The Role of Forage Legumes in Reducing On-Farm Non-Renewable Energy Use

J.W. Hoeppner [1], M.H. Entz [1], B.G. McConkey [2], G.P. Lafond [3], R.P. Zentner [2]

[1] Department of Plant Science, University of Manitoba, Winnipeg, MB, R3T 2N2
[2] Semiarid Prairie Agricultural Research Centre, Swift Current, SK, S9H 3X2
[3] Indian Head Research Farm, Indian Head, SK, S0G 2KO

Abstract

Inputs such as machinery, fuel, pesticides, and fertilizers contribute to energy expended in cropping systems. Reducing non-renewable energy use and increasing energy use efficiency can make cropping systems more sustainable. Nitrogen benefits of legumes are well documented. This study examined the effect of forage and green manure legumes on energy efficiency of crop production for three western Canadian crop rotation studies (Glenlea, MB; Indian Head, SK; Swift Current, SK). Relative to continuous grain rotations, rotations containing 50% perennial forage legumes decreased energy use by 85% and increased energy use efficiency by 409%. Relative to cereal, pulse, and oilseed rotations, they reduced energy use by 28% and increased energy use efficiency by 294%. Green manure rotations, while decreasing energy use by 26%, did not affect energy use efficiency. The primary contribution of forage legumes to lower energy use was nitrogen addition to the soil.

Introduction

During the past few decades, there has been much discussion and interest with respect to the state of the environment. Throughout recent history, human activity has had a great, usually detrimental, impact on the environment. This is especially true with regard to the use of non-renewable energy sources, particularly fossil fuels. From the large amounts of coal burned over the years, starting with the Industrial Revolution, to the large quantities of gasoline and diesel fuel used today, huge amounts of fossil fuels have been expended during the past few centuries. Burning these fossil fuels result in large amounts of pollutants being released into the atmosphere. In addition, the energy shortages of the early 1970's forced people to examine modern industrialized systems, and agriculture was criticized for being particularly inefficient in terms of fossil fuel energy inputs per unit of food energy produced (Fluck and Baird, 1980). These issues led to research which examined methods with which to decrease on-farm energy inputs, and to increase energy efficiency within agriculture. In order to accomplish this, an energy accounting, or energy budgeting, of the farm was needed to calculate how much energy was being produced and consumed by the farm. Researchers have determined how much energy is required to produce machinery, fertilizers, and pesticides, how much fuel energy is required to carry out the various field operations, and so on. In addition, researchers have calculated how much feed energy is embodied in the different crops that are produced. These energy coefficients then allow researchers to calculate the energy efficiencies of different agricultural production systems.

Mineral fertilizer accounts for largest proportion of energy expended in crop production (70%), while the amount of commercial energy devoted to mineral fertilizer accounted for by nitrogen is nearly 90% (Stout, 1990). When considering that studies have shown that up to 50% of nitrogen that is applied as fertilizer can be lost to processes such as denitrification, volatilization, or leaching below the root zone (Karlen et al. 1996), it is apparent that a great deal of energy expended in crop production is lost through the inefficiency of nitrogen fertilizer.

Including forage legumes in a crop rotation can reduce energy requirements of the cropping system in a variety of ways. Firstly, including forage legumes in a crop rotation can help break insect, disease and weed cycles that are common among monocultures, allowing producers to decrease their reliance on pesticides. For example, the corn rootworm is rarely a problem for corn during the year following alfalfa in a rotation, soybean stem rot is controlled by crop rotation, and weeds such as wild oats that are problems in monocultures are much better controlled in rotations containing forage legumes (Higgs et al. 1990). Secondly, and most obviously, forage legumes fix their own nitrogen from the atmosphere, so they do not require inorganic nitrogen fertilizers. Forage legume residue left in the field decomposes and releases nitrogen into the soil for subsequent crops to use. It has long been recognized that including a forage legume in a crop rotation can enhance the productivity of a succeeding non-legume crop (Hesterman, 1988), and this practice was commonplace for the replacement of nitrogen in cropping systems until the arrival of economical commercial nitrogen fertilizer (Heichel and Barnes, 1984). This led to a dramatic decrease in the utilization of forage legumes in rotation. The objective of this study was to examine the effectiveness of perennial forage and green manure legume crops in reducing the use of non-renewable energy inputs in rotation, and increasing energy efficiency of cropping systems, as a result of decreased nitrogen fertilizer requirements.

