EFFECTS OF TILLAGE METHOD AND CROP ROTATION ON NON-RENEWABLE ENERGY USE EFFICIENCY IN THE THIN BLACK SOIL ZONE

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INTRODUCTION

Low prices for cereal grains, coupled with changing government policies and programs, and increasing concerns about soil and environmental degradation are stimulating significant change in land use practices throughout western Canada. The adoption and use of diversified crop rotations, together with conservation tillage practices are becoming widely accepted. However, little is known about the impacts of these land use changes on the requirements for non-renewable energy inputs and on energy use efficiency.

OBJECTIVES

This study examines the effects of alternative tillage practices on nonrenewable energy inputs, energy output, and energy use efficiency for monoculture cereal, cereal-oilseed, and cereal-oilseed-pulse crop rotations in the Thin Black soil zone of Saskatchewan.

MATERIALS AND METHODS

Experimental Data:

- Experiment was initiated in 1987 on a heavy clay soil at the Indian Head Research Farm.
- Crop Rotations:
  - Spring Wheat - Spring Wheat - Winter Wheat - Fallow (SW-SW-WW-FA)
  - Spring Wheat - Spring Wheat - Flax - Winter Wheat (SW-SW-FX-WW)
  - Spring Wheat - Flax - Winter Wheat - Pea (SW-FX-WW-PE)
- Rotations were managed using conventional (CT), minimum (MT), and zero tillage (ZT) practices.
- Treatments were arranged in a split-plot design with tillage method as main plots and crop rotation as sub-plots. Plots were 13m by 18.3m with each treatment replicated four times.
- Winter wheat was planted directly into standing stubble regardless of tillage method.
- Fertilizer N, P, K and S were applied to all crops (banded at seeding) based on soil tests.
- Herbicides were applied as required using recommended methods and application rates.

Energy Analysis:

- All direct and indirect non-renewable energy going into manufacture, formulation, packaging, transportation, maintenance and application of all inputs used in each production system were included.
- Energy output was taken as gross energy content (as measured by bomb calorimeter) of harvested grain less seed requirements. Energy in straw and chaff were not included as they were returned to the land to maintain soil organic matter and protect the soil from erosion.
- Energy use efficiency was calculated as: *i*) net energy produced (energy output minus energy input), and *ii*) ratio of energy output to energy input.

RESULTS AND DISCUSSION

Grain Yields and Quality

- Tillage method significantly influenced yields of flax, field pea and spring wheat grown on stubble, but did not affect yield of winter wheat or spring wheat grown on fallow (Table 1).
  - Yields of SW grown on cereal stubble averaged 7% higher under MT and ZT (compared to CT).
  - Yields of SW grown on pea stubble averaged 6% lower under ZT, but overall, SW yields were 12% higher when grown on pea stubble compared to cereal stubble.
  - Yields of WW were not affected by tillage method, but averaged 22% higher when grown on flax stubble compared to cereal stubble.
  - FX yields averaged 13% higher, while PE yields averaged 7% higher under MT and ZT compared to CT.
- Tillage method and crop rotation showed little consistent influence on grain protein concentration.

Effect of Tillage Method on Energy Performance of Individual Crops

- Substitution of herbicides for some or all of the mechanical tillage used for weed control on summerfallow areas significantly reduced non-renewable energy requirements (Table 2).
  - MT practices generated energy savings of 11%, while ZT practices generated energy saving of 16% compared to CT practices.
  - Use of MT required 54% less fuel and lubricant energy, and 24% less energy embodied in machinery (including machine repairs) (compared to CT).
  - Use of ZT required 70% less fuel and lubricant energy, and 30% less machinery overhead energy.
  - In contrast, herbicide energy requirements increased 4.5 fold with MT and 5.3 fold with ZT.

Table 1 Effect of tillage method on fertilizer use, grain yield, and grain protein (1987 - 1998)[z]

	Fertilizer		Yield			Protein [y]		
Crop/Tillage method	**N**	**P_2O_5**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(%)	(%)	(%)
Spring wheat on fallow								
CT	45	24	2830	1534	4537	14.8	12.7	16.7
MT	51	24	2777	1043	4574	14.9	12.3	17.2
ZT	51	24	2822	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	329	3913	14.6	12.1	17.3
MT	77	25	2214	749	4081	14.6	10.5	17.6
ZT	77	25	2178	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	386	4545	14.5	12.0	16.8
MT	69	25	2499	688	4307	14.8	12.4	17.6
ZT	70	25	2303	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	491	4892	12.2	9.5	15.4
MT	105	36	2255	657	4801	12.6	9.6	16.3
ZT	105	36	2323	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	710	5020	12.4	8.5	14.8
MT	107	36	2841	685	5551	12.3	9.2	14.6
ZT	106	36	2742	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	127	2669	18.5	14.5	23.1
MT	60	21	1612	397	2636	18.6	15.9	22.7
ZT	60	21	1629	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	616	3729	18.6	15.7	22.6
MT	20	22	2407	720	3955	18.3	15.3	21.7
ZT	20	22	2450	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.

