Journal of Agricultural and Resource Economics, 18(1): 117–130

Farm Value of Topsoil in Spring Wheat Production

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Relationships among topsoil removal treatments and additions of nitrogen and phosphorus fertilizer on spring wheat yields are used to determine the effects on net returns and to estimate the marginal value of soil. The results indicate that risk-averse managers are not willing to make an expenditure for controlling erosion from the first 2.5 inches of soil if the erosion rate is 20 tons/acre/year or less and the planning horizon is 20 years or less. These managers would be willing to make an erosion control investment for the second 2.5 inches of soil equivalent to $4.90 to $5.20/acre from the twenty-first to forty-third year in the planning horizon.

Key words: risk, soil erosion, topsoil value, wheat.

Introduction

Risk influences the efficiency of resource allocation in agriculture and the decision-making processes of farm managers. Topsoil loss and the subtle changes that occur in soil properties can reduce crop productivity and create soil management problems (Tanaka and Aase). The rate of topsoil loss also can affect the riskiness of net returns from crop production, as well as the expense to control erosion. Use of improved cultivars, better weed control, and applications of commercial fertilizers has been shown to offset the effects of soil loss and increase yields (Krauss and Allmaras). Young, Taylor, and Papendick reported that, although net positive impacts of technological improvements have more than offset the negative yield impact of topsoil loss, some production loss has resulted from soil erosion. The proper measure of yield impact is the reduction in potential yield, i.e., the yield that could be achieved with reduced erosion.

Studies such as those by Larson, Pierce, and Dowdy, and Pierce et al. have attempted to estimate the accumulated yield reductions that would occur from soil erosion over a specified planning horizon. Both Klemme and Williams derived the annualized present values generated by various rates of annual percentage losses in yield of corn from soil erosion as a way of determining the additional production costs that would be accepted in changing from conventional tillage to no-tillage systems. These studies did not account for the loss of potential yield. Walker developed an erosion damage function to evaluate reduced tillage for wheat in the Idaho/Washington Palouse area. He found that on some deep soils, erosion was economically rational because the reduction in yields from the loss of the first layer of soil was small.

The analysis performed in this study addresses not only yield loss due to erosion, but the compensation of this potential yield loss with fertilizers. An economic evaluation is used to determine the effects on net returns of spring wheat and variability of these net returns for various combinations of instantaneous soil loss and fertilizer application rates for an important Northern Great Plains soil. The value of soil loss caused by erosion

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This is Contribution No. 92-268-J from the Kansas Agricultural Experiment Station.

without the masked effects of technological progress over time is then estimated. The objectives are to determine: (*a*) the most risk-efficient soil loss and fertilizer application rates for different classes of farm managers (risk-averse, risk-neutral, and risk-seeking), and (*b*) the value of the eroded soil for risk-averse managers. The derived value of soil is the annualized present value (equivalent level annuity) that spring wheat producers could incur to reduce soil erosion in the Northern Great Plains.

Procedures

Characteristics of the yield and net return distributions for spring wheat under alternative soil loss levels and fertilization rates are examined. Stochastic dominance procedures and sensitivity analysis are used to determine the most efficient levels of soil loss and fertilizer application for risk-seeking, risk-neutral, and risk-averse farm managers. The value of soil in spring wheat production for risk-averse managers also is derived.

A study conducted near Sidney, Montana, from 1982 through 1989 evaluated the effects of soil removal and fertilizer rates for spring wheat yields and yield components on Williams loam soil (Tanaka and Aase). Williams loam encompasses 10 to 12 million acres in the Northern Great Plains. This and associate soils are found in the Canadian prairie provinces as well as Montana and North Dakota. In the experiment, soil was undisturbed or mechanically removed from the surface of a Williams loam (fine–loamy mixed, Typic Argiborolls) to depths of 2.5, 5, and 7.5 inches in a spring wheat–fallow rotation. The topsoil depth prior to removal was 5 inches. This was equivalent to all of the *Ap* horizon. The removal of 7.5 inches was equal to all of the *Ap* horizon and approximately one-half of the *B21t* horizon. To these soil removal treatments, two levels of phosphorus (P) (18 and 36 lbs./acre) and two levels of nitrogen (N) (30 and 60 lbs./acre) were applied in years when wheat was planted. Controls with no N and/or no P were included. Spring wheat yields were obtained from each of the 36 combinations of the soil loss levels (S) and rates of P and N.

Cumulative probability distributions of net returns over variable costs are estimated using equation (1) for each of the 36 treatments (strategies). Net returns include an adjustment for participation in the government commodity program. When farm managers decide to participate in the government program, they elect to give up some potential income (income from set-aside acres) in return for some minimum price protection (the target price) on an established farm yield (program yield). The farms receive a deficiency payment per bushel of program yield based on the difference between the target price and average market price.

Annual per-acre net returns over variable costs (net returns to land, overhead, risk, and management) for wheat in the government program are estimated using:

$$(1)\quad NR = [((\max\{P, EL\} \cdot Y_f) - PRODC - HARVC) \cdot PA] + [(\max\{0, (TP - \max\{EP, EL\})\} \cdot Y_p) \cdot (PA - FA)] - (SC \cdot SA) - (SFC \cdot SFA),$$

where NR = net returns ($/acre); P = market price ($/bu); EL = effective national average commodity program loan rate ($/bu); Y_f = actual yield produced on planted acres (bu/acre); TP = commodity program target price ($/bu); EP = expected national average price ($/bu); Y_p = commodity program yield (bu/acre); $PRODC$ = production costs on planted acres ($/acre); $HARVC$ = harvest cost on planted acres ($/acre); PA = planted acreage as a percentage of total acres including planted, fallow, and set-aside acres (%); FA = flex acreage requirement as a percentage of total acres including planted, fallow, and set-aside acres (%); SA = set-aside acreage requirement as a percentage of total acres including planted, fallow, and set-aside acres (%); SFA = fallowed acreage as a percentage of total acres including planted, fallow, and set-aside acres (%); SC = maintenance costs on set-aside acres ($/acre); and SFC = maintenance costs on fallow acres ($/acre).

