KANSAS WHEAT VARIETY SELECTION: COMBINING ECONOMICS AND AGRONOMY TO MAXIMIZE PROFITS AND MINIMIZE RISK

Andrew Barkley,[1] Robert L. Bowden,[2] and James P. Shroyer[3]

For presentation at the Risk and Profit 2006 Conference, Kansas State University Alumni Center, Manhattan, Kansas, August 17-18, 2006.

[1]Professor, Department of Agricultural Economics, Kansas State University, Manhattan, KS 66506, barkley@ksu.edu
[2]Supervisory Research Plant Pathologist, USDA-ARS, Plant Science and Entomology Research Unit, Manhattan, KS. Adjunct Professor, Department of Plant Pathology, Kansas State University. rbowden@ksu.edu
[3]Professor - Extension Crop Production, Department of Agronomy, Kansas State University, Manhattan, KS 66506, jshroyer@ksu.edu

KANSAS WHEAT VARIETY SELECTION: COMBINING ECONOMICS AND AGRONOMY TO MAXIMIZE PROFITS AND MINIMIZE RISK.

Abstract

This presentation will report results of new 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.

KANSAS WHEAT VARIETY SELECTION: COMBINING ECONOMICS AND AGRONOMY TO MAXIMIZE PROFITS AND MINIMIZE RISK.

"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 (in press), p. 9

"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,

Introduction

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 1996 data demonstrate that by selecting an "optimal" portfolio, Kansas wheat producers could have increased yields by 8.81 bu/acre in Eastern Kansas, 4.28 bu/acre in Central Kansas, and 6.29 bu/acre in Western Kansas. This increase in wheat production would add over $137 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 (in press) 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 (in press) 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

There are three major strategies for risk reduction using wheat varieties: (1) breeding new varieties, (2) planting blends, and (3) planting a portfolio of varieties.

Therefore, we selected data that allow for the study of these strategies. The data include test performance yields for both varieties and blends across different locations and time, for the period 1994-1997 (Bowden et al. 2001). The data include blends that were prepared by mixing equal proportions of certified seed of three different varieties of hard red winter wheat in a cement mixer. Blends were grown together with individual varieties in most locations of the Kansas wheat variety performance tests from 1994-1997. Experiments were randomized complete block design with four replications in plots 5 feet wide and 15-30 feet long (Bowden et al. 2001). The data were separated into three regions, to account for differences in growing conditions across the State of Kansas.

To calculate the efficiency frontier, the complete variance-covariance matrix was necessary. Therefore, only varieties that had complete data for all location-years were included in this analysis. Data were disaggregated by region, given the large disparity in growing conditions across Kansas. In Eastern Kansas, the data included 13 varieties and 2 blends for 5 location-years; Central Kansas data included 13 varieties and 2 blends for 12 location-years; and in Western Kansas, the data were comprised of 11 varieties and 2 blends for 11 location-years. 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 tables 1-3.

The blend data from Bowden et al. (2001) provide an excellent source of yield data for individual varieties, blends, and portfolios of varieties for the period 1994-1997. To investigate wheat variety portfolios using more recent data, test performance data were collected on wheat yields at a single location (Hutchinson) for the period 2003-2006 (*Kansas Performance Tests with Winter Wheat Varieties*). This location was selected because of its location in the Kansas South Central Crop Reporting District, the district with the greatest wheat production in the State. Portfolio results for individual varieties for Hutchinson performance station are also calculated, and are reported in the next section.

Results

We use complete data on wheat variety yield means, variances, and covariances (reported in Appendix Tables A12, A2, and A3) to derive efficient portfolios. 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 Eastern Kansas (table 1, figure 1), Central Kansas (table 2, figure 2), and Western Kansas (table 3, figure 3).

For the 1994-1997 period, the maximum yielding variety in Eastern Kansas was 2137, at 77.62 bu/acre (table 1, figure 1). This high yield forms the highest point on the efficiency frontier, with a standard deviation equal to 10.05. 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 diamonds, 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.

Interestingly, the two blends included in the Eastern Kansas region outperformed most of the individual varieties, with high yields at relatively lower levels of variation across years and locations. An example of a portfolio on the efficiency frontier is presented in table 1: a combination of 70% 2137, 20% Jagger, and 10% 7853 would result in an average yield of 74.96 bu/acre, and a standard deviation equal to 7.75. The Coefficient of Variation (CV) of this portfolio is equal to 9.68, much 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 figures 1-3.

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 Eastern Kansas in the 1996 crop year (*Wheat Variety*). The average yield and standard deviation appear as the point labeled "*1996 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 (=10.62). 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 1996 to the efficiency frontier. In Eastern Kansas, the opportunity cost of the actual portfolio in 1996 was equal to 8.81 bu/acre (table 1). At the 1996 market price of wheat reported in *Kansas Agricultural Statistics*, this represented a potential gain of over $49 million 1996 dollars (table 4).

The highest yielding variety in Central Kansas is also 2137, with an average yield of 49.91 and a standard deviation equal to 22.01 (table 2, figure 2). The fundamental tradeoff between high yield and variability allows producers to select variety portfolios that reduce risk, by accepting lower average yields. Figure 2 shows that the adoption of portfolios can reduce yield variability well below the variation of each individual variety alone, due to the interrelationship, or covariance, across wheat varieties planted in Kansas. As in Eastern Kansas, the two blends provided high yields with lower variation than most individual varieties, confirming that variety mixtures are capable of responding to the growing environment in a productive fashion.

