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Economic Risk and Profitability of Soybean Fungicide/Insecticide Seed Treatments at Reduced Seeding Rates

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Abbreviations: *EOSR*, economically optimal seeding rate; UTC, untreated control.

Abstract

Earlier soybean [*Glycine max* (L.) Merr.] planting, increased seed costs, and higher commodity prices have led to a surge in the use of soybean fungicide and insecticide seed treatments, while recent studies have suggested that growers should consider lowering seeding rates to increase their return on investment. Ultimately, growers would like to know the value proposition of combining seed treatments with lowered seeding rates. Therefore, three seed treatments (untreated, ApronMaxx, and CruiserMaxx) and six seeding rates (98800, 148200, 197600, 247000, 296400, and 345800 seeds ha^{-1}) were evaluated to determine seed yield, profitability, and economic risk of various seed treatments and seeding rates, including the economically optimal seeding rate (*EOSR*) for each seed treatment. Trials were conducted at nine locations throughout Wisconsin during the 2012 and 2013 growing seasons, totaling 18 site-years. Across a wide range of seeding rates, ApronMaxx provided no yield or profitability gains, and only slight risk benefits (<0.54 break-even probability) at grain sale prices between \$0.33 and 0.55 kg^{-1}. CruiserMaxx increased yield by 12% at 98,800 seeds ha^{-1} and by 4% at 345,800 seeds ha^{-1}. In addition, CruiserMaxx was able to substantially lower risk and increase profit at both reduced and recommended (197,000 – 345,800 seeds ha^{-1}) seeding rates across a wide range of environments and grain sale prices. The lowest risk and largest average profit increase was always at the *EOSR*, which decreased as the grain sale price declined. At current seed costs, the *EOSR* for CruiserMaxx treated seed ranged from 232,000 – 261,000 seeds ha^{-1} depending on the grain sale price. These data indicate that producers should account for their expected grain sale price and seed treatment choice when determining seeding rates to reduce economic risk and increase profitability.

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Introduction

Adoption of fungicide and insecticide soybean [*Glycine max* (L.) Merr.] seed treatments has dramatically increased over the last decade (Esker and Conley, 2012). This increase is partially attributed to a shift towards earlier planting into cooler and wetter soil, which slows seedling emergence and gives the seed greater exposure to early-season root rooting pathogens (Esker and Conley, 2012) and insects like wireworms (*Melanotus* sp.) and seed corn maggots [*Delia platura* (Meigen)] (Cox et al., 2008). Seed applied fungicides and insecticides have given producers a way to manage a broad spectrum of early and mid-season pathogen and insect species. Research on the use of soybean seed treatments however, has shown inconsistent results. This inconsistency likely arises from seed quality and environmental (weather and soil conditions) and genetic complexities (Guy et al., 1989; Lueschen et al., 1991; Poag et al., 2005). Guy et al. (1989) reported 19% yield increases under no-till conditions when using metalaxyl. Similarly, Lueschen et al. (1991) reported positive stand and yield responses to captan + metalaxyl on soybean varieties susceptible to seedling diseases. In contrast, Schulz and Thelen (2008) reported few yield responses to the use of mefenoxam + fludioxonil (ApronMaxx RTA, Syngenta Crop Protection, Greensboro, NC), where only 3 of 16 site-years increased yields, which were noted to be during cold and wet growing conditions.

In past decades, seed only accounted for 10% of soybean production costs (USDA-ERS, 2001). Dry soils causing the seed to imbibe water but not germinate (Helms et al., 1996), heavy rains causing soil crusting (Johnson and Wax, 1979), seed with low vigor (Johnson and Wax, 1979), and disease and insect pressure (Murillo-Williams and Pedersen, 2008a) are all situations that can decrease final plant populations from initial seeding rates. Therefore, many farmers would use excessively high seeding rates to insure that adequate harvest plant populations were

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achieved even after less than optimal planting conditions (Cox et al., 2010). However, soybean seed costs have increased by 58% over the past five years to a national average of \$155 ha^{-1} in 2012 (USDA-ERS, 2012). Accordingly, recent studies throughout the Midwest have pointed towards lower seeding rates because lower final plant populations can potentially achieve similar yields and provide a higher return on investment (De Bruin and Pedersen, 2008; Epler and Staggenborg, 2008; Lee et al., 2008). Carpenter and Board (1997) attributed similar yields at reduced seeding rates compared to those at higher rates to increased branching and branch dry matter per plant, which resulted in more branch nodes, branch reproductive nodes and branch pods. When comparing a plant population of 70,000 plants ha^{-1} to 189,000 plants ha^{-1} the branch dry matter per plant averaged 14.0 g and 3.6 g respectively (Carpenter and Board, 1997). Suhre et al. (2014) similarly reported that today's soybean cultivars produce more compensatory yield on plant branches under lower plant populations than older cultivars and that today's cultivars have a diminishing response to the expected yield penalty from reduced plant densities.

The current seeding rate recommendation in Wisconsin is 345,800 seeds ha^{-1} (S.P. Conley, unpublished data, 2013). Epler and Staggenborg (2008) found the optimal final plant population in Kansas to be as low as 197,600 to 345,800 plants ha^{-1}. In Kentucky, 171,000 to 264,000 seeds ha^{-1} was adequate to reach 95% of maximum yield (Lee et al., 2008). At two Iowa locations, De Bruin and Pedersen (2008) reported that 199,000 to 345,700 seeds ha^{-1} in 38-cm row spacing reached 95% of maximum yield and showed no difference in seeds m^{-2}. Furthermore, De Bruin and Pedersen, (2008) determined the economically optimal seeding rate to be 185,300 seeds ha^{-1}, which averaged 171,200 plants ha^{-1}. However, they did not analyze the economic risk associated with planting the economically optimal seeding rate and seeding rates below current recommendations.

