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Sustainable Crop Rotations for Alberta's Brown Soil Zone

Crop production on the Canadian Prairies has historically focused on spring wheat. In recent decades, crops such as barley and canola have increased in areas where there is sufficient precipitation. However, in the Brown soil zone of southeastern Alberta, summer-fallow and monoculture wheat systems remain the primary cropping practice.

In the Brown soil zone:

- the average annual precipitation is approximately 350 mm (13.8 in) and growing season precipitation is about 150 mm (6 in)
- approximately 46 per cent of the cultivable land is seeded into wheat and 35 per cent is summerfallow (a total of 81 per cent together)

What is the concern?

With such low precipitation, retaining soil moisture through summerfallowing has been an important agricultural practice in the semiarid regions of the Prairies. However in the long term, summerfallowing can lead to a decline in soil quality as a result of the following factors:

- organic matter loss
- salinization
- wind and water erosion
- depleting soil nitrogen and other nutrient reserves

Producers have maintained soil productivity by applying chemical fertilizers and in fallow years, by using herbicides rather than cultivation to control weed growth. However, the long-term environmental sustainability of cropping systems that include summerfallow remains in question.

The study

In 1992, the *Long-Term Dryland Crop Rotation Study in the Brown Soil Zone* study began at the Alberta Crop Diversification Centre South's Bow Island substation. This long-term study was aimed at determining the viability of existing and alternative crops and cropping systems under differing rates of inorganic fertilizers and manure.

> *The study looked at the effects of cropping practices and the economics of various crop rotations*

The study was designed to do two things: to determine the effects of different cropping practices on soil quality in the long-term and to determine the economic performance of the various crop rotations that included:

- reduced summerfallow use
- legumes in the rotation
- inorganic fertilizers
- manure applications

Earlier research pertaining to soil quality found that:

- reducing the frequency of summerfallow improved organic carbon (measure of soil organic matter) and total nitrogen, both of which are potential measures of soil quality
- adding legumes to the rotation or using manure or compost helped improve soil quality

The study also had an economic component where a farm-level economic risk model was used to simulate decisions made by non-risk-taking producers facing variable annual returns. The net returns and variability for each tested rotation under different fertilizer treatments were calculated, including manure. The analysis included the effects of changes in crop prices and input costs.

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Experimental data and design

The soil series at the study site is Chin clay loam, a dominant soil type in southeastern Alberta. Treatments of varying levels of chemical fertilizers were applied to the following crop rotations established in 1992:

1. fallow-wheat (FW)
2. fallow-wheat-wheat (FWW)
3. continuous wheat (CW)
4. annual legume (pea)-wheat (LW)
5. flax-wheat-fallow (F_xWF)
6. grass (G)

Other design features:

- a manure treatment of the crop rotations fallow-wheat and continuous wheat
- the annual legume in the legume-wheat rotation was field peas; the grass rotation consisted of pubescent wheatgrass that was planted in spring 1992
- the wheat and flax phases of the fertilized rotations were fertilized with a 0, 18 or 36 lbs nitrogen (N) per acre per year and with 0 or 18 lb phosphate (P_2O_5) per acre per year
- fertilized grass received 90 lbs P_2O_5 per acre at the time of establishment in 1992 and an annual spring broadcast application of 36 lb N per acre per year

Economic analysis

The farm-level economic risk model developed for this study calculated the following:

- the 'best' rotation and fertilizer combinations for a given set of risk-tolerance levels (where risk-tolerance is measured by tolerable variability in annual returns, i.e., a low tolerance or high aversion would be characterized by a producer who cannot tolerate occasional low returns in exchange for higher average returns)
- expected net farm income (NFI) and annual variability for each combination
- expected net rotational income (NRI) for all rotation and fertilizer combinations in the study, i.e., the income remaining ($/acre) after paying all cash costs and depreciation of machinery and interest on outstanding loans for each rotation under test
- NRI annual variability

A representative farm was set at 1,600 acres. A machine complement typical for a crop farm of this size was specified. Machinery requirements, sizes, prices, ages, depreciation schedules, repair schedules, fuel use, and efficiency were included in the estimation. Fuel use and other machine costs were tabulated for each hour of machine use. Where required, the costs of pre-seeding tillage, seeding, early summer weed control, late summer tillage and hay harvesting, fall harvest and post-harvest tillage operations were included for each rotation.

