2001

Separating the Impacts of Crop Diversification and Rotations on Risk

Glenn A. Helmers
University of Nebraska - Lincoln, ghelmers1@unl.edu

Charles F. Yamoah
Soil Res. Inst., Kumasi, Ghana

Gary E. Varvel
University of Nebraska - Lincoln, gevarvel@windstream.net

NOTES AND UNIQUE PHENOMENA

Separating the Impacts of Crop Diversification and Rotations on Risk

Glenn A. Helmers, Charles F. Yamoah, and Gary E. Varvel

ABSTRACT

It has been commonly accepted that crop rotations reduce risk compared with monoculture systems. Quantifying this phenomenon requires that effects of yield stability on risk (positive or negative) arising from rotating crops be separated from other risk elements. Using an ARS–University of Nebraska series of yields for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] grown over a 14-yr period, both in rotation and in monoculture, the impact of crop rotation on risk was isolated and estimated. Risk was defined as the failure to meet an annual per-hectare net return target. A corn–soybean rotation had significantly less risk than monoculture practices. Diversification was found to contribute to part of this reduction while higher yields and reduced cost contributed to the remainder. This reduction in risk occurred even though the corn–soybean rotation had a higher yield variance.

Experimental yield data on crops grown under monoculture conditions as well as when sequenced are commonly available from cropping system research studies. Where the experiment is of sufficient duration, the risk consequences of alternative cropping systems can be estimated using yield data along with price and cost data. Further, in doing so, it is often possible to separate the risk effects of crop rotation and crop diversification. The risk benefits of crop diversification are generally well understood, but the additional effect of rotational cropping on risk is less understood. Further, it is important to understand the underlying causes when rotations reduce risk.

The use of crop rotations have generally been thought to reduce risk compared with monoculture cropping (Helmers et al., 1986). The benefit of crop rotations in reducing risk involves three distinct influences. First, conventionally practiced rotations involve diversification, an *offsetting* phenomenon where low returns in one year for one crop are combined with relatively high returns from a different crop. Second, rotation cropping is generally thought to reduce yield variability compared with monoculture practices. Last, rotations, as opposed to monoculture cropping, may result in overall higher crop yields as well as reduced production costs. Where risk is defined as the failure to reach a target return, these influences may reduce risk by reducing the severity of the return failures.

G.A. Helmers, Dep. of Agric. Econ., P.O. Box 830922, Univ. of Nebraska, Lincoln, NE 68583-0922; C.F. Yamoah, Soil Res. Inst., Kumasi, Ghana; and G.E. Varvel, USDA-ARS, P.O. Box 830934, Univ. of Nebraska, Lincoln, NE 68583-0934. Journal Ser. no. 13371, Agric. Res. Division, Univ. of Nebraska.

Published in Agron. J. 93:1337–1340 (2001).

Cropping System Risk

Risk is generally considered a strong behavioral force affecting decision making. At the farm level, higher risk may or may not accompany higher profit alternatives. If higher profit alternatives involve less or no greater risk than lower profit alternatives, the higher profit alternative is the obvious choice. When higher profit alternatives involve greater risk, a choice must be made between the two objectives.

Cropping system risk results from variability in returns across time and arises from year-to-year changes in yields, crop prices, and input costs. A number of risk concepts and their analytic implementations exist (Anderson et al., 1977; Harwood et al., 1999). Often variability or a second-moment concept is used in analyzing risk of individual activities or a portfolio of activities (Anderson et al., 1977; Freund, 1956). The portfolio analysis approach based on the foundation of utility maximization has also been linearized (Hazell, 1971). Another perspective of risk is how far and/or often returns fail to reach a below-mean target return level (Held et al., unpublished, 1982; available from the corresponding author) (Tauer, 1983; Watts et al., 1984). In standard second-moment analysis, the mean is used as a target; however, a disadvantage of this approach is that the mean is different for each cropping system. A below-mean target that is fixed across all systems does not have that disadvantage.

Another risk analysis approach is stochastic dominance (Quirk and Saposnic, 1962). First-degree stochastic dominance rests on the axiomatic foundation that more is preferred to less and is implemented by comparing cumulative distribution function curves of alternatives. Analysis of second- and third-degree stochastic dominance rests, however, on other behavioral assumptions.

Still another approach is when the risk focus is placed on minimizing the probability of falling below a *disaster* target level (Moscardi and de Janvry, 1977; Atwood et al., 1988) (Watts et al., unpublished, 1989; available from the corresponding author). This approach to risk, termed *safety first*, has a strong intuitive appeal and empirical support. From a survey of 149 producers in 12 states, Patrick et al. (1985) reported that many producers, "indicated what could be interpreted as substantial 'safety-first' considerations in their decision making" (p. 237–238). In this paper, we used this approach and measured risk as the cumulative sum of the shortfalls when annual net returns fell below a specified net return target for the 14-yr analysis period.

