The Influence of Conservation Tillage on Economic Returns and Riskiness of Cropping Systems in the Thin Black Soil Zone

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INTRODUCTION

Low prices for cereal grains, coupled with changing government polices and programs and increasing concerns about soil and environmental degradation are stimulating significant change in land use practices throughout western Canada (Lindwall and Larney 1993). The adoption and use of diversified crop rotations, together with conservation tillage management (i.e., minimum and zero tillage) practices are becoming widely accepted by producers.

The objectives of this study were to examine the effects of alternative tillage management practices on production costs, net returns, and riskiness for monoculture cereal, cereal-oilseed, and cereal-oilseed-pulse crop rotations in the Thin Black soil zone of Saskatchewan.

MATERIALS AND METHODS

Experimental Data

The field experiment was initiated in 1987 on a heavy clay soil at the Indian Head Research Farm (Lafond et al. 1992). The study involved three crop rotations and three methods of tillage management. The crop rotations, all four years in length, included: i) spring wheat-spring wheat-winter wheat-fallow (SW-SW-WW-FA), ii) spring wheat-spring wheat-flax-winter wheat (SW-SW-FX-WW), and spring wheat-flax-winter wheat-field pea (SW-FX-WW-PE). Each rotation was managed using conventional (CT), minimum (MT), and zero tillage (ZT) practices. All phases of each rotation were present every year, and all systems were cycled on their assigned plots. The treatments were arranged in a split-plot design, with tillage as main plots and crop rotations as sub-plots. Plot size was 13 m by 18.3 m, and each treatment was replicated four times.

With the exception of winter wheat, plots being cropped under conventional tillage management practices received one or two tillage operations in fall (depending upon weed populations and amount of crop residue present), plus one tillage operation in spring to prepare the seedbed. The main tillage implement was the heavy-duty sweep cultivator, occasionally a rodweeder or tandem disc was substituted. On CT fallow areas, weeds were controlled by tillage alone, generally involving an average of 4.9 (range 2 to 6) operations using a cultivator or rodweeder during the 20-month fallow period. Under minimum tillage management, cropped areas received a phenoxy-type herbicide in fall to control winter annual weeds, followed by one pre-seeding tillage operation in spring using a cultivator. For MT fallow areas, weeds were controlled using a combination of tillage and herbicides. A phenoxy-type herbicide was applied in fall to control of winter annual weeds, followed by one or two non-selective herbicide applications in mid- to late-spring, and this was followed by one or two tillage operations, as required, during summer and early fall. For zero tillage areas, weeds were controlled by herbicides alone and crops were planted without seedbed preparation. Areas being cropped received phenoxy herbicide in fall, followed by a non-selective herbicide in spring prior to planting. On ZT fallow areas, phenoxy-type herbicides were applied each fall, followed by an average of 3 (range 2 to 5) applications of non-selective herbicides (used alone or in combination) in spring and summer periods, as required based on weed density and diversity.

Winter wheat was planted directly into standing stubble regardless of tillage method as this is the recommended practice. In 1991 winter wheat plots were seeded to spring wheat.

In-crop herbicides were applied to all treatments as required using recommended methods and rates of application. Fertilizer N and P were applied to all crops as required based on soil tests (Table 1). Potassium and sulphur fertilizers were also applied to all crops based on soil tests at average annual rates of 4 to 6 kg K_2O ha^{-1}, and 4 to 8 kg S ha^{-1}, respectively. All of the fertilizer was banded at the time of seeding.

Grain yield and protein content (1992 - 1998) were determined at maturity of each crop by direct combining. Protein concentrations were standardized to 13.5% moisture basis.

