12-2015

Soybean Planting and Risk-Return Tradeoffs in the Mid-Southern United States

Weston Weeks
University of Arkansas, Fayetteville

Soybean Planting and Risk-Return Tradeoffs in the Mid-Southern United States

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Agricultural Economics

by

Weston Weeks
Hendrix College
Bachelor of Arts in History, 2013

December 2015
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

____

Dr. Michael P. Popp
Thesis Director

____

Dr. Larry C. Purcell
Committee Member

____

Dr. Lawton Lanier Nalley
Committee Member

ABSTRACT

This thesis is comprised of two studies on the effects of soybean (*Glycine max* (L.) *Merr.*) planting date (PD) and maturity group (MG) selection on producer expected returns. Having to replant soybean after early-season planting because of poor stand establishment is costly for producers. Replanting costs have increased in the last ten years as seed and other input costs for soybean have increased. Using five years of field trial results from two locations in Arkansas, the yield response to early and late season plant population density has been estimated to determine yield and future revenue potential for the purpose of determining whether or not replanting makes economic sense for a producer. Economically derived soybean replanting thresholds, defined as the number of plants at two or four weeks after planting for the initial planting below which replanting makes economic sense, were established for both locations. Sensitivity analyses on soybean price, seed cost, and producer replanting costs were performed to determine their relative importance on replanting thresholds. Deciding to replant earlier than four weeks after planting was suggested as the yield potential of earlier replanted soybean is higher. The replanting threshold counts, however, also need to be adjusted. In the second study, producer return variance or production risk associated with growing soybean of different maturity and at varying times during the planting season was analyzed. An efficient frontier where returns are maximized at varying levels of risk was calculated for a set of nine locations across six states using three years of data from field experiments. Because a producer can freely select what MG of soybean to plant and when to plant, risk return tradeoffs were studied for planting portfolios featuring soybeans from MG III to VI and PD ranging from as early as the beginning of April in some locations to mid-July. The median level of risk between minimal portfolio risk and the risk level of the return-maximizing MG and PD combination was solved for and expected return and risk was compared between the median-risk portfolio and the profit-maximizing portfolio. This comparison provided insight about the relative cost

of risk reduction for the nine different locations. Water consumption, price seasonality, and seed oil and protein concentration were considered in the development of return estimates. Because producer planting risk preferences vary, a spreadsheet tool that can solve for efficient MG and PD planting portfolios is envisioned that will allow the parameters of the optimization to be customizable for the producer.

ACKNOWLEDGEMENTS

I would like to thank my advisor Dr. Michael Popp for innumerable hours of time and care in making this work possible. I would also like to thank committee members Dr. Larry Purcell and Dr. L. Lanier Nalley for their time, valuable feedback, and support. I am very grateful to all of the faculty and staff of the Department of Agricultural Economics and Agribusiness at the University of Arkansas. I am especially grateful to Dr. Jeannie Popp for the assistance in joining this program. Finally I am grateful to Dr. Montserrat Salmeron Cortasa and the numerous faculty and staff of the Division of Agriculture and the partnering institutions who conducted field trials and collected data that made these studies possible.

TABLE OF CONTENTS

Chapter I. Introduction

A. Problem Statement and Study Justification

Increasing producer costs associated with planting have made soybean producer planting decisions critical to a producer's success. What to plant and when to plant are two decisions producers can make at no immediate cost that can go a long way in determining how economically successful a production year will be. These decision are not only guided by what combinations of maturity group (MG) and planting date (PD) will yield the best. Risk, which in this analysis is defined as the stability of expected return as influenced by seasonal sale price, irrigation cost and yield, is another concern. Also, producers, when deciding how they will plant or whether they need to replant are anticipated to want to maximize returns and at the same time manage risk exposure. These two considerations are often in conflict as higher returns are often achievable only with considerable risk.

Adverse weather conditions in the Mid-Southern United States often mean that early season soybean plant emergence and resultant plant population densities are sparse. Flooding, disease caused by low temperatures, and crusting of soil can reduce soybean plant population density (PPD) to a point where replanting might be economically desirable. Soybean fungicide seed treatments are often employed in this region to help protect planted seeds from pre- and post-emergent diseases. When early season PPD is low, soybean producer's yield potential is likely much less than the expected yield potential with an adequate stand. The expected yield potential of replanted soybean and producer costs associated with replanting must be weighed against the expected return of the existing soybean stand at less than profit-maximizing PPD when stand establishment is affected by environmental conditions. Five years of experimental data at two locations in Arkansas were analyzed to provide replanting stand count threshold information across the two different environments and estimated across three planting dates within a planting season.

Risk-return considerations are inevitable when producers are initially determining soybean MG and PD, but little research has been conducted that seeks to put a price on such tradeoffs. Risk is a critical economic consideration in dry-land soybeans, but it is also important when soybeans are irrigated because producer costs are greater. There has been exhaustive research on early-season soybean production and its economic efficacy or lack thereof, but an attempt to quantify differences in expected return and return stability in the Mid-Southern U.S. to diversifying planting date and maturity group selection in soybean has not be made to date. Early season production might raise yield expectations, but if planting early also exposes producers to greater return risk, such an option might not be attractive. Late-season planted varieties might offer considerably less in the way of expected return when compared to earlier planted options, but if a negative covariate relationship exists between high return and lower return varieties and planting dates, planting such lower return varieties across a range of planting dates as part of an overall planting portfolio might be in the producer's best interest.

A multi-state collaborative field trial has made yield information available for sixteen MG × PD combinations in nine locations in six states in the Mid-Southern U.S. Soybeans from early maturing MG III through late maturing MG VI were planted at four successive planting dates in nine locations over three years. From this data, risk return tradeoffs between MG × PD in nine locations was analyzed for the primary purpose of determining if producers can reduce return risk at a small cost relative to the profit-maximizing MG × PD combination. As a means of expanding this initial research, the methodology used in the manuscript that is featured in chapter III is being applied to a decision tool that will combine the empirical yield results in the dataset with producer selected parameters for the purpose of helping producers understand possible risk-return tradeoffs as they apply to their own operation.

B. Objectives

The objectives of chapter II are to estimate rate of seedling survival for soybean planted at the two considered locations, estimating yield response to PPD as measured at two and four weeks after planting for the possible planting dates, and using yield response to early-season PPD to determine economically derived soybean replanting PPD thresholds that vary by planting date, location and the time when the decision to replant is made.

The objectives of chapter III were the application of portfolio theory to illustrate how several MG × PD combinations can reduce risk compared to the MG × PD combination that maximizes expected return, define the efficient frontier of all feasible MG × PD combinations that minimize risk for possible levels of return, and finally calculated the cost in expected return associated with a median level of feasible risk while comparing irrigation water use, yield, seasonal sale price, and soybean oil and protein concentration tradeoffs between these two scenarios in all considered production environments.

C. Overview of Methods

This analysis was made possible by applying multi-variate regression analysis and portfolio theory to results from two extended field trials in Arkansas and five other states in the Mid-Southern U.S. Regression analysis was used to estimate seed survival and yield response to PPD at two Arkansas locations for the article, accepted for publication in the *Agronomy Journal*, in chapter II. Portfolio theory and optimization was used in chapter III to quantify tradeoffs between expected return and production risk. The manuscript prepared in chapter III will be submitted for review to *Field Crops Research*.

D. Overview of Chapters

As indicated above, chapter II is the article on soybean replanting thresholds. Chapter III is a manuscript that provides information about risk-return tradeoffs when selecting soybean MG at varying planting dates. Finally, chapter IV summarizes findings and offers promising areas for future research.

Chapter II: Replanting Thresholds for Soybean using Two- and Four-Week Plant Survival Metrics

A. Abstract

The rising cost of seed is causing soybean (*Glycine max* (L.) *Merr*.) producers to reconsider seeding rate and replanting decisions. Data were collected over five years, at two experimental sites in Arkansas, three planting dates, three seeding rates and two seed treatments (with or without seed treatment). Information regarding stand counts, or the number of established plants at two and four weeks after planting, along with yield is used to assess whether profit-maximizing replanting stand count thresholds differ as a function of how long a producer waits to determine whether or not to replant. As planting date negatively affects yield potential and higher seeding rates are recommended for late season plantings, delayed planting is tantamount to higher cost and yield potential lost. In addition, the rate of seed survival is affected by planting date and soil texture along with a host of other factors. To measure how replanting thresholds are affected by changes in important decision variables, soybean seed cost, soybean price, and replanting equipment costs are varied. Results suggest that i) seed treatment is cost effective; ii) replanting stand count thresholds relative to profit-maximizing stand counts are quite low as replanting charges are high and soybean can compensate for low stand counts without excessive yield loss; iii) these replanting thresholds vary whether the decision is made two or four weeks post planting depending on soil texture, yield potential, and seeding rates of the replanted soybean; iv) optimal planting dates vary by location; v) variation in soybean price and seed cost have a larger impact than range of equipment replanting charges on replanting thresholds; and vi) replanting decisions may be made earlier than the current recommendation of waiting until four weeks after planting.

Key words: Soybean, Planting Date, Seed Treatment, Replanting, Economics

Highlights:

- Rising seed cost affects seeding rate and replanting decisions. Sensitivity analyses on soybean price, seed cost, seed treatment, and equipment replant charges are performed to assess their relative effect on replanting thresholds.
- Seed treatment is cost effective for a majority of weather and soil conditions analyzed in this study.
- Yield potential declines with the planting season. If replanting is necessary, making the replanting decision earlier than four weeks past the initial planting has positive yield impacts and requires a different stand count threshold.

Abbreviations:

PPD	plant population density in plants per square meter at two and four weeks post planting
PPD^*	profit-maximizing PPD when the marginal cost of PPD is equal to its marginal revenue
PPD^T	PPD of initial crop when expected net returns are equal to returns of a subsequent crop after accounting for replanting costs and changes in yield
Y	soybean yield in Mg ha^{-1}
Y^*	estimated yield at PPD^*
ROS	rate of seed survival as the ratio of the number of established plants per seed planted. This was measured at two and four weeks post planting
SR	seeding rate in kg ha^{-1} using a seed count of 6,614 seed kg^{-1}
SC	seed cost in $ kg^{-1} with and without seed treatment at $0.09 kg^{-1}
RPC	replanting equipment charges, including equipment ownership, fuel, labor, and repair and maintenance charges

Replanting Thresholds for Soybean using Two- and Four-Week Plant Survival Metrics

B. Introduction

It is not unusual for a producer to plant a field to soybean and after two to four weeks realize that an insufficient number of plants has emerged. Guidance to determine whether the stand count is insufficient depends on a number of factors. In particular, increasing seed cost, soybean yield potential as a function of the replanting date and other replanting charges influence the profitability of this decision. As explained in Poag et al. (2005) the decision hinges on a threshold level of plant population density (*PPD*) below which a producer would want to replant. Further, how long the producer waits after planting to determine whether or not replant is critical as yield potential declines over the course of the planting season and also, because profit-maximizing seeding rates (*SR*) increase with later planting dates (Edwards and Purcell, 2005; Lee et al., 2008; Boyer et al., 2015). Yield potential declined by an average of 382 kg ha^{-1} wk^{-1} from May to June planting in the Upper Midwest in 2008 (De Bruin and Pedersen, 2008). In the Mid-South, Ashlock et al. (1999) estimated 1 to 2% daily loss of yield potential after June 15. Lee et al. (2008) found that economically optimal *PPD* increase from 23.8 plants m^{-2} in May to 28.2 plants m^{-2} in July in the Mid-Southern United States.

Poag et al. (2005) made *SR* recommendations using experimental data that was collected to estimate the effect of seed treatment, soil moisture conditions post-planting, planting date, *SR*, and seed quality from 2001 to 2003. They calculated economically optimal *PPD* replanting thresholds to arrive at producer recommendations for clayey and loamy soils. The threshold is an estimate of the minimum *PPD* needed for the initial stand not to be replanted. They had two seeding rates to make recommendations. They also used observations of seedling emergence at four weeks after planting, as is the generally accepted extension recommendation.

For replanting decisions, Wilmot et al. (1989) also discuss effects of stand uniformity. Given spatial variation in soil characteristics, stand counts are rarely uniform across an entire field. Measuring this effect takes a larger plot size than is conventionally pursued for experimental research given cost considerations. While some variation is available in replicated small plots, plot research likely underestimates this effect. Hence producers that need to make a field level decision will need to measure *PPD* at several locations throughout the field to arrive at adequate average *PPD* conditions for the field to make a replanting decision.

Finally, the choice of soybean seed maturity is expected to vary with planting date as yield potential varies as most recently shown by Salmeron et al. (2014). This is a potentially important consideration for replanting decisions as changes in soybean seed maturity between the initial and later replanted soybean affect the replanting decision given changes in yield potential.

To build on previous efforts, the objectives of this study are to use seedling emergence data observed at different locations at two and four weeks after planting to show how the cost of an extra established plant affects estimates of profit-maximizing *SR* given estimated yield responses to stand counts observed at different time intervals after planting using treated and untreated soybean seed. Specifically, this study examines: i) whether seed treatment is cost effective; ii) the effect of replanting charges, soybean price, seed cost and the shape of the yield response to *PPD* on replanting *PPD* thresholds; iii) how these replanting *PPD* thresholds vary when the decision is made two or four weeks post planting depending on soil texture, yield potential, and seeding rates of the replanted soybean; and iv) whether optimal planting dates vary by location. These analyses provide time-sensitive, profit-maximizing *SR* recommendations across two locations that differ mainly in soil texture. The analyses also guide producer replanting decisions using more data than was previously available. Effects of changes in soybean seed maturity across planting date and field level variation in stand count, were beyond the scope of this analysis.

C. Materials and Methods

1. Experimental Description

Experimental trials were conducted at two University of Arkansas research stations: i) Keiser, AR (35°40'N 90°5'W) on Sharkey silty clay soil [very fine, smectic, thermic, Chromic Epiaquerts]; and ii) Stuttgart, AR (34°29'N 91°32'W) on Crowley silt loam soil [fine, smectic, thermic, Albaquultic Hapludalfs] using a randomized complete block design. All fields were a split-plot arrangement with a main plot of three planting dates per season (Table 1) and subplots of seed treatment and seeding rate. Seeding rates in all years varied between 22.2, 37.1, and 44.5 seeds m^{-2}. Seed was treated at labeled rates of 44.4 and 8.9 ml/45.4 kg seed with a combination of ApronMaxx (mefenoxam and fludioxonil) and Dynasty (azoxystrobin), respectively, for protection against damping-off and seed rots due to *Pythium, Phytophthora, Fusarium, Rhizoctonia* spp., early season *Phytophthora* root rot and seed-borne *Sclerotinia*, and *Phomopsis* spp. fungal diseases (Mbofung et al., 2013). Untreated seed, the control, was also processed using the same equipment, but with water only. Soybean seed varieties were HBK 4924 in 2007, 2008, and 2009; whereas Armor 47G7 seed was used in 2010 and 2011. These varieties are commonly grown in the production region analyzed. Seed was planted using row spacing ranging from 76 cm at Stuttgart to 97 cm at Keiser given equipment availability at each of the experimental sites. Plants were furrow irrigated in accordance with University of Arkansas soybean production recommendations (Arkansas Soybean Production Handbook, 1999). Yield data were taken from the center two of four 6.1 - m rows in each plot and adjusted to 13% standard moisture. The number of established plants was recorded at two and four weeks past planting on 12.2 m of row per plot and converted to plants m^{-2}.

2. Estimating Rate of Seed Survival for Cost Prediction

To arrive at cost estimates necessary to develop a stand of soybean of a targeted *PPD*, an estimate of seed survival is needed. To summarize effects of different seeding rates and at what time the number of emerged seedlings are counted after planting, *PPD* was estimated as a function of seeding rate with year, location, seed treatment, and planting season interactions using *PPD* data as observed at two and four weeks after planting as follows:

(1) $$PPD_2 = SR \cdot (\alpha_1 + \alpha_{2..5} Year + \alpha_6 Loc + \alpha_7 Early + \alpha_8 Late + \alpha_9 ST) + \varepsilon$$

and

(2) $$PPD_4 = SR \cdot (\beta_1 + \beta_{2..5} Year + \beta_6 Loc + \beta_7 Early + \beta_8 Late + \beta_9 ST) + \eta$$

where PPD_2 and PPD_4 are the number of established plants m^{-2} observed at two and four weeks after planting, respectively. Seeding rate (*SR*) varied from 22.2, 37.1, and 44.5 seed m^{-2} while ε and η are error terms. Coefficients α and β estimate deviations from the base response of *SR* on *PPD* as observed at Keiser for mid-season, untreated seed planted in 2009 (the scenario with the most observations as shown in Table 1). *Year*, *Loc*, *Early*, *Late*, and *ST* are binary 0/1 variables for each of the experimental years ranging from 2007 to 2011, the location, planting season, and seed treatment effects, respectively. Included, but not shown in Equations 1 and 2, were three-way interactions with *SR* including planting season × location, year × location, year × seed treatment, and seed treatment × location effects. Note, the equation is estimated without a constant term, as zero *SR* would lead to zero *PPD.* An alternative specification with a constant term is provided in the appendix. The estimated rate of seed survival ($\hat{ROS}$), or the fraction of plants established per seed planted in year *i*, location *j*, planting season *k,* and with or without seed treatment *l* can now be calculated. For seed planted in 2008, Keiser, early-season and with seed treatment, is estimated as:

$$(3) \qquad \hat{ROS}_{ijkl} = \alpha_1 + \alpha_3 + \alpha_7 + \alpha_9$$

where α_1 captures the basic response of *PPD* to *SR* that is common across all planting season × location × year × seed treatment combinations, α_3 is the 2008 compared to the 2009 base year effect, α_7 is the early- compared to mid-planting season effect, and α_9 is the seed treatment effect. Dividing the cost per seed by $\hat{ROS}_{ijkl}$, leads to year-, location-, planting season-, and seed treatment-specific cost per extra plant m^{-2}. How that cost is used is discussed further below.

Since a producer does not know what kind of year to expect in the future, an average estimate of this cost per added plant was developed using a simple average of planting season × location × seed treatment combinations, where experimental data was available to avoid out-of-sample predictions and to equally weight each year.

3. Estimating Yield Response to Plant Population Density

To calculate profit-maximizing seeding rates, where the cost of an extra plant, as calculated in Section 2.2, is equal to the added revenue of an extra plant, the yield response to *PPD* is needed to arrive at an estimate of the revenue potential from an extra plant. Hence, yield

(Y) was estimated as a function of *PPD* and *PPD* interactions with year, location, planting season, and seed treatment using *PPD* at both two and four weeks after planting to determine whether yield response to *PPD* differed by the timing of *PPD* measurement as follows:

$$(4) \quad \begin{aligned} Y = {} & \gamma_1 PPD_2 + \gamma_2 \sqrt{PPD_2} + \gamma_{3..10} PPD \times Year + \gamma_{11..12} PPD \times Loc + \\ & \gamma_{13..14} PPD \times Early + \gamma_{15..16} PPD \times Late + \gamma_{17..18} PPD \times ST + \lambda \end{aligned}$$

and

$$(5) \quad \begin{aligned} Y = {} & \delta_1 PPD_4 + \delta_2 \sqrt{PPD_4} + \delta_{3..10} PPD \times Year + \delta_{11..12} PPD \times Loc + \\ & \delta_{13..14} PPD \times Early + \delta_{15..16} PPD \times Late + \delta_{17..18} PPD \times ST + \mu \end{aligned}$$

where Y is the yield in kg ha^{-1}, λ and μ are error terms, and all other variables and estimation technique are as described above. Note, that *PPD* enters the equation nonlinearly using a square root functional form. This allows for a rapid increase in yield at low *PPD* followed by a leveling off in response to added *PPD* and an eventual decline in yield potential at high *PPD* with too many plants causing interplant competition as in Poag et al. (2005) and Popp et al. (2006). Two-way interactions with *Year* led to eight coefficient estimates, four deviations from the 2009 base year for each of the linear *PPD* and non-linear $\sqrt{PPD}$ variables. Two-way interactions with *Loc*, *Early*, *Late*, and *ST* had two coefficient estimates each for *PPD* and $\sqrt{PPD}$. Three-way interactions of *PPD* × location × planting season are not shown for brevity. Again, the equation is estimated without a constant term as zero *PPD* would lead to zero yield and the base location is Keiser with untreated seed planted mid-season in 2009. An alternative specification for this equation is also shown in the appendix. For example, the estimated year- (i), location- (j), planting season- (k), and seed treatment- (l) specific yield for seed planted in 2009, Keiser, late with untreated seed using PPD_4 would be:

(6) $\hat{Y}_{4,ijkl} = (\delta_1 + \delta_{15})PPD_4 + (\delta_2 + \delta_{16})\sqrt{PPD_4}$

where δ_1 and δ_2 capture yield responses to *PPD* and $\sqrt{PPD}$, and δ_{15} and δ_{16} capture the changes in yield response to *PPD* and $\sqrt{PPD}$ due to late-season planting.

A plot of observed and estimated yields for mid- and late-season planted, treated soybean at Keiser in 2009 is shown in Figure 1 using PPD_2 to show the non-linear estimate of yield response. To develop an average yield response for planting season × location × seed treatment combinations that is not dependent on year, coefficient estimates for *PPD* and $\sqrt{PPD}$ for years with available data were averaged applying equal weight to each year with data to avoid out-of-sample predictions.