All-risk crop insurance (which covers yield loss due to drought, hail, frost, and other environmental factors) was included in the analysis for all crops except hay. Crop insurance was set at the 70 per cent individual coverage level, and premiums were set at year 2000 levels.

Expected costs and returns for each of the test fertilizer treatments and rotations are shown in Table 1. The average annual prices and the average annual test plot yields for each crop were used to calculate returns (see Table 2 for period averages).

Net rotational returns

At the conclusion of the study, the expected annual net rotational income and standard deviations were determined for each crop rotation and fertilizer treatment. This analysis led to the following results, ranked in the order of expected returns, from highest to lowest (except where indicated, the results refer to the case with crop insurance).

The highest expected returns, in terms of net rotational income, came from the annual legume (pea)-wheat (LW) rotations. However, these rotations also showed high variability in returns. This variability was only exceeded by hay and two continuous wheat (CW) treatments (Table 3). The increased variability is a result of relatively higher input costs and returns as compared to the other rotations (Table 1).

Of the remaining crop rotations in the series, the continuous wheat (CW) rotation with fertilizer treatments of 36 lbs per acre of N (CW(36,0)) gave the next greatest expected net rotational income, followed closely by CW(36,18) and fallow-wheat-wheat FWW(36,18).

The case without crop insurance obtained a somewhat different outcome. The highest rotational income came from the annual legume (pea)-wheat (LW) rotations. Then in descending order of net rotational income came the fallow-wheat-wheat (FWW) rotation with fertilizer treatments of 36 lbs per acre of N and 18 lbs per acres of P_2O_5 (FWW(36,18)). This rotation was followed by fallow-wheat (FW(18,18)) and FW(36,18) (Table 4).

Table 1. Average annual production costs and returns ($ per acre per year)						
	Continuous wheat	Fallow-wheat	Fallow-wheat-wheat	Legume-wheat	Flax-wheat-fallow	Hay[a]
	(CW)	(FW)	(FWW)	(LW)	(F_XWF)	Hay[a]
Seed costs	7.47	3.73	5.00	9.63	3.64	2.80
Fertilizer costs (N, P_2O_5):						
36,0	10.23	5.12	-b-			10.23
0,18	6.39	3.19		6.39		
36,18	16.62	8.31	11.14		11.14	
36,18	11.51	5.75				
Herbicide costs	20.57	15.06	16.98	20.97	16.85	1.59
Machinery repairs	13.71	8.12	10.02	14.30	7.15	9.23
Fuel costs	9.75	6.26	7.45	8.77	7.16	10.00
Average returns:						
0,0	115.68	116.36	123.59	170.67	107.30	72.18
36,0	155.35	129.72				105.25
0,18	123.57	128.61		170.70		
36,18	163.01	137.86	150.70		127.17	
18,18	145.50	135.44				
manure	129.43	127.67				

a Note that herbicide and seed costs for hay are incurred in the first year only.

b Empty cells correspond to treatments not applied to the rotation.

Table 2. Average yields for each crop by rotation and fertilizer treatment (ton per acre)						
	Treatments ((N, P_2O_5) and manure)					
	(0,0)	(36,0)	(0,18)	(36,18)	(18,18)	(Manure)
CW (wheat)	0.89	1.20	0.95	1.26	1.12	1.00
FW (wheat)	1.71	1.88	1.88	2.01	1.97	1.87
FWW (wheat)	1.35	a		.51		
LW (wheat)	1.48		1.51			
LW (peas)	1.08		1.10			
F_XWF (flax)	0.73			0.82		
F_XWF (wheat)	1.18			1.45		
Hay	1.15	1.66				

a Empty cells correspond to treatments not applied to the rotation.

Continuous wheat CW(36,18), which was the most profitable CW treatment, reached an expected net rotational income that was $2.53 per acre lower than the best fallow-wheat (FW) rotation; however, the variability was higher.

