# A Bioenergy Success Story: The Energy Savings Implications of the Increase in Legumes in Rotations Since 1990.

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## Abstract

The energy savings achieved by the increase in field peas and lentil production in western Canada between 1990 and 1995 were calculated to be 4.46 PJ (petajoules) per year, equivalent to 1.7 % of the total energy costs of agriculture production in Alberta, Saskatchewan and Manitoba, and equivalent to 7.5 % of 1990 nitrogen fertilizer use. A modem ethanol-from-grain industry would have had to produce 380 million litres of ethanol to achieve the same net energy gain. The increase in soybean production hectares in Ontario since 1990 was calculated to be saving 3.92 PJ per year, equivalent to an ethanol industry of 330 million litres. The combined energy savings from these legumes in rotations in Ontario and western Canada were calculated to be 8.38 PJ, equivalent to an ethanol industry of 710 million litres. This is much larger than the existing 31 million L/year Canadian fuel ethanol industry, and equivalent to 17.7 % of present U.S. ethanol production.

In addition, the energy costs of producing grain crops after a legume in the rotation were reduced. These reductions in energy costs of grain production would also reduce the overall energy costs of ethanol production.

## Introduction

Legumes biologically fix nitrogen from the atmosphere to provide some or all of their nitrogen fertilizer requirements (Pirnentel and Heichel, 1991). Legumes thus are a renewable energy source of nitrogen fertilizer, since they use sunlight (solar energy), nitrogen from the atmosphere, water and soil nutrients to synthesize nitrogen fertilizer compounds. In contrast, conventional nitrogen fertilizer is made in an energy intensive process from natural gas. Although the energy efficiency of manufacture of nitrogen fertilizer has improved considerably in the last two decades (Bhat et al., 1994), it is still usually the largest single energy cost in the production of crops in non-legume containing rotations.

Inclusion of a legume in a crop rotation would decrease energy costs in three ways (Pimentel and Heichel, 1991).

Firstly, the legume itself would have very low nitrogen fertilizer requirements. If the legume replaced a non-legume with high N fertilizer requirements, the nitrogen fertilizer energy costs of the rotation would decrease (substitution effect). Secondly, the legume frequently leaves some residual biologically fixed nitrogen in the soil after harvest of the legume seed or hay crop, reducing nitrogen fertilizer requirements of a following crop (N credit effect).

Thirdly, yields of crops following legumes may be increased by rotation or secondary legume effects. Rotation effects are not exclusive to legumes; Bourgeois and Entz (1996) surveyed a large number of farm field yield results and found that field peas, flax, barley and canola all increased spring wheat yields compared to spring wheat following spring wheat.

There has been a large increase in pulse crop acreages in western Canada in the last decade and a large increase in soybean acreage in Ontario in the same time period. These increases were used in the present study to calculate the energy savings/renewable energy contribution of these crops.

Energy savings are closely related to reductions in emissions of carbon dioxide from inputs (Coxworth et al., 1994, 1995). Carbon dioxide is the major greenhouse gas whose concentration is increasing in the atmosphere due to human activities, particularly the burning of fossil fuels. Energy effects are reported in this publication; carbon dioxide emissions are reported elsewhere (Coxworth et al., 1995). The year 1990 was used as the benchmark, since "Canada is committed to stabilizing emissions of carbon dioxide at 1990 levels by the year 2000" (Government of Canada, 1990, quoted by Cur-tin et al., 1994).

The energy savings from legumes were compared to the size of a hypothetical grain-based ethanol industry required to achieve the same level of fossil fuel energy savings. The reduction in energy costs of production of grain crops following a legume in the rotation was also calculated. This reduction could assist in reducing the overall energy costs of producing ethanol from grains. The production of ethanol and other renewable fuels are being investigated in a number of countries for their potential to reduce emissions of greenhouse gases from transportation fuels.

## Materials and Methods

Our energy analysis of crop production systems used similar methods to those employed by Zentner et al. (1989), based on methodology for energy accounting described in detail by Southwell and Rothwell (1977). The energy costs for manufacture of fertilizers were updated based on a recent study by Bhat et al. (1994), which documented large improvements in the energy efficiency of production of nitrogen and phosphorous (N and P) fertilizers since earlier studies such as Southwell and Rothwell (1977) were made. Energy costs included those associated with the use of large trucks on the farm and for small trucks used for farm business activities (Rutherford and Gimby, 1987). Energy costs included seed, fuel, machinery manufacture, depreciation and repair, fertilizers, and pesticides. Energy costs were calculated on the basis of energy/hectare and energy/tonne of product.

