

# Energy Performance of Alternative Cropping Systems and Tillage Methods in Saskatchewan

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## INTRODUCTION

Canada has committed to reducing its emissions of greenhouse gases (GHG) to 94% of 1990 levels by 2008 to 2012 (Neitzert et al. 1999). The agricultural production sector, which accounts for about 10% of the total Canadian GHG emissions, is expected to play an important role in helping to achieve these targets by adopting best management practices (Janzen et al. 1999). The major sources of GHG emissions from agriculture include enteric fermentation by livestock and the disposal of their manure on agricultural lands, soil microbiological and chemical processes which convert organic materials into its elemental components, and the burning of fossil fuels to power machinery for soil tillage, cultural operations, drying of crops, heating of farm buildings, and transportation of farm products. The sector is also an indirect contributor through the combustion of fossil-based energy used in the manufacture and repair of farm machinery, and in the manufacture, packaging, and transport of crop inputs (Janzen et al. 1999).

Traditional cereal-based production systems used by producers in the Canadian Prairies are heavily dependent on the input of non-renewable energy. Hopper (1984) estimated that the quantity of non-renewable energy expended in the production of spring wheat averaged 2500 MJ ha<sup>-1</sup> in 1948; by 1981 energy use had risen to 8400 MJ ha<sup>-1</sup>. Similarly, Stirling (1979) reported a 61% rise in energy inputs used on Saskatchewan farms between 1961 and 1976, and Coxworth (1997) reported a further 11% rise between 1990 and 1996. This growth in non-renewable energy use has been the result of increasing farm mechanization and the expanded use of fertilizers, herbicides, electricity, and other inputs designed to replace labor, raise productivity, and reduce the vagaries associated with the biological and environmental processes affecting production (Hirst 1974). During the 1950s and 1960s, the increase in energy inputs to crop production was counterbalanced by an equivalent increase in crop yields, such that energy intensity or energy use efficiency remained constant at about 220 kg of spring wheat per GJ of energy input, or an energy output to energy input ratio of about 3.5 (Hopper, 1984). However, other studies have suggested that the energy use efficiency of our traditional cropping systems in Saskatchewan have been trending downward in recent years due to energy inputs increasing faster than energy output as a result of the growing dependency on inorganic N fertilizers and fossil fuels (Gayton 1982; Weseen and Lindenbach 1998).

New cropping systems that substitute herbicides for some or all of the mechanical tillage, reducing the frequency of summerfallowing, and including new crop types in the rotation such as pulses and oilseeds, may offer opportunities for producers to reduce non-renewable energy input use and/or improve the overall energy use efficiency of their production systems (Coxworth et al. 1996; Zentner

et al. 1998, 2004; Nagy et al. 2000; Gill et al. 2001), and thereby contribute positively to the Canadian GHG reduction targets.

The objective of this paper was to compare conventional (CT), minimum (MT), and zero tillage (ZT) management practices for monoculture cereal, cereal-oilseed, and cereal-oilseed-pulse crop rotations in term of the impact: i) non-renewable energy input requirements, ii) energy output, and iii) energy use efficiency, for the semiarid Brown and more moist Black and Gray soil zones of Saskatchewan.

## **MATERIALS AND METHODS**

The energy performance of the various crop rotations and tillage methods were determined using process analysis (Fluck and Baird 1980). This involved identifying all direct and indirect non-renewable energy going into the manufacture, formulation, packaging, distribution, transportation, maintenance, and application of all inputs used in each crop production system. The analyses use data from four Saskatchewan field experiments conducted by Agriculture and Agri-Food Canada in the Brown soil zone at Swift Current, Thin Black soil zone at Indian Head, Thick Black soil zone at Melfort, and Gray soil zone at Tisdale. The experimental data were extrapolated to the farm-level, assuming representative farm sizes for the area and complements of equipment typical for each treatment.

The physical quantities of inputs used were converted to energy values using appropriate and the most recent energy coefficients taken from the literature and as summarized by Zentner et al. (1998) and Nagy et al. (1999). Recommended depths of tillage (where appropriate) and travel speeds were assumed for all field operations. Quantities of fuel and lubricants used by tractors and other powered machinery were as reported by Saskatchewan Agriculture and Food (1999). Grain used as seed was not included as an energy input; instead, it was subtracted from the harvested grain yield for each crop. No allowance was made for energy removed from the soil in the form of plant nutrients, energy captured in terms of soil organic matter increases or losses, nor for that which was captured directly from the sun by the growing plants. The analyses also exclude heating and electrical energy used for the home and farm buildings since these would be common to all cropping systems.

Output from the cropping systems was taken as gross energy content of the harvested grain less the seed requirements, based on bomb calorimeter analyses (direct combustion) of representative samples of each grain type. Energy in the crop residue was not included as energy output of the treatments since it was returned to the land.