Procedure

To isolate the risk contribution to income stability from rotations as opposed to diversification alone, an analysis was done using experimental dryland yield data from eastern Nebraska for the 1985–1998 time period. This involved two crops (corn and soybean fertilized at 90 and 0 kg N ha^{-1}, respectively) grown both in monoculture and in rotation with the other crop. The entire experiment also involved other crops and other fertilization levels, but for simplicity, only two crop–fertilization choices are used here (Peterson and Varvel, 1989a, 1989b). Also, the grain yield analysis of this experiment is presented in Varvel (2000), and annual yields are available from Varvel (unpublished data, 2000). Using a different time period and different cropping systems from this experiment, optimum crop–fertilization system proportions were developed based on return variability, target variability, and safety first (Helmers et al., 1998). In that analysis, no attempt was made to quantify rotation risk vs. diversification risk.

In developing net returns for each system, each year's harvest price for corn and soybean was used (Wellman, 1999). For operating input costs, a 1998 cost was used (Selley et al., 1999) for each system and deflated for prior years. For monoculture corn, monoculture soybean, corn following soybean, and soybean following corn, these costs (1998 basis) were \$317.22, \$292.70, \$280.49, and \$238.70 ha^{-1}, respectively. Hence, net returns (returns to land, labor, machine ownership, overhead, and management) varied between years because of both yield and product price variability. The estimated net returns for four cropping sequences over the 14-yr period are presented in Table 1. These cropping sequences are monoculture corn (CC), monoculture soybean (SBSB), corn following soybean (C/SB), and soybean following corn (SB/C). For corn following soybean, corn was grown each year but on alternating plots with soybean. This is similarly the case for soybean following corn. The two monoculture sequences are also considered systems. The other two systems developed here (CC-SBSB and C-SB) make use of the two monoculture series as well as the two rotation sequence series, respectively.

The series of annual net returns for a diversified system, constructed by averaging annual monoculture corn and monoculture soybean returns, is presented in Table 1. It is termed diversified because no rotation is involved, yet both crops are grown. This system could be termed 50% monoculture corn and 50% monoculture soybean. In addition, the net-return series for a rotation-diversified system is also presented in Table 1. This is found by averaging the annual entries for corn following

Table 1. Estimated net returns (1985–1998) for four cropping sequences and the diversified and rotation-diversified systems.

	Cropping sequences and systems†					
	CC	SBSB	C/SB	SB/C	CC-SBSB (diversified)	C-SB (rotation diversified)
	$/ha					
1985	546.34	243.79	750.76	210.59	395.07	480.68
1986	223.98	374.13	349.06	467.67	299.06	408.37
1987	221.44	394.56	480.24	433.53	308.00	456.89
1988	237.00	273.77	447.34	295.73	255.39	371.54
1989	364.74	14.92	88.57	96.16	189.83	92.37
1990	277.73	195.38	279.41	334.31	236.56	306.86
1991	358.74	133.45	513.02	349.78	246.10	431.40
1992	438.35	314.68	623.75	321.72	376.52	472.74
1993	426.45	392.73	654.48	439.31	409.59	546.90
1994	326.56	276.29	582.20	451.96	301.43	517.08
1995	−109.67	87.27	179.08	121.23	−11.20	150.16
1996	506.08	428.57	618.07	647.16	467.33	632.62
1997	439.24	312.53	432.52	431.24	375.89	431.88
1998	217.09	434.87	419.80	475.87	325.98	447.84
Avg.	319.58	276.92	458.45	362.59	298.25	410.52
SD	158.51	125.44	180.60	143.41	113.16	139.84

† CC, monoculture corn; SBSB, monoculture soybean; C/SB, corn following soybean; SB/C, soybean following corn; CC-SBSB, corn and soybean grown each year but not in rotation; C-SB, corn and soybean grown each year and in rotation.

soybean and soybean following corn. This alternative is termed rotation diversified because in addition to having corn and soybean grown each year, each crop is grown in rotation.

The diversified system is rarely practiced and can be considered artificial. Yet its construction is useful for analysis. Comparing its risk with the rotation-diversified system allows the identification of risk benefits of rotations. The rotation-diversified system involves risk benefits from both diversification and rotation while only risk benefits of diversification are observed for the diversification system. Diversification may reduce risk because a year of low returns for one crop may be offset by high returns from another crop. The risk advantage of diversification relative to a single crop cannot be evaluated using annual physical output from each system. This is because (i) corn and soybean differ in their relative value and (ii) the prices of corn and soybean do not move uniformly through time. Hence, net returns of each system are presented in Table 1.