Means, minimums, maximums, standard deviations, and coefficients of variation statistics for the distributions of per-acre net returns are compared for each treatment. Examining the average net returns and selected costs can be useful, but it is important to recognize that the distribution of net returns for each strategy will reflect a different amount of risk. Stochastic dominance is a risk analysis technique that chooses among a set of alternatives by comparing the distribution of possible returns for each strategy and selecting preferred strategies based on risk preferences and not just the mean and standard deviations. A detailed discussion of the usefulness of stochastic dominance efficiency criteria can be found in Robison and Barry.

Stochastic dominance techniques are used in this article to select the most efficient combination of soil loss and application rates of N and P fertilizers. This technique relies on comparing probability distributions of possible returns for each treatment (strategy). Several stochastic dominance efficiency criteria exist, including first-degree stochastic dominance (FSD), second-degree stochastic dominance (SSD), and stochastic dominance with respect to a function (SDWRF).

The simplest of these criteria is FSD. FSD holds for most decision makers who prefer strategies providing more income to less, which limits it somewhat. A strategy will be first-degree stochastic dominant over all other strategies only if each observation of the net return in that distribution is equal to or greater than (at least one observation being higher) the return in the other distributions at all levels of the cumulative probability. FSD usually will not select a single strategy or small set of efficient strategies from among the choices.

SSD holds for those decision makers who are risk-neutral or risk-averse and is more discriminating than FSD in that it reduces the number of strategies that are risk-efficient. It is useful when risk aversion is the normal behavior of the individual. Strategies that are SSD-efficient will have a smaller area under their cumulative probability distribution (for each and every income observation) than those that are not, because the area is summed across the observations of net return from lowest to highest. Although SSD is more discriminating than FSD, it has low discriminating power in many practical applications and may not be able to reduce the possible combinations to a small set.

Greater flexibility is allowed with the use of SDWRF. This criterion orders the uncertain combinations for more specific levels of risk preference, ranging from risk-averse to risk-seeking. Although risk-seeking behavior is not considered to be typical among successful managers, using the SDWRF risk-seeking criteria, along with risk-averse criteria, shows that some strategies are riskier than others. The SDWRF criterion orders the choices by defining intervals using an absolute risk-aversion function $R(x)$. These risk preference intervals are bounded by a lower risk-aversion coefficient, $R_1(x)$, and an upper risk-aversion coefficient, $R_2(x)$, which characterize the general degree of risk aversion for a manager. A risk-efficient set of strategies will include the choices preferred by each manager having risk preferences consistent with the restrictions imposed by the interval.

King and Robison suggested that most intervals should be established within the range from $R(x) = -.0001$ to $R(x) = -.0010$ for whole-farm analysis. If, for instance, $R(x)$ is .0001 per dollar, then the manager's added utility or satisfaction from an additional dollar is falling at a rate of .01% per dollar increase in net return. Likewise, the value $R(x) =$ .00001 per dollar indicates that satisfaction is falling at a rate of .001% per dollar of additional net return. The manager receives less satisfaction from an increase in income in the first case than in the second. For this reason, values close to .0001 can be defined as more risk-averse than those near .00001, because less satisfaction is received from an additional dollar of income. Risk-neutral behavior for whole-farm analysis generally would be defined as values at, or close to, zero (range of $-.00001$ to .00001). Intervals above this range characterize more risk-averse behavior. An interval below $-.00001$ characterizes more risk-seeking behavior.

FSD, SSD, and eight risk preference intervals are used to determine the preferred strategies in this study. The risk preference categories used here are whole-farm risk-aversion coefficients adjusted to evaluate per-acre net returns using a method suggested by Raskin and Cochran. In this case 2,000 acres is used to convert the coefficients. For example, an interval of −.00001 to .00001 is converted by multiplying the coefficients by 2,000, with a resulting interval of −.02 to +.02. The stochastic dominance analysis is conducted using a program developed by Cochran and Raskin.

Data

Brief descriptions of the strategies, yield data, prices, and production costs are provided.

Yields

Spring wheat yields were obtained from the study conducted by Tanaka and Aase near Sidney, Montana. The study was initiated in 1982, with yields collected each year through 1989. Soil was mechanically removed and three levels each of N and P were applied to the experimental plots. The 36 treatments (strategies) are referred to throughout the remainder of this article as follows:

Soil Removal Levels (inches)	Phosphorus (lbs./acre)	Nitrogen (lbs./acre)
$S0$ – 0.0	$P0$ – 0	$N0$ – 0
$S1$ – 2.5	$P1$ – 18	$N1$ – 30
$S2$ – 5.0	$P2$ – 36	$N2$ – 60
$S3$ – 7.5		

For example, $S1P2N1$ refers to a strategy that has a 2.5 inch soil loss, 36 lbs. P/acre, and 30 lbs. N/acre.

One crop was planted and harvested on each plot every two years. Fertilizer was applied just before wheat was drilled in late April. Chemicals for weed control were applied after emergence in early June. Wheat was harvested in August of each year. The land remained in fallow for 21 months following harvest. Stubble–mulch fallow was used and tillage consisted of sweep tillage in late May of the following year. This operation was followed by two or three rod weeder operations to control weeds.

The eight years of yield data from the 36 strategies, combined with historical cost and price data, are used to estimate the potential net return distributions for each strategy. A brief explanation of the estimates of prices and the variable costs for each strategy used in computing the cumulative probability distribution of net returns follows.

