The Effects of Legume Green Manures, Perennial Forages, and Cover Crops on Non-Renewable Energy Use in Western Canadian Cropping Systems

BY

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A Thesis
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ABSTRACT

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Inputs such as machinery, fuel, pesticides and fertilizers contribute to energy expended in cropping systems. Reducing non-renewable energy use (EU) and increasing energy use efficiency (EUE) can make cropping systems more sustainable. Nitrogen benefits of legumes to succeeding non-leguminous crops are well documented. This study examined the effect of green manure and perennial forage legumes on energy efficiency of crop production for four western Canadian crop rotation studies: Lethbridge, AB; Swift Current, SK; Indian Head, SK; Glenlea, MB. Relative to continuous grain rotations, rotations containing 50% perennial forage legumes decreased EU by up to 85% and increased EUE by up to 438%. Relative to cereal, pulse and oilseed rotations, they reduced EU by up to 28% and increased EUE by up to 294%. Rotations containing green manure legumes decreased EU by up to 65%, and increased EUE by up to 196%. The primary contribution of legumes to lower energy use was nitrogen addition to the soil. Depending on site and rotation, economic performance of legume rotations varied compared to annual grain rotations. The rotational benefits of relay intercropped and double cropped legumes in continuous grain systems in Manitoba were also investigated. When examining relay intercropped alfalfa and red clover and double cropped chickling vetch and lentil, it was found that considerable nitrogen benefits were provided to a succeeding oat crop by all legumes at Winnipeg, and by some legumes at Carman. Reduced legume growth at Carman, due to drought conditions, resulted in few yield benefits from the relay intercropped and double cropped legumes. Including

relay intercropped and double cropped legumes in continuous grain rotations reduced energy use by up to 39%, and increased energy use efficiency by up to 28%. Increasing the frequence of legumes in cropping systems shows promise to enhance agricultural sustainability.

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

TABLES IN APPENDICES

1. INTRODUCTION

During the latter part of the 20th century, there has been much discussion and interest with respect to the environment, and the impact of humans upon it. Throughout recent history, human activity has had many detrimental impacts on the environment. One example of these detrimental impacts regards the use of non-renewable energy sources, particularly fossil fuels. From the large amounts of coal burned over hundreds of years, starting with the Industrial Revolution, to the large quantities of gasoline and diesel fuel used today, vast amounts of these fossil fuels have been expended over the past few centuries. The burning of these fossil fuels has resulted 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 to decrease on-farm energy inputs, and to increase energy efficiency within agriculture.

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 pest cycles that are common among monocultures, allowing producers to decrease their reliance on pesticides (Higgs et al. 1990; Ominski et al. 1999). Secondly, forage legumes fix atmospheric nitrogen, so they do not require inorganic nitrogen fertilizers, which requires tremendous amounts of energy to produce. Forage legume residue left in the field decomposes and releases nitrogen into the soil for subsequent crops to use. Therefore, the first objective of this study was to determine, using historical data from a variety of locations across western Canada, the effects of including green manure and perennial forage legumes in crop rotations on energy use, energy production, energy use efficiency and economic performance of cropping systems.

Including forage legumes in a crop rotation can reduce energy requirements of the cropping system in a variety of ways, in addition to providing numerous agronomic benefits to succeeding non-leguminous crops. However, having a green manure or perennial forage legume in a crop rotation means that a producer cannot harvest grain from the land. A way in which to gain the benefits of a legume in rotation, while being able to harvest a grain crop in the same year, is by multiple cropping with legumes. The legume is a secondary crop that is put in place once the primary crop of the growing season is well-established or harvested. Including legumes in this manner can slow soil erosion, improve soil structure and smother weeds (Clark, 1998), and add nitrogen to the soil. By utilizing this legume nitrogen, nitrogen fertilizer use could be decreased, thereby decreasing commercial energy use within such rotations. Therefore, the second objective was to determine, through field studies in south-central Manitoba, the effects of relay intercropping and double cropping green manure legume cover crops with winter cereals in southern Manitoba on companion cereal crops and subsequent cereal crops, as well as on energy use, energy production and energy use efficiency of the cropping system.

2. LITERATURE REVIEW

2.1 Energy in Crop Production

The amount of energy expended for food production, distribution and processing in the United States has been estimated at approximately 17% of total U.S. fossil energy use, with approximately one-third of that, 6%, used solely for food production (Pimental, 1980). Researchers have been investigating methods of how to reduce on-farm energy use, in order to make crop production systems more energy efficient. In order to accomplish this, farm energy accounting, or energy budgeting, was needed in order to calculate how much energy was being produced on the farm, and how much energy was being consumed on the farm. Researchers such as Stout (1990), Pimental (1980), and Nagy (1999) have calculated the amount of energy required for such aspects as production of machinery, fertilizers, and pesticides, and how much fuel energy is required to carry out the various farming operations. Together with information on the food energy of the crop produced, researchers calculated the energy efficiencies of agricultural production systems. Other researchers (Campbell et al. 1990; Heichel, 1978 and 1980; Spedding and Walsingham, 1976) included comparisons of energy use and efficiency between different crop rotations, as well as the influence of varying inputs on energy use and efficiency of cropping systems (Clements et al. 1995; Zentner et al. 1989).

The primary energy inputs, such as machinery, fuel, fertilizer, seed, and pesticides, as well as energy outputs (i.e. food and feed energy of crops) in western Canada will be discussed in the following sections, as well as energy savings realized by including legumes in a cropping system.

2.1.1 Energy inputs in crop production

Crop production systems require inputs of energy, through the use of machinery, fuel, fertilizers, seed, and pesticides. While different production systems will use varying amounts of input energy, all require inputs of energy to initiate and maintain the system.

Energy use is dependent on the type of crop grown. An American study investigated fossil energy use by major crops type. The fossil energy flux (FEF), or the average daily rate of energy use per acre for growing the crop (Mcal acre·day^{-1}) ranged from 0.03 for native range to 138 for vegetables and fruit (Heichel, 1978). Vegetables and fruit are energy intensive crops to produce, primarily due to the need for high rates of fertilizer, intensive pest control through pesticides, and irrigation, while native range requires energy inputs in the form of infrequent herbicide applications. Fossil energy flux values for other crops common to western Canada, such as grain corn (*Zea mays* L.), barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), and fertilized pasture were calculated to be 42, 15, 12, 10, and 5 Mcal ha·day^{-1}, respectively. (Heichel, 1978). Barley, wheat, oats, and fertilized pasture consume much less energy than vegetable and fruit crops, as fewer inputs are required (i.e. less intensive fertilization and pest control).

