Energy Efficiency of Integrated Crop Management Systems in the Dark Brown Soil Zone

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INTRODUCTION

Low commodity prices, rising input costs, and increasing concerns about environmental degradation are encouraging producers in western Canada to consider alternative soil tillage and weed management methods that are designed to conserve resource inputs. However, little is known about the merits of these management changes on the overall input requirements and use efficiency of nonrenewable energy forms.

This study determines the effects of six integrated soil, cultural, and weed management practices on nonrenewable energy inputs, energy outputs, and energy use efficiency for a Wheat (**W**)-Canola (**C**)-Barley (**B**)-Pea (**P**) rotation in the Dark Brown soil zone of Saskatchewan.

MATERIALS AND METHODS

Experimental Data

Trials were conducted from 1997 through 2000 on a clay soil at Saskatoon and on a clay-loam soil at Watrous.

Each W-C-B-P rotation was operated using six integrated management systems:

i) High Herbicide / Zero Tillage (**HH/ZT**)
ii) Medium Herbicide / Zero Tillage (**MH/ZT**)
iii) Low Herbicide / Zero Tillage (**LH/ZT**)
iv) Low Herbicide / Low Tillage (**LH/LT**)
v) Medium Herbicide / Medium Tillage (**MH/MT**)
vi) No Herbicide / High Tillage (**NH/HT**)

Within these systems there were differences in seeding rates, fall weed control, pre-seeding weed control, in-crop herbicide rate, and seeding date (Table1). In addition, half of each plot received fungicide (i.e., Quadris) each year applied at flagleaf for wheat and barley, at 2 to 5 leaf stage for canola, and at flowering for pea.

Recommended rates of fertilizer N, P, and S were applied (banded at time of seeding) to all crops based on soil tests (Table 2).

Table 1. Summary of Management System Variables.

	Seeding Rate				Fall				Burn off				Incrop				Seeding Date			
	W	C	B	P	W	C	B	P	W	C	B	P	W	C	B	P	W	C	B	P
HH/ZT	1	1	1	1	2,4-D	2,4-D	2,4-D	2,4-D	yes	yes	yes	yes	yes	yes	yes	yes	mid	mid	early	early
MH/ZT	1	1	1	1	2,4-D	no	2,4-D	no	no	yes	no	yes	(2/3)	(2/3)	(1/2)	yes	early	mid	early	early
LH/ZT	1.5	1.5	1.5	1.3	2,4-D	no	2,4-D	no	no	yes	no	yes	(2/3)	no	no	yes	early	late	early	early
LH/LT	1.5	1	1.5	1	till	no	till	till	no	till	no	no	(2/3)	(2/3)	no	yes	early	mid	early	early
MH/MT	1	1	1	1	til	till	till	till	till	yes	till	yes	(2/3)	(2/3)	(1/2)	yes	mid	mid	early	early
NH/HT	1.5	1.5	1	1.3	till	till	till	till	till	till	till	till	p-e till	no	p-e till	p-e till	mid	late	early	early

Table 2. Summary of fertilizer rates applied.

	Saskatoon			Watrous		
	N	P_2O_5	S	N	P_2O_5	S
	----------	----------	(kg ha^{-1})	----------	----------	
Wheat	64	27	7	47	24	0
Canola	88	24	14	66	22	12
Barley	59	27	7	50	24	0
Pea	17	23	7	9	20	0

Energy Analysis

All direct and indirect nonrenewable energy going into the manufacture, packaging, transportation, and application of all purchased inputs, and in performing all cultural, tillage, and transport (to the initial point of sale) operations used in the cropping systems were included (Nagy 1999).

Energy output was taken as gross energy content (measured by bomb calorimeter) of harvested grain less seed requirements (Nagy 1999). Energy in the 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), ii) grain produced per unit of energy input, and iii) energy output to energy input ratio.

RESULTS AND DISCUSSION

Weather Conditions

Saskatoon

1997 Growing season was favorable for crop growth. April was wetter than normal with adequate rainfall throughout the growing season.

1998 Canola failed to establish because of the very dry spring soil moisture conditions. Rainfall amounts were adequate for the remainder of the summer.

1999 Growing season was cool and wet, with a dry fall.

2000 Growing season started with a very dry soil surface, followed by below normal rainfall in May and June and above normal rainfall in July.