Prices and Costs

Prices used in this analysis are the eight-year (1982–89) market prices for the Sidney, Montana area. Prices are adjusted to 1990 dollars using the U.S. Department of Agriculture index of crop prices received by farmers. The loan rate, target price, and acreage reduction requirement for the 1992 commodity program are used. The program yield used in equation (1) for estimating the net return of each strategy is the average yield of each respective strategy. The target price and loan rate for wheat are \$4/bu and \$2.21/bu, respectively. The acreage reduction requirement (set-aside) for wheat is 5%. The analysis is based on per-acre costs and returns including fallow costs. For this reason, the planted acre costs of spring wheat are weighted by .475 (950 acres planted for each 2,000 acres) and the per-acre costs of set-aside and fallow acres are weighted by .025 and .50, respectively (50 set-aside acres and 1,000 fallow acres in each 2,000). The required flex acreage for wheat is 15%. It is assumed that wheat is planted on the flex acreage, although deficiency payments are not received on this acreage. Therefore, returns from the market per acre are weighted by .475 and those from deficiency payments are weighted by .40.

The input levels for labor and machinery are based on Montana State University Cooperative Extension budgets for conventional tillage spring wheat (Johnson et al.). Labor costs are estimated using an input level of .35 hours/acre for planted acres and .32

hours/acre for set-aside and fallow acres. Set-aside acres are assumed to be in fallow. A labor charge of \$6/hour is used. The seeding rate is one bushel (60 lbs.)/acre. Seed costs are \$6.50/planted acre. Chemical costs are based upon application rates of three pints/acre of Hoelon and two pints/acre of Buctril. Total chemical costs are \$26.65/planted acre. Equipment and machinery expenses including depreciation are equal to \$10.37/acre for planted acres and \$7.33/acre for set-aside and fallow acres. Refer to Johnson et al. for a more detailed explanation of the cost estimates.

The remainder of the variable input costs, which vary by strategy, are explained below. Fertilizer costs are estimated using the pounds per acre of N and P applied. The eight-year average prices of ammonium nitrate (34–0–0) and triple superphosphate (20% P) are used. Average costs are \$.25/lb. for N and \$.545/lb. for P. All fertilizer is assumed to be applied at planting. A charge of \$.06/bu is used to estimate the hauling expense. Interest on one-half of the variable input cost is charged at a nominal rate of 12%.

Results and Discussion

Characteristics of the yield distribution for each of the 36 strategies are examined. These results are followed by a discussion of the analysis of the net return distributions and the estimation of soil value.

Yields

Yield distribution results are reported in table 1. The highest average yield is for the strategy with 2.5 inches of soil loss and the highest application levels of P and N (*S1P2N2*). However, comparison of the mean spring wheat yield for each combination of fertilizer rates, across soil loss levels, indicates yields from no soil loss (*S0*) to be the highest except for two strategies that have a small amount of soil loss and both P and N applied. The strategies *S1P1N1* and *S1P2N2* have higher yields than *S0P1N1* and *S0P2N2*. The soil removal levels of 5 and 7.5 inches (*S2* and *S3*) provide the lowest yields for each fertilizer combination. The maximum individual yield for the eight-year period is in the no soil removal group (*S0P2N2*) and minimum yield is in the *S1* group (*S1P2N2*). The largest minimum yield for each fertilizer level generally is found in the *S1* soil loss group.

Standard deviations tend to increase as the average yield increases. Within a given set of soil removal and P levels, standard deviations for yield generally increase as the level of N increases. This is also generally the case when N is held constant and P is increased.

Within each set of soil removal and P levels, the coefficient of variation for yields generally increases with application of N. This indicates a higher degree of relative variability with increased N application. A consistent pattern is not apparent for P application.

Duncan tests for mean separation were performed to determine if the means of the yields for each strategy were significantly different ($\alpha = .05$). A weighted Duncan's analysis was performed because the means and variances did not appear to be independent (higher variances are associated with higher means). For each strategy, the residuals were weighted by the reciprocal of the variance of the distributions. The impact of this analysis incorporates the variability associated with each strategy into the comparison estimates. This statistical test indicates that strategies *S0P2N1*, *S0P2N2*, *S1P1N1*, *S1P2N2*, and *S2P2N2* have the highest mean yields and are not significantly different from each other (table 1).

Net Returns

Net returns over variable costs, as well as standard deviations, coefficients of variation, and other distribution characteristics, are reported for each combination of soil removal levels and application rates of N and P (table 1).

The strategy with the highest net return of \$12.90/acre is *S0P0N0*, which is followed closely by *S1P0N0* and *S1P1N1*, with net returns of \$11.02 and \$11/acre, respectively.

Table 1. Yield and Net Return Distribution Characteristics for Soil Removal and N and P Fertilizer Strategies