Energy use in United Kingdom agriculture was investigated by Spedding and Walsingham (1976). Three crops were studied: alfalfa (*Medicago sativa* L.), spring barley, and perennial ryegrass (*Lolium perenne* L.). The energy required to produce these crops was 2,811 MJ ha^{-1} for alfalfa, 8,806 MJ ha^{-1} for barley, and 31,006 MJ ha^{-1} for perennial ryegrass. The majority of the difference in energy used was attributed to differences in nitrogen fertilizer requirements between crops (Spedding and Walsingham, 1976). This, once again, demonstrates the effects of different crops, and the management needs of those crops, on total energy use.

Pimental et al. (1984) determined that the major fossil energy inputs in cropping systems are fuel used for machinery operations and synthetic nitrogen fertilizers. For example, in a typical corn silage production system in southeastern Minnesota, approximately 36% (1,621 Mcal ha^{-1}) of the total input energy was allocated to fuel to run the machinery, and approximately 38% (1,676 Mcal ha^{-1}) was allocated solely to the production of nitrogen fertilizer. On the other hand, only 3% (138 Mcal ha^{-1}) of the total input energy of the system was allocated towards pesticides, 1% (42 Mcal ha^{-1}) was allocated to machinery manufacture, 3% (112 Mcal ha^{-1}) was accounted for by phosphorous and potassium fertilizers, 10% (457 Mcal ha^{-1}) was allocated to transportation costs, and 9% (422 Mcal ha^{-1}) is accounted for the input energy requirements of the corn seed (Heichel, 1980). In this production system, approximately three-quarters of the input energy was accounted for by fuel and fertilizer requirements. By way of comparison, in a typical alfalfa production system (in the year of establishment), 38% (1,084 Mcal ha^{-1}) of the total energy expenditures was allocated towards fuel, 1% (30 Mcal ha^{-1}) was accounted for by machinery, 9% (267 Mcal ha^{-1}) was allocated towards phosphorous and potassium fertilizers, 31% (868 Mcal ha^{-1}) was accounted for by alfalfa seed, 5% (138 Mcal ha^{-1}) was allocated towards the production of pesticides, and 16% (441 Mcal ha^{-1}) of the total energy expenditures for the system were accounted for by transportation costs. In both rotations, energy allocated to pesticides, machinery, transportation and non-nitrogen fertilizers accounted for less than one-third of the total energy use (Heichel, 1980). While the proportion of energy accounted for by fuel use in both systems was similar (36% for the corn system vs. 38% for the alfalfa system), total fuel use in the alfalfa system (1,084 Mcal ha^{-1}) was only 67% of that in the corn production system (1,621 Mcal ha^{-1}). In addition, while 38% of the energy budget for the corn production system was accounted for by nitrogen fertilizer, there was no nitrogen fertilizer used in the alfalfa production system. Together, the reduction in fuel use and the absence of nitrogen fertilizer application in the alfalfa system lowered the total amount of energy expended from 4,468 Mcal ha^{-1} to 2,830 Mcal ha^{-1}, 63% of the total energy consumed by the corn system (Heichel, 1980). Therefore, in this case, a forage system (i.e., alfalfa) decreased the amount of energy consumed in a crop rotation compared with a traditional forage system (i.e., corn silage). By leaving the alfalfa in rotation for more than one year, the energy savings become even more substantive. In the establishment year, 31% of energy expenditures in the alfalfa system are allocated to seed production costs; there would be no need to seed alfalfa after the year of establishment.

The trend of energy savings with legumes has also been observed on the Canadian prairies. Three- and four-year annual crop rotations from four soil zones in Alberta were compared, where green manure legumes were substituted for fallow. When comparing similar rotations at the same site, the rotations containing the green manure legumes used between 12% and 25% less energy than the fallow-containing rotations. In each case, most of the energy savings were as a result of a decreased need for nitrogen fertilizer rising from the legume nitrogen (Rice and Biederbeck, 1983).

As was observed in the previous examples, nitrogen fertilizer accounts for a large proportion of the energy consumed in a cropping system. Mineral fertilizer accounts for nearly 70% of the total commercial energy used in agriculture, with the production of nitrogen fertilizer consuming approximately 90% of that energy (Stout, 1990). Ammonia, which is used to produce inorganic nitrogen fertilizer, is synthesized by using the Haber-Bosch process. Nitrogen and hydrogen are combined at a pressure of 200 atmospheres and a temperature of 500 ^{0}C to produce liquid ammonia (Smil, 1997; 1999), which requires large amounts of energy. As well, world consumption of nitrogen fertilizer increased from 5 megatons of nutrient in 1950 to 45 megatons of nutrient in 1975 to almost 80 megatons of nutrient presently (Smil, 1997). This trend is also evident on the Canadian Prairies. In 1987, there were 559,800 tonnes of ammonium phosphate, ammonium nitrate, urea, anhydrous ammonia, and nitrogen solution fertilizers sold in Manitoba. In 1997, there were 726,800 tonnes of these products sold in Manitoba, representing an increase of approximately 30% during the 10-year period (Manitoba Agriculture, 1987; 1997). Not only does nitrogen fertilizer use consume great amounts of fossil fuel energy, but it is quite inefficient in doing so. Studies have shown that approximately 50% of nitrogen that is applied as fertilizer is lost through denitrification, volatilization, or leaching below the root zone (Karlen et al. 1996; Tran and Giroux, 1998). As a result, with mineral fertilizer accounting for nearly 70% of the total commercial energy used in agriculture, and nitrogen fertilizer accounting for 88% (in 1982) of the commercial energy devoted to mineral fertilizer production (Stout, 1990), approximately 30% of the total commercial energy used in agriculture is lost through the inefficiency of nitrogen fertilizer.

It has long been recognized that including a legume in a crop rotation can enhance the productivity of a succeeding non-legume crop and sustain the productivity of soils

(Hesterman, 1988; Entz et al. 1995); this management practice, along with the use of summerfallow to exploit soil organic nitrogen, was commonplace for supplying nitrogen in Prairie cropping systems until the arrival of economical commercial nitrogen fertilizers (Heichel and Barnes, 1984), which led to a dramatic decrease in the utilization of legumes in rotation. Including legumes in a cropping system can also assist in breaking weed, insect, and disease cycles that are common among monocultures, allowing the producer to decrease the amount of pesticides used. For example, the corn rootworm (*Diabrotica* spp.) is rarely a problem for corn during the year following alfalfa in a rotation (Higgs et al. 1990), and weeds such as wild oat (*Avena fatua* L.), Canada thistle [*Cirsium arvense* (L.) Scop.], wild mustard (*Brassica kaber* L.) and catchweed bedstraw (*Galium aparine* L.) that are problems in monocultures are much less prevalent in rotations containing forage legumes (Ominski et al. 1999). This often results in lower energy costs for cropping systems that contain legumes, as a result of decreased pesticide requirements.