The effects of inclusion of field peas and lentils in the rotation were determined from crop rotation experiments in the Brown soil zone for lentils and in the Black soil zone for field peas, These case studies were adjusted to average levels of N fertilizer for stubble crops replaced by field peas or lentils across the region. Other energy inputs (fuel, machinery, pesticides, P fertilizer) were not adjusted for estimated average values across the region, since it was the relative change in energy associated with replacing a cereal with a legume that was of interest. The level of N fertilizer was known to be the main energy difference occurring between seed legume and non-legume containing rotations (Coxworth et al., 1994, 1995).

The energy effects of lentils in the rotation were measured from a long-term conventional tillage experiment at Swift Current, SK, which compared a spring wheat-lentil rotation with continuous spring wheat and spring wheat-fallow (Campbell et al., 1992). All crops were well fertilized (N and P) to meet soil requirements. Over time, since the experiment was commenced (1979), the nitrogen fertilizer requirements of wheat in the wheat-lentil system declined relative to wheat in the continuous spring wheat system. The time period of 1986-1993 was used for the present analysis.

The energy effects of inclusion of field peas in the rotation were analyzed for conventional tillage rotation studies at Winnipeg and Portage la Prairie, MB, in the Black soil zone (Entz et al., 1995) conducted since 1989. The studies compared spring wheat-spring wheat-field peas (W-W-P) with spring wheat-spring wheat-flax (W-W-FX) and with 1 to 5 years of alfalfa included at the beginning of the W-W-P system (A,_,-W-W-P-W-W-P).

For the estimate of the energy effects of inclusion of field peas and lentils in the rotation for the whole prairie region the following approach was used: Both field peas and lentils were assumed to be sown on stubble. Spring wheat was the crop assumed to follow the pulses in the rotation. Pulse crops were assumed to replace spring wheat in the rotation by comparison with Saskatchewan agricultural statistics for 1990 and 1995. The amount of summerfallow in each major soil zone (Brown, Dark Brown and Black), relative to cropped area, was calculated from data provided by crop district in the 1991 Census of Agriculture (Statistics Canada, 1991).

Nitrogen fertilizer rates for crops (non-legumes) on summer-fallow and pulse crops were based on cost data provided in The Costs of Grain Production in Saskatchewan (Saskatchewan Agriculture and Food, 1991, 1992, 1994) and average costs of nitrogen fertilizer. Total area in crops after summerfallow was obtained from provincial statistics. Area in field peas and lentils was obtained from Biederbeck et al. (1995). Area multiplied by N rate gave total N fertilizer used for crop after fallow and for pulse crops. This was deducted from the total N fertilizer sales. The remainder was assumed to represent N fertilizer rates applied to non-legume crops on stubble.

The relative recommended rates of N fertilizer for stubble spring wheat in the different soil zones were obtained from the Saskatchewan Guide to Farm Practice (1987): These data were combined with the calculation of average N rate on stubble in western Canada and the area of non-legume stubble crop in each soil zone to calculate average N fertilizer rates for stubble wheat in the major soil zones of western Canada. The computed average rates were combined with data on the relative amounts of production of lentils and field peas in the major soil zones to calculate the average rate of N fertilizer used on wheat which was replaced by lentils or field peas.

These results were used to adjust the N fertilizer rates for spring wheat in the two crop rotation case studies to more closely reflect average N rates across the region. Based on the hectares of field peas and lentils in 1990 and 1995, the increase in hectares was combined with data on the adjusted energy savings in the two rotation experiments to estimate the total energy savings for the whole region.

Energy costs for corn grain and soybean production in Ontario were obtained from a report by Ouellette-Babin (1982), updated for corn from a study by Cemcorp (1992) and updated for soybeans from a study by Swanton et al. (1996). Energy costs for fodder corn were obtained from Southwell and Rothwell (1977). Ontario agricultural statistics indicated that soybeans replaced mainly corn grain and fodder corn in the rotation (Ontario Ministry of Agriculture and Food, Statistics Canada, various years). Nitrogen fertilizer benefits for corn following soybeans ranged from none (Pimentel and Heichel, 1991) to 30 kg N/ha (Girouard, 1996). Both figures were used in the present study to estimate a possible range of N credits.

