AN ECONOMIC ANALYSIS OF FARMER DECISIONS WITH RESPECT TO SOIL EROSION IN SASKATCHEWAN

Abstract

A dynamic economic model is used to evaluate the farm decision process with respect to the intensity of cropping in the brown soil zone of Saskatchewan. Based on this model, and several agronomic relationships estimated from data collected as part of the Innovative Acres project, we reach the following conclusions: (1) Flexible cropping increases net discounted returns and substantially reduces soil erosion, when compared to the predominant crop rotation in the region. (2) Unless soils are already substantially eroded, conventional summerfallow is preferred to chem-fallow by profit maximizing decision makers. (3) The overall risk of flexcropping may be less then the traditional rotations used in the study region.

by

Ward P. Weisensel

G.C. Van Kooten

and

R.A. Schoney*

February, 1989

1. Introduction

In the last decade, the issue of soil degradation in Canada has become a controversial topic. In spite of the importance attached to soil erosion research by politicians,[1] it appears that soil conservation is still not a priority of agricultural producers. A possible reason for this neglect is that technological advance has led to increases in yields even though soils have deteriorated over time (Walker and Young; Taylor).

The major contributor to soil erosion in western Canada is the practice of summerfallowing. However, economists maintain that the level of soil loss from increased summerfallowing is the result of an economic decision and that there are economic reasons why farmers permit soil degradation (Clark and Furtan). The agricultural producer makes cropping decisions based on available soil moisture at seeding time. If soil moisture is low, summerfallow is preferred because cropping in this case will likely lead to crop failure, while summerfallow results in moisture storage for the following crop year if precipitation is sufficient. In practice, farmers in southwestern Saskatchewan employ a fixed crop rotation which includes summerfallow every second year. The predominance of summerfallow in a fixed crop rotation can be traced to risk averse behaviour on the part of farmers (Young and Van Kooten).

The purpose of this paper is to investigate optimal farmer decisions in the dryland cropping region of the brown soil zone in southwestern

---

[1] Recent reports on soil erosion by the Senate Standing Committee on Agriculture, Fisheries and Forestry (Sparrow), PFRA, Rennie and by the Science Council of Canada are indicative of the importance placed upon soil conservation.

Saskatchewan.[2] We investigate soil erosion under various cropping alternatives. In addition, we investigate the use of chem-fallow as a viable alternative to tillage fallow for the purposes of erosion control. A stochastic dynamic programming model is employed (Burt and Allison; Burt and Johnson), with available soil moisture at planting time (May 1) and soil depth as state variables.[3] The decision variables are the agronomic decisions made; (i) crop wheat, (ii) conventional fallow, and (iii) chem-fallow.

The paper is divided up into a number of sections. The next section illustrates and discusses the economic decisions faced by the farmer. In particular, it discusses the economic tradeoffs faced by a farmer making cropping and conservation decisions. The third section discusses the data used to estimate the relationships which are crucial to the farm decision model. In addition, the estimated equations for each of the relationships are illustrated. The fourth section illustrates the results of the simplified decision model illustrated in the second section as well as the results of the overall stochastic dynamic programming model.[4] The final section provides our conclusions.

---

[2] This paper is a shortened and simplified version of a larger research project (Weisensel). Therefore, this paper summarizes many of the results of this larger project and two subsequent technical papers (Weisensel et al; Van Kooten and Weisensel).

[3] A state variable defines the condition or level of a specific factor important in the decision process.

[4] The stochastic dynamic program incorporates the randomness of soil moisture and soil depth changes. Therefore, it more accurately depicts profit maximizing behavior in the study region.

2. Economic Model of Farm Decision Process

It is assumed that farmers maximize net returns (NR) which are a function of available soil moisture at planting time (SM) solum depth (SD), the planting/summerfallow (agronomic) decisions (u) and production costs. The objective function is:

$$\max \sum_{t=0}^{T} NR_t(SM_t, SD_t, u_t)\beta^t, \tag{1}$$

where β is the discount factor, t refers to the year and the length of planning horizon is T. In the current model it is assumed that farmers have three choices at spring seeding time; (1) plant spring wheat, (2) summerfallow to store moisture for next year's crop, or (3) use chem-fallow to store moisture. Therefore, it is assumed that farmers have two choices to reduce soil erosion which are consistent with continued crop production. The first of these choices is to reduce the frequency of summerfallow. The second choice is the use of chem-fallow rather than conventional fallow. Chem-fallow uses herbicides to control weed growth and rather than tillage used in regular fallow. Unfortunately, this practice is expensive when compared to conventional tillage because of the high costs of herbicides. However, chem-fallow has two advantages: (1) It prevents soil moisture loss caused by tillage, and (2) it maintains high levels of crop residue which prevent erosion by binding the soil together, thus protecting it from the natural elements.

Each of the choices available to the decision maker can be evaluated using a simple break-even equation which is derived from a more detailed version of equation (1). In economics these conditions are denoted as the marginal conditions of profit maximization. Below is a heuristic explanation of these conditions.