All-risk crop insurance reduced the variability of net rotational income for all rotation and fertilizer treatment combinations. With the insurance, the expected net rotational income of the continuous wheat (CW), legume-wheat (LW), and flax-wheat-fallow (F_XWF) rotations increased, while it decreased for fallow-wheat (FW) rotations, and results were mixed for the fallow-wheat-wheat (FWW) rotations (compare Tables 3 and 4). Crop insurance of this sort favored the continuous cropping rotations because those rotations showed greater variability from year-to-year.

Table 3. Expected annual net rotational income – with crop insurance ($ per acre per year)

	Fertilizer application ((N,P) and manure)					
	0,0	**36,0**	**0,18**	**36,18**	**18,18**	**Manure**
CW	1.79 (28.15)[a]	27.47 (31.41)	3.66 (39.54)	26.77 (33.73)	15.41 (34.82)	9.71 (33.57)
FW	11.64 (20.76)	16.17 (25.55)	16.80 (21.61)	19.66 (24.41)	19.81 (24.37)	17.10 (24.04)
FWW	12.55 (24.03)	[b]		25.66 (31.53)		
LW	38.09[c] (35.19)		34.43[c] (31.65)			
F_XWF	9.84 (24.43)			17.29 (30.45)		
Hay	-11.88 (59.66)	4.31 (61.44)				

a Values in parenthesis are variances.

b Empty cells correspond to treatments not applied to the rotation.

c Based on data from 1994-2000 only.

Table 4. Expected annual net rotational income – without crop insurance ($ per acre per year)

	Fertilizer application ((N,P) and manure)					
	0,0	**36,0**	**0,18**	**36,18**	**18,18**	**Manure**
CW	-2.21 (36.25)[a]	18.74 (46.17)	-1.28 (46.81)	19.50 (45.97)	10.70 (43.24)	4.15 (41.07)
FW	12.58 (21.88)	18.39 (25.54)	19.02 (21.63)	21.87 (24.41)	22.03 (24.38)	17.17 (24.44)
FWW	12.89 (27.12)	[b]		24.12 (35.98)		
LW	36.59[c] (43.82)		31.74[c] (40.87)			
F_XWF	6.10 (23.86)			12.32 (23.78)		
Hay	-11.88 (59.66)	4.31 (61.44)				

a Values in parenthesis are variances.

b Empty cells correspond to treatments not applied to the rotation.

c Based on data from 1994-2000 only.

The continuous wheat (CW(manure)) treatment performed poorly, but was not a money loser. Fallow-wheat (FW(manure)) only moderately underperformed FW(18,18) by $2.70 per acre. The flax-wheat-fallow (F_XWF) rotations performed poorly.

The hay yields of grass (G(36,0)) and G(0,0)) were very poor in this dryland test, and although the expected net rotational income appears variable, this result is misleading. The 1993 yields were abnormally high as a result of high precipitation while the remaining years provided little yield. If the analysis had included only the years 1994-2000, hay would be the least variable crop. Even so, the returns were very low or negative.

Combinations

The analysis also evaluated how producers might combine the rotations under test to maximize their average annual returns and reduce their exposure to risk (or variability in returns from year-to-year). Without the introduction of the legume-wheat (LW) rotations, the results from the economic risk analysis suggested that only combinations of the continuous wheat (CW(36,0)) and fallow-wheat-wheat (FWW(36,18)) would be planted as risk aversion is varied. With increasing risk aversion (i.e., the case where a producer cannot tolerate occasional low returns in exchange for higher average returns), the FWW(36,18) rotation began to supplant CW(36,0), but even at very high risk aversion, only 30 per cent of the land was planted in FWW(36,18) with the remainder in CW(36,0).

Without crop insurance, the results from the economic risk analysis suggested that only combinations of the fallow-wheat (FW) and fallow-wheat-wheat (FWW) rotations would be planted as risk aversion is varied (Table 5). The only exceptions were at very high risk-aversion levels (i.e., the case where a producer cannot tolerate occasional low returns in exchange for higher average returns). These results are consistent with the cropping practices of producers in this area and may indicate why producers have so predominantly used the FWW and FW rotations.

When legume-wheat (LW) rotations were included, crop insurance reduced the variability in the net rotational income for these rotations. Variability was reduced to the point that only under very high risk-aversion was any other rotation included in the optimal mix (fallow-wheat (FW(18,18)) at only 150 acres or about 9 per cent of the cropped land). Similarly, without crop insurance, the LW rotation was a major component of the optimal rotational mix, even at very high risk-aversion levels (see Table 6).