The energy costs for ethanol production were based on the Cemcorp study (1992) for ethanol produced from corn grain in Ontario. Energy costs for equipment were obtained from a study by Giampetro and Pimentel (1990). The energy credits for byproducts from grain fermentation were obtained from a recent study by Shapouri et al. (1995). It was assumed that similar energy costs of production would be obtained for high-starch wheat in western Canada or for corn grain in Ontario. Byproduct credits were assumed to be the same for both raw materials.

## Results

### Effect of Lentils in Rotations.

The energy use in the various spring wheat rotations compared at Swift Current is shown in Table 1.

Table 1. Energy use of wheat-lentil (W-L) compared to wheat-fallow (W-F) and continuous wheat. Brown soil zone.

| Rotation | N rate kg N/ha | Energy use GJ/ha/yr | Yield t/ha | Energy efficiency GJ/t |
|---|---|---|---|---|
| Cont. W | 42 | 6.64 | 1.61 | 4.12 |
| W-L | 30 | 5.37 | 1.54 | 3.49 |
| W-L | 15 | 3.94 | 1.29 | 3.05 |
| W-L (avg. year) | 23 | 4.65 | 1.41 | 3.30 |
| W-F | 20 | 4.57 | 2.36 | 1.94 |
| W-F (avg year) | 10 | 3.20 | 1.18 | 2.71 |

The annual energy savings from replacing wheat with lentil in rotations is the sum of (a) the difference between lentil and wheat (continuous) energy costs (substitution effect)(6.64 GJ/ha - 3.93 GJ/ha = 2.70 GJ/ha) and (b) the difference between wheat energy costs following lentils and following wheat (N credit to following crop effect)(6.64 GJ/ha - 5.37 GJ/ha = 1.27 GJ/ha). The total energy savings is 3.97 GJ/ha, i.e., the total energy effect of substituting lentils for wheat in the rotation.

There are situations where lentils might replace fallow and extend the rotation, e.g., W-L-F replacing W-F. More energy would be expended for the W-L-F system than was used in the W-F system (see Table 1). However, the W-L system was shown to store about 3,870 kg/ha more carbon in the soil than the W-F system over a seven year period (Campbell, unpublished data, 1996). Thus the W-L system should be given a credit for stored carbon even though the energy costs (and related carbon emissions) are higher. Based on results from another study (Coxworth et al., 1995), the W-L system had carbon emissions which were higher than the W-F system by 22.24 kg C/ha/yr. Thus it would take 174 years (3,870 kg C/ha divided by 22.24 kg C/ha/yr) for the higher carbon emissions from the W-L system to cancel out the extra carbon storage benefits from seven years of the W-L system.

Energy Savings from Inclusion of Field Peas in the Rotation.

Rotation studies at Winnipeg and Portage la Prairie were used to calculate the effects of field peas in the rotation (Table 2).

Table 2. Energy costs and energy efficiency effects of inclusion of field peas in rotations.

| Rotation | N rate kg N/ha | Energy use GJ/ha | Crop yield t/ha | Energy efficiency GJ/t |
|---|---|---|---|---|
| FP-W-W | 10 | 4.99 | 2.60 | 1.92 |
| FP-W-W | 75 | 9.21 | 2.96 | 3.11 |
| FP-W-W | 90 | 10.71 | 2.70 | 3.97 |
| FX-W-W | 90 | 10.79 | 2.85 | 3.78 |
| FX-W-W | 90 | 10.93 | 2.70 | 4.05 |

FP = field pea, W = spring wheat, FX = flax.

The energy savings from inclusion of field peas in the rotation were calculated to be the sum of the substitution effect (wheat replaced by field peas in the rotation)( 10.71 GJ/ha - 4.99 GJ/ha = 5.72 GJ/ha) plus the N credit effect (10.71 GJ/ha - 9.21 GJ/ha = 1.50 GJ/ha) for a total of 7.22 GJ/ha. Wheat two years after field peas did not show any influence of the field peas. In some studies, wheat two years after field peas still showed influences of the pulse crop (Wright, 1990). If wheat two years after flax was replaced by field peas, the substitution effect would be 5.94 GJ/ha, and the total savings would be 7.44 GJ/ha, about 3 % higher than the value used in further calculations.