4. *Profit-Maximizing PPD, Yield and Seeding Rate*

The profit-maximizing *PPD* occurs where the extra revenue generated by an extra plant is equal to its added cost (*c*) and is a function of the seeding rate chosen by the producer. Mathematically, the product of the partial derivative of Equation 6 with respect to *PPD* and the price of soybean is the revenue potential of an extra plant m^{-2} on a per hectare basis or its marginal revenue. The marginal cost for an extra plant ha^{-1} is a function of the expected rate of seed survival from Equation 3. Equating marginal revenue to marginal cost maximizes profit at a profit-maximizing PPD^*:

(7) $$\frac{\partial Y}{\partial PPD} \cdot P = SC / \left(\frac{\partial PPD}{\partial SR} \right) \cdot 10{,}000$$

where and P is the soybean price in \$ kg^{-1}, SC is the seed cost per added seed, $\partial PPD / \partial SR$ is the rate of seed survival or *ROS* and multiplying by 10,000 m^2 ha^{-1} scales cost to \$ ha^{-1}. The left side of the equation is the marginal revenue in \$ ha^{-1} and the right side is the marginal cost in \$ ha^{-1}. Since marginal revenue is a function of *PPD*, Equation 7 is solved for *PPD* as follows:

$$(8) \qquad PPD^* = \frac{b^2 P^2}{4(c - aP)^2}$$

where *a* is the sum of *i*, *j*, *k*, and *l*-specific *γ*- and *δ*- coefficients from Equations 4 and 5 for PPD_2 and PPD_4 variables and interactions, respectively, and *b* is the sum of *i*, *j*, *k*, and *l*-specific *γ*- and *δ*- coefficients from Equations 4 and 5 for $\sqrt{PPD_2}$ and $\sqrt{PPD_4}$ variables and interactions, respectively. As an example, the profit-maximizing $PPD^*_{4,ijkl}$ for seed planted at Keiser in 2009, late, and with untreated seed using PPD_4 is:

$$(9) \qquad PPD^*_{4,ijkl} = \frac{(\delta_2 + \delta_{16})^2 P^2}{4(c_{4,ijkl} - \delta_1 P - \delta_{15} P)^2}, \text{ where}$$

$$(10) \qquad c_{4,ijkl} = \frac{SC_l}{\hat{ROS}_{4,ijkl}} \cdot 10{,}000 = \frac{SC_l}{(\beta_1 + \beta_8)} \cdot 10{,}000, \text{ and}$$

where SC_l is the cost of untreated seed in \$ seed^{-1} obtained by dividing the seed cost in \$ kg^{-1} by the number of seeds kg^{-1}, the denominator to SC_l is the $\hat{ROS}_{4,ijkl}$ from Equation 3, and *P* is the soybean price in \$ kg^{-1}.

The profit-maximizing yield, $Y^*_{4,ijkl}$, follows by substituting $PPD^*_{4,ijkl}$ for PPD_4 in Equation 5. It is a function of *P*, *SC*, and conditions *i*, *j*, *k*, and *l*. The profit-maximizing *SR*, $SR^*_{4,ijkl}$, is the $PPD^*_{4,ijkl}$ divided by the $\hat{ROS}_{4,ijkl}$. Subscripts for scenario specific information including year, location, planting season, seed treatment, and timing of decision after planting are excluded from the remainder of the paper for brevity.

5. *Replanting Threshold Establishment*

With Y^*calculated, replanting thresholds may now be calculated for early and mid-season planting dates if targeted PPD^* are not achieved for a variety of reasons (e.g. frost, soil crusting, flooding or seedling disease). The threshold yield (Y^T) needed for a subsequent planting to be at least as profitable as the initial planting is determined as follows:

(11) $$Y^T = Y_N^* - \frac{(SR_N^* \cdot SC + RPC)}{P}$$

where Y_N^* is the optimal yield for the next planting date in kg ha^{-1}, and $\frac{(SR_N^* \cdot SC + RPC)}{P}$ represents the cost of replanting expressed in terms of yield in kg ha^{-1}. The cost of replanting is comprised of needed seed for the replanting $(SR_N^* \cdot SC)$ in \$ ha^{-1} plus equipment, labor, and fuel charges for replanting (*RPC* in \$ ha^{-1}) divided by the soybean price.

With Y^T determined, the corresponding PPD^T, or replant threshold PPD, was calculated by replacing Y^T for $\hat{Y}$ in Equation 6 and solving for *PPD*:

(12) $$PPD^T = \left(\frac{-\sqrt{4ab^2Y^T + b^4} + 2aY^T + b^2}{2a^2} \right)$$

where *a* and *b* are described in Equation 8 and Y^T is specified using Equation 11.

Needed calculations in Sections 2.2 through 2.5 are presented graphically in Figure 2. Yield response to *PPD* of the first planting is shown by the solid line. Yield increases rapidly at low *PPD* and levels off at higher *PPD*. The same leveling off in yield with *PPD* holds for the later planting, but at lower yield potential. The profit-maximizing PPD^* for late planting occurs at the point where the added revenue resulting from an extra *PPD* equals its cost. This occurs at yield level Y_N^*. However, to achieve Y_N^*, the producer incurs replanting charges that are expressed in terms of yield and shown as the vertical distance between Y_N^* and the replanting yield threshold, Y^T, for the earlier planting. The Y^T is used to calculate the replanting *PPD* threshold shown at the end of the arrow pointing to the horizontal axis. A producer observing fewer established plants for the initial planting than PPD^T would end up with less yield than available with replanting (net of the replanting cost expressed in terms of yield).

While the shape of the yield response to *PPD* does not change with the price of soybean, seed cost, or replanting cost, Y_N^* depends on soybean price and seed cost. The replanting charges, *RPC*, are also a function of soybean price and seed cost as well as the fuel, labor, and equipment charges associated with replanting. Since these prices and costs change over time, the replanting threshold and *SR* recommendations change over time as well.

6. Economic Data

Thresholds were all calculated using the 2002-2011, 10-year average soybean harvest price of \$284.33 Mg^{-1}, or 28.4 ¢ kg^{-1}, that was adjusted for inflation to constant 2009 dollars (\$), as shown in Table 2, using the commodity prices received index provided by the National Agricultural Statistics Service. Using this average helps to avoid the problems associated with using annual seasonally or cyclically high or low prices that might otherwise influence the results. The year 2009 is chosen because it reflects the middle year when experiments were conducted. Sensitivity analyses, discussed in a later section, alter these price assumptions. Labor, fuel, chemical, and equipment charges for replanting were initially set at \$59 ha^{-1} because this cost point represented the mid-point of the range of replanting costs for a variety of production methods as outlined in the following section.

7. Replanting Charges

Replanting charges a producer incurs are not expected to be affected whether a producer elects to replant two or four weeks after initial planting. Destroying the established stand, either mechanically or chemically, is advisable for producers before replanting to be able to time weed control and irrigation practices to a stand that is uniform in production characteristics (Wigham et al., 2000). Nonetheless, some state extension services in the upper Midwest have recommended "filling in" the stand rather than complete stand destruction (Gaspar et al., 2014).

Mechanical destruction of the stand for replanting involves one pass with a field cultivator followed by a seed bed forming implement (disk bedder with roller) for a field using furrow irrigation. Using the Mississippi State Budget Generator (Laughlin and Spurlock, 2015), historical information from 2009 revealed cost estimates for a 7.3 m field cultivator drawn by a 142 kW MFWD tractor to be \$14.18 ha^{-1} at a fuel cost of \$0.65 L^{-1} with prevailing equipment and labor charges. One pass with a 7.6 m disk bedder with roller drawn by a similar tractor costs \$14.97 ha^{-1} and one pass with an 8-row planter with 97 cm row spacing cost \$27.85 ha^{-1}. Rebedding the field is not required for producers using flood irrigation. Mechanical destruction of plants thus ranged in cost from \$42.03 ha^{-1} to \$57.01 ha^{-1} in 2009 dollars (\$).

Using herbicides to control the previous crop can be more expensive in comparison to mechanical destruction, but is likely less time intensive and less dependent of appropriate soil moisture needed for seedbed preparation. Depending on the type of herbicide resistant seed technology employed, using Gramoxone (*paraquat*), Liberty (*glufosinate*), or Glyphosate (*glyphosate*) at labeled rates was estimated to cost \$18.42, \$32.95, and \$14.83 ha^{-1}, respectively. Using custom application charges of \$14.83 ha^{-1} or owner operated equipment (18 m wide, 3,029

Liter sprayer drawn by 142 kW MFWD tractor) at a cost of \$5.39 ha^{-1} leads to a range of cost from \$48.06 ha^{-1} with owned spraying equipment using Glyphosate to \$75.63 ha^{-1} with custom applied Liberty.

Given the above range of cost, initial PPD^T were calculated using RPC of \$59 ha^{-1} with a range of \$42 to \$76 ha^{-1} for sensitivity analysis. Seed cost for soybean is a critical consideration for replanting. A 2013 survey of row crop input costs in Arkansas found that seed costs make up 27% of total soybean input costs (Flanders, 2013). It is, thus, the largest single item on soybean cost of production budgets. As such, producers pay close attention to this cost when evaluating their seeding rate. A review of enterprise budgets from 2001 to 2011 reveals seed prices ranging from \$1.22 to \$2.53 kg^{-1}, as shown in Table 2. By comparison, current seed prices are \$1.68 and \$3.31 kg^{-1} in 2015 dollars and the cost of production budgets for 2015 use 67.25 kg ha^{-1} of seed. Given the prevalence of use of biotechnology, a seed price of \$2.10 kg^{-1} was used for initial estimates of Y^* and PPD^*. A seed count of 6,614 seed kg^{-1} was used to arrive at the marginal cost of an additional plant.

8. Cost effectiveness of Seed Treatment

To make seed treatment profitable, the rate of seed survival with seed treatment, $\hat{ROS}_{ST}$, needs to be sufficiently greater than the rate of seed survival without seed treatment, $\hat{ROS}$, to allow enough seed cost savings to offset the seed treatment cost. With a charge of 0.09 \$ kg^{-1} for seed treatment (*TC)* (Popp et al., 2010) and untreated seed cost (*SC*) of 2.12 \$ kg^{-1} the breakeven rate of seed survival, $\hat{ROS}_{ST}^{BE}$, for treated seed is calculated as follows:

(13) $$\hat{ROS}^{BE}_{ST} = \frac{\hat{ROS} \cdot (SC + TC)}{SC}.$$

Note, the more valuable the seed and the lower the seed treatment cost, the lower the need for improvement in rate of seed survival for seed treatment to be profitable. Further, variation in the rate of seed survival is not assessed here and seed treatment is expected to lower such variation as demonstrated by Gaspar et al. (2015).

All statistical analyses where performed using econometric software EViews 9.0 (Lilien et al., 2015) estimating equations 1 and 4 as well as 2 and 5 as systems using full information maximum likelihood estimates for coefficient estimates and their White's heteroscedasticity-consistent standard errors. Binary variable techniques using linear and non-linear regression with and without a constant term are described in Gujarati (1995).

D. Results

1. Rate of Seed Survival

Regression results for Equations 1 and 2 are shown in Table 3. The signs of coefficient estimates were as expected and the overall goodness of fit for the regression as measured by r^2 was deemed adequate to estimate seedling survival, $\hat{ROS}$, as a precursor to developing cost estimates per added plant. The average $\hat{ROS}$ information in Table 4 reveals higher $\hat{ROS}$ when measured at four weeks post planting compared to just two weeks after planting at Stuttgart. The same trend was not observed at Keiser, if not the opposite. Overall, $\hat{ROS}$ were highest early-season at Stuttgart and declined with later planting. Again, the Keiser location showed no such trend. Adding a constant term to the estimation procedure led to slightly lower estimates with similar differences across treatment combinations when comparing the last two rows in Table 4.

Table 4 revealed seed treatment to be profitable for a majority of planting season × location × year conditions. Note, the profitability of seed treatment was not necessarily affected by the level of $\hat{ROS}$, as seed treatment in 2007 was generally not profitable regardless of the level of $\hat{ROS}$. Since seed cost projections point to higher value seed, making seed treatment more likely to be profitable, as discussed in Section 2.8, the remainder of the paper discusses results using treated seed.

2. *Yield Results*

Regression results for yield response to *PPD* are shown in Table 5. The signs of coefficient estimates were again in line with expectations and showed yield to increase rapidly at low *PPD.* Yield response to added *PPD* leveled off at higher *PPD* and eventually leveled off and/or declined. On the basis of r^2, the functional form for the yield response to *PPD* provided a good fit for the observed data. Adding a constant term as shown in the appendix did not improve goodness of fit.

For some planting season × location × year conditions, the yield response to *PPD* showed relatively little leveling off in yield response over the *SR* analyzed. For these scenarios, while yield estimates as a function of *PPD* were close to observed yields as shown in Figure 2, calculation of optimal PPD^* may lead to high values outside the range of observed *PPD* and yields. A solution for this issue is provided in Section 3.3.

3. *Economically Optimal PPD and Yield*

Calculations of profit-maximizing PPD^* and resultant Y^* mostly provided results that met with expectations (Table 6). There were, however, some locations and years where estimates of PPD^* were higher than the experimentally observed maximum *PPD* discussed previously. These situations are highlighted in Table 6 using italicized entries. For these conditions, the profit-maximizing yield (Y^*) and PPD^* reflect estimated yields based on maximum estimated *PPD* using the $\hat{ROS}$ for that planting season × location × year combination along with the maximum seeding rate of 44.5 seeds m^{-2}. That is, the profit-maximizing yield is curtailed to the yield estimated at the maximum *SR* used in the study to avoid out-of-sample predictions.

While yield forecasts were similar whether using PPD_2 or PPD_4, corresponding PPD^* tended to be higher, on average, for the estimation technique using stand counts at four weeks after planting. This is a function of the different explanatory power of the yield response equations. Moreover, lower PPD_2^* compared to PPD_4^* are evidence of more plants emerging between two and four weeks post planting. For all scenarios at Keiser, using either the two- or four-week *PPD* data, Y^* was highest with mid-season planting. At Stuttgart, by contrast, early-season planting provided greater yield which is likely a result of relatively high $\hat{ROS}$ on loamy soils offering *PPD* near maximum estimated yields and lesser exposure to high summer temperatures which may adversely affect yield potential with late planting. Keiser has higher clay content in the soil which can lead to significant soil crusting and thereby lower $\hat{ROS}$. For these locations, mid-season planting allowed for greater yields, which is typically coincident with lesser likelihood of rainfall amounts that may lead to soil crusting that inhibits seed establishment.

The findings in Table 6 translate to SR^*, as shown in Table 7. Examination of the average SR^* reported by planting season and location showed trends that were in line with the $\hat{ROS}$ results for Stuttgart. Higher seed survival leads to seed cost savings with early and mid-season planting. For early- and mid-season plantings at Stuttgart, calculated *SR* are similar regardless of when stand count data was collected. At Keiser, calculated *SR* varied randomly across years, planting season and timing of taking the stand count. Mid-season plantings with highest yields also required the most seed using the four week *SR* recommendation. These findings are likely attributable to the soil texture at that location being less conducive to successful plant emergence. For either location, calculated *SR* are generally less than the current University of Arkansas Extension cost of production recommendation of 67.25 kg ha^{-1}. At Stuttgart, in particular, using approximately 25 kg ha^{-1} less seed for advisable early- and mid-season planting would translate to cost savings around $50 ha^{-1}. Results are similar using the alternative specification for the seed survival and yield response equations. Overall, the calculated seeding rates based on survival at four weeks post planting rather than at the earlier measurement time are likely more reliable estimates as the yield response equations using PPD_4 had better explanatory power. Expected seed survival rate, seed cost, producer risk aversion and translating results from experimental plots to field conditions are additional factors to consider in this decision, however.

4. Replanting Thresholds

Table 8 shows replanting threshold PPD^T for early- and mid-season plantings using Equations 11 and 12. It is a summary of all planting season × location × year × timing of *PPD* observation that represents the key data points from yield responses to *PPD* as explained in Figure 2 and in Section 2.5. Replanting was advisable regardless of existing stand count for early-season plantings at Keiser. A replant decision is a reflection of the greater yield potential associated with planting the following month. As such, planting early at Keiser is not advised based on the findings in this study. At Stuttgart, however, where early-season plantings typically led to highest yields, replanting thresholds were calculable for early- and mid-season plantings.

Overall, the table shows PPD^T that are lower when using two week stand counts than if the decision was made at four weeks post planting. The level of PPD^T is also a function of the succeeding planting season's yield potential; the lower the subsequent crop's yield potential, the lower the PPD^T threshold as demonstrated by the higher PPD^T for Keiser compared to Stuttgart. In addition to changes in yield potential with time of planting, the trend of greater seed requirements for late planting at Stuttgart with delayed planting decreased replanting thresholds further. Finally, using either time frame for stand count measurement, PPD^T were quite a bit lower than their PPD^*, as shown by fractions in parentheses in Table 8. The PPD^T using the functional form with the intercept terms as shown in the appendix and summarized in the bottom row of Table 8 are lower than calculated using no intercept shifters. Revisiting Figure 2, this makes sense as the slope of the yield response function at low *PPD* is affected.

Table 8 provides different PPD^T for stand counts taken at different times after planting. Therefore, replanting decisions may be made somewhat earlier than the conventional rule-of-thumb of waiting for four weeks after planting. However, it is important to use the PPD^T provided for the different times of measurement, especially at Stuttgart where differences in thresholds due to timing of measurement are larger. Also, quite sparse stands ranging from 11 to 27% of targeted PPD^* may be economically viable to maintain rather than replant. Not considered in this analysis is the potential for greater weed control costs with sparse stands and the potential for field variation in stand count as pointed out by Wilmot et al. (1989). Note that calculated PPD^T were typically above observed *PPD* for most scenarios as some of the plots with the low seeding rate treatment had low observed stand counts when combined with low seed survival (Figure 1).

5. Sensitivity Analysis

When replanting costs (*RPC*) for the model was decreased by 10%, PPD^T increased for all scenarios as expected, but only slightly (Figure 3). For all PPD_2^T, a 10% reduction in *RPC* increased PPD^T by no more than 3.3%, or 2.1% on average. Similarly, sensitivity of PPD_4^T to changes in *RPC* were at a maximum of 3.2%, and 1.9% on average. While certain factors, such as low diesel prices, might cause *RPC* to decrease slightly in a given year, it is unlikely that producers will see replanting charges fall by a larger magnitude in the future.

To evaluate how a more expensive replanting process would influence PPD^T, the previously described maximum of 75.63 \$ ha^{-1} for *RPC* was used. As expected, this 28% increase in *RPC* decreased PPD^T for each condition, but not more than 8.7% for PPD_2^T and 8.5% for PPD_4^T or 5.4% on average. Because such a large increase in replanting costs only influences PPD^T to a small degree, changes in *RPC* should not be a great concern for the replant decision process, as PPD^T changes were less than +/- 0.3 plants m^{-2} for any of the changes in *RPC* analyzed and +/- 0.1 plants m^{-2} for -/+ 10% changes in *RPC*.

Changes to PPD^T were slightly more responsive to changes in seed cost than changes in *RPC*. Decreasing seed cost by 10% increased estimated PPD^T by as much as 7.9% and 7.7% for two and four week thresholds, respectively, and approximately 4.2% on average. A 10% increase in seed cost decreased PPD^T by a maximum of 7.5% and 7.3% using two week and four week data, respectively. Noteworthy, is how changes in seed cost also modified the profit-maximizing *SR* and thereby estimated Y^* -- higher *SC* lead to lower SR^* and Y^*, whereas lower

SC leads to higher SR^* and Y^*. These changes in Y^* and SR^* resulting from changes in *SC* are generally very small with the greatest SR^* increase/decrease of 4.9%/4.6% leading to an associated 0.9%/1.0% increase/decrease in Y^* when *SC* decreased/increased. The percentage changes translated to no more than +/- 0.3 plants m^{-2} for replanting thresholds.

Changes to PPD^T as a result of modifications in soybean price were the largest compared to *RPC* and *SC* changes. When soybean prices were lowered by 10%, PPD^T decreased by as much as 11.9%, or 6.6% on average. The decrease in soybean price also decreased SR^*, but by no more than 5.3%, or an average of 1.7%, with attendant maximum decreases in Y^* of 1.1%. A 10% increase in soybean price increased estimated PPD^T by as much as 10.6 or 5.8% on average. In addition, a 10% higher price increased SR^* by no more than 4.7% and Y^* increased by no more than 0.9%. The percentage changes translated to no more than +/- 0.4 plants m^{-2}.

In sum, the influence of changes in *RPC*, seed cost, and soybean price were found to be very comparable between two and four week estimated replanting thresholds. With 10% +/- changes in soybean price, seed cost, and replanting charges, replanting thresholds changed by no more than +/- 0.4, -/+ 0.3, and -/+ 0.1 plants m^{-2}, respectively, across the planting season × year × location × seed treatment combinations analyzed.

E. Discussion

This analysis sought to develop profit-maximizing replanting plant population thresholds using data collected from 2007 to 2011, across two locations in Arkansas. The conditions from which data were collected are expected to be representative of soybean production in Arkansas and results are likely applicable to other regions with similar weather and soil conditions.

Analysis of the seed treatment proved seed treatment to be profitable for most conditions analyzed and hence, ensuing discussions were focused on treated seed. Using stand count data collected either two or four weeks after planting led to similar estimated yields and lower replanting thresholds (PPD^T) using two rather than the four week data. The driving factors for PPD^T was the yield potential of the subsequent, replanted crop. At Stuttgart, yield potential declined over the growing season which resulted in replanting thresholds that were lower compared with Keiser. The replanting thresholds also declined further with higher late-season recommended seeding rates at Stuttgart. Early and mid-season plantings at Stuttgart had similar yield potential at relatively lower calculated *SR* compared to the current recommended *SR*. At Keiser, calculated *SR* for planting seasons recommended in this study were lower than the current extension recommendation but to a lesser extent than observed at Stuttgart. Early- and mid-season plantings demonstrated higher yield potential at Stuttgart in this study. At Keiser, early planting was not recommended and PPD^T were relatively higher than those at Stuttgart, as the yield potential for late-season plantings were higher relative to those at Stuttgart. Seeding rate recommendations for late-season plantings were either nearly the same, or lower, compared to mid-season plantings at Keiser. These findings are consistent with similar Mid-South studies by Lee et al. (2008) and Boyer et al. (2015). The results also support attainable seed cost savings for early- and mid-season planting at Stuttgart where seed survival was less variable than at Keiser with greater clay content in the soil. At Keiser, by contrast, early-season planting was not recommended and calculated seeding rates were closer to current recommendations. Overall, replanting thresholds were quite low and ranged from 11 to 27% of profit-maximizing *PPD*. Results, therefore, suggest to plan initial plantings with care, as replanting for fuel, equipment, and labor near \$59 ha^{-1}, along with seed costs that may exceed \$100 ha^{-1} (or in excess of 20% of the replanted yield potential in Figure 2, for example), are not easily recouped. Fortunately, yields remain relatively high at *PPD* < 10 plants m^{-2}, as soybean plants can compensate for low stand counts by growing larger plants (Edwards et al., 2005). Nonetheless, weed control at low *PPD* may become a problem, as canopy closure would be delayed. This effect was not analyzed in this paper.

