Journal of Agricultural and Applied Economics, 42,1(February 2010):39–55

Wheat Variety Selection to Maximize Returns and Minimize Risk: An Application of Portfolio Theory

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This research shows that a portfolio of wheat varieties could enhance profitability and reduce risk over the selection of a single variety for Kansas wheat producers. Many Kansas wheat farmers select varieties solely based on published average yields. This study uses portfolio theory from business investment analysis to find the optimal, yield-maximizing and risk-minimizing combination of wheat varieties in Kansas.

Key Words: portfolio theory, wheat variety selection

JEL Classifications: Q12, Q16

"It makes sense to decrease the dependence on one cultivar, since even a 'superior' cultivar has its flaws. Combining cultivars that have complementary characteristics reduces risks of crop failure and increases stability." Garrett and Cox (2008)

"Investors shouldn't and in fact don't hold single assets; they hold groups or portfolios of assets . . . ***there is a risk reduction from holding a portfolio of assets if assets do not move in perfect unison."*** Elton et al. (2003, p. 44)

Prior to planting each year, Kansas wheat producers select wheat seed varieties from a long list of choices of varieties produced by both public research institutions and private seed companies. The variety decision is often made by intuitively comparing variety yields from wheat variety yield performance tests conducted and published by the Kansas Agricultural Experiment Station (Kansas State University; Watson, 2006), and test results from private seed companies, such as Agripro or Westbred. In these publications, each wheat variety is characterized by average yield, and other characteristics, including agronomic and end-use qualities. Producers often select the single variety that is most likely to maximize performance for their individual set of growing conditions, including average rainfall, soil type, and agronomic practices.

Wheat yields are subject to risk. The "genotype-environment interaction" describes how well each variety of wheat seeds will respond to different growing conditions. In Kansas, wheat variety selection is complicated by the unpredictable climate and diversity of soil conditions, since different varieties respond to

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The funding support of the Kansas Wheat Commission is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the Kansas Wheat Commission. Thanks to Professor Jeffrey Gillespie, *Journal of Agriculture and Applied Economics* editor, and two reviewers for excellent comments and suggestions, and participants at the NCCC-134 Conference on Applied Commodity Price Analysis, Forecasting, and Market Risk Management, St. Louis, MO, April 21–22, 2008.

weather and growing conditions in different ways. There are three major strategies for risk reduction using Kansas wheat varieties: (1) wheat breeding that develops new cultivars (varieties) that combine traits of multiple varieties to lower variability across growing environments, (2) blends, or mixtures of seeds from several varieties, and (3) planting a portfolio of multiple wheat varieties on different fields. Currently, many Kansas farmers plant more than one variety each year in the attempt to diversify the risk by growing varieties that respond differently to the environment. These variety combinations are typically selected based on variety descriptions, intuition, and published average yields from wheat variety tests. This study investigates the hypothesis that variety selection could be enhanced with the use of a quantitative portfolio model that incorporates yield variance and covariance between varietal yields to increase yield, minimize risk, or both.

In recent years, wheat producers have mixed the seeds of several pure varieties together into a "blend" of seeds, in the attempt to stabilize yields (Bowden et al., 2001). Blends were not planted at all in Kansas in 1997, but the percentage of acres planted to wheat blends increased steadily to reach a peak of 15.2% in 2004. In 2006, 10% of seeded acreage in Kansas was planted to blends (Kansas Department of Agriculture). While planting a portfolio of varieties and blends are outstanding strategies for Kansas wheat producers to reduce risk, the selection of varieties to include in the portfolio or blend could be improved. The objective of this research is to apply portfolio theory from the business investment literature to the selection of wheat varieties to maximize yields and minimize variability in yields. Portfolio theory provides a set of efficient outcomes that have higher average yields and lower variation than individual varieties alone. Results from the time period 1993–2006 demonstrate that by selecting an "optimal" portfolio, Kansas wheat producers could have increased yields by 2.87 bu/acre. This increase in wheat production would add over $120 million (2006 dollars) annually to wheat producer revenues, offsetting the cost of certified seed used in the portfolio.

Literature Review

Wheat variety selection is timely, important, and interesting in Kansas, since public and private wheat breeders continue to develop higher-yielding wheat varieties over time. Since it is possible to save wheat seed from one year to plant in the next, wheat producers are confronted with a difficult question about whether to purchase new certified seed, or plant saved seed from the previous harvest. A large literature on plant variety adoption decisions exists, beginning with the seminal work of Griliches (1957), who evaluated the determinants of hybrid corn adoption in the United States. Heisey and Brennan (1991) studied the demand for wheat replacement seed in Pakistan, and Traxler et al. (1995) documented and analyzed the steady growth of yields of new wheat varieties in Mexico. Smale, Just, and Leathers (1994) summarized several explanations for a relatively slow adjustment to a newly introduced variety, including (1) input fixity, (2) portfolio selection, (3) safety-first behavior, and (4) farmer experience and learning. The authors concluded that, "the major implication of this result is the need to recognize the importance of competing hypotheses in the applied study of technology adoption" (p. 544).

Barkley and Porter (1996) analyzed Kansas wheat producer variety selection decisions for the period 1974–1993, and found that variety choice was statistically related to production characteristics such as disease resistance and end-use qualities. They concluded, ". . . wheat producers in Kansas take into account end-use quality in varietal selection decisions, but economic considerations lead many farmers to plant higher-yielding varieties, some of which are characterized by low milling and baking qualities" (p. 209). Barkley and Porter (1996) also found that yield stability was a significant determinant of variety selection decisions, as discussed in Porter and Barkley (1995).

The use of mixtures of cultivars (varieties) has also been studied from ecological and pathological perspectives. Garrett and Cox (2008) reported that, "The construction of crop variety mixtures is an example of a technology that draws heavily on ecological ideas and has also contributed to our understanding of disease ecology through experiments examining the effects of patterns of host variability on disease through time and space" (pp. 1–2). Garrett and Cox (2008) discussed how crop diversity can be manipulated to manage disease, with an emphasis on plant-based agricultural systems, as detailed in case studies in Garrett et al. (2001) and Garrett and Mundt (1999).

In Kansas, blends of wheat varieties have become more widely used since 1997 as a method of reducing yield variability. The blends are typically made from equal proportions of three cultivars (Bowden et al., 2001). Garrett and Cox (2008) stated, "Mixtures of at least two crop cultivars increases the genetic diversity and has been shown to be effective at reducing disease and pest severity, increasing yield stability, and strengthening resilience of the crop to physiological stress." Wheat mixtures are also commonly grown in the Pacific Northwest (Mundt, 2002). Cox et al. (2004) provided evidence that cultivar mixtures can increase yield and reduce yield variability.

The study of decision making under risk has a long history, beginning with early decision models of resource allocation that maximized expected returns. Portfolio theory significantly improved our ability to analyze and identify optimal choices under risk by extension of the analysis to include variability, as well as expected returns. Portfolio theory was initially developed by Tobin (1958) and Markowitz (1959), with extensions by Lintner (1965) and Sharpe (1970). A "portfolio" is defined simply as a combination of items: securities, assets, or other objects of interest. Portfolio theory is used to derive efficient outcomes, through identification of a set of actions, or choices, that minimize variance for a given level of expected returns, or maximize expected returns, given a level of variance. Decision makers can then use the efficient outcomes to find expected utility-maximizing solutions to a broad class of problems in investment, finance, and resource allocation (Robison and Brake, 1979). Simply stated, portfolio theory can be used to maximize profits and minimize risk in a wide variety of settings and choices, including wheat variety selection in Kansas.