Economic Analyses

The economic performance of the nine rotation-tillage treatments was determined annually using methods described by Zentner et al. (1996). Each system was evaluated in regard to costs of production, gross return, net return, and riskiness. Net return was defined as the income remaining after paying for all cash costs (seed, fertilizer, pesticides, fuel, oil, repairs, crop insurance, miscellaneous, land taxes, and interest), ownership costs for machinery and grain storage, and labor. Riskiness was assessed using stochastic dominance analysis (Goh et al., 1989) to compare the probability distributions of net returns from each treatment for groups of producers having low, medium, and high risk aversion as defined by Zentner et al. (1992). All purchased inputs and machine operations were valued at their 1998 costs levels. No allowance was made for interest costs associated with land equity, or for differences in management requirements among the rotation-tillage treatments. The research plot data were extrapolated to the farm-level using a 907 ha representative farm with a typical complement of machinery and labor supply for each treatment. Participation in the Canada/Saskatchewan Crop Insurance program was assumed to be at the 70% yield coverage for all crops. Premium rates and payout criteria for each crop in Risk Area #8 of Saskatchewan were assumed. The base farm-gate prices for grains (net of rail transportation and elevator handling costs) were \$138 t^{-1} (protein content < 12%) for spring wheat, \$129 t^{-1} for winter wheat, \$295 t^{-1} for flax, and \$184 t^{-1} for field pea. The price for spring wheat was adjusted by treatment and year in accordance with the 1998-99 schedule for grain protein content as established by the Canadian Wheat Board. The performance of each cropping system was also evaluated for a range of product prices (representing 25% lower to 25% higher than the base values) to test the sensitivity of the findings to changes in these price conditions. The economic performance results were expressed on a per hectare basis for the complete rotation systems, which includes the costs and returns for all cropped and fallow portions of each rotation-tillage treatment, and for individual crops within the rotations. Data collected over the 1987 to 1998 period were used in the analyses.

RESULTS AND DISCUSSION

Weather Conditions

Growing season (May - August) precipitation over the 12-year study period averaged 227 mm, which is similar to the long-term mean of 224 mm for the Indian Head region (Table 1). However, on an annual basis, growing season precipitation was less than 85% of normal (i.e., dry) in 4 years (1989, 1990, 1996, and 1997), was about normal in 4 other years (1987, 1988, 1992, and 1993), and was more than 115% of normal (i.e., wet) in the 4 remaining years (1991, 1994, 1995, and 1998).

Grain Yields

Tillage method significantly influenced (P<0.10) the yield of flax, field pea, and spring wheat grown on stubble, but did not affect the yield of winter wheat or the yield of spring wheat grown on fallow (Table 2). The use of ZT and MT practices increased the mean yield of spring wheat grown on spring wheat and winter wheat stubble by 7% (compared to CT); much of this yield advantage with conservation tillage was attributed to improvements in spring soil water conditions (Lafond et al. 1996). In contrast, yield of spring wheat grown on pea stubble averaged 6% lower under ZT compared to MT and CT, but overall, yields of spring wheat grown on pea stubble averaged 12% higher than those grown on cereal stubble. Similarly, winter wheat yields, although not affected by tillage because all systems were direct seeded, averaged 22% higher when grown on flax stubble compared to those grown on spring wheat stubble. These latter rotational yield benefits have been attributed to reduced root and leaf diseases in the mixed rotations (compared to monoculture cereals) (Lafond et al. 1996). The 12-year mean yield of flax averaged 13% higher, while pea yields averaged 7% higher under MT and ZT compared to CT management. These yield responses to tillage method are in general agreement to those reported elsewhere in the Black soil zone and in other soil-climatic regions of western Canada (Lafond et al. 1996).

On an annual basis, the yields of spring wheat grown on cereal stubble were significantly influenced by tillage method (P<0.10) in 7 of 12 years (data not shown). In 5 of these years (1987, 1988, 1989, 1992, and 1997), spring wheat yields were lowest for CT management. The average yield advantage of MT and ZT was 25% during these

Table 1. Growing season precipitation at Indian Head (1987-1998)

Year	May	June	July	August	Growing season
	(mm)				
1987	73	58	84	18	233
1988	70	49	58	39	216
1989	26	51	54	42	173
1990	20	49	64	31	164
1991	104	123	48	39	314
19920	68	43	74	23	208
1993	23	72	102	57	254
1994	33	120	55	90	298
1995	80	87	29	131	327
1996	30	48	30	23	131
1997	13	44	18	40	115
1998	49	175	23	39	286
Long-term mean	43	88	49	44	224

years, all of which received normal to below normal levels of growing season precipitation (Table 1). In the remaining two years (1991 and 1993) yields were lowest for ZT management (average of 11% less than CT and MT). For spring wheat grown on pea stubble, ZT yields were significantly higher than CT yields in 2 years (1988 and 1989), but were significantly lower in 3 other years (1990, 1992, and 1995).