Materials and Methods

Crop rotation studies from three different western Canadian locations were examined: Glenlea, MB, Indian Head, SK, and Swift Current, SK. A number of treatments from each location were selected for inclusion in the study, based upon their suitability for comparison. At Glenlea, the two rotations selected were a wheat-pea-wheat-flax rotation and a wheat-alfalfa-alfalfa-flax rotation. In addition, treatments with and without fertilizer and pesticides were investigated. In the Indian Head study, three rotations were examined: two continuous wheat rotations (with and without nitrogen fertilizer applied) and a fallow-wheat-wheat-hay-hay-hay rotation (where hay consisted of an alfalfa/bromegrass mixture). At Swift Current, the rotations selected were as follows: green manure-wheat-wheat, fallow-wheat-wheat, and a continuous wheat rotation. Eight, twelve and nine years of data were analyzed from the Glenlea, Indian Head, and Swift Current studies, respectively. Data used included crop yields and records of all crop inputs and field operations carried out in the different rotations. Energy budgets were created for each rotation using this data, along with updated energy coefficients for agricultural inputs and outputs (Nagy, 1999), in order to calculate energy consumption and production on a per hectare basis. Energy use and efficiency of the rotations were then calculated.

Results

In rotations where fertilizers were used, nitrogen accounted for 91 to 96% of the energy allocated to fertilizer production. Energy attributed to nitrogen fertilizer production also accounted for 40 to 67% of total rotational energy use.

Including a two-year stand of alfalfa in the Glenlea rotations decreased energy use between 10 and 26% as compared to the annual cropping rotation. Energy efficiencies of the rotation containing perennial forage legumes were also increased between 258% and 296%. Compared to the unfertilized wheat rotation, including a three-year stand of alfalfa/bromegrass in the Indian Head rotations decreased energy use 10% compared to the unfertilized continuous wheat rotation, and 83% as compared to the fertilized continuous wheat rotation. Energy efficiency of the Indian Head rotation with the perennial forage legumes was 340% and 383% greater than the unfertilized and fertilized continuous wheat treatments, respectively.

Including green manure in the Swift Current rotations decreased energy use by 27% over continuous wheat, while consuming a similar amount of energy as the fallow-wheat-wheat rotation. Energy efficiency of the green manure rotation was similar to those of the continuous wheat and fallow-wheat-wheat rotations.

Discussion

Including perennial forage and green manure legumes resulted in decreased energy use in all cases (except when compared to the fallow-wheat-wheat rotation) due primarily to the absence of inorganic nitrogen fertilizer in these rotations. There was no decrease in energy use when compared to the fallow-wheat-wheat rotation because there is no crop grown during the fallow year of the rotation. The only energy expended during this time was as a result of tillage operations used to control weeds. By comparison, the green manure crop (lentils) consumed energy embodied in the production of the seed and energy attributed to seeding the lentils, in addition to energy used during the tillage operations.

The presence of perennial forage legumes in rotation resulted in increased rotational energy efficiencies. This was due not only to decreases in energy use, but to higher energy output levels. When perennial forage legumes are harvested, it is the aboveground biomass that is collected, as compared to annual crops, of which generally only the seed is harvested. By gathering all of the aboveground biomass, more energy that is produced by the land is utilized for feed. In addition, perennial forage legumes are usually harvested several times per growing season, whereas grain crops are only harvested once on the Prairies; this results in even more feed

