Wheat Variety Selection: An Application of Portfolio Theory to Improve Returns

by

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Wheat Variety Selection:
An Application of Portfolio Theory to Improve Returns

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Wheat Variety Selection:
An Application of Portfolio Theory to Improve Returns

This presentation will report results of research that shows that a **portfolio** *of wheat varieties can enhance profitability and reduce risk over the selection of a single variety. Many Kansas wheat farmers select varieties based on average yield. This study uses portfolio theory from business investment analysis to find the optimal, profit-maximizing and risk-minimizing combination of wheat varieties in Kansas.*

Keywords: wheat variety selection, portfolio theory.

Introduction

"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 comparing variety yields from wheat variety yield performance tests conducted and published by the Kansas Agricultural Experiment Station (KAES), and test results from private seed companies, such as Agripro or Westbred.

Publications such as *Kansas Performance Tests with Winter Wheat Varieties.* (KAES, annual), and *Wheat Varieties for Kansas and the Great Plains: Your Best Choices for 2007* (Watson, 2006) provide unbiased yield results for each wheat variety, and are outstanding sources of information to determine the optimal wheat variety to plant. Each wheat variety is characterized by average yield, together with several 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 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. However, these variety combinations are typically selected based on variety descriptions, intuition, and average yields, rather than on data and statistical information that could enhance yields and minimize risk.

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 percent in 2004. In 2006, ten percent of seeded acreage in Kansas was planted to blends (*Wheat Variety*).

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 enhanced. 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 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 (a) input fixity, (b) portfolio selection, (c) safety-first behavior, and (d) 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). Garrent and Cox (2008) discuss how crop diversity can be manipulated to manage disease, with an emphasis on plant-based agricultural systems (p. 5), 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.). Garrett and Cox state, "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" (p. 9). Wheat mixtures are also commonly grown in the Pacific Northwest (Mundt 2002). Cox et al. (2004) provide 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 Markowitz (1959) and Tobin (1958), 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 mimimize 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 et al. (1985) compared a full variance-covariance (Markowitz) 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 (CAPM), and applied the model to farm real estate. More recently, Nyikal and Kosura (2005) used quadratic programming (QP) 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 (CAPM) to timber asset investments in the United States. Figge (2002) summarized the literature on how portfolio theory has been applied to biodiversity, and Sanchirico et al. (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, as detailed in the next section.

Model

The model used to estimate the efficiency frontier for wheat varieties in Kansas is the model developed by Markowitz 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, …, n, and $\Sigma_i x_i = X$. Quadratic programming is used to solve for the efficiency frontier of mean-variance (MV) 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 (1),

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

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) emphasize the intuition embedded in equation (1): 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 returns 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 (2).

(2) $\min V = \Sigma_j \Sigma_k x_j x_k \sigma_{jk}$, subject to:

(3) $\Sigma_j x_j y_j = \lambda$ and

(4) $x_j \geq 0$ for all j

The sum of the mean variety yields in equation (3) is set equal to the parameter λ, 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 (2) is quadratic in x_j, resulting in the use of the Excel Solver program to solve the nonlinear equation. The Microsoft Excel Solver tool 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.). The next section will describe the data utilized in the portfolio model.

Data

Data on wheat yields for all varieties planted in Kansas were collected from the publication, *Kansas Performance Tests with Winter Wheat Varieties* for the period 1993-2006. The initial year of 1993 was selected based on observations of varieties that are currently planted. Mean yields, standard deviation, and the coefficient of variation (equal to standard deviation divided by the mean yield) were calculated for each variety across all location-years, and are reported in table 1.

Results

We use 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 fashion, resulting in potential bias. To trace out the efficient frontier of portfolios, the level of λ, 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 1, figure 1).

For the 1993-2006 period, the maximum yielding variety in Kansas was TAM111, at 62.94 bu/acre (table 1, figure 1). 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 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 1: a combination of 60% TAM111 and 40% 2137 would result in an average yield of 59.96 bu/acre, and a standard deviation equal to 18.71. The Coefficient of Variation (CV) 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. 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 1.