Flax yields were significantly affected by tillage method (P<0.10) in 8 of the 12 study years (1987-89, 1992-94, and 1997-98) (data not shown). In nearly all of these years, flax yields were higher for conservation tillage compared to CT; the average yield advantage for MT and ZT in these years was 22%. Pea yields were significantly increased by use of MT and ZT management practices in only 3 of 12 years (1988, 1994, and 1996, with an average yield advantage of 12%), although the yields tended to be higher with conservation tillage in most years (data not shown).

The relative annual variability in grain yields (as measured by CV) tended to be lowest for crops grown under ZT and highest for crops grown under CT management (Table 2), reflecting the improved available soil water conditions with ZT (Lafond et al. 1996).

Method of tillage management and crop rotation showed little consistent effect on grain protein concentration (Table 2). For spring wheat grown on fallow, the 1992-1998 average grain protein was significantly lower under ZT compared to MT management. In contrast, for field pea protein concentrations were similar for MT and ZT, but both were lower than for CT management. Finally, in the case of winter wheat grown on spring wheat stubble, protein content was similar for MT and ZT, but was significantly higher compared to CT.

Table 2. Effect of tillage method on fertilizer rates applied, grain yield, and grain protein (1987-1998) [z]

Crop/Tillage method	Fertilizer N	Fertilizer P_2O_5	Yield Mean	Yield CV	Yield Min	Yield Max	Protein [y] Mean	Protein Min	Protein Max
	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(%)	(%)	(%)
Spring wheat on fallow									
CT	45	24	2830	27	1534	4537	14.8	12.7	16.7
MT	51	24	2777	30	1043	4574	14.9	12.3	17.2
ZT	51	24	2822	25	1305	4547	14.7	12.5	16.5
Contrast CT vs MT & ZT			NS				NS		
MT vs ZT			NS				**		
Spring wheat on spring wheat and winter wheat stubble									
CT	75	25	2044	42	329	3913	14.6	12.1	17.3
MT	77	25	2214	36	749	4081	14.6	10.5	17.6
ZT	77	25	2178	37	679	4298	14.5	10.5	18.3
Contrast CT vs MT & ZT			**				NS		
MT vs ZT			NS				NS		
Spring wheat on pea stubble									
CT	69	25	2418	41	386	4545	14.5	12.0	16.8
MT	69	25	2499	35	688	4307	14.8	12.4	17.6
ZT	70	25	2303	34	752	3688	14.6	11.0	17.2
Contrast CT vs MT & ZT			NS				NS		
MT vs ZT			**				NS		
Winter wheat on spring wheat stubble [x]									
CT	102	36	2366	53	491	4892	12.2	9.5	15.4
MT	105	36	2255	55	657	4801	12.6	9.6	16.3
ZT	105	36	2323	50	919	4716	12.4	8.1	14.9
Contrast CT vs MT & ZT			NS				**		
MT vs ZT			NS				NS		
Winter wheat on flax stubble [x]									
CT	101	36	2861	45	710	5020	12.4	8.5	14.8
MT	107	36	2841	42	685	5551	12.3	9.2	14.6
ZT	106	36	2742	43	899	5004	12.5	9.0	15.3
Contrast CT vs MT & ZT			NS				NS		
MT vs ZT			NS				NS		
Flax on spring wheat stubble									
CT	57	21	1440	41	127	2669	18.5	14.5	23.1
MT	60	21	1612	31	397	2636	18.6	15.9	22.7
ZT	60	21	1629	30	650	2639	18.6	15.4	22.5
Contrast CT vs MT & ZT			*				NS		
MT vs ZT			NS				NS		
Pea on winter wheat stubble									
CT	17	21	2272	38	616	3729	18.6	15.7	22.6
MT	20	22	2407	35	720	3955	18.3	15.3	21.7
ZT	20	22	2450	31	1038	4116	18.4	15.2	20.7
Contrast CT vs MT & ZT			*				**		
MT vs ZT			NS				NS		

[z] +, *, **, and *** reflect significance at P<0.10, P<0.05, P<0.01 and P<0.001, respectively; NS = not significant.
[y] 1992-1998. All protein levels adjusted to 13.5% moisture.
[x] Excludes 1991.

Production Costs

Total costs for the complete cropping systems (i.e., each tillage-rotation treatment) were similar (P>0.10)for all methods of tillage management, but they were significantly influenced (P<0.10) by crop rotation (Table 3). Total costs were lowest for the monoculture cereal rotation (SW-SW-WW-FA) (mean \$233 ha^{-1}), intermediate for the cereal-oilseed rotation (SW-SW-FX-WW) (mean \$288 ha^{-1}), and highest for the cereal-oilseed-pulse rotation (SW-FX-WW-PE) (mean \$296 ha^{-1}).