2.1.2 Energy outputs in crop production

The energy content of the different crops and livestock produced is that which can be used as food energy by humans or livestock, or as fuel energy by machinery. The most common type of fuel energy derived from crops is in the form of ethanol. Presently, ethanol is produced by fermenting the starch in grains. Research examing conversion of other parts of crop plants (i.e. stalks, leaves) to ethanol has been conducted in the United States (Vogel, 1996). However, production of ethanol from this source is not yet commercially viable, due to the need for increased improvements in the conversion of biomass to fuel . While ethanol from grain is currently blended with some gasolines, it is currently a minor use for corn and other grains.

Energy output from agricultural land is primarily in terms of food energy for humans and livestock. It has been estimated that 26% of the average energy intake for a person in industrialized countries comes from cereals, 13% from roots and tubers, 0.5% from pulses, 7% from sugar, 3% from vegetable oils, 14.5% from meat, and 36% from milk (Alexandratos, 1995), all of which are important elements of Canadian prairie agriculture.

The output energy of a crop can be measured using laboratory bomb calorimeter tests. Energy coefficients for crops commonly grown in western Canada are shown in Table 2-1. So, while different crops can have varying energy input requirements (i.e. seed, fuel, machinery, fertilizer, pesticides, etc.), they also have varying levels of output energy.

Table 2-1. Energy content of crops commonly grown in western Canada (Nagy, 1999)

Crop	Energy Content (MJ ha^{-1})
Alfalfa	17.77
Barley	18.50
Dry Beans (*Phaseolus vulgaris* L.)	14.00
Canola (*Brassica napus* L., *Brassica rapa* L.)	29.43
Field Pea (*Pisum sativum* L.)	18.64
Flax (*Linum usitatissimum* L.)	25.98
Oats	19.40
Wheat	18.71

2.1.3 Energy use efficiency in crop production

In order to properly assess energy efficiency of a crop rotation, both energy input and energy output must be taken into account. One example of energy efficiency research was conducted by Zentner et al. (1989). In comparing continuous wheat treatments that did and did not receive nitrogen fertilizer, it was found that the fertilized treatment yielded 17% higher, but required 59% more energy, than the unfertilized treatment. This resulted in the unfertilized treatment being 31% more energy efficient than the fertilized treatment (Zentner et al. 1989). However, the unfertilized continuous wheat treatment, while having a higher energy use efficiency, would be less sustainable than the fertilized treatment, because it would not replace the amount of organic nitrogen removed from the soil. Eventually, soil nitrogen levels in the unfertilized treatment could be depleted to the point where wheat yields would drop, resulting in lower levels of energy production, and a decrease in energy use efficiency. While energy use efficiency can be an important tool in measuring the sustainability of a cropping system, it should not be the only factor taken into account.

Another study, conducted in southern Ontario, examined the effect of variable tillage and herbicide inputs on energy efficiency (Clements et al. 1995). The researchers compared a corn-soybean [*Glycine max* (L.) Merr.]-wheat rotation with conventional and reduced weed control input levels, and found that while yields between the two were similar, the low input system used less energy and was more energy efficiency. The researchers also surveyed 12 farms and found that there was no strong relationships between energy expended for weed control and the yields attained (although these results are likely very site and temporal specific), which indicates that yield potential was not sacrificed when weed control was reduced. This would result in the reduced input systems having higher energy efficiencies (Clements et al. 1995).

Environmental conditions can vary from year to year, resulting in a wide range of input requirements and crop yields on the same land over a number of years (Pimental, 1980). As a result, energy use efficiency of a crop rotation should be measured over a number of rotation cycles, so that variable environmental conditions may be averaged out.

2.2 Role of Legumes in Prairie Cropping Systems

Environmental concerns such as leaching of nitrates from inorganic nitrogen fertilizers (in which all of the nitrogen is in a readily-available form) into groundwater and the large amounts of commercial energy needed to produce these fertilizers suggest that alternate methods of adding nitrogen to soil should be considered. Incorporating legumes into rotations can provide numerous benefits to succeeding crops, such as higher protein levels, higher yields, weed control, and improved soil physical properties (Spratt, 1966; Hoyt and Leitch, 1983; Badaruddin and Meyer, 1989; Entz et al. 1995). However, the greatest attribute of a legume is the ability it has, in concert with soil bacteria known as *rhizobia*, to fix nitrogen from the atmosphere (Scheppers, 1988).

2.2.1 Grain legumes

One of the more common ways of including a legume in a western Canadian crop rotation is by growing an annual grain legume. By growing a grain legume, the producer can harvest a grain crop, while still being able to capture some of the benefits of having a legume crop in rotation. In addition, many grain legumes grown in western Canada do not require nitrogen fertilizer to maximize yield potential. Legume grain crops, which are high in protein, have a wide variety of uses as food crops (Ledgard and Giller, 1995); grain legume crops grown on the Canadian Prairies include chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medikus), dry beans, faba beans (*Vicia faba* L.), pea and soybean. However, while providing rotation benefits to a cropping system, the actual N contribution to the soil from a legume crop may be small or even negative, as most of the fixed nitrogen is removed from the land as protein in the harvested grain (Buttery et al. 1992). Ledgard and Giller (1995) found that the net annual contribution to soil nitrogen from fixed nitrogen from lentil and pea ranged from -143 to 26 kg N ha^{-1}, and from -32 to 96 kg N ha^{-1}, respectively. Experiments in Saskatchewan showed the nitrogen residual effect from the peas on succeeding crops of barley and flax averaged 27 and 12 kg N ha^{-1} at Melfort (moist Black soil climactic zone) and Scott (moist Dark Brown soil climactic zone), respectively (Beckie and Brandt, 1997). A second Saskatchewan study showed that nitrogen fixation by lentil and pea was increased 10% and 31%, respectively, when grown using zero tillage as compared to conventional tillage practices (Matus et al. 1997). In conclusion, with such low levels of nitrogen contribution to succeeding non-legume crops, grain legumes are not primarily grown for nitrogen contribution to the soil.

2.2.2 Green manure legumes

In a green manure system, the legume is grown for one year (or less in drier climates) and is traditionally not harvested for seed. The legume stand is terminated using chemicals and/or tillage, and a non-leguminous crop is seeded to capture the nitrogen benefits from the legume (Hesterman, 1988); in Canada, the succeeding non-legume crop is seeded the following year. While generally not contributing nitrogen to the soil in as large quantities as perennial forage legume stands, green manure forage legumes can contribute significant amounts of nitrogen to the soil for subsequent non-legume crops to utilize.