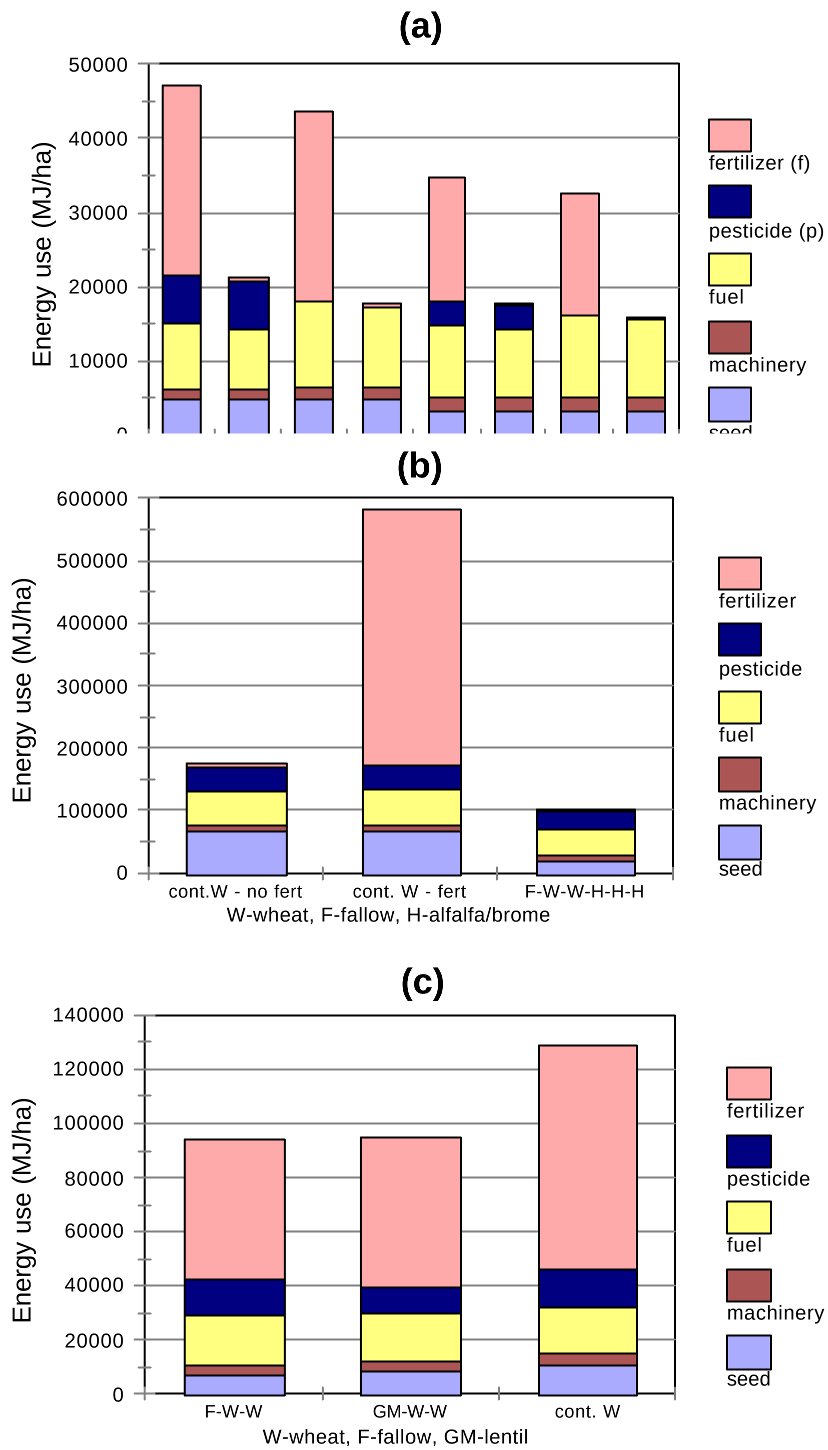

Figure 1 - Energy use of (a) Glenlea, (b) Indian Head, and (c) Swift Current crop rotations