	Yield Distribution Characteristics					Net Return Distribution Characteristics				
Strategy[a]	Mean	SD	CV	Max.	Min.	Mean	SD	CV	Max.	Min.
	(bu/acre)		(%)	(bu/acre)		($/acre)		(%)	($/acre)	
S0P0N0	23.18	9.67	.42	38.4	12.1	12.90[c]	13.84	1.07	33.83	−4.47
S0P0N1	23.74	10.84	.46	42.2	11.5	10.06[d]	15.90	1.58	38.61	−9.28
S0P0N2	24.20	10.93	.45	43.0	12.8	7.70	16.79	2.18	36.20	−10.69
S0P1N0	24.09	9.81	.41	39.0	14.3	9.53	14.02	1.47	32.86	−5.60
S0P1N1	26.13	11.26	.43	45.7	12.5	10.10[d]	17.40	1.72	39.73	−12.25
S0P1N2	26.11	12.13	.46	48.7	12.8	5.56	17.99	3.24	40.42	−15.50
S0P2N0	26.61	10.05	.38	43.2	16.9	9.25	14.50	1.57	34.91	−5.69
S0P2N1	27.41[b]	12.20	.44	49.7	14.6	7.39	18.75	2.54	41.07	−13.34
S0P2N2	27.85[b]	12.87	.46	52.7	14.7	4.36	19.85	4.55	41.98	−16.83
S1P0N0	21.98	7.53	.34	33.7	12.6	11.02[d]	11.22	1.02	29.11	−4.44
S1P0N1	23.36	8.71	.37	37.6	14.5	9.61	12.66	1.32	31.62	−4.69
S1P0N2	23.23	9.26	.40	38.8	13.3	6.60	14.23	2.35	29.57	−10.71
S1P1N0	23.84	8.50	.36	37.3	13.5	9.28	12.25	1.32	26.78	−7.82
S1P1N1	27.00[b]	10.76	.40	46.0	17.6	11.00[d]	15.65	1.42	40.43	−3.88
S1P1N2	24.81	10.36	.42	44.7	15.6	3.93	15.86	4.03	33.97	−11.40
S1P2N0	23.78	6.55	.28	35.3	17.2	4.50	8.99	2.00	17.76	−5.76
S1P2N1	26.43	10.19	.39	44.3	17.0	5.74	15.69	2.73	32.67	−9.94
S1P2N2	27.88[b]	11.69	.42	52.3	17.7	4.55	17.90	3.94	41.42	−12.34
S2P0N0	16.56	5.90	.36	25.8	8.0	1.32	8.89	6.73	12.17	−13.09
S2P0N1	17.53	7.00	.40	26.4	8.6	−.78	10.82	—	13.05	−15.74
S2P0N2	20.24	7.75	.38	31.9	11.6	.27	11.70	43.50	18.30	−13.93
S2P1N0	21.41	6.45	.30	32.2	12.1	5.10	9.36	1.84	17.56	−10.07
S2P1N1	24.51	9.31	.38	39.5	15.1	6.69	13.91	2.08	29.83	−8.60
S2P1N2	24.56	9.57	.39	41.6	15.4	2.94	14.02	4.77	29.28	−11.81
S2P2N0	23.15	6.60	.29	33.2	14.7	3.38	9.97	2.95	18.91	−10.48
S2P2N1	24.52	8.08	.33	37.4	16.1	1.84	11.51	6.24	18.46	−11.60
S2P2N2	26.80[b]	11.44	.43	49.6	15.5	1.95	17.04	8.73	37.05	−16.44
S3P0N0	15.97	7.23	.45	23.3	4.9	.27	11.84	43.21	14.05	−18.97
S3P0N1	16.93	7.73	.46	26.4	6.0	−1.91	12.28	—	11.00	−20.68
S3P0N2	15.93	7.55	.47	25.3	5.1	−7.10	12.46	—	7.10	−26.21
S3P1N0	19.51	6.73	.35	28.0	8.2	1.65	10.78	6.53	11.55	−17.66
S3P1N1	20.57	8.53	.41	32.6	9.4	−.52	12.89	—	16.54	−19.22
S3P1N2	21.65	9.14	.42	35.2	9.7	−2.40	13.76	—	14.20	−22.52
S3P2N0	19.56	6.46	.33	27.9	9.9	−3.15	10.10	—	7.64	−19.50
S3P2N1	22.91	8.68	.38	34.6	10.9	−1.12	13.24	—	17.15	−21.37
S3P2N2	26.34	10.74	.41	43.4	12.6	1.08	16.25	15.11	27.52	−21.90

[a] Please refer to the text for an explanation of the strategies.
[b] Not significantly different at $\alpha = .05$ from *S1P2N2*.
[c] Not significantly different at $\alpha = .05$ from *S0P0N0*.
[d] Not significantly different at $\alpha = .05$ from *S1P0N0*.

A weighted Duncan's analysis indicates that the *S0P0N0* strategy is statistically different from *S1P0N0* and *S1P1N1* (table 1). This implies that substitution of N and P inputs for soil, in the increments studied here, is not effective in maintaining net returns. None of the strategies in soil removal groups *S1*, *S2*, and *S3* generate a return as high as that from *S0P0N0*. In addition, none of the strategies in soil removal groups *S2* and *S3* generate a return as high as that from *S1P0N0*. Although strategy *S3P1N0* has a higher return than *S2P0N0*, it is not statistically different. Further, a strategy that has more soil loss never has a statistically significant higher net return than a strategy with a lower soil loss and equivalent fertilizer rates. Soil removal groups *S0* and *S1* also have lower coefficients of variation than soil removal groups *S2* and *S3*.

The addition of N and P fertilizer can be used to increase net returns within soil removal groups to a limited extent. The strategies *S2P1N0* through *S2P2N2* all have higher returns

Table 2. Stochastic Dominance Analysis Results of All Strategies and by Soil Loss Group

			SDWRF							
			Increasing Risk Seeking ←			Risk Neutral	Increasing Risk Aversion →			
Group	FSD	SSD								
R_1 =	$-\infty$	0	−.40	−.20	−.10	−.02	.02	.10	.20	.40
R_2 =	$+\infty$	$+\infty$	−.20	−.10	−.02	+.02	.10	.20	.40	.60
All Strategies	S0P0N0	S0P0N0			S0P0N0	S0P0N0	S0P0N0	S0P0N0		
	S0P0N1									
	S0P0N2									
	S0P1N1				S0P1N1					
	S0P2N0									
	S0P2N1			S0P2N1	S0P2N1					
	S0P2N2		S0P2N2	S0P2N2						
	S1P0N0	S1P0N0						S1P0N0	S1P0N0	S1P0N0
	S1P1N1	S1P1N1			S1P1N1					S1P1N1
	S1P2N2									
Soil Loss S0	P0N0	P0N0			P0N0	P0N0	P0N0	P0N0	P0N0	P0N0
	P0N1									
	P0N2									
	P1N1				P1N1					
	P1N2									
	P2N0									
	P2N1			P2N1	P2N1					
	P2N2		P2N2	P2N2						
Soil Loss S1	P0N0	P0N0				P0N0	P0N0	P0N0	P0N0	P0N0
	P0N1									
	P1N0									
	P1N1	P1N1		P1N1	P1N1	P1N1				P1N1
	P2N2		P2N2	P2N2						
Soil Loss S2	P1N0	P1N0					P1N0	P1N0	P1N0	
	P1N1	P1N1			P1N1	P1N1	P1N1	P1N1	P1N1	P1N1
	P2N0									
	P2N2		P2N2	P2N2	P2N2					
Soil Loss S3	P0N0									
	P0N1									
	P1N0	P1N0				P1N0	P1N0	P1N0	P1N0	P1N0
	P1N1									
	P1N2									
	P2N1									
	P2N2		P2N2	P2N2	P2N2	P2N2				

Note: Please refer to the text for an explanation of the strategies.

than *S2P0N0*. In addition, *S3P1N0* and *S3P2N2* have higher returns than *S3P0N0*. The addition of N, with constant levels of P, within each soil removal group does not consistently raise or lower the net return. The same is true of the addition of P, with constant levels of N within each soil removal group. The addition of N tends to reduce net returns for soil removal groups *S0* and *S1*, and the addition of 18 lbs./acre of P tends to increase net returns for *S2* and *S3*.