The first decision which must be made is whether to crop or fallow in the current year. Solving equation (2) for the current values of available soil moisture and solum depth (state variables) yields the appropriate profit maximizing decision.

$$[p*y(sm_t,sd_t)-c] + (\text{mv of soil saved by cropping }\{MVSS\}) >=<$$

$$\beta*[p*y(sm^F{}_{t+1},sd_{t+1}) - p*y(sm^C{}_{t+1},sd_{t+1})] - Cf, \qquad (2)$$

where p is the price of wheat, $y(sm_t,sd_t)$ is yield as a function of soil moisture (sm) and solum depth (sd), c is the appropriate cost of production for spring wheat, $sm^F{}_{t+1}$ is available soil moisture in the spring after fallow, $sm^C{}_{t+1}$ is available soil moisture in the spring after a crop, and Cf is the cost of fallow. The left hand side (LHS) of equation (2) represents the expected value of this years crop less the cost of production ($[p*y(sm(t),sd(t)) - c]$) plus the value of the marginal soil saved because of the decision to crop rather than fallow (MVSS).[5] Therefore, it represents the benefit of cropping in the current year. The right hand side (RHS) of equation (2) represents the discounted expected value of the difference in net returns of next years crop given the choice to fallow this year ($\beta*[p*y(sm^F(t+1),sd(t+1))-p*y(sm^C(t+1),sd(t+1))]$). Note as well that subtracted from the right hand side is the cost of summerfallow (Cf).[6] Overall, the RHS represents the cost of cropping in the current year. Consequently, based on the equation above, the profit maximizing producer

---

[5] The MVSS is equal to the present value of soil saved for the year t by the decision to crop rather than fallow. Therefore, MVSS depends crucially on the length of the farmers decision horizon as well has the rate at which the farmer discounts future farm returns relative to the present.

[6] At this stage the fallow operation could be regular or chem-fallow. The second optimal condition below analyzes this decision.

will seed wheat in the current year if the LHS > RHS. However, if the RHS < LHS then the profit maximizing decision is to fallow, and finally, if they are equal, the producer is indifferent between the two alternatives.

The second decision faced by the producer within this model is with respect to the decision to fallow. We have already shown that if the RHS < LHS in equation (2), then the optimal decision is to fallow rather than crop. However, this does not determine the type of fallow alternative which maximizes profits. Equation (3) illustrates the relative tradeoffs of this profit maximizing decision.

$$
\begin{aligned}
Ce - Cf \;{>}{=}{<}\; & (\text{marginal value of soil saved by chem-fallow } \{MVSS\}) \\
& + (\text{marginal value of moisture saved by chem-fallow } \{MVMS\}), \qquad (3)
\end{aligned}
$$

where Ce and Cf are the costs of chem-fallow and regular fallow, respectively. As the LHS is greater than, less than or equal to the RHS, the profit maximizing decision is to regular fallow, chem-fallow or indifference between the two, respectively. Note that both of these optimal equations depend crucially on the marginal value of soil saved by the respective management decision. Therefore, the productivity of soil for different soil types, depths and levels of potential erosion are crucial to the optimal decision process. In the results section we illustrate the relative values of the components of equations (2) and (3) for different levels of soil depth and soil moisture based on the data and relationships discussed in the next section.

3. Data Employed in the Study

Data from the Innovative Acres program is used to estimate a yield-soil depth relationship as well as soil moisture transition relationships.

Innovative Acres is a province-wide program that is directed and administered by the Department of Soil Science at the University of Saskatchewan. The major objectives of the program are to maximize crop productivity and sustain high soil quality through the implementation of water efficient farming practices. Information about the project and data collection are available from the Department of Soil Science at the University of Saskatchewan and through the annual Innovative Acres reports. For each farm in the program, data are collected from an average of 24 plots located on two research fields; the data are currently available for a period of 4 years (1984-87).[7] For the current study, only data from 11 farms located in southwestern Saskatchewan and participating in Innovative Acres are used.

The following variables are included in the present analysis: (1) the depth of the A and B soil horizons (solum depth), (2) the level of available soil moisture at planting time, and (3) the type of crop seeded and its yield. Table 1 illustrates the distributional characteristics of each of these variables. An examination of the data in Table 1 indicates that there is a reasonable dispersion of observations for each variable. The average spring wheat yield of 1,622.87 kg/ha (24.1 bu/acre) is not unreasonable when one compares these with historical yields for wheat on stubble and on summer-fallow for the brown soil zone.[8]

---

[7] Data for 1988 may now be available.

[8] For Saskatchewan Crop Districts 3, 4 and 7A that are located in the brown soil zone, the 10-year (1977-86) average spring wheat yield was 1,649.93 kg/ha (24.5 bu/ac) (Saskatchewan Agriculture, pp.44-46).

Table 1: Distribution of Variables Used in Study.

Variable	Mean	Variance	Minimum	Maximum
Spring Wheat Yield (kg/ac)	1,622.8	854,546.0	129.0	4,780.0
Solum Depth (cm)	38.27	710.10	8.00	99.00
Available Soil Moisture in May (cm)	11.13	21.82	1.47	28.03

Number of Observations = 488

---

* Data from brown soil zone of Innovative Acres project.

