The smallest increase in net returns also occurred on the Parnell soil under NT with expected net returns increasing $1,377 or 2.7%

**Table 6.** Expected Value of Polymer-coated Seed

| Soil Type and Tillage System | Polymer Corn and Soybean Seed ($/ac[a]) | Polymer Corn Seed Only ($/ac[a]) | Polymer Corn Seed Only ($/bag[b]) | Polymer Soybean Seed Only ($/ac[a]) | Polymer Soybean Seed Only ($/bag[c]) |
|---|---|---|---|---|---|
| 100% Aastad CT | 7.18 | 3.31 | 8.82 | 9.70 | 8.08 |
| 100% Parnell CT | 6.56 | 3.57 | 9.53 | 8.30 | 6.91 |
| 50% Aastad/50% Parnell CT | 7.00 | 3.65 | 9.73 | 8.97 | 7.47 |
| 100% Aastad NT | 4.39 | 2.83 | 7.54 | 6.04 | 5.03 |
| 100% Parnell NT | 4.92 | 6.13 | 16.33 | 6.16 | 5.14 |
| 50% Aastad/50% Parnell NT | 5.72 | 6.86 | 18.30 | 7.43 | 6.19 |

Note: CT is conventional tillage; NT is no-till.

[a] Value per acre planted with polymer-coated seed.

[b] Assuming a planting rate of 30,000 seeds per acre and 80,000 seeds per bag.

[c] Assuming a planting rate of 60 pounds per acre and 50 pounds per bag.

with the introduction of both corn and soybean polymer-coated seed. Again the largest part of the increase occurred with the introduction of soybean polymer-coated seed alone, with an increase of $1,053 over the no-polymer case. Whole-farm changes in expected net returns depended both on the per acre values of polymer-coated seed, which were determined by expected yield increases, and the expected acres that could be planted with the seed, which were determined by field day availability.

The expected values per acre of introducing both corn and soybean polymer-coated seed are listed in Table 6. These values represent the changes in expected net returns per acre planted with polymer-coated seed. The values are also reported as an added value per bag of seed assuming a seeding rate of 30,000 seeds per acre for corn and 60 pounds per acre for soybeans and bag sizes of 80,000 seeds and 50 pounds, respectively. This allows a direct comparison with the per acre and per bag added costs of polymer-coated seed. When both polymer-coated corn and soybean were introduced, the highest per acre values occurred under CT. This was a result of the higher expected corn and soybean yield increase with early planting and the more rapid decline in expected yield with delayed planting under CT than under NT.

However, when polymer-coated corn seed was introduced alone, the highest values occurred under NT and on the Parnell and the Aastad-Parnell mixed soil scenarios. This was a direct result of the extreme limiting field conditions that occurred on the Parnell soil under NT. Table 7 shows the expected crop planting for each seed type as a percentage of total possible acres for each crop, and Table 8 shows expected crop planting by planting date as a percentage of total possible acres for each crop. As long as the net returns to earlier planting were higher than the net returns under late planting, the acreage planted to polymer-coated seed would be directly related to the increase in field day availability. Since field day availability for the 100% Parnell and the 50% Aastad–50% Parnell soil scenarios were determined by the Parnell soil, these scenarios had identical expected planting dates and showed identical expected polymer seed use. The extreme field day constraints for the Parnell soil under NT meant that an expected 8.0% of potential soybean acres were not planted and 20.6% of the corn was planted in the final period when no polymer-coated seed was available for both the 100% Parnell and the 50% Aastad–50% Parnell scenarios. The introduction of polymer-coated seed in these scenarios allowed the expected unplanted area to drop to 6.5% of potential soybean acres and corn planting in the final period to drop to 17.5%. Although these were relatively small acreage changes, the benefits of avoiding unplanted soybeans were $66–$72 per acre, and

**Table 7.** Expected Polymer-coated Seed Use as a Percentage of Total Possible Acres for Each Crop

| | Polymer Corn and Soybean Seed | | Polymer Corn Seed Only | Polymer Soybean Seed Only |
|---|---|---|---|---|
| Soil Type and Tillage System | Corn (%) | Soybean (%) | (%) | (%) |
| 100% Aastad CT | 61.4 | 97.4 | 61.4 | 97.4 |
| 100% Parnell CT | 40.0 | 69.1 | 40.0 | 69.1 |
| 50% Aastad/50% Parnell CT | 40.0 | 69.1 | 40.0 | 69.1 |
| 100% Aastad NT | 60.0 | 72.4 | 60.0 | 76.4 |
| 100% Parnell NT | 40.4 | 49.2 | 40.4 | 54.7 |
| 50% Aastad/50% Parnell NT | 40.4 | 49.2 | 40.4 | 54.7 |

Note: CT is conventional tillage; NT is no-till.

the benefits of avoiding corn planting in the final period were $18–$20 per acre in the optimization model.