Stochastic Dominance

Although examining average net return information is useful, it is important to recognize that each combination of soil removal and N and P has a different level of net return risk. Stochastic dominance analysis is used to select the best strategy for managers with different levels of risk aversion.

The FSD criterion only narrows the efficient set to 10 distributions (table 2). All of the preferred strategies are from soil removal groups *S0* and *S1*. The efficient set under SSD criteria contains combinations *S0P0N0*, *S1P0N0*, and *S1P1N1*. The mean of strategy *S0P0N0* is statistically different from all others. The strategies *S1P0N0* and *S1P1N1* are not statistically different from each other or from *S0P0N1* and *S0P1N1*, but are from all others. SDWRF criteria indicate that the strategies preferred by risk-seeking managers are *S0P2N1* and *S0P2N2*. These strategies have high maximum returns. A manager using the maximax decision criteria would prefer *S0P2N2*. The extremely risk-averse decision maker would prefer either *S1P0N0* or *S1P1N1*. A manager using the maximin decision criteria would prefer *S1P1N1*. In general, SDWRF criteria indicate low levels of soil removal and fertilizer rates are preferred by risk-averse managers if there is no cost associated with erosion control.

The distributions also are analyzed by soil removal group to determine which combinations of fertilizers are preferred. In the no soil removal group (*S0*), highest returns and least variability occur when fertilizer is not applied (table 1). SDWRF criteria indicate that a risk-neutral to risk-averse individual would prefer the strategy *P0N0* (table 2). With 2.5 inches of soil removal (*S1*), risk-averse managers would prefer the *P0N0* and *P1N1* combinations. For soil removal group *S2* (5 inches), the SDWRF criteria indicate that slightly risk-averse managers prefer *P1N1* and *P1N0*, whereas the most risk-averse managers prefer only *P1N1*. In soil removal group *S3* (7.5 inches), the highest returns are achieved with *P1N0* and this combination is preferred by risk-averse managers. Extreme risk-seekers would prefer the highest levels of both N and P (*P2N2*) in any soil loss group.

Sensitivity Analysis

Sensitivity analysis is conducted to determine the value of soil by examining the magnitude of a parallel shift of the preferred (dominant) strategy required to eliminate its dominance and produce an efficient set containing both the previously dominant strategy and the specified alternative. For further description of the sensitivity procedure, refer to Goh et al.

The results of this analysis for all strategies in four risk-aversion intervals are reported in table 3. The reported results are limited to risk-averse ranges because farmers generally are believed to be risk-averse. The dollar value of the shift ($/acre) is indicated in columns 2–7 of the table. In the risk-aversion interval .02 to .10, the net return of the *S0P0N0* strategy need be only $1.80/acre less (table 3, column 2) for the *S1P1N1* strategy to be equivalently preferred. The dollar value of this shift can be interpreted as the maximum amount a manager would be willing to pay in net return (give up per acre) to continue to use the original preferred strategy. A comparison of the dominant strategy of *S0P0N0*, which has no soil removal, to those strategies that have higher soil removal indicates the amount a manager would be willing to spend ($/acre/year) on soil conservation measures to reduce soil erosion. Because *S0P0N0* and *S1P0N0* are equally preferred in the interval .10 to .20, the sensitivity analysis indicates that a $0/acre shift is required. For a risk-averse manager, there apparently is little incentive (based on net return risk) to prevent all soil erosion. The results in table 3 indicate that *S0P0N0* is preferred to *S1P0N0* by only $.20/acre in the least risk-averse interval and *S1P0N0* is preferred to *S0P0N0* by only $.10/acre in the most risk-averse interval. However, a risk-averse manager (.20 to .40) could spend as much as $5.20/acre/year to prevent an additional 2.5 inches of soil loss from a level of *S1* (*S1P0N0*) to a level of *S2* (*S2P1N0*). The strategy *S2P1N0* would be preferred to *S1* (*S1P0N0*) if it cost more than $5.20/acre/year to reduce soil erosion from *S2* (*S2P1N0*) to *S1* (*S1P0N0*).

Other relationships are found in the results in table 3. Higher levels of soil erosion (*S2* and *S3*) are relatively less preferred. For example, a comparison of *S1P0N0* with *S2P0N0* and *S3P0N0* in the interval .10 to .20 indicates that the strategy *S1P0N0* would require a larger decrease in the net return for *S3P0N0* to be equally preferred ($12.30) than *S2P0N0* ($8.20). A similar comparison can be made between *S1P1N1* and *S2P1N1* and *S3P1N1* in the interval .40 to .60. Further analysis, not presented in tabular form in this