Energy efficiencies or intensities of the cropping systems were calculated as (i) net energy produced (energy output minus energy input); (ii) quantity of grain produced per unit of energy input; and (iii) ratio of energy output to energy input.

## **RESULTS AND DISCUSSION**

### **Brown soil zone**

In this region, where available water is the major factor limiting crop production, producers have traditionally selected cropping systems that rely on monoculture cereals (spring wheat and durum), frequent summerfallowing, and use of mechanical tillage for weed control on fallow areas and for

seedbed preparation. An energy evaluation of these monoculture wheat systems conducted over a 12-year period (1982 to 1993) at Swift Current by Zentner et al. (1998) reported that the total input of non-renewable energy averaged 2636 MJ ha<sup>-1</sup> for N & P fertilized Fallow-Wheat (F-W) and 5709 MJ ha<sup>-1</sup> for Continuous Wheat (Cont W) (Table 1). Within the F-W systems, energy input was lowest with MT management (2500 MJ ha<sup>-1</sup>), intermediate with CT (4% more), and highest with ZT (12% more), while within the Cont W systems, use of ZT practices required 8% more non-renewable energy compared to use of CT practices. These less than encouraging results were attributed to four main factors. First, the substitution of herbicides for some or all of the mechanical tillage in this region offers only a small potential energy savings because of the few tillage operations that are traditionally employed to prepare the seedbed (i.e., typically one operation) and to control weeds on summerfallow areas (i.e., typically 3 to 4 operations throughout the 21-month fallow period). Although energy for applying herbicides is less than for performing tillage, the saving were partly offset by a greater number of field passes that were required with ZT management. Second, the ZT managed systems placed a heavy reliance on use of glyphosate for summerfallow and preseed weed control, and with monoculture cereal cropping, foxtail barley became a major problem weed after 2 to 4 years of ZT (Tessier et al. 1990), and this required occasional applications of high rates of glyphosate (using complete and spot spraying) to maintain control. The high use rate of glyphosate, plus the fact that it is one of the most energy intensive herbicides to manufacture, contributed to the general lack of net energy savings with conservation tillage management. Third, the rates of applied N fertilizer increased directly with cropping intensity, with wheat grown on stubble receiving more

Table 1. Effect of tillage method on non-renewable energy input, energy output, and energy use efficiency for monoculture wheat systems in the Brown soil zone (1982-1993)<sup>1</sup>

	Fallow-Wheat			Continuous Wheat	
	CT	MT	ZT	CT	ZT
	----- (MJ ha <sup>-1</sup> ) -----				
Fertilizer	928	905	994	3401	3623
Herbicides	170	270	726	257	610
Fuel & oil	991	856	670	1165	1096
Machinery	509	469	400	656	609
Total energy input	2597 <sub>d</sub>	2500 <sub>d</sub>	2810 <sub>c</sub>	5479 <sub>b</sub>	5938 <sub>a</sub>
Energy output	22568 <sub>b</sub>	21656 <sub>b</sub>	21374 <sub>b</sub>	34572 <sub>a</sub>	34501 <sub>a</sub>
Net energy produced	19971 <sub>b</sub>	19156 <sub>b</sub>	18564 <sub>b</sub>	29093 <sub>a</sub>	28563 <sub>a</sub>
Grain/Energy input (kg GJ <sup>-1</sup> )	468 <sub>a</sub>	470 <sub>a</sub>	412 <sub>b</sub>	343 <sub>c</sub>	316 <sub>c</sub>
Energy Output/Input ratio	8.7 <sub>a</sub>	8.7 <sub>a</sub>	7.6 <sub>b</sub>	6.3 <sub>c</sub>	5.8 <sub>c</sub>

<sup>1</sup> Values within a row followed by the same letter do not differ significantly.

than double the rate of N applied to wheat grown on fallow (Table 2). Fourth, the soil-test recommended rates of N fertilizer applied to the ZT managed systems averaged 2 to 5 kg N ha<sup>-1</sup> higher than for CT, reflecting the slower rates of residue decomposition and nutrient release as soil tillage is reduced (McConkey et al. 1996).

Energy associated with fertilizer inputs, primarily N, represented 62% of the total energy requirement for Cont W, while herbicides averaged 5 to 10%, fuel and lubricants 18 to 21%, and machine manufacture and repair 10 to 12% (Table 1). For F-W systems, fertilizer energy represented 36% of the total, herbicides 7 to 26%, fuel and lubricants 24 to 38%, and machinery 14 to 20% of the total energy input. The lower fertilizer energy requirements for F-W than Cont W systems reflects the fact that summerfallowing Amine<sup>s</sup> mineral N from soil organic matter (particularly with CT management) thereby reducing the requirement for N fertilizer, but studies have shown that long-term use of this practice leads to declining soil fertility and crop productivity (Campbell et al. 1990).