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 (*Wheat Variety*). The average yield and standard deviation appear as the point labeled "*2006 ACTUAL*" in figure 1, also found in table 1. 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 "*1996 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 1). At the 2006 market price of wheat reported in *Kansas Agricultural Statistics*, ($4.60) this represented a potential gain of over $210 million 2006 dollars (table 2).

It is straightforward to calculate conditions under which the purchase of certified seed is worth the additional costs. Since movement from the current varieties to an efficient portfolio would require acquisition of certified seeds, this is relevant to the discussion on variety portfolios. Boland et al. (2001) reported that the average cost of certified seed over the 1992-1999 period was equal to $7.85/bu, and the costs of farmer-saved seed, including storage, interest, cleaning, treatment, labor, and cleanout costs were $4.34/bu during the same 8-year time period. The difference in costs is $3.51/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 is approximately $3.51/acre. If the price of wheat is $3/bu, then the "break-even" point of buying certified seed is equal to 1.17bu/acre (3.51/3), since any yield increase greater than 1.17 bu/acre will 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 a sound investment for producers who could increase average yields by 1.17 bu/acre.

Implications and Conclusions

Variety portfolios can enhance profits and lower yield risk for wheat producers in Kansas. The portfolios take advantage of differences in how wheat varieties perform under different growing conditions. Since growing conditions such as rainfall and temperature are not known prior to planting, variety diversification can result in positive economic benefits to Kansas wheat producers. The foundation of portfolio analysis, whether it is applied to financial investments, or wheat variety decisions, or any other decision under risk, is the ***interrelationship***, or ***covariance***, between possible investments. The variability of individual variety yields, and the relationship between variety yields, has major agronomic and economic implications for the Kansas wheat industry.

Since wheat yields are not deterministic, but subject to a distribution of possible outcomes, wheat producers are often interested in reducing yield risk. There are three ways to take advantage of differing varietal traits to enhance yield stability. First, traditional wheat breeding and advanced biotechnology breeding techniques can combine desirable traits of multiple varieties to result in superior varieties. This has led to a long history of successful yield improvement in the Kansas wheat industry (Nalley et al. 2006). Second, blends of varieties take advantage of different genetic responses to environmental conditions. Blends, or mixtures of multiple varieties planted in the same field, have been shown to outperform single varieties in many field trials. Third, variety portfolios can be formulated so that a wheat producer can select a combination of varieties to plant in different fields to enhance yields, reduce yield variability, or both.

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 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 evidence for this success is the increasing number of acres planted to blends in Kansas. 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. The results of this study suggest that it is the interrelationship between varieties, together with the average yield of each individual variety, that will result in the highest-performing blends.

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 and statistical tools are available to improve the choice of wheat varieties to plant each year. Current variety decisions are typically not based on the complete set of information available. Efficient variety portfolios, if adopted, would enhance wheat yields in Kansas, and the economic gains have been shown to be large.

A first step towards 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.