Table 3. Sensitivity Analysis of Stochastic Dominance Results

	Risk-Aversion Interval					
	.02 to .10	.10 to .20		.20 to .40	.40 to .60	
Compared Strategy	Dominant Strategy: *S0P0N0*	*S0P0N0*	*S1P0N0*	*S1P0N0*	*S1P0N0*	*S1P1N1*
	Decrease in Net Return of Dominant Strategy ($/acre)[a]					
S0P0N0	—	—	0	.10	.10	0
S0P0N1	3.30	3.70	3.70	4.20	4.70	4.40
S0P0N2	5.90	6.10	6.20	6.20	6.20	6.00
S0P1N0	2.90	2.30	2.40	1.90	1.60	1.60
S0P1N1	3.70	5.50	5.30	6.50	7.50	7.30
S0P1N2	8.30	9.60	9.50	10.20	10.80	10.60
S0P2N0	3.30	2.80	2.80	2.10	1.70	1.85
S0P2N1	6.70	8.00	8.00	8.30	8.70	8.50
S0P2N2	10.10	12.00	11.80	12.30	12.40	12.10
S1P0N0	.20*	0*	—	—	—	0
S1P0N1	2.10	1.40	1.50	.90	.60	.70
S1P0N2	6.30	5.80	5.90	5.80	6.10	5.90
S1P1N0	2.60	2.50	2.60	2.90	3.30	3.00
S1P1N1	1.80	1.10	1.20	.30	0.00	—
S1P1N2	8.90	8.40	8.50	7.90	7.60	7.60
S1P2N0	4.90	3.40	3.60	2.40	1.90	2.50
S1P2N1	7.30	6.90	7.00	6.30	5.90	6.00
S1P2N2	9.10	9.10	9.20	8.70	8.40	8.40
S2P0N0	8.70	8.10	8.20	8.40	8.60	8.40
S2P0N1	12.10	11.90	11.90	12.00	11.80	11.80
S2P0N2	11.30	10.90	11.00	10.60	10.30	10.40
S2P1N0	5.20*	4.80*	4.90*	5.20*	5.50	5.30
S2P1N1	6.00	5.70	5.80	5.30	4.90*	5.00*
S2P1N2	9.20	8.40	8.50	7.80	7.50	7.50
S2P2N0	7.00	6.30	6.40	6.20	6.10	5.90
S2P2N1	9.30	8.40	8.50	7.80	7.50	7.50
S2P2N2	11.40	11.30	11.40	11.40	11.80	11.60
S3P0N0	11.50	12.40	12.30	13.70	14.40	14.20
S3P0N1	13.90	14.80	14.70	15.90	16.30	16.10
S3P0N2	19.20	20.30	20.20	21.50	21.90	21.70
S3P1N0	9.40*	10.70*	10.60*	12.30*	13.20*	12.90*
S3P1N1	12.80	13.80	13.70	14.80	15.00	14.90
S3P1N2	15.00	16.50	16.30	17.60	18.10	17.90
S3P2N0	14.00	14.20	14.20	15.00	15.20	15.10
S3P2N1	13.60	14.90	14.70	16.20	16.90	16.60
S3P2N2	12.50	14.80	14.70	16.50	17.40	17.10

Note: Please refer to the text for an explanation of the strategies.
* Indicates the smallest shift required to make the succeeding increment of soil loss equivalent to the preferred strategy.
[a] The number indicates the magnitude of a parallel shift ($/acre) of the preferred (dominant) strategy required to eliminate its dominance and produce an efficient set containing both the previous dominant strategy and the specified alternative.

article, reveals that for any of the fertilizer combination groups, soil loss groups *S*0 or *S*1 are preferred.

The addition of N generally is not preferred by risk-averse managers. For example, in the interval .20 to .40, *S*0*P*1*N*0 ($1.90) enters the efficient set before *S*0*P*1*N*1 ($6.50) does. Table 3 also indicates that with the exception of the *S*1*P*1, *S*2*P*1, and *S*3*P*2 groups, addition of N is not preferred in any risk-aversion interval. The strategy *S*_*P*_*N*0 always enters the efficient set before *S*_*P*_*N*1, given the previous exceptions. With the exception of the *S*2*P*0 and *S*3*P*2 groups, the *S*_*P*_*N*1 group enters the efficient set before *S*_*P*_*N*2 in any risk-aversion interval. At higher levels of soil erosion (*S*2 and *S*3), an application

Table 4. Sensitivity Analysis to Obtain Marginal Values of Soil

Risk-Aversion Interval .02 to .10

	S0P0N0	*S1P0N0*	*S2P1N0*	*S2P1N1*	*S3P1N0*
	($/acre)				
S0P0N0	—				
S1P0N0	.20*	—			
S2P1N0	5.20	5.00	—		
S2P1N1	6.00	4.90*	0	—	
S3P1N0	9.40	8.80	3.70*	3.00	—

Risk-Aversion Interval .10 to .20

	S0P0N0	*S1P0N0*	*S2P1N0*	*S2P1N1*	*S3P1N0*
	($/acre)				
S0P0N0	—				
S1P0N0	0*	—			
S2P1N0	4.80	4.90*	—		
S2P1N1	5.70	5.80	0	—	
S3P1N0	10.70	10.60	5.70*	4.60	—

Risk-Aversion Interval .20 to .40

	S0P0N0	*S1P0N0*	*S2P1N0*	*S2P1N1*	*S3P1N0*
	($/acre)				
S0P0N0	—				
S1P0N0	−.10*	—			
S2P1N0	5.00	5.20*	—		
S2P1N1	5.10	5.30	0	—	
S3P1N0	12.20	12.30	7.20	6.50*	—

Risk-Aversion Interval .40 to .60

	S0P0N0	*S1P0N0*	*S1P1N1*	*S2P1N1*	*S3P1N0*
	($/acre)				
S0P0N0	—				
S1P0N0	−.10*	—			
S1P1N1	0	0	—		
S2P1N1	4.80	4.90*	5.00	—	
S3P1N0	13.00	13.20	12.90	8.00*	—

Notes: The strategies indicated in the rows and columns are the risk efficient strategies for each of the soil loss groups *S*0, *S*1, *S*2, and *S*3 for each respective risk-aversion interval. The number indicates the magnitude of a parallel shift ($/acre) of the preferred (dominant) strategy required to eliminate its dominance and produce an efficient set containing both the previously dominant strategy and the specified alternative. The numbers marked with an asterisk (*) indicate the marginal value of soil for each increment of soil loss. This is the amount ($/acre/year) a manager would be willing to spend to prevent further erosion at the margin.

of 18 lbs./acre of P is preferred. For example, in all risk-aversion intervals, the *S2P1N0* strategy would enter the efficient set before *S2P0N0*, and *S3P1N0* would enter the efficient set before *S3P0N0*.