The economic consequences of growing the actual portfolio of varieties in Central Kansas in 1996 ("*1996 ACTUAL*" in figure 2) instead of a point on the efficiency frontier was calculated as for Eastern Kansas (above), and was equal to 4.28 bu/acre (table 2), resulting in a potential gain of more than $97 million 1996 dollars (table 4). An example of a risk-reducing portfolio for Central Kansas is illustrated in table 2: 50% Karl 92, 35% Jagger, and 15% Tonkawa. This particular portfolio is characterized by an average yield of 47.11 bu/acre, and a standard deviation of 17.32. Planting 100% 2137 has a average yield of 49.91 bu/acre, and a standard deviation equal to 22.01. These two possibilities demonstrate two different "optimal" combinations of wheat varieties in Central Kansas. The actual decision of which point on the efficiency frontier to select depends on each individual producer's preference for expected returns (average yield) and risk (yield stability). Producers with an interest in reducing risk could select portfolios of varieties that are characterized by greater yield stability and lower average yields, due to differences in "genotype-environment interactions" of different wheat varieties available for planting in Kansas.

Efficient variety portfolios for Western Kansas are presented in table 3 and figure 3. The highest yielding variety in Western Kansas in the 1994-1997 period was Vista, with a yield of 54.03 and a standard deviation of 8.84. The portfolio of 100% Vista forms the highest-yielding portfolio in the set of all efficient portfolios on the efficiency frontier. The lowest-risk portfolio is 100% Karl 92, which is also an efficient portfolio, with the lowest variability (the standard deviation is equal to 6.79) of all possible combinations of wheat varieties available for planting in Western Kansas during 1994-1997. The potential gain from planting an efficient portfolio, instead of the actual portfolio of varieties planted in 1996 was equal to 6.29 bu/acre (table 3), or $78 million in 1996 dollars (table 4).

When the opportunity costs from all three regions of Kansas are summed, the potential for economic gain by adoption of variety portfolios is equal to over $137 million 1996 dollars (table 4). This calculation uses data on harvested acres and market prices from *Kansas Agricultural Statistics*. The adoption of a portfolio of wheat varieties is not a costless activity: wheat producers are able to save seed from one harvest to plant in the next crop year. Stanelle et al. (1986) found that use of certified seed in Eastern Kansas was 31-43 percent of total planted acres, and 5-20 percent in western crop reporting districts. Almost 60 percent of producers reported planting two or more varieties in 1986. Many studies have shown benefits of planting certified seed, including Shroyer et al. 1997 and Boland et al. 2001. The benefits of planting certified seed often outweigh the costs, since certified seed is typically more pure and higher yielding than farmer-saved seed (Boland et al. 2001).

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 greatly 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.

The wheat variety data used in this study were selected to evaluate performance measures of (1) individual varieties, (2) blends, and (3) portfolios of varieties planted in different fields. Therefore, the data available from Bowden et al. (2001) with comparable yields for both varieties and blends were used, for the period 1994-1997. To investigate the potential for wheat variety portfolios today, portfolios were also developed for the most recent data available that includes complete yields for all available varieties. Hutchinson test performance data were used for the period 2003-2006, using four years of yield test data at a single location to derive expected returns and risk for wheat varieties. Within this four year time frame, the variety Overley was not available in 2003, but has become a top variety in the South Central region in 2006, so a second portfolio analysis was conducted for the leading five varieties, including Overley, for the 3-year period 2004-2006. This second set of portfolios allows producers to include Overley in potential portfolios.

The Hutchinson efficiency frontier for 2003-2006 includes 9 individual varieties, presented in table 5 and figure 4. The results for these most recent data are similar to those of the blend data: the opportunity for yield risk reduction is available through portfolio adoption. Portfolios of varieties located on the efficiency frontier provide higher yields and/or lower yield risk than individual varieties (table 5, figure 4). The leading five varieties planted in the South Central region in 2006 are used in table 6 and figure 5 to develop an efficiency frontier of optimal combinations of varieties (the varieties included in the 2004-2006 figure differ due to data availability in the test performance published data). The variety Overley provides high average yields. However, yield risk can be reduced significantly by planting a portfolio of Overley with 2174 (table 6, figure 5). The potential gains from moving from the actual 2006 portfolio to the efficiency frontier are equal to 3.74 bu/acre. These potential gains demonstrate that variety portfolios are a strategy that enable producers to maximize profits, minimize risk, or both.

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.

References

Barkley, Andrew P., and Lori L. Porter. "The Determinants of Wheat Variety Selection in Kansas, 1974-1993." *American Journal of Agricultural Economics* Feb. 1996(78):202-211.

Barry, P.J. "Capital Asset Pricing and Farm Real Estate." *American Journal of Agricultural Economics* August 1980(62):549-553.

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

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. March 2001. *Performance of Wheat Variety Blends in Kansas.* Keeping Up with Research No. 128. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Manhattan, Kansas.

Collins, R.A. and P.J. Barry. "Risk Analysis with Single-Index Portfolio Models: An Application to Farm Planning." *American Journal of Agricultural Economics* Feb. 1986(68):152-161.

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):961-969.

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

Figge, F. "Bio-folio: Applying Portfolio Theory to Biodiversity." Biodiversity and Conservation 13(2004):822-849.

Frontline Systems, Inc. http://www.solver.com

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

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):984-990.

Griliches, Zvi. "Hybrid Corn: An Exploration in the Economics of Technical Change." Econometrica 25(October 1957):50-122.

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

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

Kansas Agricultural Statistics. Various years.

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

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

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

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 Agronomic and Economic Impact of the Kansas Agricultural Experiment Station Wheat Breeding Program, 1977-2005.* Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Manhattan, Kansas. Report of Progress 948. June 2006.

Nyikal, R.A. and W.O. Kosura. "Risk Preference and Optimal Enterprise Combinations in Kahuro Division of Murang'a District, Kenya." *Agricultural Econoomics* 2005(32): 131-140.