The use of conservation tillage management provided significant energy savings in fuel and machinery, particularly for F-W systems (14% with MT and 32% with ZT); but these savings were largely offset by increases in energy input for herbicides and for fertilizers due to the higher rates of N application required with the ZT systems.

Energy output averaged 58% higher for Cont W than for F-W, reflecting the higher total grain production as cropping intensity is increased, but it was little affected by method of tillage management (Table 1). For Cont W systems the latter effect reflects that spring soil water reserves under stubble conditions were similar for CT and ZT because cropped areas in this soil zone traditionally receive no fall tillage, thus leaving all of the stubble standing to enhance snow trapping (Table 2). For the F-W systems, CT and MT management produced higher energy output than ZT in 3 of 12 years, all were wet years except 1984 (McConkey et al. 1996). However, in dry years energy output from ZT managed F-W typically exceeded that from the tilled systems. Although the use of ZT management on fallow areas often resulted in increased soil water reserves (McConkey et al. 1996), the extra water was seldom translated into higher grain yields (Table 2) and thus higher energy output. This was attributed to a number of factors including greater denitrification losses of soil N with ZT, poor plant establishment in heavy crop residue conditions because of uneven spreading of residues, and greater weed competition due to the occasional heavy infestation of foxtail barley on the ZT treatments (Tessier et al. 1990; McConkey et al. 1996).

Table 2. Effect of tillage method and crop rotation on spring soil water reserves, fertilizer N applied, and yield of spring wheat grown in the Brown soil zone (1982-1993)<sup>1</sup>

Crop/Tillage method	Fallow-Wheat			Continuous Wheat	
	CT	MT	ZT	CT	ZT
Soil water (mm 120-cm <sup>-1</sup> )	222 <sub>c</sub>	229 <sub>b</sub>	236 <sub>a</sub>	177 <sub>d</sub>	178 <sub>d</sub>
Fertilizer N (kg ha <sup>-1</sup> )	21	21	24	44	47
Wheat yield (kg ha <sup>-1</sup> )	2480 <sub>a</sub>	2382 <sub>a</sub>	2353 <sub>a</sub>	1915 <sub>b</sub>	1911 <sub>b</sub>

<sup>1</sup> Values within a row followed by the same letter do not differ significantly.

Net energy produced (energy output minus energy input) by the cropping systems displayed similar trends as was observed for energy output (Table 1). Net energy produced averaged 28828 MJ ha<sup>-1</sup> with Cont W and 19230 MJ ha<sup>-1</sup> (or 33% less) with F-W systems, and was generally unaffected by method of tillage management. In contrast, energy efficiency, measured as energy output/input ratio, was greater for F-W than for Cont W, averaging 8.3 for F-W versus 6.1 for Cont W, with a tendency for the energy ratio to be lowest for ZT managed systems. In the long-term, however, because of the degrading impact of conventionally tilled fallow on soil quality (Biederbeck et al. 1984; Campbell et al. 1996a,b), the higher energy ratios favoring the fallow systems and CT management will probably not persist. Similarly, when energy efficiency was measured in terms of wheat produced per unit of energy input, F-W produced 450 kg of wheat GJ<sup>-1</sup> of energy input, while Cont W systems produced 330 kg of wheat GJ<sup>-1</sup> of energy input.

The study concluded that the potential for achieving significant energy savings or improvements in energy use efficiency by extending monoculture wheat rotations and adopting conservation tillage management practices was low in this semiarid region; however, use of mixed cropping systems that include pulse and oilseed crops together with conservation tillage practices may offer better opportunities.

### **Thin Black Soil Zone**

In the more moist Thin Black soil zone at Indian Head, Zentner et al. (2004) compared the energy performance of monoculture cereal, cereal-oilseed, and cereal-oilseed-pulse rotations, each managed using CT, MT, and ZT practices over the 12-year period 1987 to 1998. They reported that total energy use for the complete cropping systems was also largely unaffected by tillage method, but it differed significantly with crop rotations (Table 3). Energy requirements were lowest for Wheat-Wheat-Winter Wheat-Fallow (W-W-Ww-F) (average 6389 MJ ha<sup>-1</sup>), intermediate for Wheat-Flax-Winter Wheat-Pea (W-Fx-Ww-P) (11% more), and highest for the Wheat-Wheat-Flax-Winter Wheat (W-W-Fx-Ww) (28% more) rotation. The substitution of pea for spring wheat in the W-Fx-Ww-P versus W-W-Fx-Ww rotation reduced total energy use by 13%, reflecting the minimal requirement for N fertilizer with pulses due to their ability to biologically fix N (Coxworth and Wright 1988), and from the lower fertilizer N rate (average of 6 kg N ha<sup>-1</sup> less) that was applied to spring wheat when grown after the legume.