Financial portfolio analysis provides a useful framework for conceptualizing wheat variety decisions, and implementing variety seed purchase and planting decisions. Variety choices are similar to investment decisions in financial markets, where financial managers allocate money across investment opportunities with relative risks and returns across a set of correlated assets. Since different varieties of wheat respond differently to environmental conditions, risks associated with wheat varieties are correlated. Some varieties will be positively related to other varieties, and some may be negatively correlated with other variety yields. Because of this correlation, or relationship, there are potential benefits from considering planting multiple varieties on separate fields.

The application of portfolio theory to wheat variety decisions is new, but applications of portfolio theory to risky decisions in agriculture has been around a long time. Collins and Barry (1986) applied Sharpe's (1970) extension of the Markowitz model to a "single index" portfolio model to study diversification of agricultural activities. The single index model does not require a complete, balanced data set, and is computationally less demanding. Turvey, Driver, and Baker (1988) compared a full variance-covariance (Markowitz, 1959) model to a single index model in a case farm in southern Ontario, and found that the single index model is in many applications a practical alternative to the complete model for deriving mean-variance efficient farm plans. Schurle (1996) investigated the relationship between acreage size to variability of yield for several crops in Kansas, including wheat.

Robison and Brake (1979) provided a thorough and informative literature review of portfolio theory, with applications to agriculture and agricultural finance. Barry (1980) extended portfolio theory to the Capital Asset Pricing Model, and applied the model to farm real estate. More recently, Nyikal and Kosura (2005) used quadratic programming to solve for the efficient mean-variance frontier to better understand farming decisions in Kenyan agriculture. Another recent application of portfolio theory was conducted by Redmond and Cubbage (1988), who applied the capital asset pricing model to timber asset investments in the United States. Figge (2004) summarized the literature on how portfolio theory has been applied to biodiversity, and Sanchirico, Smith, and Lipton (2005) use portfolio theory to develop optimal management of fisheries. The portfolio approach used in these previous studies will be applied to Kansas wheat variety selection decisions. Purcell et al. (1993) used a portfolio model to find the optimal crops for a nursery, and Blank (2001) used portfolio theory to study the future of American agriculture.

An Economic Theory of Wheat Variety Selection

Previous studies of wheat variety selection include Barkley and Porter (1996), Dahl et al. (2004), and Detlefsen and Jensen (2004). These studies used the neoclassical input characteristic model developed by Ladd and Martin (1976), and extended by Melton, Colette, and Willham (1994), to derive the demand for each wheat variety, given varietal characteristics such as agronomic factors, end-use quality, and yield stability. The model assumes that an individual wheat producer maximizes expected profits, $E(\pi)$, given a normal wheat output distribution $Q_w \sim N(E(Q_w), \sigma^2)$, where Q_w is wheat output in bushels, $E(Q_w)$ is the mean, and σ^2 the variance. Following Barkley and Porter (1996), the profit equation to be maximized is in Equation (1).

$$(1)\qquad E(\pi) = P_w E(Q_w) - w_i x_i - \mathbf{K}'\mathbf{Z} - \lambda[\mathrm{var}(Q_w)]$$

Where P_w is the price of wheat, x_i is the i^{th} wheat variety, purchased at price w_i, and all other inputs are represented by the vector $\mathbf{Z}$, with $\mathbf{K}$ the vector of other input prices. Following Carlton (1979) and Barkley and Porter (1996), the costs of yield variability (λ) are assumed to be linearly increasing with the variability of output (σ^2). Wheat output is related to wheat characteristics: q_{ij} ($j = 1, \ldots n$) is the quantity of the j^{th} characteristic found in one unit of the i^{th} seed variety, such that q_j is the total amount of the j^{th} characteristic used in the production of Q_w, as in Equation (2).

$$(2)\qquad Q_w = f(q_{0.1}, q_{0.2}, q_{.n}; \mathbf{Z})$$

All inputs other than seed varieties ($\mathbf{Z}$) are assumed to be exogenous at the time of varietal selection. Barkley and Porter (1996) stated, "*Ex ante*, costs are assumed to be exogenous at the time of seed variety purchase. Unanticipated production costs are captured *ex post* by λ, the cost of yield stability" (p. 204). At the time of seed variety selection, the cost differences associated with a given variety are unknown. Examples include fungicides, harvesting, and drying costs that could vary across varieties, depending on the genotype-environment interaction.

First-order conditions with respect to a single variety characteristic are in Equation (3).

$$(3)\qquad \begin{aligned} w_i = {} & P_w \Sigma_j \left[\partial E(Q_w)/\partial q_j\right] \left(\partial q_j/\partial x_i\right) \\ & - \lambda \Sigma_j \left[\partial \sigma^2/\partial q_j\right] \left(\partial q_j/\partial x_i\right), \text{ where} \\ & \left(\partial q_j/\partial x_i\right) = q_{ij} \end{aligned}$$

Thus, the price of each variety is set equal to the value marginal product of each of the variety characteristics that is embedded in a given wheat variety, together with the variability costs associated with each variety (λ_i). Barkley and Porter (1996) showed that the demand for each wheat variety (x_i) is a function of prices (p_w and w_i), variety variability costs (λ_i), and production characteristics (q_{ij}), as shown in Equation (4).

$$(4)\qquad \begin{aligned} & x_i = x_i(P_w, w_i, \lambda_i; q_1, \ldots, q_n) \quad \text{for all} \\ & i = 1, \ldots, m \end{aligned}$$

In the current application of the input characteristic model, the output price (P_w) and all of the seed variety prices (w_i) are considered to be equal across all varieties. Following previous literature on variety selection including Barkley and Porter (1996); Dahl et al. (2004); Di Falco and Chavas (2006); and Di Falco and Chavas (2008), the focus of this research is on maximizing *ex ante* yield across varieties, rather than maximizing profits or revenues. This approach provides information valuable for wheat producers to enhance their ability to manage production risk, and wheat breeders, who can use the results to identify yield-increasing and risk-reducing variety combinations. Price risk is not considered here, as it can be mitigated through financial instruments (e.g., McKenzie and Kunda, 2009).

Similarly, seed prices are considered homogeneous across all varieties, following Barkley and Porter (1996) and Dahl et al. (2004). This assumption is based primarily on the lack of availability of seed price data. Experts on the Kansas wheat seed industry report that prices are similar across varieties, with local differences based on geographical availability (Ehmke, 2009; Strouts, 2009). Availability, and thus price, are related to the number of years since release, as more seed stock becomes available the older the variety becomes. Dahl et al. (2004) concluded, "... trade practices in most cases are for seed costs to be similar across varieties within a year due to institutional arrangements with the releasing agency. Consequently, even if these data were available, their effect would not affect the results" (p. 319). This holds for the present research, also. Given this assumption, the demand for each wheat seed characteristic can be considered to be a function of average varietal yield ($E(Q_w)$), varietal yield variation (σ^2), and the covariance of yield between varieties (σ_{ij}), for all m varieties, as in Equation (5).

$$(5) \qquad x_i = x_i\left(E(Qw), \sigma^2, \sigma_{ij}\right)$$

This theoretical model is the foundation of the empirical model of a portfolio of input characteristics developed in the next section.