Table 3. Effect of crop rotation and tillage method on production costs, gross returns, and net returns (1987 - 1998)

		SW-SW-WW-FA			SW-SW-FX-WW			SW-FX-WW-PE		
		CT	MT	ZT	CT	MT	ZT	CT	MT	ZT
		(\$ ha^{-1})								
Seed		22.61	22.61	22.61	29.77	29.77	29.77	37.56	37.56	37.56
Fertilizer		53.73	55.38	55.40	69.74	70.79	71.71	61.65	62.83	63.32
Herbicides		27.36	39.16	43.35	43.81	48.32	49.90	43.59	48.79	51.27
Fuel & oil		18.23	14.85	13.40	20.41	18.30	16.13	22.53	19.89	17.66
Repairs		15.38	13.94	13.30	18.34	18.07	16.83	21.48	20.81	19.51
Crop insurance		3.84	3.84	3.84	5.80	5.80	5.80	6.88	6.88	6.88
Other [z]		17.98	17.98	17.98	17.98	17.98	17.98	17.98	17.98	17.98
Interest		6.82	7.13	7.19	8.75	8.85	8.79	9.06	9.17	9.09
Labor		12.07	10.85	10.36	13.74	13.23	12.33	15.46	14.60	13.66
Machine overhead		52.05	48.40	46.50	61.33	59.30	55.98	62.14	59.04	55.72
Total cost [y]		230.07_c	234.14_c	233.93_c	289.67_b	290.44_b	285.22_b	298.33_a	297.55_a	292.65_a
Gross return [x]		283.21_e	280.03_e	285.37_e	372.82_d	396.13_{bc}	392.91_c	410.84_{ab}	423.12_a	412.87_a
Net return	Mean[y]	53.14_e	45.90_e	51.44_e	83.14_d	105.69_{bc}	107.79_{bc}	112.51_{abc}	125.56_a	120.22_{ab}
	CV (%)[w]	183	210	160	149	110	106	115	95	92

z Includes land taxes and miscellaneous costs.
Y Means followed by the same letter are not significantly different at P<0.10.
x Shown for base grain prices.
w Coefficient of variation calculated over years.

The total costs (per unit of land area) of producing individual crops within the rotations were also little affected by the method of tillage management, except for spring wheat grown on fallow where total costs (including fallow preparation) were lower for CT than for MT and ZT (Table 4). This latter result largely reflects the higher costs of controlling weeds on summerfallow areas when herbicides are substituted for some or all of the mechanical tillage operations (Table 5). Although the use of conservation tillage practices required lower expenditures for machine operation (i.e., fuel, oil, repair, and overhead) and for labor compared to CT, these savings were offset (or were more than offset in the case of summerfallow) by increases in expenditures for herbicides. The savings in machine related costs with conservation tillage practices arise from either fewer trips across the field, combining two or more activities into one field operation (e.g., seeding and fertilizing), or using machines with greater capacity or lower draft requirements (e.g., sprayer versus cultivator). The savings in machinery overhead costs arise from eliminating the need for tillage machines, using smaller power units with lower capital investment, or extending the life of major machines

Table 4. Effect of tillage method on production costs and economic returns for individual crops within rotations (1987-1998).