Sensitivity of the results was tested by:

1. varying wheat, pea, flax, and hay prices
2. varying fertilizer prices
3. lowering interest rates

As long as pea prices remain at least 70 per cent of their average price for the period, the legume-wheat (LW(0,0)) net rotational income remained above the next best rotation in the study. However even at this level, the results indicated that risk-averse producers would still mix the LW rotation with fallow-wheat (FW(18,18)) to obtain their optimal production choice. They would not just replace it with the FW rotation.

Table 5. Farm-level optimal rotations and economic performance under risk aversion (without legume crop, 1992-2000)

	Levels of risk aversion			
Optimal rotations	**Low**	**Medium**	**High**	**Very high**
Continuous wheat (36,18)	0.00[a]	0.00	6.06	6.06
Wheat-fallow (18,18)	0.00	75.14	93.94	93.94
Wheat-wheat-fallow (36,18)	100.00	24.86	0.00	0.00
Expected net returns ($ per acre)	24.12	22.55	21.90	21.90
St. dev.* of returns ($ per acre)	35.98	26.66	23.29	23.29

a Measured as a percentage of total cultivated land

* St. dev. = standard deviation

Table 6. Farm-level optimal rotations and economic performance under risk aversion (with legume crop, 1996-2000)

	Levels of risk aversion			
Optimal rotations	**Low**	**Medium**	**High**	**Very high**
Wheat-fallow (36,18)	0.00[a]	0.00	24.99	62.06
Legume-wheat (18,18)	100.00	100.00	75.01	37.94
Expected net returns ($ per acre)	36.59	36.59	32.74	26.77
St. dev.* of returns ($ per acre)	43.82	43.82	37.80	30.55

a Measured as a percentage of total cultivated land

* St. dev. = standard deviation

Alternatively, wheat prices would need to increase by 35 per cent before the expected net rotational income for another rotation would exceed that of legume-wheat (LW(0,0)). Because of the low net rotational income with flax-wheat-fallow (F_xWF), even reasonable increases in flax prices would not be enough to get risk-averse producers to add the rotation to their optimal mix.

Fertilizers

The study suggested that as chemical fertilizer costs rise, producers would be more likely to shift toward rotations with reduced chemical fertilizer treatments. The wheat-fallow (WF(0,18)) rotation, for example, provides some solutions, but only after 50 per cent increases in chemical fertilizer prices.

For fallow-wheat (FW) or continuous wheat (CW) manure treatments to become attractive to producers, the prices on chemical fertilizers would need to increase by 80 per cent over the period average in the study. This is the point at which fallow-wheat (manure) finally entered the solution.

Although there are good reasons to apply manure as an organic fertilizer, it is costly to do so. In addition, the yield response, at least in this short-term study, does not compare to that obtained from chemical fertilizers. Applying manure at heavier rates also introduces a set of environmental problems associated with phosphorous loading. Additional research is required to determine if some combination of manure and chemical fertilizers could be profitable.

Conclusions

The results of the *Long-Term Dryland Crop Rotation Study in the Brown Soil Zone* indicate that introducing legumes into dryland rotations in southern Alberta would increase producer profits. Legumes would lower production costs as their ability to fix nitrogen in the soil would reduce or eliminate the need for chemical fertilizers.

Risk-averse producers would be expected to plant a combination of pea/wheat (LW(0,0)) and fallow wheat (FW(36,18)) or FW(18,18). The relative rates would depend on each producer's degree of risk-aversion and level of crop insurance. With this combination of rotations, producer expected net farm income could be expected to increase from $5 to $8 per acre.

The study results also suggest that organic soil amendments, in the form of manure, are profitable. However, the data implies that manure use on a wide scale is not likely because it is more profitable in the short-term to use chemical fertilizers.

Summerfallow and monoculture wheat systems have been the most widely accepted cropping systems in the semiarid regions of southern Alberta. These systems retain soil moisture and therefore experience less variability from year-to-year. However the long-term environmental sustainability and impact on soil quality of continued summerfallow in the rotation is a concern.

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