Energy expended on fertilizer inputs (primarily N) accounted for 66 to 71% of the total energy requirements of the cropping systems, and they tended to be marginally higher with MT and ZT, reflecting the higher rates of N fertilizer (average 2 to 6 kg N ha<sup>-1</sup> more) that were applied to these systems compared to CT management. As in the Brown soil zone, higher fertilizer N rates are often required during a transition period from conventional to conservation tillage management due to lower N mineralization (Campbell et al. 2001b). However, as organic matter levels increase in soils under long-term conservation tillage management (Campbell et al. 2001a, 2001b), fertilizer N requirements should decline, thereby reducing fertilizer energy inputs.

On-farm use of fuel and lubricants was the second highest energy input category, representing between 17 and 22% of the total energy use. Although the use of MT and ZT practices provided significant energy savings in on-farm fuel and lubricants (12 to 22% less for MT, and 25 to 31% less

for ZT compared to CT), these savings were largely offset by higher energy expenditures for herbicides and fertilizer N with the conservation tillage methods. Energy expended on herbicides represented between 7 and 9% of the total energy input of the cropping systems, while energy expended on machinery repair and manufacture represented from 5 to 7% of the total. The machine-related energy savings with conservation tillage practices in this soil zone arise from fewer trips across the field, use of machines with greater capacity and lower draft requirements (sprayer vs cultivator), and from extending the life of some machines because of their reduced annual use (e.g., tractors) or eliminating the need for certain machines (e.g., tillage implements) (Zentner et al. 2002).

Table 3. Effect of crop rotation and tillage method on non-renewable energy inputs, energy output, and energy use efficiency for cropping systems in the Thin Black soil zone (1987-1998)<sup>1</sup>

	W-W-Ww-F			W-W-Fx-Ww			W-Fx-Ww-P		
	CT	MT	ZT	CT	MT	ZT	CT	MT	ZT
	----- (MJ ha <sup>-1</sup> ) -----								
Fertilizer	4082	4278	4279	5663	5942	5837	4559	4706	4749
Herbicides	394	605	677	494	596	649	402	503	568
Fuel & oil	1419	1109	976	1585	1388	1196	1758	1517	1318
Machinery	332	313	303	374	374	355	409	404	383
Total energy input	6227 <sub>c</sub>	6305 <sub>c</sub>	6235 <sub>c</sub>	8116 <sub>a</sub>	8300 <sub>a</sub>	8037 <sub>a</sub>	7128 <sub>b</sub>	7130 <sub>b</sub>	7018 <sub>b</sub>
Energy output	32296 <sub>d</sub>	31938 <sub>d</sub>	32711 <sub>d</sub>	39295 <sub>c</sub>	42552 <sub>ab</sub>	42014 <sub>b</sub>	42377 <sub>ab</sub>	43904 <sub>a</sub>	42603 <sub>ab</sub>
Net energy produced	26069 <sub>c</sub>	25633 <sub>c</sub>	26476 <sub>c</sub>	31179 <sub>d</sub>	34252 <sub>bc</sub>	33977 <sub>c</sub>	35249 <sub>b</sub>	36744 <sub>a</sub>	35585 <sub>ab</sub>
Grain/Energy input <sup>2</sup>	310 <sub>c</sub>	285 <sub>e</sub>	290 <sub>de</sub>	293 <sub>de</sub>	303 <sub>cd</sub>	307 <sub>c</sub>	359 <sub>b</sub>	381 <sub>a</sub>	379 <sub>a</sub>
Output/Input ratio	5.19 <sub>c</sub>	5.07 <sub>c</sub>	5.25 <sub>c</sub>	4.84 <sub>d</sub>	5.13 <sub>c</sub>	5.23 <sub>c</sub>	5.95 <sub>b</sub>	6.16 <sub>a</sub>	6.07 <sub>a</sub>

<sup>1</sup> Values within a row followed by the same letter do not differ significantly.

<sup>2</sup> Units are kg of grain produced per GJ of energy input.

Energy output from the cropping systems averaged 32315 MJ ha<sup>-1</sup> for the W-W-Ww-F system, 41287 MJ ha<sup>-1</sup> (or 28% more) for W-W-Fx-Ww, and 42961 (or 33% more) for W-Fx-Ww-P (Table 3). Tillage method had no significant influence on energy output for the monoculture cereal and cereal-oilseed-pulse rotations, but it was generally higher with MT and ZT than with CT management for the cereal-oilseed rotation. These results directly reflect the effects of tillage methods on grain yields (Table 4), wherein yields were typically higher with conservation tillage management for spring wheat grown on spring wheat or winter wheat stubble, and for flax and pea.

As in the Brown soil zone, net energy production for the cropping systems displayed generally similar trends as energy output. Overall, W-Fx-Ww-P produced the highest net energy at 35860 MJ ha<sup>-1</sup>, followed by W-W-Fx-Ww at 33136 MJ ha<sup>-1</sup> (8% less), and then W-W-Ww-F at 26060 MJ ha<sup>-1</sup> (27% less) (Table 3).