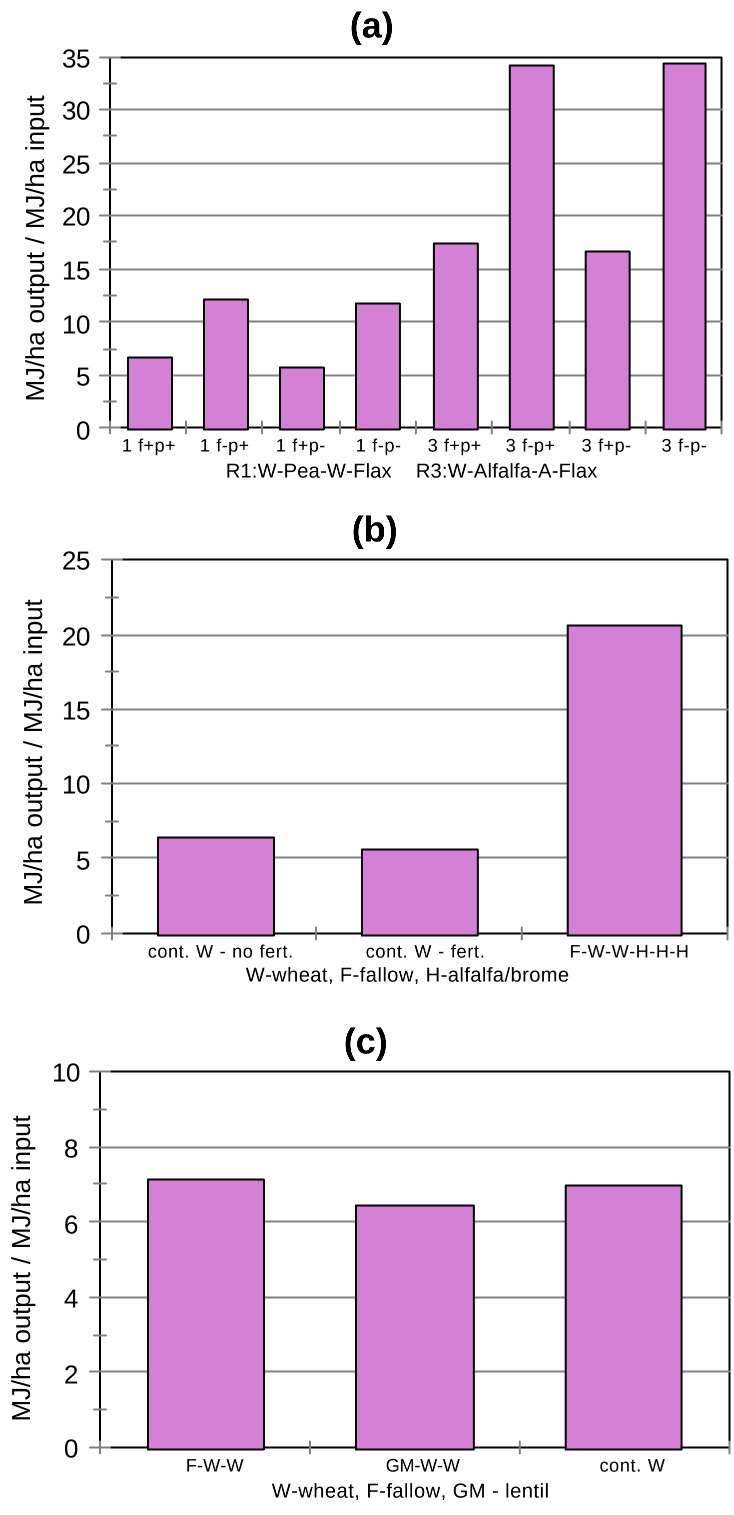

Figure 2 - Energy efficiencies of the (a) Glenlea, (b) Indian Head, and (c) Swift Current rotations

energy being harvested when perennial forage legumes are included in rotation, and in higher levels of energy output from the land.

When including green manure legumes in rotation, energy efficiency was lower than in rotations with perennial forage legumes, and similar to those of conventional crop rotations; this was due primarily to the lack of legume harvest. As previously discussed, the presence of a green manure legume in a crop rotation did lower the amount of energy expended in crop production (with the exception of the fallow-wheat-wheat rotation). However, green manure legumes are not harvested, therefore, the energy produced by the rotation is not harvested and utilized as feed. Total energy output of the rotation is decreased, resulting in lower energy efficiency than for rotations with perennial forage legumes in them.