The results suggest that waiting four weeks for replanting may be excessive, particularly in locations where seed survival is less predictable. At both locations, PPD_2^T were approximately 4/5th of PPD_4^T as more plants predictably emerged in the time period between two and four weeks after planting. Knowing this differential in PPD^T for different times of measurement after planting allows advancing a replant decision by as much as two weeks. Such a change in the timing of replanting has the potential to increase the yield potential of the replanted crop, as earlier detection of a problem means an earlier replant date associated with higher yields (approximately 0.25 Mg ha^{-1} or ~\$70 ha^{-1} for two week earlier plantings were estimated in this study).

Sensitivity analyses of PPD^T, with respect to replanting charges, soybean seed cost, and soybean price, showed soybean price to have the largest effect, followed by soybean seed cost. Nonetheless, PPD^T changed by < 0.4 plant m^{-2} for 10% deviations in cost or soybean price. PPD^T thresholds shown in Table 8 are thus expected to hold for a range of cost and price situations. As shown in Figure 3, these thresholds should increase/decrease with lower/greater cost and greater/lower soybean price, respectively.

Finally, *SR* recommendations are a contentious issue, as using higher *SR* allows room for error and increases yield potential. The replanting decision is also one fraught with uncertainty. Results reported in this study do not adjust for such producer risks in this decision. Making the decision to replant earlier is potentially risky as more plants could emerge. While the reader is left to make their own judgment, they are better equipped to make that decision given the information resulting from this study. Modifying maturity group selection by planting season and specifically addressing spatial variability in plant emergence would be interesting areas for future research.

F. Tables and Figures

Figure 1. Yield response to plant population density (PPD) for Keiser in 2009 using mid- and late-season planting with treated seed and PPD collected at two weeks post planting.

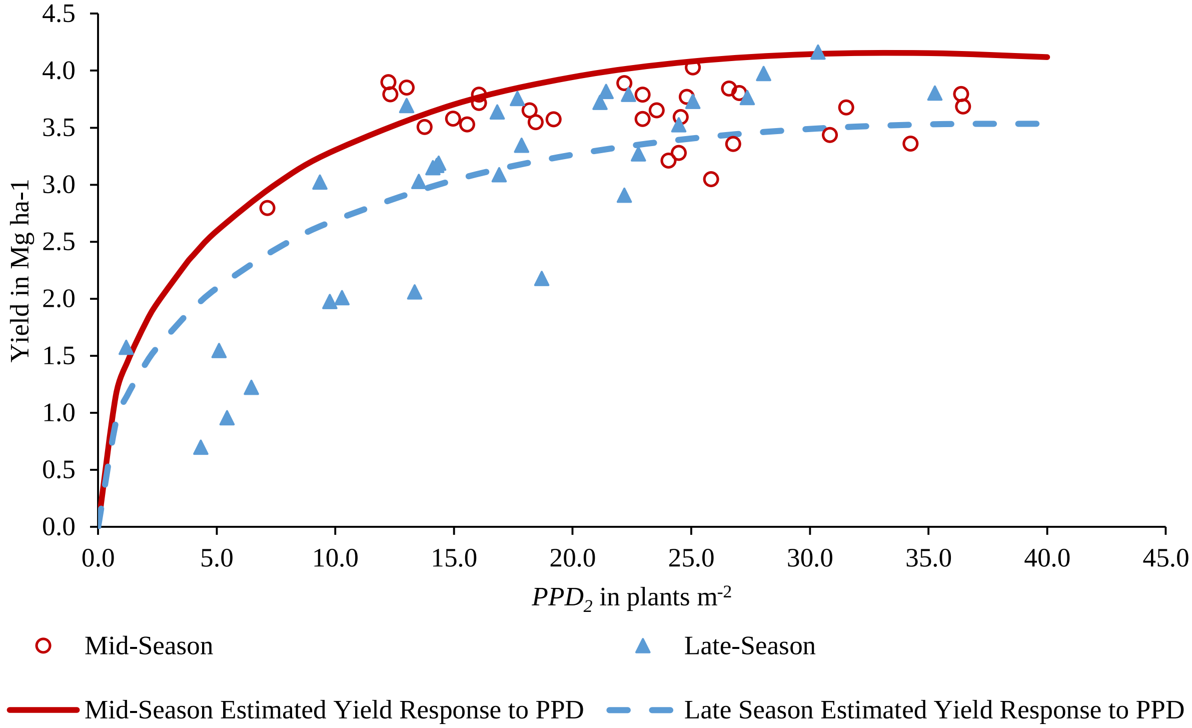


Figure 2. Yield response to plant population density (PPD) and replant PPD threshold (PPD^T) for Keiser, 2009, mid-season plantings using treated seed and PPD at four weeks post planting.

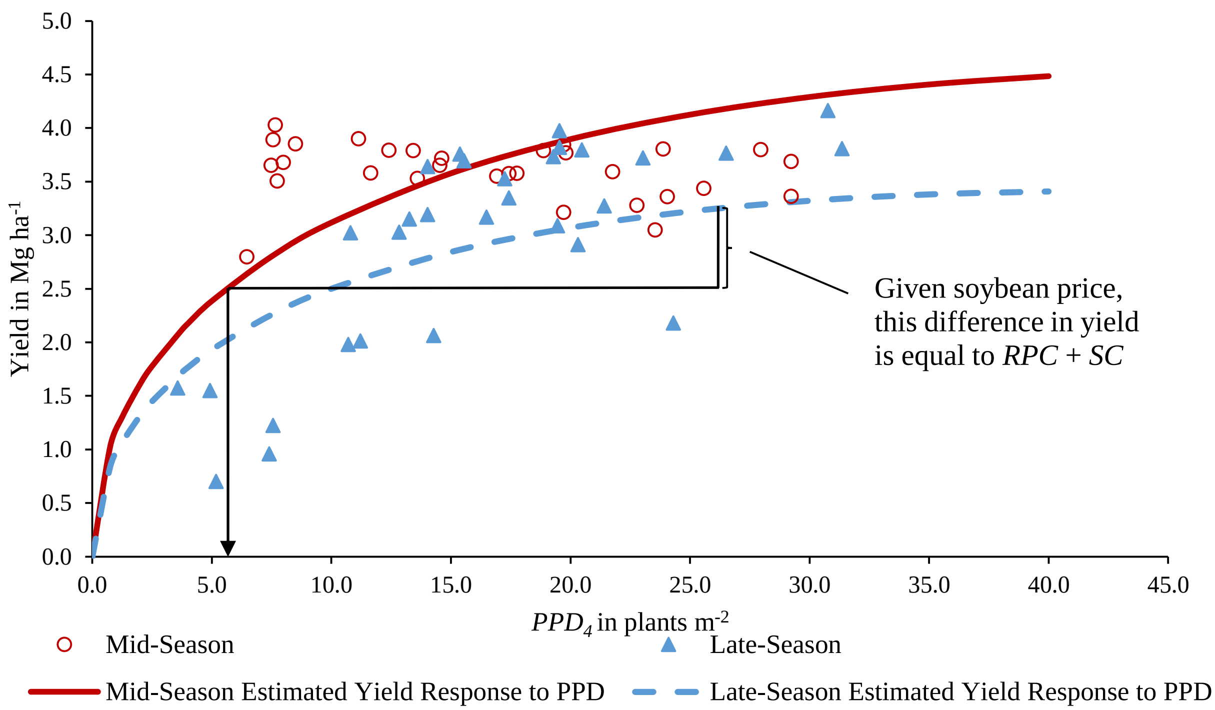
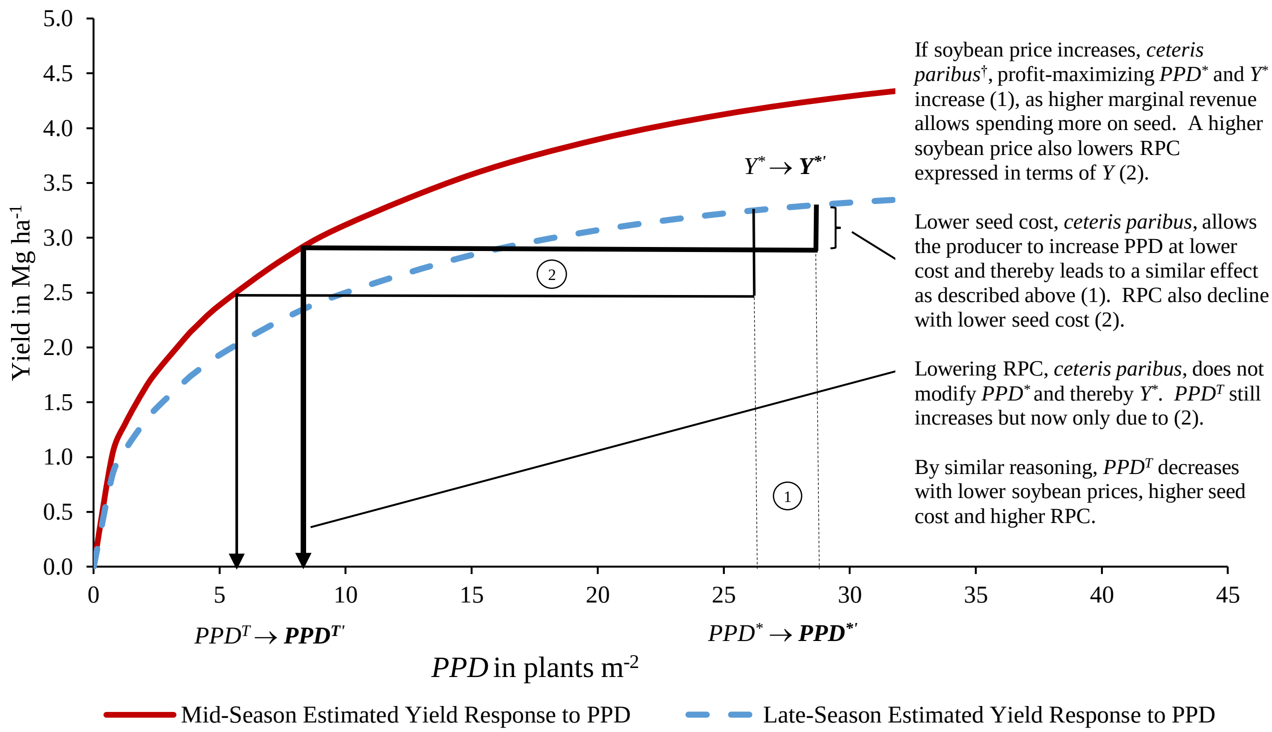


Figure 3. Economic repercussions of changes in soybean price, seed cost and replanting costs (RPC) on replanting plant population thresholds (PPD^T).



† Holding all other factors constant.

Table 1. Planting dates for seed treatment trials, Arkansas, 2007 - 2011.

Location	Planting Season	Year				
		2007	2008	2009	2010	2011
Keiser	Early	4/24	-	4/24	4/22	-
	Mid	5/14	5/22	6/01	6/1	5/30
	Late	6/20	6/19	6/19	6/17	6/20
Stuttgart	Early	4/30	5/01	4/27	-	-
	Mid	5/24	5/20	5/28	-	6/01
	Late	6/13	6/20	6/17	-	6/21

Note: Dashes (-) indicate the experiment was not performed, lead to crop failure, or weather conditions did not allow timely planting.

Table 2. Ten-year average, deflated US soybean price and Arkansas soybean seed cost in 2009 dollars.

	Year											
Description	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	**Avg.**†
					Soybean Price‡ in \$ Mg^{-1}							
#2 Soybean	na	253.52	295.72	226.74	238.07	230.16	279.30	336.06	339.21	323.97	320.50	284.33
					Soybean Seed Cost§ in \$ kg^{-1}							
Conventional	1.50	1.49	1.28	1.34	1.22	1.38	1.23	0.97	1.34	na	na	1.31
Roundup Ready ®	2.40	2.23	2.14	2.00	2.04	2.28	2.07	1.63	2.16	1.88	2.53	2.10

Notes:

† The average is the 2001 to 2009 simple average for conventional seed. Conventional seed prices for 2010 and 2011 were not available as an overwhelming majority of producers had adopted Roundup Ready seed by that time. The average for Roundup Ready seed is for 2002-2011 to match the ten-year average of soybean prices.

‡ All prices listed are in the USDA ERS nation-wide average prices at harvest (USDA Economic Research Service, 2015). Prices were deflated to 2009 dollars (\$), using the Commodity Prices Received Index (USDA National Agricultural Statistics Service, 2015).

§ All prices listed are from 2001-2011 University of Arkansas, Division of Agriculture, Extension Crop Cost of Production Estimates (UAEX) and converted to \$ kg^{-1}. An average seed count of 6,614 seed kg^{-1} is used arrive at cost per individual seed (*SC*). Prices were deflated to 2009 dollars using the Seed Prices Paid Index (USDA National Agricultural Statistics Service, 2015).

Table 3. Regression statistics for plant population density (PPD) at two and four weeks post planting as a function of year, location, planting season, seed treatment, and seeding rate.

Variable[†]		Two Week[‡]		Four Week[b]	Variable		Two Week		Four Week
SR	α_1	0.50***[§]	β_1	0.40***	*SR × Early × Stuttgart*	α_{10}	0.09**	β_{10}	0.15***
		(0.03)[¶]		(0.02)			(0.04)		(0.03)
SR × 2007	α_2	0.24***	β_2	0.29***	*SR × Late × Stuttgart*	α_{11}	-0.04	β_{11}	-0.13***
		(0.03)		(0.03)			(0.04)		(0.02)
SR × 2008	α_3	-0.08**	β_3	-0.01	*SR × 2007 × Stuttgart*	α_{12}	-0.30***	β_{12}	-0.30***
		(0.03)		(0.03)			(0.05)		(0.03)
SR × 2010	α_4	-0.10***	β_4	0.03	*SR × 2008 × Stuttgart*	α_{13}	0.08*	β_{13}	-0.08***
		(0.04)		(0.03)			(0.05)		(0.03)
SR × 2011	α_5	na[#]	β_5	-0.05**	*SR × 2011 × Stuttgart*	α_{14}	0.14***	β_{14}	0.12***
				(0.03)			(0.05)		(0.03)
SR × Stuttgart	α_6	0.04	β_6	0.23***	*SR × ST × 2007*	α_{15}	-0.11**	β_{15}	-0.11***
		(0.05)		(0.03)			(0.05)		(0.03)
SR × Early	α_7	-0.05***	β_7	-0.03*	*SR × ST × 2008*	α_{16}	0.001	β_{16}	-0.01
		(0.02)		(0.02)			(0.04)		(0.03)
SR × Late	α_8	0.01	β_8	0.05***	*SR × ST × 2010*	α_{17}	-0.11**	β_{17}	-0.11***
		(0.02)		(0.01)			(0.05)		(0.03)
SR × ST	α_9	0.13***	β_9	0.13***	*SR × ST × 2011*	α_{18}	-0.05	β_{18}	-0.07**
		(0.04)		(0.03)			(0.06)		(0.03)
r^2 [††]		0.60		0.70	*SR × ST × Stuttgart*	α_{19}	-0.04	β_{19}	-0.02
Observations		538		711			(0.04)		(0.02)

Notes:

[†] *PPD* are the number of established plants m^{-2} observed at 2 and 4 wk after planting. Year (2007.. 2011), location (Stuttgart), planting season (Early and Late), and seed treatment (ST) are binary variables where 1 = meeting the condition and 0 = not meeting the condition. Seeding rate represents the number of seeds planted m^{-2}. Given available data shown in Table 1, Keiser, mid-season plantings of untreated seed were the base case.

[‡] Two week and Four week refer to using PPD_{2wk} and PPD_{4wk} as in Equations 1 and 2.

[§] *, **, and *** denote significance at the 90%, 95%, and 99%, respectively.

[¶] Numbers in parentheses are standard errors of coefficient estimates.

[#] *PPD* was only measured four weeks after planting in 2011 at Keiser.

[††] The square of the partial correlation between predicted and actual yields or the coefficient of determination.

Table 4. Estimated marginal rate of seed survival as the fraction of the number of established plants measured at two and four weeks after planting per seed planted across observed conditions.

		Planting Season					
		Early[†]	Mid	Late	Early	Mid	Late
Year	**Time of Stand Count**	**Keiser**			**Stuttgart**		
2007	2 wk	0.68 (*0.70*[‡])	0.74 (*0.76*)	0.75 (*0.77*)	0.51 (*0.49*)	0.47 (*0.45*)	0.44 (*0.43*)
	4 wk	0.66 (*0.68*)	0.69 (*0.71*)	0.74 (*0.76*)	0.73 (*0.74*)	0.62 (*0.62*)	0.53 (*0.54*)
2008	2 wk	na[§]	0.42 (0.55)	0.43 (0.56)	0.58 (0.67)	0.55 (0.64)	0.52 (0.61)
	4 wk	na	0.39 (0.51)	0.44 (0.56)	0.66 (0.75)	0.54 (0.63)	0.46 (0.55)
2009	2 wk	0.45 (0.58)	0.50 (0.63)	0.51 (0.64)	0.58 (0.67)	0.54 (0.63)	0.51 (0.60)
	4 wk	0.37 (0.50)	0.40 (0.53)	0.45 (0.58)	0.75 (0.85)	0.63 (0.74)	0.55 (0.66)
2010	2 wk	0.35 (*0.36*)	0.40 (*0.42*)	0.41 (*0.43*)	na	na	na
	4 wk	0.40 (0.42)	0.43 (0.45)	0.48 (0.50)	na	na	na
2011	2 wk	na	na	na	na	0.68 (0.72)	0.65 (0.69)
	4 wk	na	0.35 (0.41)	0.40 (0.46)	na	0.70 (0.74)	0.62 (0.66)
Avg.[¶]	2 wk	0.49 (0.55)	0.52 (0.59)	0.52 (0.60)	0.56 (0.61)	0.56 (0.61)	0.53 (0.58)
	4 wk	0.48 (0.54)	0.45 (0.52)	0.50 (0.57)	0.71 (0.78)	0.62 (0.68)	0.54 (0.60)
Avg.[#]	2 wk	0.47 (0.52)	0.50 (0.57)	0.50 (0.57)	0.52 (0.55)	0.52 (0.56)	0.52 (0.56)
	4 wk	0.43 (0.48)	0.40 (0.47)	0.45 (0.52)	0.66 (0.73)	0.57 (0.63)	0.49 (0.55)

Notes:

[†] See Table 1 for planting dates.

[‡] Treated seed data is presented in parentheses. Italicized entries indicate situations where seed treatment cost of $0.09 kg^{-1} was not profitable.

[§] Experimental data was not available.

[¶] Simple average of available information.

[#] Simple average calculated using coefficient estimates for equation 2 with a constant term as shown in Appendix Table 2.

Table 5. Regression statistics for yield response plant population density (PPD) at 2 and 4 weeks post planting, year, location, planting season, and seed treatment.

Variable[†]		Two Week[‡]		Four Week	Variable		Two Week		Four Week
PPD	γ_1	$-84.9^{***,\S}$	δ_1	-81.7^{***}	*PPD* × *Early*	γ_1	-25.0	δ_1	-
		(18.6)[¶]		(17.2)			(20.4)		(16.8)
$\sqrt{PPD}$	γ_2	$1,253.4^{**}$	δ_2	$1,239.1^{**}$	$\sqrt{PPD}$ × *Early*	γ_1	-163.8^{*}	δ_1	-85.7
		(85.6)		(75.3)			(98.1)		(76.4)
PPD × *2007*	γ_3	-78.4^{***}	δ_3	-38.9^{***}	*PPD* × *Late*	γ_1	39.0^{**}	δ_1	6.5
		(16.8)		(13.8)			(17.6)		(17.8)
$\sqrt{PPD}$ × *2007*	γ_4	401.9^{***}	δ_4	[illegible]	$\sqrt{PPD}$ × *Late*	γ_1	- [illegible]	δ_1	-214.4^{***}
		(81.0)		(67.9)			(79.2)		(79.1)
PPD × *2008*	γ_5	-21.3	δ_5	-22.6^{*}	*PPD* × *ST*	γ_1	-19.4^{*}	δ_1	-0.6
		(20.1)		(13.0)			(10.1)		(8.4)
$\sqrt{PPD}$ × *2008*	γ_6	51.5	δ_6	107.7^{*}	$\sqrt{PPD}$ × *ST*	γ_1	91.4^{*}	δ_1	0.8
		(94.7)		(61.0)			(49.3)		(40.4)
PPD × *2010*	γ_7	-127.5^{***}	δ_7	-66.9^{***}	*PPD* × *Stuttgart* × *Early*	γ_1	-14.7	δ_1	9.7
		(24.0)		(23.4)			(39.8)		(21.9)
$\sqrt{PPD}$ × *2010*	γ_8	[illegible]	δ_8	420.5^{***}	$\sqrt{PPD}$ × *Stuttgart* × *Early*	γ_2	558.8^{***}	δ_2	373.5^{***}
		(103.7)		(94.9)			(190.1)		(106.2)
PPD × *2011*	γ_9	-61.5^{***}	δ_9	-41.6^{***}	*PPD* × *Stuttgart* × *Late*	γ_2	66.2^{***}	δ_2	81.8^{***}
		(19.9)		(14.0)			(24.2)		(23.1)
$\sqrt{PPD}$ × *2011*	γ_{10}	533.0^{***}	δ_1	432.2^{***}	$\sqrt{PPD}$ × *Stuttgart* × *Late*	γ_2	- [illegible]	δ_2	-367.7^{***}
		(95.2)		(67.7)			(115.1)		(107.2)
PPD × *Stuttgart*	γ_{11}	-5.3	δ_1	-25.1					
		(19.6)		(18.0)					
$\sqrt{PPD}$ × *Stuttgart*	γ_{12}	-152.4	δ_1	-81.4	r^2[#]		0.66		0.72
		(92.9)		(82.1)	Observations		538		711

Notes:

† Yield, the dependent variable, is measured in kg ha^{-1}. *PPD* are the number of established plants m^{-2} observed at 2 and 4 weeks after planting. Year (2007- 2011), location (Stuttgart), planting season (Early and Late), and seed treatment (ST) are binary variables where 1 = meeting the condition and 0 = not meeting the condition. Given available data shown in Table 1, Keiser, mid-season plantings of untreated seed were the base case.

