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RESEARCH CASE

Downsizing an Agricultural Field Experiment Alters Economic Results: A Case Study

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Downsizing the replications of an agricultural experiment altered profit and utility rankings of different cropping systems less than cutting the duration of the experiment. However, failing to plant all crops in a rotation each year altered economic rankings the most. Estimates of system profit variability, and associated economic rankings, were especially sensitive to downsizing experiment length and to failing to plant all crops in a rotation annually. Despite the scientific importance of long full-rotation experiments, short run publication pressures favoring "new data" and methodological innovations might discourage such rich experiments.

Decisions regarding the duration and design of agricultural field experiments represent major research policy questions. Because field experiments are relatively expensive, these decisions also significantly influence institutional research budgets. Concurrently, funding has stagnated for public institutions that conduct most cropping systems research (Rausser). Consequently, pressures exist to downsize field experiments with major implications for the quality of economic analysis of alternative technologies. Some research agronomists have argued that long-term complex cropping systems experiments are now rarely attempted because of their cost and complexity (Cady, F. Young et al.). Agricultural scientists might also be discouraged from conducting long-term experiments because several short-term experiments may generate more publications, which facilitate professional advancement.

Despite downsizing pressures, agricultural field experiments spanning several years and realistic crop rotations are critical for assessing the biological

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sustainability of new agricultural systems, identifying their environmental consequences, and measuring the expected level and variability of profit (Army and Kemper). Long-term field experiments play an essential role in understanding the complex interactions of plants, soils, pests, climate, and management (Frye and Thomas, Smith et al., Wei et al.). Field experiments are also critical in validating computer models of crop growth and environmental processes. A recent example requiring long-term experiments relates to the biological and economic sustainability of no-till farming in new regions (Zentner et al., Dhuyvetter et al.). Agronomists have observed that the conversion to no-till involves a transition over time in soil structure, weed populations, soil moisture, and yields (Tracy et al., Clements et al., Needlemen et al.). Similarly, environmental assessments of nitrogen leaching, resistance in weed populations, and vulnerability to soil erosion all require multiyear testing of new cropping systems.

The selection of cropping systems and technologies based on the expected value, variance, and sometimes higher moments of the profit distributions of cropping systems has been a staple product of agricultural economics research for decades (Anderson, Dillon, and Hardaker; Barry; Lybecker, Schweizer, and King; Hardaker, Huirne, and Anderson). While researchers have used a variety of field experiment, aggregate time series, and simulated data to estimate variance-covariance structures for candidates for optimal portfolios, less attention appears to have been devoted to the optimal length and design of field experiments to supply such data.

On the other hand, a rich literature exists on the design and size of experiments to optimize the statistical efficiency of detecting treatment differences, heritability of traits, and other biological factors (Hoshmand). However, this literature has focused primarily on the number of replications and size of plots within a year. For example, Gauch and Zobel provide tables specifying the number of replications that optimizes selection of genotypes with the highest true yields. There is also a rich literature on deriving variability measures from sparse time series data and on appropriate statistical procedures for analyzing combined cross-sectional and time-series experimental data (Anderson, Dillon and Anderson).

Unfortunately, most of the statistical literature on optimal plot size and number of replications within a year does not relate to how weather affects estimates of expected profit and variability of profit over time. However, these issues are of central interest to farmers and agricultural economists. The purpose of this case study is to demonstrate how downsizing a long-term experiment in southeastern Washington state would have affected economic preference rankings of dryland cropping systems under different levels of risk aversion. Specifically, this study will examine the consequences of reducing the duration from six to three, cutting the number of replications from four to two, and reducing from all crops in a three-crop rotation each year to just one crop. Economic rankings obtained from the downsized experiments are statistically compared with those of the full-sized experiment. Research policy implications of the results are discussed.

This study draws from and extends an earlier analysis of the data, which focused primarily on agronomic and statistical efficiency consequences of downsizing, with some partial risk neutral economic results (Wei et al.). The current study focuses on consequences of experiment downsizing on economic results, explores some new downsizing scenarios, adds the influence of risk aversion, and provides a discussion of implications for research planners and users.

Readers interested in a discussion of a broader set of statistical design and economic interpretation issues, beyond the specific issues in this case study, are referred to the seminal work by Hoffnar and Johnson and useful review and references in Dillon and Anderson.