There was no improvement in energy efficiency when green manure legumes were included in rotation. However, it is a more sustainable practice for prairie agriculture than a continuous wheat or fallow-wheat-wheat rotation. The use of nitrogen fertilizers in continuous wheat rotations can be somewhat risky due to uncertain weather conditions, while the use of fallow to provide mineralized nitrogen and store soil water for subsequent grain crops can lead to a deterioration in soil quality (Campbell et al. 1991). However, replacing fallow with green manure legumes can provide nitrogen to the soil, while minimizing soil erosion and degradation (Biederbeck et al. 1996).

While grain is digestible by both livestock and humans, forages are only digestible by livestock. Therefore, it would be most appropriate to compare energy efficiencies of rotations with perennial forages to continuous grain rotations in which some portion of the grain produced is fed to livestock. This would ensure that comparisons would be made on an equal basis, as the energy output of harvested forage legumes is measured in terms of livestock feed energy. When considering these comparisons, it should be noted that approximately one-third of all grain produced on earth goes to support livestock, and 70% of all grain produced in the United States is fed to cattle (Rifkin, 1992), so perhaps comparisons of energy use and efficiency between rotations with and without forage legumes are more appropriate than one might think.

In addition to this work, we are presently investigating the rotational benefits (including energy savings) of living mulch and relay-/double-cropped legumes in continuous grain systems in Manitoba. Traditional (red clover, alfalfa, vetch, lentil) and novel (self-regenerating medics and subterranean clover) forage legumes are being investigated. Many producers want the nitrogen benefits provided by forage legumes in a rotation, but do not want to give up a year or more of grain cropping in order to do so; these systems being studied may offer a compromise.

Summary

Results from this study indicate that when perennial forage legumes and green manure legumes are included in a western Canadian crop rotation, the levels of input energy required by the system are

reduced. The reduction in energy use occurred mainly as a result of the legumes providing alternate means of nitrogen addition to the soil as opposed to fertilizing field crops with high rates of nitrogen fertilizer. Legumes also maintained or increased energy efficiency of crop rotations in this study. This was as a result of lower levels of input energy, but also, when perennial forage legumes were included in crop rotation, higher levels of energy output.

References

Biederbeck, V.O., Bouman, O.T., Campbell, C.A., Baily, L.D. and Winkleman, G.E. 1996. Nitrogen benefits from four green-manure legumes in dryland cropping systems. Can. J. Plant Sci. 76:307-315.

Campbell, C.A., Schnitzer, M., Lafond, G.P., Zentner, R.P. and Knipfel, J.E. 1991. Thirty-year crop rotations and management practices effects on soil and amino nitrogen. Soil Sci. Soc. Am. J. 55:739-745.

Fluck, R.C. and Baird, C.D. 1980. Agricultural energetics. The AVI Publishing Company, Inc., Westport, CT. 192 pp.

Heichel, G.H. and Barnes, D.K. 1984. Opportunities for meeting crop nitrogen needs from symbiotic nitrogen fixation. Pp. 49-60 *In* Kral, D.M. (Ed.). Organic Farming: current technology and its role in a sustainable agriculture, ASA special publication number 46. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. 192 pp.

Hesterman, O.B. 1988. Exploiting forage legumes for nitrogen contribution in cropping systems Pp. 155-166 *In* Hargrove, W.L. (ed.). Cropping strategies for efficient use of water and nitrogen, ASA special publication number 51. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. 218 pp.

Higgs, R.L., Peterson, A.E. and Paulson, W.H. 1990. Crop rotations: sustainable and profitable. J. Soil and Water Cons. 45:68-70.

Karlen, D.L., Hunt, P.G. and Matheny, T.A. 1996. Fertilizer ^{15}Nitrogen recovery by corn, wheat, and cotton grown with and without pre-plant tillage on Norfolk loamy sand. Crop Sci. 36:975-981.

Nagy, C. 1999. Energy coefficients for agricultural inputs in western Canada. Centre for Studies in Agriculture, Law and the Environment, Saskatoon, SK. 41 pp.

Rifkin, J. 1992. Bovine burden. Geographical magazine. 64:10-15.

Stout, B.A. 1990. Handbook of energy for world agriculture. Elsevier Applied Science, New York. 504 pp.