The nitrogen fertilizer savings for wheat after lentils (Table 1) or field peas (Table 2) are similar to the nitrogen credits estimated by Biederbeck et al. (1995)(18.1 kg N/ha for field peas and 9.4 kg N/ha for lentils).

Estimates of the Nitrogen Fertilizer Rates for Crops in the Prairie Region in 1994.

Based on provincial statistics, there were 18.00 million ha of land in annual crops on stubble and 6.85 million ha of crop after summerfallow. There were 1.16 million ha of land in annual pulse crops (mainly field peas and lentils) leaving 16.84 million ha for non-legume crops on stubble, assuming that all pulses were planted on stubble. N fertilizer rates for crops on summerfallow and for pulses were estimated to be 5 kg N/ha, mainly as 12-51-O fertilizer, based on the Cost of Producing Grain Crops in Saskatchewan for years 1994, 1992, 1991 (Saskatchewan Agriculture and Food, 1991, 1992, 1994) and average N fertilizer prices for the respective years. The total amount of N fertilizer sold in 1994 was 1.05 1 billion kg (Biederbeck et al., 1995). Thus the amount of N fertilizer applied to non-legume stubble crops was 1 .01 1 billion kg or 60 kg N/ha.

Stubble crop areas in 1994 were similar to 1991 (Census of Agriculture, 1991), which in that year were 1,267,550 ha (Brown), 3,718,500 ha (Dark Brown) and 13,629,000 ha (Black and Gray). The relative recommended rates of N fertilizer for the soil zones were 1: 1.50:2.54 (Saskatchewan Guide to Farm Practice, 1987). Thus the average rates applied to stubble crops in 1994 were calculated to be 26.9 kg N/ha (Brown), 40.4 kg N/ha (Dark Brown) and 68.4 kg N/ha (Black and Gray).

<u>Average N Fertilizer Rate for Wheat Replaced by Lentils or Field Peas and Total Energy Savings in the Prairie Region.</u>

Based on the amounts of lentil and field pea production in each soil zone (Biederbeck et al. (1995), the average amounts of N fertilizer which would have been applied to wheat replaced by the two pulse crops were 48.6 kg N/ha for lentils and 64.7 kg N/ha for field peas. The results of the two field experiments (Tables 1 and 2) were corrected for the average rates of N fertilizer of wheat replaced by the pulses. The adjusted energy savings were combined with the increase in area in the pulse crops since 1990 to calculate the total energy savings (Table 33. Savings include adjusted substitution effects (wheat replaced by pulse crops) and N credit effects to following crops (from the case studies).

Table 3. Estimated energy savings from the increase in field peas and lentil production between 1990 and 1995.

| Crop | Energy savings GJ/ha | Increase in area ha | Total savings PJ |
|---|---|---|---|
| Lentils | 4.31 (3.04 + 1.28) | 188,000 | 0.81 |
| Field peas | 5.32 (3.82 + 1.50) | 686,000 | 3.65 |
| Total | | | 4.46 |

PJ = petajoule, $10^{15}$ joules. ()= subst'n + N credit effects.

Total savings were equivalent to 1.7% of total energy costs (fuels, machinery, fertilizers, pesticides and buildings) of agriculture in the three prairie provinces or equivalent to 7.5 % of 1990 N fertilizer sales.

<u>Energy Savings from the Increase in Soybean Production in Ontario.</u>

During the period 1980 to 1991, Ontario statistics indicated that the increase in soybean production area matched the decrease in corn fodder (56 %) and corn grain (44%) production. This period was used for the model. Decreases in crops replaced by soybeans were more complex since 1991 and would require a more detailed study. Energy costs of production of corn grain, fodder corn and soybeans are shown in Table 4.

Table 4. Energy costs of corn and soybean production in Ontario.

| | Corn fodder | Corn grain | Soybeans |
|---|---|---|---|
| Energy costs (GJ/ha) | 17.23 | 21.18 | 4.57 |
| Yield (t/ha) | 30.27 | 6.66 | 2.44 |
| Energy efficiency (GJ/t) | ND | 3.18 | 1.87 |

Note: corn fodder represents whole plant material and yields are on a silage moisture content basis.