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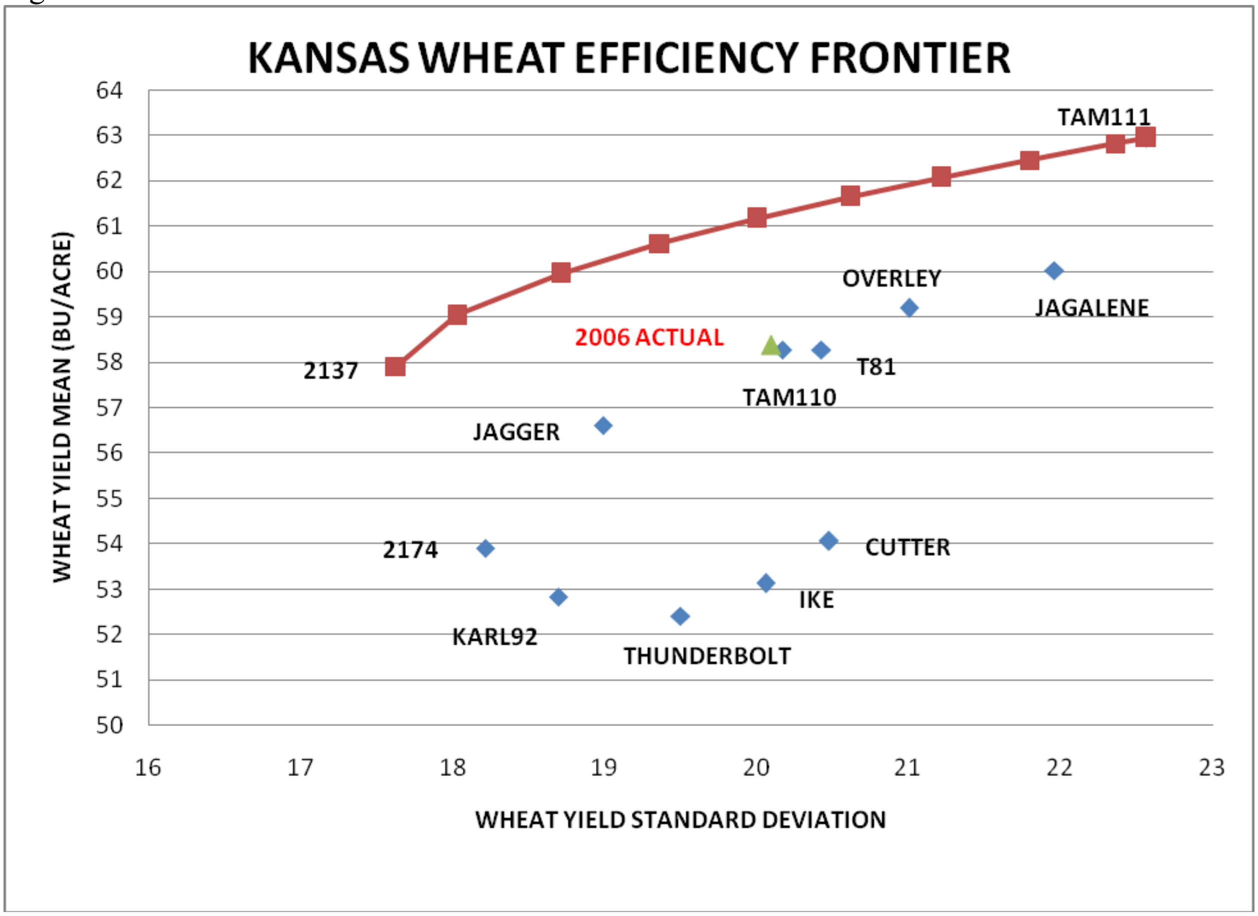
Figure 1.



KANSAS WHEAT EFFICIENCY FRONTIER
WHEAT YIELD MEAN (BU/ACRE)
64
63
62
61
60
59
58
57
56
55
54
53
52
51
50
16
17
18
19
20
21
22
23
WHEAT YIELD STANDARD DEVIATION
TAM111
OVERLEY
JAGALENE
2006 ACTUAL
2137
T81
TAM110
JAGGER
2174
CUTTER
IKE
KARL92
THUNDERBOLT

Table 1. Portfolio Analysis of Kansas Wheat Varieties, 1993-2006.[1]

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	
59.96	18.71	3.20	60% 2137, 40% TAM111
60.62	19.36	3.13	
61.17	20.00	3.06	50% 2137, 50% TAM111
61.64	20.62	2.99	
62.07	21.21	2.93	17% 2137, 83% TAM111
62.46	21.79	2.87	
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

Mean	Standard Deviation	Coefficient of Variation
58.38	20.10	2.90

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

[1]Data and blend definitions are from Kansas Peformance Tests with Winter Wheat.

Table 2. Economic Gains from a Movement to the Efficiency Frontier in 2006.

2006 Acres Harvested in Kansas 9,100,000 acres

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 2.87 bu/acre
Total Potential Gain from movement to Efficiency Frontier = 26,117,000 bu
Total Dollar Gain from Movement to Efficiency Frontier at Market Price[1] = $120,138,200

Total Economic Gain for State of Kansas = $120,138,200
Percent Increase in total revenues from wheat in Kansas = 15.7%

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[1]Market price of wheat in 2006 was $4.60/bu (Kansas Agricultural Statistics).

Table A1. Summary Statistics of Wheat Variety Yield Data in Kansas, 1993-2006.[1]

Variety	2137	2174	Cutter	Ike	Jagal	Jagger	Karl92	Over	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

[1]Data and blend definitions are from *Kansas Performance Tests with Winter Wheat*.