Empirical Model

The model used to estimate the efficiency frontier for Kansas wheat variety yields is the model developed by Markowitz (1959) to study investments, applied to wheat variety yields in Kansas. Markowitz (1959) developed portfolio theory as a systematic method of minimizing risk for a given level of expenditure. To derive an efficient portfolio of wheat varieties, measures of expected returns (average yields) and variance of yields are required for each variety, together with all of the pairwise covariances across all varieties. The efficient mean-variance frontier for a portfolio of wheat varieties is derived by solving a sequence of quadratic programming problems. Based on a wheat producer's preferences for higher yield and less risk, a particular point on the efficiency frontier can be identified as the "optimal" portfolio of wheat varieties.

We assume that a wheat producer has land comprised of a given number of acres (X), and desires to choose the optimal allocation of wheat varieties to plant. Thus, the decision variable is x_i, the percentage of total acres planted to variety i, where $i = 1, \ldots, n$, and $\Sigma_i x_i = X$. Quadratic programming is used to solve for the efficiency frontier of mean-variance combinations. This frontier is defined as the maximum mean for a given level of variance, or the minimum variation for a given mean yield. If we define y_i as the mean yield of variety i, then the total yield on the farm is simply the weighted average yield, equal to: $\Sigma_i x_i y_i$.

The variance of total wheat variety yield for the entire farm (V) is defined in Equation (6),

$$(6) \qquad V = \Sigma_j \Sigma_k x_j x_k \sigma_{jk}$$

where x_j is the level of activity j, in this application is the percentage of acres planted to variety j, σ_{jk} is the covariance of variety yields between the jth and kth wheat varieties, and σ_{jk} is the variance when $j = k$.

Hazell and Norton (1986) emphasized the intuition embedded in Equation (6): The total farm variance for all wheat varieties planted (V) is an aggregate of the variability of individual varieties and covariance relationships between the varieties. Two conclusions are useful to better understand the portfolio approach to wheat variety selection: (1) combinations of varieties that have negative covariate yields will result in a more stable aggregate yield for the entire farm than specialized strategies of planting single varieties, and (2) a variety that is risky in terms of its own yield variance may still be attractive if its yields are negatively covariate with yields of other varieties planted.

The mean-variance efficiency frontier is calculated by minimizing total farm variance (V) for each possible level of mean yields (y_i), as given in Equation (7).

(7) $\min V = \Sigma_j \Sigma_k x_j x_k \sigma_{jk}$, subject to:
(8) $\Sigma_j x_j y_j = \phi$ and
(9) $x_j \geq 0$ for all j

The sum of the mean variety yields in Equation (8) is set equal to the parameter φ, defined as the target yield level, which is varied over the feasible range to obtain a sequence of solutions of increasing farm-level mean yield and variance, until the maximum possible mean yield is obtained.

Equation (7) is quadratic in x_j, necessitating the use of the Excel Solver program to solve the nonlinear equation. The Microsoft Excel Solver tool (Microsoft Corporation, Redmond, WA) uses the Generalized Reduced Gradient (GRG2) nonlinear optimization code developed by Leon Lasdon, University of Texas at Austin, and Allan Waren, Cleveland State University (Winston 2004). Linear and integer problems use the simplex method with bounds on the variables, and the branch-and-bound method, implemented by John Watson and Dan Fylstra (Frontline Systems, Inc., 2009).

Data

Data on wheat yields for all varieties planted in Kansas were collected from the publication, *Kansas Performance Tests with Winter Wheat Varieties* (KSU) for the period 1993–2006. The initial year of 1993 was selected based on observations of varieties that were planted in 2006. Table 1 and Figure 1 document the percentage of planted acres of the major wheat varieties in Kansas for the time period 1993–2006. Mean yields, standard deviations, and the coefficient of variation (equal to standard deviation divided by the mean yield) were calculated for

Table 1. Kansas Wheat Varieties Source, Year of Release, and Percent Planted Acres, 1993–2006

		Release														
Variety	Source	Year	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Public Varieties																
Larned	KSU	1976	8.3	8.3	7.6	4.8	3.6	2.4	1.9	1.2	1	0.9	0.8	0.4	0.3	0.2
Newton	KSU	1977	3.2	2.5	1.6	1.3	0.6	0.3	0.4	0	0	0	0	0	0	0
TAM107	TAMU	1984	19.8	19	20.6	17.1	17	12.6	8.3	6.3	5.3	2.9	2.3	1.3	1	0.4
TAM200	TAMU	1987	3.1	2.2	1.4	1.3	0.4	0.4	0	0	0	0	0	0	0	0
2163	KSU	1989	9	13.8	17.1	19.8	15.4	10.5	3.4	2.3	2	1.3	0.8	0.3	0.2	0.2
Karl92	KSU	1992	23	23.6	22.4	20.9	22.1	10.8	5.9	3.5	3.3	3.6	3.2	2.3	1.5	1.1
Ike	KSU	1993	0	0	0.9	7.2	10.5	7	5.5	4.1	3.6	2.6	2.1	2	1.4	1.1
Jagger	KSU	1994	0	0	0	1	6.4	20.2	29.2	34	35.8	42.8	45.2	40.9	28.2	19.7
2137	KSU	1995	0	0	0	0	1	13.5	22	23.1	22.3	15.5	13.3	8.6	5.7	3.1
TAM110	TAMU	1996	0	0	0	0	0	0	0.5	1.3	2.8	3	3.8	4.2	3.3	2.2
2174	OSU	1997	0	0	0	0	0	0	0	1.1	3	3.1	3.1	2.8	3	1.2
Trego	KSU	1998	0	0	0	0	0	0	0	0	0	0	1.8	3.5	2.9	0.4
2145	KSU	2001	0	0	0	0	0	0	0	0	0	0	0	1.5	2.2	0.8
Overley	KSU	2003	0	0	0	0	0	0	0	0	0	0	0	0	2.2	15.3
TAM111	TAMU	2003	0	0	0	0	0	0	0	0	0	0	0	0	0.2	2.2
Private Varieties																
Abilene	AgriPro	1987	2.2	1.1	0.6	0.5	0.4	0	0.4	0	0	0	0	0	0	0
Tomahawk	AgriPro	1990	1.5	6.2	7	4.7	3.1	1.8	1.2	0.8	0.4	0.3	0.2	0.2	0	0
Victory	AgriPro	1995	8.1	3.9	2.2	1.1	0.7	0.6	0.3	0	0	0	0	0	0	0
Thunderbird	AgriPro	1995	5.5	3.4	2.6	1.5	1	0.5	0.2	0	0	0	0	0	0	0
7853	Agseco	1995	1.4	2.1	3.7	4.6	4	3.4	1.9	1.5	0.9	0.4	0	0	0	0
Dominator	Polansky	1996	0	0	0	0	0	0.2	0.8	1.4	1.5	2	2.2	1.5	1.1	0.8
T81	Trio	1997	0	0	0	0	0	0	0	0.2	0.2	0.8	0.6	1.8	1.6	2.6
Thunderbolt	AgriPro	1999	0	0	0	0	0	0	0	0	0.2	0.6	0.8	1.4	1.7	1.1
Jagalene	AgriPro	2001	0	0	0	0	0	0	0	0	0	0	0	3	21.2	27.2
Cutter	AgriPro	2001	0	0	0	0	0	0	0	0	0	0	0	0.7	1.7	1.6

Source: Kansas Department of Agriculture. Division of Statistics. Wheat Variety, various years. TAMU, Texas A&M University.