‡ Two week and Four week refer to using PPD_2 and PPD_4 as in Equations 4 and 5.

§ *, **, and *** denote significance at the 90%, 95%, and 99%, respectively.

¶ Numbers in parentheses are standard errors of coefficient estimates.

\# The square of the partial correlation between predicted and actual yields or the coefficient of determination..

Table 6. Profit-maximizing yield (Y^* in Mg ha^{-1}) and associated plant population density (PPD^* in plants m^{-2} in parentheses) by location, year, planting season, and time of stand count using treated seed.

Year	Time of Stand Count	Planting Season					
		Early[†]	Mid	Late	Early	Mid	Late
			Keiser			**Stuttgart**	
2007	2 wk	3.0 (12.5)	4.2 (19.5)	3.5 (20.0)	4.3 (15.7)	3.3 (13.9)	2.5 (17.9)
	4 wk	2.8 (14.0)	4.3 (28.1)	3.3 (22.9)	3.8 (17.7)	3.2 (17.4)	2.5 (*23.8*)
2008	2 wk	na	3.8 (22.7)	3.2 (24.9)	3.9 (19.1)	2.9 (17.4)	2.3 (*27.0*)
	4 wk	na	4.0 (*22.7*)	3.2 (22.6)	3.6 (18.4)	3.0 (18.2)	2.4 (*24.5*)
2009	2 wk	2.6 (15.6)	4.2 (*28.0*)	3.6 (*28.4*)	4.2 (22.7)	3.2 (21.7)	2.6 (*26.8*)
	4 wk	2.5 (14.6)	4.1 (*23.7*)	3.3 (*25.9*)	3.6 (21.3)	3.1 (22.1)	2.6 (*29.2*)
2010	2 wk	3.3 (10.3)	4.3 (15.0)	3.6 (14.7)	na	na	na
	4 wk	3.1 (12.6)	4.4 (*20.2*)	3.6 (19.0)	na	na	na
2011	2 wk	na	na	na	na	4.3 (21.2)	3.9 (*30.7*)
	4 wk	na	4.9 (*18.2*)	4.2 (*20.5*)	na	4.2 (23.3)	3.7 (*29.2*)
Avg.[¶]	2 wk	3.0 (12.8)	4.1 (21.3)	3.4 (22.0)	4.1 (19.2)	3.4 (18.6)	2.8 (25.6)
	4 wk	2.8 (13.7)	4.2 (22.6)	3.5 (22.2)	3.7 (19.1)	3.4 (20.2)	2.8 (*26.7*)
Avg.[#]	2 wk	3.0 (18.2)	4.0 (19.2)	3.3 (19.2)	4.3 (24.4)	3.5 (24.8)	2.5 (24.8)
	4 wk	2.9 (18.6)	4.0 (18.6)	3.3 (19.5)	3.6 (21.7)	3.4 (20.6)	2.5 (19.6)

Notes: Using a soybean price of \$284.33 Mg^{-1} and soybean seed cost of \$2.10 kg^{-1}.

† See Table 1 for planting dates.

‡ Stand counts are *PPD* in plants m^{-2}. Italicized entries indicate situations where calculated PPD^* were replaced by the maximum *PPD* observed given condition-specific $\hat{ROS}$ and the maximum seeding rate of 445 k seed ha^{-1}.

§ Experimental data was not available.

¶ Calculated using the weighted average of coefficient estimates across available years of data.

\# Calculated using regression coefficients from equations using constant terms as shown in Appendix Table 1.

Table 7. Profit-maximizing seeding rates (SR^* in kg ha^{-1}) by location, year, planting season, and time of stand count using treated seed.

		Planting Season					
	Time of	Early[†]	Mid	Late	Early	Mid	Late
Year	**Stand Count**		**Keiser**			**Stuttgart**	
2007	2 wk	26.8	38.8	39.5	48.3	46.4	63.5
	4 wk	30.9	59.6	45.4	36.4	42.6	67.3
2008	2 wk	na[‡]	62.2	67.2	42.8	41.4	67.3
	4 wk	na	67.3	60.9	37.1	43.6	67.3
2009	2 wk	41.0	67.3	67.3	51.4	52.0	67.3
	4 wk	44.1	67.3	67.3	37.7	45.4	67.3
2010	2 wk	42.5	54.3	52.1	na	na	na
	4 wk	45.0	67.3	57.1	na	na	na
2011	2 wk	na	na	na	na	44.7	67.3
	4 wk	na	67.3	67.3	na	47.7	67.3
Avg.[§]	2 wk	35.3	54.6	55.7	47.4	46.1	66.6
	4 wk	38.7	65.2	58.4	37.1	45.0	67.3
Avg.[¶]	2 wk	49.9	48.3	48.3	64.5	64.2	64.2
	4 wk	52.5	53.5	50.9	41.2	45.2	49.0

Notes: Using a soybean price of \$284.33 Mg^{-1} and soybean seed cost of \$2.10 kg^{-1}. Multiply table results by 6,614 seed kg^{-1} to arrive at seed ha^{-1}.

[†] See Table 1 for planting dates.

[‡] Lack of available experimental data.

[§] Calculated using the weighted average of coefficient estimates across available years of data.

[¶] Calculated using regression coefficients from equations using constant terms as shown in Appendix Table 1.

Table 8. Estimated replanting plant population density thresholds (PPD^T in plants m^{-2}) as a fraction of PPD^* (the estimated profit-maximizing plant population density) in parentheses by location, year, planting season, and time of stand count using treated seed.

	Time of Stand Count	**Planting Season**			
		Early[†]	Mid	Early	Mid
Year		**Keiser**		**Stuttgart**	
2007	2 wk	replant[‡]	4.9[§] (0.25)	3.0 (0.19)	1.7 (0.12)
	4 wk	replant	5.6 (0.20)	4.3 (0.24)	2.4 (0.14)
2008	2 wk	na[¶]	4.8 (0.21)	3.2 (0.17)	2.3 (0.13)
	4 wk	na	5.0 (0.22)	4.2 (0.23)	2.4 (0.13)
2009	2 wk	replant	7.2 (0.26)	4.0 (0.17)	3.7 (0.17)
	4 wk	replant	5.9 (0.25)	5.0 (0.23)	3.7 (0.17)
2010	2 wk	replant	3.7 (0.25)	na	na
	4 wk	replant	4.9 (0.24)	na	na
2011	2 wk	na	na	na	5.6 (0.27)
	4 wk	na	6.5 (0.36)	na	5.7 (0.25)
Avg.[#]	2 wk	replant	4.7 (0.22)	3.3 (0.17)	2.1 (0.11)
	4 wk	replant	5.6 (0.25)	4.4 (0.23)	2.4 (0.12)
Avg.[††]	2 wk	replant	2.8 (0.15)	ns[‡‡]	ns
	4 wk	replant	3.7 (0.20)	3.3 (0.15)	1.9 (0.09)

Notes: Using a soybean price of \$284.33 Mg^{-1}, soybean seed cost of \$2.10 kg^{-1}, and replanting charges (*RPC*) of \$59 ha^{-1}.

† See Table 1 for planting dates.

‡ Conditions listed as "replant" have revenue opportunity that exceeds the cost associated with replanting and planting on the later planting date, regardless of observed *PPD* in the field at that given point in time. This is due to considerably greater yield potential associated with the next planting date.

§ Stand counts are *PPD* in plants m^{-2}. The number in parentheses is the ratio of PPD^T to PPD^*.

¶ Lack of available experimental data.

\# Calculated using the weighted average of coefficient estimates across available years of data.

†† Calculated using regression coefficients from equations using constant terms as shown in Appendix Table 1.

‡‡ ns = no solution. Replanting thresholds could not be calculated as the yield response equation with intercept shifters resulted in no estimates of yields sufficiently low to solve for PPD^T.

G. Technical Appendix

Two approaches were used in this study to calculate Y^*, PPD^*, PPD^T, and SR^*. Results discussions are very similar regardless of method chosen. The first approach used coefficient estimates of the seed survival and yield response equations without a constant term where year, location, planting season and seed treatment effects mainly modified the slope or shape of the response function. In the second approach, the location, planting season and seed treatment effects are primarily modeled using intercept changes and thereby shifts in the seed survival and yield response functions. The regression results are summarized in Appendix Tables 1 and 2 along with attendant replanting PPD^T in Appendix Table 3. In essence, the inclusion of constant terms marginally lowered the goodness of fit measure, r^2, and made the yield response functions flatter. This led to different profit-maximizing seeding rates and lower replanting thresholds.

For the functional form without constant terms, coefficient estimates of binary *YEAR* × *PPD* variables together with the *PPD* and $\sqrt{PPD}$ coefficients were used to arrive at an average coefficient estimate on *PPD* and $\sqrt{PPD}$. For example, for *EARLY* planted soybean at Keiser, for which observations exist in 2007, 2009, and 2010, the year weighted average coefficient on *PPD* is $[(\gamma_1 + \gamma_3) + \gamma_1 + (\gamma_1 + \gamma_8)]/3$ for the equation using two week old stand count data. This weights the results equally across experimental years observed, accounts for average curvature in or position of the yield response equation needed for calculating the profit-maximizing seeding rate and replanting threshold, and avoids out-of-sample predictions. The same approach, except with *Year* intercept shifters was used for the equations using the second functional form.

Appendix Table 1. Regression statistics for seed survival and at two and four weeks post planting, location, planting season and seed treatment with a constant term.

Variable[†]		**Two Week**[‡]		**Four Week**[b]	**Variable**		**Two Week**		**Four Week**
Constant	α_0	0.93[§]	β_0	1.79***	*SR × ST*	α_9	0.13***	β_9	0.12***
		(0.72)[¶]		(0.51)			(0.02)		(0.02)
SR	α_1	0.50***	β_1	0.35***	*SR × Early × Stuttgart*	α_{10}	0.09**	β_{10}	0.14***
		(0.04)		(0.02)			(0.03)		(0.03)
SR × 2007	α_2	0.21***	β_2	0.29***	*SR × Late × Stuttgart*	α_{11}	-	β_{11}	-0.13***
		(0.03)		(0.02)					(0.02)
SR × 2008	α_3	-0.10***	β_3	-	*SR × 2007 × Stuttgart*	α_{12}	-0.27***	β_{12}	-0.31***
		(0.02)					(0.03)		(0.03)
SR × 2010	α_4	-0.11***	β_4	0.03	*SR × 2008 × Stuttgart*	α_{13}	0.15***	β_{13}	-0.10***
		(0.03)		(0.02)			(0.03)		(0.02)
SR × 2011	α_5	na[#]	β_5	-0.05**	*SR × 2011 × Stuttgart*	α_{14}	0.09***	β_{14}	0.11***
				(0.02)			(0.03)		(0.03)
SR × Stuttgart	α_6	-[††]	β_6	0.24***	*SR × ST × 2007*	α_{15}	-0.11**	β_{15}	-0.10***
				(0.03)			(0.03)		(0.03)
SR × Early	α_7	-0.06***	β_7	-0.03	*SR × ST × 2010*	α_{17}	-0.12***	β_{17}	-0.10***
		(0.02)		(0.02)			(0.04)		(0.03)
SR × Late	α_8	-	β_8	0.05***	*SR × ST × 2011*	α_{18}	-	β_{18}	-0.06**
				(0.01)					(0.03)
r^2 [‡‡]		0.60		0.70	*SR × ST × Stuttgart*	α_{19}	-0.06*	β_{19}	-0.02
Observations		538		711			(0.03)		(0.02)

Notes:

† *PPD* are the number of established plants m^{-2} observed at 2 and 4 wk after planting. Year (2007.. 2011), location (Stuttgart), planting season (Early and Late), and seed treatment (ST) are binary variables where 1 = meeting the condition and 0 = not meeting the condition. Seeding rate represents the number of seeds planted m^{-2}. Given available data shown in Table 1, Keiser, mid-season plantings of untreated seed were the base case.

‡ Two week and Four week refer to using PPD_{2wk} and PPD_{4wk} as in Equations 1 and 2.

§ *, **, and *** denote significance at the 90%, 95%, and 99%, respectively.

¶ Numbers in parentheses are standard errors of coefficient estimates.

\# *PPD* was only measured four weeks after planting in 2011 at Keiser.

†† Coefficient estimates with |z-statistics| < 1 where removed from the equation given their lack of explanatory power and to avoid multi-collinearity bias (Gujarati, 2007).

‡‡ The square of the partial correlation between predicted and actual yields or the coefficient of determination.

Appendix Table 2. Regression statistics for yield response to plant population density at two and four weeks post planting, location, planting season and seed treatment with a constant term.

Variable†		Two Week‡		Four Week	Variable		Two Week		Four Week
Constant	γ_0	842.6*,§	δ_0	365.7***	*2008*	γ_8	-	δ_8	-110.2
		(455.8)¶		(326.8)					(75.4)
ST	γ_1	60.4	δ_1	-#	*2010*	γ_9	733.3***	δ_9	509.8***
		(42.2)					(68.2)		(67.5)
Early	γ_2	-1,128.2***	δ_2	-1,185.3***	*2011*	γ_{10}	1,242.0***	δ_{10}	702.3***
		(-97.1)		(71.5)			(74.5)		(78.0)
Late	γ_3	-701.5***	δ_3	-734.3***	*Stuttgart × 2008*	γ_{11}	-379.4***	δ_{11}	189.3**
		(-59.6)		(54.3)			(100.2)		(91.8)
Stuttgart	γ_4	1,043.2*	δ_4	-	*Stuttgart × 2011*	γ_{12}	na	δ_{12}	618.3***
		(575.5)							(96.2)
Stuttgart × Early	γ_5	2,239.5***	δ_5	1,733.5***	*PPD*	γ_{13}	-107.2***	δ_{13}	-135.4***
		(143.3)		(96.4)			(24.0)		(21.0)
Stuttgart × Late	γ_6	-279.6***	δ_6	-82.3	$\sqrt{PPD}$	γ_{14}	1,125.1***	δ_{14}	1,396.0***
		(88.1)		(77.1)			(208.6)		(164.6)
2007	γ_7	279.1***	δ_7	184.1***	*PPD × Stuttgart*	γ_{15}	101.3***	δ_{15}	46.3***
		(62.4)		(51.6)			(31.3)		(13.8)
r^2 ††		0.64		0.71	$\sqrt{PPD}$ × *Stuttgart*	γ_{16}	-836.6***	δ_{16}	-417.4***
Observations		538		711			(271.4)		(70.1)

Notes:

† Yield, the dependent variable, is measured in kg ha^{-1}. *PPD* are the number of established plants m^{-2} observed at two and four weeks after planting. Location (Stuttgart), planting season (Early and Late), and seed treatment (ST) are binary variables where 1 = meeting the condition and 0 = not meeting the condition. Given available data shown in Table 1, Keiser, mid-season plantings of untreated seed were the baseline.

‡ 'Two Week' and 'Four Week' refer to using PPD_2 and PPD_4 as in Equations 4 and 5.

§ *, **, and *** denote significance at the 90%, 95%, and 99%, respectively.

¶ Numbers in parentheses are standard errors of coefficient estimates.

\# Coefficient estimates with |z-statistics| < 1 where removed from the equation given their lack of explanatory power and to avoid multi-collinearity bias (Gujarati, 2007).

†† The square of the partial correlation between predicted and actual yields or coefficient of determination.

Appendix Table 3. Estimated replanting plant population density thresholds (PPD^T in plants m^{-2}) as a fraction of PPD^* (the estimated profit-maximizing plant population density) in parentheses by location, year, planting season, and time of stand count using treated seed using yield response equations with intercept shifters.

		Planting Season			
	Time of Stand	Early[†]	Mid	Early	Mid
Year	**Count**	**Keiser**		**Stuttgart**	
2007	2 wk	replant[‡]	3.2[§] (0.15)	ns[††]	ns
	4 wk	replant	4.2 (0.20)	3.2 (0.15)	1.7 (0.09)
2008	2 wk	na[¶]	2.7 (0.14)	ns	ns
	4 wk	na	3.7 (0.20)	3.3 (0.15)	1.8 (0.09)
2009	2 wk	replant	3.0 (0.15)	ns	ns
	4 wk	replant	3.7 (0.20)	3.6 (0.16)	2.1 (0.10)
2010	2 wk	replant	2.2 (0.13)	na	na
	4 wk	replant	3.5 (0.19)	na	na
2011	2 wk	na	na	na	ns
	4 wk	na	0.0 (0.00)	na	2.1 (0.10)
Avg.[#]	2 wk	replant	2.8 (0.15)	ns	ns
	4 wk	replant	3.7 (0.20)	3.3 (0.15)	1.9 (0.09)

Notes: Using a soybean price of \$284.33 Mg^{-1}, soybean seed cost of \$2.10 kg^{-1}, and replanting charges (*RPC*) of \$59 ha^{-1}.

† See Table 1 for planting dates.

‡ Conditions listed as "replant" have revenue opportunity that exceeds the cost associated with replanting and planting on the later planting date, regardless of observed *PPD* in the field at that given point in time. This is due to considerably greater yield potential associated with the next planting date.

§ Stand counts are *PPD* in plants m^{-2}. The number in parentheses is the ratio of PPD^T to PPD^*.

¶ Lack of available experimental data.

\# Calculated using the weighted average of coefficient estimates across available years of data.

†† ns = no solution. Replanting thresholds could not be calculated as the yield response equation with intercept shifters resulted in no estimates of yields sufficiently low to solve for PPD^T.

H. References

Arkansas Soybean Handbook - MP197. 1999. http://www.uaex.edu/publications/mp-197.aspx (accessed 27 Jan. 2015).

Boyer, C.N., M. Stefanini, J.A. Larson, S. Aaron Smith, A. Mengistu, and N. Bellaloui. 2015. "Profitability and Risk Analysis of Soybean Planting Date by Maturity Group." Agronomy Journal 107(6):2253-2262.

De Bruin, J.L. and P. Pedersen. 2008. Soybean Seed Yield Response to Planting Date and Seeding Rate in the Upper Midwest. Agron. J. 100(3): 696.

De Bruin, J.L. and P. Pedersen. 2009. New and Old Soybean Cultivar Responses to Plant Density and Intercepted Light. Crop Sci. 49(6): 2225.

Edwards, J.T. and L.C. Purcell. 2005. Soybean Yield and Biomass Responses to Increasing Plant Population Among Diverse Maturity Groups. Crop Sci. 45(5): 1770.

Flanders, A., R. Baker, T. Barber, T. Faske, H. Ginn, C. Grimes, J. Hardke, K. Lawson, G. Lorenz, R. Mazzanti, C. Norton, B. Robertson, and G. Studebaker. 2015. 2015 Crop Production Budgets for Farm Planning. University of Arkansas Cooperative Extension Service, Division of Agriculture. http://www.uaex.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx (accessed 20 Jan. 2015).

Gujarati, D. 2007. Basic Econometrics. New York, NY: McGraw-Hill/Irwin.

Gaspar, A.P., S.P. Conley, and J.M. Gaska. 2014. Think Twice Before Replanting Soybeans. http://www.coolbean.info/library/documents/SoybeanReplant_2014_FINAL.pdf (accessed Jan.15 2015).

Gaspar, A.P., P.D. Mitchell, and S.P. Conley. 2015. Economic Risk and Profitability of Soybean Fungicide and Insecticide Seed Treatments at Reduced Seeding Rates. Crop Sci. 55(2): 924–933.

Laughlin, D.H., and, S.R. Spurlock. 2014. Mississippi State Budget Generator. Mississippi State Department of Agricultural Economics. http://www.agecon.msstate.edu/whatwedo/budgets/generator/index.asp (accessed Feb.17 2015).

Lilien, D., G. Sueyoshi, C. Wilkins, J. Wong, G. Thomas, S. Yoo, E. Lee, K. Sadri, R. Erwin, G. Liang, P. Fuquay, R. Startz, R. Hall, R. Engle, S. Ellsworth, H. Kwakatsu, J. Noh. 2015. EViews 9. IHS Global Inc., Irvine: CA.

Lee, C.D., D.B. Egli, and D.M. TeKrony. 2008. Soybean Response to Plant Population at Early and Late Planting Dates in the Mid-South. Agron. J. 100(4): 971.

Mbofung, G.C.Y., A.S. Goggi, L.F.S. Leandro, and R.E. Mullen. 2013. Effects of Storage Temperature and Relative Humidity on Viability and Vigor of Treated Soybean Seeds. Crop Sci. 53(3):1086-1095.