Spring wheat yield as a function of available soil moisture at seeding time and depth of solum was estimated as part of a larger research project (Weisensel). After extensive investigation of other functional forms, it was determined that a modification of the Mitscherlich-Spillman (M-S) functional form gave the best agronomic results for the current data. The modified M-S functional form was originally used by Pawson et al., where they used soil depth and organic matter content as the explanatory variables. Soil moisture rather than organic matter is included in the functional relationship because it is the most important input into production in the dryland cropping region of southwestern Saskatchewan and data on organic matter was unavailable. Not only is soil moisture used as a proxy for all the other inputs, but lack of moisture is the prime reason for the erosive, moisture conserving practice of summerfallow.

The M-S function is nonlinear in parameters and, therefore, must be estimated using nonlinear least squares. The estimated equation is:

$$\underset{(0.27)}{Y = 84.02} + \underset{(7.67)}{2808.0}\,(1 - \underset{(2.16)}{0.634}^{SD})\,(1 - \underset{(28.3)}{0.926}^{SM}), \quad \text{Rbar}^2 = 0.21 \qquad (4)$$

where Y refers to spring wheat yield measured in kilograms per hectare, SD is solum depth measured in centimeters (cm), and SM is soil moisture measured in cm of available moisture at spring planting time. There are 484 degrees of freedom and the t-statistics are provided in parentheses. The importance of soil moisture is indicated by the large t-statistic associated with the SM parameter.

The foregoing result is an expected yield function and, therefore, has the following interpretation. Given that the producer knows the solum depth and available soil moisture for a particular field before he seeds, Y represents the yield the producer could expect given that average conditions prevail for the remainder of that growing season. In this case, average conditions refer to average rainfall, average season length, recommended levels of fertilizer applications, and so on.

The estimated yield function is realistic with regards to the yields it predicts given various solum depth and soil moisture scenarios. Perhaps this is best exemplified by the minimum and maximum expected yields predicted by the estimated equation. The minimum yield--the expected yield if both solum depth and soil moisture are zero at seeding time--is 84.0 kg/ha (1.2 bu/ac). The maximum yield--the expected yield if solum depth is nonconstraining and soil moisture is at field capacity--is 2,612.3 kg/ha (38.9 bu/ac). Both the minimum and maximum predicted yields assume that the crop receives average precipitation over the growing season. These estimates are not unreasonable given historical yields for the brown soil zone in Saskatchewan.[9]

---

[9] In Saskatchewan Crop Districts 3, 4 and 7A, the highest average yield in a given year during the period 1977-86 was 2,445 kg/ha (1986) while the lowest was 380 kg/ha (1985) (Saskatchewan Agriculture, pp.44-46). Forecasts for 1988 indicate that average yields may be substantially below the latter figure due to both a lack of spring soil moisture and insufficient growing

The importance of the nonlinear yield response function is most evident when one calculates the marginal products of solum depth and soil moisture. The respective marginal products for soil depth and soil moisture are:

$$MP_{\text{soil moisture}} = \delta Y/\delta SD = 1{,}279.62\ (1-0.926^{SM})\ 0.634^{SD}$$

$$MP_{\text{solum depth}} = \delta Y/\delta SM = 215.88\ (1-0.634^{SD})\ 0.926^{SM}$$

The marginal productivity of soil and water increase markedly as their availability is reduced because the second partial derivatives of the yield function are negative. For example, the marginal product of solum depth at its average level (38.27 cm) given average soil moisture levels (11.13 cm) is practically zero. In contrast, the marginal product of solum depth at 1 cm given average soil moisture levels is 466.5 kg/ha/cm. For the average level of solum depth, the marginal product of soil moisture at 11.13 cm is 91.7 kg/ha/cm, but 199.9 kg/ha/cm for soil moisture levels of 1 cm.

Also important in the decision model are estimates (transitional equations) of annual changes in soil moisture based on the decision to crop, fallow or chem-fallow. These equations are presented below where the estimate is for available soil moisture in May of year t+1.

$$\text{fallow:}\quad \underset{(18.66)}{\ln SM_{t+1} = 2.021} + \underset{(4.95)}{0.2286} \ln SM_t \qquad R^2 = 0.1052 \quad SEE = 0.3075 \tag{5}$$

$$\text{crop:}\quad \underset{(12.33)}{\ln SM_{t+1} = 1.602} + \underset{(4.07)}{0.2271} \ln SM_t \qquad R^2 = 0.0434 \quad SEE = 0.5075 \tag{6}$$

$$\text{chem-fallow:}\quad \underset{(10.71)}{\ln SM_{t+1} = 1.9693} + \underset{(3.04)}{0.2587} \ln SM_t \qquad R2 = 0.1371\ SEE = 0.3301 \tag{7}$$

The t-statistics are provided in parentheses and the standard error of the regression is indicated below each equation. The SEE for equation (6) is

---

season rainfall.

larger than for equation (5) and (7), which suggests that yearly changes in soil moisture are more variable when a field is cropped as opposed to fallowed or chem-fallowed. In addition note that the estimated coefficients for equations (5) and (7) are extremely close. This indicates that there is little difference between chem-fallow and regular fallow with respect to soil moisture conservation.

Finally, we need to have estimates of expected annual rates of erosion which are based on the decision to crop, fallow or chem-fallow. Table 2 illustrates the estimates used in this analysis which were derived from annual estimates of Kiss et al.