Data

The six-year cropping systems experiment was located in a dryland wheat-growing region in southeastern Washington state. Annual precipitation averaged 18.1 and 21.4 inches in the first three and second three years of the experiment. Detailed field procedures, biological data, and economic feasibility assessments are documented in Boerboom et al. and Young, Kwon, and Young.

The experiment was a randomized complete block design with four replications. The twelve cropping systems compared in the experiment represented all combinations of two crop rotations, two tillage systems, and three weed management levels. The two three-year crop rotations were winter wheat (ww)–winter wheat (ww)–spring wheat (sw) and winter wheat (ww)–spring barley (sb)–spring pea (sp). The tillage systems were conservation (Cons) and conventional (Conv). The weed management levels were minimum (Min), moderate (Mod), and maximum (Max).

Each cropping system was based on seventy-two plot observations: three rotational crops per year × one tillage × one weed management level × four replications × six years. The complete experiment with 864 observations is assumed to represent the standard against which all downsized experiments are compared. While the six-year data set is more complete in terms of varying weather and number of spatial replications than the downsized experiments, it does not supply perfect estimates of long-term average crop yields or net returns. However, it contains a larger sample size over space and time than many experiments and it is the best available standard for the current case study.

For analysis on an acre unit basis, a cropping system was assumed to have one-third acre in each rotational crop annually; for example, one-third acre each winter wheat, barley, and peas for a ww–sb–sp rotation. This is realistic because farmers in the region typically allocate land equally to rotated crops each year. This practice smoothes seasonal labor and machinery demands and captures the annual risk reducing effect of diversification.

The first set of downsized experiments was obtained by reducing the duration from six to three years, namely Years 1, 2, 3; Years 2, 3, 4; Years 3, 4, 5; and Years 4, 5, 6. Each of these downsized experiments includes 432 observations or thirty-six per system. The second set of downsized experiments was formed from all possible combinations of two of the four replications (i.e., Reps. 1, 2; Reps 1, 3; Reps 1, 4; Reps 2, 3; Reps 2, 4; and Reps 3, 4). These downsized experiments include 432 observations or thirty-six per system. Reducing the experiment so that only one crop in each three-year rotation is grown each year yields a third set of three downsized experiments (Wei et al.). For example, in the wheat–barley–pea rotation, plots beginning with barley or peas in year one of the experiments were deleted, leaving only those beginning with wheat. Each downsized experiment contains 288 observations or twenty-four per system.

Economic and Statistical Methodology

Economic preference rankings based on mean profit and variance of profit over the six years of the experiment are calculated for each of the twelve cropping systems for both the full-sized and downsized experiments. Variability in annual profit is induced only by crop yields and production costs. Crop prices are held constant at 1995–2000 average levels to focus on production risk consistent with the original experiment objectives.

The full-sized experiment, the four three-year experiments, and the six two-replication experiments all preserve the diversification effect for a farmer growing all rotational crops each of the six years. The full cropping systems did not exist for any of the six years for the reduced rotation experiments because all three crops in a rotation were not grown every year. Consequently, it was not possible to compute the actual annual economic performance parameters for cropping systems for this particular downsized experiment. However, it was possible to compute performance parameters for "synthesized" annual cropping systems that were formed from successive years' data. Of course, these synthetic systems do not contain the diversification effect within years, as do the true systems. Results for these synthetic systems will be presented for comparison.

Mean and variance of profit (expected net returns over total costs) of a particular system with the full data set is calculated as in (1) and (2). The scope of summation indices is reduced appropriately for the downsized experiments.

$$(1) \qquad \Pi_j = 1/72 \sum_{t=1}^{6} \sum_{r=1}^{4} \sum_{i=1}^{3} (\mathrm{Y}_{irtj}\mathrm{P}_{ij} - \mathrm{C}_{itj} - \mathrm{WMC}_{itj}) \quad \text{for } j = 1, 2, \ldots, 12$$

where Π_j is expected net returns of system *j* (\$/ac), Y_{irtj} is subplot yield of crop *i* in the system *j* at replication *r* in year *t* (unit/ac), P_{ij} is price of crop *i* in the system *j* (\$/unit), WMC_{itj} is weed management costs of crop *i* in the system *j* in year *t* (\$/ac), and C_{itj} is the other costs of crop *i* in the system *j* in year *t* (\$/ac).