Table 2. Effect of tillage method on non-renewable energy requirements for "Summerfallow" preparation (1987 - 1998)[z]

Energy parameter	CT	MT	ZT
	(MJ ha^{-1})		
Herbicides	152	682	805
Fuel and lubricants	1200	554	366
Machinery overhead	229	174	161
Total energy input	1580_{a}	1410_{b}	1332_{c}

[z] Means followed by the same letter do not differ at P<0.10.

- Total non-renewable energy input used in the production of SW was highest when the crop was grown on cereal stubble, and lowest (and about similar) when grown on fallow or on field pea stubble, largely reflecting the reduced N fertilizer rates applied in these latter situations (Table 3).
  - Energy input requirements were generally lowest with ZT management; they were generally similar for MT and CT management.
  - Gross energy output and net energy produced displayed similar trends as for grain yields.
  - Energy use efficiency was not affected by tillage method, but tended to be highest when the SW was grown on fallow, intermediate when grown on pea stubble, and lowest when grown on cereal stubble.

Table 3. Effect of tillage method on non-renewable energy requirements and energy use efficiency of "Spring Wheat" production (1987 - 1998)[z]

	Grown on Fallow[y]			Grown on Cereal Stubble			Grown on Pea Stubble		
Energy parameter	**CT**	**MT**	**ZT**	**CT**	**MT**	**ZT**	**CT**	**MT**	**ZT**
	(MJ ha^{-1})								
Fertilizer	3551	4013	4015	5886	6002	6003	5410	5410	5471
Herbicides	710	1361	1536	555	712	779	416	601	669
Fuel & lubricants	2847	1900	1602	1668	1382	1132	1693	1425	1140
Machinery overhead	626	551	530	375	366	340	389	380	345
Total energy input	7734_{ab}	7825_{a}	7683_{b}	8483_{a}	8462_{a}	8253_{b}	7908_{a}	7816_{b}	7626_{c}
Gross energy output	50407_{a}	49409_{a}	50260_{a}	35713_{b}	38894_{a}	38211_{a}	42693_{ab}	44225_{a}	40568_{b}
Net energy produced	42673_{a}	41584_{a}	42577_{a}	27230_{b}	30432_{a}	29957_{a}	34785_{ab}	36409_{a}	32942_{b}
Output/Input ratio	6.52_{a}	6.31_{a}	6.54_{a}	4.21_{b}	4.60_{a}	4.63_{a}	5.39_{a}	5.66_{a}	5.32_{a}

[z] Means in the same row for each cropping system followed by the same letter do not differ at P<0.10.
[X] Includes energy used for summerfallowing.

- Total energy requirements for WW production averaged 7% higher when grown on flax stubble compared to cereal stubble (Table 4).
  - Total energy requirements for WW production was lowest with CT management, mainly reflecting the lower rate of N fertilizer that was applied.
  - As with yields, gross energy output from WW production averaged 22% higher and net energy produced averaged 26% higher when grown after flax than after another cereal.
  - Energy use efficiency averaged 14% higher when the WW was grown in a mixed rotation compared to a monoculture cereal rotation, reflecting the higher grain yields.

Table 4. Effect of tillage method on non-renewable energy requirements and energy use efficiency of "Winter Wheat" Production (1987 - 1998)[z]

	Grown on Cereal Stubble			Grown on Flax Stubble		
Energy parameter	**CT**	**MT**	**ZT**	**CT**	**MT**	**ZT**
	---(MJ ha^{-1})---					
Fertilizer	6773	6905	6905	7131	7631	7463
Herbicides	357	363	409	379	381	368
Fuel and lubricants	1153	1156	1168	1218	1251	1235
Machinery overhead	324	335	342	348	364	359
Total energy input	8606_c	8759_b	8824_a	9075_c	9627_a	9426_b
Gross energy output	42152_a	39744_a	41459_a	51032_a	50650_{ab}	48792_b
Net energy produced	33546_a	30985_b	32635_a	41957_a	41023_{ab}	39366_b
Output/Input ratio	4.90_a	4.54_b	4.70_a	5.62_a	5.26_b	5.18_b

[z] Means in the same row for each cropping situation followed by the same letter do not differ at P<0.10.