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Producers are concerned with crop inputs being cost effective, meaning they at least break even or hopefully increasing profit (Marra et al., 2003). In North Dakota, Bradley (2008) found that the use of a fungicide seed treatment on a specific cultivar was only cost effective 33% of the time, which was primarily in cool and wet environments. Esker and Conley (2012) reported that the probability of seed treatments being cost effective was >80% with a high grain sale price (\$0.44 kg^{-1}) or a high yield (5380 kg ha^{-1}), but <50% with both a low grain sale price (\$0.22 kg^{-1}) and low yield (2690 kg ha^{-1}). However, multiple seeding rates were not used in their study and we are not aware of any work addressing the potential economic risk associated with lower seeding rates. Therefore, our goal was to expand upon the Esker and Conley (2012) study and we hypothesized that seed treatment use will stabilize or reduce producer economic risk and increase profit at lower than currently recommended seeding rates.

The objectives of our research were to (i) quantify the effects of seeding rate and seed treatment on plant stands, harvest plant populations, seed mass, seeds m^{-2}, and yield and (ii) assess the economic risk and profitability of various seed treatments and seeding rates, including the economically optimal seeding rate for each seed treatment.

Materials and Methods

Field Experiment

Field trials were conducted at nine locations, which vary in yield potential, throughout Wisconsin during 2012 and 2013, for a total of 18 environments (Location x Year) (Table 1). The trials were arranged in a randomized complete block design with four replications of three seed treatments and six seeding rates. The three seed treatments were ApronMaxx RFC (mefenoxam [0.0057 mg a.i. per seed] and fludioxonil [0.0039 mg a.i. per seed]), CruiserMaxx (thiamethoxam [0.0762 mg a.i. per seed], mefenoxam [0.0057 mg a.i. per seed], and fludioxonil [0.0039 mg a.i. per seed]), and untreated seed as the control treatment (UTC). The fungicidal components (mefenoxam and fludioxonil) target *Pythium, Phytophthora, Fusarium,* and *Rhizoctonia* spp. The insecticidal component (thiamethoxam) targets many insects such as bean leaf beetle [*Cerotoma trifurcata* (Forster)] and seed corn maggot. Each product was applied to the glyphosate [*N*-(phosphomethyl) glycine] resistant soybean variety S20-Y2 (Syngenta Seeds Inc. Minnetonka, MN). The six seeding rates were 98800, 148200, 197600, 247000, 296400, and 345800 seeds ha^{-1}. Planting occurred during May in both years (Table 1). Plots were seeded in six, 38-cm rows at a length of 7.6 m. Plots were later trimmed to 6.4 m in length and the middle four rows of each plot were harvested at maturity with a plot combine (Almaco SPC-40, ALMACO, Nevada, IA) to determine yield. Yield was computed by adjusting moisture to 130 g kg^{-1}. Plant stands (V2) and harvest plant populations (R8) were collected by counting the number of plants in 1.5 m of the center four rows. Seed mass was calculated based on the average mass of three subsamples of 100 seeds and seeds m^{-2} was determined by yield and seed mass following the methods described by De Bruin and Pedersen (2008).

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Soil samples were taken at each location and analyzed for percent clay, organic matter, soil pH, and macronutrients at the University of Wisconsin Soil and Plant Analysis Laboratory (Madison, WI) (Table 1). In-season pest control followed University of Wisconsin-Madison recommendations for best management practices (Cullen et al., 2012).

Statistical Analysis

Statistical analysis was performed using PROC MIXED in SAS (SAS Institute, 2010). Multi-location analysis was used to examine the effects of soybean seed treatments and seeding rates on plant stand, harvest plant population, seed mass, seeds m^{-2} and yield (Littell et al., 2006). Boxplots and residual plots were evaluated to confirm variance assumptions (Oehlert, 2000). Seeding rate, seed treatment, location, and all two-way and three-way interactions were treated as fixed effects, while replicate within location and the overall error term were treated as random effects (Littell et al., 2006). The level of significance was set at 5% and means comparisons were conducted according to Fischer's protected LSD. The Kenward-Rogers method was used to calculate degrees of freedom (Littell et al., 2006). In addition, yield was regressed over seed mass, seeds m^{-2}, plant stand, and harvest plant population and the coefficient of determination (R^2) was calculated. Omitted locations include the 2012 Janesville location because of herbicide carryover damage and the 2013 Marshfield location due to flooding.

Yield was modeled separately for the three different seed treatments. The response of yield (*Yield* kg ha^{-1}) to seeding rate (*SR*, seeds ha^{-1}) (Table 2) was modeled similarly to Edwards and Purcell (2005) using a negative exponential equation based on coefficient of determination (R^2) values:

$$Yield = Y_{max} \times (1 - e^{-\beta \times SR}) \quad \text{(Equation 1)}$$

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The non-linear least squares (NLS) function in RStudio (RStudio, 2012) was used to estimate the parameters Y_{max} and β separately for each seed treatment (Table 2). Seeding rate was treated as a continuous input and seed treatment as a discrete input. In Eq. [1], Y_{max} is the estimated asymptotic yield maximum, and β determines the responsiveness of yield as seeding rate increases. Therefore, a smaller β indicates that a higher seeding rate is needed to reach maximum yield for that seed treatment.

Economic Risk Analysis

Economic risk analysis was conducted at the pre-set seeding rates and a calculated *EOSR* for each seed treatment. To determine both the probability of increasing profit over a pre-determined base case of untreated seed at 345,800 seeds ha^{-1} and the average profit increase, a three step process was performed using Monte Carlo simulation in RStudio (RStudio, 2012). Similar to Henke et al. (2007), this simulation method accounted for variation in model parameter estimates and ultimately the uncertainty of each seeding rate and seed treatment profiting in various environments. Methods similar to Jaynes (2010) were used to compute the *EOSR* for each seed treatment.