$$(2) \qquad \mathrm{Var}(\Pi_j) = 1/5 \sum_{t=1}^{6} (\Pi_{tj} - \Pi_j)^2 \quad \text{for } j = 1, 2, \ldots, 12$$

where $\mathrm{Var}(\Pi_j)$ is estimated variance of net returns for system *j*, Π_{tj} is annual average net returns of system *j* in year *t* (\$/ac). The variance of profit is calculated over years, because farmers are generally concerned about the adequacy of variable annual net returns to meet yearly debt repayment and family living requirements. In agriculture, variable annual weather can make inferences about mean profitability and risk very vulnerable to small-sample bias over years. For example, three consecutive years of drought will produce misleading estimates of the absolute mean profit of different cropping systems and possibly misleading estimates of relative profits of different systems. Because larger samples over time and space generally provide more precise estimates of both expected profitability and risk of cropping systems, the full-sized experiment over six years and four replications will be compared with the downsized experiments. To assess the degree to which downsized experiments might generate misleading inferences about economic desirability of systems, the systems are ranked from 1 (most economically preferred) to 12 (least preferred) for all experiments. The analysis ranks the twelve cropping systems both for growers who are risk neutral and for those who are risk averse. Ranks rather than absolute profits were used because farmers are more likely to look at the general ranking of systems given their uncertainty about point estimates of expected profit values from experiments. Furthermore, expected utility equivalents under risk aversion are inherently ordinal.

Risk neutral profit maximizing growers will rank systems in descending order of mean profitability. In accordance with expected utility theory (Robison and Barry; Anderson, Dillon, and Hardaker), risk-averse growers, under common preference and distributional assumptions, will discount a system's farm-wide mean profit (E) by its farm-wide variance (V) as follows:

$$\text{Preference} = E - (R/2)V. \tag{3}$$

R is the coefficient of "constant absolute risk aversion" for a particular decision maker. R was scaled to the size of the gamble; in this case, the typical 1,400-acre farm size in the study region (Raskin and Cochran). The analysis examines the sensitivity of the system profit rankings to different levels of risk aversion by assuming R's of 0.000004, 0.000008, 0.000018 represent "slightly, moderately, and highly risk-averse" farmers.

A descriptive method of comparing the agreements in profit rankings for each downsized experiment versus the complete experiment was to compute the average of the absolute value differences in rankings over the twelve systems. For example, if each of the twelve systems over the two experiments differed by exactly one rank in profitability, the average absolute value difference in ranks would be 1.0. The closer this measure is to the lower bound of zero, the greater the similarity in rankings.

Spearman's coefficients (ρ) were also used to measure correlations in profit rankings of systems for downsized experiments and the full-sized experiment. The distribution of the Spearman's correlation coefficients is symmetrical about zero and tends to normality for large n (numbers of pairs of comparisons). For $n > 10$, Zar provides a transformation for testing null hypotheses for ρ equal to one, which is adapted to our problem. The closer ρ is to its upper bound of 1.0, the greater the similarity in rankings.

Results

The four short-duration experiments (years 1–3, years 2–4, years 3–5, and years 4–6) produce sharply different inferences about mean profitability and economic risk (standard deviation) over cropping systems compared with the complete six-year experiment (table 1). Mean profit over all twelve systems averaged a positive $23.70/ac in the higher precipitation Years 4–6, but no other three-year interval averaged positive net returns. Over the complete six-year experiment, which received a representative span of weather, profit over the twelve systems averaged –$16.16/ac, about $40 above (under) the years 1–3 (years 4–6) estimate. A $40 error in per acre profit would potentially misrepresent annual profit on the typical 1,400-acre farm in the study region by $56,000. Standard deviation, as a measure of annual profit risk, averaged only $23.43/ac and $25.29/ac, respectively, in years 1–3 and 4–6 compared with $49.37/ac in the complete experiment. This is not surprising since the first three years experienced somewhat uniform dry weather and the last three years somewhat uniform wet weather. The complete experiment experienced a more representative range of precipitation (Boerboom et al.).

More importantly from the standpoint of making technology recommendations, the shorter-duration experiments produce different economic preference rankings over the twelve cropping systems than the complete experiments, both for risk neutral and risk-averse farmers. The average of the absolute value changes in ranks from the short duration experiments versus the complete experiment range from 1.33 to 2.17 for risk neutral growers (table 1). Average absolute ranking changes remain sizable under risk aversion ranging from 0.33 to 4.33.