2.2.2.1 Species descriptions Two important green manure legumes used in western Canada are chickling vetch (*Lathyrus sativus* L.) and lentil. Chickling vetch is a new type of annual legume for the Prairies which has shown great potential as a green manure crop. Chickling vetch grows in a branched manner, with stems that are sub-erect and climbing. Chickling vetch grows quite vigorously once it has established, and possesses excellent nitrogen fixation ability (Bellido, 1994), most notably the variety 'AC Greenfix'. Nitrogen fixation from chickling vetch grown for a six- to seven-week period reached 69 kg N ha^{-1} in a study conducted in Saskatchewan (Biederbeck et al. 1996). Chickling vetch originated in the Near East/Mediterranean region, so it is suited to dry climates, although it can tolerate an excess of rain (Cocks, 1999). Lentil has been used as a green manure crop on the Prairies for some time. Like chickling vetch, lentil originated in the Near East/Mediterranean region, so it is also suited to the drier climate of the Canadian Prairies. Lentil plants are slender, semi-erect annuals with compound leaves; plants normally range from 20 to 50 cm in height. Depending on population levels in the field, plants can have single stems or many branches. The lentil cultivar 'Indianhead' can provide significant amounts of fixed nitrogen to succeeding non-legume crops (Oplinger et al. 1990). The authors of a study in Saskatchewan found that nitrogen fixation from lentil grown for a six- to seven-week period reached 26 kg N ha^{-1} (Biederbeck et al. 1996).

2.2.2.2 Performance in cropping systems An experiment conducted by Biederbeck et al. (1996) examined the nitrogen benefits from a number of green manure legumes to a succeeding crop of spring wheat over a period of seven years in southwestern Saskatchewan. Four green manure legumes were selected: Black lentil, Tangier flatpea (*Lathyrus tingitanus* L.), Chickling vetch, and pea. The legumes were grown for a six- to seven-week period, from emergence to full bloom, at which time they were incorporated into the soil with a tandem disc. While the amount of nitrogen fixed by the green manure legumes varied considerably with growing-season weather conditions and legume type, the average amount of nitrogen fixed was 18, 16, 49, and 40 kg N ha^{-1} for black lentil, Tangier flatpea, chickling vetch, and pea, respectively (Biederbeck et al. 1996).

A study conducted by Bremer and van Kessel (1992) examined plant available nitrogen from lentil green manure, lentil straw remaining after lentil harvest, wheat straw and spring-applied fertilizer during a subsequent growing season. It was found that only 7% of the ^{15}N in lentil straw (and wheat straw) from the previous year was mineralized by the time of wheat harvest, while 37% of the ^{15}N in lentil green manure was mineralized. This difference was due to rapid mineralization of plant residues with a low carbon/nitrogen (or C/N) ratio, such as immature whole legume plants, because nitrogen was in excess of what was required for microbial growth of the organisms that are breaking down the residue. On the other hand, plant residues with a high C/N ratio (e.g. straw from mature wheat plants) are mineralized more slowly, as the nitrogen in the residues is retained by the microbial biomass during residue decomposition(Bremer and van Kessel, 1992). Low bioavailability of nitrogen from mature legume straw is the reason green manures are traditionally not allowed to mature; in legume crops such as lentil, the majority of the nitrogen that is fixed from the atmosphere ends up in the above ground portion of the plant (eventually the seed). Harvest would result in much of the nitrogen being removed from the field, and not being made available to subsequent crops.

Bremer and van Kessel (1992) found that denitrification and leaching losses of ^{15}N from lentil green manure, while greater than that from lentil and wheat straw, were approximately 20% lower than occurred with nitrogen fertilizer. As well, the results showed that less ^{15}N from the green manure was absorbed by the following wheat crop than from fertilizer (19% as opposed to 34%). These findings correspond to findings of other researchers, suggesting that only a portion of nitrogen incorporated in legume residue is made available to the following crop, with the rest accounted for by soil organic matter, the inorganic soil nitrogen pool, and denitrification and leaching losses (Hesterman, 1988). With green manure nitrogen being made available to plants less rapidly than nitrogen fertilizer, the nitrogen benefits generally last longer and can be more efficiently utilized (eg. less denitrification and leaching losses).

Green manure as a fallow replacement in drier areas of the Canadian Prairies is becoming increasingly popular. A lentil green manure grown for 8 to 10 weeks can add nitrogen and organic matter to the soil without depleting soil water to the same degree as a full-season crop (Bremer and van Kessel, 1992). A study conducted in southwestern Saskatchewan examined water use by a number of annual green manure legumes. Over a seven-year period, subsoil water after wheat was recharged to only 68% of fallow, but was recharged to 81% of fallow following the green manures (Biederbeck and Bouman, 1994). The earlier the stand is terminated, the less water is used by the legume, leaving more water available for the succeeding crop. If more water is available, the succeeding crops will grow better, and will better be able to make use of the available nitrogen from the legumes. In the drier areas of the Canadian Prairies, a year of fallow has traditionally been used to store water for succeeding crops, despite the loss of soil quality, due to soil erosion that occurs (Biederbeck et al. 1996). Using green manure as a fallow replacement reduces soil erosion, while also adding nitrogen to the soil for subsequent crops to use.

2.2.3 Perennial forage legumes

Perennial forage legumes are a botanical group of legumes that are seeded once and harvested as forage for a period of two or more years. Many studies have reported that the grain yield of non-legume crops are significantly increased by a previous legume crop in rotation (Badaruddin and Meyer, 1989; Entz et al. 1995), and the rotation of seeding a non-leguminous grain crop after a perennial stand of a forage legume is likely the most practiced method utilized to capture nitrogen added to the soil by forage legumes (Hesterman, 1988).

2.2.3.1 Species description Alfalfa has a deep tap root and herbage, which originates from a large crown, that can reach 1.3m in height. Leaflets are serrated on up to one-half of the leaf margin. Alfalfa originated in southwestern Asia and is the most important perennial forage grown in North America. ‘Nitro’ is a non-dormant variety which displays a low degree of winter-heartiness, as it was developed to maximize forage yield and nitrogen fixation in annual alfalfa stands (Sheaffer et al. 1989; Sheaffer, 1993). In studies, “Nitro” alfalfa has been shown to contributed an average of 84 kg N ha^{-1} in Minnesota (Sheaffer et al. 1989), and 121.4 kg N ha^{-1} in Manitoba (Kelner and Vessey, 1995) to the soil in the fall after only one season of growth.

Red clover (*Trifolium pratense* L.), a biennial forage legume, also has a tap root, although it does not penetrate the soil as deeply as that of alfalfa. Stems are pubescent and grow in an upright manner originating from a narrow crown near the soil surface. Red clover originated in Asia/southern Europe, and is the most widely-distributed and important clover crop (Sheaffer, 1993; Smith, 1978). Full season, overwintered red clover can fix between 62 kg N ha^{-1} and 134 kg N ha^{-1} (Clark, 1998).