The first step used the parameters Y_{max} and β (Table 2), which were estimated from Eq. [1], to calculate the *EOSR* for each seed treatment separately. Partial profit (\$ ha^{-1}) is revenue minus costs, or the product of the soybean grain sale price (*GSP*, \$ kg^{-1}) and yield as defined by Eq. [1], minus the product of the seed price (*SP*, \$ unit^{-1}) and the chosen seeding rate (*SR*, seeds ha^{-1}):

$$Partial\ Profit\ = GSP \times \left(Y_{max} \times \left(1 - e^{-\beta \times SR}\right)\right) - SP \times SR \qquad \text{(Equation 2)}$$

More specifically, Eq. [2] is partial profit because it does not include other production costs, as they do not affect the *EOSR*. For each seed treatment, the *EOSR* (seeds ha^{-1}) was determined by

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substituting the estimated parameters (Y_{max} and β), a given seed price (*SP*, \$ unit^{-1}), and a given soybean grain sale price (*GSP*, \$ kg^{-1}) (Table 2) into the first derivative of Eq. [2] with respect to the seeding rate (*SR*, seeds ha^{-1}), and then solving for the *EOSR*. Based on this process, the general solution for *EOSR* is:

$$EOSR = \ln \frac{SP}{GSP \times \beta \times Y_{max}} \times \frac{-1}{\beta} \quad \text{(Equation 3)}$$

The second step calculated partial profit based on variation in the estimated model parameters for each seed treatment. This process involved simulating 10,000 random draws of the parameters Y_{max} and β from a bivariate normal distribution, using the estimated parameters (Y_{max} and β) for the means and the variance-covariance matrix from estimating Eq. [1]. The MU, VCOV, and RMULTNORM functions in RStudio (RStudio, 2012) were used to implement this process. Partial profit was calculated for each of these 10,000 randomly drawn pairs of the parameters (not listed) using Eq. [2] with various pre-set values for grain sale price (*GSP*), seed price (*SP*), and seeding rate (*SR*) (Table 2) to calculate 10,000 random partial profits. Three grain sale prices and three seed prices, based upon the seed treatment, were used (Table 2). For each seed treatment, values for the seeding rate included not only the six rates used in the field trials, but also the calculated *EOSR*.

The third step involved subtracting the partial profit of the pre-determined base case of untreated seed at 345,800 seeds ha^{-1} (not listed) from the partial profit of each seeding rate (pre-set and *EOSR*) for each seed treatment for each of the 10,000 random draws. This process gave 10,000 differences in partial profit for each pre-set seeding rate and *EOSR* for each seed treatment. The proportion of these differences that were positive is a Monte Carlo estimate of the break-even probability for that seed treatment at that seeding rate, i.e., the probability that a treatment combination (seeding rate + seed treatment) will generate increased profit over the

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base case. Similarly, the average of all differences for a given treatment combination is the Monte Carlo estimate of the expected increase in profit for that seed treatment at that seeding rate relative to the base case. Finally, the average of all positive differences (or negative differences) is the Monte Carlo estimate of the expected increase (or decrease) in profit for that seed treatment at that seeding rate relative to the base case. This process was repeated for each treatment combination, giving 20 different comparisons to the base case for each grain sale price.

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Results and Discussion

Growing conditions, especially rainfall amounts and patterns, were variable among locations (Table 1). In 2012, southern locations experienced dry planting conditions in May that continued into a drought through June and July until normal precipitation occurred during August. In contrast, northern locations received slightly above average rainfall during May and were not as severely affected by mid-season drought (Table 1). In May 2013, rainfall totals were above average at all locations and in excess at Galesville, Chippewa Falls, Marshfield, and Arlington with 241, 236, 168, and 152 mm of rain, respectively (Table 1). Even so, all locations were planted at optimal dates in 2013 except the Marshfield location, which was omitted from the analysis. Rainfall in June and July was average while August experienced below average rainfall amounts. Precipitation was relatively stable across years at the Hancock location due to supplemental irrigation (Table 1).

Plant Stand and Harvest Plant Population

Both plant stand and harvest plant population were affected by seed treatment use (Table 3). When pooled over all locations and seeding rates, CruiserMaxx plant stands were 179,000 plants ha^{-1} compared to 147,000 plants ha^{-1} for the UTC, while harvest plant populations were 161,000 plants ha^{-1} compared to 138,000 plants ha^{-1} for the UTC (data not shown). In addition, there were no significant increases in plant stand or harvest plant population for ApronMaxx compared to the UTC (data not shown). These results are consistent with those of previous research in which Schulz and Thelen (2008) found no response to mefenoxam and fludioxonil (ApronMaxx) in 15 out of 16 site years in Michigan, while Esker and Conley (2012) saw no response in Wisconsin, and Murillo-Williams and Pedersen (2008b) found no effect of ApronMaxx on plant stands in Iowa. The component difference between CruiserMaxx and ApronMaxx is the addition

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of thiamethoxam in CruiserMaxx, evidence that this active ingredient was responsible for the stand increases. Cox and Cherney (2011) saw similar percent plant stand increases from an insecticide/fungicide seed treatment containing thiamethoxam over untreated seed in a large field scale study in New York. However, in our results, plant stand ($R^2 = 0.11$) and harvest plant population ($R^2 = 0.10$) did not relate well to yield (data not shown).

Seed Yield

The main effects of seeding rate, seed treatment, and location affected seed yield (Table 3). When pooled over all seed treatments and locations, the highest seeding rate (345,800 seeds ha^{-1}) yielded 4272 kg ha^{-1}, which was greater than all other seeding rates, except 296,400 seeds ha^{-1} (data not shown). This result is consistent with other reports across the Midwest that slightly lower seeding rates can produce similar yields (Bertram and Pedersen, 2004; Cox et al., 2010; De Bruin and Pedersen, 2008; Epler and Staggenborg, 2008; Lee et al., 2008). When seed treatment was pooled over all seeding rates and locations, CruiserMaxx provided a 227 kg ha^{-1} (6%) yield gain over ApronMaxx and the UTC, while ApronMaxx (3879 kg ha^{-1}) and the UTC (3873 kg ha^{-1}) did not differ (data not shown).