Table 1. Means and standard deviations (SD) of net returns over total costs ($/acre/yr), average absolute value change in rank from years 1 to 6, and Spearman's rank correlation coefficients (ρ) between the full experiment and the reduced period experiments

	Years 1–6	Years 1–3	Years 2–4	Years 3–5	Years 4–6
Mean of net returns	−16.16[a]	−56.03	−28.22	−3.77	23.70
SD of net returns	49.37	23.43	47.19	62.64	25.29
Av. ab. value change[b]					
Risk neutral	—	1.67	1.67	1.33	2.17
Low risk	—	1.33	1.50	0.83	3.00
Mod. risk	—	0.67	1.00	1.00	3.33
High risk	—	0.33	0.83	1.00	4.33
Spearman's ρ					
Risk neutral	—	0.76**	0.83**	0.87*	0.69**
Low risk	—	0.87*	0.81**	0.94*	0.46**
Mod. risk	—	0.95*	0.87*	0.90*	0.24**
High risk	—	0.98	0.95*	0.94*	−0.18**

[a] Negative net returns over total costs, imply that labor, capital, land, or other resources are yielding below market rates of return at assumed output prices.

[b] Average absolute value change in rank from years 1 to 6.

**ρ is significantly less than 1.0 at 0.05 level.

*ρ is significantly less than 1.0 at 0.10 level.

Spearman's correlation coefficients relating rankings for the full experiment to those for the reduced-duration experiments are not high, ranging from 0.69 to 0.87 for risk neutrality, and –0.18 to 0.98 for risk aversion. All correlation coefficients except for Years 1–3 under high risk aversion were significantly less than 1.00 at $\rho = 0.05$ or $\rho = 0.10$. The risk-averse rankings incorporate information on both the mean and variance of cropping system profit, so poor estimates of either or both parameters in short-duration experiments can distort economic recommendations. As is often the case in economic decisions, incorporating risk, which varies over cropping systems, causes the risk-averse rankings to differ from the risk-neutral rankings.

It is difficult to generalize about how the degree of risk aversion alters the average rank changes and correlations in this case study. The results are sensitive to the proximity of adjacent systems' mean net returns and the variance of net returns. Depending on the data, small or large changes in risk aversion can trigger changes in rankings of risk-adjusted profit.

Similar results in table 2 show that reducing replications from four in the complete experiment to two also altered profitability results and economic preference rankings, but by much less than reducing the duration of the experiment. For example, the across-system net returns average for the full experiment is again −\$16.16/ac, which was bounded by a relatively narrow range of –\$20.68 to −\$11.65 for the downsized experiments. Standard deviations

Table 2. Means and standard deviations (SD) of net returns over total costs (\$/acre/yr), average absolute value change in rank from replications 1 to 4, and Spearman's rank correlation coefficients (ρ) between the full experiment and the reduced replications experiments

	Reps 1–4	Reps 1, 2	Reps 1, 3	Reps 1, 4	Reps 2, 3	Reps 2, 4	Reps 3, 4
Mean of net returns	−16.16[a]	−14.63	−14.72	−11.65	−20.68	−17.61	−17.70
SD of net returns	49.37	45.15	48.40	47.54	51.83	50.94	54.86
Av. ab. value change[b]							
Risk neutral	—	0.67	0.50	0.83	1.50	0.17	1.00
Low risk	—	0.67	0.67	1.17	1.33	1.00	1.33
Mod. risk	—	0.83	0.50	1.50	1.17	0.67	1.00
High risk	—	1.00	0.50	1.17	0.83	0.67	0.83
Spearman's ρ							
Risk neutral	—	0.94*	0.97*	0.92*	0.85**	0.99	0.94*
Low risk	—	0.96*	0.95*	0.90*	0.88*	0.92*	0.89*
Mod. risk	—	0.96*	0.96*	0.87*	0.90*	0.96*	0.92*
High risk	—	0.94*	0.98	0.88*	0.94*	0.95*	0.92*

[a] Negative net returns over total costs, imply that labor, capital, land, or other resources are yielding below market rates of return at assumed output prices.

[b] Average absolute value change in rank from replications 1 to 4.

**ρ is significantly less than 1.0 at 0.05 level.

*ρ is significantly less than 1.0 at 0.10 level.

ranged from \$45.15/ac to \$54.86/ac in the two-replication experiments compared with \$49.37/ha in the complete (four-replication) experiment.