2.2.3.2 Performance in cropping systems A study conducted in Manitoba found that residual benefits from alfalfa were present for up to 6 years in a continuous wheat rotation, in terms of increased wheat yields and protein levels (Forster, 1999), while the author of another study noted significant yield increases to unfertilized wheat in the thirteenth year after alfalfa termination (Hoyt, 1990). Studies such as these tend to suggest that the nitrogen benefits to the soil provided by forage legumes extend beyond one growing season.

Many producers will leave a forage stand in rotation for relatively long periods of time, with an average forage stand duration of at least 5 years reported on the Canadian Prairies, and will terminate a stand due to cultural reasons (i.e. weed problems, declining forage productivity, pocket gophers) as opposed to rotational considerations (Entz et al, 1995). However, significant nitrogen benefits for subsequent crops could be realized with forage stands of shorter duration. A study conducted in Manitoba by Kelner et al. (1997) examined the nitrogen contribution of shorter-term alfalfa stands (i.e. up to three years in length) to the soil. It was found that the net nitrogen contribution to the soil from two- and three-year stands of alfalfa were 148 kg N ha^{-1} yr^{-1} and 137 kg N ha^{-1} yr^{-1}, respectively. The authors concluded that shorter-term perennial forage legume stands, as short as two years, can have a significant impact on increasing soil nitrogen levels (Kelner et al, 1997).

Having shorter-term forage legume stands in rotation provides not only short-term benefits to the soil, but longer-term benefits as well. A study carried out by McGill et al. (1986) in Alberta examined the long-term effects of different rotations on the proportion of active soil nitrogen after 50 years. Two different rotations were examined: a wheat-fallow rotation, and a 5-year wheat-oat-barley-forage-forage rotation, where the forage stand was a mixture of alfalfa and bromegrass (*Bromus inermis* L.). Both treatments received N, P, K, and S fertilizer, manure, or no fertilizer at all (control). The researchers found that there was 38% more soil nitrogen and 117% more microbial nitrogen in the 5-yr rotation than in the 2-yr rotation after 50 years.

The long-term effects of forage legumes in rotation were also examined in a study conducted in Saskatchewan (Campbell et al. 1991). Rotations included fertilized and unfertilized continuous wheat, fertilized and unfertilized fallow-wheat and fallow-wheat-wheat rotations, and a 6-year unfertilized fallow-wheat-wheat-hay-hay-hay rotation. The hay treatment consisted of an alfalfa and bromegrass mixture that was not fertilized with nitrogen. The change in soil nitrogen concentrations over the 30 years of the study showed that while the fallow-wheat, fallow-wheat-wheat, and unfertilized continuous wheat rotations failed to maintain soil nitrogen levels, the fertilized continuous wheat and fallow-wheat-wheat-hay-hay-hay rotations both increased soil nitrogen levels. These results suggest that including perennial forage legumes can increase the sustainability of cropping systems.

Results such as these are not merely confined to North America. Studdert et al. (1997) conducted a long-term study spanning 18 years in Argentina, which examined the effect of different crop rotations on soil quality and productivity. The researchers examined crop-pasture rotations (the pasture consisting of a mixture of forage grasses and legumes) with cropping:pasture ratios of 50:50 and 75:25, in addition to a number of continuous cropping rotations. Crops grown included spring wheat, potato (*Solanum tuberosum* L.), corn, sunflower (*Helianthus annus* L.), oat, and oat and hairy vetch (*Vicia villosa* Roth) as green manure. Pastures with grass-legume mixtures included orchardgrass (*Dactylis glomerata* L.), bulbous canarygrass (*Phalaris tuberosa* L.) tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass, white clover (*Trifolium repens* L.), red clover and alfalfa. Pastures were kept for two years and four or five years. They found that under six or seven years of continuous cropping, light-fraction carbon (LFC) and microbial biomass nitrogen (MBN) levels fell sharply. By comparison, after a three to five years of pasture, LFC and MBN recovered to the levels that were present in the soil at the start of the crop rotation. LFC and MBN are the most active pools of organic nitrogen, and are responsible for the majority of short-term nitrogen turnover (Studdert et al. 1997), so decreasing levels of LFC and MBN would result in a greater need for nitrogen fertilization. The researchers concluded that rotations containing a maximum of seven years of conventional cropping alternated with a minimum of three years of pasture would maintain LFC and MBN levels in the soil, thereby maintaining nitrogen available for non-legume crops.

2.2.4 Multiple Cropping with Legumes

One way in which to attain the benefits of a legume in rotation, while being able to harvest a grain crop in the same year, is by multiple cropping with legumes. The legume is a secondary crop that is put in place once the primary crop is well-established or harvested. By utilizing the legume nitrogen, nitrogen fertilizer use could be decreased, thereby decreasing commercial energy use within such rotations. In these systems, as with green manures, the legumes are grown primarily as a source of nitrogen for the succeeding non-legume crop, rather than as a hay crop. However, other benefits include slowed soil erosion, improved soil structure and suppression of weeds (Clark, 1998). The advantage of multiple cropping with legumes is that a producer does not have to sacrifice a year of grain cropping, while receiving legume benefits a green manure crop. Three primary ways to achieve this are through mixed intercropping, relay intercropping, and double cropping.

2.2.4.1 Mixed intercropping In mixed intercropping, a legume is seeded in combination with a main, non-legume crop. In experiments where legumes were intercropped with corn, corn grown in the intercropping system had 10 to 75% higher yields than corn grown alone without nitrogen fertilizer. However, corn yield was decreased by 10 to 31% when nitrogen fertilizer was applied both to monocropped and intercropped corn. When corn in the monocrop system was fertilized, corn yield decreases in the unfertilized intercropped system ranged from 30 to 54% (Triplett, 1962; Nordquist and Wicks, 1974; Scott et al. 1987). A study conducted in North Dakota in 1992 and 1993 examined the effect on sunflower yield of different planting times for five intercropped legumes: hairy vetch, yellow-flowered sweetclover [*Melilotus officinalis* (L.) Lam.), alfalfa, snail medic [*Medicago scutellata* (L.) Mill.], and black lentil. The legumes were sown on the same day as sunflower planting, 29 days after planting (emergence of fourth true sunflower leaf), and 46 days after planting (emergence of tenth true sunflower leaf). With the exception of black lentil, legumes reduced sunflower seed yield when sown at the same time as the sunflowers, due to competition from the legumes. However, when the legumes were intercropped with the sunflowers at the four- and ten-leaf stages, sunflower yields were not significantly lowered compared to the control treatment (Kandel et al. 1997). A study conducted in eastern Texas from 1983 through 1985 examined the effect of interseeded clover on wheat yield. The researchers found that in the first year of the system, wheat yields where clover was interseeded was only 47% to 71% of the yield in the control treatment. However, in the second year, wheat yields where clover was interseeded was 25% to 79% greater than the wheat yield in the control treatment. These variations in wheat yields were attributed to differences in legume stand density (Brandt et al. 1989). An Iowa study examined the influence of three interseeded soybean varieties on corn yields during the year of interseeding and the following year. The researchers found that during the year when soybeans were intercropped with corn, corn yields at three sites were not affected, while corn yields were reduced by an average of 8% at the other two sites. Second-year corn yields were increased by soybean interseeding an average of 12% at three of the five sites. However, when corn yields from both years were considered, there was a statistically significant yield increase from the soybeans at one of the five sites (Sundberg and Shibles, 1991). These results show that where grain production is the primary objective, mixed intercropping systems should not be used due to variability of both the grain yields in the year of interseeding and the benefits to succeeding crops.