Rotation risk involves two additional aspects. The first is the phenomenon that by growing one crop after another, yield variability may be affected. The yield variability component of rotation can be stabilizing (risk reducing) or destabilizing (risk increasing).

The second risk component derived from rotations centers on the net-return benefits of rotations resulting from higher yields and reduced growing costs. Risk benefits of rotations arising from these two aspects can be observed by comparing risk for all systems where risk is defined as accumulated returns below a target level. Risk defined as a deficit return is impacted by yield variability because low yields lead to low returns. In addition, however, risk is impacted by influences that lead one system to have persistently higher net returns than another.

The four cropping systems of Table 1 (monoculture corn, monoculture soybean, diversified, and rotation diversified) were evaluated for average net returns and risk, with their estimates placed in Table 2. Risk is calculated by totaling the dollar deficits for all years where returns fall below \$250 ha^{-1}. For example, for monoculture corn, this occurs in years 1986, 1987, 1988, 1995, and 1998. The deficits for these years total \$460.16. In addition, net-return deficits under \$100 ha^{-1} were also examined for each cropping system because the choice of a target is arbitrary. Deficits are obviously lower using a lower disaster target. For most cropping systems, net returns were noticeably low in 1989 and 1995. These were caused by low yields resulting from abnormally low precipitation (Varvel, 2000).

Table 2. Average net returns and risk of four systems involving monoculture and rotational cropping.

	Avg. net return	Risk-accumulated returns Below \$250	Below \$100
	\$/ha		
Monoculture cropping			
a) CC†	319.58	460.16	290.67
b) SBSB‡	276.92	575.19	97.80
Diversified cropping			
CC-SBSB§	298.25	338.71	111.20
Rotation diversified cropping			
C-SB¶	410.52	257.47	7.63

† CC, monoculture corn.
‡ SBSB, monoculture soybean.
§ CC-SBSB, corn and soybean grown each year but not in rotation.
¶ C-SB, corn and soybean grown each year and in rotation.

RESULTS

Comparison of net-return variability (standard deviation of net returns) in Table 1 for monoculture corn, monoculture soybean, diversified, and rotation-diversified systems allows a determination of the yield stability phenomenon. In this case, diversification significantly reduces net-return variability (\$113.16) compared with the average (\$141.98) of monoculture corn (\$158.51) and monoculture soybean (\$125.44). This is due to the offsetting phenomenon where when returns of one crop are low, returns of the other crop tend not to be low. However, net-return variability is greater for the rotation-diversified system (\$139.84) than for the diversified system. This is due almost exclusively to yield variability differences between the systems. Thus, rotation cropping is seen here to be destabilizing with respect to yields. Another perspective of this can be seen in the comparisons of net-return variability of corn grown under monoculture (\$158.51) vs. following soybean (\$180.60). It is also similarly seen when comparing the standard deviation of monoculture soybean (\$125.44) vs. rotation soybean (\$143.41).

An exact measure of the yield stability effect of rotations is the standard-deviation comparison of diversified vs. rotation-diversified systems using constant product prices and input costs. This measure is expected to be close to the 81% proportional comparison (\$139.84 vs. \$113.16) using the process for product prices and inputs previously described. This was, in fact, the case here where when using constant product prices and input costs, the estimate was 74%.

Comparing the risk results for both monoculture systems with the diversification system (Table 2) again demonstrates the benefits of diversification on risk. Compared with monoculture corn, diversification reduces risk from \$460.16 to \$338.71 using \$250 ha^{-1} as the risk target. Using monoculture soybean as the comparison, the benefits of diversification are even greater (\$575.19 vs. \$338.71). If the average risk of monoculture corn and monoculture soybean (\$517.68) is used as a comparison point, diversification reduces risk by 34.6%. Comparing the diversified and the rotation-diversified system indicates that risk is further decreased with the rotation-diversified system an additional 15.1%, from \$338.71 to \$257.47, due to enhanced yields and reduced costs. The overall risk from rotational cropping is 49.7% of the average of monoculture corn and monoculture soybean. This overall reduction occurs in the face of what previously was shown to be an increased yield variability phenomenon arising from rotation cropping.

When \$100 ha^{-1} is used as the risk target, a more dramatic reduction in risk is observed from the rotation. The accumulated deficits for monoculture corn and monoculture soybean are \$209.67 and \$97.80, respectively, or an average of \$153.74. Diversification results in a 27.7% reduction (to \$111.20 ha^{-1}), but the rotation-diversified system leads to a further 67.3% risk reduction (to \$7.63 ha^{-1}).