Reducing replications also precipitated some changes in economic preference rankings, but by a lesser degree than shortening the duration of the experiment. The average absolute value of changes in preference ranks of downsized experiments compared with the complete experiment ranged from 0.17 to 1.50 integer ranks (table 2). The Spearman's correlation coefficients between the full experiment and the reduced replication experiments ranged from 0.85 to 0.99 under risk neutrality, and 0.87 to 0.98 for risk aversion. All correlation coefficients except those for Reps 1, 3 under high risk aversion and Reps 2, 4 under risk neutrality were significantly less than 1.00 at $\rho = 0.05$ or $\rho = 0.10$. Nonetheless, the correlations substantially exceed those of most of the reduced-duration experiments.

Table 3 presents results for synthetic systems that were formed when only one crop in a three-crop rotation was grown each year. Estimates of mean profitability averaged over all systems ranged from −\$42.83/ac to \$5.15/ac compared with −\$16.16 for the complete experiment. Estimates of standard deviations ranged from \$68.29/ac to \$96.76/ac compared with \$49.37 for the full experiment (table 3).

On average, downsizing rotations annually altered economic preference rankings more than reducing the experiment's duration or replications. The average absolute value of changes in preference rankings of reduced rotation

Table 3. Means and standard deviations (SD) of net returns over total costs (\$/acre/yr), average absolute value change in rank, and Spearman's rank correlation coefficients (ρ) between the full experiment and the reduced rotation (Rot) experiments

	Rot Full	Rot One	Rot Two	Rot Three
Mean of net returns	−16.16[a]	5.15	−42.83	−6.81
SD of net returns	49.37	68.29	69.66	96.76
Av. ab. value change[b]				
Risk neutral	—	1.50	1.17	3.67
Low risk	—	1.17	2.17	2.33
Mod. risk	—	1.83	2.33	2.00
High risk	—	3.00	3.67	2.67
Spearman's ρ				
Risk neutral	—	0.82**	0.88*	0.28**
Low risk	—	0.87*	0.72**	0.64**
Mod. risk	—	0.80**	0.62**	0.70**
High risk	—	0.47**	0.08**	0.57**

[a] Negative net returns over total costs, imply that labor, capital, land, or other resources are yielding below market rates of return at assumed output prices.
[b] Average absolute value change in rank from the full experiment.
**ρ is significantly less than 1.0 at 0.05 level.
*ρ is significantly less than 1.0 at 0.10 level.

experiments compared with the complete experiment ranged from 1.2 to 3.7 integer ranks (table 3). Only the Years 4–6 reduced-duration experiment showed greater changes in preference rankings relative to the complete experiment.

The Spearman's correlation coefficients between the full experiment and the reduced rotation experiments ranged from 0.28 to 0.88 for risk neutrality, and 0.08 to 0.87 for risk aversion. These correlations are relatively low compared to those for the duration and replication downsized experiments. All correlation coefficients were significantly less than 1.00 at $p = 0.05$ or $p = 0.10$ levels.

Conclusions

For this case study, downsizing the replications of an agricultural experiment altered profit rankings of different cropping systems less than did cutting the length of the experiment. However, failing to plant all crops in a rotation each year altered profit rankings the most compared with the complete experiment. All three downsizing options altered the economic ranking of systems for both risk-neutral and risk-averse decision makers to some degree. If informed risk management is to play a part in farming, experiments must be extended over sufficient time to provide reasonable estimates of annual income risk as well as mean income. This case study showed that estimates of system profit variability were especially sensitive to downsizing experiment length and failing to plant all crops in a rotation annually.

It was not possible to measure actual performance of annual cropping system profitability when the experiment was downsized by failing to grow every crop in the rotation every year. Synthetic annual cropping systems from these downsized experiments caused system profit rankings to deviate from those in the full experiment by greater amounts than when the experiment was downsized in terms of duration or replications. System profit variability estimates were inflated in these synthetic systems, which failed to capture the within-year crop diversification effect. These results support the principle in the statistics literature that each crop of a rotation should be present every year to properly portray system statistical properties (Cochran, Yates).