Watrous

1997 April, May and June were above average for temperature and slightly below average for moisture. July was both cooler and drier than normal.

1998 April, May and June were above average for temperature and received close to normal rainfall. Rainfall for July and August was below normal, while temperatures for July were normal but August was warmer than normal.

1999 April, May, June and July had above average rainfall and August and September were below average. The temperatures were above normal for April but equal or below normal for the rest of the summer. Moderate hail damage was recorded.

2000 April, May, June and July received above normal rainfall, while August, September and October received below normal rainfall. The temperatures in April were below normal but the rest of the summer was warmer than normal. Light hail damage was recorded.

Grain Yields

Generally, zero-till managed systems produced higher grain yields than mechanically-tilled systems (14% more at Saskatoon and 5% more at Watrous), with yields declining as the intensity of tillage increased (Fig 1).

The HH/ZT management system produced the highest grain yields, while NH/HT generally produced the lowest yields (24% less at Saskatoon and 11% less at Watrous).

Yields for MH/ZT, LT/ZT, and MH/MT were generally similar and averaged from 6 to 9% lower than for HH/ZT at Saskatoon, and from 2 to 8% lower at Watrous.

Yields for the LH/LT system ranked second-lowest, and averaged 15% lower than for HH/ZT at Saskatoon and 8% lower at Watrous.

Yield of crops differed greatly across years reflecting the variable weather conditions at each test location (data not shown).

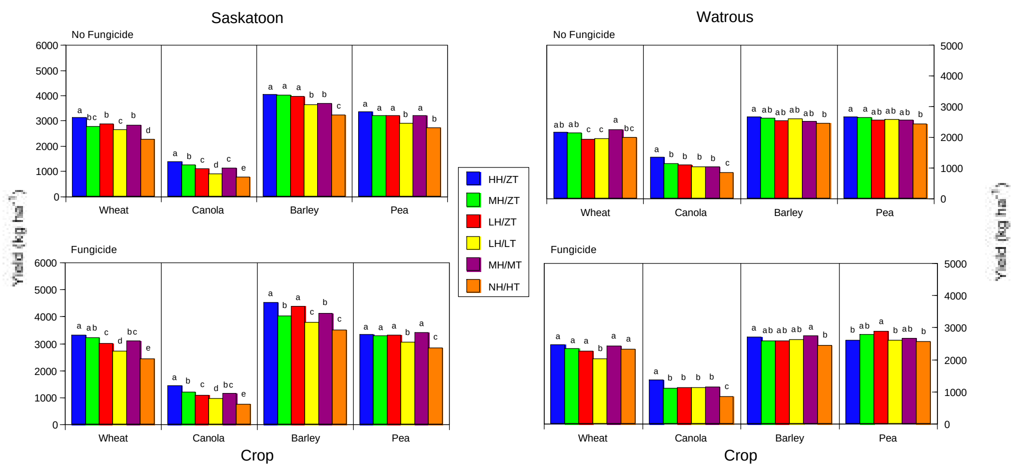

Figure 1. Grain yields.

Reducing herbicide inputs (HH/ZT vs MH/ZT vs LH/ZT) reduced the relative yields of canola and wheat most (about 20% and 9%, respectively), while yields of barley and pea declined least (Fig. 1).

Application of fungicide consistently increased yields of wheat and barley at Saskatoon, and yields of wheat at Watrous; but, the effects for other crops were often inconsistent and/or nonsignificant. In general, the yield increases were W = B > P > C at Saskatoon and W > P > B = C at Watrous. The greatest response to fungicide application occurred in the wetter years.

<u>Nonrenewable Energy Inputs</u>

Total energy inputs to the cropping systems were higher at Saskatoon (6614 MJ ha^{-1}) than at Watrous (21% less), mainly reflecting the higher rates of fertilizers applied (Fig 2).