2.2.4.2 Relay intercropping Relay intercropping is defined as a system in which there are two crops in the field at the same time for a portion of the growing season (Fig. 2-1). A second crop, or relay crop, is seeded directly into the established first crop. In North America, the first crop has typically been a winter cereal. Winter cereals are harvested approximately two weeks to one month earlier than spring cereals, allowing for a greater window of opportunity for a second crop to make use of available resources remaining in the growing season. On the Canadian prairies, the winter cereal is seeded in early September for winter wheat and fall rye (*Secale cereale* L.). The relay crop is then no-till planted or broadcast seeded into the winter cereal in early spring. The relay crop, while well established, will not usually grow very large under the first crop, due to limitations to light, water and nutrient sources imposed by the larger first crop. However, once the first crop has been harvested, the relay crop will begin to grow rapidly, as there will no longer be a cereal crop utilizing these resources (Moomaw et al. 1991a). In more southerly parts of the United States, it is possible to grow a grain or oilseed crop, such as soybeans, for harvest as the relay crop (Moomaw et al. 1991a). However, the shorter growing season on the Canadian Prairies does not allow for two grain crops to be harvested in one season. By planting a legume as the relay crop, nitrogen would be added to the soil for subsequent crops to use (Samson et al. 1991).

In a Michigan study, different cultivars of alfalfa and red clover were relay cropped into winter wheat in spring, and were succeeded by corn the following growing season. The fertilizer replacement values of the legumes to a succeeding corn crop ranged from 32 to 51 kg N ha^{-1} for alfalfa and from 50 to 108 kg N ha^{-1} for red clover, depending on site and cultivar. When soil water was adequate, corn grain yields following the winter wheat with the legume relay crop were 4 to 62% greater than corn yields following winter wheat only. When precipitation levels were below normal, corn yields in the legume system were reduced by 3 to 27% (Hesterman et al. 1992). Another Michigan study examined the effect of relay intercropping burr medic (*Medicago polymorpha* L.) and snail medic legumes with corn. The fertilizer replacement values of the medics to a succeeding corn crop ranged from 13 kg N ha^{-1} to 37 kg N ha^{-1} (Jeranyama et al. 1998). In a study in Manitoba, Thiessen Martens et al. (2000) found that "Nitro" alfalfa relay cropped into winter wheat contributed up to 62 kg N ha^{-1} to the soil for a subsequent oat crop. A study conducted in New Mexico examined the effect of relay intercropping hairy vetch, barrel medic (*Medicago truncatula* Gaertn), alfalfa, black lentil and red clover with corn. The fertilizer replacement values to a succeeding sorghum crop from alfalfa and hairy vetch ranged from 78 kg N ha^{-1} to 140 kg N ha^{-1}, and ranged from 10 kg N ha^{-1} to 72 kg N ha^{-1} for the barrel medic, red clover and black lentil (Guldan et al. 1997). An Ontario study which ran from 1994 through 1996 examined the effect of red clover underseeded in wheat to a succeeding corn crop. All treatments received 155 kg N ha^{-1}, which is the recommended fertilizer rate for corn production in southwestern Ontario. However, after fertilizer had been added, no-till corn yields in the relay crop system were 5% higher than following monocrop wheat (Drury et al. 1999).

2.2.4.3 Double cropping Double cropping is defined as a cropping systems in which there are two crops grown in succession in the same field in the same season; there is no overlap between the two crops as there is with relay intercropping (Fig. 2-1). As with relay cropping in cooler temperate zones, the first crop seeded is usually a winter cereal, in order to allow the second crop to capture more heat and water (Moomaw et al. 1991b). In a Kentucky study, legumes were broadcast seeded into a standing corn crop shortly before harvest, closely approximating a true double cropping system (Blevins et al. 1990). The legumes, hairy vetch, and bigflower vetch (*Vicia grandiflora* W. Koch), germinated and grew for the