While these results from a single cropping system case study will not be representative of all cropping systems experiments, we would expect the general patterns to be fairly common since small-sample bias occurs often under variable annual weather. In our judgment, the potential small-sample misrepresentation of economic performance of competing systems from downsized experiments is worthy of concern. Of course, the increased precision and generality in system performance rankings from more complete experiments must be measured against the cost of larger experiments. In our experience, the marginal cost of additional plots in the form of additional years, replications, or rotational positions varies greatly among experiments. These costs depend upon several factors, including distance of the experiment from headquarters, number and type of measurements conducted, and types of crops and treatments. Due to the commingling of activities with adjacent experiments and the absence of detailed cost records, it was not possible to disaggregate cost savings for the different downsizing alternatives for this case study. Ideally such benefit-cost judgments should be made during the experiment planning stage.

This case study suggests that some principles of cropping system experiment planning may transcend simple cost accounting. If the intent is to measure economic performance at the farm level of cropping systems, then it is critical to include the entire system, including the crop rotation, in the design every year. Otherwise, measurements of mean system profit can be confounded by interactions between annual weather and crop characteristics. Also, the potential risk-reducing effect of within-year crop diversification will be entirely lost. Another principle is that serious attempts to measure both mean and variability of system profit require repeating the experiment over a reasonable span of years. What is reasonable will depend on the variability of weather in the study region. In our experience, experiments in dryland cropping regions that are repeated for only three or fewer years often provide suspect estimates of mean profitability and are nearly useless for estimating variability. In this case study, estimates of system profit based only on the first three "dry years" or last three "wet years" produced very different indicators of economic performance than those from the six-year experiment.

The results of this case study reinforce the oft-repeated advice that agricultural economists should be involved at the planning stage of agricultural experiments. It is impossible to properly assess system profitability and risk of an experiment where inappropriate design and duration has precluded the collection of necessary data. The extensive farming systems literature confirms the importance of participation of agricultural scientists, economists, sociologists, and others in research planning, implementation, and technology transfer (Couger and Knapp, Checkland). On more than one occasion the authors have discussed with agricultural science colleagues the importance of including full annual rotations and longer durations in experiments.

Resolving the problem of conducting experiments of adequate duration and complexity to properly measure risks and trade-offs faced by farmers goes beyond communication between agricultural scientists and economists. Part of the problem is the short-run and narrow disciplinary focus of some research funding. The need to move from one short-term research grant to another discourages obtaining adequate data over variable weather to measure risks and average returns of new practices accurately. Short-run publication pressures at universities and federal agricultural research agencies might also discourage long-run experiments. Yearly publication quotas may demand multiple new experiments. Some agricultural science journals discourage multiple publications from "previously published data." It is sometimes difficult for agricultural economists working on multidisciplinary teams to publish economic feasibility results in agricultural economics journals that prefer papers with theoretical or quantitative innovations. On the positive side, some USDA programs have favored multidisciplinary research approaches and have provided long-term funding to solve particular environmental and production problems. Furthermore, some multidisciplinary journals publish joint submissions from agricultural scientists and economists. These journals often welcome assessments of the risk, spatial adaptability, and social-environmental acceptability of new practices. Policies to promote these trends should be encouraged to provide a favorable environment for long-term research, which permits risk assessments.

References

Anderson, J.R. "Sparse Data, Climatic Variability, and Yield Uncertainty in Response Analysis." *Am. J. Agri. Econ*. 55(February 1973):77–82.

Anderson, J.R., J.L. Dillon, and J.B. Hardaker. *Agricultural Decision Analysis*. Ames: Iowa State University Press, 1977.

Army, T.J., and W.D. Kemper. "Support for Long-Term Agricultural Research." *Agronomy J*. 83(January-February 1991):62–65.

Barry, P.J. *Risk Management in Agriculture*. Ames: Iowa State University Press, 1984.

Boerboom, C.M., F.L. Young, T. Kwon, and T. Feldick. "IPM Research Project for Inland Pacific Northwest Wheat Production." *Agri. Res. Ctr. Bull*. XB 1029, Washington State University, 1993.

Cady, F.B. "Experimental Design and Data Management of Rotation Experiment." *Agronomy J*. 83(January-February 1991):50–56.

Checkland, P.G. *Systems Thinking, Systems Practice*. Chichester: Wiley, 1981.

Clements, S.R., D.L. Benoit, S.D. Murphy, and C.J. Swanton. "Tillage Effects on Weed Seed Return and Seedbank Composition," *Weed Sci*. 44(April-June 1996):314–22.