Table 3: Estimated Annual Rates of Soil Erosion and the Adjustment Factor by Decision and Slope Grade Position

	0-3%		3-10%		10-24%	
crop	erosion	std dev	erosion t/ha/yr	std dev	erosion	std dev
wheat	7.5 (0.61)	2.6 (0.21)	8.7 (0.71)	2.9 (0.27)	15.5 (1.26)	5.2 (0.42)
fallow	38.5 (3.13)	13.4 (1.09)	45.3 (3.68)	15.1 (1.23)	80.4 (6.53)	26.8 (2.18)
chem-fallow	14.3 (1.16)	5.00 (0.41)	16.9 (1.37)	5.60 (0.46)	29.9 (2.43)	9.96 (0.81)

Figures in parentheses are estimates of soil erosion in millimetre/year, assuming a 15 cm hectare furrow slice of solum weighing 1,800t/ha.
Source: Weisensel, 1988.

Note that regular fallow results in the highest expected rate of erosion. In addition, regular fallow has the highest variance of erosion when compared with the crop and chem-fallow alternatives. Therefore, regular fallow not only has the highest expected level of erosion, but it has the highest possible potential erosion as well.

4. Empirical Results

In this section, the relationships illustrated in the previous section are used to illustrate the economics of equations (2) and (3). In addition to this, the results of the farm level decision model are examined with the use of stochastic dynamic programming. This model is based on the marginal conditions illustrated in equations (2) and (3), but is further complicated by the fact that changes in soil moisture and soil depth are random in nature. Consequently, while it is more complicated, the stochastic dynamic programming model more accurately models actual climatic and managerial conditions. Cost of production data for the economic model was obtained from Schoney and is provided in Table 3. The data is based on total variable costs of production. The cost of chem-fallow was unavailable from Schoney but was available from Innovative Acres.

Table 3: Cost of Production Data for Brown Soil Zone of Saskatchewan.

Description	Cost ($/hectare)
Wheat on fallow	98.60
Wheat on stubble	112.73
Cost Adjustment for seeding on summerfallow vs stubble	14.13
Regular summerfallow	20.85
Chem-fallow	47.42

Source: Schoney (1987) and Innovative Acres Annual Reports.

Tables 4 and 5 illustrate the relative values of equation (2) for two different expected wheat prices and various levels of solum depth. Notice that the marginal value of soil saved is much higher when solum depth is shallow. Therefore, as soil erodes it becomes more economic to conserve soil.[10] In each of the tables, the column titled Net Difference in

---

[10] In Table 4, the marginal value of soil saved increases from $0.07/hectare to $65.89/hectare for a change in solum depth of 20 to 5 centimeters. Notice that as solum depth is reduced, the marginal value of

Alternatives represents the difference in value of the LHS and RHS of equation (2). If this column is positive, the profit maximizing decision is to crop. However, if it is negative, the optimal decision is to fallow. Finally, the Net difference in Alternatives has one other economic interpretation which may be useful to policy makers concerned about soil erosion. If the Net difference is negative, a payment of the difference could alter the producers decision to crop rather than fallow thus avoiding the higher potential of erosion of regular fallow.

Tables 4 and 5 can be used to determine a flexcropping strategy which would maximize discounted net returns. For instance, at wheat prices of \$165.30/t (\$4.50/bu) it is optimal to crop if soil moisture is above 5.25 cm available and fallow below it (Table 4). However, for wheat prices of \$128.30/t (\$3.50/bu) the critical soil moisture threshhold increases by over 1 cm (5.25 cm to over 6.5 cm).

Table 4: Evaluation of Economic Decision to Crop—High Prices[a]

MOISTURE (CM) = 5.25 PRICE ($/TONNE) = $165.30
DISCOUNT RATE = 5.0% PLANNING HORIZON = 30

	LHS		RHS		<=>
Solum Depth	Current Expected Return	Marginal Value of Soil Saved	Gain in Next Year Expected Return	Cost of Fallow	Net Difference of Alternatives
20	$55.29	$0.07	$77.62	$20.85	($1.41)
15	$55.14	$0.69	$77.56	$20.85	($0.88)
10	$53.69	$6.75	$76.96	$20.85	$4.33
5	$39.52	$65.89	$71.06	$20.85	$55.20

a Each column of the table refers to a term in equation (2).

---

soil saved increases at an increasing rate.

Table 5: Evaluation of Economic Decision to Crop—Low Prices.[a]

MOISTURE (CM) = 6.50 PRICE ($/TONNE) = $128.30
DISCOUNT RATE = 5.0% PLANNING HORIZON = 30

	LHS		RHS		<=>
Solum Depth	Current Expected Return	Marginal Value of Soil Saved	Gain in Next Year Expected Return	Cost of Fallow	Net Difference of Alternatives
20	$39.73	$0.07	$64.00	$20.85	($3.36)
15	$39.59	$0.64	$63.95	$20.85	($2.88)
10	$38.26	$6.20	$63.48	$20.85	$1.83
5	$25.23	$60.57	$58.83	$20.85	$47.81

[a] Each column of the table refers to a term in equation (2).

Table 6 is similar in format to Tables 4 and 5 above but it is concerned with the marginal tradeoffs originally illustrated in equation (3), where the profitability of chem-fallow was examined. In this case however, if the net difference in alternatives is positive it is optimal to use regular fallow. On the other hand if the net difference is negative, it is optimal to chem-fallow. Therefore, if the net difference is positive the profit maximizing producer would have to be paid this net difference to chem-fallow rather than regular fallow. Note that chem-fallow becomes much more economical as solum depth is reduced because this substantially increases the marginal value of soil saved. In fact at a solum depth of slightly below 10 cm, the optimal profit maximizing decision is to chem-fallow.