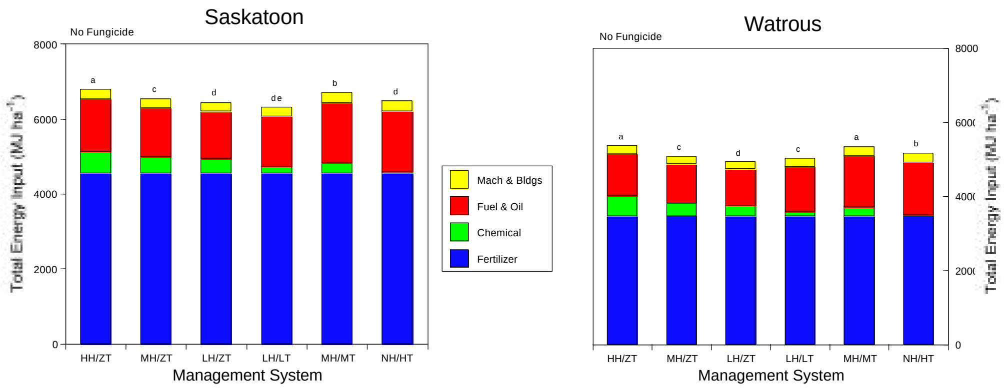

Figure 2. Total energy input by management system.

Energy inputs were highest for HH/ZT and MH/MT, and generally lowest for LH/ZT and/or LH/LT; although the range in energy requirements for the management systems was only about 7%. Total energy inputs for the management systems were relatively constant across years (data not shown).

Fertilizer (primarily N), and fuel and oil, were the major energy inputs to the management systems, accounting for 68% and 23%, respectively, of the total energy input usage.

Energy expended on pesticides (herbicides, fungicides, and insecticides) generally represented less than 8% of the total energy input.

Substituting herbicides for mechanical tillage (MH/ZT vs MH/MT) produced savings in 'on-farm' use of fuel and oil energy (25 to 30% less) and in energy embodied in machines and buildings (including repairs), but these savings were nearly offset by higher 'off-farm' energy expended in the manufacture and distribution of the additional herbicides used.

Reducing herbicide use in the zero-till managed systems (HH/ZT vs MH/ZT vs LH/ZT) lowered overall energy use by 5 to 8%.

Use of in-crop fungicide increased total energy requirements by only 2 to 3% (data not shown).

Energy requirements were generally highest for producing canola, intermediate for wheat and barley (17% less), and lowest for pea (52% less) (Fig 3). The latter result reflects the capability of pea to fix its own nitrogen from the air.

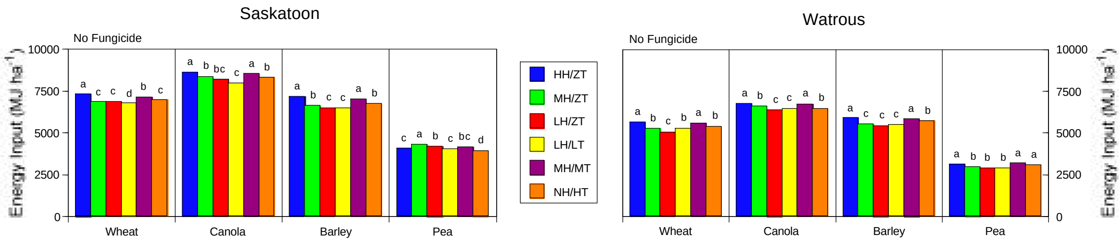

Figure 3. Energy inputs by management system for individual crops.

Gross Energy Output

Gross energy output for the complete management systems, as with grain yields, declined as the level of input use was reduced. In general, energy output for HH/ZT > MH/ZT = LH/ZT = MH/MT > LH/LT > NH/HT (Fig. 4).

The application of fungicide increased gross energy output of the management systems by 6% at both Saskatoon and Watrous.