Table 4. Effect of tillage method on yield of crops grown in the Thin Black soil zone (1987-1998)<sup>1</sup>

Crop/Tillage method	CT	MT	ZT
	----- (kg ha <sup>-1</sup> ) -----		
W on fallow	2830 <sub>a</sub>	2777 <sub>a</sub>	2822 <sub>a</sub>
W on W or on Ww stubble	2044 <sub>b</sub>	2214 <sub>a</sub>	2178 <sub>a</sub>
W on P stubble	2418 <sub>a</sub>	2499 <sub>a</sub>	2303 <sub>b</sub>
Ws on W stubble	2366 <sub>a</sub>	2253 <sub>a</sub>	2323 <sub>a</sub>
Ws on Fx stubble	2861 <sub>a</sub>	2841 <sub>a</sub>	2742 <sub>a</sub>
Fx on W stubble	1440 <sub>b</sub>	1612 <sub>a</sub>	1629 <sub>a</sub>
P on Ws stubble	2272 <sub>b</sub>	2407 <sub>a</sub>	2450 <sub>a</sub>

<sup>1</sup> Values within a row followed by the same letter do not differ significantly.

The quantity of grain produced per unit of non-renewable energy input was highest for the cereal-oilseed-pulse rotation at 373 kg GJ<sup>-1</sup> and lower, but generally similar, for the cereal-oilseed (301 kg GJ<sup>-1</sup>) and monoculture cereal (295 kg GJ<sup>-1</sup>) rotations (Table 3). The energy output/energy input ratios were highest for the most diversified cropping system (average 6.1), and lower and generally similar for the cereal-oilseed and monoculture cereal rotations (average 5.1). The use of conservation tillage management generally enhanced energy use efficiency for the mixed rotations, but not for the monoculture cereal rotation.

The study concluded that adoption of diversified crop rotations that include pulses, together with conservation tillage management practices, provide opportunity to enhance non-renewable energy use efficiency of annual grain production in this sub-humid region.

### **Thick Black Soil Zone**

In the most productive Thick Black soil zone at Melfort, Nagy et al. (2000) compared the energy performance of Canola-Wheat-Barley-Barley (C-W-B-B), Canola-Barley-Pea-Wheat (C-B-P-W), and Canola-Pea-Flax-Barley (C-P-Fx-B) rotations, each managed using CT, MT, and ZT practices over the 1994 to 1997 period. In this case, the class of wheat grown was Canada Prairie Spring (versus Canada Western Red Spring used in the Swift Current and Indian Head studies) and the malt barley cultivar was >Harrington=. They reported that total energy inputs were lowest for C-P-Fx-B (6373 MJ ha<sup>-1</sup>), intermediate for C-B-P-W (12% higher), and highest for C-W-B-B (21% more) (Table 5). Further they reported overall energy savings of 4% with MT compared to CT practices and 6% savings with ZT management. The use of MT practices required 12% less energy being expended on fuel and lubricants and 8% less on machinery repair and manufacture compared to CT, while ZT required 39% and 19% less energy for fuel and machinery inputs, respectively. However, herbicide energy requirements were increased by 32% with ZT management. Since fertilizer application rates used in this study were based on average soil test values for each crop, fertilizer energy was similar for all tillage methods and differed only by rotation. Fertilizer energy was highest for the rotation that included an oilseed and three cereal crops, intermediate for the rotation that included an oilseed, a pulse and two cereal crops,

and lowest for the rotation that included two oilseed crops, a pulse and a cereal crop. These latter results reflect that recommended rates of fertilizer application (particularly N) are lower for pea and flax than for cereal and canola crops.

In contrast to energy input, energy output was highest for the C-W-B-B rotation (61826 MJ ha<sup>-1</sup>), intermediate for C-B-P-W (5% less), and lowest for C-P-Fx-B (21% less) (Table 5); however, tillage method did not significantly influence grain yields (Table 6) and thus had little effect on total energy output. Net energy produced displayed similar patterns as energy output. Grain produced per unit of energy input averaged 399, 429, and 361 for the C-W-B-B, C-B-P-W, and C-P-Fx-B rotations, respectively, and was not influenced by tillage method. In contrast, energy output/energy input ratio was significantly higher with ZT management for all rotations, but especially so for the two rotations that included a pea crop. Energy use efficiency was also higher with MT than CT management for the C-W-B-B and C-B-P-W rotations.

