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THE RELATIVE RISKINESS OF FIXED VERSUS FLEXIBLE CROP ROTATIONS IN THE BROWN SOIL ZONE OF SOUTHWESTERN SASKATCHEWAN

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Summerfallow is a distinctive cropping practice in the southern Great Plains of western Canada. While summerfallow reduces the need for nitrogen applications through demineralization of organic matter, and improves weed and pest control, its primary purpose is to increase the amount of soil moisture available for growing next year's crop (Molberg et al.; Michalayna and Hedlin). In Saskatchewan, precipitation averages 12 to 18 inches per year. As a result, the province experiences an annual soil moisture deficit of 4 to 12 inches (Environment Canada). Thus, it is not surprising that summerfallow is a common practice in Saskatchewan, with the summerfallow (SF) ratio—the ratio of summerfallow to total tillable acreage—as high as 0.456 in parts of the province.[1] In 1981, the SF ratio was 0.456, 0.413, and 0.303 for the brown, dark brown and black soil zones, respectively.

By increasing the following year's soil moisture, summerfallow contributes to higher and more stable crop yields and, thereby, higher and more stable net returns (Zentner et al., 1979 and 1984). In contrast to the direct and immediate economic benefits, summerfallow has adverse effects on soil quality through lower soil organic matter content, increased soil salinity and increased soil erosion. Depleted soil organic matter levels directly affect future production through reduced tilth, moisture holding ability and available soil nitrogen (Rennie). However, the greatest and most immediate concern is its impact on soil erosion, since it generates soil losses five to ten times greater than those associated with cropped land.[2] Therefore, to maintain soil quality, it may be necessary to either increase cropping intensity or adopt other forms of soil conservation.

Traditionally, farm management extension specialists in Saskatchewan have based crop/fallow recommendations on static crop budgeting models and fixed crop rotations that generate break-even yields or yield ratios. For example, the break-even ratio between fallow and stubble wheat yields is between 0.72 and 0.82, depending upon price, yield and machinery assumptions (Schoney).[3] If spring soil moisture levels cannot generate expected yields above these ratios, fallowing is recommended over stubble cropping. Alternatively, the crop/fallow choice can be based on critical soil moisture thresholds where the decision to stubble crop varies according to actual spring soil moisture. Therefore, crop strategies are no longer fixed. In 1963, Burt and Allison employed Stochastic Dynamic Programming (SDP) to determine optimal critical soil moisture thresholds between crop and fallow alternatives. More recently, Young and Van Kooten have determined optimal flexcrop soil moisture thresholds for the Palouse region in the state of Washington, while Weisensel developed a similar flexcrop model for the brown

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[1] Summerfallow is a common practice in dryland agriculture. It involves keeping a field weed free through the use of cultivation to store two years of moisture for a single crop. It is also a useful weed control practice.

[2] Personal communication with soil scientists at the University of Saskatchewan.

[3] Stubble yields must be 72% to 82% of fallow yields to be profitable.

University of Saskatchewan

soil zone of southwestern Saskatchewan. The concept of a critical soil moisture threshold is quite simple, however, one can question the potential superiority of the flexcrop model over the traditional break-even model as an extension tool.

Therefore, the objective of this paper is to appraise the relative profitability and riskiness of three different crop decision models that might be used in an extension setting. These include (1) several fixed crop rotations, (2) variable cropping patterns using the break-even approach, and (3) a flexcrop model. Of particular interest is the value of information added by the dynamic approach implicit in the flexcropping model. In particular, what is the value of measuring soil moisture just prior to spring planting time.

Methodology

A bioeconomic simulation model of crop and climatic conditions in the brown soil zone of Saskatchewan is used to generate probability distributions for each of the three decision rules examined in this study. The simulation model incorporates two key agronomic/climatic relationships; namely, (1) expected yield as a function of available soil moisture at seeding time and (2) the transitional equations for available soil moisture at spring planting time from one year to the next year. Estimates of fallow and crop moisture transitions are based on cross-sectional and time series data from 11 farms located in the brown soil zone of Saskatchewan.[4] Each farm has observations from 24 plots over a 4 year period. The data include (i) the depth of the A and B soil horizons (solum depth), (ii) the level of available soil moisture at planting time, and (iii) the type of crop seeded and its yield. Average spring wheat yield for the data is 1,622 kg/ha (24.1 bu/acre).