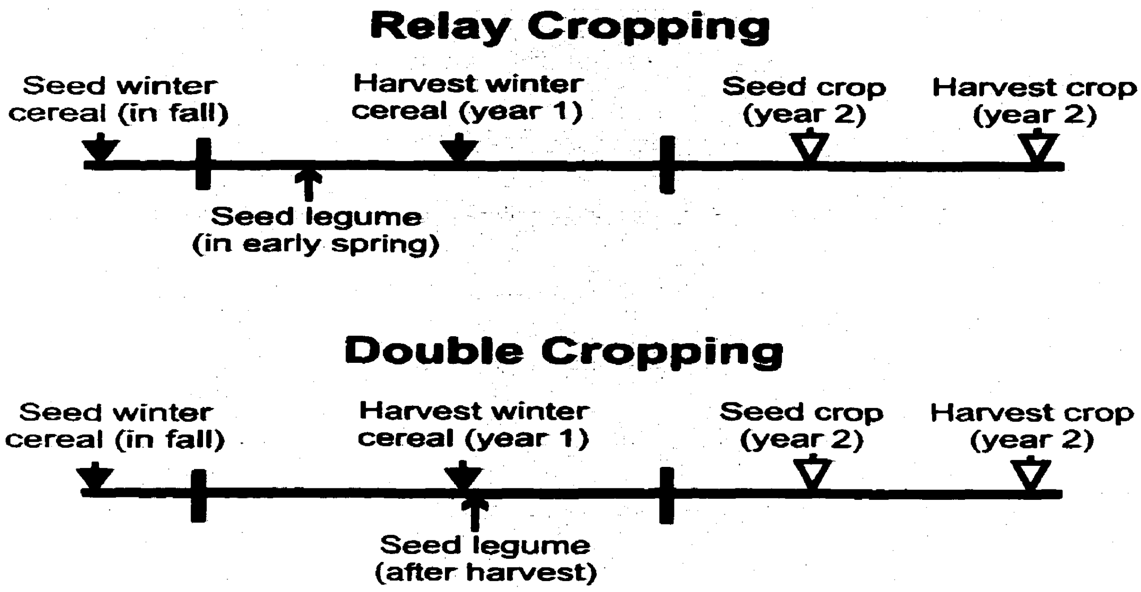

Fig. 2-2. Time line of legume multiple cropping systems

remainder of the growing season. In spring, the legume stands were terminated with herbicides, and corn and sorghum were seeded using a no-till seeder. The estimated fertilizer replacement value(FRV) for hairy vetch were 75 kg N ha^{-1} in a succeeding crop of corn, while the estimated fertilizer equivalency value for bigflower vetch were 65 kg N ha^{-1} in the corn (Blevins et al. 1990). A study conducted in North Carolina examined the effect of double cropping crimson clover (*Trifolium incarnatum* L.) and hairy vetch after corn. Nitrogen contribution to a succeeding corn crop was estimated at 40 kg N ha^{-1} to 45 kg N ha^{-1} for the two legumes, averaged over two years (Wagger, 1989). A study conducted in Maine examined the effect of double cropping a mixture of hairy vetch and winter rye after barley. The nitrogen FRV to a subsequent corn crop ranged from 120 kg N ha^{-1} to 151 kg N ha^{-1} (Griffin et al. 2000). While the values described here may be higher than what could be expected on the Canadian Prairies, due to the shorter growing season, double cropping forage legumes on the Canadian Prairies should still add nitrogen to the soil for subsequent non-legume crops to use.

2.3 Fertilizer Replacement Value

Estimates of the amount of nitrogen added to the soil by legumes, or the nitrogen credit (N-credit), have varied considerably over the years with region and climate (Ding et al. 1998). Some estimates of nitrogen credits provided by legumes included -32 to 96 kg N ha^{-1} from pea (Beckie and Brandt, 1997; Ledgard and Giller, 1995) harvested for grain, 18, 16, 49 and 40 kg N ha^{-1} for black lentil, Tangier flatpea, chickling vetch and pea, respectively (Biederbeck et al. 1996) grown as green manure crops and 137 kg N ha^{-1} for a three-year alfalfa stand (Kelner et al. 1997).

A common method of determining the N-credit from legumes to a subsequent non-legume crop is known as fertilizer replacement value (FRV) (Fig. 2-2). Nitrogen FRV is defined as the quantity of fertilizer nitrogen required to produce a yield in a crop that does not follow a legume that is identical to that produced by incorporation of a legume (Hesterman, 1988). When determining FRV, a non-legume test crop is seeded onto land that did and did not have legumes during the previous year. Where legumes were not present, the test crop is fertilized with a number of nitrogen fertilizer rates. A fertilizer response curve is created using the yield responses to the incremental rates of nitrogen fertilizer to create a response surface (Ding et al. 1998). The yield of the test crop seeded where legumes were present is fitted to the equation in order to calculate the nitrogen FRV of the legume.

Calculating the FRV in the previously described manner assumes that all yield

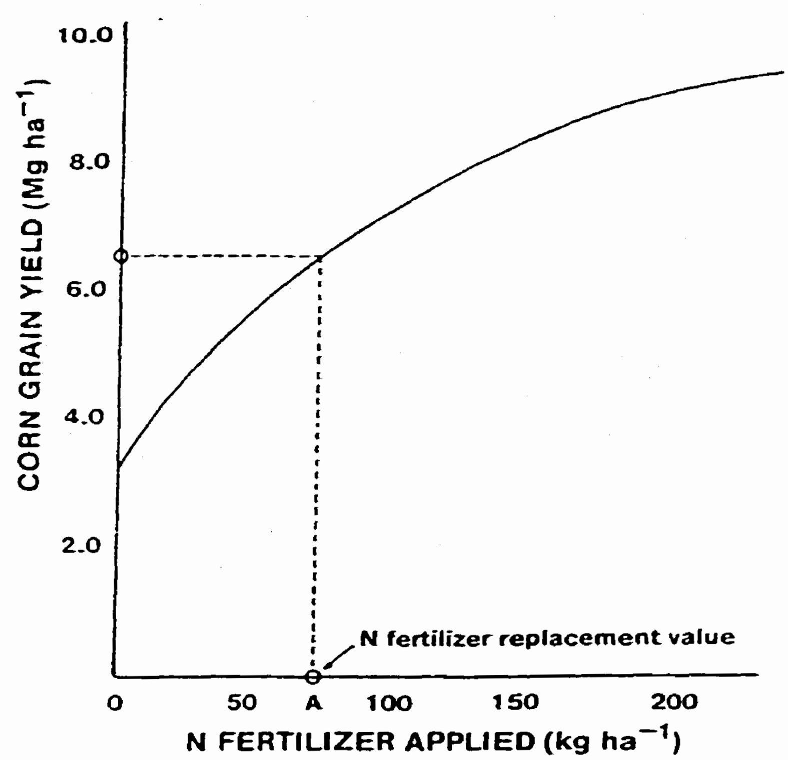

Fig. 2-3. Typical N-fertilizer response curve with N-fertilizer replacement value example (point A) where corn yield following the legume = 6.5 Mg ha^{-1} (Hesterman, 1988).

benefits to the subsequent non-legume crop are due to the addition of nitrogen. In fact, including legumes in a crop rotation provide numerous other benefits to subsequent crops (Spratt, 1966; Hoyt and Leitch, 1983; Badaruddin and Meyer, 1989; Entz et al. 1995) that can contribute to increases in yield. Therefore, the FRV term can be somewhat misleading. Taking this into account, sometimes FRV is calculated using the difference method (Fig. 2-3), in which the economic nitrogen rate of the non-legume crop grown in the rotation is compared with that of a continuously cropped non-legume (Lory et al. 1995). However, while the beneficial factors of legumes outside of nitrogen are taken into consideration, the benefit to subsequent crop yields is measured in terms of the equivalent amount of nitrogen fertilizer that would be needed to achieve the same yields. This is because much of the benefit of legumes is due to nitrogen addition to the soil, and it is easiest to quantify the benefits in terms of kg ha^{-1} of nitrogen.