Table 5. Effect of crop rotation and tillage method on non-renewable energy input, energy output, and energy use efficiency for cropping systems in the Thick Black soil zone (1994-1997)

	C-W-B-B			C-B-P-W			C-P-Fx-B		
	CT	MT	ZT	CT	MT	ZT	CT	MT	ZT
	----- (MJ ha <sup>-1</sup> ) -----								
Fertilizer	5663	5663	5663	4557	4557	4557	3924	3924	3924
Herbicides	574	574	855	600	600	882	628	628	898
Fuel & oil	1804	1601	1088	1804	1578	1143	1657	1428	1003
Machinery	440	412	346	442	406	365	406	371	326
Total energy input	8482	8250	7952	7402	7141	6947	6615	6351	6152
Energy output	61817	63239	60422	58589	58348	59831	49323	47483	50282
Net energy produced	53335	54989	52470	51187	51207	52883	42708	41131	44130
Grain/Energy input <sup>1</sup>	391	407	400	422	428	438	353	361	370
Output/Input ratio	7.3	7.7	7.6	7.9	8.2	8.6	7.5	7.5	8.2

<sup>1</sup> Units are kg of grain produced per GJ of energy input.

The study concluded that in this region the addition of a pulse crop significantly reduced energy input requirements and improved energy use efficiency, particularly when combined with ZT management.

### **Gray Soil Zone**

Nagy et al. (2000) also evaluated these same three mixed rotations in the moist but less fertile Gray soil zone at Tisdale (Table 7). They reported, as at Melfort, that total energy requirements were lowest for C-P-Fx-B (6943 MJ ha<sup>-1</sup>), intermediate for C-B-P-W (11% more), and highest for C-W-B-B (28% more), again mainly reflecting the energy savings associated with including a grain legume or a flax

crop (which receives lower recommended rates of fertilizer) in the rotation. Although the use of conservation tillage practices generated significant energy savings in fuel and lubricants (15 to 39% less) and in machine manufacture and repair (9% to 18% less), the overall energy savings was only about 3% with MT and 5% with ZT management.

Table 6. Effect of tillage method on yield of crops grown in the Thick Black and Gray soil zones (1994-1997)

Crop/Tillage method	Thick Black soil zone			Gray soil zone		
	CT	MT	ZT	CT	MT	ZT
	----- (kg ha <sup>-1</sup> ) -----					
C on W or B stubble	1842	1869	1874	1897	1869	1786
P on C or B stubble	2094	1831	1942	1960	2029	2099
Fx on P stubble	1830	1716	1777	1325	1290	1163
B on C stubble	3663	3521	3315	3123	3081	2902
B on W stubble	3389	3820	3100	2912	2658	2860
B on B stubble	3078	3054	2866	2717	2566	2567
B on Fx stubble	3581	3748	3524	2996	2924	2839
W on P stubble	4881	5003	5037	3569	3207	2801
W on C stubble	4968	4671	4868	3303	3120	3099

As at the Melfort site, energy output was highest for C-W-B-B (52836 MJ ha<sup>-1</sup>), followed by C-B-P-W (5% less) and C-P-Fx-B (23% less) (Table 4). Furthermore, energy output was highest with CT management (49672 MJ ha<sup>-1</sup>), and tended to decline as tillage intensity was reduced (3% less with MT and 8% less with ZT). These latter results mainly reflect the lower yields of wheat that were obtained with MT and ZT practices due to increased weed competition (Table 6); available soil water reserves and plant establishment were generally similar for all tillage methods (Nagy et al. 2000).

Net energy production displayed similar trends as total energy output. Grain produced per unit of energy input averaged 293, 328, and 291 kg GJ<sup>-1</sup> of energy input for C-W-B-B, C-B-P-W, and C-P-Fx-B, respectively, and was little affected by tillage method. Energy output/energy input ratio was highest for C-B-P-W (average 6.5), and similar but lower for the C-W-B-B and C-P-Fx-B rotations (average 5.9). In contrast to the Melfort site, energy use efficiency tended to be lowest with ZT management.

Table 7. Effect of crop rotation and tillage method on non-renewable energy inputs, energy outputs and energy use efficiency for cropping systems in the Gray soil zone (1994-1997)

	C-W-B-B			C-B-P-W			C-P-Fx-B		
	CT	MT	ZT	CT	MT	ZT	CT	MT	ZT
	----- (MJ ha <sup>-1</sup> ) -----								
Fertilizer	6153	6153	6453	4948	4948	4948	4334	4334	4334
Herbicides	932	932	1214	934	934	1201	941	941	1222
Fuel & oil	1670	1416	1023	1658	1422	1023	1518	1296	912
Machinery	404	363	328	401	365	330	367	334	298
Total energy input	9159	8864	8717	7941	7669	7502	7160	6904	6766
Energy output	54610	51444	51070	52453	50844	48000	41953	41574	38501
Net energy produced	45541	42580	42353	44512	43176	40498	34793	34670	31736
Grain/Energy input <sup>1</sup>	295	288	296	332	332	320	286	294	292
Output/Input ratio	6.0	5.8	5.9	6.6	6.6	6.4	5.9	6.0	5.7

<sup>1</sup> Units are kg of grain produced per GJ of energy input.