Porter, Lori L. and Andrew P. Barkley. *Selection of Wheat Varieties in Kansas: Does Quality Matter?* April 1995. Report of Progress 730. Kansas State University Agri. Experiment Station & Cooperative Extension Service. Manhattan, Kansas.

Redmond, C.H., and F.W. Cubbage. "Portfolio Risk and Returns from Timber Asset Investments." *Land Economics* November 1988(64):325-337.

Robison, L.J., and J.R. Brake. "Application of Portfolio Theory to Farmer and Lender Behavior." *American Journal of Agricultural Economics* Feb. 1979(61):158-164.

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, Wyoming, June 2005.

Schurle, B. "The Impact of Size on Yield Variability and Crop Insurance Premiums." *Review of Agricultural Economics* 18(1996):415-422.

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

Shroyer, J.P., H. Kok, and C.R. Thompson. 1997. Planting Practices. In *Wheat Production Handbook*. C-529. Cooperative Extension Service, Kansas State University, Manhattan, Kansas.

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(August 1994):535-46.

Stanelle, J.R., L.A. Burchett, R.L. Vanderlip, and J.P. Shroyer. 1986. *Quality of Wheat Seed in Kansas.* Bulletin 651. Agricultural Experiment Station, Kansas State Univerisity, Manhattan, Kansas.

Tobin, James. "Liquidity Preference as Behavior towards Risk." *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(February 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* November 1988(80):831-836.

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

Wheat Variety. Various years. Kansas Agricultural Statistics Service. Kansas Department of Agriculture. Topeka, Kansas.

Winston, Wayne L. January 2004. *Microsoft Excel Data Analysis and Business Modeling.* Redmond, Washington: Microsoft Press.

Figure 1.

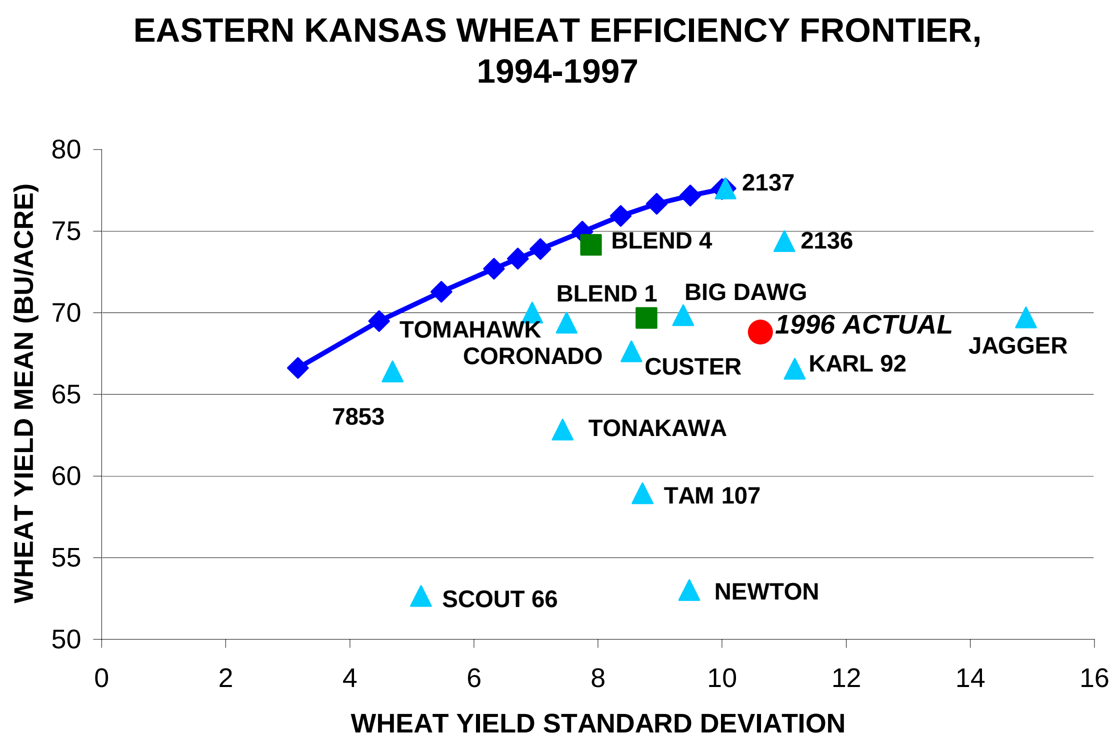


Figure 2.