Cochran, W.G. "Long-term Agricultural Experiments." *Suppl. J. Royal Stat. Soc*. 6(Number 2, 1939):104–48.

Couger, J.D., and Knapp, R.W. (Eds.) *Systems Analysis Techniques*. New York: Wiley, 1974.

Dhuyvetter, K.C., C.R. Thompson, C.A. Norwood, and A.D. Halvorson. "Economics of Dryland Cropping Systems in the Great Plains: A Review." *J. Prod. Agri*. 9(April-June 1996):216–22.

Dillon, J.L., and J.R. Anderson. *The Analysis of Response in Crop and Livestock Production*, 3rd. ed. Oxford: Pergamon Press, 1990.

Frye, W.W., and G.W. Thomas. "Management of Long-Term Field Experiments." *Agronomy J*. 83(January-February 1991):38–44.

Gauch, H.G. Jr., and R.W. Zobel. "Crop Breeding, Genetics & Cytology." *Crop Sci*. 36(July-August 1996):838–43.

Hardaker, J.B., R.B.M. Huirne, and J.R. Anderson. *Coping with Risk in Agriculture*. Oxon: Cab International, 1997.

Hoffnar, B.R., and G.L. Johnson. "Summary and Evaluation of the Cooperative Agronomic Economic Experimentation at Michigan State University. Michigan State University Experiment Station Research Bulletin 11, East Lansing, 1966.

Hoshmand, A.R. *Experimental Research Design and Analysis*. Boca Ratan, FL: CRC Press, 1994.

Lybecker, D.W., E.E. Schweizer, and R.P. King. "Economic Analysis of Four Weed Management Systems." *Weed Sci*. 36(November 1988):846–49.

Needlemen, B.A., M.M. Wander, G.A. Bollero, C.W. Boast, G.K. Sims, and D.G. Bullock. "Interaction of Tillage and Soil Texture: Biologically Active Soil Organic Matter in Illinois." *Soil Sci. Soc. Am. J*. 63(September-October 1999):1326–34.

Raskin, R., and M.J. Cochran. "Interpretation and Transformations of Scale for the Pratt-Arrow Absolute Risk Aversion Coefficient: Implications for Generalized Stochastic Dominance." *Western J. Agri. Econ*. 11(December 1986):204–10.

Rausser, G. "Private/Public Research: Knowledge Assets and Future Scenarios." *Am. J. Agr. Econ*. 81(1999):1011–27.

Robison, L.J., and P.J. Barry. *The Competitive Firm's Response to Risk*. New York: Macmillan, 1987.

Smith, E.G., Y. Peng, M. Lerohl, and F.J. Larney. "Economics of N and P Fertilization to Restore Wheat Yields on Three Artificially Eeroded Sites in Southern Alberta. *Can. J. Soil Sci*. 80(February 2000):165–69.

Tracy, P.W., D.G. Westfall, E.T. Elliott, and G.A. Peterson. "Tillage Influence on Soil Sulfur Characteristics in Winter-Summer Fallow Systems." *Soil Sci. Soc. Am. J*. 54(November-December 1990):1630–4.

Wei, W., J.R. Alldredge, D.L. Young, and F.L. Young. "Downsizing an Integrated Crop Management Field Study Affects Economic and Biological Results." *Agronomy J*. 93(March-April 2001):412–7.

Yates, F. "The Design of Rotation Experiments." In Technical Communication No. 46, Proceedings of the First Commonwealth Conference on Tropical and Sub-Tropical Soils, Harpenden, England: Commonwealth Bureau of Soil Science, 1948, 142–55.

Young, D.L., T.J. Kwon, and F.L. Young. "Profit and Risk for Integrated Conservation Farming Systems in the Palouse." *J. Soil Water Cons*. 49(November-December 1994):601–06.

Young, F.L., A.G. Ogg, Jr., R.I. Papendick, D.C. Thill, and J.R. Alldredge. "Tillage and Weed Management Affects Winter Wheat Yield in an Integrated Pest Management System." *Agronomy J*. 86(January-February 1994):147–54.

Zar, J.H. *Biostatistical Analysis*. 3rd. ed. Upper Saddle River: Prentice Hall, 1996.

Zentner, R.P., McConkey, B.G., Campbell, C.A., Dyck, F.B., and Selles, F. "Economics of Conservation Tillage in the Semiarid Prairie." *Can. J. Plant Sci*. 76(October 1996):697–705.