Crop/Tillage method	Fertilizer	Herbicides	Machine operation	Labor	Total cost	Average cost	Gross return[z]	Net return[z]
	($ ha^{-1})					($ t^{-1})	($ ha^{-1})	
Spring wheat on fallow[y]								
CT	45	48	154	23	352	124	466	114
MT	48	86	127	19	363	131	458	95
ZT	48	97	118	18	365	129	464	99
Contrast CT vs MT & ZT					*	*	NS	*
MT vs ZT					NS	NS	NS	NS
Spring wheat on spring wheat and winter wheat stubble								
CT	63	42	103	14	284	139	342	59
MT	64	49	96	13	284	128	361	77
ZT	64	53	87	12	277	127	357	80
Contrast CT vs MT & ZT					NS	*	+	*
MT vs ZT					NS	NS	NS	NS
Spring wheat on pea stubble								
CT	59	33	105	14	273	113	401	128
MT	59	43	98	13	275	110	411	135
ZT	60	46	87	12	267	116	377	111
Contrast CT vs MT & ZT					NS	NS	NS	NS
MT vs ZT					NS	NS	**	*
Winter wheat on spring wheat stubble[x]								
CT	107	22	85	12	286	120	320	33
MT	108	23	86	12	290	128	301	11
ZT	108	25	88	12	294	125	311	18
Contrast CT vs MT & ZT					NS	+	+	**
MT vs ZT					NS	NS	NS	NS
Winter wheat on flax stubble[x]								
CT	113	23	89	13	299	105	372	73
MT	115	23	91	13	303	107	367	64
ZT	118	23	90	13	305	111	354	49
Contrast CT vs MT & ZT					NS	NS	NS	*
MT vs ZT					NS	NS	NS	+
Flax on spring wheat stubble								
CT	50	62	104	14	294	204	433	139
MT	52	71	98	14	299	185	476	178
ZT	52	71	89	13	289	177	481	192
Contrast CT vs MT & ZT					NS	**	***	***
MT vs ZT					NS	NS	NS	NS
Pea on winter wheat stubble								
CT	29	58	126	20	332	147	425	92
MT	31	59	112	18	320	133	444	124
ZT	31	65	106	18	319	130	451	132
Contrast CT vs MT & ZT					**	**	*	***
MT vs ZT					NS	NS	NS	NS

[z] Shown for base grain prices.
[y] Includes costs of summerfallowing.
[x] Includes 1991 when winter wheat failed and plots were re-seeded to spring wheat.
+, *, **, and *** reflect significance at P<0.10, P<0.05, P<0.01, and P<0.001, respectively; NS not significant.

Table 5. Effect of tillage method on costs of summerfallow preparation (1987 - 1998).

	CT			MT			ZT		
Resource	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
	($ ha^{-1})								
Fuel & oil	14.95	8.20	20.96	7.95	4.89	10.52	5.95	4.89	8.01
Machine repair	8.35	4.85	11.19	5.18	3.40	6.32	4.28	3.40	6.14
Herbicides	7.16	0	21.50	38.01	18.66	77.83	47.34	31.45	77.83
Machine overhead	26.79	15.07	38.78	18.01	12.83	21.76	16.41	12.83	24.01
Labor	7.81	5.13	10.21	5.42	4.15	6.39	4.77	4.15	6.02
Interest	2.24	1.65	2.88	3.43	2.10	4.43	3.22	2.47	4.43
Other[z]	17.98	17.98	17.98	17.98	17.98	17.98	17.98	17.98	17.98
Total Cost[y]	85.28_c	64.67	106.54	95.98_b	68.94	135.34	99.95_a	77.16	135.34

Z Include land taxes and miscellaneous costs.

Y Total costs for min and max columns do not equal the sum of the respective columns. Mean values followed by same letter are not significantly different at P<0.10.

because of their reduced annual use. The savings in labor are a direct result of less time spent performing field operations under MT and ZT management. These results (except for summerfallowing costs) are in contrast those reported for the drier Brown and Dark Brown soil zones where the total costs of producing most individual crops using MT and ZT practices were higher compared to CT practices (Zentner et al. 1992, 1996).

The total cost per unit of land area tended to be highest for spring wheat grown on fallow ($360 ha^{-1}, including the cost of summerfallow preparation) and for field pea production ($324 ha^{-1}), and lowest for spring wheat grown after field pea ($272 ha^{-1}) (Table 4). The higher unit area cost of producing winter wheat ($290 ha^{-1}) compared to producing spring wheat on cereal stubble ($282 ha^{-1}) reflects, in part, the much higher rates of N and P fertilizer that were applied to winter wheat (Table 2), despite winter wheat having lower requirement for herbicides. The cost of producing flax averaged about $12 ha^{-1} higher than the comparable cost of producing spring wheat.

The average cost per unit of grain produced is shown for the individual crops in Table 4. These values represent the breakeven grain price that is required to recover production costs. The average cost of producing spring wheat ranged from $110 to $139 t^{-1}, winter wheat from $105 to $128 t^{-1}, flax $177 to $204 t^{-1}, and field pea from $130 to $147 t^{-1}. For spring wheat grown on cereal stubble, flax grown on spring wheat stubble, and pea grown on winter wheat stubble, the cost per unit of grain produced was lower with MT and ZT compared to CT. In contrast, for spring wheat grown on fallow, and for winter wheat grown on spring wheat stubble, the cost per unit of grain produced was lower with CT compared to the use of conservation tillage practices.