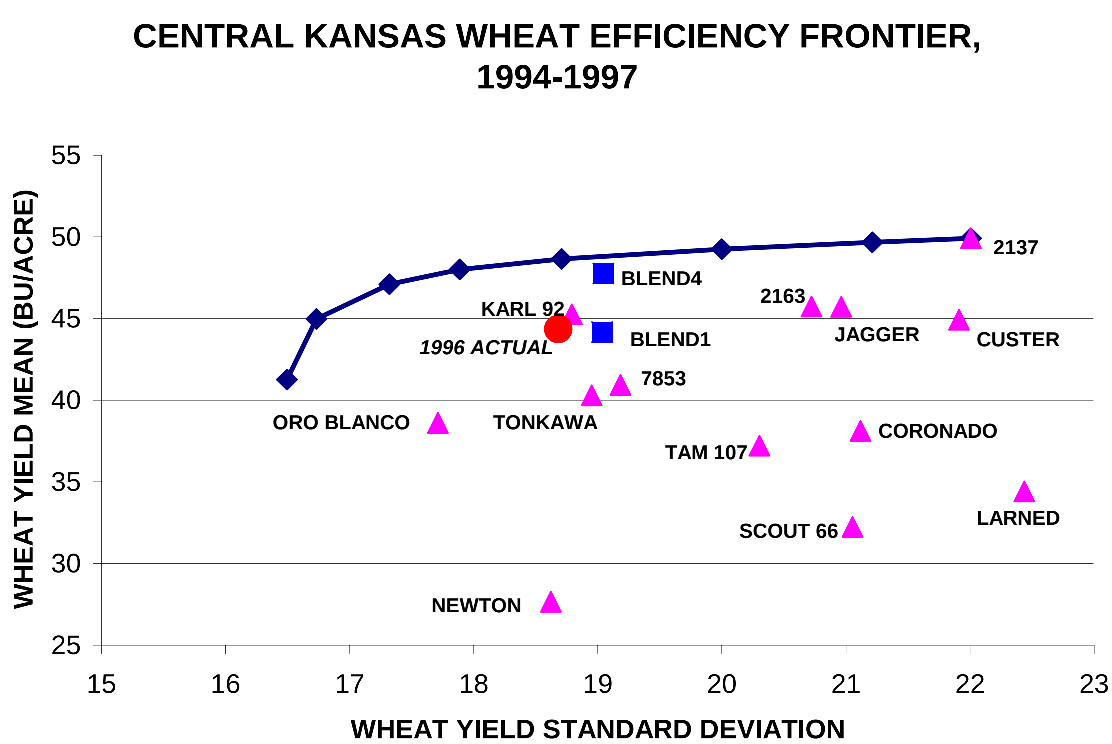


Figure 3.

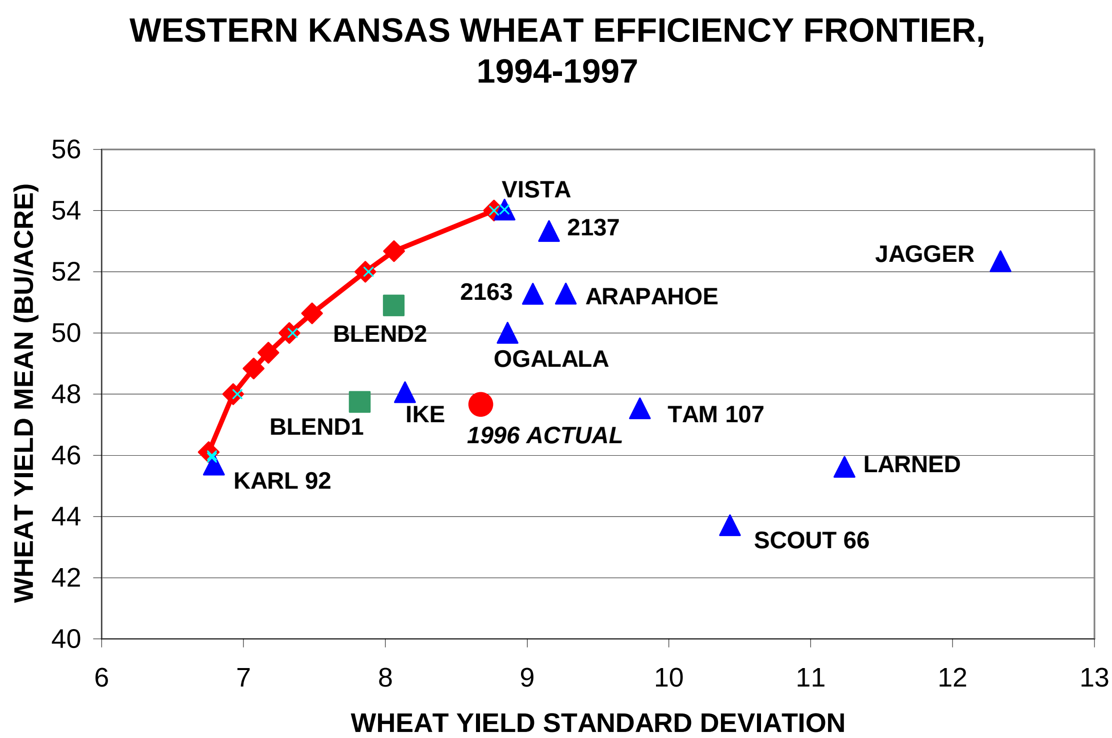


Figure 4.