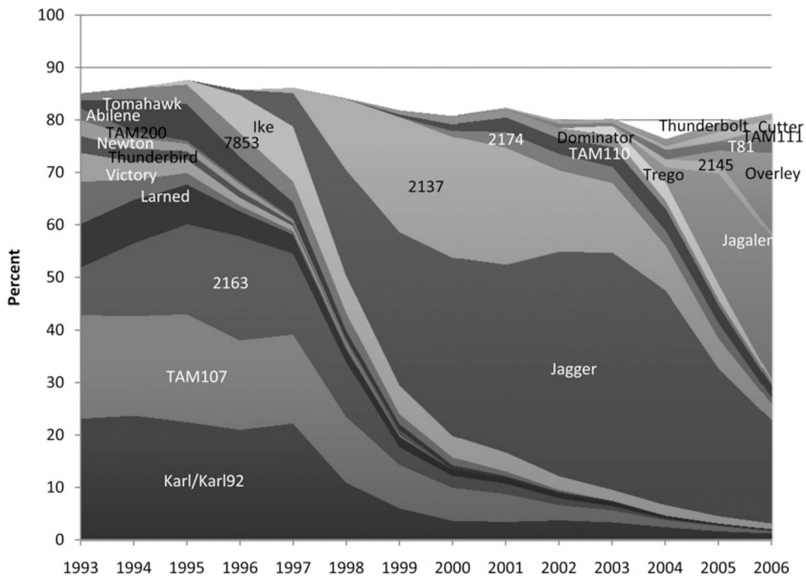

Figure 1. All Kansas Wheat Varieties Planted Acres, 1993–2006

each variety across all location-years, and are reported in Table 2. The varieties Karl/Karl92 and TAM107 dominated the early years of this time period, with 23% and 19.8% planted acres in 1993, respectively. Karl92 is characterized by high yields, but is susceptible to low-pH soils and leaf rust (Watson, 2006). Both Karl92 and TAM107 became less prevalent over time, as varieties 2137 and Jagger were extensively planted during 1995–2005.

Variety 2137, developed by Kansas State University (KSU), has very good grain yield potential (Watson, 2006), and averaged 57.91 bushels per acre over the time period investigated here (Table 2). The variety 2137 was also consistent relative to other varieties, with a standard deviation of 17.63 $(\text{bu/acre})^2$ during 1993–2006. Jagger, also a KSU variety, is characterized by fast establishment in the fall, making it a popular choice among producers (Watson, 2006), as evidenced in Table 1 and Figure 1.

Jagalene, produced by AgriPro, was quickly adopted, moving from zero acres planted in 2003–27.2% of all Kansas acres in 2006 (Table 1, Figure 1). Jagalene is best adapted to growing conditions and climate in Western Kansas, and has high yields (Watson, 2006). Overley, was also widely adopted after release, and comprised 15.3% of Kansas wheat acres planted in 2006. Overley can be hurt by scab, freeze injury, and leaf rust (Watson, 2006). Figure 2 demonstrates the percent planted acres of Kansas wheat varieties for the major varieties included in this study. The varieties were selected based on complete data and availability in 2006, as is evidenced by the increased planting of these varieties over the period 1993–2006.

Portfolio theory asserts that Kansas wheat producers may be able to increase yield and reduce yield variability by combining varieties that differ in how they interact with the environment. Mathematically, these varietal differences are captured in the means and covariances reported in Appendix Table A1. Intuitively, the covariances differ due to differences in the genotype-environment interaction. These interactions are characterized by the selected trait characteristics reported in Table 3. Varieties react differently to drought, weather, rainfall, and other environmental conditions to create differences in covariances across varieties that provide gain from portfolios, or variety combinations.

Results

We used complete data on wheat variety yield means, variances, and covariances (reported in Appendix Table A1) to derive efficient portfolios. Covariance was calculated in a pairwise

Table 2. Portfolio Analysis of Kansas Wheat Varieties, 1993–2006[a]

Individual Varieties

Variety Name	Mean	Standard Deviation	Coefficient of Variation
2137	57.91	17.63	3.29
2174	53.91	18.21	2.96
Cutter	54.06	20.48	2.64
Ike	53.13	20.06	2.65
Jagalene	60.03	21.96	2.73
Jagger	56.62	18.99	2.98
Karl92	52.83	18.69	2.83
Overley	59.20	21.00	2.82
T81	58.27	20.43	2.85
TAM110	58.28	20.17	2.89
TAM111	62.94	22.56	2.79
Thunderbolt	52.41	19.50	2.69

Portfolio Efficiency Frontier

Mean	Standard Deviation	Coefficient of Variation	Description of Portfolio
57.91	17.63	3.29	100% 2137
59.03	18.03	3.27	74% 2137, 3% Jagger, 23% TAM111
59.96	18.71	3.20	60% 2137,40% TAM111
60.62	19.36	3.13	46% 2137,54% TAM111
61.17	20.00	3.06	50% 2137,50% TAM111
61.64	20.62	2.99	26% 2137,74% TAM111
62.07	21.21	2.93	17% 2137,83% TAM111
62.46	21.79	2.87	10% 2137,90% TAM111
62.82	22.36	2.81	2.5% 2137,97.5% TAM111
62.94	22.56	2.79	100% TAM111
2006 Actual Portfolio of Planted Varieties in Kansas[b]			
58.38	20.10	2.90	(from Table 1)

Note: Opportunity Cost of Planting Actual instead of Efficiency Frontier = 2.87 bu/acre

[a] Data and blend definitions are from Kansas State University, *Kansas Performance Tests with Winter Wheat.*

[b] The "actual portfolio" defined here is the proportion of each of the 12 varieties listed above in the total acreage planted of these 12 varieties, to equal 100%. Varieties that are not included have a small percentage of planted acres.

fashion, resulting in potential bias. To trace out the efficient frontier of portfolios, the level of φ, the target average yield, is varied when solving the quadratic programming problem that minimizes the variance of a portfolio of wheat variety yields. The efficiency frontiers are reported for Kansas (Table 2, Figure 3).