Tables 4 through 6 are helpful tools to illustrate the economics of soil conservation at the farm level. However, since they fail to incorporate the inherently random characteristics of soil moisture changes in the prairie climate, they can not be as accurate as alternative methodologies which include the random component. Therefore, the remainder of this paper will discuss the results of the stochastic dynamic programming (DP) model mentioned previously and described in Weisensel.

Table 6: Evaluation of Economic Decision to Chem-Fallow[a]

MOISTURE (CM) = 11.13 PRICE ($/TONNE) = $165.30
DISCOUNT RATE = 5.0% PLANNING HORIZON = 30

	LHS		RHS	<=>	
Solum Depth	Cost of Chem Fallow	Cost of Regular Fallow	Marginal Value of Soil Saved	Marginal Value of Moisture Saved	Net Difference of Alternatives
20	$47.42	$20.85	$0.09	$16.81	$9.67
15	$47.42	$20.85	$0.91	$16.81	$8.86
10	$47.42	$20.85	$8.84	$16.78	$0.95
5	$47.42	$20.85	$86.34	$16.47	$76.24)

[a] Each column in the table refers to a term in equation (3).

To better understand the relationship between management strategies and soil erosion, ten alternative scenarios were simulated. These are found in Table 7. The scenarios are based on wheat prices of $4.50/bu and $2.50/bu, the latter reflecting recent conditions. Two rates of erosion are used—the rate denoted "high" refers to the potential rate of erosion on a slope grade of 10-24%; the rate denoted "low" is the potential rate of erosion on a slope grade of 0-3%. The optimal flexcrop strategies are determined for each of these scenarios using stochastic DP.

Table 7: Basic Parameter Scenarios used in DP Model.

Scenario	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Price ($/bu)	2.50	2.50	2.50	2.50	4.50	4.50	4.50	4.50	3.50	3.50
Discount Rate (%)	0	5.0	0	5.0	0	5.0	0	5.0	0	15.0
Erosion Rate	low	low	high	high	low	low	high	high	high	high

The stochastic DP algorithm is used to calculate the optimal flexcrop strategy for every possible state over a 30 year planning horizon. For scenarios S1, S3 and S7, the net present values of following an optimal decision path for each of the ten soil moisture states (as indicated on the abscissa) are plotted in Figure 1.[11] For each scenario, the optimal decision rule and net present value were calculated for two different solum depth states—a high solum depth (20cm) and a solum depth where the optimal strategy is altered. The corresponding solum depth is indicated along the right ordinate, while a letter is used to denote the optimal decision at each soil moisture node—F refers to regular fallow, W to wheat and CF to chem-fallow. (Note that, for 20 cm, S1 and S3 are almost identical.)

The solum depth of 20 cm represents the optimal decision rule given that solum depth is not a constraint in the farmer's decision (i.e., the MVSS is low). Therefore, this is the optimal profit maximizing decision rule for producers who farm on deep soils. The second solum depth state (which differs for each scenario) represents the maximum solum depth at which the profit maximizing producer switches his optimal flexcrop strategy because excessive erosion today lowers future profits enough to warrant a change in the optimal decision rule (MVSS becomes large). For S1 through S4, the optimal decision at 20 cm of solum depth is to crop if soil moisture is greater than 7.5 cm and to fallow if it is less than or equal to 7.5 cm, and this is unaffected by changes in the discount rate.

Although not indicated in Figure 1, as soil erodes, the optimal decision for S1 and S2 does not change until solum depth is substantially reduced.

---

[11] There are 10 soil moisture states where each state has an interval of 2.5 cm. The abscissa of Figure 1 illustrates the midpoints of each of these intervals. Therefore, the second soil moisture state illustrated in the Figure, denoted as 3.75 cm, is the midpoint of the interval 2.5 cm to 5.0 cm.

The change in the optimal strategy, when it does occur, is to crop if soil moisture is greater than 5.0 cm and fallow if it is less than or equal to 5.0 cm. This is the only change in the optimal decision rule for S1 and S2 shown, but, after the initial switch, additional changes to the optimal decision rule occur quite rapidly. In fact, in almost all cases, the optimal decision rule changes from regular fallow below 5.0 cm to chem-fallow below 5.0 cm of available soil moisture at planting time for solum depth states within 1 cm of the initial change. Simulations S1 and S2 indicate that higher discount rates result in greater soil erosion. With higher rates of erosion (S3 and S4), the optimal decision rule is much more conservative. For S3, the optimal decision rule changes at 13.2 cm of solum as opposed to 7.6 cm for S1. For S3 and S4, the optimal decision changes to crop wheat if available soil moisture at planting time is greater than 7.5 cm, chem-fallow if soil moisture lies in the interval 5.0 cm to 7.5 cm, and regular fallow if soil moisture is less than or equal to 5.0 cm. After the initial change in strategy, further changes occur so that within 1-2 cm of the initial change the decision rule is to crop if soil moisture is greater than 5.0 cm and to chem-fallow if it is less then 5.0 cm. This seems to indicate that, for erosive soils, chem-fallow is a viable alternative to regular fallow.