Gross Returns

The 12-year mean gross returns (at base grain prices) for the complete cropping systems were unaffected (P>0.10) by tillage method, except under the SW-SW-FX-WW rotation where CT was less profitable than MT or ZT management (Table 3). On an annual basis, tillage method influenced gross returns in only 4 of 12 years (data not shown); in 3 of these 4 years, MT and ZT practices provided higher gross returns than CT. As with total production costs, gross returns were significantly influenced (P<0.10) by crop rotation. Gross returns were lowest (in 11 of 12 years) for SW-SW-WW-FA (mean $283 ha^{-1}), intermediate (in 8 of 12 years) for SW-SW-FX-WW (mean $387 ha^{-1}), and highest (in 11 of 12 years) for SW-FX-WW-PE (mean $416 ha^{-1}). There was a significant interaction (P<0.10) between tillage method and crop rotation in only 3 years. In 1987, gross returns for CT > MT = ZT under the SW-SW-WW-FA rotation, whereas gross returns for MT > ZT > CT in SW-SW-FX-WW, and ZT > MT = CT in SW-FX-WW-PE. In 1988, gross returns for ZT > MT > CT in SW-SW-WW-FA, MT > ZT > CT in SW-SW-FX-WW, and MT = ZT > CT for SW-FX-WW-PE. Similarly, in 1993 gross returns for ZT > CT > MT for SW-SW-WW-FA, MT > CT > ZT for SW-SW-FX-WW, and CT = MT > ZT for SW-FX-WW-PE.

Gross returns for individual crops within the rotations displayed similar patterns as for grain yields (Table 4). Gross returns for spring wheat grown on fallow were similar for all tillage methods. However, they were higher with MT and ZT than with CT practices for spring wheat grown on cereal stubble, and for flax and field pea production. In contrast, gross returns for spring wheat grown on pea stubble were lower with ZT compared to MT and CT.

Net Returns

The 12-year mean net returns (at the base grain prices) were highest for the MT- and ZT-managed SW-FX-WW-PE rotation ($120 ha^{-1}), and lowest for the SW-SW-WW-FA rotation ($50 ha^{-1}) (Table 3). Net returns for the MT- and ZT-managed SW-SW-FX-WW rotation were similar, and significantly higher than the respective CT-managed rotation, but all of these systems were generally intermediate ($99 ha^{-1}) between the cereal-oilseed-pulse and monoculture cereal rotations. On an annual basis, net returns were significantly affected (P<0.10) by tillage method in 5 of 12 years (1987, 1988, 1989, 1993, and 1996), in three of these years (i.e., the same years as for gross return) there was a significant interaction (P<0.10) of tillage method and crop rotation. In 1987, net returns were similar with all methods of tillage management for the SW-SW-WW-FA rotation, but MT = ZT > CT for SW-SW-FX-WW, while MT > ZT > CT for SW-FX-WW-PE. In 1988, net returns with ZT = MT > CT for SW-SW-WW-FA and for SW-FX-WW-PE, but ZT > MT > CT for SW-SW-FX-WW. Finally, in 1993, net returns were ZT = CT > MT for SW-SW-WW-FA, MT > CT > ZT for SW-SW-FX-WW, and CT > MT > ZT for SW-FX-WW-PE.

The annual variability in net returns for the cropping systems (as measured by CV) were lower for MT and ZT compared to CT practices in most cases, and tended to decline as the crop rotation was diversified away from monoculture cereals (Table 3).

For individual crops within rotations, the effects of tillage method on net returns were often significant, but were not consistent (Table 4). For example, the use of CT practices were more profitable than MT and ZT practices for winter wheat and for spring wheat grown on fallow, but MT and ZT were more profitable than CT practices for flax, pea, and spring wheat grown on cereal stubble. Finally, MT and CT were more profitable than ZT practices when spring wheat was grown on pea stubble.