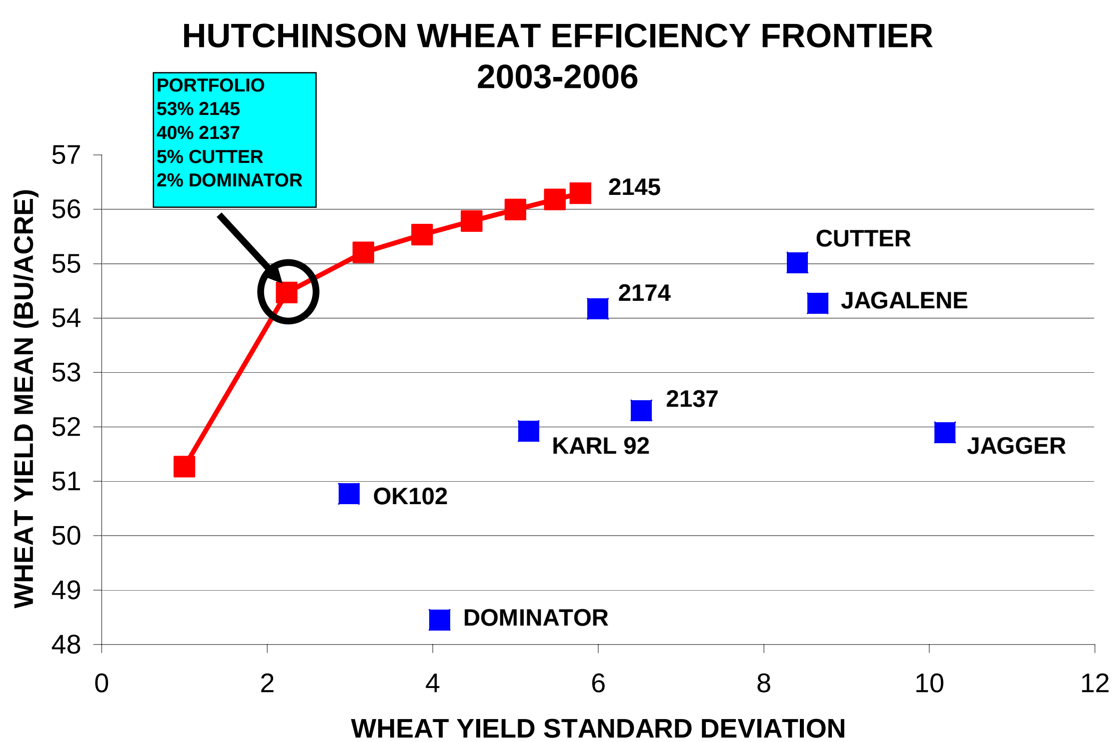
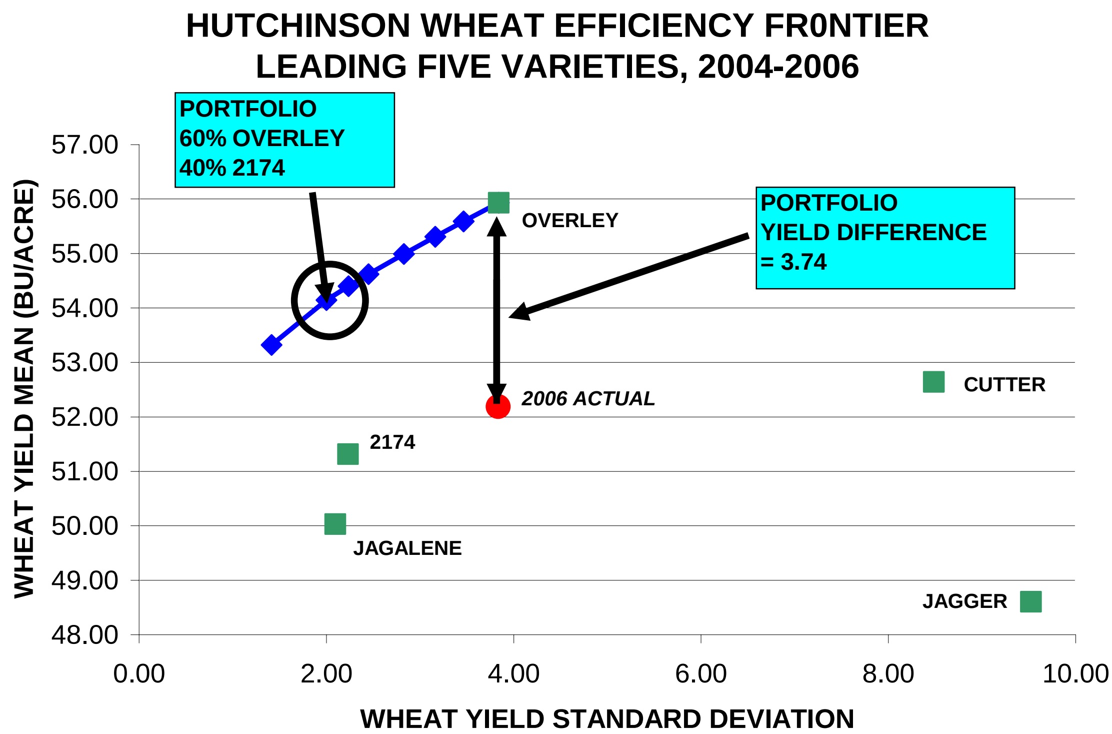


Figure 5.



HUTCHINSON WHEAT EFFICIENCY FR0NTIER
LEADING FIVE VARIETIES, 2004-2006
PORTFOLIO
60% OVERLEY
40% 2174
PORTFOLIO
YIELD DIFFERENCE
= 3.74
OVERLEY
2006 ACTUAL
CUTTER
2174
JAGALENE
JAGGER
WHEAT YIELD MEAN (BU/ACRE)
57.00
56.00
55.00
54.00
53.00
52.00
51.00
50.00
49.00
48.00
0.00
2.00
4.00
6.00
8.00
10.00
WHEAT YIELD STANDARD DEVIATION

Table 1. Portfolio Analysis of Eastern Kansas Wheat Varieties, 1994-1996.[1]

Variety Name	Mean	Standard Deviation	Coefficient of Variation	Description of Blend or Portfolio
Individual Varieties				
2137	77.62	10.05	7.72	
2163	74.39	11.00	6.76	
7853	66.41	4.69	14.16	
Big Dawg	69.85	9.37	7.45	
Coronado	69.40	7.49	9.26	
Custer	67.63	8.54	7.92	
Jagger	69.71	14.90	4.68	
Karl 92	66.58	11.17	5.96	
Newton	53.01	9.47	5.60	
Scout 66	52.66	5.14	10.24	
TAM 107	58.95	8.72	6.76	
Tomahawk	70.02	6.94	10.09	
Tonkawa	62.85	7.43	8.46	
Blends				
BC1	69.68	8.78	7.93	Karl 92, 2163, Tomahawk
BC4	74.16	7.89	9.40	Jagger, Tomahawk, 2137
Portfolio Efficiency Frontier				
	66.41	4.69	14.16	100% 7853
	66.62	3.16	21.07	
	69.49	4.47	15.54	
	71.28	5.48	13.01	
	72.70	6.32	11.49	
	73.32	6.71	10.93	
	73.90	7.07	10.45	
	74.96	7.75	9.68	70% 2137, 20% Jagger, 10% 7853
	75.93	8.37	9.08	
	76.67	8.94	8.57	
	77.17	9.49	8.13	
	77.58	10.00	7.76	
	77.62	10.05	7.72	100% 2137
1996 Actual Portfolio of Planted Varieties in Eastern Kansas				
	68.81	10.62	6.48	