## CONCLUSIONS

The results of these studies indicate that the choice of crop rotation and cropping mix has a greater impact on total energy use and energy use efficiency than does method of tillage management. Fertilizer energy, primarily N, and fuel are the major energy inputs of annual cropping systems in all major soil zones of Saskatchewan; together they account for 60 to 75% of the total energy requirements for fallow-type rotations and 80 to 85% for continuously cropped systems. Total energy inputs to the cropping systems also increase from the semiarid Brown to the more moist Black and Gray soil zones, reflecting the increased rates of fertilizer application and greater use of tillage/herbicides for weed control and seedbed preparation. Including a pulse crop in cereal-based rotations can generate energy savings of about 13% because the legume is capable of fixing much of its own N requirement and because the subsequent cereal crop grown on pulse stubble also requires less fertilizer N. Further, including a pulse crop plus flax, with its lower fertilizer requirement, can provide overall energy savings of about 22% compared to monoculture cereal or cereal-canola rotations. Although use of MT and ZT practices do provide significant on-farm energy savings in terms of fuel and in machine manufacture and repair, these savings are largely offset by increased energy expenditures for herbicides and N fertilizer, particularly in the Brown and Thin Black soil zones; in the Thick Black and Gray soil zones a small net energy savings of about 3 to 6% can be realized with conservation tillage management. This largely reflects that as one moves from the dry Brown to the more moist Black and Gray soil zones, the amount of tillage required to control weeds on fallow areas, and that used for seedbed preparation and for post-harvest residue management increases, thus increasing the potential energy savings from substituting herbicides for some or all of this mechanical tillage.

Energy output and net energy produced increased directly with cropping frequency, reflecting the increase in total grain production as the proportion of fallow in the rotation is decreased, but they were generally little affected by method of tillage management. In contrast, energy use efficiency as measured by grain produced per unit of energy input and energy output/energy input ratio varied by soil zone, cropping system, and tillage method. In the Brown soil zone, energy use efficiency for fallow-wheat rotations was higher with CT and MT than with ZT management, reflecting that tilled-fallow reduces the requirement for applied N fertilizer at least in the short-term. But for continuous wheat systems, energy use efficiency was similar for CT and ZT management, despite the higher recommended rates of N fertilizer that were applied to the ZT managed areas. In the Thin Black and Thick Black soil zones, grain produced per unit of energy input and energy output/energy input ratios were typically highest for the cereal-oilseed-pulse or cereal-oilseed rotations when managed using MT and ZT practices. While in the Gray soil zone, energy use efficiency tended to be highest for the cereal-oilseed-pulse rotation, and it was little influenced by tillage method.

## REFERENCES

- Biederbeck, V.O., Campbell, C.A. and Zentner, R.P. 1984. Effect of crop rotation and fertilization on some biological properties of a loam in southwestern Saskatchewan. *Can. J. Soil Sci.* 64: 355-367.
- Campbell, C.A., McConkey, B.G., Zentner, R.P., Selles, F. and Curtin, D. 1996a. Tillage and crop rotation effects on soil organic matter in a coarse-textured Typic Haploboroll in southwestern Saskatchewan. *Soil & Tillage Res.* 37: 3-14.
- Campbell, C.A., McConkey, B.G., Zentner, R.P., Selles, F. and Curtin, D. 1996b. Long-term effects of tillage and crop rotations on soil organic C and N in a clay soil in southwestern Saskatchewan. *Can. J. Soil Sci.* 76: 395-401.
- Campbell, C.A., Selles, F., Lafond, G.P. and Zentner, R.P. 2001a. Adopting zero tillage management: Impact on soil C and N under long-term crop rotations in a thin Black Chernozem. *Can. J. Soil Sci.* 81: 139-148.
- Campbell, C.A., Selles, F., Lafond, G.P., Biederbeck, V.O. and Zentner, R.P. 2001b. Tillage-fertilizer changes: Effect on some soil quality attributes under long-term crop rotations in a thin Black Chernozem. *Can. J. Soil Sci.* 81: 157-165.
- Campbell, C.A., Zentner, R.P., Janzen, H.H. and Bowren, K.E. 1990. Crop rotation studies on the Canadian Prairies. Public. 1841/E, Canadian Government Publication Centre, Supply and Services Canada, Ottawa, Ont., 133 pp.
- Coxworth, E. 1997. Energy Use Trends in Canadian Agriculture: 1990 to 1996. Report to Canadian Agricultural Energy End Use Data Analysis Centre. University of Saskatchewan, Saskatoon, SK, 26 pp.
- Coxworth, E., Biederbeck, V.O., Campbell, C.A., Entz, M.H. and Zentner, R.P. 1996. A bioenergy success story: The energy savings implications of the increase in legumes in rotations since 1990. In: *Proc. Soils & Crops >96*. University of Saskatchewan, Saskatoon, SK, Feb. 22-23, pp. 165-174.
- Coxworth, E. and Wright, A.T. 1988. Energy and Economic Benefits of Pulse Crops in Continuous Cropping Systems Using Zero or Minimum Tillage. Saskatchewan Research Council Publ. R-812-1-E-88, Saskatoon, SK, 43 pp.
- Fluck, R.C. and Baird, C.D. 1980. Agricultural energetics. AVI publishing Co. Westport, CT. 192 pp.
- Gayton, D.V. 1982. Direct energy use and conservation potential on Saskatchewan straight grain farms. In: *Proc. Energex 1982, Vol II*, Solar Energy Society of Canada, Winnipeg, MB, pp. 687-690.
- Gill, R.S., Nagy, C.N., Zentner, R.P., Hucq, A., MacGregor, R.J., Entz, M.H. and Giraldez, J.C., 2001. Opportunities for reduced non-renewable energy use in Canadian Prairie agricultural production systems. Publ. 2082/B. Agriculture and Agri-Food Canada. Policy Branch. Ottawa, ON, August, 49 pp.
- Hirst, E. 1974. Food related energy requirements. *Science* 184, 134-138.
- Hopper, G.R. 1984. The energetics of Canadian Prairie wheat production 1948-1981. In: *Proc. Energex 1984, Energy Developments: New Forms, Renewables, Conservation*. Regina, SK, pp. 677-683.
- Janzen, H.H., Desjardins, R.L., Asselin, J.M.R. and Grace, B. 1999. The Health of Our Air: Toward Sustainable Agriculture in Canada. Research Branch, Agriculture and Agri-Food Canada, Publ. 1981/E, Ottawa, ON, 98 pp.
- McConkey, B.G., Campbell, C.A., Zentner, R.P., Dyck, F.B. and Selles, F. 1996. Long-term tillage effects on spring wheat production on three soil textures in the Brown soil zone. *Can. J. Plant Sci.* 76: 747-756.
- Nagy, C.N. 1999. Energy Coefficients for Agriculture Inputs in Western Canada. CSALE Working Paper Series #2.