Kansas Portfolio Results

For the 1993–2006 period, the maximum yielding variety in Kansas was TAM111, at 62.94 bu/acre (Table 2, Figure 3). This high yield forms the highest point on the efficiency frontier, with a standard deviation equal to 22.56. Additional efficient portfolios are found at lower yield levels, demonstrating the tradeoff between expected returns (average yield) and risk (yield stability). This tradeoff is identified on the efficiency frontier, or the line connecting the efficient mean/standard deviation pairs, which are the optimal portfolios derived from the quadratic programming model. The efficiency frontier in Figure 1 demonstrates how variety

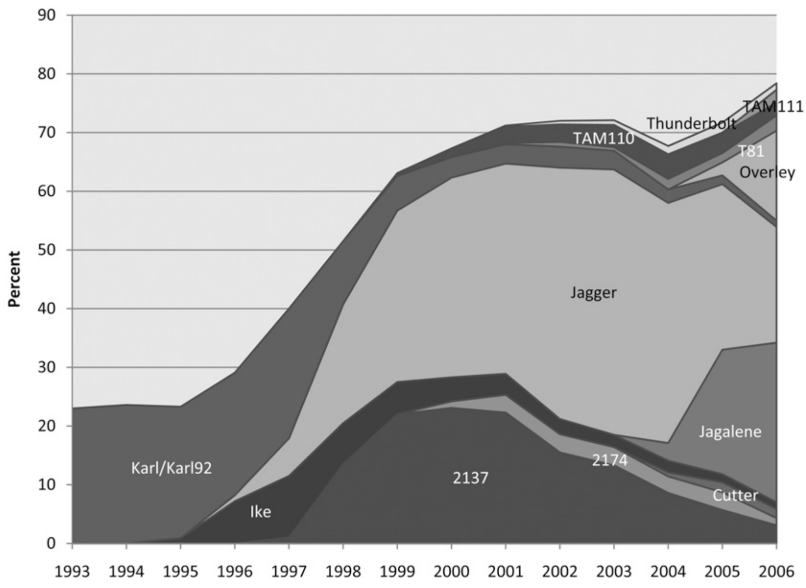

Figure 2. Kansas Wheat Varieties Included in Portfolio Study, Planted Acres, 1993–2006

yield risk can be reduced by planting a portfolio of varieties; portfolios located on the efficiency frontier are characterized by: (1) higher yields, (2) lower yield variance, or (3) both.

An example of a portfolio on the efficiency frontier is presented in Table 2 and Figure 3: a combination of 40% TAM111 and 60% 2137 would result in an average yield of 59.96 bu/acre, and a standard deviation equal to 18.71. The Coefficient of Variation of this portfolio is equal to 3.20, lower than higher-yielding portfolios. For producers interested in reducing risk, portfolios of multiple wheat varieties are capable of greatly reducing yield risk, due to the relationship between variety yields. Watson (2006) provided a detailed account of varietal characteristics (Table 3). Intuitively, since some varieties perform better in certain growing conditions (e.g., rainfall, subsoil moisture, soil type and quality, presence of disease, etc.), Kansas wheat producers can gain yield stability by planting a combination of varieties, as shown in Figure 3.

Economic Impact of Variety Portfolio Adoption in Kansas

To measure the potential economic consequences of moving from the currently-planted varieties to the efficiency frontier, a portfolio was developed using the actual percentage of each variety planted in Kansas in the 2006 crop year for the major varieties included here (Kansas Department of Agriculture, *Wheat Variety*). The average yield and standard deviation appear as the point labeled "*2006 ACTUAL*" in Figure 3, also found in Table 2. To investigate the opportunity cost of yield given up by being below the efficiency frontier, the quadratic programming problem was solved by maximizing yield, given a target level of variability. The standard deviation of the actual planted variety portfolio was used (= 20.10). This measures the vertical distance between the "*2006 ACTUAL*" portfolio and the efficiency frontier, or the potential increase in yield from moving from the actual portfolio planted in 2006 to the efficiency frontier. In Kansas, the opportunity cost of the actual portfolio in 2006 was equal to 2.87 bu/acre (Table 2). At the 2006 market price of wheat reported in Kansas Department of Agriculture *Kansas Agricultural Statistics*, ($4.60) the movement to the efficiency frontier represented a potential gain of over $120 million 2006 dollars (2.87 bu/acre*9.1 mil planted acres*$4.60/bu), or a potential 15.7% increase in total revenues from wheat production in Kansas.

Table 3. Selected Trait Comparisons of Kansas Wheat Varieties Included in Portfolios

	Yield Potential[a]	Drought Tolerance[b]	Maturity[c]
Kansas			
2137	Very Good	Below Average	Medium
Jagger	Very Good	Good	Early
TAM111	Excellent	Good	Medium
Western Kansas			
2137	Very Good	Below Average	Medium
TAM110	Good	Very Good	Early
Thunderbolt	Average	Very Good	Late
TAM111	Excellent	Good	Medium
Jagger	Very Good	Good	Early
Central Kansas			
2137	Very Good	Below Average	Medium
2174	Average	Below Average	Medium
Jagger	Very Good	Good	Early
Karl92	Good	Below Average	Early
Overley	Excellent	Average	Early
Eastern Kansas			
2137	Very Good	Below Average	Medium
Cutter	Excellent	Average	Medium
Karl92	Good	Below Average	Early
Overley	Excellent	Average	Early

[a] Relative top-end yield potential, under good growing conditions (Watson, 2006, p. 80).
[b] Ability to yield under prolonged hot, dry periods in the spring (Watson, 2206, p. 84).
[c] Heading data (Watson, 2006, p. 87).

At the individual farm level, the movement from a single variety to a variety portfolio will increase production costs. At the state level, the movement from the current allocation of varieties planted to the efficiency frontier would also require additional expenditures on certified wheat seed. It is straightforward to demonstrate that the economic gains from the adoption of an efficient wheat variety portfolio outweigh the costs. Boland, Dhuyvetter, and Howe (2001) found that for the period 1992–1999, "an increase in yield of two bushels has a positive return when the price of wheat is $2.50/bu or higher per bushel" (p. 5). Kansas wheat industry experts report that a typical certified seed pricing decision for newer varieties is to price the seed at approximately 225% of the prevailing market wheat price (Ehmke, 2009; Strouts, 2009). This pricing rule is confirmed in the data used by Boland, Dhuyvetter, and Howe (2001), where the certified seed price markup averaged 227% for 10 winter wheat producing states during the period 1992–1999. During 2006, the average wheat price was $4.60/bu. Using the certified seed rate, the average cost of certified seed would be $10.35/bu. We will compare the cost of certified seed with the costs of farmer-saved seed. The cost of certified seed is overstated, due to omission of costs such as storage, interest, cleaning, treatment, labor, and cleanout costs (Boland, Dhuyvetter, and Howe, 2001).

The difference in costs is $5.75/bu ($10.35/bu–$4.60/bu). A typical seeding rate in Kansas is 60 pounds per acre, or one bushel per acre. Therefore, the cost associated with purchasing certified seed in 2006 is approximately $5.75/acre. At the 2006 price of wheat of $4.60/bu, the "break-even" point of buying certified seed was equal to 1.25 bu/acre (5.75/4.60), since any yield increase greater than 1.25 bu/acre would result in net revenue increases. This condition for breaking even is exceeded by the movement from the current variety portfolio to the efficiency frontier. Thus, the additional cost of purchasing new seed to develop a portfolio is

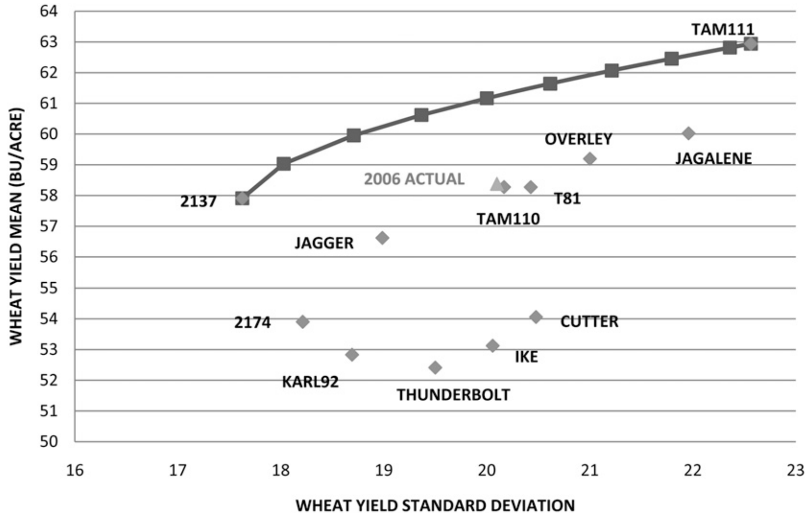

Figure 3. Kansas Wheat Efficiency Frontier, 2006

a sound investment for producers who could increase average yields by 1.25 bu/acre.