Salmeron, M., E. Gbur, F. Bourland, N. Buehring, L. Earnest, F. Fritschi, B. Golden, D. Hathcoat, J. Lofton, T. Miller, C. Neely, G. Shannon, T. Udeigwe, D. Verbree, E. Vories, W. Wiebold and L. Purcell. 2014. "Soybean Maturity Group Choices for Early and Late Plantings in the MidSouth". Agron. J. 106(5):1893-1901.

Gujarati, D.N. 1995. Basic Econometrics. 3rd Edition. McGraw-Hill Inc., New York: NY.

Poag, P.S., M. Popp, J. Rupe, B. Dixon, C. Rothrock, and C. Boger. 2005. Economic Evaluation of Soybean Fungicide Seed Treatments. Agron. J. 97(6):1647-1657.

Popp, M., J. Edwards, L. Purcell, and P. Manning. 2006. Profit-Maximizing Seeding Rates and Reseeding Thresholds for Soybean: Maturity Group Interactions in the Mid-South. Ag. Sys. 91(3):211-228.

Popp, M., J. Rupe, and C. Rothrock. 2010. Economic Evaluation of Soybean Fungicide Seed Treatments. J. Farm Manag. Rur. Appr. 73(1):50-62.

United States Department of Agriculture, National Agricultural Statistics Service. Index for Prices Paid, Seed 1990-1992 Base. http://quickstats.nass.usda.gov/results/357C5209-0444-3C87-942D-9E3C0D289E3E? pivot=short_desc (accessed Feb. 17 2015).

United States Department of Agriculture, National Agricultural Statistics Service. Index for Prices Paid, Supplies 2011. http://quickstats.nass.usda.gov/results/C265EA49-781E-340A-811F-28DC930FAEB6 (accessed Feb. 17 2015).

United States Department of Agriculture, National Agricultural Statistics Service. Index for Prices Received Index. Available at http://quickstats.nass.usda.gov/results/EDF2C269-8C33-3326-817C-5A3A34E389D8 (accessed Feb. 14 2015).

United States Department of Agriculture, Economic Research Service. Commodity Costs and Returns. http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx (verified Sep. 3 2015).

Wilmot, D. B., G. E. Pepper, and E.D. Nafziger. 1989. "Random Stand Deficiency and Replanting Delay Effects on Soybean Yield, Yield Components, Canopy, and Morphological Responses". Agron. J 81(3):425-430.

Chapter III. Diversifying Soybean Production Risk using Maturity Group and Planting Date

Wes Weeks[a], Michael P. Popp[*a], Montserrat Salmeron[b], Larry C. Purcell[b] Edward E. Gbur[c], Fred M. Bourland[d], Normie W. Buehring[e], Larry Earnest[f], Felix B Fritschi[g], Bobby R. Golden[h], Daniel Hathcoat[i], Josh Lofton[j], Travis D. Miller[i], Clark Neely[i], Grover Shannon[k], Theophilus K. Udeigwe[l], David A. Verbree[m], Earl D. Vories[k], and William J. Weibold[g]

a Univ of Arkansas, Dep. Of Agricultural Economics and Agribusiness., 217 Agriculture Building, Fayetteville, AR, 72701, Ph: 479-575-6838, mpopp@uark.edu
b Univ. of Arkansas, Dep. of Crop, Soil, and Environ. Sci., 1366 W. Altheimer Dr., Fayetteville, AR 72704
c Univ. of Arkansas, Agricultural Statistics Laboratory, 101 Agricultural Annex, Fayetteville, AR 72701
d Univ. of Arkansas, Northeast Research and Extension Center, 1241 W. County Rd. 780, Keiser, AR 72351
e Mississippi State Univ., North Mississippi Research and Extension Center, 5421 Highway 145 South, Verona, MS 38879
f Univ. of Arkansas, Southeast Branch Experiment Station, 140 Experiment Station Loop, Watson, AR 71674
g Univ. of Missouri, Div. of Plant Sciences, 1-31 Agriculture Building, Columbia, MO 65211
h Mississippi State Univ., Delta Research and Extension Center, P.O. Box 197, 82 Stoneville Rd., Stoneville, MS 38776
i Texas A&M, Texas AgriLife Extension Service, 370 Olsen Blvd, College Station, TX 77843
j LSU Ag Center, Macon Ridge Research Station, 212A Macon Ridge Road, Winnsboro, LA 71295
k Univ. of Missouri, Delta Research Center, 147 State Hwy T, Portageville, MO 63873
l Texas Tech Univ., Dep. of Plant and Soil Sci., 2907 15th Street, Lubbock, TX 79409-2122
m Univ. of Tennessee, Dep. of Plant Sci., AgResearch and UT Extension Center, 605 Airways Blvd, Jackson, TN 38301

Diversifying Soybean Production Risk using Maturity Group and Planting Date

A. Abstract

Due to the long growing season for soybean (*Glycine max*) production in the region, producers in the Mid-southern US plant from late March to June and have a range of maturity group (MG) choices that are physiologically and economically viable. Three years of field trial data from nine locations in six states were analyzed to determine risk-return tradeoffs across MG and planting date (PD). Producer revenue expectations were adjusted by soybean harvest date, assessing oil and meal premiums or discounts, and differential irrigation requirements by MG and PD whereas costs for seed, fuel, fertilizer, equipment and chemicals were held constant. Using portfolio theory, an efficient frontier – maximizing returns for a given level of risk or minimizing risk for a given level of return – was estimated by location. Cultivars from MG III and MG IV had higher expected returns than MG V and VI at all locations. Early season planting combinations were found to be riskier than the three successive planting dates but led to quality and seasonal sale price premia. Planting two to five MG × PD combinations was sufficient to lower risk by at least 39% when compared to the single, profit-maximizing MG × PD. Depending on location, this risk reduction cost 1 to 14% of the returns achievable with the profit-maximizing MG × PD choice.

Key words: Soybean, Planting Date, Risk-Return Tradeoff, Efficient Frontier, Portfolio Theory

Highlights:

- Producers face many maturity group (MG) choices when planting over an extending planting window in the mid-southern U.S.
- MG × planting date (PD) interactions were analyzed across nine locations to determine profit-maximizing MG × PD choices by location
- Return risk was lowered by an average 37% at the cost of 9% of returns across locations by utilizing portfolios of two to five different MG x PD combinations in comparison with the profit-maximizing, single MG × PD choice.

Abbreviations:

MG soybean maturity group ranging from MG III to VI in this study

PD planting date for soybean ranging from early to late planting using three more or less equal intervals between planting dates that differed by location

Y_i Soybean yield in kg ha^{-1}

S_k 2005-2014 ten-year average seasonal price index for soybean delivered in Julian week *k* at five different regional cash markets

P_k Annual centered moving average of weekly soybean prices in Julian week *k* at four different regional cash markets

PA Ten-year average of annual average US soybean price

$P_{Adj,i}$ Ten-year average US soybean price adjusted for regional seasonality for harvest week *k* matched to each Y_i

PD_{Oil} Premium or discount for soybean in \$ kg^{-1} of soybean yield based on percent oil concentration matched to each Y_i

O_i Oil concentration by weight as a fraction of soybean yield matched to each Y_i

PD_{Meal} Premium or discount for soybean in \$ kg^{-1} of soybean yield based on percent protein concentration matched to each Y_i

P_i Protein concentration by weight as a fraction of soybean meal matched to each Y_i

PD_i Total premium or discount in \$ kg^{-1} of soybean. All premia and discounts are relative to the experiment-wide oil and protein concentration of harvested soybean, are valued using ten-year average US soybean meal and soybean oil prices, and matched to each Y_i

TSE Total specified soybean production cost in \$ ha^{-1} except variable irrigation expense (labor, fuel, repair, and maintenance) associated with differential water use

IC Labor, maintenance, and fuel costs incurred for a producer per ha cm^{-1} of irrigation applied in \$ ha-cm^{-1}

R_i Estimated returns to management and land in \$ ha^{-1} accounting for total specified expenses including differential irrigation cost across MG × PD treatment group *a* for each Y_i

IR_a Irrigation in ha-cm^{-1} applied by treatment combination *a* varies by MG, PD, location and year but not cultivar or replicate within MG, PD, location and year

x_a Percentage of a producer's land dedicated to a particular MG × PD combination *a* at a particular location irrespective of year, cultivar and replicate

E_a Expected value or average of returns R_i associated with a MG × PD land use choice at a particular location across year, cultivar and replicates

V_a Variance of returns R_i associated with a MG × PD land use choice at a particular location across year, cultivar and replicates

V_{Mid} The average of the minimum and maximum V_a for a specific location

Diversifying Soybean Production Risk using Maturity Group and Planting Date

B. Introduction

In the mid-southern United States (US) (West Tennessee, Mississippi, Louisiana, Arkansas, Southeast Missouri, and East Texas) irrigated soybean [*Glycine max* L. (Merr.)] can be planted during an extended period from late March to mid-July (Egli and Cornelius, 2009; Salmeron et al., 2014). Such a long planting season offers producers time-management flexibility for irrigated soybean production as the potential for staggered plantings with cultivars from a broad range of soybean maturity groups (MG) allows an extended harvest window.

Irrigation, planting date (PD), and MG selection have been identified as major drivers for increasing yield potential and managing production risk. In Arkansas, the fraction of the crop that is irrigated has nearly doubled from 43 to 82% since 1994 (USDA NASS, Quick Stats). Increased irrigation in the region has led to both increased yields and net returns and has stabilized yield in drought years (Heatherly and Spurlock, 1999). Optimizing the PD by avoiding poor plant establishment often associated with planting too early and heat stress during reproduction as a result of delayed planting (Egli and Cornelius, 2009; Poag et al., 2005; Popp et al., 2006; Salmeron et al., 2015), has been tied yield and profit potential. Nonetheless, the benefit of early PD is that irrigation requirements can be considerably lower, in particular for earlier soybean MG (Edwards et al., 2003). As such, the choice of soybean MG and PD influence soybean yield and stability in the mid-southern US (Salmeron et al., 2014). For relatively early PD (from late March to May depending on the location and year), MG IV cultivars were identified as the highest yielding and more stable choice among MG III to VI cultivar choices across environments in the mid-southern US, followed by MG V cultivars (Salmeron et al., 2014). A later analysis of best MG choices by locations within the same study region still identified MG IV choices as the maximum yielding genotype across most locations and PD (Salmeron et al., 2015). However, additional risk reduction may be attainable by planting over a range of dates rather than all at once and/or choosing an array of soybean cultivars with different MG as is recommended in many extension publications including the Arkansas Soybean Production Handbook (Purcell et al., 2014). Such a strategy could avoid all land planted to soybean to be exposed to the same weather risk in a particular year. Further, harvesting different MG across a range of harvest dates spreads out soybean price risk due to seasonal changes in cash prices (Popp et al., 2004). Finally, seed quality in terms of oil and protein concentration is expected to vary with MG and PD (Hu and Wiatrak, 2012). While soybean cash price premia and discounts for oil and protein concentration are currently not a universal practice by elevators, downstream processing implications exist for the soybean industry as oil and meal prices translate to derived farm gate demand for soybean (Updaw et al., 1976).

Changes in expected returns across MG and PD are thus a function of differences in yield, needed irrigation, seed oil and protein premia or discounts, and seasonal price effects. Production risk at locations with varying soil and weather conditions can be summarized using variance of yield and applied irrigation across production year, cultivar and replications for a particular MG and PD. Seasonal price effects and quality premia or discounts capturing price risk also affect the overall return volatility associated with changing MG × PD choices. As such, a producer's decision of what MG to plant and when can be likened to an investor's choice of what stocks to invest in a stock portfolio. Thereby portfolio theory (Markowitz, 1959) can be applied to evaluate diversification of production risk (Hazell and Norton, 1986) by estimating an efficient frontier of MG × PD choices where returns are maximized for a given level of risk or risk is minimized for a given level of return using quadratic programming with MG and PD as choice variables. Nalley and Barkley (2010) recently applied this methodology to a rice variety selection optimization. The goal is to not only state that it makes sense not to plant all soybean on a single PD and single MG to maximize profit, but to quantify risk-return tradeoffs associated with planting soybean on multiple PD and or across multiple MG in comparison to the single, profit-maximizing MG × PD selection.

1. Objectives

The objectives of this study were therefore to use portfolio theory common in financial risk analysis, to: i) demonstrate how production risks can be decreased by using a combination of several MG × PD selections as opposed to planting only the profit-maximizing MG planted on one PD, and ii) illustrate similarities and differences in risk-return tradeoffs across nine locations with variation in production environment.

C. Material and Methods

1. Data

Experiments were conducted at seven locations in 2012 and nine locations in 2013 and 2014 (Table 1 and Figure 1). Within every year and location, four PD were tested as well as sixteen cultivars, four from each of MG III through VI. In 2012, latitudes ranged from 30.6 and 36.4°N with the remaining years including a more northern location at 38.9°N. In a few instances, cultivars used in earlier years were unavailable the following year and hence replaced with a similar cultivar from the same MG. For a complete listing of cultivars please see Table 2. Cultivars from MG III and IV were indeterminate, while those from V and VI were determinate with the exception of AG5332 that had an indeterminate growth habit. The three years of the experiment are assumed to be indicative of typical mid-southern conditions although 2012 was a major drought year. For example, April to October rainfall in Rohwer, AR, located centrally relative to all experiment locations totaled 64.5, 77.2, and 91.4 cm in 2012, 2013, and 2014 respectively (NOAA, National Center for Environmental Information) which compares to a ten-year average of 73.0 cm. The average of daily maximum temperatures from April to October in the considered years were 28.9, 27.9, and 27.6 degrees Celsius respectively with a ten year average of 28.8 Celsius.

2. Experimental Design

A split-plot design was utilized in all locations with PD as a whole-plot factor and MG as the split-plot factor. The four cultivars within each MG were grouped together in the MG-specific plot to capture irrigation-use differences across MG. Planting dates were assigned to early and late season dates that were considered typical for a given location. The two middle planting dates were spaced as evenly as possible between the early and late dates as weather conditions allowed (Table 1). Individual plots were four rows or four sets of twin rows wide and 6 m long. At all locations, seeding rate was fixed at 35 seeds m^{-2}. Row spacing and irrigation type varied between locations, but were selected to be representative of producer practices common to each location (Table 1). Soil water deficits were calculated using daily weather data from each location to estimate crop evapotranspiration and accounting for precipitation and irrigation (Purcell et al., 2004). When soil-water deficits reached specific thresholds for each location, irrigation was applied. These deficits ranged between 30 to 50 mm depending on the location's soil class and the type of irrigation technique employed. Yield was determined from the two middle rows (or two pairs of twin rows) of each plot and reported at 130 g kg^{-1} water basis. Harvested seed was analyzed for oil and protein concentration using near-infrared spectroscopy (Foss Instruments, model 1241, Eden Prairie, MN).

3. Cultivar Effects and Production Risk Estimate

Yields were analyzed using analysis of variance (SAS, v. 9.4, SAS Institute Inc., Cary, NC) with Location, PD, and MG treated as fixed effects and cultivar implicitly nested within MG (Table 3). Since cultivar effects, across all years, showed the least impact on yield variation, cultivar seed oil and protein concentration, and yield effects across replications and years were used to estimate production risk. This production risk was defined as the variance of four cultivar × four replicates accounting for yield and attendant irrigation use and seed quality observations for each MG, PD and experimental year. Since observations were limited to three years a bootstrap, first described in Efron (1979), was utilized for the purpose of estimating the covariance matrix among the sixteen different MG × PD combinations. Each observation from a MG × PD group in a particular location was assumed equally likely to occur and each group was sampled one thousand times with replacement. This addresses the issue of otherwise making pairwise comparisons – as is conventional with time series data typically used when comparing stock returns in an investment portfolio – by randomizing the pairwise comparisons. Also, this technique allows for heteroskedasticity that may exist due to cultivar or year effects. Still, weather effects are mitigated by irrigation in this experiment and a range of cultivars were chosen to allow generalization of results from this study to conditions producers face in the region at the time of this analysis. From this large sample of randomly drawn observations, attendant covariance estimates were obtained across PD and MG at each location. Price risk for

MG × PD choice, however, was not estimated given the short time frame of the experiment. Nonetheless, expected seasonal price changes due to harvest date and premia or discounts for oil and protein were applied as described subsequently.

4. Seasonal Index

A weekly seasonal soybean price index was calculated using daily #2 soybean prices over the course of ten years (2005-2014) as reported by USDA AMS for five locations – Kansas City, MO, Joplin, MO, Memphis, TN, Elaine, AR, and New Orleans, LA (USDA AMS, 2015). Using ten-years of data removes the effect of unusually high or low soybean prices in a particular year (Goodwin, 1994). For each treatment, the harvest week *k* associated with the date soybean reached R8 or harvest maturity, an annual seasonal index value was defined as:

$$(1) \qquad S_k = {}^{P_k}/_{PA}$$

where S_k is the unitless seasonal index value for a given harvest week, P_k is the observed average of daily cash soybean prices for week *k* in a particular year in \$ kg^{-1}, and *PA* is the 53-week, centered moving average of weekly soybean prices for week *k* in \$ kg^{-1}. Using a centered moving average rather than an annual average price for *PA* accounts for price cycles and trends (Goodwin, 1994). Since regional differences in this seasonal index were small (Figure 2), values of S_k were averaged across years for each week across all locations to develop a common weekly seasonal index, $\overline{S_k}$. An $\overline{S_k}$ value > 1 means that a producer may expect a premium for harvesting and delivering soybean in harvest week *k* relative to the moving average annual price for that same week. Soybean harvested during a week with a $\overline{S_k}$value < 1 leads to a discount. The soybean price for each individual yield observation *i*, adjusted for seasonality, $P_{Adj,i}$ in \$ Mg^{-1}, was:

(2) $P_{Adj,i} = \overline{S_k} \cdot Average\ Price$

where the Average Price is the ten-year average of the annual US soybean price that is adjusted for inflation (Table 4). This latter Average Price was chosen over a regional price as comparisons across location are now devoid of regional soybean price level differences as production costs, discussed below, were also not adjusted for regional differences. The focus of this investigation is thus not on regional differences in production cost and price levels but rather on differences in agronomic performance and producer risk as measured by yield, soybean oil and protein concentration, seasonal price effects, and irrigation needs that are expected to be driven by environment and MG × PD choice.

5. Downstream Oil vs. Protein Premia and Discounts

Soybean that vary in oil and protein concentration by MG and PD lead to different amounts of oil and meal as well as different protein content in meal when processed downstream. Using ten-year, deflated average, US prices for oil and meal (Table 4), soybean price premia and discounts were calculated to account for oil and protein concentration deviations from the experimentally observed average oil and protein concentrations (Updaw et al., 1976).

Oil premia or discounts (PD_{Oil}) applied to each yield observation are thus:

(3) $PD_{Oil} = Oil\ Price \cdot (1.15 \cdot (O_i - 0.196))$

where PD_{Oil} is in \$ kg^{-1} of soybean yield. *Oil Price* is in \$ kg^{-1} and O_i is the oil concentration by weight as a fraction of soybean at 13% moisture for yield observation *i*. Yield observations with oil concentration > 19.6%, the experiment-wide average, thus received a premium whereas observations with lower oil concentration were discounted.

Soybean with higher oil concentration yield less meal and vice versa. Hence, a premium or discount based on percentage of protein concentration in soybean was:

$$(4)\qquad PD_{Meal} = \frac{Meal\ Price}{0.48} \cdot \{0.82 \cdot (O_i - 0.196) + 1.31 \cdot (P_i - 0.352) - 0.77 \cdot (O_i^2 - 0.196^2) - 1.52 \cdot [O_i \cdot P_i - (0.196) \cdot (0.352)]\}$$

where PD_{Meal} is the premium or discount based on protein concentration of soybean in \$ kg^{-1} of soybean yield. It is based on the ten-year average price of 48% soybean meal and is relative to the average experiment-wide protein concentration of 35.2% by weight as a fraction of soybean at 13% moisture. P_i and O_i are the protein and oil concentration of a particular sample.

An overall premium or discount for oil and protein concentration, PD_i in \$ kg^{-1} of soybean yield for a particular yield observation *i* is thus:

$$(5)\qquad PD_i = PD_{Oil} + PD_{Meal}$$

6. Cost of Production and Net Return Estimates

To study the influence of MG and PD on producer profitability and risk, irrigation costs of fuel, labor, repair and maintenance that vary with amount of irrigation applied were treated as variable expenses. All other costs including fuel, labor, repair and maintenance (other than used for irrigation) as well as seed, chemicals, marketing and hauling charges as well as ownership charges for equipment (including irrigation) comprised total specified expenses. The University of Arkansas Extension cost of production estimates, averaged across 2012 to 2014, for glyphosate-resistant soybean using furrow irrigation were used regardless of location and year even though three locations used different irrigation methods. Variable irrigation expenses for furrow irrigation were estimated at \$4.15 $ha\text{-}cm^{-1}$ (*IC*) and total other specified expenses (*TSE*) amounted to \$820.09 ha^{-1} (Flanders et al., 2012-2014). These cost estimates were applied to all observations for calculation of soybean returns to land and management. Profitability (R_i) was thus calculated for each yield observation i as follows:

(6) $$R_i = \left[\left(P_{Adj,i} \pm PD_i\right) \cdot Y_i\right] - (IR_a \times IC) - TSE$$

where Y_i is a yield observation in kg ha^{-1}, $P_{Adj,i}$ is the seasonal sale price in harvest week k in \$ kg^{-1}, PD_i is the combined protein and oil premium or discount in \$ kg^{-1}, IR_a is the total amount of irrigation in ha-cm applied to plots of a particular MG × PD × LOC combination. These returns were subsequently averaged across year, cultivar and replicate for a MG × PD × LOC combination to arrive at location (*LOC*) and MG × PD-specific average profitability of soybean production, E_a, in \$ ha^{-1} as:

(7) $$E_a = {\sum_i R_i}/{t} \qquad \forall \quad a \in MG \times PD \times LOC$$

where t is the total number of observations for a particular MG × PD × LOC combination. The variance of individual R_i, V_a, for each subset $a \in$ MG × PD × LOC was calculated using common methods. The risk-return profile of a MG × PD choice at a particular location is thus represented by E_a and V_a. Note that variation in *TSE* across locations would not impact V_a and variation in *IC* and $P_{Adj,i}$ by location would have only minor ramifications for comparisons of V_a within a location.