- Total energy requirements for FX and PE production declined as tillage was reduced, reflecting the strong yield responses of these crops to the use of conservation tillage practices (Table 5).
  - Total energy inputs for PE production averaged 35% lower than for FX, reflecting the substantial savings in fertilizer energy, but these savings were offset somewhat by higher energy requirements for fuel and lubricants with PE.
  - Total energy requirement for FX production was highest with MT and lowest with ZT management; for PE production it was highest with CT and lowest with ZT management.
  - Energy use efficiency was highest for PE production; energy use effciency of FX production was generally similar to wheat.

Effect of Tillage Method and Crop Rotation on Energy Performance of Complete Cropping Systems

- Total input of non-renewable energy was lowest for SW-SW-WW-FA, intermediate for SW-FX-WW-PE, and highest for SW-SW-FX-WW (Table 6).

- Tillage method had little overall impact on total energy input of the complete rotations. The energy savings with the MT and ZT in terms of fuel, lubricants and machinery overhead were offset by increased energy going into herbicide and fertilizer application.
- Gross energy output, net energy produced and energy use efficiency were highest for the most diversified SW-FX-WW-PE rotation, and lowest for SW-SW-WW-FA and SW-SW-FX-WW.

Table 5. Effect of tillage method on non-renewable energy requirements and energy use efficiency of "Flax" and "Field Pea" production (1987 - 1998)[z]

	Flax on Cereal Stubble			Pea on Cereal Stubble		
Energy parameter	**CT**	**MT**	**ZT**	**CT**	**MT**	**ZT**
	(MJ ha^{-1})					
Fertilizer	4455	4658	4658	1503	1724	1724
Herbicides	430	585	664	411	467	578
Fuel & lubricants	1761	1503	1250	2329	1894	1674
Machinery Overhead	395	392	369	502	481	464
Total energy input	7041_{ab}	7139_{a}	6941_{b}	4746_{a}	4566_{b}	4439_{c}
Gross energy output	35889_{b}	40340_{a}	40794_{a}	39038_{b}	41547_{a}	42350_{a}
Net energy produced	28848_{b}	33201_{a}	33852_{a}	34292_{b}	36980_{ab}	37911_{a}
Output/Input ratio	5.10_{b}	5.65_{a}	5.88_{a}	8.23_{c}	9.10_{b}	9.54_{a}

[z] Means in the same row for each cropping situation followed by the same letter do not differ at P<0.10.

Table 6. Effect of crop rotation and tillage method on the nonrenewable energy performance of the "Complete" cropping systems[z]

	SW-SW-WW-FA			SW-SW-FX-WW			SW-FX-WW-PE		
Energy parameter	**CT**	**MT**	**ZT**	**CT**	**MT**	**ZT**	**CT**	**MT**	**ZT**
	(MJ ha^{-1})								
Fertilizer	4082	4278	4279	5663	5942	5837	4559	4706	4749
Herbicides	394	605	677	494	596	649	402	503	568
Fuel & lubricants	1419	1109	976	1585	1388	1196	1758	1517	1318
Machinery overhead	332	313	303	374	374	355	409	404	383
Total energy input	6227_{c}	6305_{c}	6235_{c}	8116_{a}	8300_{a}	8037_{a}	7128_{b}	7130_{b}	7018_{b}
Gross energy output	32296_{d}	31938_{d}	32711_{d}	39295_{c}	42552_{ab}	42014_{b}	42377_{ab}	43904_{a}	42603_{ab}
Net energy produced	26069_{c}	25634_{c}	26476_{c}	31178_{d}	34253_{bc}	33978_{c}	35249_{b}	36744_{a}	35586_{ab}
Output/Input ratio	5.2_{c}	5.1_{c}	5.2_{c}	4.8_{d}	5.1_{c}	5.2_{c}	5.9_{b}	6.2_{a}	6.1_{a}

[z] Means in the same row followed by the same letter do not differ at P<0.10.

CONCLUSIONS

- Producers in the Thin Black soil zone of Saskatchewan should expect to receive similar or higher grain yields with conservation tillage practices.

- Crop rotation had a greater influence on crop yields than tillage method. Mixed or diversified cropping systems produced higher and more stable grain yields.

- Fertilizers (primarily N) and fuel were the major non-renewable energy inputs to all cropping systems.

- Total energy input for SW, FX and PE production tended to be lowest with ZT management, and were generally similar for MT and CT management. Total energy input for WW production displayed the reverse trend with respect to tillage method.

- Overall, total energy input for the complete cropping systems were little affected by tillage method, but was lowest for the rotation that included fallow, intermediate for the rotation that included a pulse crop, and highest for cereal-oilseed rotation.

- Energy use efficiency, although influenced to a greater degree by crop rotation, tended to be higher with conservation tillage management due to the higher grain yields.

- Energy use efficiency was highest for the rotation that included a pulse crop.

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