Regional Portfolio Results

Kansas was subdivided into three regions based on similar growing conditions, using the Crop Reporting District definitions (Kansas Department of Agriculture, *Kansas Agricultural Statistics*). Results for Western Kansas appear in Table 4. The highest-yielding variety in the Western Kansas region experiment trials during the period 1993–2006 was Jagger, with a mean yield of 55.37, and a standard deviation equal to 22.18 (Table 4). As such, Jagger forms the highest-yielding point of the Western Kansas efficiency frontier. Risk could be reduced by adoption of multiple varieties, and the lowest-risk combination of varieties includes 2137, TAM110, and Thunderbolt (Table 4). This portfolio results in lower risk, with a standard deviation equal to 18.34, and lower yields, equal to 52.10. Thus, there is a tradeoff between higher yield and reduced risk in Western Kansas wheat production. Table 4 provides wheat producers in Western Kansas with greater information about reducing risk than the information currently available in the performance test publications.

Only a subset of varieties currently planted in Western Kansas result in efficient outcomes: many older varieties (e.g., Karl92, Ike) are inferior in providing efficient planting decisions. In fact, a comparison of the actual region-wide portfolio of varieties currently planted with the efficient frontier in Table 4 shows the possibility of a gain of 3.89 bu/acre by moving from currently-planted varieties to the efficient frontier. The yield gains are more than enough to offset the additional costs of certified seed, as discussed above.

The Central Kansas results appear in Table 5. In Central Kansas, the variety Overley provided the highest yields in experimental variety trials during the period 1993–2006, with a yield of 67.02 bu/acre, and a standard deviation equal to 22.60. Production risk in Central Kansas can be reduced from a standard deviation of 22.6 to a minimum of 16.77 by combining the risk-reducing combination of varieties, which include 2137, 2174, Jagger, and Karl92. This combination is not intuitively obvious from the data on mean yields and standard deviations in Table 5. Instead, it is due to the relationship, or covariance, between varieties. These relationships form the foundation of this research, and the economic benefits in wheat yield gains, and reductions in risk that are available to wheat producers who adopt a portfolio approach to variety selection. Table 5 reports the potential gain from moving from the actual varieties planted in Central Kansas in 2006 to the efficiency frontier: 3.11 bu/acre.

Table 4. Portfolio Analysis of Western Kansas Wheat Varieties, 1993–2006[a]

Individual Varieties

Variety Name	Mean	Standard Deviation	Coefficient of Variation
2137	52.50	18.78	2.79
2174	48.53	20.86	2.33
Cutter	46.47	22.12	2.10
Ike	52.09	18.77	2.77
Jagalene	50.06	22.86	2.19
Jagger	55.37	22.18	2.50
Karl92	49.70	21.43	2.32
Overley	46.22	22.73	2.03
T81	51.52	20.52	2.51
TAM110	53.66	19.94	2.69
TAM111	53.57	22.49	2.38
Thunderbolt	50.18	19.84	2.53

Portfolio Efficiency Frontier

Mean	Standard Deviation	Coefficient of Variation	Description of Portfolio
52.10	18.34	2.84	48% 2137, 23% TAM110, 29% Thunderbolt
53.15	18.71	2.84	42% 2137, 44% TAM110, 13% TAM111
54.14	20.00	2.71	15% 2137, 38% Jagger, 41% TAM110, 6% TAM111
54.90	21.21	2.59	73% Jagger, 27% TAM110
55.37	22.18	2.50	100% Jagger
2006 Actual Portfolio of Planted Varieties in Western Kansas[b]			
50.89	21.01	2.42	(from Table 1)

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 3.89 bu/acre

[a] Data and blend definitions are from Kansas State University, *Kansas Performance Tests with Winter Wheat.*

[b] The "actual portfolio" defined here is the proportion of each of the 12 varieties listed above in the total acreage planted of these 12 varieties, to equal 100%. Varieties that are not included have a small percentage of planted acres.

Eastern Kansas results are shown in Table 5. The results demonstrate how combining varieties into portfolios can result in major reductions in production risk by planting variety combinations with inverse covariances: The standard deviations can be reduced from 12.91 to 11.99 through the portfolio approach. The potential gain in Eastern Kansas from moving from the actual varieties planted to the efficiency frontier is equal to 2.31 bu/acre (Table 6).

Implications and Conclusions

Variety portfolios can enhance profits and lower yield risk for wheat producers in Kansas by taking advantage of differences in how wheat varieties perform under different growing conditions. There are three ways to take advantage of differing varietal traits to enhance yield stability: (1) traditional wheat breeding and advanced biotechnology breeding techniques; (2) blends of varieties, and (3) variety portfolios. Traditional wheat breeding has led to a long history of successful yield improvement in the Kansas wheat industry (Nalley et al., 2008). The results of this initial application of financial portfolio theory to wheat variety selection provide implications for all three of these risk-reducing strategies. Breeders could benefit by careful examination of the quantitative

Table 5. Portfolio Analysis of Kansas Central Wheat Varieties, 1993–2006[a]

Individual Varieties

Variety Name	Mean	Standard Deviation	Coefficient of Variation
2137	61.57	17.50	3.52
2174	57.14	17.48	3.27
Cutter	59.93	21.81	2.75
Ike	53.75	21.21	2.53
Jagalene	63.07	24.12	2.61
Jagger	57.51	19.36	2.97
Karl92	53.71	18.88	2.84
Overley	67.02	22.60	2.97

Portfolio Efficiency Frontier

Mean	Standard Deviation	Coefficient of Variation	Description of Portfolio
58.38	16.77	3.48	42% 2137, 12% 2174, 24% Jagger, 21% Karl92
61.45	17.32	3.55	81% 2137, 12% Jagger, 7% Overley
63.70	18.71	3.41	61% 2137, 39% Overley
65.01	20.00	3.25	37% 2137, 63% Overley
66.01	21.21	3.11	18% 2137, 82% Overley
66.85	22.36	2.99	3% 2137, 97% Overley
67.02	22.60	2.97	100% Overley
2006 Actual Portfolio of Planted Varieties in Central Kansas[b]			
62.23	20.38	3.05	(from Table 1)

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 3.11 bu/acre

[a] Data and blend definitions are from Kansas State University, *Kansas Performance Tests with Winter Wheat.*

[b] The "actual portfolio" defined here is the proportion of each of the eight varieties listed above in the total acreage planted of these eight varieties, to equal 100%. Varieties that are not included have a small percentage of planted acres.

relationship between varieties. Specifically, there are large potential gains from combining varieties that are characterized by ***inverse*** yield responses to growing conditions such as drought or the presence of a disease. Careful measurement and analysis of the yield variance and covariance between varieties could lead to major increases in yield stability through both traditional breeding techniques, and biotechnology.