7. Portfolio Return and Variance Estimates and E-V Frontier

Because a producer can plant several MG of soybean across several PD in a given year, returns E to a particular portfolio of those choices is defined as:

(8) $$E = \sum_a x_a \cdot E_a$$

$$s.t. \ \sum_a x_a = 1$$

$$x_a \geq 0$$

where x_a is the proportion of total land in any of the 16 possible MG × PD combinations at a particular location.

The variance of such a portfolio of MG × PD choices is defined as:

(9) $$V = \sum_a \sum_b x_a \cdot x_b \cdot \sigma_a \cdot \sigma_b$$

where subscripts a and b cover the range of MG × PD choices at a particular location, x is the proportion of land in a particular MG × PD choice, and $\sigma_a \sigma_b$ are the variance ($a = b$) and covariances ($a \neq b$) of MG × PD choices subject to similar constraints as in equation 8.

An E-V frontier can now be estimated using quadratic programming (Hazel and Norton, 1986) such that:

(10) $$\max_x E = \sum_a x_a \cdot E_a$$

$$s.t. \ \sum_a x_a = 1$$

$$x_a \geq 0$$

$$\sum_a \sum_b x_a \cdot x_b \cdot \sigma_a \cdot \sigma_b = A \qquad \forall \qquad V_{min} \leq A \leq V_{max}$$

where A is varied over the range of $V_{\min}$ to $V_{\max}$ or the range of possible portfolio variances obtainable by modifying x_a and subscripts a and b cover the range of MG × PD choices at a particular location.

D. Results

Premia or discounts based on oil and protein concentration, irrigation water use, seasonal sale price as a function of harvest maturity week, yield, and E_a were recorded for all MG × PD combinations and locations. As an example, averages of all of these variables for each tested MG × PD combination over 3 years for all observations from Rohwer, Arkansas can be found in Table 5. Rohwer is central to all locations (Figure 1) and is intended to serve as an example of risk-return tradeoff results described below. Discussed in turn are effects of harvest week on seasonal sale price, soybean oil and protein concentration premia or discounts, risk-return and irrigation tradeoffs by location.

1. Seasonal Price Effects

Figure 2 shows a graph of the average ten-year seasonal index for all five locations and the average week-by-week seasonal index, $\overline{S_k}$, used in the calculation of P_{Adj}. As expected, prices received by producers were higher in the weeks prior to the onset of typical harvest, which can occur in Arkansas as early as the 33rd week of the year (August 16) for MG IV cultivars planted in mid-March (Purcell et al., 2014). The earliest week of observed harvest maturity in the experimental data, using MG III soybean planted early, occurred in the 27th week of the year (July 1). The average seasonal index, $\overline{S_k}$ declined below 1 after the 37th week of the year (mid-September) and remained less than 1 for the remainder of the calendar year. An earlier study of seasonality effects on soybean cash bids in the Mid-south found this decline occurred after the 36th week of the year (Popp et al. 2004). In Rohwer, for example, MG III, IV and V cultivars planted at the first planting date and MG III and IV cultivars planted at the second planting date on average reached harvest maturity before the 37th week of the year and commanded seasonal sale price premia when compared to later-maturing soybean. In all locations except the most northern location, Columbia, MO, MG III and IV beans planted on the earliest PD on average reached harvest maturity at or before the 37th week of the year. In Columbia early planted MG III and IV reached harvest maturity in the 39th and 40th weeks of the year and thus could not expect a premium as a result of price seasonality. In the most southern location, College Station, TX, MG III and IV beans from the first three PD reached harvest maturity before the 37th week of the year on average. Given differences in potential harvest times by location, producers in more southern locations compared to producers in more northern location are expected to place greater emphasis on early planting to capture price premia as high as 4%, relative to expected annual price, for the 35th harvest week (Figure 2). Regardless of location, avoiding harvest in the 40th to the 42nd week at expected discounts as high as 10% lower than the annual price, is achievable by selecting earlier maturing cultivars and planting early.

2. Seed Oil and Protein Premia and Discounts

Premia and discounts were calculated based on whether soybean contained more or less oil and protein than the average. Ninety-two percent of all recorded yield observations included information about oil and protein concentration. Entries without recorded oil and protein concentration were assigned a premium of \$0.00 kg^{-1}. The per-kg premium or discount calculated in equations 3 to 5 were converted to \$ Mg^{-1} and to \$ ha^{-1} to allow assessment of premia or discounts relative to the seasonally adjusted soybean price of average quality or expected returns.

Average premia and discounts varied by location. College Station had the greatest average premium amongst locations of \$6.17 Mg^{-1} followed by St. Joseph with an average premium of \$4.90 Mg^{-1}. Discounts were the greatest for Columbia (average of \$21.17 Mg^{-1}) and Portageville (\$9.57 Mg^{-1}). As such, more southern locations (Figure 1) appear to be conducive for recovering a premium. To the authors' knowledge there are currently no other studies that have incorporated oil and protein premia and discounts when analyzing MG and PD profitability and risk considerations.

For each planting date, MG III soybean had the greatest average premia compared to MG IV, V, and VI cultivars planted on the same date. Premia were greatest for early-planted (PD 1) soybean. At all locations MG V and MG VI soybean received an average discount. The MG III combinations with the earliest and second earliest PD had the highest average premium at \$10.79 and \$10.71 Mg^{-1}, respectively. An exception to this trend was Portageville, MO where the earliest planted MG III cultivars were discounted by (\$1.39 per Mg^{-1}). Earliest planted MG IV cultivars had the greatest premia in four of the nine locations and earliest planted MG III cultivars had the highest average premia in three of nine locations.

For this paper, oil and protein concentration were considered to affect sale prices, but other factors related to seed quality can further influence soybean price, such as seed grade. Previous research has demonstrated that seed produced from MG III and IV cultivars, when planted early in the Midsouth under rainfed conditions, often have poor germination and purple seed-stain from infection with *Phomopsis longicolla* (Mayhew and Caviness, 1994). Seed quality of early-maturing cultivars in the Midsouth is improved by irrigation and by delaying planting until May (Heatherly, 1996). Hence, harvest date may impact seed grade, and possible dockage for lower grade soybean can be economically significant. In this report, we assume all grain to be #2 yellow soybean and thereby use the national average soybean price of that grade in this analysis. Analyses of seed grade effects on prices in addition to oil, protein and seasonal effects are relevant and will be pursued in a separate analysis.

3. Risk Reduction through E-V Analysis

According to our experimental design, a producer could plant as many as four different MG across all four PD as shown by the sixteen individual MG× PD choices plotted by risk and return level in Figure 3. As discussed by Markowitz (1959), MG× PD choices that have negatively covariate relationships with other MG × PD choices can result in a portfolio variance, *V*, smaller than the variance of the least risky individual MG × PD choice, or point (1), in Figure 3. The E-V frontier as shown in Figure 3 thus shows the range of maximum-return portfolios of MG × PD choices at Rohwer for different levels of risk exposure. The dotted portion of the E-V frontier, connecting the least profitable MG × PD choice (4) to the minimum portfolio variance choice marked as V_{min} represents MG × PD choices typically not analyzed as higher returns are available at the same level of risk. At the upper limit of portfolio risk is the MG × PD choice with maximum return, (2), and its associated level of risk as no combination of MG × PD choices can yield more returns than the profit-maximizing MG × PD choice. Note that this profit-maximizing MG × PD choice may well not be the riskiest of MG × PD choices.

Overall average and variance for returns to management and land for each location were recorded to provide a measure of central tendency in returns observed across the planting season using the range of potential MG choices (Table 6, Figure 3, 4, and 5). Average returns observed for the nine experimental locations falling within the USDA ERS "Southern Seaboard" and "Mississippi Portal" region are similar at 676 and 797 $ ha^{-1}, respectively, for the years 2013 and 2014 (USDA ERS, 2015). Yield averages for these two regions were 2.5 and 3.1 Mg ha^{-1} (USDA ERS, 2015). Average yield in this experiment was much higher at 4.1 Mg ha^{-1} for all observations. This can be attributed to irrigation for all observations in the experiment with regional yields reported as a weighted average of both irrigated and non-irrigated production. Another reason for the discrepancy is the tendency for experimental plots to yield higher than observed under typical field conditions. It is, however, the difference across treatments and the covariance among treatments that mattered in this analysis and hence the findings are valuable (Brennan, 1984 and Nalley et al. 2009) for identifying risk-return tradeoffs.

Expected profit for MG III, IV, and V was also close to simulated net returns reported in Tennessee for both early and late planting dates. Boyer et al. (2015) reported expected net returns ranging from 294 to 342 $\$$ ha^{-1} with a range in returns from -200 $\$$ ha^{-1} to well over 1,000 $\$$ ha^{-1}. A three-year study on soybean replanting in Arkansas in the early 2000's found economically optimal partial returns considering only soybean yield, price and irrigation cost to range between 367 to 904 $\$$ ha^{-1} in similar conditions as reported in this research for 2001 to 2003 (Popp et al. 2006). Under different growing conditions in the mid-west, expected returns were estimated to be over 1,000 $\$$ ha^{-1} using an expected soybean price of 330 $\$$ Mg^{-1} (Gaspar et al. 2015).

The MG × PD combination with the highest E_a and lowest V_a was recorded for each location in Table 6, and these points are labeled as points (2) and (1), respectively, in Figure 3. Also, IR_a or the average amount of irrigation used for the combinations with the highest E_a and lowest V_a are recorded in Table 6. In five of the nine locations, MG IV soybean planted on PD 1 resulted in the highest average E_a. While this choice was profitable in every location, V_a for earliest planted soybean was generally also the riskiest. Early-planted soybean, particularly from MG III and IV, offered the highest expected returns but in many cases these higher returns came with high risk. These results are in line with Salmeron et al. (2014 and 2015) except that early maturing MG III with lower yields, higher seasonal sale price, greater oil and protein premia, and lower irrigation needs enter the mix of highest performing cultivar choices using economic returns rather than yield as the metric. This tendency is demonstrated for the Rohwer location in

Figure 3 as earlier MG, regardless of planting date tended to cluster near the top right of the risk-return graph. This observation is in line with findings by Boquet (1998) in Louisiana, where early-planted MG III through VI varieties resulted in greater yield risk than that observed for the same cultivars at later planting dates.

The efficient *E-V* frontiers for each location as shown in Figures 3 to 5, demonstrate benefits of diversification (planting on more than one date and/or using more than one MG soybean cultivar). The solid line represents the efficient frontier where a producer's V_a is minimized at a specific level of *E*. To define the low risk end of the efficient frontier, V_a was minimized using quadratic programing. In Figures 3 through 5 this is represented by the end of the solid line closest to the vertical axis, labeled V_{Min} in Figure 3. At some locations, the MG × PD portfolio that minimized V_a was found to include as many as ten of a possible sixteen MG × PD combinations. While planting so many different cultivars at different times is not technically feasible for small farmers, a large producer could choose such combinations and such an approach is theoretically feasible and essential to defining the E-V frontier. Note further, that V_a-minimizing MG × PD portfolios for all locations are not reported in this paper, as the expected returns associated with that level of risk was often significantly below the profit-maximizing choice. To make comparisons about risk return tradeoffs across location, expected returns were maximized by varying the proportion of land planted to a particular MG and PD, at a point on the E-V frontier that exhibited half the level of risk (V_{mid}) between the profit-maximizing and risk-minimizing MG × PD combinations. At the Keiser location in Figure 4, MG IV soybean planted on PD 1 boasted the highest expected returns of all MG × PD combinations at an estimated \$451 ha^{-1}. To achieve the V_{Mid} level of risk, a producer would need to sacrifice 13.8%

returns to achieve a 40.1% reduction in risk by planting 38% MG III, 50% MG IV, and 12% MG V on the earliest planting date. To a risk-averse producer, cutting risk by more than 40% may be attractive. At Stoneville, MS, the risk-return tradeoff provides an easy choice for most risk-averse producers. A 40.1% reduction in risk could be achieved at the cost of only 1.4% of returns or for \$9 ha^{-1}. Figures 4 and 5 as well as Table 6 indicate that some locations show risk-return tradeoffs where significant reductions in risk are attainable at low cost whereas at other locations such risk reductions are more costly as the slope of the E-V frontier is much steeper.

In part this is a function of inherent production risk across all choices but also the possibility of negative covariate relationships among choices. Achieving risk reduction is often attainable by diversifying to as few as two MG × PD combinations and no more than five combinations. This suggests that even on moderate size farms planting different fields to different MG × PD combinations is feasible.

It is interesting to note that early planting and choice of early maturing soybean cultivars dominated the mix of V_{mid} portfolios. Late planted soybean did not offer an economically viable solution to risk management as yield penalties, low seasonal price and high irrigation needs outweighed enhanced yield stability associated with the practice of late planting. Later maturing cultivars from MG VI did not enter the mix for similar reasons.

Irrigation use ramifications associated with risk reduction, as reported in Table 6 suggested relatively little change. In two cases, Portageville and Rohwer, choosing a lesser risk, V_{mid} - portfolio compared to the profit-maximizing choice led to water savings. At College Station, water use increased to allow a risk reduction, whereas at the seven other locations, no change in expected irrigation water use was apparent.

Managing production risk by diversifying across planting date and cultivar choice has recently been studied for wheat and rice. In Kansas, risk reduction of as much as 17% was attainable at a cost of less than 5% of expected wheat yield (Barkley and Peterson, 2008). In Mexico, risk could be decreased by 22 to 33% by entertaining planting of several varieties in comparison to yields observed using conventional varieties for the region analyzed (Nalley and Barkley, 2010). At a statistically insignificant cost in expected yield in Texas, incorporating a second wheat variety reduced risk over sixty percent (Park et al. 2012). In rice, holding portfolio yield equal to average county yield, risk could be reduced by over sixty percent in five of six locations by planting a portfolio of varieties (Nalley et al. 2009). The above studies, while not conducted with soybean suggest that diversifying across cultivars can lead to significant risk reduction at relatively low cost and in the case of Park et al. by diversifying using only one additional variety.

4. Conclusions

This study reports on return repercussions of soybean cultivar selection and planting dates across mid-southern soybean production locations. Yield, irrigation cost, seasonal and soybean oil and protein concentration differences across MG and planting date were accounted for. Early-planted MG III and MG IV soybean were more profitable than later-planted combinations on average. Early-season MG III and IV cultivars had higher average oil and protein concentration than other MG × PD combinations which resulted in price premia. Also, early-planted soybean on average meant higher seasonal sale prices for soybean as harvest could occur prior to the onset of typical seasonal soybean surplus conditions. Seed grade ramifications were left of further study. Early planting, however, is also associated with higher risk.

Selecting the MG × PD combination that offers the highest expected return might seem like an obvious decision for someone unfamiliar with farming, but to risk-averse producers the greater risk assumed by planting early is also of critical concern. Diversifying across MG and planting date using a portfolio approach to planting demonstrated that producers could substantially reduce production risk by planting as few as two and as many as five MG × PD combinations. Depending on location, this risk reduction was attainable at relatively low cost. Irrigation water use ramifications associated with risk reduction were mainly neutral and water saving on average.

E. Acknowledgments:

The authors gratefully acknowledge partial financial support for this research from the United Soybean Board and the U.S. Midsouth Soybean Board as well as professional assistance with the bootstrapping technique by Diana Danforth.

F. Tables and Figures

Table 1. Description of production practices and environmental parameters by location, 2012-2014.

Location	Latitude	Planting Dates 2012 PD1, PD2†	2012 PD3, PD4	2013 PD1, PD2	2013 PD3, PD4	2014 PD1, PD2	2014 PD3, PD4	Row spacing	Soil series	Irrigation type
	°N			Day/Month				cm		
Columbia, MO	38.9	-	-	4/22, 5/14	6/14, 6/25	4/23, 5/21	6/17, 6/27	76	Mexico silt loam	lateral
Portageville, MO	36.4	4/2, 4/17	5/10, 6/12	4/9, 5/9	5/29, 6/20	4/22, 5/7	5/27, 6/17	76	Tiptonville silt loam	furrow
Milan, TN	35.9	-	-	4/22, 5/9	6/5, 6/25	4/24, 5/7	6/17, 7/3	76	Routon silt loam	pivot
Keiser, AR	35.4	3/30,4/19	5/16, 6/8	6/13	6/26, 7/8‡	4/23, 5/8	5/22, 6/5	19 twins on 97	Sharkey silty clay	furrow
Verona, MS	34.6	3/21,4/11	5/17, 6/6	4/23, 5/15	5/30, 6/17	4/23, 5/13	5/27, 6/17	20 twins on 97	Leeper silty clay loam	furrow
Stoneville, MS	33.4	3/20, 4/13	5/10, 6/7	4/18, 5/31	6/12, 6/27	5/8, 5/23	6/6, 7/2	76 & 46§	Dubbs silt loam	furrow
Rohwer, AR	33.4	3/29, 4/24	5/15, 6/26	4/26, 5/20	6/10, 6/28	4/21, 5/19	6/5, 6/30	48 & twins¶	Herbert silt loam	furrow
St. Joseph, LA	32.0	4/6, 4/20	5/15, 6/1	4/29, 5/14	5/28, 6/12	4/24, 5/8	5/22, 6/19	51	Sharkey clay	furrow
College St, TX	30.6	3/26, 4/12	5/4, 5/25	4/9, 4/26	5/13, 5/30	4/9, 4/25	5/12, 6/2	38	Weswood clay loam	lateral

Notes:

† The first planting date is listed above the second planting date with the third and fourth planting date in the adjacent column to the right.

‡ Rain caused planting to be divided with some plots planted on 7/8 and others on 7/17.

§ Row spacing was 76 cm in 2012 and 2013, and 46 cm in 2014.

¶ Row spacing was 48 cm in 2012 and 20 cm twin rows on 97 cm beds in 2013 and 2014. Notes.

Table 2. Soybean maturity group (MG) classification, seed company, cultivar name, relative maturity (rMG), and years used.

MG†	Company	Cultivar	rMG	Years Used
III	Mycogen	5N342R2	3.4	2012-2014
III	Morsoy	RT 3644	3.6	2012
III	Morsoy	R2 36X82N	3.6	2013-2014
III	Pioneer	P39T67R	3.6	2014
III	Pioneer	P93Y72	3.7	2012, 2013
III	Pioneer	P93Y92	3.9	2012-2014
IV	Armor	42-MI	4.2	2012-2014
IV	Pioneer	P94Y40	4.4	2012, 2013
IV	Pioneer	P46T212R	4.6	2014
IV	Asgrow	AG4732	4.7	2012, 2013
IV	Asgrow	AG4730	4.7	2014
IV	Terrell Norris	REV49R11	4.8	2012
IV	Terrell Norris	REV48R33	4.9	2013-2014
V	Asgrow	AG5332	5.3	2012, 2013
V	Pioneer	P54T94R	5.4	2014
V	Asgrow	AG5532	5.5	2012-2014
V	Pioneer	P95Y50	5.5	2012, 2013
V	Progeny	P5811RY	5.8	2012
V	Progeny	P5711RY	5.7	2013, 2014
VI	Asgrow	AG6132	6.1	2013
VI	Stine	6202-4	6.2	2012, 2013
VI	Asgrow	AG6534	6.5	2014
VI	Pioneer	P96M60	6.6	2012
VI	Asgrow	AG6732	6.7	2012-2014
VI	Progeny	P6710RY	6.7	2013-2014
VI	HBK	HBKR7028	7.0	2012

Notes:

† Trial cultivars were changed as older cultivars became unavailable. HBKR 7028 was grouped with MG VI cultivars during the single year the cultivar was used.

Table 3. Four-factor analysis of variance of soybean yield for 2012, 2013 and 2014. Degrees of freedom, sum of squares, mean square, F, probability, and % of total variability explained by each source of variation (% of the total sum of squares of the model). Error sum of squares not shown in the table but is used for calculating the % of total variability.