Effect of Changes in Grain Price on Net Returns

A change in grain price has its greatest impact on those cropping systems which devote a high proportion of the land area to that crop whose price has changed, and/or to those tillage methods which foster a yield advantage for that crop type. For example, an increase in the price of wheat (both spring and winter wheat) by 25% from the base levels (prices for other grains held constant) increased the mean net return of all cropping systems, but the relative improvement in profitability was greater for monoculture cereal ($56 ha^{-1} higher) and cereal-oilseed ($54 ha^{-1} higher) than for the cereal-oilseed-pulse rotation ($39 ha^{-1} higher) (Table 6). Nonetheless, SW-SW-WW-FA remained the least profitable rotation, while SW-SW-FX-WW and SW-FX-WW-PE generally provided similar and the highest net return. The relative profitability or ranking of tillage methods within the rotations were largely unchanged by the increase in wheat price. A 25% reduction in the price of wheat caused the monoculture cereal rotation to incur economic losses, while SW-FX-WW-PE with MT and ZT management practices were the most profitable cropping systems.

By comparison, a 25% increase in flax price or in field pea price, although impacting the absolute profitability of the mixed rotations, did not change the rank order of the rotation-tillage treatments (from the base price situation). In contrast, a 25% decrease in field pea price resulted in the SW-SW-FX-WW generally becoming the most profitable cropping system.

Table 6. Effect of grain price changes on mean net returns (1987 - 1998)[z]

	Base[y]	Wheat price		Flax price		Field pea price	
Rotation/Tillage method	Prices	High[x]	Low[x]	High	Low	High	Low
	($ ha^{-1})						
SW-SW-WW-FA							
CT	53_{e}	109_{c}	-3_{e}	53_{e}	53_{cd}	53_{e}	53_{e}
MT	46_{e}	101_{c}	-9_{e}	46_{e}	46_{d}	46_{e}	46_{e}
ZT	51_{e}	108_{c}	-5_{e}	51e	51_{cd}	51_{a}	51_{e}
SW-SW-FX-WW							
CT	83_{d}	135_{b}	32_{d}	109_{d}	58_{c}	83_{d}	83_{d}
MT	106_{bc}	161_{a}	50_{c}	134c	77_{b}	106_{c}	106_{a}
ZT	108_{bc}	162_{a}	53c	137_{bc}	79_{b}	108_{c}	108_{a}
SW-FX-WW-PE							
CT	113_{abc}	154_{a}	71_{b}	136_{bc}	89_{a}	135_{b}	90_{dc}
MT	126_{a}	166_{a}	85_{a}	153a	98_{a}	150_{a}	101_{abc}
ZT	120_{ab}	158_{a}	82_{ab}	148_{ab}	93_{a}	145_{ab}	96_{bcd}

z Means within columns followed by the same letter do not differ at P<0.10.

Y Base price for spring wheat = $138 t^{-1} (protein content = 12%), winter wheat = $129 t^{-1}, flax = $295 t^{-1}, and field pea = $184 t^{-1}.

X High price reflect a 25% increase in the respective base grain price, while low price reflects a 25% decrease in the respective base grain price.

Riskiness of Rotation-Tillage Systems

When choosing among cropping systems, producers are often faced with a trade-off between increases in annual net returns and increases in income variability or financial risk. As producers become increasingly risk averse, they tend to choose cropping systems that display lower income variability. The final choice or selection of a cropping system depends upon the risk attitudes of individual producers (their willingness to gamble), expectations on product prices and input costs, and the nature of the distributions of probable net returns that can be earned with each cropping system. Under the conditions of this study, producers with low risk aversion (i.e., those most willing to accept risk), would choose the SW-FX-WW-PE rotation with either MT or ZT management practices assuming expected grain prices were at base levels (Table 7). In contrast, producers with high risk aversion (i.e., those least willing to accept risk) would only consider SW-SW-FX-WW with ZT management at these same grain prices.

In general, producers with low risk aversion would choose SW-FX-WW-PE with either MT or ZT management, except when expected price for wheat was high or price for field pea was low, in which case they would choose SW-SW-FX-WW with ZT and/or MT management. Producers with medium and high risk aversion would also choose either SW-SW-FX-WW or SW-FX-WW-PE rotation (depending upon grain prices), but only with ZT management. Only in the case of a low flax price would these more risk averse producers consider using

Table 7. Risk efficient rotation-tillage systems at various grain prices.