Soil Value

The marginal value of soil for each of the increments of soil loss used in this study also is estimated using the previously described sensitivity analysis technique. The risk-efficient strategies within each soil loss group are identified (table 2). These strategies for each group are compared directly with each other to determine the marginal value of soil by examining the magnitude of a parallel shift of the preferred (dominant) strategy required

Table 5. Years Required for Total and Incremental Soil Loss

Soil Removal Treatment	Soil Loss (inches/acre)	Soil Loss (tons/acre)	Years Required for Total Soil Loss @ 15 Tons/Acre/Year	Years Required for Total Soil Loss @ 20 Tons/Acre/Year	Marginal Soil Loss	Years Required for Incremental Soil Loss @ 15 Tons/Acre/Year	Years Required for Incremental Soil Loss @ 20 Tons/Acre/Year
*S*0	0.0	0					
*S*1	2.5	400	26.67	20	400	26.67	20
*S*2	5.0	860	57.33	43	460	30.67	23
*S*3	7.5	1,360	90.67	68	500	33.33	25

to eliminate its dominance and produce an efficient set containing both the previously dominant strategy and the specified alternative (table 4). The marginal values of the three increments of soil for a risk-averse manager (risk-aversion interval .10 to .20) are $0 per acre for the first increment of 2.5 inches and $4.90 and $5.70 per acre, respectively, for the second and third 2.5-inch increments. The *S*1*P*0*N*0 strategy is equally preferred to the best *S*0 strategy (*S*0*P*0*N*0) in this interval. In the interval .20 to .40, the *S*1*P*0*N*0 strategy is preferred to the best *S*0 strategy (*S*0*P*0*N*0); therefore, the value is −$.10. The value of −$.10/acre in table 4 indicates that these risk-averse managers would have to receive more than −$.10/acre/year in addition to the subsidized cost of soil erosion control to be induced to use *S*0*P*0*N*0 instead of *S*1*P*0*N*0. However, such a manager would be willing to spend $5.20/acre/year (table 4) to prevent the additional soil erosion above *S*1 to the *S*2 level (*S*1*P*0*N*0 versus *S*2*P*1*N*0). The ranges in marginal soil values for all risk-aversion intervals are −$.10/acre to $.20/acre for the *S*1 increment, $4.90/acre to $5.20 for the *S*2 increment, and $3.70/acre to $8/acre for the *S*3 increment.

The Soil Conservation Service (SCS) estimates soil erosion in eastern Montana to be 15 to 20 tons/acre/year. The four soil removal levels are equivalent to 0, 400, 860, and 1,360 tons/acre. The difference between no soil loss (*S*0*P*0*N*0) and soil removal strategy *S*2 (*S*2*P*1*N*0) is 860 tons/acre. However, the risk-averse manager is essentially indifferent to the increase in soil loss between *S*0 and *S*1, which is equivalent to 400 tons/acre. The cost of using reduced tillage systems to reduce soil erosion instead of conventional tillage in a spring wheat–fallow rotation in eastern Montana (Major Land Resource Area 58A) ranges from $4.48/acre for minimum tillage to $10.57/acre for a no-tillage system. These costs represent the reduction in returns [weighted according to the same method reported in equation (1)] caused by changing from a conventional tillage system to a reduced tillage system with constant yields, as reported by Johnson et al. Therefore, based on net returns, the likelihood that a manager would undertake soil conservation strategies by adopting reduced tillage is small unless increased yields from reduced tillage result in revenue to offset the soil conservation cost less the value of the additional increment of soil.

The amount a risk-averse manager would be willing to invest in soil erosion control depends upon the rate of erosion and the planning horizon. At 20 tons/acre/year, it would take 43 years to lose 860 tons/acre (table 5). The manager would experience only a soil loss in addition to *S*1 after the twentieth year. The manager would be willing to spend $4.90 to $5.20/acre/year depending upon the degree of risk aversion (table 4) in real dollars after the twentieth year to prevent the additional soil loss of 460 tons/acre from occurring over the next 23-year period. If the costs of reduced tillage systems could be reduced or additional yield obtained from these practices, the likelihood of a manager undertaking erosion control practices using reduced tillage systems is increased after the twentieth year.

The present value of the $4.90/acre annual payment to prevent increasing soil erosion to the *S*2 level, given a 3% real discount rate, is equal to $44.61/acre (table 6). The $44.61/acre is the present value of $4.90/acre spent from years 21 to 43 in the planning horizon (present value of an annuity) to control erosion. In other words, a risk-averse manager

Table 6. Marginal Present Values of Soil Loss for Two Erosion Rates and Planning Horizons

Erosion Rate (tons/acre/year)	20	20	20	15	15	15
Years of Conservation for Previous Soil Increments						
$S0$–$S1$	20			26.67		
$S1$–$S2$		23			30.67	
$S2$–$S3$			25			33.33
Total	20	43	68	26.67	57.33	90.67
Planning Horizon (years)	20	43	68	26.67	57.33	90.67
Soil Increment	$S0$–$S1$	$S1$–$S2$	$S2$–$S3$	$S0$–$S1$	$S1$–$S2$	$S2$–$S3$
Soil Loss per Increment (tons/acre)	400	460	500	400	460	500
Total Soil Loss (tons/acre)	400	860	1,360	400	860	1,360

Annual Payment ($)	Discount Rate	Present Values of Soil Loss ($/acre)					
0	1%	0[a]			0[a]		
4.90	1%		82.15[b]			98.83[b]	
5.70	1%			81.83[c]			90.95[c]
0	3%	0[a]			0[a]		
4.90	3%		44.61[b]			44.26[b]	
5.70	3%			27.85[c]			21.87[c]
0	5%	0[a]			0[a]		
4.90	5%		24.91[b]			20.70[b]	
5.70	5%			9.86[c]			5.58[c]

[a] This figure is derived from using the present value of an annuity formula:

$$PV_{soil01} = A_1 \frac{(1 + r)^t - 1}{r(1 + r)^t},$$

where PV_{soil01} is the present value of soil in increment $S0$–$S1$, A_1 is the annual payment to prevent soil erosion from $S0$ to $S1$, r is the annual real discount rate, and t is the period of years during the planning horizon that the manager is willing to make expenditures to prevent erosion for soil increment $S0$–$S1$.