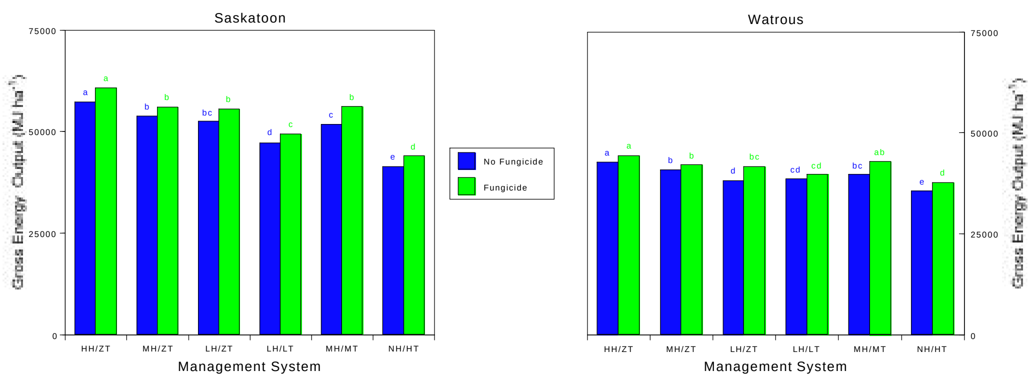

Figure 4. Gross energy output by management system.

Gross energy output was highest with barley, intermediate with pea (4 to 23% less) and wheat (16 to 27% less), and lowest with canola (31 to 55% less) production.

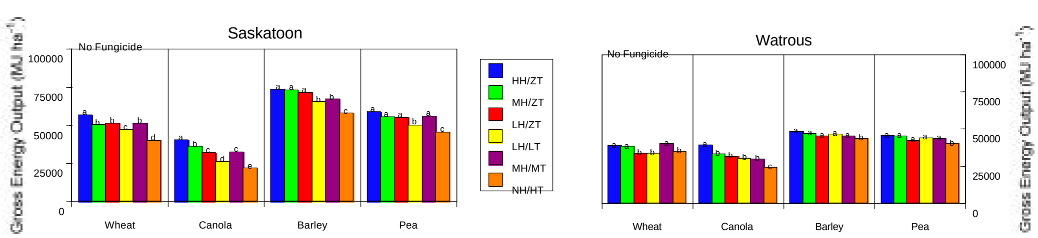

Figure 5. Gross energy output by management system for individual crops.

Energy Use Efficiency

Net energy produced (energy output minus energy input) was 30% higher at Saskatoon than at Watrous (Fig. 6).

Trends in net energy produced for the management systems, and for individual crops, were similar to those displayed for gross energy output.

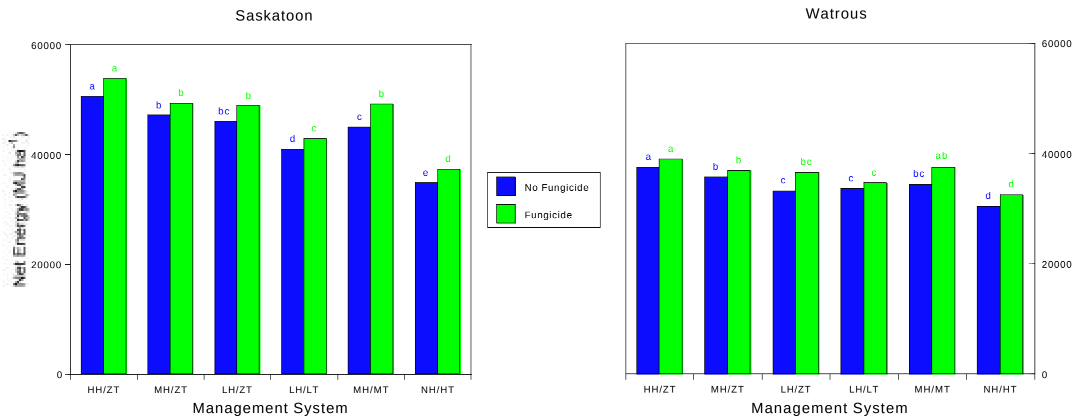

Figure 6. Net energy produced by management system.

Grain produced per unit of energy input was marginally higher at Watrous (471 kg GJ^{-1}) than at Saskatoon (457 kg GJ^{-1}), reflecting the lower total energy input requirements, but also lower yields at Watrous (Fig. 7).