- Centre for Studies in Agriculture, Law and the Environment. University of Saskatchewan, Saskatoon, SK, 41 pp.
- Nagy, C.N., Johnston, A.M., Wall, D.D., Zentner, R.P. and Gill, R. 2000. Influence of tillage method on nonrenewable energy use efficiency in the Black and Gray soil zones. In: Proc. Climate Change Workshop, Saskatoon, SK, Dec. [CD-ROM] Available: Saskatchewan Agriculture and Food, Regina, SK, 7 pp.
- Neitzert, F., Olsen, K. and Collas, P. 1999. Canada=s Greenhouse Gas Inventory: 1997 Emissions and Removals with Trends. Publ. #En49-8/5-9E, Greenhouse Gas Division, Environment Canada, Ottawa, ON, April, 174 pp.
- Saskatchewan Agriculture and Food. 1999. Farm Machinery Custom and Rental Rate Guide 1999. Sustainable Production Branch, Saskatchewan Agriculture and Food, Regina, SK, 36 pp.
- Stirling, B. 1979. Use of Non-renewable Energy on Saskatchewan Farms: A preliminary study. Saskatchewan Research Council, Province of Saskatchewan, Regina, SK, 38 pp.
- Tessier, S., Peru, M. Dyck, F.B., Zentner, R.P. and Campbell, C.A. 1990. Conservation tillage for spring wheat production in the semi-arid Saskatchewan. *Soil Till. Res.* 18: 73-89.
- Weseen, S. and Lindenbach, R. 1998. An energy use efficiency indicator for agriculture. In: Lindenbach, R., Weseen, S., Diarra S., Kowalski J. (eds.). *The Kyoto Protocol: Greenhouse Gas Emissions and the Agricultural Sector. CSALE Working Paper Series #1, Vol. 2*, Centre for Studies in Agriculture, Law and the Environment, University of Saskatchewan, Saskatoon, SK. 39 pp.
- Zentner, R.P., Lafond, G.P., Derksen, D.A., Nagy, C.N., Wall, D.D. and May W.E. 2004. Effects of tillage method and crop rotations on non-renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies. *Soil & Tillage Res.* 77: 125-136.
- Zentner, R.P., McConkey, B.G., Stumborg, M.A., Campbell, C.A. and Selles, F. 1998. Energy performance of conservation tillage management for spring wheat production in the Brown soil zone. *Can. J. Plant Sci.* 78, 553-563.
- Zentner, R.P., Wall, D.D., Nagy, C.N., Smith, E.G., Young, D.L., Miller, P.R., Campbell, C.A., McConkey, B.G., Brandt, S.A., Lafond, G.P., Johnston, A.M. and Derksen, D.A. 2002. Economics of crop diversification and soil tillage opportunities in the Canadian Prairies. *Agron. J.* 94: 216-230.