The nitrogen credit for corn produced after soybeans ranged from none (Pimentel and Heichel, 1991) to 30 kg N/ha (Girouard, 1996). The latter figure was obtained from actual farm results in Quebec on a farm with a soybean-corn-small grain rotation. Based on average rates of different N fertilizer sources used on corn in Ontario, an average energy cost for N was calculated to be 76.02 MJ/kg N (Cemcorp, 1992). The N credit at 30 kg N/ha was 2.28 GJ/ha.

The energy saved by replacing corn with soybeans was therefore:
Energy costs for corn: 56 % corn fodder + 44% corn grain = 18.97 GJ/ha. Energy costs for soybeans: 4.57 GJ/ha. Total substitution savings = 14.40 GJ/ha. Credit for legume N for following crops = zero to 2.28 GJ/ha. Total savings = 14.40 GJ/ha to 16.68 GJ/ha. The increase in soybean hectarage between 1990 and 1995 was 272,000 ha. Thus the total energy savings were 3.92 PJ.

Energy Reauired for Ethanol Production from Grain; Comnarisons with Energy Saved by the Increase in Legumes in Rotations.

Present Canadian fuel ethanol production is very small (31 million litres), so energy costs were projected to the year 2000 for new plants taking advantage of recent energy savings in grain and ethanol production (Cemcorp, 1992). Energy costs per litre of ethanol were based on a yield of 387 L/t of grain, and energy costs of grain production in 2000 of 2.35 GJ/t. Energy costs were reported in MJ/L (Table 5).

The combustion energy content of ethanol is 23.39 MJ/L. Thus the energy ratio of output:input is 2.10: 1 .00, or roughly 2: 1. This contrasts with a ratio of 1.24: 1 which Shapouri et al. (1995) calculated was the ratio for the average of present ethanol plants in the U.S.A.

The size of ethanol production required to equal the net energy savings achieved by the increase in pulse crops and soybeans was calculated , based on the 2: 1 ratio of ethanol output to input (Table 6).

Table 5. Energy costs of ethanol production, new plants in 2000.

| Item | Energy costs (MJ/L) | Reference |
|---|---|---|
| Grain production | 6.07 | Cemcorp, 1992 |
| Transport grain | 0.34 | Shapouri et al., 1995 |
| Ethanol production | 6.21 | Cemcorp, 1992 |
| Production materials | 1.40 | Giampetro and Pimentel, 1990 |
| Transport ethanol | 0.88 | Shapouri et al., 1995 |
| Total | 14.90 | |
| By-products credit | 3.74 | Shapouri et al., 1995 |
| Net energy costs | 11.16 | |

Note: higher heating values used throughout.

Table 6. Energy savings from the increase in pulse crop and soybean production; comparison to ethanol production.

| Legume crop | Time period | Energy savings (PJ) | Ethanol production Millions L |
|---|---|---|---|
| Field peas and lentils | 1990-1995 | 4.46 | 380 |
| | 1990-2005 | 11.62 | 990 |
| Soybeans | 1990-1995 | 3.92 | 330 |
| Total | 1990-1995 | 8.38 | 710 |
| | 1990-2005 | 15.54 | 1,320 |
| Canadian fuel ethanol production | | | 31 |
| U.S.A. fuel ethanol production | | | 4,000 |

The present total energy savings from pulse crops and soybeans were estimated to be equivalent to an ethanol industry production of 710 million L, much larger than present Canadian fuel ethanol production of 31 million L, and about 18% of the present U.S. production of 4 billion L. If future predicted increases in pulse crop production (Biederbeck et al., 1995) are achieved, the energy savings would equal 1.32 billion L of ethanol (33 % of present U. S. production).

## Conclusions

The increase in seed legume production since 1990 represents a considerable energy savings, equivalent to a large, modem ethanol industry. Energy costs of grain crops produced after legumes are reduced, which would reduce the energy costs of production of ethanol from grain. This study did not address such issues as changes in grain prices and their effect on pulse crop production, no till crop production with legumes, potential lower draft requirements for tillage of soils with legumes in the rotation, improved N fertilizer use efficiency with legumes in rotations, reduced N fertility losses, or nitrous oxide emissions from cropping systems with or without legumes. The potential increase in pulse crop production to 2005 would considerably increase energy savings over the present.

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