Locations varied in yield (Table 3). For example, mean yield at the 2013 Chippewa Falls location was 973 kg ha^{-1} compared to 5390 kg ha^{-1} at the 2012 Hancock location (data not shown). A wide range in yield and environmental conditions (Table 1) was achieved by pooling over location. This allowed us to examine the seed treatment x seeding rate interaction (P = 0.07) across a wide range of environments to capture the uncertainty of seed treatments producing positive yield gains in different environments, which is considered important by Bradley (2008) and Schulz and Thelen (2008). In Figure 1, the seed treatment X seeding rate interaction is shown and modeled using a negative exponential model (Eq. [1]). CruiserMaxx

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modeled yield was significantly higher at all seeding rates compared to the UTC and ApronMaxx and displayed a trend of larger yield increases as the seeding rate was lowered (Figure 1). We observed a 4% and 12% yield increase at 345,800 and 98,800 seeds ha^{-1}, respectively, over the UTC and ApronMaxx. Cox and Cherney (2011) also reported a 4% yield increase for a thiamethoxam containing seed treatment over the UTC at 345,800 seeds ha^{-1}. ApronMaxx showed no improvements in yield compared to the UTC at any seeding rate similarly to Murillo-Williams and Pedersen (2008b) and Schulz and Thelen (2008).

Yield Components

The main effects of location and seeding rate and their interaction affected seed mass (Table 3). Across all locations and seed treatments, seed mass was the largest (17.2 g 100 seeds^{-1}) at the lowest seeding rate (98,800 seeds ha^{-1}), but oddly the next largest seed mass (17.0 g 100 seeds^{-1}) was at the highest seeding rate (345,000 seeds ha^{-1}) and was not significantly different than the other four seeding rates (data not shown). Examination of the interaction showed that no consistent trend existed between seeding rate and seed mass at any location (data not shown), which is not unexpected based on previous contradicting studies. De Bruin and Pedersen (2008) and Elmore (1991) both reported larger seed mass as seeding rate increased, while Egli (1988) and Ethredge et al. (1989) reported the inverse. This indicates that seed mass may be affected more by site-specific environmental conditions (Bastidas et al. 2008; Schapaugh 2012), such as precipitation events during seed fill, than seeding rate. In addition, the relationship between seed mass and yield was weak (R^2 = 0.31) (data not shown). In contrast, seeds m^{-2} related very well to yield (R^2 = 0.83) (Figure 2) and displayed similar treatment trends as yield (Table 3). These results suggest that seeds m^{-2} is a better determinate of yield, which agrees with Board et al. (1999) and De Bruin and Pedersen (2008).

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Grower Return

Grower return as partial profit (\$ ha^{-1}), as affected by the seed treatment and seeding rate choice for the three different grain sale prices (\$0.33, 0.44, and 0.55 kg^{-1}) is displayed in Figure 3. CruiserMaxx increased profit compared to ApronMaxx and the UTC while no differences were observed between the UTC and ApronMaxx at each grain sale price and across all seeding rates (Figure 3). The *EOSR*, or the seeding rate corresponding to the highest point on the profit curves (Figure 3), for the three seed treatments and grain sale prices are displayed in Table 2. The *EOSR* is dependent on seed treatment and the grain sale price. When the grain sale price moves higher, the *EOSR* for each seed treatment also increases (Table 2). The *EOSR* for all three seed treatments increased by 12% between the grain sale prices of \$0.33 and \$0.55 kg^{-1} (Table 2). The *EOSR*'s for ApronMaxx and the UTC are nearly identical for each grain sale price, while the CruiserMaxx *EOSR* was 49000, 46000, and 43000 seeds ha^{-1} less than ApronMaxx and the UTC at \$0.55, 0.44, and 0.33 kg^{-1}, respectively (Table 2). This mirrors results from Cox and Cherney (2011), who reported maximum partial profit for a thiamethoxam containing seed treatment at 50,000 seeds ha^{-1} less than the UTC. Based upon our findings, using lower than currently recommended seeding rates (345,800 seeds ha^{-1}) may increase grower return, especially at lower grain sale prices (\$0.33 kg^{-1}) and when a fungicide/insecticide seed treatment is used. This finding is supported by a study conducted in Iowa across varying yield potential locations where the reported *EOSR* was 185,300 seeds ha^{-1} (De Bruin and Pedersen, 2008).

Economic Risk and Break-Even Probability

Economic risk was applied to the partial profit curves (Figure 3) in terms of a break-even probability over the base case (UTC at 345,800 seeds ha^{-1}) and displayed in Tables 4, 5, and 6 for soybean grain sale prices of \$0.33, 0.44, and 0.55 kg^{-1}, respectively. For example, in Table 4,

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CruiserMaxx at 345,800 seeds ha^{-1} had a 0.71 (71% chance) probability of increasing profit over the base case and on average for all simulated outcomes (all environments), increased profit by \$24 ha^{-1}. In addition, an average \$45 ha^{-1} increase was observed for the positive simulated outcomes and an average \$27 ha^{-1} loss for negative simulated outcomes. The positive outcomes column represents responsive environments while the negative outcomes column represents non-responsive environments (Tables 4-6).

At a grain sale price of \$0.33 kg^{-1} (Table 4), ApronMaxx and the UTC obtained break-even probabilities >0.50 at seeding rates of 296,400 and 247,000 seeds ha^{-1}, but only increased the average profit for all outcomes by less than \$7 ha^{-1}. UTC at 296,400 seeds ha^{-1} had the lowest risk (0.91) of any treatment combination in Table 4, but provided a relatively low profit increase of \$7 ha^{-1}. ApronMaxx showed fairly low break-even probabilities and average profit increases, with a majority of ApronMaxx treatment combinations having negative profits for all outcomes. ApronMaxx at its *EOSR* provided its highest break-even probability (0.54) and largest average profit increase for all outcomes (\$8 ha^{-1}). For the low grain sale price of \$0.33 kg^{-1}, ApronMaxx at 345,800 seeds ha^{-1} could not increase average profit for all outcomes enough to cover the cost of the seed treatment, which agrees with Esker and Conley (2012). Seeding rates must be reduced by 49,400 seeds ha^{-1} to produce positive average profit increases for all outcomes with ApronMaxx. However, this seeding rate reduction did not substantially reduce risk (increase the break-even probability) or increase average profits. CruiserMaxx produced break-even probabilities >0.50 for all seeding rates except at 98,800 seeds ha^{-1}, and the average profit increase for all outcomes was >\$40 ha^{-1} at seeding rate between 197,600 and 296,400 seeds ha^{-1}. The lowest risk (0.89) and largest average profit increase for all outcomes (\$50 ha^{-1}) with CruiserMaxx was at its *EOSR* (232,000 seeds ha^{-1}).