2012	**DF**	**Sum of squares**	**Mean square**	**F**	**P-value**	**% of total variability**
Location (L)	7	26.0	37.17	228.33	<0.0001	20
Planting Date (PD)	3	7.0	23.42	143.83	<0.0001	5
L*PD	18	14.7	8.15	50.08	<0.0001	11
Maturity Group (MG)	3	9.4	31.42	192.98	<0.0001	7
L*MG	21	13.6	6.47	39.74	<0.0001	10
PD*MG	9	7.1	7.86	48.26	<0.0001	5
L*PD*MG	54	12.5	2.32	14.22	<0.0001	10
Cultivar(MG)	12	3.9	3.29	20.18	<0.0001	3
L*Cultivar(MG)	84	5.4	0.64	3.92	<0.0001	4
PD*Cultivar(MG)	36	2.4	0.68	4.15	<0.0001	2
L*PD*Cultivar(MG)	213	7.8	0.36	2.24	<0.0001	6
Combined sources of variation						
Environment†						36
MG‡						32
Cultivar§						15
2013						
Location (L)	8	72.0	90.03	797.08	<0.0001	40
Planting Date (PD)	3	18.2	60.80	538.30	<0.0001	10
L*PD	21	14.4	6.85	60.61	<0.0001	8
Maturity Group (MG)	3	14.3	47.52	420.75	<0.0001	8
L*MG	24	15.9	6.65	58.83	<0.0001	9
PD*MG	9	1.4	1.57	13.87	<0.0001	1
L*PD*MG	62	8.7	1.40	12.34	<0.0001	5
Cultivar(MG)	12	2.2	1.83	16.22	<0.0001	1
L*Cultivar(MG)	95	6.6	0.69	6.15	<0.0001	4
PD*Cultivar(MG)	36	1.1	0.31	2.76	<0.0001	1
L*PD*Cultivar(MG)	243	6.0	0.25	2.17	<0.0001	3
Combined sources of variation						
Environment†						58
MG‡						23
Cultivar§						11

… cont'd

2014	**DF**	**Sum of squares**	**Mean square**	**F**	**P-value**	**% of total variability**
Location (L)	9	36.2	40.18	308.06	<0.0001	19
Planting Date (PD)	3	22.8	75.94	582.22	<0.0001	12
L*PD	24	11.1	4.61	35.32	<0.0001	6
Maturity Group (MG)	3	35.7	119.08	912.97	<0.0001	18
L*MG	27	15.2	5.63	43.17	<0.0001	8
PD*MG	9	4.4	4.88	37.42	<0.0001	2
L*PD*MG	71	11.4	1.61	12.31	<0.0001	6
Cultivar(MG)	12	6.2	5.15	39.48	<0.0001	3
L*Cultivar(MG)	108	11.9	1.10	8.43	<0.0001	6
PD*Cultivar(MG)	36	1.7	0.48	3.68	<0.0001	1
L*PD*Cultivar(MG)	285	9.1	0.32	2.45	<0.0001	5
Combined sources of variation						
Environment†						37
MG‡						34
Cultivar§						15

Notes:

† Environmental effect estimated as: L + PD + L*PD

‡ Maturity Group effect estimated as: MG + L*MG + PD*MG + L*PD*MG

§ Cultivar effect estimated as: Cultivar(MG) + L*Cultivar(MG) + PD*Cultivar(MG) + L*PD*Cultivar(MG)

Table 4. US soybean oil, soybean meal and soybean price, 2005 – 2014[†]**.**

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	**Average**
Oil	0.74	0.78	1.03	1.46	0.82	1.05	1.53	1.22	1.06	0.84	n/a[¶]	**1.05**
Meal[‡]	0.30	0.29	0.34	0.47	0.42	0.45	0.50	0.47	0.53	0.54	n/a[¶]	**0.43**
Soybean[§]	-[¶]	139.95	138.00	185.47	319.08	277.32	270.04	388.04	450.71	529.10	480.13	**317.98**

Notes:

† Prices were deflated to 2013 dollars using the Commodity Prices Received Index (USDA National Agricultural Statistics Service, 2015).

‡ Soybean meal is for 458% protein concentration.

§ Soybean prices reflect prices received by farmers for #2 Soybean according to the 2015 Oil Crops Yearbook (USDA, AMS, 2015). Average oil and protein prices represent yearly averages according to the 2015 Oil Crops Yearbook (USDA, AMS, 2015).

¶ Oil and protein prices for 2014 were unavailable so 2004 prices were used in calculating a ten-year average.

Table 5. Average yield, harvest week, irrigation, seasonal sale price, quality premia or discounts, expected returns, and standard deviation for all MG × PD combinations: Rohwer, AR, 2012-2014.

MG	PD[†]	Yield ($Mg\ ha^{-1}$)	Harvest Week[‡]	Average Annual Irrigation (ha cm)	P_{Adj} ($\$\ Mg^{-1}$)	Oil and Protein Premium or Discount ($\$\ Mg^{-1}$)	Oil and Protein Premium or Discount ($\$\ ha^{-1}$)	Expected Returns[§] Avg. ($\$\ ha^{-1}$)	Expected Returns[§] Std. Dev. ($\$\ ha^{-1}$)
III	PD 1	4.9	32	32.0	$325.65	$16.77	$83	$741	$266
IV		5.3	34	34.0	$321.48	$16.29	$86	$820	$360
V		4.7	36	36.0	$317.55	$3.61	$17	$539	$296
VI		3.7	38	38.7	$298.60	$(4.82)	$(19)	$144	$189
III	PD 2	4.6	34	34.8	$322.21	$16.66	$73	$516	$197
IV		4.6	36	35.6	$319.02	$14.69	$67	$558	$261
V		4.1	39	38.6	$300.67	$(2.98)	$(12)	$245	$241
VI		3.8	41	41.0	$296.62	$(2.27)	$(9)	$149	$256
III	PD 3	4.2	37	36.6	$317.35	$15.34	$65	$436	$228
IV		4.1	38	38.0	$309.78	$8.59	$36	$351	$327
V		3.8	39	39.3	$300.21	$(2.61)	$(10)	$128	$194
VI		3.8	41	41.4	$289.33	$(3.92)	$(16)	$156	$205
III	PD 4	2.9	39	39.0	$302.17	$4.45	$13	$(56)	$197
IV		3.5	40	40.1	$291.44	$4.79	$17	$74	$166
V		3.3	42	41.5	$289.12	$(4.73)	$(16)	$(13)	$182
VI		3.9	43	42.9	$301.50	$(6.06)	$(24)	$233	$224
Average[¶]		4.1	38	38.1	$ 306.55	$4.97	$22.01	$ 290	$320

Notes:

[†] PD vary by year. PD1 is the earliest date and PD4 is the latest with PD2 and PD3, weather permitting, spread at equal time intervals between PD1 and PD4.

[‡] Harvest Week denotes average Julian week when soybean from a given combination reached the R8 growth stage or harvest maturity.

[§] Expected returns are to management and land with average and standard deviation of MG × PD combination reported using equations 6 and 7 to summarize revenue less specified expenses of irrigation, seed, fertilizer, chemicals, labor, fuel, maintenance, hauling, and marketing as well as equipment ownership charges. Parentheses indicate an expected loss. The standard deviation is calculated across replicates, cultivars, and years for a particular MG × PD combination.

[¶] Simple average of all MG × PD combination results.

Table 6. Overall location-specific average returns and risk along with individual MG × PD choices that are the profit-maximizing MG × PD choice or least risky.

Location	Overall Returns†	Overall Risk‡	Profit-maximizing MG × PD§					Risk-minimizing MG × PD¶				
			MG#	PD#	E_a	$\sqrt{V_a}$	IR_a††	MG	PD	E_a	$\sqrt{V_a}$	IR_a
Columbia, MO	$ 281	$ 331	III	2	$ 709	$ 131	16	VI	4	$(265)	$ 115	16
Portageville, MO	$ 111	$ 308	IV	1	$ 491	$ 253	35	VI	4	$(162)	$ 150	40
Milan, TN	$ 253	$ 267	IV	1	$ 602	$ 236	19	IV	4	$ 170	$ 80	28
Keiser, AR	$ 150	$ 338	IV	1	$ 451	$ 262	17	V	1	$ 320	$ 134	19
Verona, MS	$ 205	$ 253	IV	1	$ 516	$ 196	35	VI	1	$ 174	$ 74	36
Stoneville, MS	$ 495	$ 423	IV	1	$ 672	$ 479	27	III	3	$ 591	$ 261	24
Rohwer, AR	$ 320	$ 353	IV	1	$ 821	$ 360	34	IV	4	$ 75	$ 165	37
St. Joseph, LA	$ 521	$ 403	IV	2	$ 892	$ 272	10	VI	4	$ 5	$ 174	10
College St, TX	$(91)	$ 417	IV	1	$ 334	$ 272	14	VI	4	$ 116	$(798)	17

Notes:

† Simple average of all $R_i = \left[\left(P_{Adj,i} \pm PD_i\right) \cdot Y_i\right] - (IR_a \times IC) - TSE$ at a particular location with variables as described in equation 6 to summarize revenue less specified expenses of irrigation, seed, fertilizer, chemicals, labor, fuel, maintenance, hauling, and marketing as well as equipment ownership charges. Parentheses indicate an expected loss.

‡ Standard deviation of all R_i at a particular location to summarize riskiness across all observations.

§ The MG × PD combination with the largest E_a as defined in equation 7.

¶ The MG×PD combination with the lowest $V_a = \sum_i [R_i - E_a]^2 \big/ (t-1)$ $\forall\, a \in MG \times PD \times LOC$ with t as the number of possible observations by MG and PD combination.

\# Maturity Group (MG) varied from III to VI and planting dates were split among four dates arranged from earliest = 1 to latest = 4 as determined by location-specific recommendations in equal increments weather permitting (Table 1).

†† IR_a represents the average amount of irrigation used reported in ha cm for the specific MG × PD combination in the experimental trials.

Table 7. MG × PD planting portfolios for V_{Mid} in comparison to the profit-maximizing MG × PD choice in terms of returns, risk and irrigation water use by location.

MG	**III**	**IV**	**V**	**III**	**IV**	**V**	**III**	**VI**	**Expected Returns[†] (E_a)**		**Risk (V_{mid})**		**Irrigation Applied[¶] (IR_a)**	
PD	**1**	**1**	**1**	**2**	**2**	**2**	**3**	**3**						
Location	% of land allocated to a MG × PD choice (x_a)[†]								(\$ ha^{-1})	% Δ[‡]	(\$ ha^{-1})	% Δ[§]	(ha cm)	% Δ
Columbia, MO	38	3	0	48	11	0	0	0	\$ 680	-4.1	\$ 85	-35.4	16	0
Portageville, MO	55	38	0	7	0	0	0	0	\$ 487	-1.0	\$ 153	-39.6	32	-8.6
Milan, TN	28	48	24	0	0	0	0	0	\$ 542	-10.0	\$ 136	-42.3	19	0
Keiser, Ar	38	50	12	0	0	0	0	0	\$ 389	-13.8	\$ 157	-40.1	17	0
Verona, MS	0	46	0	44	10	0	0	0	\$ 480	-6.9	\$ 116	-40.6	35	0
Stoneville, MS	0	47	0	0	16	37	0	0	\$ 662	-1.4	\$ 287	-40.1	27	0
Rohwer, AR	53	41	0	0	6	0	0	0	\$ 759	-7.7	\$ 208	-42.2	31	-4.0
St. Joseph, LA	0	16	0	5	53	0	17	9	\$ 828	-7.2	\$ 167	-38.7	10	0
College St, TX	0	38	0	42	20	0	0	0	\$ 327	-2.0	\$ 161	-41.0	15	7.1

Notes:

† The model, equation 10, did not call for any soybean to be planted in MG VI and PD 4. For PD 3 only MG III was selected. MG × PD choices with no land allotted to them are not shown but were considered.

† Expected returns associated with the V_{Mid} planting portfolio shown in the columns to the left.

‡ The percentage change in E_a associated with a producer selecting the V_{Mid} portfolio for planting rather than planting all available land in the most profitable MG × PD combination for a given location.

§ The percentage change from V_a, the profit-maximizing MG × PD choice, associated with the V_{Mid} planting portfolio for a given location.

¶ IR_a represents the expected amount of irrigation used in ha cm by the described planting portfolio. The amount of IR_a listed in this column is then compared to the amount of irrigation required by the profit-maximizing MG × PD choice listed in Table 6.

Figure 1. Map of study locations.

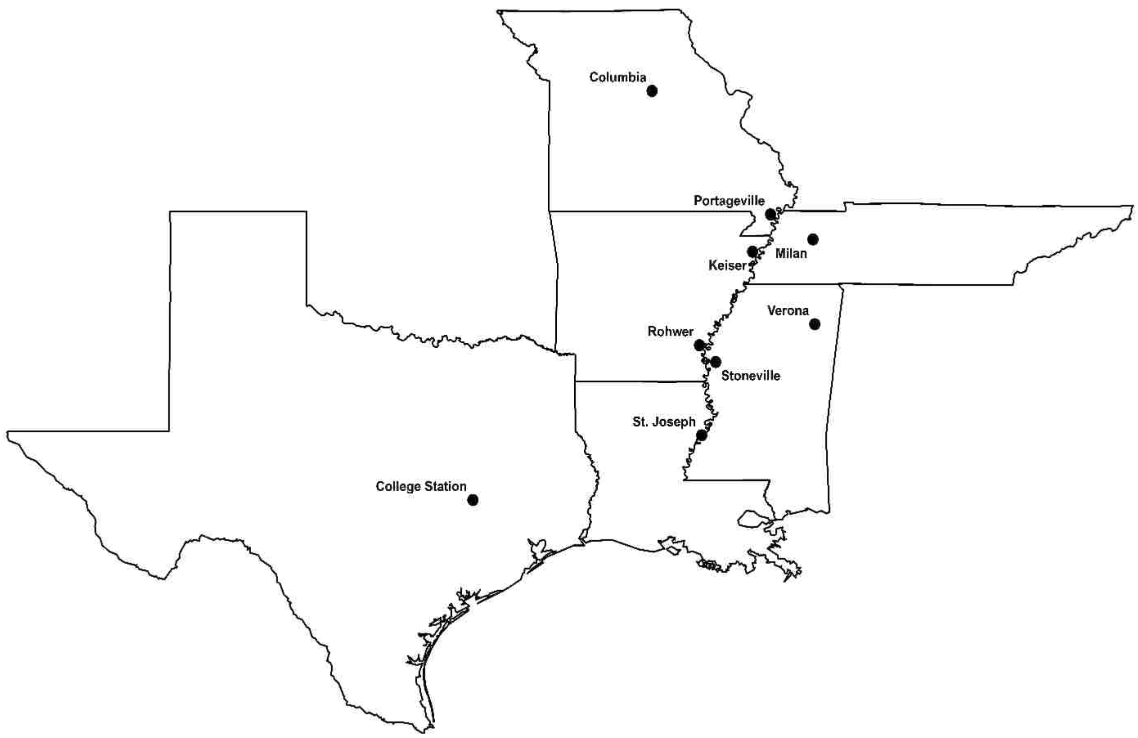
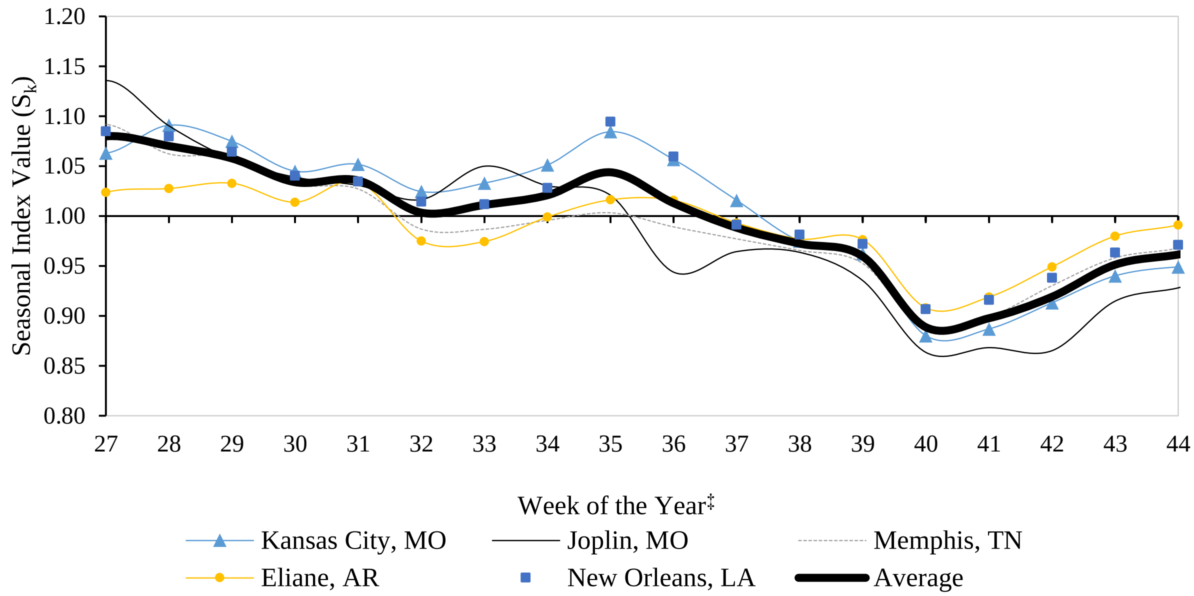


Figure 2. Weekly seasonal index of soybean prices using 2005-2014 weekly cash soybean market prices as reported by USDA AMS.†

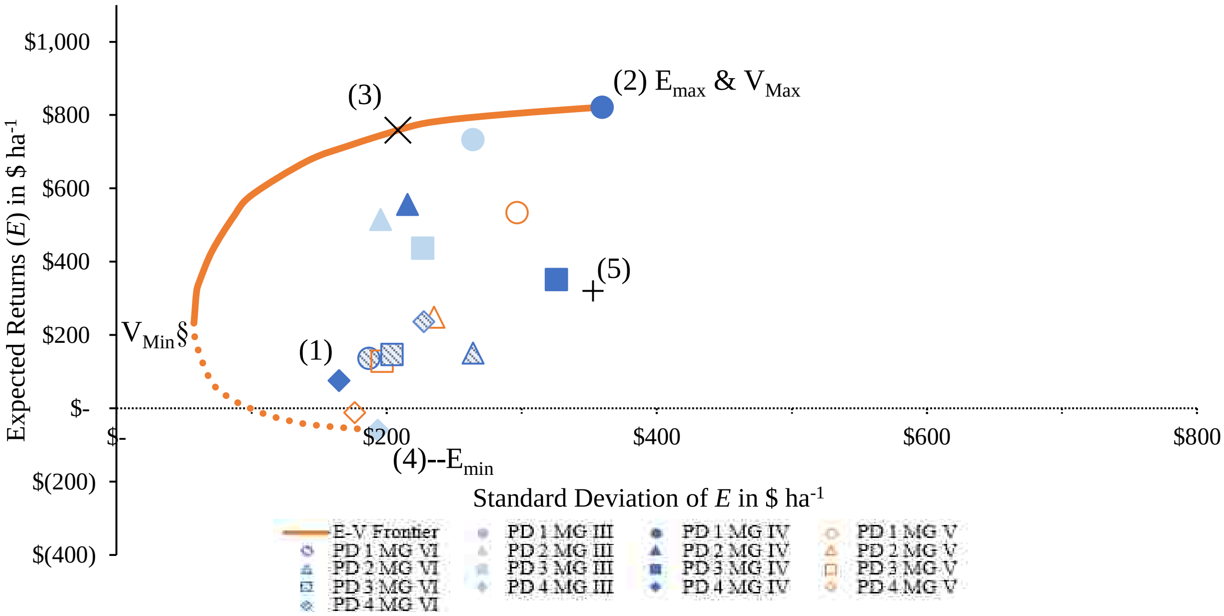


Notes:

† For a definition of S_k please see equation 1. Values greater/less than 1 suggest an average premium/discount relative to the annual moving average soybean price over the course of 2005-2014.

‡ The earliest possible harvest date in the experiments occurred in the 27th week of the year, the latest in the 44th week of the year.

Figure 3. Expected returns vs. return risk, e-v frontier and median risk portfolio choice (3) by maturity group (MG) and planting date (PD) combinations at Rohwer, AR, 2012-14[†, ‡].



Notes:

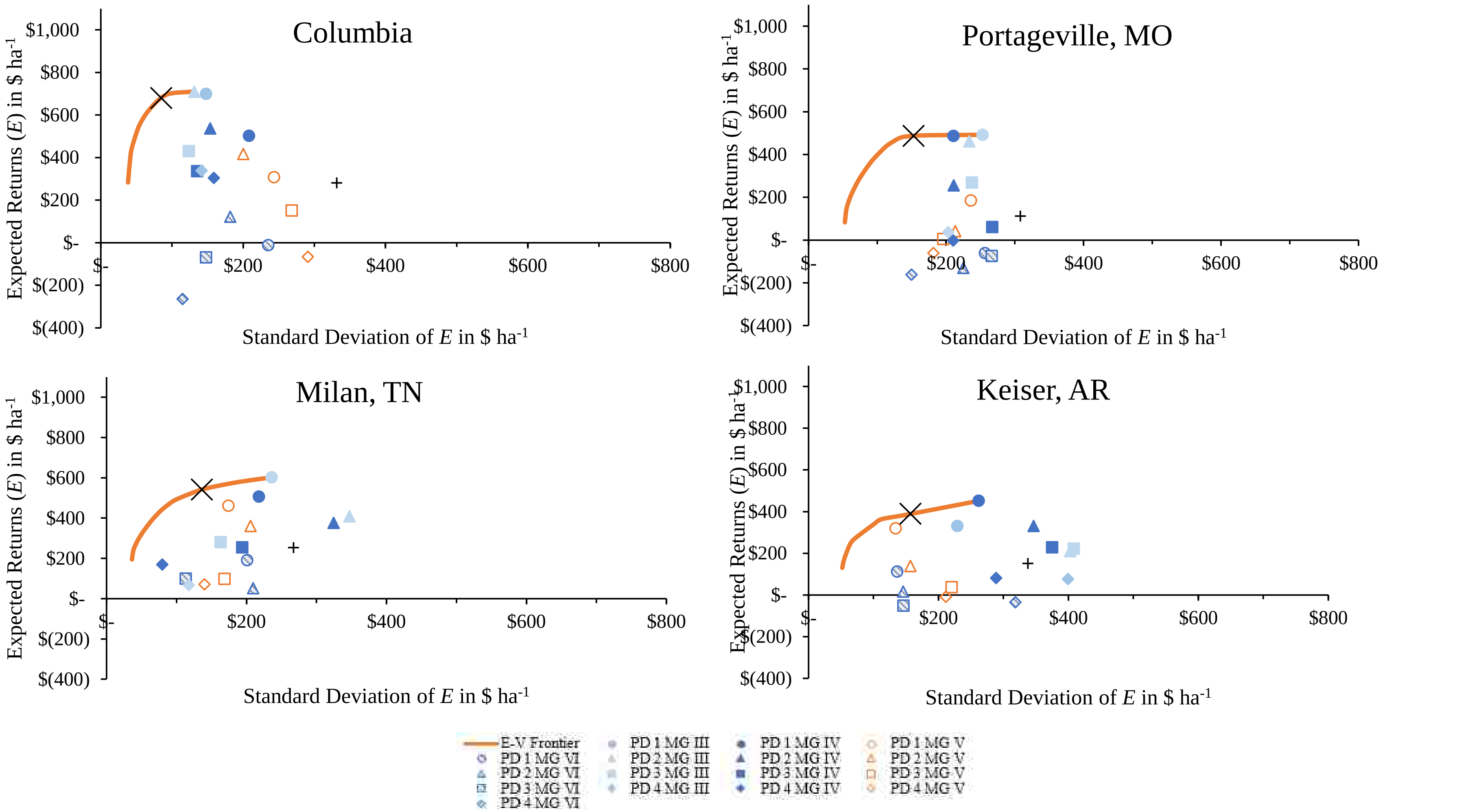
† MG × PD combinations with a V more than two times greater than the combination with the highest E_i were omitted from the graph.