The real discount rate can be estimated using the formula:

$$r = \frac{1 + nr}{1 + ir} - 1,$$

where r is the real discount rate (interest rate), nr is the nominal discount rate (interest rate), and ir is the inflation rate.

[b]
$$PV_{soil12} = A_2 \frac{(1 + r)^t - 1}{r(1 + r)^t} \cdot \frac{1}{(1 + r)^{n-t}},$$

where PV_{soil12} is the present value of soil in increment $S1$–$S2$, A_2 is the annual payment to prevent soil erosion from $S1$ to $S2$, n is the planning horizon measured in years, t is the period of years during the planning horizon that the manager is willing to make expenditures to prevent erosion from $S1$ to $S2$, and all other variables are as defined previously.

[c]
$$PV_{soil23} = A_3 \frac{(1 + r)^t - 1}{r(1 + r)^t} \cdot \frac{1}{(1 + r)^{n-t}},$$

where PV_{soil23} is the present value of soil in increment $S2$–$S3$, A_3 is the annual payment to prevent soil erosion from $S2$ to $S3$, t is the period of years during the planning horizon that the manager is willing to make expenditures to prevent erosion from $S2$ to $S3$, and all other variables are as defined previously.

would be willing to invest approximately $44.61/acre to prevent a soil loss of 460 tons/acre in excess of 400 tons/acre if the planning horizon was 43 years. However, if soil was eroding at 20 tons/acre/year and the manager had a planning horizon of less than 43 years, the present value of the investment would be less. If the planning horizon was 20 years or less, the farm manager would have soil erosion only equivalent to $S1$ or less; therefore, no expenditure for erosion control would be made because *S*1 (*S*1*P*0*N*0) is preferred to *S*0 (*S*0*P*0*N*0). If the planning horizon was greater than 43 years, the investment would be larger. The manager would be willing to spend an additional $3.70 to $8/acre each year depending upon the degree of risk aversion to prevent soil erosion above *S*2 to the *S*3 level (*S*2*P*1*N*0 versus *S*3*P*1*N*0). Although this planning horizon is long for a single manager, society may desire to have public policies that require, encourage, or subsidize erosion control because, as this study illustrates, valuable productivity is lost over an extended planning horizon, given the current state of crop production technology.

The results are sensitive to the real discount rate selected. By increasing the rate from 1% to 3%, the present value of soil increment *S*1–*S*2 declined from $82.15/acre to $44.61/acre. Increasing the rate by another 2% caused a decline to $24.91/acre.

Conclusions

Although this study demonstrates that valuable on-farm productivity is lost over an extended planning horizon for soils typical of the Williams soil in the Northern Great Plains, managers with shorter planning horizons may not undertake conservation measures without coercion because it is uneconomical to do so.

Stochastic dominance criteria indicate that risk-averse individuals prefer to have low levels of soil erosion and apply little fertilizer (*S*0*P*0*N*0, *S*1*P*0*N*0, or *S*1*P*1*N*1) when erosion control is without cost. High levels of N fertilizer as a substitute for soil at any level of P fertilizer are generally less preferred. Therefore, soil conservation is important in sustainable agricultural systems. However, prevention of soil erosion is not without cost. Managers must make expenditures if they wish to control soil erosion. The results of the study indicate that risk-averse managers are not willing to make an expenditure for erosion control if erosion is occurring at a rate of 20 tons/acre/year or less and the planning horizon is 20 years or less. With a planning horizon longer than 20 years, risk-averse managers would be willing to make an investment equivalent to the present value of an annuity of $4.90 to $5.20/acre from the twenty-first to forty-third year in the planning horizon to control soil erosion.

During the study period, growing season precipitation was limited, as it is in most of the Great Plains. Growing season precipitation was 68% of the long-term average. Increased precipitation generally would increase the demand for both P and N by the crop. Therefore, under higher precipitation the use of P and N may be more economical. A higher level of precipitation may substitute for topsoil to some degree and discourage the use of conservation. However, reduced tillage practices may conserve soil moisture and improve yields, thereby increasing the incentive to use them for erosion control.

Soil erosion and the decision to allow soil erosion or reduce the rate of erosion is a dynamic process. Productivity damage from erosion occurs continuously and not necessarily in discrete increments as modeled in this study. Therefore, a farm manager faces at least an annual decision of determining whether it is economical to allow erosion to occur without conservation or to make an investment to reduce the rate of erosion. In each subsequent year, soil depth, productivity, production costs, commodity prices, institutional constraints, and technology vary and influence the soil conservation decision. Our analysis does not consider all of these variables in a dynamic decision process. It is limited to determining the present value of soil for discrete increments given constant technology, prices, costs, and institutional constraints. These soil increments also are larger than what normally would be removed by a typical year of erosion. Therefore, a dynamic analysis including variables which change as a function over time may indicate a manager would be willing to adopt erosion control practices before the twentieth year. For example, our static analysis did not consider the impact of improved technology (such as improved tillage practices) that may act as a complement with soil. If new crop production technology develops in such a way that soil becomes an even stronger complement in the production process, the value of soil would increase and this would encourage the use of more erosion control practices. Therefore, the value of the soil increments reported here would be too low. However, if crop production technology develops over time such that it is a strong substitute for soil, the value of soil would decrease and also decrease the incentive for erosion control. Under these circumstances, the soil values estimated in the study would be too high. Further research that examines tillage and rotational strategies under various soil loss increments as well as different price and cost structures would be useful.

[*Received December 1991; final revision received September 1992.*]

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