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When the grain sale price was increased to \$0.44 kg^{-1} (Table 5), we again saw a trivial average profit increase for all outcomes (\$4 ha^{-1}) for the UTC at 296,400 seeds ha^{-1}, but this was a relatively low risk option (0.77). The lowest risk ApronMaxx treatment combination (0.52) was at its *EOSR*. However, this option only attained a \$3 ha^{-1} average profit increase for all outcomes and a wide range of possibilities existed when accounting for the average positive (\$47 ha^{-1}) and negative (-\$45 ha^{-1}) outcomes. CruiserMaxx displayed relatively high break-even probabilities (>0.76) for seeding rates between 197,600 and 345,600 seeds ha^{-1}, with the lowest risk (0.87) and largest average profit increase for all outcomes (\$61 ha^{-1}) at its *EOSR* (249,000 seeds ha^{-1}).

At the highest grain sale price of \$0.55 kg^{-1} (Table 6), reducing seeding rates below the base case by only 49,400 seeds ha^{-1} resulted in break-even probabilities of 0.61 and 0.51 for the UTC and ApronMaxx, respectively, and the average profit increase for all outcomes was <\$1 ha^{-1}. CruiserMaxx provided the highest break-even probability (0.86) and largest average profit increase for all outcomes (\$74 ha^{-1}) at its *EOSR*, which was 84,000 seeds ha^{-1} less than the base case. This treatment combination (CruiserMaxx at its *EOSR*) with a high grain sale price (\$0.55 kg^{-1}) resulted in the 5th highest break-even probability and largest average profit increase for all outcomes compared to every other treatment combination and grain sale price (Tables 4-6).

Indifferent to the grain sale price (Table 4-6), CruiserMaxx was able to substantially lower risk and increase profit at both reduced and recommended (197,000 – 345,800 seeds ha^{-1}) seeding rates unlike ApronMaxx and the UTC, where reducing the seeding rate below 345,800 seed ha^{-1} was only slightly advantageous at lower grain sale prices (\$0.33 – 0.44 kg^{-1}). Reducing the seeding rate with CruiserMaxx to its *EOSR* produced the largest average profit increase for all outcomes at each grain sale price (Tables 4-6). In relation, the break-even probabilities for

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the three seed treatments at their *EOSR* increased as the grain sale price decreased. Looking across all grain sale prices (Table 4-6) and holding the seeding rate at currently recommended levels (345,800 seeds ha^{-1}), ApronMaxx was fairly risky with break-even probabilities near 0.50 and average profit increases for all outcomes under \$1 ha^{-1}. In contrast, CruiserMaxx produced less risky results, with break-even probabilities between 0.70 and 0.80, and average profit increases for all outcomes of \$24, 42, and 60 ha^{-1} for \$0.33, 0.44, and 0.55 kg^{-1} grain sale prices, respectively.

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Conclusions

Our analysis of soybean fungicide and insecticide seed treatments and seeding rate in terms of economic risk and profitability provides a useful methodology for examining agriculture products and their value to producers. Results from this study indicate that the decision to use a certain seed treatment in conjunction with seeding rate can have large effects on soybean yield, profitability, and economic risk. Across a wide range of seeding rates, ApronMaxx, a fungicide only seed treatment, provided no gains in plant stand, harvest plant population, yield, or profitability, and only slight risk benefits (<0.54) at grain sale prices between \$0.33 and 0.55 kg^{-1}. Although minimal (<\$5 ha^{-1}), reducing seeding rates to the *EOSR* for ApronMaxx was needed before a positive profit increase occurred for all outcomes, but this profit increase was relatively risky. CruiserMaxx, a combined fungicide/insecticide seed treatment, showed increases in plant stand (21%), harvest plant population (16%), yield, and profitability and reduced economic risk across a wide range of seeding rates. Yield increased by 12% at 98,800 seeds ha^{-1} and by 4% at the currently recommended seeding rate (345,800 seeds ha^{-1}) mainly through increased seeds m^{-2}. At current seed and seed treatment costs, CruiserMaxx at 345,800 seeds ha^{-1} reduced economic risk (>0.71) and increased average profit (>\$24 ha^{-1}) across an array of realistic environments and grain sale prices (\$0.33 – 0.55 kg^{-1}). Furthermore, to realize the lowest risk and highest profit increase with CruiserMaxx, producers should consider lowering their seeding rate to the *EOSR* (232,000 – 261,000 seeds ha^{-1}) according to their expected grain sale price.

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Figure Captions

Figure 1. Yield (kg ha^{-1}) modeled with a negative exponential model (Eq. [1]) for the UTC (square), ApronMaxx (circle), and CruiserMaxx (triangle) across all seeding rates and locations. Shapes represent treatment means. Coefficients for the estimated model parameters for each seed treatment are listed in Table 2.

Figure 2. Regression of yield (kg ha^{-1}) over seeds m^{-2} pooled across all locations, seeding rates, and seed treatments.

Figure 3. Partial profit ($ ha^{-1}) of the UTC (dotted), ApronMaxx (dashed), and CruiserMaxx (solid) across all seeding rates and locations for grain sale prices of (a) $0.33 kg^{-1}, (b) $0.44 kg^{-1}, and (c) $0.55 kg^{-1}.

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Table 1. Location description of the trials throughout Wisconsin during 2012 and 2013.