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 8.81 bu/acre

[1]Data and blend definitions are from Bowden et al. 2001. Eastern Kansas includes the three eastern crop reporting districts in Kansas. Data include 13 varieties and 2 blends for 5 location-years.

Table 2. Portfolio Analysis of Central Kansas Wheat Varieties, 1994-1996.[1]

Variety Name	Mean	Standard Deviation	Coefficient of Variation	Description of Blend or Portfolio
Individual Varieties				
Oro Blanco[2]	38.62	17.71	2.18	
2137	49.91	22.01	2.27	
2163	45.74	20.72	2.21	
7853	40.95	19.18	2.13	
Coronado	38.12	21.12	1.81	
Custer	44.92	21.91	2.05	
Jagger	45.72	20.96	2.18	
Karl 92	45.26	18.79	2.41	
Larned	34.42	22.44	1.53	
Newton	27.66	18.62	1.49	
Scout 66	32.24	21.05	1.53	
TAM 107	37.21	20.30	1.83	
Tonkawa	40.30	18.95	2.13	
Blends				
BC1	44.17	19.03	2.32	Karl 92, 2163, Tomahawk
BC4	47.76	19.05	2.51	Jagger, Tomahawk, 2137
Portfolio Efficiency Frontier				
	41.26	16.50	2.50	30% Karl 92, 20% Oro Blanco,[2] 20% Jagger, 20% Tonkawa, 10% Newton
	44.97	16.73	2.69	
	47.11	17.32	2.72	50% Karl 92, 35% Jagger, 15% Tonkawa
	48.01	17.89	2.68	
	48.65	18.71	2.60	
	49.24	20.00	2.46	
	49.66	21.21	2.34	
	49.91	22.01	2.27	100% 2137
1996 Actual Portfolio of Planted Varieties in Central Kansas				
	44.35	18.68	2.37	

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 4.28 bu/acre

[1]Data and blend definitions are from Bowden et al. 2001. Central Kansas includes the three central crop reporting districts in Kansas. Data include 13 varieties and 2 blends for 12 location-years.
[2]White wheat.

Table 3. Portfolio Analysis of Western Kansas Wheat Varieties, 1994-1996.[1]

Variety Name	Mean	Standard Deviation	Coefficient of Variation	Description of Blend or Portfolio
Individual Varieties				
2137	53.34	9.15	5.83	
2163	51.28	9.04	5.67	
Arapahoe	51.29	9.27	5.53	
Ike	48.06	8.14	5.91	
Jagger	52.35	12.34	4.24	
Karl 92	45.70	6.79	6.73	
Larned	45.62	11.24	4.06	
Ogallala	50.00	8.86	5.64	
Scout 66	43.71	10.43	4.19	
TAM 107	47.54	9.80	4.85	
Vista	54.03	8.84	6.11	
Blends				
BNW1	47.74	7.82	6.11	TAM 107, 2163, 7853
BNW2	50.90	8.06	6.31	TAM 107, Vista, Ike
Portfolio Efficiency Frontier				
	45.70	6.79	6.73	100% Karl 92
	46.10	6.75	6.83	
	48.00	6.93	6.93	
	48.84	7.07	6.91	
	49.35	7.18	6.88	
	50.00	7.32	6.83	60% Karl 92, 27% Vista, 13% Ogallala
	50.64	7.48	6.77	
	52.00	7.86	6.62	
	52.67	8.06	6.53	
	54.00	8.77	6.16	
	54.03	8.84	6.11	100% Vista
1996 Actual Portfolio of Planted Varieties in Western Kansas				
	47.66	8.67	5.50	

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 6.29 bu/acre

[1]Data and blend definitions are from Bowden et al. 2001. Western Kansas includes the three western crop reporting districts in Kansas. Data include 11 varieties and 2 blends for 11 location-years.

Table 4. Economic Gains from a Movement to the Efficiency Frontier in 1996.

Eastern Kansas

1996 Acres Harvested	
NE Crop Reporting District	281,000
E Crop Reporting District	340,000
SE Crop Reporting District	588,000
Total	1,209,000 acres

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 8.81 bu/acre
Total Potential Gain from movement to Efficiency Frontier =10,651,290 bu
Total Dollar Gain from Movement to Efficiency Fronter at Market Price[1] = $49,315,473

Central Kansas

1996 Acres Harvested	
NC Crop Reporting District	1,249,000
C Crop Reporting District	1,461,000
SC Crop Reporting District	2,194,000
Total	4,904,000 acres

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 4.28 bu/acre
Total Potential Gain from movement to Efficiency Frontier =120,989,120 bu
Total Dollar Gain from Movement to Efficiency Fronter at Market Price[1] = $97,179,626

Western Kansas

1996 Acres Harvested	
NW Crop Reporting District	1,002,000
WC Crop Reporting District	605,000
SW Crop Reporting District	1,080,000
Total	2,687,000 acres

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 6.29 bu/acre
Total Potential Gain from movement to Efficiency Frontier =16,901,230 bu
Total Dollar Gain from Movement to Efficiency Fronter at Market Price[1] = $78,252,695

Total Economic Gain for State of Kansas = $137,347,793.20
Percent Increase in total revenues from wheat in Kansas = 11.5%

---

[1]Market price of wheat in 1996 was $4.28/bu (Kansas Agricultural Statistics).