As much as 79% of total corn and soybean acres would be expected to be planted using polymer-coated seed on the Aastad soil under CT, with 61% of corn acres and 97% of soybean acres planted with polymer-coated seed. Note that since the price of the polymer-coated seed was the same as regular seed for this analysis, this represented an upper limit on the use of polymer-coated seed when the marginal cost was zero.

Potential use of polymer-coated corn seed was not largely affected by tillage system, with 40% of corn acres planted to polymer-coated seed when available field days were determined by the Parnell soil and 60%–61% of the corn acres planted to polymer-coated seed when available field days were determined by the Aastad soil. Although there tended to be fewer available field days under NT than under CT, the differences were small early in the season and were offset by smaller labor requirements per acre for NT. However, as the season progressed, differences in drying rates under the two tillage systems led to larger differences in field day availability. Consequently, tillage system did have an effect on the use of polymer-coated soybean seed, with lower polymer-coated soybean seed acreage under NT than under CT for both soil types. Note that a larger portion of the acreage was planted to polymer-coated soybeans when only polymer-coated soybean seed was available than when both polymer-coated corn and soybean seed were available, since some of the early soybean plantings were displaced by early corn plantings.

Although the introduction of polymer-coated seed was expected to lead to reductions in late plantings, this was a relatively small effect in most cases. For the Aastad soil under CT, there was no reduction in expected acres planted later than the normal planting period. There were some reductions in late planting for the other scenarios, with the greatest reductions for the Parnell and the Aastad-Parnell soil scenarios. In these scenarios late, planting was reduced by 5.5% of the total expected corn acres, and 1.5% of the total expected soybean acres were shifted from prevented planting to late planting. The greatest shifts were toward earlier planting dates, which provided direct yield benefits, rather than benefits through reductions in delayed planting.

An anticipated benefit of polymer-coated seed was that it could lead producers to plant longer maturity varieties or avoid planting early maturity varieties. However, Table 9 shows that polymer-coated seed generally had limited effect on crop maturity selection. The most dramatic shift occurred on the Aastad soil under CT where 61.4% of expected corn plantings shifted from normal maturity to late maturity varieties with the availability of polymer-coated seed. This was the only case where expected yields for late maturity varieties exceeded ex-

**Table 8.** Expected Crop Planting by Planting Date as a Percent of Total Possible Acres for Each Crop

| | 100% Aastad | | 100% Parnell | | 50% Aa/50% Pa | |
|---|---|---|---|---|---|---|
| Crop and Tillage System Planting Period | With Polymer-coated Seed (%) | Without Polymer-coated Seed (%) | With Polymer-coated Seed (%) | Without Polymer-coated Seed (%) | With Polymer-coated Seed (%) | Without Polymer-coated Seed (%) |
| Conventional tillage | | | | | | |
| Corn | | | | | | |
| March 31–April 13 | 36.0 | 0.0 | 4.5 | 0.0 | 4.5 | 0.0 |
| April 14–April 28 | 25.3 | 0.0 | 35.5 | 0.0 | 35.5 | 0.0 |
| April 29–May 12 | 38.6 | 100.0 | 41.2 | 78.9 | 41.2 | 78.9 |
| May 13–May 26 | 0.0 | 0.0 | 18.8 | 21.1 | 18.8 | 21.1 |
| May 27–June 9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Not planted | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Soybean | | | | | | |
| March 31–April 13 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| April 14–April 28 | 49.6 | 0.0 | 34.6 | 0.0 | 34.6 | 0.0 |
| April 29–May 12 | 47.9 | 0.0 | 34.5 | 0.0 | 34.5 | 0.0 |
| May 13–May 26 | 2.6 | 100.0 | 26.6 | 95.7 | 26.6 | 95.7 |
| May 27–June 9 | 0.0 | 0.0 | 4.3 | 4.3 | 4.3 | 4.3 |
| Not planted | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| No-till | | | | | | |
| Corn | | | | | | |
| March 31–April 13 | 11.0 | 0.0 | 9.0 | 0.0 | 9.0 | 0.0 |
| April 14–April 28 | 49.0 | 0.0 | 31.4 | 0.0 | 31.4 | 0.0 |
| April 29–May 12 | 19.6 | 75.7 | 14.3 | 49.2 | 14.3 | 49.2 |
| May 13–May 26 | 20.4 | 24.3 | 27.8 | 30.2 | 27.8 | 30.2 |
| May 27–June 9 | 0.0 | 0.0 | 17.5 | 20.6 | 17.5 | 20.6 |
| Not planted | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Soybean | | | | | | |
| March 31–April 13 | 22.8 | 0.0 | 0.0 | 0.0 | 16.8 | 0.0 |
| April 14–April 28 | 30.5 | 0.0 | 0.0 | 0.0 | 16.3 | 0.0 |
| April 29–May 12 | 19.1 | 0.0 | 49.2 | 0.0 | 16.1 | 0.0 |
| May 13–May 26 | 18.3 | 89.0 | 21.9 | 71.1 | 21.9 | 71.1 |
| May 27–June 9 | 9.3 | 11.0 | 22.4 | 20.9 | 22.4 | 20.9 |
| Not planted | 0.0 | 0.0 | 6.5 | 8.0 | 6.5 | 8.0 |

pected yields for normal maturity varieties. No late maturity corn varieties were planted under any other soil type or tillage system. Polymer-coated seed led to a slight reduction in the use of early season corn varieties ranging from 0.3% to 2.1% for the other soil types and tillage systems. The availability of polymer-coated seed had no effect on the varieties of soybeans planted.