It should be noted that when risk is defined only by variability, the rotation-diversified system has a greater standard deviation than the diversified system. However, using the safety-first risk criterion of Table 2, the opposite is true. This demonstrated that the diversified system has less upside potential than the rotation-diversified system even though the variability of the diversified system is relatively low.

The yield stability factor for the rotation is negative here (reduced stability); however, this should not be assumed to always hold. Were risk defined only as variability in net returns, the rotation analyzed here increases risk because of increased yield instability. However, the risk benefits resulting from increased yields and lower costs from rotational cropping strongly override the yield instability factor.

SUMMARY AND CONCLUSIONS

Rotation cropping of corn and soybean was found to have a significant risk advantage over monoculture production. Part of the reduced risk resulted from diversification inherent in a rotation. However, another major influence was the positive yield interaction and reduced production-cost aspect of the corn–soybean rotation. Risk was defined as the cumulative net-return deficits relative to a target net return for a 14-yr period.

Statistical variability analysis was used to examine whether a corn–soybean rotation reduced yield variability compared with a system of 50% monoculture corn and 50% monoculture soybean. It was found that the rotation led to increased yield instability. Thus, the corn–soybean rotation had significant risk advantages over monoculture production but not because of enhanced yield stability.

The process of analyzing net-return series for monoculture systems and rotation systems using yield trials, product prices, and input costs allows risk and yield stability comparisons to be made. The relative impacts of rotations on risk and yield stability are expected to differ significantly for different crops and locations.

REFERENCES

Anderson, J.R., J.L. Dillon, and J.B. Hardaker. 1977. Agricultural decision analysis. Iowa State Univ., Ames.

Atwood, J.A., M.J. Watts, G.A. Helmers, and L.J. Held. 1988. Incorporating safety-first constraints in linear programming production models. West. J. Agric. Econ. 13:29–36.

Freund, R.J. 1956. The introduction of risk into a programming model. Econometrica 24:253–263.

Harwood, J.L., R. Heifner, K. Coble, J. Perry, and A. Somwaru. 1999. Managing risk in farming: Concepts, research, and analysis. Agric. Econ. Rep. 774. Econ. Res. Serv., USDA, Washington, DC.

Hazell, P.B.R. 1971. A linear alternative to quadratic and semivariance programming for farm planning under uncertainty. Am. J. Agric. Econ. 53:53–62.

Helmers, G.A., W. Dias, M.R. Langemeier, and J.A. Atwood. 1998. Risk analysis of cropping systems using experimental cropping system–fertilizer data. Am. Agric. Econ. Assoc., Salt Lake City, UT.

Helmers, G.A., M.R. Langemeier, and J. Atwood. 1986. An economic analysis of alternative cropping systems for east-central Nebraska. Am. J. Altern. Agric. 1:153–158.

Moscardi, E., and A. de Janvry. 1977. Attitudes toward risk among peasants: An econometric approach. Am. J. Agric. Econ. 59:710–716.

Patrick, G.R., P.N. Wilson, P.J. Barry, W.G. Boggess, and D.L. Young. 1985. Risk perceptions and management responses: Producer-generated hypothesis for risk modeling. South. J. Agric. Econ. 17(2): 231–238.

Peterson, T.A., and G.E. Varvel. 1989a. Crop yield as affected by rotation and nitrogen rate: I. Soybean. Agron. J. 81:727–731.

Peterson, T.A., and G.E. Varvel. 1989b. Crop yield as affected by rotation and N rate: III. Corn. Agron. J. 81:735–738.

Quirk, J.P., and R. Saposnic. 1962. Admissibility and measurable utility functions. Rev. Econ. Stud. 29(2):140–146.

Selley, R.A., P.K. Cox, R.T. Clark, T. Holman, and R.N. Klein. 1999. Nebraska crop budgets. EC99-872-S. Univ. of Nebraska Coop. Ext., Lincoln.

Tauer, L.W. 1983. Target MOTAD. Am. J. Agric. Econ. 65:606–610.

Varvel, G.E. 2000. Crop rotation and nitrogen effects on normalized grain yields in a long-term study. Agron. J. 92:938–941.

Watts, M.J., L.J. Held, and G.A. Helmers. 1984. A comparison of target MOTAD to MOTAD. Can. J. Agric. Econ. 32:175–186.

Wellman, A.C. 1999. Crop and livestock prices for Nebraska producers. EC99-883-C. Univ. of Nebraska Coop. Ext., Lincoln.