Table 5. Portfolio Analysis of Hutchinson Wheat Varieties, 2003-2006.[1]

Variety Name	Mean	Standard Deviation	Coefficient of Variation	Description of Portfolio
Individual Varieties				
2137	52.31	6.52	0.12	
2145	56.30	5.79	0.10	
2174	54.17	6.00	0.11	
Cutter	55.02	8.41	0.15	
Dominator	48.45	4.08	0.08	
Jagalene	54.27	8.65	0.16	
Jagger	51.90	10.19	0.20	
Karl 92	51.93	5.16	0.10	
Ok102	50.77	2.99	0.06	
Portfolio Efficiency Frontier				
	51.27	1.00	0.02	
	54.47	2.24	0.04	53% 2145, 40% 2137, 5% Cutter, 2% Dominator
	55.21	3.16	0.06	
	55.53	3.87	0.07	
	55.78	4.47	0.08	
	55.99	5.00	0.09	
	56.18	5.48	0.10	
	56.30	5.79	0.10	
2006 Actual Portfolio of Planted Varieties in Southcentral Crop Reporting District				
	52.19	3.83	0.07	

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 3.33 bu/acre

[1]Data from *Kansas Performance Tests with Winter Wheat Varieties*, 2003-2006.

Table 6. Portfolio Analysis of Hutchinson Wheat Varieties, 2004-2006.[1]

Variety Name	Mean	Standard Deviation	Coefficient of Variation	Description of Portfolio
Individual Varieties				
Overley	55.93	3.84	0.07	
Jagalene	50.03	2.10	0.04	
Jagger	48.61	9.52	0.20	
2174	51.32	2.23	0.04	
Cutter	52.64	8.49	0.16	
Portfolio Efficiency Frontier				
	53.32	1.41	0.03	43% Overley, 57% 2174
	54.15	2.00	0.04	60% Overley, 40% 2174
	54.40	2.24	0.04	
	54.62	2.45	0.04	
	54.99	2.83	0.05	
	55.31	3.16	0.06	
	55.59	3.46	0.06	
	55.93	3.84	0.07	100% Overley
2006 Actual Portfolio of Planted Varieties in Southcentral Crop Reporting District				
	52.19	3.83	0.07	

Opportunity Cost of Planting Actual instead of Efficiency Frontier = 3.74 bu/acre

[1]Data from *Kansas Performance Tests with Winter Wheat Varieties*, 2004-2006.

Table A1. Summary Statistics of Wheat Variety Yield Data in Eastern Kansas, 1994-1996.[1]

Variety	BC1[2]	BC4[3]	2137	2163	7853	Big Dawg	Coro-nado	Custer	Jagger	Karl 92	New-ton	Scout 66	TAM 07	Toma-hawk	Tonk-awa
Mean	69.68	74.16	77.62	74.39	66.41	69.85	69.40	67.63	69.71	66.58	53.01	52.66	58.95	70.02	62.85
Variance	77.15	62.24	101.08	121.05	22.00	87.82	56.17	72.90	221.92	124.78	89.68	26.47	75.97	48.18	55.19
Covariance															
BC1[2]	--	60.81	68.91	93.47	15.69	77.09	55.64	53.71	62.69	95.98	77.89	6.24	68.74	49.07	39.27
BC4[3]		--	77.73	76.49	24.11	53.49	39.62	30.36	6.47	83.08	64.74	-9.74	49.16	45.38	41.15
2137			--	85.53	31.77	54.96	38.51	32.83	-7.43	96.56	74.30	-16.58	55.16	55.54	47.70
2163				--	28.14	93.37	75.75	49.19	50.45	120.06	92.24	-3.11	73.84	54.15	52.76
7853					--	6.69	13.49	-12.53	-36.15	26.33	10.94	-20.75	-1.01	4.62	10.77
Big Dawg						--	64.20	58.58	77.43	94.88	83.51	16.38	74.19	51.63	48.14
Coronado							--	26.19	33.82	71.53	57.09	1.87	43.52	30.02	38.53
Custer								--	110.56	56.77	58.29	32.02	68.80	42.44	15.77
Jagger									--	48.99	55.46	65.08	88.32	31.35	-13.48
Karl 92										--	100.42	-0.92	81.76	64.87	59.71
Newton											--	10.73	76.80	62.10	56.44
Scout 66												--	22.62	8.70	-2.39
TAM 107													--	53.99	36.77
Tomahawk														--	41.23
Tonkawa															--

[1]Data and blend definitions are from Bowden et al. 2001. Eastern Kansas includes the three eastern crop reporting districts in Kansas. Data include 13 varieties and 2 blends for 5 location-years.
[2] BC1 is a blend of the following varieties in equal proportions: Karl 92, 2163, and Tomahawk.
[3] BC4 is a blend of the following varieties in equal proportions: Jagger, Tomahawk, and 2137.