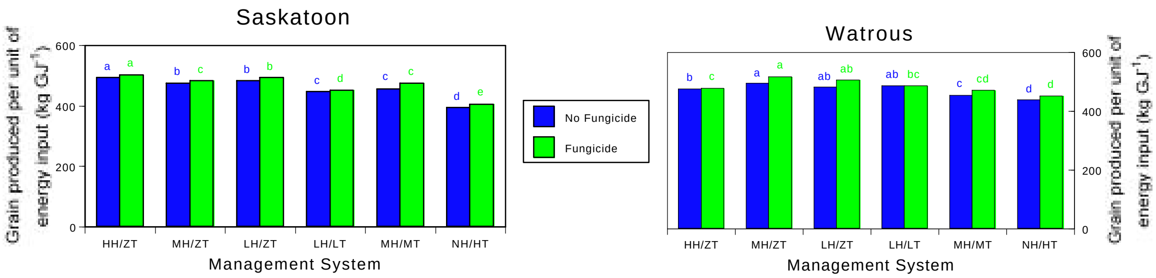

Figure 7. Grain produced per unit of energy input.

Grain produced per unit of energy input (no fungicide) at Saskatoon ranked

HH/ZT > MH/ZT = LH/ZT > LH/LT = MH/MT > NH/HT,

while at Watrous the rankings were

MH/ZT > HH/ZT = LH/ZT = LH/LT > MH/MT > NH/HT.

Fungicide application increased the quantity of grain produced per unit of energy input by only 10 to 12 kg.

Grain produced per unit of energy input was Pea (804 kg GJ^{-1}) > Barley (514 kg GJ^{-1}) > Wheat (418 kg GJ^{-1}) > Canola (144 kg GJ^{-1}).

Energy output/energy input ratios for the complete management systems averaged 8.5 at Saskatoon and 8.8 at Watrous, and displayed generally similar patterns as for grain produced per unit of energy input (Fig. 8).

Energy output/energy input ratios were Pea (13.7) > Barley (9.3) > Wheat (7.5) > Canola (4.2).

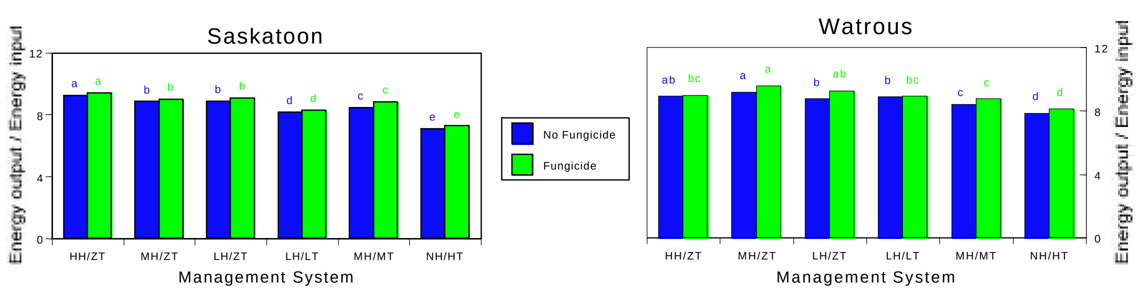

Figure 8. Energy output/energy input ratios.

CONCLUSIONS

Grain yields were highest for the zero-till managed systems, with yields being highest for HH/ZT and lowest for NH/HT.

Application of in-crop fungicide enhanced yields of wheat, barley and pea, but not canola; although the yield increases were generally small.

Total nonrenewable energy inputs were highest for HH/ZT and MH/MT, and lowest for LH/ZT and LH/LT.

Fertilizer (68%) (primarily N) and fuel (23%) were the major nonrenewable energy inputs; chemicals represented only about 8% of the total.

Zero tillage management provided 'on-farm' energy savings in fuel, but they were mostly offset by higher 'off-farm' energy expended in the manufacture and distribution of herbicides.

Total energy inputs used in production were Canola > Wheat = Barley > Pea.

Gross energy output from the management systems were Barley > Pea = Wheat > Canola.

Energy use efficiency was highest for HH/ZT and/or MH/ZT, and lowest for NH/HT.

Zero tillage management (MH/ZT vs MH/MT) generally improved overall energy use efficiency.

Reducing herbicide use (HH/ZT vs MH/ZT vs LH/ZT) reduced overall energy use efficiency at Saskatoon, but it had the opposite or no effect at Watrous.

REFERENCES

Nagy, C.N. 1999. Energy coefficients for agriculture inputs in Western Canada. CSALE Working Paper Series #2. Canadian Agricultural Energy End-Use Data Analysis Centre. University of Saskatchewan, Saskatoon, SK. 41 pp.

ACKNOWLEDGEMENTS

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