Wheat yields are assumed to follow a modified Mitscherlich-Spillman form: $Y = a + b\,(1 - R_1^{SD})(1 - R_2^{SM})$, where a, b, R_1 and R_2 are the parameters to be estimated; SD and SM are centimeters of solum depth and available soil moisture, respectively; and Y represents expected yield in kilograms per hectare. The estimated relationship is:

$$Y = 84.0 + 2808.0\,(1-0.634^{SD})(1-0.926^{SM}), \qquad (1)$$

(0.27) (7.67) (2.16) (28.3)

Degrees of freedom = 484 $\quad$ $Rbar^2 = 0.21$ $\quad$ SEE = 822.1

where the t-statistics are provided in parentheses. As equation (1) is based solely on information available to the producer at seeding time, it is not surprising that the standard error of the estimate is large. Assuming a solum depth of 40 cm, which is the approximate average solum depth for the study region, expected yield at seeding time is:

$$Y = 84.0 + 2808.0\,(1 - 0.926^{SM}). \qquad (2)$$

[4]The farm data were collected as part of the Innovative Acres project. This program is administered by the Soil Science Department at the University of Saskatchewan.

Finally, spring wheat yields are assumed to be normally distributed.[5]

The transitional equations representing annual changes in available spring soil moisture in May of year t+1 are based on previously available soil moisture in May of year t and the crop/fallow decision:

$$\text{fallow:} \quad \ln SM_{t+1} = \underset{(18.66)}{2.021} + \underset{(4.95)}{0.2286} \ln SM_t \qquad R^2 = 0.1052 \quad SEE = 0.3075 \tag{3}$$

$$\text{crop:} \quad \ln SM_{t+1} = \underset{(12.33)}{1.602} + \underset{(4.07)}{0.2271} \ln SM_t \qquad R^2 = 0.0434 \quad SEE = 0.5075 \tag{4}$$

The t-statistics are provided in parentheses and the standard error of the regression is indicated below each equation. The SEE for equation (4) is larger than for equation (3), which suggests that yearly changes in soil moisture are more variable when a field is cropped as opposed to fallowed.

Decision Rules for Cropping

Fixed Decision Rules

Fixed cropping decision rules maintain the same pattern of crop and fallow regardless of spring soil moisture. The predominant rotation in the brown soil zone of Saskatchewan is a two-year, wheat-fallow rotation (see Table 1). However, a total of six fixed crop rotations can be delineated by varying the number of successive crop years from one to five. Fixed rules are a special case of the flexcrop decision rule discussed below. Moreover, since these rules disregard all spring soil moisture information, they can be used to value such information.

Break-Even Decision Rules

The second decision rule is the break-even yield analysis that is commonly used to evaluate the profitability of extended crop rotations. The decision rule is:

$$Y_s = \frac{Y_f}{2} + \frac{(C_s - (Cs_f + C_f)/2)}{Pw}, \tag{5}$$

where Y_s = break-even wheat yield on stubble,
Y_f = wheat yield on summerfallow,
C_s = direct costs of stubble cropping,
Cs_f = direct cost of summerfallow,
C_f = direct cost of cropping on fallow, and
Pw = price of wheat.

If the expected stubble yield is greater than the break-even yield, the profit maximizing decision is to crop rather than fallow. Expected stubble crop yields for the current crop year are based on current soil moisture and

[5]The yield distribution is truncated at zero, with yields less than zero set equal to zero.

yields calculated from equation (2). Expected summerfallow yields are also forecasted using equation (2), but they incorporate higher expected soil moisture due to fallowing as projected by equation (3). Although the break-even rule uses the same current information as the flexcrop system, it does not employ the same "look ahead features" of dynamic optimization; thus, it can be used as a crude measure of the value of soil moisture information.

The FlexCrop Decision Rule

Dynamic optimization takes into account the impact of today's decision upon all future states of the world and is, therefore, a more precise and comprehensive decision rule than either the fixed decision rule or the break-even rule. Using, the same yield and soil moisture equations, Weisensel determined optimal flexcrop decision rules using stochastic dynamic programming. The critical soil moisture levels are displayed in Table 2 for two wheat price scenarios—$91.80/tonne ($2.50/bu) and $165.30/tonne ($4.50/bu). Under the low price scenario, a crop is planted if available soil moisture at planting time is above 7.5 cm; otherwise the field would be fallowed. The critical soil moisture threshold falls to 5.0 cm under the high price scenario.