Table A2. Summary Statistics of Wheat Variety Yield Data in Central Kansas, 1994-1996.[1]

Variety	BC1[2]	BC4[3]	Oro Blanco	2137	2163	7853	Coro-nado	Custer	Jagger	Karl 92	Larned	New-ton	Scout 66	TAM 07	Tonk-awa
Mean	44.17	47.76	38.62	49.91	45.74	40.95	38.12	44.92	45.72	45.26	34.42	27.66	32.24	37.21	40.30
Variance	362.32	362.77	313.69	484.31	429.41	367.95	445.89	480.05	439.36	353.13	503.44	346.79	443.25	412.19	359.17
Covariance															
BC1[2]	--	326.72	292.98	362.56	338.74	309.72	322.84	308.95	230.33	319.24	375.27	284.62	345.94	336.73	269.64
BC4[3]		--	294.89	367.43	326.90	312.11	328.47	327.16	234.91	312.24	374.00	281.32	344.17	334.76	296.19
Oro Blanco			--	318.55	303.05	297.79	308.97	288.56	238.06	278.45	340.86	270.70	311.10	311.37	258.74
2137				--	341.68	314.59	328.74	313.95	174.54	359.00	417.05	293.12	385.34	370.49	301.13
2163					--	333.77	356.74	353.64	297.45	311.84	395.03	317.24	364.41	345.16	277.17
7853						--	350.82	345.88	301.23	285.60	371.39	309.53	341.98	338.36	295.75
Coronado							--	394.15	345.16	282.61	378.71	326.27	353.37	354.36	314.03
Custer								--	349.73	265.93	376.00	325.39	355.50	336.55	354.58
Jagger									--	186.77	265.15	262.23	237.06	254.72	256.25
Karl 92										--	358.58	262.68	327.03	318.21	241.48
Larned											--	359.77	429.33	405.81	329.86
Newton												--	339.18	332.01	257.82
Scout 66													--	377.48	306.66
TAM 107														--	289.76
Tonkawa															--

[1]Data and blend definitions are from Bowden et al. 2001. Central Kansas includes the three central crop reporting districts in Kansas. Data include 13 varieties and 2 blends for 12 location-years.

[2] BC1 is a blend of the following varieties in equal proportions: Karl 92, 2163, and Tomahawk.

[3] BC4 is a blend of the following varieties in equal proportions: Jagger, Tomahawk, and 2137.

Table A3. Summary Statistics of Wheat Variety Yield Data in Western Kansas, 1994-1996.[1]

Variety	BNW1[2]	BNW2[3]	2137	2163	Arapa-hoe	Ike	Jagger	Karl 92	Larned	Ogal-lala	Scout 66	TAM 107	Vista
Mean	47.74	50.90	53.34	51.28	51.29	48.06	52.35	45.70	45.62	50.00	43.71	47.54	54.03
Variance	61.16	64.97	83.81	81.73	85.99	66.24	152.21	46.14	126.30	78.53	108.79	95.96	78.17
Covariance													
BNW1[2]	--	53.08	61.02	55.98	56.79	54.80	82.73	42.91	71.47	51.25	61.79	63.42	49.53
BNW2[3]		--	63.54	59.57	64.87	56.98	82.14	47.78	68.77	54.94	60.23	59.03	59.17
2137			--	68.82	68.55	61.06	89.75	50.78	80.02	60.68	70.26	70.82	63.23
2163				--	68.40	55.36	90.85	45.54	65.39	65.28	56.72	55.65	61.76
Arapahoe					--	61.08	94.02	52.24	67.17	67.07	58.09	58.06	71.52
Ike						--	84.06	45.68	74.43	52.98	62.30	61.04	55.20
Jagger							--	65.66	97.11	92.46	83.96	84.92	79.35
Karl 92								--	51.26	43.54	44.06	47.94	47.14
Larned									--	56.79	102.94	94.59	59.44
Ogallala										--	50.85	50.39	55.16
Scout 66											--	87.93	48.02
TAM 107												--	48.45
Vista													--

[1]Data and blend definitions are from Bowden et al. 2001. Western Kansas includes the three western crop reporting districts in Kansas. Data include 11 varieties and 2 blends for 11 location-years.

[2] BNW1 is a blend of the following varieties in equal proportions: TAM 107, 2163, and 7853.

[3] BNW2 is a blend of the following varieties in equal proportions: TAM 107, Vista, and Ike.

Table A4. Summary Statistics of Wheat Variety Yield Data at Hutchinson Test Performance Station, 2003-2006.[1]

Variety	2137	2145	2174	Cutter	Dom-inator	Jaga-lene	Jagger	Karl92	Ok102
Mean	52.31	56.30	54.17	55.02	48.45	54.27	51.90	51.93	50.77
Variance	42.52	33.48	35.94	70.66	16.67	74.84	103.84	26.60	8.92
Covariance									
2137	--	-27.17	-20.85	-10.15	15.49	-36.32	-26.46	-24.51	-13.69
2145		--	22.48	12.83	-15.54	34.47	22.56	21.86	12.91
2174			--	25.67	-17.84	36.31	27.86	17.27	11.77
Cutter				--	-19.35	37.62	56.27	4.84	6.17
Dominator					--	-26.14	-23.90	-11.91	-7.95
Jagalene						--	51.86	27.38	17.45
Jagger							--	14.43	10.37
Karl92								--	11.25
Ok102									--

--

[1]Data are from *Kansas Performance Tests with Winter Wheat Varieties*, 2003-2006. Data include 9 varieties for 4 years.

Table A5. Summary Statistics of Wheat Variety Yield Data at Hutchinson Test Performance Station, 2004-2006.[1]

Variety	Over-ley	Jaga-lene	Jagger	2174	Cutter
Mean	55.93	50.03	48.61	51.32	52.64
Variance	14.76	4.39	90.68	4.98	72.01
Covariance					
Overley	--	2.88	13.68	-4.84	-0.65
Jagalene		--	13.30	-0.02	9.80
Jagger			--	-0.48	43.68
2174				--	7.04
Cutter					--

[1]Data are from *Kansas Performance Tests with Winter Wheat Varieties,* 2003-2006. Data include 5 varieties for 3 years.