For higher wheat prices ($4.50/bu), the optimal decision rule is more conservative at all solum depth levels, that is, the land is cropped more intensively. For S5 and S6, the optimal decision rule given that solum depth is not constraining is to crop wheat if soil moisture is greater than 5.0 cm and to fallow when it is less than or equal to 5.0 cm. Higher grain prices cause the profit maximizing farmer to seed more often, thereby conserving soil. If solum depth is constraining, the optimal decision rule changes to chem-fallow if soil moisture is between 2.5 and 5.0 cm and to conventional fallow if it is less than or equal to 2.5 cm. As was true of the other scenarios, further changes in the optimal decision occur rapidly as solum depth falls (by 1 cm) so that the optimal decision is to crop if moisture is greater than 5.0 cm and to chem-fallow if it is below it.

Scenarios S7 and S8 provide optimal decision rules given highly erodible soil and high prices. The optimal decisions are identical to those for S5 and S6, except that the initial switch in the optimal decisions occurs at higher levels of solum depth. The initial switch for scenarios S7 and S8 are at 12.6 and 9.8 cm of solum, respectively. These solum depths are much higher than for the comparable scenarios at the lower slope (S5 and S6). This illustrates the relative importance of the impact of current decisions on future returns. The greater the potential rate of erosion, the more costly it is to use agronomic practices which are erosive.

5. Time Paths of Solum Depth

It is also possible to illustrate how soil is depleted over time for the various optimal flexcropping strategies, and for the predominant fixed rotation in the study region, namely, a 2-year, wheat-fallow rotation. This is an important component of the current study because we would like to know how soil is conserved under an optimal, flexible cropping strategy as opposed to the fixed rotation.

The soil depletion time paths are based on the optimal strategies determined in the preceding section. Soil moistures are simulated based on historical data thus determining the optimal cropping sequence.[12] The soil

---

[12] This historical data is incorporated within equations (5) through (7).

depletion time paths for the fixed rotations were easier to simulate since they did not depend on simulated soil moisture data.

The soil depletion time paths for scenarios S1, S3, S5 and S7 are provided in Figure 2. In addition, the soil depletion time paths for the fixed rotation, for both a 0-3% slope (W/F-Lo) and a 10-24% slope (W/F-Hi), are illustrated. Figure 2 highlights the seriousness of soil erosion on the prairies. Using erosion rates based on a 10-24% slope, a two-year, wheat-fallow rotation will erode 36 centimeters of soil in approximately 90 years. The flexcrop strategy, given wheat prices of $2.50 per bushel, extends the erosion process by more than 50 years. In both cases, it is assumed that erosion stops at 4.0 cm of solum depth because, at this level, it is no longer profitable to crop. It is assumed that the land is put into pasture or some other alternative use at this point. If wheat prices are $4.50/bu or higher then it takes over 190 years to erode 40 cm of soil to 4 cm. However, due to the higher price, it is still profitable to continue farming the land until there is only 1.0 cm of topsoil left. Consequently, higher commodity prices mean that the profit maximizing farmer is able to conserve soil, but, in contrast, he will erode the soil to a lower depth than a farmer facing lower commodity prices.

The same basic results hold for the scenarios based on a slope grade of 0-3%. A fixed wheat-fallow rotation erodes the top 36 cm of solum in less than 200 years. In contrast, an optimal flexcrop strategy at wheat prices of $2.50/bu (S1) takes more than 280 years to erode the same amount of soil. Finally, if wheat prices are $4.50/bu or greater (S5), the profit maximizing farmer takes substantially more than 350 years to erode 36 cm of soil.

6. Conclusions

Upon comparing each of the scenarios, several conclusions emerge. (1) Flexible cropping increases net discounted returns and substantially reduces soil erosion, when compared to the predominant crop rotation in the region. (2) Unless soils are already substantially eroded, conventional summerfallow is preferred to chem-fallow by profit maximizing decision makers. However, higher prices do not necessarily result in increased use of chem-fallow rather than regular fallow as a soil conservation practice. Upon comparing scenarios S3 and S7, one observes that at $2.50 wheat prices chem-fallow is implemented at a higher solum depth than at $4.50 wheat prices (13.2 cm of soil as compared to 12.6 cm). Therefore, higher wheat prices may make chem-fallow a more affordable agronomic practice, but not necessarily a more profitable one. (3) Finally, preliminary results suggest that flexcropping has encouraging risk characteristics.