Table 2: Optimal Critical Soil Moisture Levels at Seeding Time

Spring Wheat Price Level	Critical Soil Moisture Level
($/tonne)	(cm)
91.80	7.5
165.30	5.0

Source: Weisensel

Measurement Error in Soil Moisture Readings

Both the flexcrop and break-even decision rules require that farmers make quite good measurements of available spring soil moisture prior to making a decision to crop or fallow.[6] Imprecise measurements can result from two errors: (1) pure measurement error due to user misinterpretation or use of an imprecise instrument, and (2) sampling error arising from varying soil profiles and soil moisture levels over the same field. The exact nature of errors in spring soil moisture measurement is unknown, but based on discussions with soil scientists at the University of Saskatchewan, it is assumed that soil moisture measurement error is normally distributed with a

[6]Field measures of soil moisture from Innovative Acres fields were used in equations (1), (3) and (4). These measurements were obtained by soil scientists using better instruments than those generally available to farmers. Further, the yield and moisture measures used in the estimations are for a very small plot as opposed to a field, the unit of concern to farmers.

mean of zero and a standard deviation of 1.5 cm.[7]

Simulation Results

Farm returns over direct costs of a typical Saskatchewan wheat farm located in the brown soil were simulated 1,000 times over a 30-year planning horizon for each decision rule. Two scenarios, a low wheat price ($2.50/bu) and a high wheat price ($4.50/bu), were selected. Initial available soil moisture was set at 11.0 cm, which is the average soil moisture level for the Innovative Acres fields in the study region.[8] Variable costs of crop production were obtained from Schoney and are presented in Table 3. The cumulative density function of net present value of returns over direct costs was constructed using a real discount rate of 5.0 percent. The expected present value of net returns (NPV), standard deviation and summerfallow intensity for each of the scenarios are presented in Table 4.

Table 3: Average Variable Costs of Production, Brown Soils, Saskatchewan, 1987.

Description	Cost ($/hectare)
Wheat on fallow	98.60
Wheat on stubble	112.73
Regular summerfallow	20.85

Source: Schoney

[7]Pure measurement error is not expected to be very large, but according to soil scientists a confidence interval of ± 1.0 cm is not uncommon. In contrast, since crop fields in Saskatchewan are seldom level, the second component of the measurement error is somewhat larger. For a gently undulating field, measurements across different sites are assumed to fall in a confidence interval of ± 2.0 cm.

[8]The initial soil moisture state had an appreciable effect upon the net present value of the optimal flexcrop strategy (Weisensel). Since we are interested only in comparing the decision rules, it is important that each of the simulations start in the same state.

Table 4: Simulated Net Present Value of Returns Over Variable Costs by Price Scenario

Decision Model	Low Price: SF[b] Ratio	Low Price: NPV Mean	Low Price: NPV StdDev	Low Price: NPV Over FlexCrop	High Price: SF[b] Ratio	High Price: NPV Mean	High Price: NPV StdDev	High Price: NPV Over FlexCrop
		($/hectare)				($/hectare)		
W-F	0.50	358	179	-153	0.50	1,361	326	-687
W-W-F	0.33	358	213	-153	0.33	1,659	396	-389
W-W-W-F					0.25	1,963	406	-85
W-W-W-W-F					0.20	1,937	433	-111
W-W-W-W-W					0.17	1,985	453	-63
CONTINUOUS					0.00	2,038	500	-10
Measurement Error:								
Break-even	0.40	462	203	-49	0.30	1,971	442	-77
FlexCrop	0.30	511	238	0	0.17	2,048	451	0
No Measurement Error:								
Break-even	0.40	497	207		0.30	1,905	423	
FlexCrop	0.30	571	213		0.17	2,137	455	

a Based on an initial level of available soil moisture of 11.0 cm, and a 5.0% discount rate.

b SF ratio is the long-run frequency of summerfallow.

Low Price Scenario

As expected, the two- and three-year fixed rotations generate the lowest present value of returns above variable costs under the low wheat pricescenario (Table 4). They both generate the same expected NPV ($358/hectare), but the three-year fixed rotation generates greater risk. The break-even decision rule is more profitable than either of the fixed decision rules, even if there is measurement error in spring soil moisture, but its standard deviation is similar to that of the three year rotation. The flexcrop strategy generates the highest NPV, but also the highest standard deviation of net returns. The mean NPV is increased by $153/ha over the fixed rotations and by $49/ha over the break-even decision rule.