‡ Point (5) represents the overall return and risk in Rohwer (Table 6) and is plotted as ✚.

§ The dashed line represents the portion of the E-V frontier typically not analyzed as higher returns are available at the same level of risk.

¶ (1) is the minimum risk MG × PD choice, (2) is the maximum return MG × PD choice that also coincides with maximum risk at this location, (3) is the median risk or V_{mid} portfolio as described in Table 7, and (4) is the least profitable MG × PD choice.

Figure 4. Expected cash returns in $ per ha vs. return standard deviation across maturity group (MG) and planting date (PD) combinations at Columbia and Portageville, MO, Milan, TN and Keiser, AR, 2012-14†. The e-v frontier‡ represents combinations of MG and PD that maximizes returns (E) for a given level of return variance (V) or risk.

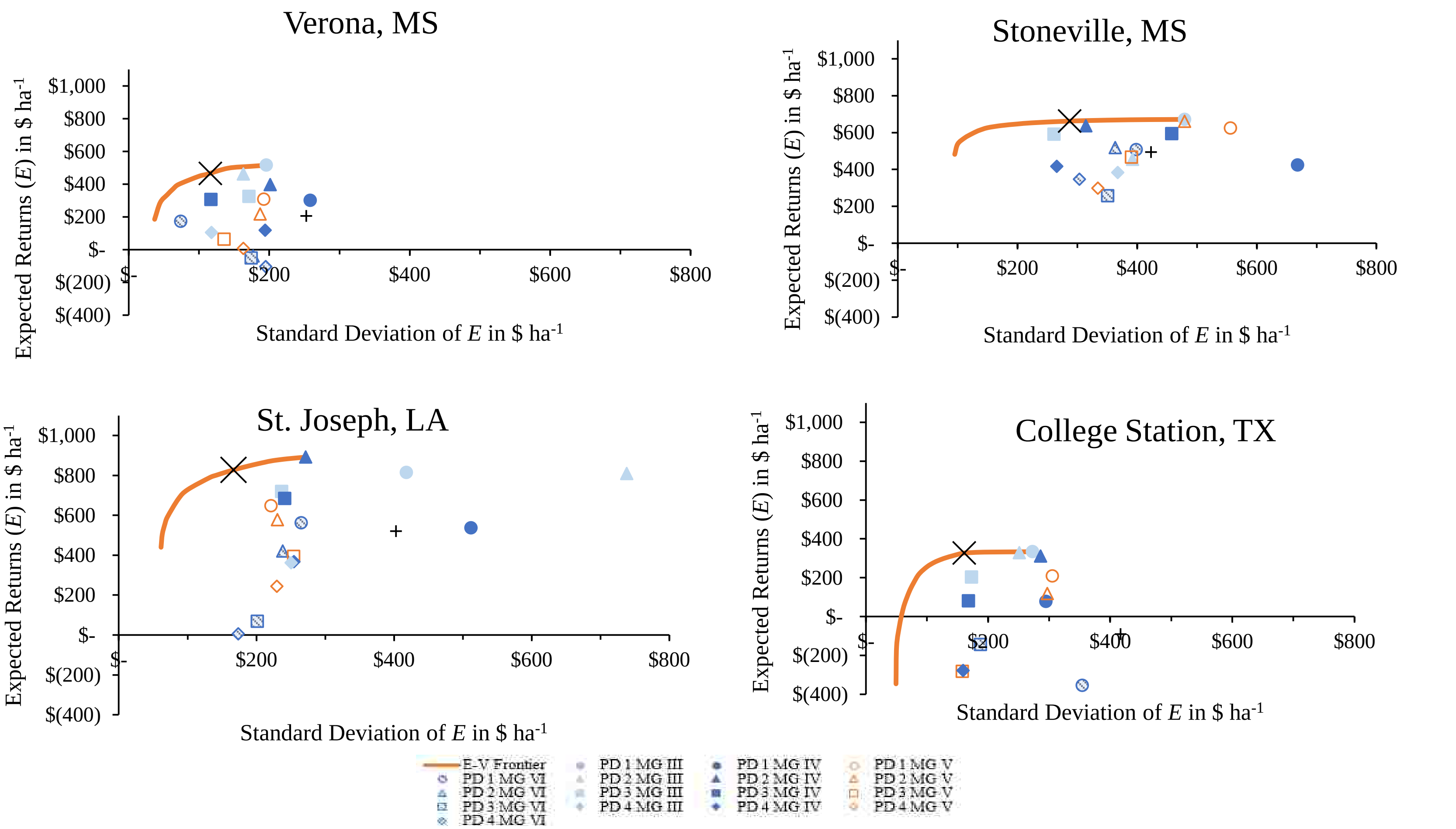


Notes: The dashed line represents minimized profit at a given level of risk. ✚ represents overall risk and returns reported in Table 6.

† MG PD Combinations with a V_a more than two times greater than the combination with the highest E_a were omitted from the graph.

‡ V_{Mid} is represented by the marker on the efficient frontier. For information on the different V_{Mid} portfolios see Table 7.

Figure 5. Expected cash returns in $ per ha vs. return standard deviation across maturity group (MG) and planting date (PD) combinations at Verona and Stoneville, MS, St. Joseph, LA and College Station, TX, 2012-14†. The e-v frontier‡ represents combinations of MG and PD that maximizes returns (E) for a given level of return variance (V) or risk.



Notes: The dashed line represents minimized profit at a given level of risk. ✚ represents overall risk and returns reported in Table 6.
†MG PD Combinations with a V_a more than two times greater than the combination with the highest E_a were omitted from the graph.
‡V_{Mid} is represented by the marker on the efficient frontier. For information on the different V_{Mid} portfolios see Table 7.

G. References

Barkley, A.P., and H.H. Peterson. 2008. Wheat Variety Selection: An Application of Portfolio Theory to Improve Returns. NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management. Available at http://ageconsearch.umn.edu/bitstream/37597/2/confp03-08.pdf.

Boquet, D.J. 1998. Yield and Risk Utilizing Short-Season Soybean Production in the Mid-Southern USA. Crop Sci. 38(4): 1004–1011.

Boyer, C.N., M. Stefanini, J.A. Larson, S. Aaron Smith, A. Mengistu, and N. Bellaloui. 2015. "Profitability and Risk Analysis of Soybean Planting Date by Maturity Group." Agron. J. 107(6):2253-2262.

Brennan, J.P. 1984. Measuring the Contribution of New Varieties to Increasing Wheat Yields. Review of Marking and Agricultural Economics 52: 175–195.

Edwards, J.T., L.C. Purcell, E.D. Vories, J.G. Shannon, and L.O. Ashlock. 2003. Short-Season Soybean Cultivars Have Similar Yields With Less Irrigation Than Longer-Season Cultivars. cm 2(1): 0.

Efron, B. 1979. Bootstrap Methods: Another Look at the Jackknife. The Annals of Statistics 7(1): 1–26.

Egli, D.B., and P.L. Cornelius. 2009. A Regional Analysis of the Response of Soybean Yield to Planting Date. Agron. J. 101(2): 330–335.

Gaspar, A.P., P.D. Mitchell, and S.P. Conley. 2015. Economic Risk and Profitability of Soybean Fungicide and Insecticide Seed Treatments at Reduced Seeding Rates. Crop Sci. 55(2): 924–933.

Goodwin, J.W. 1994. Agricultural Price Analysis and Forecasting. 1st ed. Wiley.

Hazel, P.B., and Norton, R.D., 1986. Mathematical Programing of Economic Analysis in Agriculture. Macmillan, Germany.

Heatherly, L.G. 1996. Yield and Germination of Harvested Seed from Irrigated and Nonirrigated Early and Late Planted MG IV and V Soybean. Crop Sci. 36:1000-1006.

Heatherly, L.G., and S.R. Spurlock. 1999. Yield and Economics of Traditional and Early Soybean Production System (ESPS) Seedings in the Midsouthern United States. Field Crop. Res. 63(1): 35–45.

Hu, M., and P. Wiatrak. 2012. Effect of Planting Date on Soybean Growth, Yield, and Grain Quality: Review. Agron. J. 104(3): 785–790.

Markowitz, H.M., 1959. Portfolio Selection: Efficient Diversification of Investments. John Wiley & Sons, New York.

Mayhew, W.L., and C.E. Caviness. 1994. Seed Quality and Yield of Early-Planted, Short-Season Soybean Genotypes. Agron. J. 86-16-19.

Flanders, A., R. Baker, T. Barber, and T. Faske. 2011. 2014-2012 Crop Enterprise Budgets: AG-1302. Available at http://uaex.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx (verified 25 August 2015).

Nalley, L.L., and A.P. Barkley. 2010. Using Portfolio Theory to Enhance Wheat Yield Stability in Low-Income Nations: An Application in the Yaqui Valley of Northwestern Mexico. J. Agric. Resour. Econ. 35(2): 334–347.

Nalley, L.L., A. Barkley, B. Watkins, and J. Hignight. 2009. Enhancing Farm Profitability through Portfolio Analysis: The Case of Spatial Rice Variety Selection. Journal of Agricultural and Applied Economics 41(3): 641-652.

National Oceanic and Atmospheric Administration, National Centers for Environmental Information. 2015. "Annual Climatological Summary: Rohwer, AR". 2005-2014. Available by request at http://www.ncdc.noaa.gov/cdo-web/.

Park, S.C., J. Cho, S.J. Bevers, S. Amosson, and J.C. Rudd. 2012. Dry Wheat variety selection in the Texas High Plain. Selected Paper Southern Agricultural Economics Association Annual Meeting. Available at http://core.ac.uk/download/pdf/6653565.pdf.

Poag, P.S., M. Popp, J. Rupe, B. Dixon, C. Rothrock and C. Boger. 2005. "Economic Evaluation of Soybean Fungicide Seed Treatments". Agron. J. 97(6):1647-1657.

Popp, M., J.T. Edwards, L.C. Purcell, and P.M. Manning. 2004. Early-Maturity Soybean in a Late-Maturity Environment: Economic Considerations. Agron. J. 96(6): 1711–1718.

Popp, M.P., J.T. Edwards, L.C. Purcell, and P.M. Manning. 2006. Profit-Maximizing Seeding Rates and Replanting Thresholds for Soybean: Maturity Group Interactions in the Mid-South. Agricultural Systems 91(3): 211–228.

Purcell, L., M. Salmeron, and L.O. Ashlock. 2014. Arkansas Soybean Production Handbook - MP197 Chapter 2: Soybean Growth and Development. p. Chapter 2. *In* Arkansas Soybean Production Handbook - MP197.

Purcell, L.C., T.R. Sinclair, and R.W. McNew. 2003. Drought Avoidance Assessment for Summer Annual Crops Using Long-Term Weather Data. Agron. J. 95(6): 1566–1576.

Salmeron, M., E.E. Gbur, F.M. Bourland, N.W. Buehring, L. Earnest, F.B. Fritschi, B.R. Golden, D. Hathcoat, J. Lofton, T.D. Miller, C. Neely, G. Shannon, T.K. Udeigwe, D.A. Verbree, E.D. Vories, W.J. Wiebold, and L.C. Purcell. 2014. Soybean Maturity Group Choices for Early and Late Plantings in the Midsouth. Agronomy Journal 106(5): 1893.

Salmeron, M., E.E. Gbur, F.M. Bourland, N.W. Buehring, L. Earnest, F.B. Fritschi, B.R. Golden, D. Hathcoat, J. Lofton, T.D. Miller, C. Neely, G. Shannon, A.T. McClure, T.K. Udeigwe, D.A. Verbree, E.D. Vories, W.J. Wiebold, and L.C. Purcell. 2015. Yield response to planting date among soybean maturity groups for irrigated production in the US Midsouth. (Accepted in Crop Science).

SAS Institute Inc. *SAS Online 9.1.* Cary, NC: SAS Institute Inc., 2014.

Updaw, N.J., B. Bullock, and T.E. Nichols Jr. 1976. Pricing Soybeans on the Basis of Oil and Protein Content. Southern Journal of Agricultural Economics: 129–132.

United States Department of Agriculture, Agricultural Marketing Service. 2015. "Soybean meal: Supply, disappearance, and price, U.S." Oil Crops Yearbook 2015. Available at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290 (verified 12 May 2015).

United States Department of Agriculture, Agricultural Marketing Service. 2015. "Soybean oil: Supply, disappearance, and price, U.S." Oil Crops Yearbook 2015. Available at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290 (verified 12 May 2015).

United States Department of Agriculture, Agricultural Marketing Service. 2015. "Soybeans: Supply, disappearance, and price, U.S." Oil Crops Yearbook 2015. Available at http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290 (verified 12 May 2015).

United States Department of Agriculture, Agricultural Marketing Service. 2015. Custom Grain Report: Grain: Oilseed: Soybeans: US No. 2. Available at https://marketnews.usda.gov/mnp/ls-report-config?category=Grain (verified 1 August 2015).

United States Department of Agriculture, Economic Research Service. Recent Costs and Returns: Soybeans: 2013-2014. 2015. United States Department of Agriculture Economic Research Service. Available at http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx.

United States Department of Agriculture, National Agricultural Statistics Service. 2015. "Ag. Services: Index for Price Paid, 2011". USDA NASS Quick Stats. Available at http://quickstats.nass.usda.gov/results/6E75AFFE-9DC8-3023-8C82-AF75E0EFFD3E (verified 27 June 2015).

United States Department of Agriculture, National Agricultural Statistics Service. 2015. "Food Commodities – Index for Price Received, 2011". USDA NASS Quick Stats. Available at http://quickstats.nass.usda.gov/#00DD57E2-7F6B-3841-AD0C-13ABD54836C6 (verified 27 June 2015).

United States Department of Agriculture, National Agricultural Statistics Service. 2015. "Soybeans, Irrigated and Non-Irrigated Acres Planted: Arkansas: 1994 and 2014". USDA NASS Quick Stats. Available at http://quickstats.nass.usda.gov/#00DD57E2-7F6B-3841-AD0C-13ABD54836C6 (verified 27 June 2015).

Chapter IV. Summarizing Comments and Directions for Further Research

A. Summary of Results and Conclusions

In chapter II, comparison of fungicide-treated soybean seed to untreated seed over three years in two Arkansas locations revealed seed treatment to be profitable, if only slightly so. As expected, PPD thresholds were lower for two week PPD than four week PPD. The results suggest that waiting four full weeks before making a replanting decision might be excessive, because the difference between two and four week PPD thresholds were very similar for different planting dates and locations. Chapter II also concludes that understanding yield potential associated with succeeding planting dates is the most critical determinant of replanting thresholds. A decision tool highlighting planting date effects would make this decision easier for producers by enabling analysis of late planting date effects on yield for a range of conditions. Understanding seed survival and optimizing seeding rates are important factors also.

Chapter III discussed MG selection in conjunction with planting dates across a large range of environments with changes in weather and soil conditions. Over all locations, early-planted MG III and MG IV soybeans were found to be more profitable than other MG × PD combinations on average. Also, soybeans planted earlier are likely to receive seasonally higher soybean prices as harvest occurs prior to the main harvest season when typical price declines to annual average prices are a function of excess supply conditions. The standard deviation of expected returns for the profit-maximizing MG × PD was compared to the median risk portfolio that consisted of portfolios of MG × PD including two to five different MG, PD or both. The shape of the efficient frontier determined how expensive the cost of risk reduction was relative to the profit-maximizing MG × PD selection. For several locations, significant risk reduction of 40% relative to the profit-maximizing MG × PD choice was attainable by sacrificing less than

10% of returns. Portfolios of MG × PD choices near the top right of the EV frontier were devoid of late-season planted soybean and latest maturing soybean MG VI. This suggested that early planting was found to expose producers on average to higher return risk than later planting dates. However, the cost of extra irrigation, yield penalties associated with late planting, seasonal sale price declines and oil- and protein concentration discounts associated with late planting were large enough for MG VI and late planting not to enter risk-efficient solutions. The extent of these tradeoffs varied by location and as such, a tool that would allow producers to compare their planting intentions with an EV frontier for conditions closest to their farm operation appears as a logical extension to this work.

B. Limitations of Past Research

In Chapter III quadratic programing was applied to the compiled field trial results using cost and return parameters that were chosen to approximate costs and prices received typical for production in the Mid-Southern US. While this approach was adequate for the objectives of this initial study, affording producers the ability to employ thousands of simulated yield and irrigation cost observations, calibrated using the field trial data as observed for chapter III would allow for estimates of yield and irrigation use that would add information for producers that may have to adjust their soybean MG selection as the planting season progresses. Field conditions, for example, may preempt early planting and MG would change if the producer were forced to plant at a later date. Irrigation limitations may also preempt the use of later maturing MG soybean and thereby limit the degree of risk mitigation available. Also, for the purpose of the initial report, only #2 quality grade soybean prices were used and adjusted for relative meal and protein concentration. Adding seed grade information to the analysis may modify the shape of the EV frontier.

C. Proposal for SoyRisk

The most sophisticated current soybean planting decision tool in North America was developed by Iowa State University from actual and simulated soybean data in the Upper Midwest and this program boasts eleven total locations: nine in Iowa locations and two in Minnesota and Central Missouri (Licht et al. Accessed 2015). The dataset that drives their decision tool utilizes both empirical observations and simulated data generated via the APSIM method. Similar to data used in this thesis, the Iowa State Decision tool used four actual planting dates and observations for the in-between planting dates are simulated. Cultivars used in the Iowa State tool were from MG II through IV as appropriate for the region and planting recommendations yield a single MG.

A tool that would add further detail to planning soybean planting decisions is attainable with both the data from Chapter III and validated simulated data currently under development at the University of Arkansas. The experimental trials that made these analyses possible were costly. As such, a decision tool that would provide more information for Mid-Southern soybean producers by allowing them to use E-V frontiers to determine the effect of MG and PD selection on risk and returns, is deemed valuable. A decision tool would build on this research by allowing price and cost parameters to be customized as close as possible to a producer's farm situation.

Producers are aware that planting non-yield maximizing varieties cost profit potential, but a decision tool that applied yield estimates of feasible maturity group and planting date combinations for specific locations to a producer's own expected costs could give producers the ability to better compare return-maximizing varieties to planting portfolios that could reduce risk, irrigation, or possibly both. The primary objective of future work would be to produce a decision tool that could allow producers to compare differences in expected yield and return of MG and PD portfolios they currently prefer to alternative portfolios.

For example, if a producer were able to reduce expected water use by 10% and return risk by 30%, he or she might be willing to sacrifice 10% of expected returns when compared to the profit-maximizing choice for a particular location. In attempting to quantify changes in not only return, but also water consumption and risk changes, producers may begin to frame reductions in risk or water use not as “losses” but instead as “tradeoffs” because the expected cost of changes in planting profile will be estimated. In addition, the tool will be able to be constrained by restricting the choice of MG and planting dates so that the tool will come up with planting portfolios that are expected to return the best outcome in the case of late-season planting or early-season planting to minimize exposure to late-season drought conditions.

In sum, the proposed tool will allow producers to manually enter typical MG and PD portfolios to compare against a computer-based solution that solves for a planting portfolio that may be able to reduce irrigation, risk, or both given a user-selected target. That target is customizable for a particular level of return, a maximum amount of irrigation use and/or level of risk exposure.

D. Works Cited

Licht, M., Archontoulis, S., and R. Dietsel. Soybean Planting Decision Tool. 2015. http://agron.iastate.edu/CroppingSystemsTools/soybean-decisions.html.

Salmeron, M., E.E. Gbur, F.M. Bourland, N.W. Buehring, L. Earnest, F.B. Fritschi, B.R. Golden, D. Hathcoat, J. Lofton, T.D. Miller, C. Neely, G. Shannon, T.K. Udeigwe, D.A. Verbree, E.D. Vories, W.J. Wiebold, and L.C. Purcell. 2014. Soybean Maturity Group Choices for Early and Late Plantings in the Midsouth. Agronomy Journal 106(5): 1893.

Weeks W., Popp, M.P., Purcell, L.C., 2015. Replanting Thresholds for Soybean using Two- and Four-Week Plant Survival Metrics. Agronomy Journal. Accepted for Publication.

Young, K.B., E.J. Wailes, J.S. Popp, and J. Smartt. 2004. Value of Water Conservation Improvements on Arkansas Rice Farms. Journal of the ASFMRA 2004: 119=126.

Department of

Agricultural Economics and Agribusiness

217 Agriculture Building, University of Arkansas, Fayetteville, AR 72701-1201

479-575-2256 • Fax 479-575-5306

M E M O

From: Michael Popp

To: Graduate School

Date: December 9, 2015

Subject: Weston Weeks M.Sc Thesis

This memorandum is to certify that Weston Weeks has performed at least 51% of the work associated with work entitled “Soybean Planting and Risk-Return Tradeoffs in the Mid-Southern United States”. Should you have any questions, please feel free to contact me at 479-575-6838 or mpopp@uark.edu.