## Conclusion

Temperature-activated polymer-coated seed is a recent technological innovation that allows more flexible planting options for producers in the northern Corn Belt. The potential value and use of this new technology was estimated combining biophysical simulation with a discrete stochastic programming representative

**Table 9.** Expected Crop Planting by Maturity Rating as a Percent of Total Possible Crop

| | Polymer Seed | | | No Polymer Seed | | |
|---|---|---|---|---|---|---|
| Crop<br>Soil Type and Tillage System | Early (%) | Normal (%) | Late (%) | Early (%) | Normal (%) | Late (%) |
| Corn | | | | | | |
| 100% Aastad CT | 0.0 | 38.6 | 61.4 | 0.0 | 100.0 | 0.0 |
| 100% Parnell CT | 18.8 | 81.2 | 0.0 | 21.1 | 78.9 | 0.0 |
| 50% Aastad/50% Parnell CT | 18.8 | 81.2 | 0.0 | 21.1 | 78.9 | 0.0 |
| 100% Aastad NT | 0.0 | 100.0 | 0.0 | 0.0 | 100.0 | 0.0 |
| 100% Parnell NT | 17.5 | 82.5 | 0.0 | 20.6 | 79.4 | 0.0 |
| 50% Aastad/50% Parnell NT | 17.5 | 82.5 | 0.0 | 20.6 | 79.4 | 0.0 |
| Soybean | | | | | | |
| 100% Aastad CT | 0.0 | 100.0 | 0.0 | 0.0 | 100.0 | 0.0 |
| 100% Parnell CT | 4.3 | 95.7 | 0.0 | 4.3 | 95.7 | 0.0 |
| 50% Aastad/50% Parnell CT | 4.3 | 95.7 | 0.0 | 4.3 | 95.7 | 0.0 |
| 100% Aastad NT | 9.3 | 90.7 | 0.0 | 11.0 | 89.0 | 0.0 |
| 100% Parnell NT | 22.4 | 71.1 | 0.0 | 20.9 | 71.1 | 0.0 |
| 50% Aastad/50% Parnell NT | 22.4 | 71.1 | 0.0 | 20.9 | 71.1 | 0.0 |

Note: CT is conventional tillage; NT is no-till.

farm model. Analysis for a sample farm in Minnesota showed that temperature-sensitive polymer-coated seed could see significant use. Polymer-coated seed could increase net returns by increasing yields for early planting, reducing yield loss due to delayed planting, and by increasing the use of longer season varieties. Although per acre values were relatively small, ranging from $2.83 to $9.70 per acre, a substantial portion of the crop acreage could be planted with polymer-coated seed. Expected use of polymer-coated seed ranged from 40% to 61% of the total corn acres and from 49% to 97% of total soybean acres for our sample farm.

Although there is interest in the potential use of polymer-coated seed in NT systems, this analysis generally showed greater benefits in increasing yield and reducing yield loss under CT. In addition, greater field day availability under CT allowed greater use of polymer-coated soybeans seed. The exception occurred when field day availability was more limited and polymer-coated seed significantly reduced delayed or prevented plantings. Although polymer-coated seed could be economically more beneficial for NT systems in this limited situation, it generally should provide higher benefits in CT systems.

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## Appendix

The optimization model for generating feasible 2-point estimates, when the GQ estimates produced negative estimates of available field days, is given by

$$\text{(A1)} \quad \min e_1 + e_2,$$

subject to

$$\text{(A2)} \quad p_1 + p_2 = 1$$

$$\text{(A3)} \quad p_1D_1 + p_2D_2 = E(X)$$

$$\text{(A4)} \quad p_1D_1^2 + p_2D_2^2 = E(X^2)$$

$$\text{(A5)} \quad e_1 - e_2 = E(X^3) - p_1D_1^3 - p_2D_2^3,$$

where $D_1$ and $D_2$ are the 2-point estimates of available field days, $p_1$ and $p_2$ are their associated probabilities, $e_1$ and $e_2$ represent the positive and negative deviations of the third moments of the point estimates from the sample third moment, and $E(X)$, $E(X^2)$ and $E(X^3)$ are the sample moments. $D_1$, $D_2$, $p_1$, $p_2$, $e_1$, and $e_2$ are all positive variables.