Year	Location	Latitude and longitude	Planting date	Soil type†	Clay‡	OM§	pH	P	K	Precip.¶
					g kg^{-1}	g kg^{-1}		Bray-1	Bray-1, ICP	mm
2012	Arlington	43° 18’ 8’’ N, 89° 20’ 8’’ W	11 May	Plano silt loam	180 to 270	39	6.9	79	206	74 (-20)
	Janesville	42° 43’ 33’’ N, 89° 1’ 17’’ W	10 May	Plano silt loam	180 to 270	35	7	41	107	18 (-79)
	Lancaster	42° 49’ 49’’ N, 90° 47’ 21’’ W	8 May	Fayette silt loam	240 to 320	24	6.3	20	86	99 (-5)
	Fond du Lac	43° 43’ 34’’ N, 88° 34’ 18’’ W	16 May	Pella silt loam	270 to 350	39	7	29	80	125 (43)
	Galesville	44° 4’ 27’’ N, 91° 19’ 58’’ W	15 May	Downs silt loam	240 to 320	36	6.2	46	181	119 (25)
	Hancock	44° 7’ 10’’ N, 89° 32’ 7’’ W	2 May	Plainfield sand	0	7	6.3	74	62	152 (58)
	Chippewa Falls	44° 57’ 0’’ N, 91° 21’ 1’’ W	15 May	Sattre loam	180 to 230	33	6.6	16	76	117 (28)
	Marshfield	44° 38’ 29’’ N, 90° 7’ 59’’ W	17 May	Withee silt loam	180 to 250	38	6.8	32	111	97 (5)
	Seymour	44° 31’ 25’’ N, 88° 19’ 46’’ W	16 May	Solona silt loam	150 to 230	27	7.5	41	132	86 (13)
2013	Arlington	43° 18’ 8’’ N, 89° 20’ 8’’ W	7 May	Plano silt loam	180 to 270	37	7.0	69	188	152 (61)
	Janesville	42° 43’ 33’’ N, 89° 1’ 17’’ W	16 May	Plano silt loam	180 to 270	39	6.5	56	153	99 (3)
	Lancaster	42° 49’ 49’’ N, 90° 47’ 21’’ W	15 May	Fayette silt loam	240 to 320	23	7.2	37	88	145 (38)
	Fond du Lac	43° 43’ 34’’ N, 88° 34’ 18’’ W	20 May	Pella silt loam	270 to 350	35	6.9	29	124	112 (31)
	Galesville	44° 4’ 27’’ N, 91° 19’ 58’’ W	15 May	Downs silt loam	240 to 320	41	6.0	19	171	241 (147)
	Hancock	44° 7’ 10’’ N, 89° 32’ 7’’ W	6 May	Plainfield sand	0	7	6.6	99	74	127 (31)
	Chippewa Falls	44° 57’ 0’’ N, 91° 21’ 1’’ W	14 May	Sattre loam	180 to 230	34	6.3	20	138	236 (147)
	Marshfield	44° 38’ 29’’ N, 90° 7’ 59’’ W	4 June	Withee silt loam	180 to 250	37	6.7	40	142	168 (76)
	Seymour	44° 31’ 25’’ N, 88° 19’ 46’’ W	27 May	Solona silt loam	150 to 230	24	6.9	20	101	94 (20)

†Soil type from web soil survey. Plano: fine-silty, mixed, superactive, mesic Typic Argiudolls; Fayette: fine-silty, mixed, superactive, mesic Typic Hapludalfs; Pella: fine-silty, mixed, superactive, mesic Typic Endoaquolls; Downs: fine-silty, mixed, superactive, mesic Mollic Hapludalfs; Plainfield: mixed, mesic Typic Udipsamments; Sattre: fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Mollic Hapludalfs; Withee: fine-loamy, mixed, superactive, frigid Aquic Glossudalfs; Solona: coarse-loamy, mixed, superactive, frigid Aquic Argiudolls.

‡Range in percent clay basis for this soil type.

§OM, organic matter. pH, P, and K values are a composite of individual sites each year.

¶Precip., Precipitation within the month of May. Deviation from the 30-year average is reported in parentheses. The Hancock location received irrigation. Data collected from the Wisconsin State Climatology office (Madison, WI).

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Table 2. Components of the economic risk analysis including seed prices, model parameters, grain sale prices, economically optimal seeding rates, and pre-set seeding rates.

		Estimated parameters‡		Economically optimal seeding rate (*EOSR*)¶ Grain sale price (*GSP*) ($ kg^{-1})§			
Seed treatment (*ST*)	Seed price (*SP*)†	Y_{max}	β	0.33	0.44	0.55	Pre-set seeding rates (*SR*)¶
	$ seed^{-1}			Seeds ha^{-1}			
Untreated control	0.00036	4184	0.015	276,000	295,000	310,000	(345,800)#
							296,400
							247,000
							197,600
							148,200
							98,800
ApronMaxx	0.00039	4213	0.014	275,000	295,000	310,000	345,800
							296,400
							247,000
							197,600
							148,200
							98,800
CruiserMaxx	0.00044	4329	0.017	232,000	249,000	261,000	345,800
							296,400
							247,000
							197,600
							148,200
							98,800

†Based on a combination price of one soybean seed unit (140,000 seeds for $50) and a seed treatment of untreated control ($0 unit^{-1}), ApronMaxx ($5 unit^{-1}), or CruiserMaxx ($12 unit^{-1}).
‡Parameters are estimated using Eq. [1] and substituted into Eq. [2] to randomly draw partial profit ($ ha^{-1}). Y_{max} is the estimated, asymptotic yield maximum and β is the responsiveness of yield (kg ha^{-1}) as seeding rate increases for each seed treatment.
§The three grain sale prices were used throughout the analysis to determine the *EOSR* and economic risk for each seed treatment and seeding rate combination.
¶Both *EOSR* and pre-set seeding rates are used in Eq. [2] as the seeding rate for each seed treatment.
#Untreated seed at 345,800 seeds ha^{-1} is the BASE CASE for comparison in the economic analysis.

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Table 3. Seed yield, seeds m^{-2}, seed mass, early season stand, and harvest population analysis of variance.