FIG. 1: DECISION BASED ON CURRENT STATE

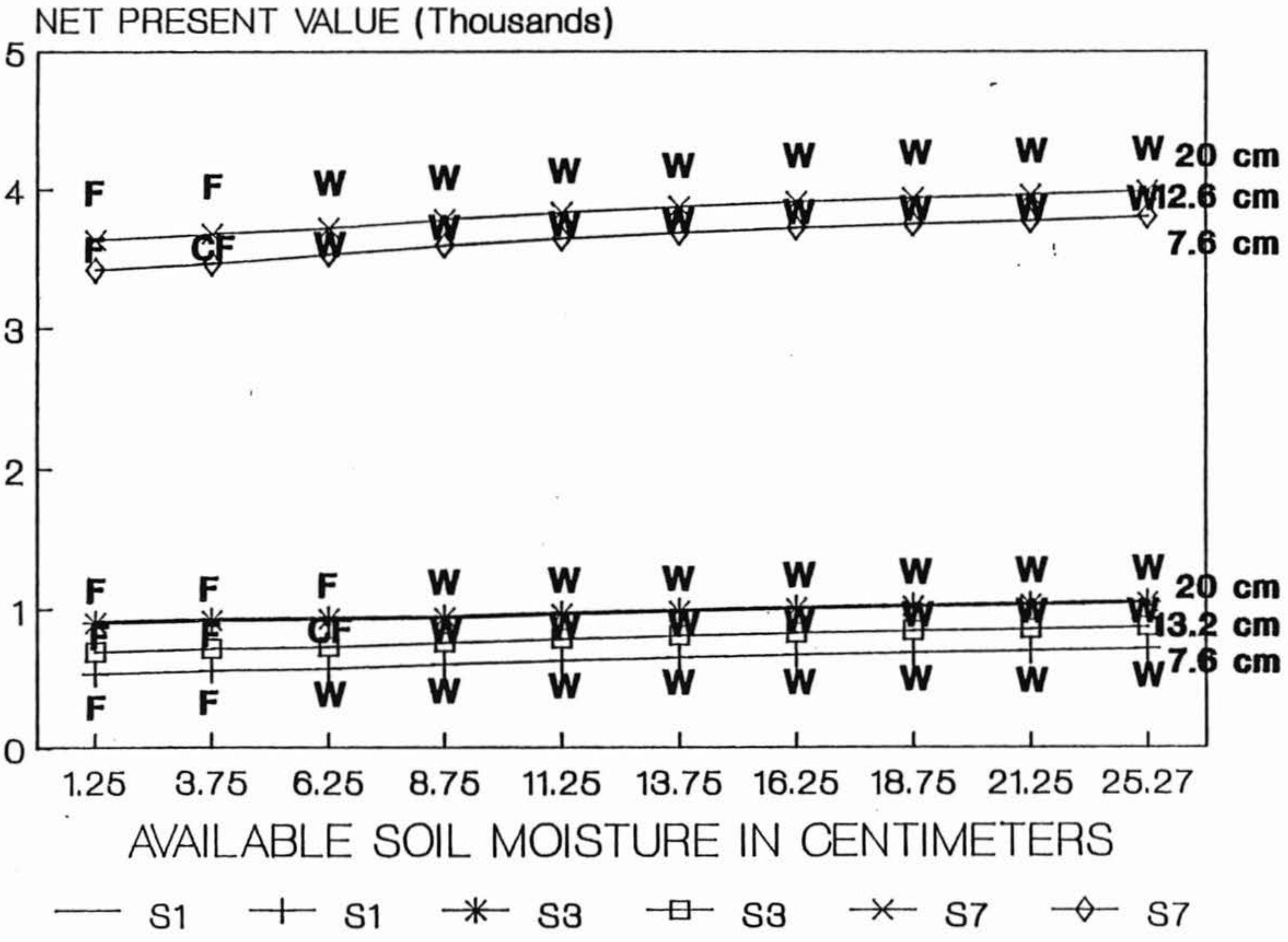
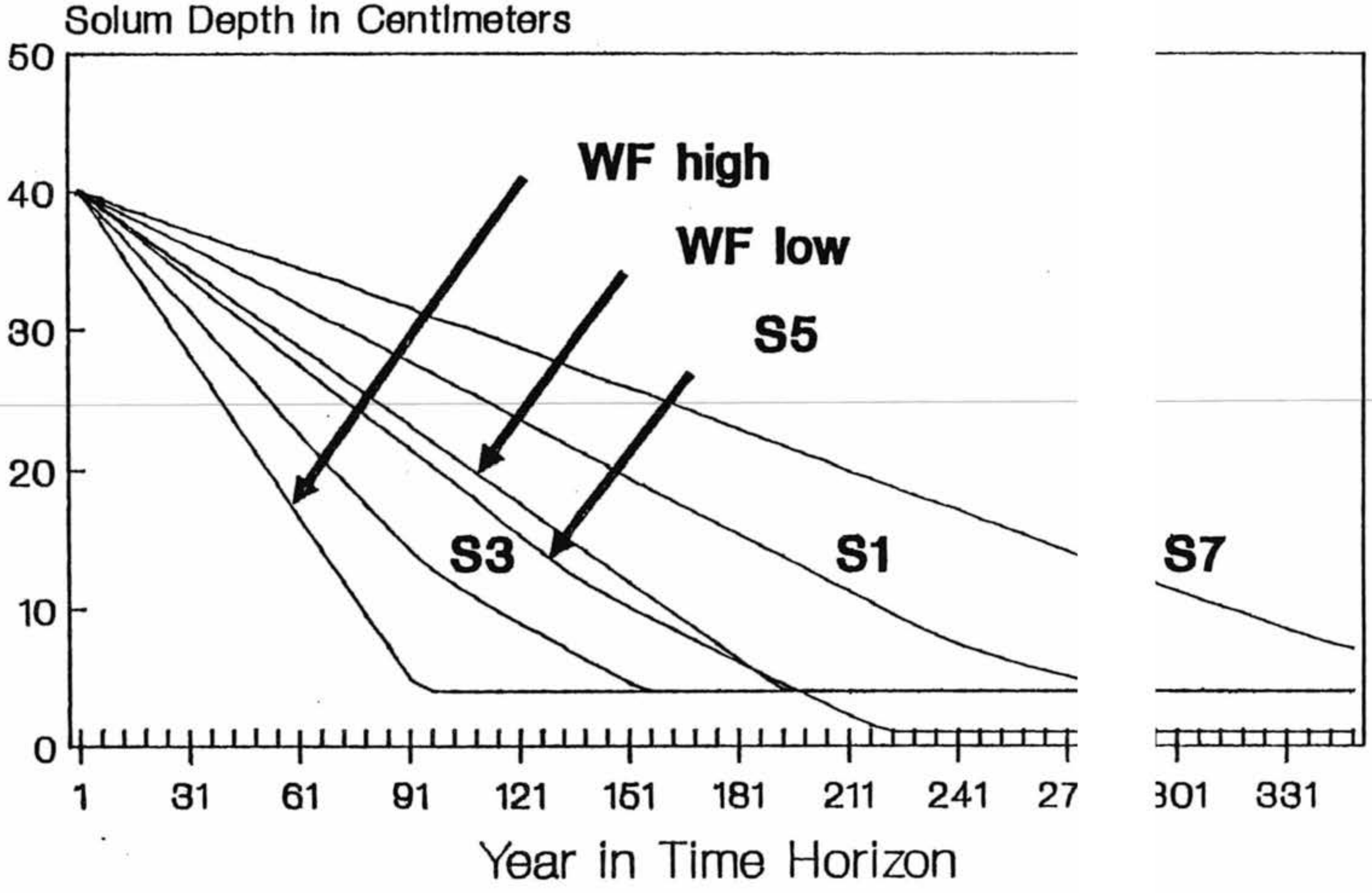