In order to better assess the risk characteristics of the various decision rules, the cumulative density functions (cdfs) are tested for stochastic dominance. The two year rotation is second degree stochastic dominant over the three year rotation. Consequently, risk averse producers prefer the two year rotation. One expects the break-even and flexcrop decision rules to dominate the fixed rules because they incorporate more information (i.e., the fixed rotations are a special case of the flexcrop strategy), although the results with the inclusion of measurement error are less clear. However, both the flexcrop and break-even strategies are first degree stochastic dominant over the two-year and three-year fixed rotations, even with measurement error. If one ignores measurement error, the flexcrop strategy dominates the break-even decision rule with the exception of the minimum observation. However, if one includes measurement error, it appears that the flexcropping decision rule is penalized to a greater degree than the break-even decision rule. The break-even decision rule dominates the flexcropping decision rule for wealth levels below a cumulative probability of 10%. This is not surprising because the break-even decision rule results in a higher moisture threshold than the optimal flexcrop decision rule. Consequently, the downside error associated with the decision to crop results in one cropping closer to the dynamic flexcrop critical moisture threshold. Therefore, while the flexcrop strategy cannot dominate the break-even decision rule in a strict sense, incorporation of additional information as to decision maker risk attitudes is likely to result in flexcropping as the decision rule of choice.

High Price Scenario

When expected wheat prices are $4.50/bu, more intensive rotations become more profitable with a commensurate increase in their standard deviation. The most profitable rotation is continuous cropping with a NPV of $2,038 per hectare—about 50 percent greater than the traditional, two year rotation. In terms of stochastic dominance tests, the four year rotation is first degree stochastic dominant over the two and three year rotations.[9] For fixed rotations more intensive than four years, there is greater variability in returns, but expected returns are not substantially increased.

While not as important as with lower prices, the additional information incorporated in the break-even rule, even with measurement error, still results in greater profitability and dominance over most of the fixed rotations. However, the four year and more intense rotations are more profitable than that determined by the break-even rule. The dominance tests are not effective in finding a single efficient rule among the more intense fixed rotations and the break-even rules.

As in the low price scenario, the flexcrop strategy generates the highest expected net present value of returns, resulting in land being cropped 83 percent of the time. The flexcrop strategy without measurement error is first degree stochastic dominant over all other scenarios when measurement error is excluded. When measurement error is included, the flexcrop strategy stochastically dominates all other decision rules except the four year fixed rotation.

The Value of Information

The break-even decision rule dominates all fixed decision rules at low prices ($2.50/bu) because the cost of a wrong decision is higher. At higher wheat prices ($4.50/bu), cropping patterns shift to more intensive rotations and the cost of a wrong decision is not nearly as great. Then the break-even rule only dominates the less intensive rotations. The flexcrop decision incorporates the most information because the stochastic dynamic programming model evaluates how today's decision will affect future returns. However, there is one weakness associated with the flexcrop strategy: it may recommend that a farmer crop or fallow his entire farm in a given year. Although such a recommendation is unlikely to be followed by farmers, flexcropping is nonetheless, a valuable decision tool.

Soil moisture information has an important role in the crop/fallow

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[9] As expected, with higher wheat prices it becomes less risky to crop more intensively.

decision. While prices and other sources of uncertainty are not considered in this study, the annualized expected value of spring soil moisture information for the flexcrop rule lies between $10 and $45/hectare when compared to the typical 2 year rotation which is predominant in the study region.[10] Further, precise moisture measurements are not as important in favorable economic times, but they are critical when prices are low.

Conclusions

Current cropping patterns in the brown soil zone of Saskatchewan are based on a SF ratio of approximately 0.456—close to the two year rotation that is most prevalent in the region. This is supported by the data as the two year rotation dominates the three year rotation (at low prices). In addition, it has the lowest standard deviation of returns of all alternative cropping strategies. However, the research results reported here suggest that there may be considerable gains from encouraging farmers to adopt a more flexible rotation rule.[11] A more flexible decision rule could result greater income, with (perhaps) an acceptable increase in risk and, more importantly, considerably less soil degradation. At low prices, the farmer following the break-even rule summerfallows 42 percent of the time, while at high prices he summerfallows 30 percent of the time. This compares with 30 percent and 17 percent, respectively, for the flexcrop decision.

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[10]These annualized values are based on a 5% discount rate and a 30 year planning horizon.

[11]One possible system could be to flexcrop between a whole farm summerfallow ratio of 25 to 75%.

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