Source	df	Yield	Seeds m^{-2}	Seed mass	Plant stand (V2)	Harvest population (R8)
				P > F		
Location (L)	15	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Seed Treatment (ST)	2	<0.0001	<0.0001	0.9213	<0.0001	<0.0001
Seeding Rate (SR)	5	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
L x ST	30	<0.0001	0.0005	0.2864	<0.0001	0.0156
L x SR	75	<0.0001	<0.0001	<0.0001	0.0762	<0.0001
ST x SR	10	0.0704	0.0189	0.3377	0.0684	0.1787
L x ST x SR	150	0.1796	0.3212	0.1409	0.1891	0.3638

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Table 4. Break-even probabilities and average profit increases for the seeding rate X seed treatment economic risk analysis with a grain sale price of $0.33 kg^{-1}.

Treatment combination†			Avg. profit increase over the Base Case‡		
Seed treatment	Seeding rate	Break-even probability§	Positive outcomes	All outcomes	Negative outcomes
	Seeds ha^{-1}			$ ha^{-1}	
UTC	296,400	0.91	9	7	-5
	247,000	0.69	12	5	-12
	197,600	0.26	10	-19	-29
	148,200	0.01	4	-83	-84
	98,900	0.00	na¶	-233	-233
ApronMaxx	345,800	0.46	35	-4	-38
	296,400	0.54	36	4	-33
	247,000	0.51	33	1	-32
	197,600	0.28	26	-23	-42
	148,200	0.02	16	-89	-91
	98,900	0.00	na	-242	-242
CruiserMaxx	345,800	0.71	45	24	-27
	296,400	0.83	53	40	-23
	247,000	0.89	58	49	-19
	197,600	0.86	53	43	-20
	148,200	0.51	35	0	-36
	98,900	0.01	12	-127	-128
UTC	*EOSR*	0.84	11	8	-7
ApronMaxx	*EOSR*	0.54	35	5	-32
CruiserMaxx	*EOSR*	0.89	58	50	-19

†Treatment combination includes all possible seed treatment and seeding rate combinations for comparison to the base case.
‡Base case is untreated seed (UTC) at 345,800 seeds ha^{-1}.
§Break-even probability is the probability that a treatment combination will at least provide the same profit ($ ha^{-1}) as the base case.
¶na, no outcomes are possible.

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Table 5. Break-even probabilities and average profit increases for the seeding rate X seed treatment economic risk analysis with a grain sale price of \$0.44 kg^{-1}.

Treatment combination†			Avg. profit increase over the Base Case‡		
Seed treatment	Seeding rate	Break-even probability§	Positive outcomes	All outcomes	Negative outcomes
	Seeds ha^{-1}		\$ ha^{-1}		
UTC	296,400	0.77	7	4	-6
	247,000	0.44	9	-6	-18
	197,600	0.08	8	-43	-47
	148,200	0.00	2	-135	-135
	98,900	0.00	na¶	-340	-340
ApronMaxx	345,800	0.49	48	-1	-49
	296,400	0.52	47	3	-45
	247,000	0.44	42	-7	-46
	197,600	0.20	31	-46	-64
	148,200	0.01	19	-141	-142
	98,900	0.00	na	-350	-350
CruiserMaxx	345,800	0.76	66	42	-34
	296,400	0.84	72	56	-30
	247,000	0.87	74	61	-26
	197,600	0.80	64	45	-29
	148,200	0.38	40	-19	-55
	98,900	0.00	16	-195	-196
UTC	*EOSR*	0.76	7	4	-7
ApronMaxx	*EOSR*	0.52	47	3	-45
CruiserMaxx	*EOSR*	0.87	74	61	-26

†Treatment combination includes all possible seed treatment and seeding rate combinations for comparison to the base case.
‡Base case is untreated seed (UTC) at 345,800 seeds ha^{-1}.
§Break-even probability is the probability that a treatment combination will at least provide the same profit (\$ ha^{-1}) as the base case.
¶na, no outcomes are possible.

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Table 6. Break-even probabilities and average profit increases for the seeding rate X seed treatment economic risk analysis with a grain sale price of \$0.55 kg^{-1}.

Treatment combination†			Avg. profit increase over the Base Case‡		
Seed treatment	Seeding rate	Break-even probability§	Positive outcomes	All outcomes	Negative outcomes
	Seeds ha^{-1}			\$ ha^{-1}	
UTC	296,400	0.61	6	0	-8
	247,000	0.26	8	-16	-24
	197,600	0.02	7	-66	-68
	148,200	0.00	na¶	-186	-186
	98,900	0.00	na	-447	-447
ApronMaxx	345,800	0.51	61	1	-60
	296,400	0.51	58	2	-56
	247,000	0.40	50	-16	-60
	197,600	0.16	36	-68	-88
	148,200	0.00	22	-192	-193
	98,900	0.00	na	-459	-459
CruiserMaxx	345,800	0.80	86	60	-41
	296,400	0.85	92	72	-37
	247,000	0.86	90	73	-34
	197,600	0.76	75	47	-38
	148,200	0.31	45	-38	-75
	98,900	0.00	7	-264	-264
UTC	*EOSR*	0.69	5	2	-5
ApronMaxx	*EOSR*	0.51	59	3	-57
CruiserMaxx	*EOSR*	0.86	92	74	-34

†Treatment combination includes all possible seed treatment and seeding rate combinations for comparison to the base case.
‡Base case is untreated seed (UTC) at 345,800 seeds ha^{-1}.
§Break-even probability is the probability that a treatment combination will at least provide the same profit (\$ ha^{-1}) as the base case.
¶na, no outcomes are possible.