Fig 2: Time Paths for Solum D th
for Various Price and Erosion Sc arios



REFERENCES

Burt, Oscar R. and John R. Allison. "Farm Management Decisions with Dynamic Programming", *Journal of Farm Economics* 45(November 1963): 121-36.

Burt, Oscar R. and Ralph D. Johnson. "Strategies for Wheat Production in the Great Plains", *Journal of Farm Economics* 49(November 1967): 881-899.

Clark, J. S. and W. H. Furtan. "An Economic Model of Soil Conservation/ Depletion", *Journal of Environmental Economics and Management* 10(1983): 356-70.

Innovative Acres Project. *Innovative Acres Report*. Saskatoon: Saskatchewan Institute of Pedology, various issues (annual).

Kiss, J.J., E. De Jong, and H.P.W. Rostad. "An Assessment of Soil Erosion in west-central Saskatchewan using Cesium-137", *Canadian Journal of Soil Science* 66(1986):591-600.

Prairie Farm Rehabilitation Administration. *Land Degradation and Soil Conservation Issues on the Canadian Prairies*. Regina: Soil and Water Conservation Branch, 1983.

Rennie, D. A. "Soil Degradation: A Western Perspective", *Canadian Journal of Agricultural Economics: Proceedings Issue* 33(June 1986): 19-29.

Saskatchewan Agriculture. *Agricultural Statistics 1986*. Regina: Economics Branch.

Schoney, R.A. *Results of the 1987 Saskatchewan Top Management Workshops*. Department of Agricultural Economics Bulletin: FLB 87-01. Saskatoon: University of Saskatchewan, June, 1987.

Science Council of Canada. *A Growing Concern: Soil Degradation in Canada*. Ottawa: Science Council of Canada, September, 1986.

Sparrow H.O. *Soil at Risk*. Report of the Standing Senate Committee on Agriculture, Fisheries and Forestry. Ottawa: Supply and Services Canada, 1984.

Taylor, Daniel Blaine. *Evaluating the Long Run Impacts of Soil Erosion on Crop Yields and Net Farm Income in the Palouse Annual Cropping Region of the Pacific Northwest*. Unpublished Ph.D. Dissertation. Pullman: Washington State University, 1982.

Van Kooten, G.C., and W.P. Weisensel. "A Dynamic Flexcropping Model with Soil Erosion: An Application to Saskatchewan" Department of Agricultural Economics, University of Saskatchewan, 1989.

Walker, David J. and Douglas L. Young. "The Effect of Technical Progress on Erosion Damage and Economic Incentives for Soil Conservation", *Land Economics* 62(February 1986): 83-93.

Weisensel, Ward P. The Economics of Soil Erosion in Saskatchewan: A Stochastic Dynamic Programming Approach. Unpublished M.Sc. Thesis. Saskatoon: University of Saskatchewan, 1988.

Weisensel, W.P., G.C. Van Kooten, and R.A. Schoney. "The Relative Riskiness of Fixed versus Flexible Crop Rotations in the Brown Soil Zone of Southwestern Saskatchewan." Department of Agricultural Economics, University of Saskatchewan 1988.

Young, D.L. and G.C. Van Kooten. "Incorporating Risk into a Dynamic Programming Application: Flexcropping". In Risk Analysis for Agricultural Production Firms: Concepts, Informational Requirements and Policy Issues. Raleigh, N.C.: North Carolina State University, June, 1988:45-63.