Variety blends have been shown to outperform single varieties in many situations. The results of this analysis suggest that greater attention could be placed on the development, testing, and dissemination of blends. As in breeding programs, superior blends could be developed by careful study of not just average yields, but also the covariance between variety yields. Although seed developers may fear losing market share to blends, since blends use only a fraction (typically one third) of a single variety instead of complete reliance on one variety, there is also an opportunity to increase the use of a variety through blends. The identification and adoption of variety blends will result in an increase in the use of the varieties with the best yield performance, both individually and within a portfolio. To the extent that a new variety demonstrates good portfolio performance, more acres will be planted to blends that include the variety, and more seed will be sold.

Perhaps most importantly, the results of this study indicate that a carefully-selected portfolio of wheat varieties is a major risk-reducing strategy for Kansas wheat producers. Currently, many producers plant several varieties in rotation, as a way of diversification and adoption of new varieties over time. This is a good strategy, but could be greatly enhanced with the careful use of portfolio theory. The major implication of this research is that data

Table 6. Portfolio Analysis of Eastern Kansas Wheat Varieties, 1993–2006[a]

Individual Varieties

Variety Name	Mean	Standard Deviation	Coefficient of Variation
2137	56.81	15.58	3.65
2174	51.80	15.14	3.42
Cutter	54.02	14.03	3.85
Jagalene	58.52	14.61	4.01
Jagger	52.51	15.46	3.40
Karl92	51.00	14.60	3.49
Overley	58.65	12.91	4.54

Portfolio Efficiency Frontier

Mean	Standard Deviation	Coefficient of Variation	Description of Portfolio
54.83	11.99	4.57	22% 2137, 39% Cutter, 21% Karl92, 18% Overley
55.00	11.99	4.59	22% 2137, 39% Cutter, 19% Karl92, 20% Overley
56.00	12.03	4.65	21% 2137, 34% Cutter, 9% Karl92,36% Overley
57.00	12.12	4.70	21% 2137, 27% Cutter, 52% Overley
58.00	12.45	4.66	15% 2137, 8% Cutter, 77% Overley
58.65	12.91	4.54	100% Overley
2006 Actual Portfolio of Planted Varieties in Eastern Kansas[b]			
56.33	12.91	4.36	(from Table 1)

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 2.31 bu/acre

[a] Data and blend definitions are from Kansas State University, *Kansas Performance Tests with Winter Wheat.*

[b] The "actual portfolio" defined here is the proportion of each of the seven varieties listed above in the total acreage planted of these seven varieties, to equal 100%. Varieties that are not included have a small percentage of planted acres.

and statistical tools are available to improve the choice of wheat varieties to plant each year. Efficient variety portfolios, if adopted, would enhance wheat yields in Kansas, and the economic gains have been shown to be large. A first step toward improved variety selection would be to collect, measure, and report data on varietal ***yield variability*** and ***covariance*** with other varieties. Performance test data could be supplemented with these statistics, and extension education programs could develop "user-friendly" computer tools that could use location-specific data to derive optimal portfolios, leading to enhanced producer profits in the future.

[Received June 2009; Accepted September 2009.]

References

Barkley, A.P., and L.L. Porter. "The Determinants of Wheat Variety Selection in Kansas, 1974–1993." *American Journal of Agricultural Economics* 78(1996):202–11.

Barry, P.J. "Capital Asset Pricing and Farm Real Estate." *American Journal of Agricultural Economics* 62(1980):549–53.

Blank, S.C. "Globalization, Cropping Choices, and Profitability in American Agriculture." *Journal of Agricultural and Applied Economics* 33(2001):315–26.

Boland, M., K.C. Dhuyvetter, and M. Howe. "Economic Issues with Certified and Farmer-Saved Wheat Seed." Agricultural Industry Competitiveness MF-2498. Manhattan, KS: Kansas State University Agricultural Experiment Station and Cooperative Extension Service, July 2001.

Bowden, R., J. Shroyer, K. Roozeboom, M. Claassen, P. Evans, B. Gordon, B. Heer, K. Janssen, J. Long, J. Martin, A Schlegel, R. Sears, and M. Witt. "Performance of Wheat Variety Blends in Kansas." Keeping Up with Research No. 128. Manhattan, KS: Kansas State University Agricultural Experiment Station and Cooperative Extension Service, March 2001.

Carlton, D.W. "Contracts, Price Rigidity, and Market Equilibrium." *The Journal of Political Economy* 87(1979):1034–62.

Collins, R.A., and P.J. Barry. "Risk Analysis with Single-Index Portfolio Models: An Application to Farm Planning." *American Journal of Agricultural Economics* 68(1986):152–61.

Cox, C.M., K.A. Garrett, R.L. Bowden, A.K. Fritz, S.P. Dendy, and W.F. Heer. "Cultivar Mixtures for the Simultaneous Management of Multiple Diseases: Tan Spot and Leaf Rust of Wheat." *Phytopathology* 94(2004):961–69.

Dahl, B.L., W.W. Wilson, and D.D. Johnson. "Valuing New Varieties: Trade-Offs between Growers and End-Users in Wheat." *Review of Agricultural Economics* 26(2004):82–96.

Detlefsen, N.K., and A.L. Jensen. "A Stochastic Model for Crop Variety Selection." *Agricultural Systems* 81(2004):55–72.

Di Falco, S., and J.P. Chavas. "Rainfall Shocks, Resilience, and the Effects of Crop Biodiversity on Agroecosystem Productivity." *Land Economics* 84(2008):83–96.

———. "Crop Genetic Diversity, Farm Productivity and the Management of Environmental Risk in Rainfed Agriculture." *European Review of Agricultural Economics* 33(2006): 289–314.

Ehmke, V. Personal communication. Ehmke Seed, Healy, KS. August 2009.

Elton, E.J., M.J. Gruber, S.J. Brown, and W.N. Goetzmann. *Modern Portfolio Theory and Investment Analysis*. 6th Ed. New York: John Wiley and Sons, 2003.

Figge, F. "Bio-folio: Applying Portfolio Theory to Biodiversity." *Biodiversity and Conservation* 13(2004):822–49.

Frontline Systems, Inc. Solver.com. Internet site: http://www.solver.com (Accessed September 16, 2009).

Garrett, K.A., and C.M. Cox. "Applied Biodiversity Science: Managing Emerging Diseases in Agriculture and Linked Natural Systems Using Ecological Principles." *Infectious Disease Ecology: The Effects of Ecosystems on Disease and of Disease on Ecosystems*. R. Ostfeld, F. Keesing, and V. Eviner, eds. Princeton, NJ: Princeton University Press, 2008.