	Level of risk aversion [z]		
Grain price scenario	Low	Medium	High
<u>Base prices</u>	SW-FX-WW-PE $_{MT}$ SW-FX-WW-PE $_{ZT}$	SW-SW-FX-WW $_{ZT}$ SW-FX-WW-PE $_{ZT}$	SW-SW-FX-WW $_{ZT}$
<u>High wheat</u>	SW-SW-FX-WW $_{MT}$ SW-SW-FX-WW $_{ZT}$ SW-FX-WW-PE $_{MT}$ SW-FX-WW-PE $_{ZT}$	SW-SW-FX-WW $_{ZT}$	SW-SW-FX-WW $_{ZT}$
<u>Low wheat</u>	SW-FX-WW-PE $_{MT}$ SW-FX-WW-PE $_{ZT}$	SW-FX-WW-PE $_{ZT}$	SW-SW-FX-WW $_{ZT}$ SW-FX-WW-PE $_{ZT}$
<u>High flax</u>	SW-FX-WW-PE $_{MT}$ SW-FX-WW-PE $_{ZT}$	SW-SW-FX-WW $_{ZT}$ SW-FX-WW-PE $_{ZT}$	SW-SW-FX-WW $_{ZT}$
<u>Low flax</u>	SW-FX-WW-PE $_{MT}$ SW-FX-WW-PE $_{ZT}$	SW-SW-WW-FA $_{ZT}$ SW-SW-FX-WW $_{ZT}$ SW-FX-WW-PE $_{ZT}$	SW-SW-WW-FA $_{ZT}$
<u>High pea</u>	SW-FX-WW-PE $_{MT}$ SW-FX-WW-PE $_{ZT}$	SW-FX-WW-PE $_{ZT}$	SW-FX-WW-PE $_{ZT}$
<u>Low pea</u>	SW-SW-FX-WW $_{ZT}$	SW-SW-FX-WW $_{ZT}$	SW-SW-FX-WW $_{ZT}$

z The Pratt-Arrow coefficients of absolute risk aversion were defined as low = 0 - .0075, medium = .0075 - 0.0225, and high = 0.0225-0.05. The low, medium, and high designations reflect that producers are becoming less willing to gamble or accept risk.

the SW-SW-WW-FA rotation. From a risk perspective, these results suggest that CT management would not be selected by any producers under any of the grain price scenarios examined. Further, MT management would only be considered by the producers with low risk aversion. Increases in the cost of herbicides and/or the cost of fertilizer favor (in relative terms) the use of CT management, while increases in the cost of nonrenewable energy further strengthens the use of conservation tillage management methods; however, the results of these latter scenarios are not reported in this paper.

CONCLUSIONS

The results of this 12-year study showed that producers in the Thin Black soil zone should expect to achieve similar or higher crop yields with conservation tillage management methods. Yields of field pea, flax and spring wheat grown on cereal stubble averaged about 7-13% higher with minimum and zero tillage compared to conventional tillage practices. Only when spring wheat was grown on field pea stubble were yields lower under zero tillage management. However, crop rotation had a much larger affect than tillage method on yields of spring and winter wheat, with the yields of these crops averaging 12-22% higher when grown in mixed cereal-oilseed or cereal-oilseed-pulse rotations. Thus producers should pay close attention to their choice of crop sequence to maximize grain production.

Production costs were greatly influenced by crop rotation, but they differed relatively little among methods of tillage management. Minimum and zero tillage practices had lower expenditures for fuel, machine operation, and labor, but these savings were generally offset by higher expenditures for herbicides. The average cost per unit of grain produced (or breakeven grain price) was lowest with conservation tillage practices when spring wheat was grown on cereal, and for flax and field pe production. In contrast, the unit cost of producing spring wheat on fallow and winter wheat on spring wheat stubble were lowest with conventional tillage practices.

Net returns were generally highest for the minimum-till and zero-till managed cereal-oilseed-pulse rotation, and lowest for the monoculture cereal rotation. This latter rotation consistently provided the lowest net return under all plausible price scenarios examined. These results reinforce the fact producers need to practice proper crop rotations and that there is little need for summerfallowing for moisture conservation in this soil-climatic region.

Income variability or riskiness was clearly lowest with zero tillage management practices and for the mixed crop rotations. Conventional tillage management practices displayed the highest level of financial risk for all crop rotations and grain price scenarios, and would generally not be selected by producers who are averse to risk.

ACKNOWLEDGMENT

Funding for the economic analysis was provided by the Saskatchewan Soil Conservation Association and the AAFC Matching Investment Initiative.

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