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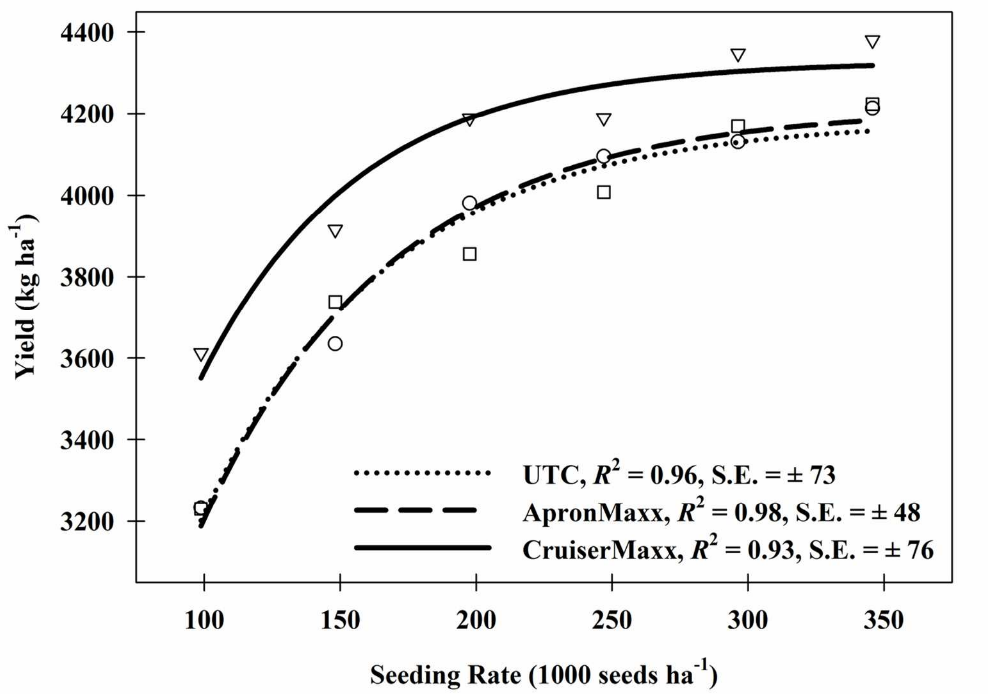

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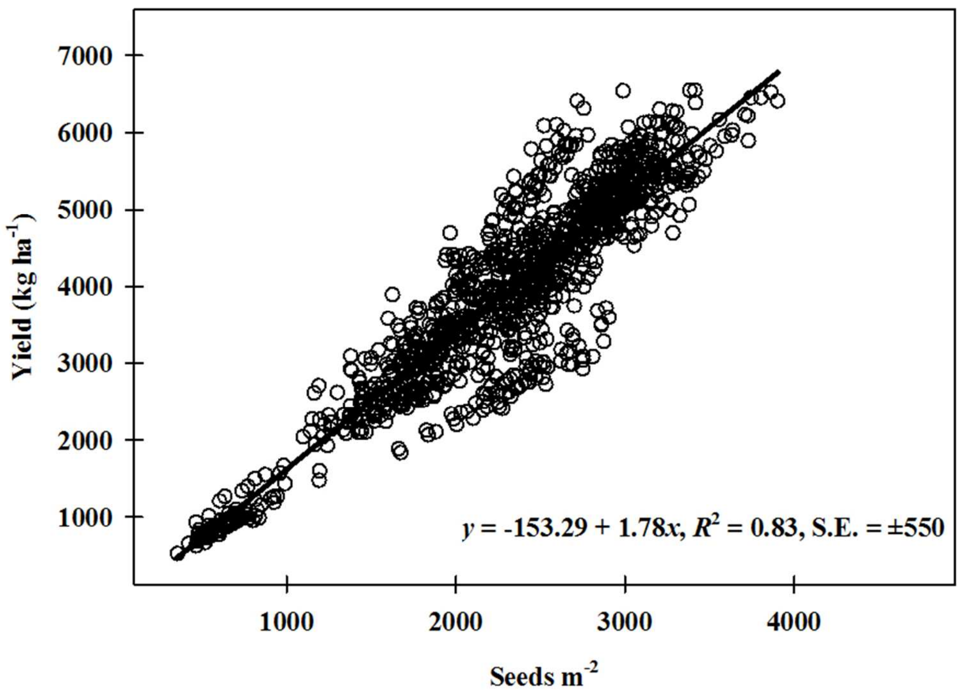

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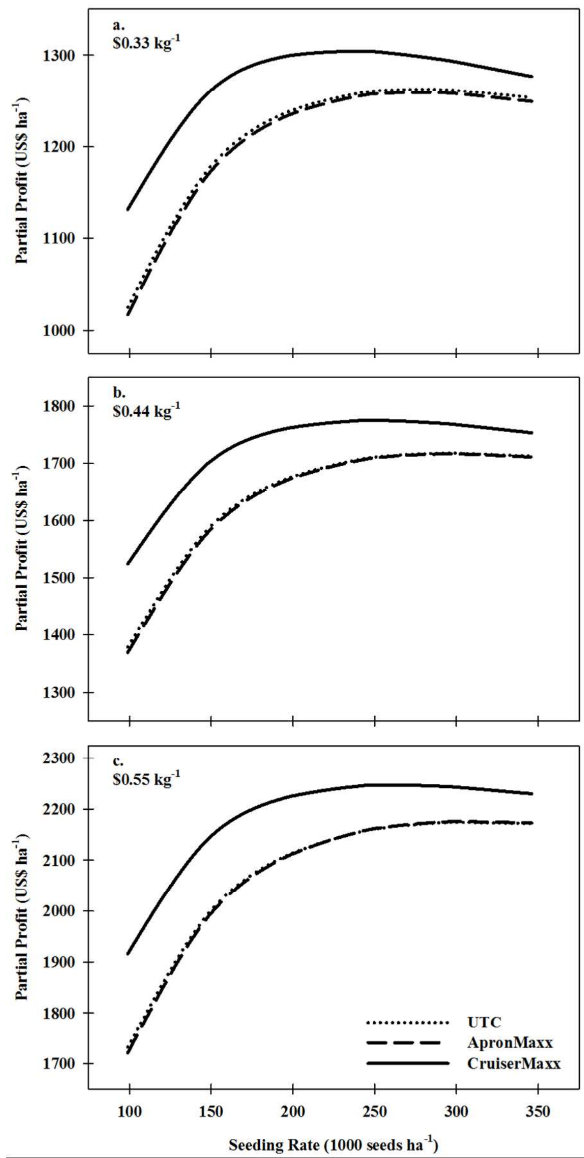

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