Garrett, K.A., R.J. Nelson, C.C. Mundt, G. Chacon, R.E. Jaramillo, and G.A. Forbes. "The Effects of Host Diversity and Other Management Components on Epidemics of Potato Late Blight in the Humid Highland Tropics." *Phytopathology* 91(2001):993–1000.

Garrett, K.A., and C.C. Mundt. "Epidemiology in Mixed Host Populations." *Phytopathology* 89(1999):984–90.

Griliches, Z. "Hybrid Corn: An Exploration in the Economics of Technical Change." *Econometrica* 25(1957):50–122.

Hazell, P.B.R., and R.D. Norton. *Mathematical Programming for Economic Analysis in Agriculture*. New York: MacMillan Publishing Company, 1986.

Heisey, P.W., and J.P. Brennan. "An Analytical Model of Farmers' Demand for Replacement Seed." *American Journal of Agricultural Economics* 73(1991):1044–52.

Kansas Department of Agriculture. Division of Statistics. *Wheat Variety*. Various years. Topeka, KS.

Kansas Department of Agriculture. *Kansas Agricultural Statistics*. Various years. Topeka, KS. Internet site: http://www.ksda.gov/statistics/ (Accessed September 16, 2009).

Kansas State University. Kansas Agricultural Experiment Station and Cooperative Extension Service. *Kansas Performance Tests with Winter Wheat Varieties*. Various years. Manhattan, KS.

Ladd, G.W., and M.B. Martin. "Prices and Demands for Input Characteristics." *American Journal of Agricultural Economics* 58(1976):21–30.

Lintner, J. "Security Prices, Risk, and Maximum Gains from Diversification." *The Journal of Finance* 21(1965):587–615.

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

McKenzie, A.M., and E.L. Kunda. "Managing Price Risk in Volatile Grain Markets, Issues and Potential Solutions." *Journal of Agricultural and Applied Economics* 41(2009):353–62.

Melton, B.E., W.A. Colette, and R.L. Willham. "Imputing Input Characteristic Values from Optimal Commercial Breed or Variety Choice Decisions." *American Journal of Agricultural Economics* 76(1994):478–91.

Mundt, C.C. "Use of Multiline Cultivars and Cultivar Mixtures for Disease Management." *Annual Review of Phytopathology* 40(2002): 381–410.

Nalley, L.L., A. Barkley, and F.G. Chumley. "The Impact of the Kansas Wheat Breeding Program on Wheat Yields, 1911–2006." *Journal of Agricultural and Applied Economics* 40(2008): 913–25.

Nyikal, R.A., and W.O. Kosura. "Risk Preference and Optimal Enterprise Combinations in Kahuro Division of Murang'a District, Kenya." *Agricultural Economics* 32(2005):131–40.

Porter, L.L. and A.P. Barkley. "Selection of Wheat Varieties in Kansas: Does Quality Matter?" Report of Progress 730. Kansas State University Agricultural Experiment Station and Cooperative Extension Service, April 1995.

Purcell, D.L., S.C. Turner, J. Houston, and C. Hall. "A Portfolio Approach to Landscape Plant Production and Marketing." *Journal of Agricultural and Applied Economics* 25(1993):13–26.

Redmond, C.H., and F.W. Cubbage. "Portfolio Risk and Returns from Timber Asset Investments." *Land Economics* 64(1988):325–37.

Robison, L.J., and J.R. Brake. "Application of Portfolio Theory to Farmer and Lender Behavior." *American Journal of Agricultural Economics* 61(1979):158–64.

Sanchirico, J.N., M.D. Smith, and D.W. Lipton. "Ecosystem Portfolios: A Finance-Based Approach to Ecosystem Management." Paper presented at the AERE Workshop 2005: Natural Resources at Risk, Jackson, WY, June 2005.

Schurle, B. "The Impact of Size on Yield Variability and Crop Insurance Premiums." *Review of Agricultural Economics* 18(1996):415–22.

Sharpe, W. *Portfolio Theory and Capital Markets*. New York: McGraw-Hill, 1970.

Smale, M., R.E. Just, and H.D. Leathers. "Land Allocation in HYV Adoption Models: An Investigation of Alternative Explanations." *American Journal of Agricultural Economics* 76(1994):535–46.

Strouts, D. Personal communication. Executive Director, Kansas Crop Improvement Association. Manhattan, KS. August 2009.

Tobin, J. "Liquidity Preference as Behavior towards Risk." *The Review of Economic Studies* 25(1958):65–86.

Traxler, G., J. Falck-Zepeda, J.I. Ortz-Monasterio, and K. Sayre. "Production Risk and the Evolution of Varietal Technology." *American Journal of Agricultural Economics* 77(1995): 1–7.

Turvey, C.G., H.C. Driver, and T.G. Baker. "Systematic and Nonsystematic Risk in Farm Portfolio Selection." *American Journal of Agricultural Economics* 80(1988):831–36.

Watson, S. *Wheat Varieties for Kansas and the Great Plains: Your Best Choices for 2007*. Topeka, KS: Lone Tree Publishing Co., 2006.

Winston, W.L. *Microsoft Excel Data Analysis and Business Modeling*. Redmond, WA: Microsoft Press, 2004.

Appendix

Table A1. Summary Statistics of Wheat Variety Yield Data in Kansas, 1993–2006[a]

Variety	2137	2174	Cutter	Ike	Jagalene	Jagger	Karl92	Overley	T81	TAM110	TAM111	T'bolt
Mean	57.91	53.91	54.06	53.13	60.03	56.62	52.83	59.20	58.27	58.28	62.94	52.41
Variance	310.67	331.69	419.32	402.28	482.20	360.48	349.37	441.03	417.24	406.70	509.13	380.23
Variance/Covariance												
2137	310.67	279.46	340.95	334.92	349.78	262.91	256.33	314.60	317.23	332.70	324.16	317.50
2174	279.46	331.69	367.36	381.96	403.89	298.67	316.40	374.42	390.06	396.59	438.10	363.72
Cutter	340.95	367.36	419.32	595.30	442.93	389.87	374.62	407.71	388.48	297.76	424.35	431.56
Ike	334.92	381.96	595.30	402.28	588.39	364.37	400.96	571.65	352.18	370.52	397.01	391.42
Jagalene	349.78	403.89	442.93	588.39	482.20	426.79	411.59	382.63	435.63	434.89	428.09	365.69
Jagger	262.91	298.67	389.87	364.37	426.79	360.48	287.51	346.71	397.64	390.19	398.96	395.18
Karl92	256.33	316.40	374.62	400.96	411.59	287.51	349.37	368.31	397.34	399.81	456.73	407.49
Overley	314.60	374.42	407.71	571.65	382.63	346.71	368.31	441.03	433.82	407.97	463.60	510.47
T81	317.23	390.06	388.48	352.18	435.63	397.64	397.34	433.82	417.24	371.72	477.97	321.34
TAM110	332.70	396.59	297.76	370.52	434.89	390.19	399.81	407.97	371.72	406.70	383.01	293.18
TAM111	324.16	438.10	424.35	397.01	428.09	398.96	456.73	463.60	477.97	383.01	509.13	356.09
Thunderbolt	317.50	363.72	431.56	391.42	365.69	395.18	407.49	510.47	321.34	293.18	356.09	380.23

[a] Data and blend definitions are from Kansas State University, *Kansas Performance Tests with Winter Wheat*.