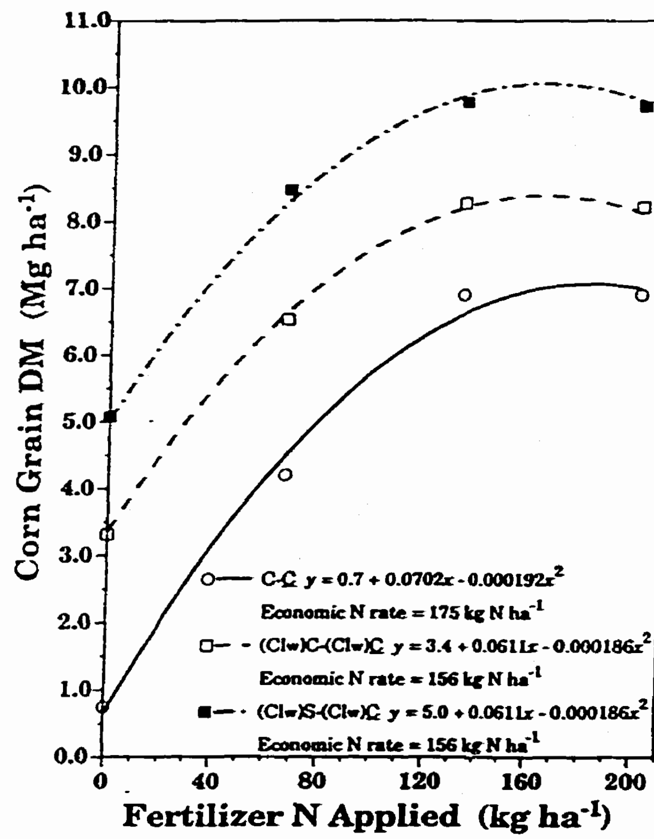

Fig. 2-4. Fertilizer N response of continuous corn (C-C), continuous corn with winter cover crop of crimson clover [(Clw)C-(Clw)C], or corn in a soybean-corn rotation with winter crops of crimson clover [(Clw)S-(Clw)C] (Oyer and Touchton, 1990).

2.4 Prairie Climate, Soil Zones and Cropping Systems Opportunities

There are several major agronomic factors that influence crop rotations and legume performance. Two of the most important are climate and soil type.

2.4.1 Climate

There is a wide range in average climatic conditions across the Canadian Prairies. Average annual precipitation levels range from 513 mm at Winnipeg, MB in the eastern prairies, to 427 mm at Indian Head, SK in the central region of the Prairies, to 334 mm at Swift Current, SK and 413 mm at Lethbridge, AB. Precipitation levels are also generally higher in the northern portions of the prairies. In southern Alberta, Lethbridge receives an average of 413 mm of precipitation, while in northern Alberta, Beaverlodge receives an average of 467 mm annually (Campbell et al. 1990; Environment Canada, 1999).

Temperature also varies across the Canadian Prairies, generally increasing from east to west. Average annual temperature ranges from 2.1°C at Winnipeg, MB in the eastern Prairies, to 2.0 °C at Indian Head, SK in the central region of the Prairies, to 3.3 °C at Swift Current, SK and 5.0 °C at Lethbridge, AB in the west. Temperature decreases from south to north. In southern Alberta, the average annual temperature at Lethbridge is 5.0 °C, while in northern Alberta, the average annual temperature at Beaverlodge is 1.6 °C (Campbell et al. 1990; Environment Canada, 1999).

As a result of climate variation, different legume recommendations will be made in different regions. For example, perennial forage legumes would be appropriate to include in a rotation in areas that receives adequate rainfall, such as central Alberta or south-central Manitoba. However, green manure legumes would be a more appropriate choice for a crop rotation in dryland regions, such as southern Alberta and southwestern Saskatchewan. This variation in climate also affects the appropriateness of including legumes as relay intercrops and/or double crops in a rotation. After harvesting winter wheat, which requires 1143 growing-degree-days (GDDs) from spring to harvest (Thiessen Martens and Entz, 2000), an average of 754 GDDs (base temperature of 5°C) and 152 mm of precipitation remain in the growing season at Morden, MB. By comparison, Arborg, MB has, on average, only 370 GDDs and 118 mm of precipitation, while Lethbridge, AB has 566 GDDs, but only 84 mm of precipitation remaining after winter wheat harvest (Thiessen Martens and Entz, 2000). This suggests that sufficient heat and water remain after winter wheat harvest to successfully use legumes as relay intercrops and double crops at Morden, in south-central Manitoba. However, while receiving adequate precipitation, Arborg, located in the Interlake region of Manitoba, does not receive enough heat. Conversely, Lethbridge, located in southern Alberta, while receiving adequate heat, is likely too dry for relay intercropping and double cropping to be a viable option.

2.4.2 Soil type

Another environmental factor that should be considered when selecting a legume management system is soil characteristics. Soil type affects water availability for plants. Fine-textured soil, such as a heavy clay soil, will store more water than will a coarse-textured soil, such as a sandy soil . As moisture is often the most limiting factor in crop production on the Canadian Prairies (Campbell et al. 1990), appropriate legumes for the soil type in question should be chosen.

Of the approximately 30,000,000 ha of cultivated land on the Canadian Prairies, approximately 50% is located in the Black and Dark Gray soil zones, 27% in the Dark Brown soil zone, and 23% in the Brown soil zone (Campbell et al. 1986; 1990). The Brown and Dark Brown soil zones occupy the south-western and south-central portions of the Prairies.

The average depth of the soil surface layer is 12.5 cm and 7.5 cm for the Brown and Dark Brown soil zones, respectively, while organic matter content of these soils is about 2% and 4%, respectively, for the Brown and Dark Brown soils (Campbell et al. 1990). The soil in these zones is of a medium texture, and the Dark Brown soils are more level in topography than the Brown soils. Wind erosion and moisture deficits are serious problems for these soils, but are less of a problem in the Dark Brown soil zone.

The Black soil zone dominates the eastern portion of the Canadian Prairies, in the parkland and true grassland areas. The average depth of the surface layer is 20-25 cm, and the soil organic matter level is approximately 7%. The soil is mostly medium textured and the land is mainly level (Campbell et al. 1990).

The Gray Brown and Gray Luvisolic forest soils occur in the transitional areas of grassland and forests, north of the Black soil zone. These soils generally range in organic matter content from 1% to 10%. Wind erosion is not a serious problem, but water erosion is a major concern (Campbell et al. 1990). Selecting a legume that is suited to a specific soil zone (e.g. utilizing a legume with lower levels of water use in the Brown and Dark Brown soil zones, where moisture deficits pose serious problems) can aid in ensuring that soil improvement benefits from legumes can be optimized.

2.5 Tillage Management of Legumes in a Crop Rotation

Tillage operations (e.g. using cultivators, plows, etc.) can influence legume performance and energy efficiency. For example, if a zero-tillage management system is utilized, then a legume that will be more susceptible to herbicides at the time of termination should be selected to minimize energy expenditures. This section will examine factors such as this in more detail.

2.5.1 Tillage effects on energy use

Weed control in Prairie crop production is achieved through the use of tillage and/or herbicides. Using herbicides to control weeds as opposed to tillage, as is the case in a zero-tillage system, can result in lower levels of energy use and improved levels of energy use efficiency. More energy is required to use a cultivator (11 m wide) once for primary tillage on hard or clay soils and clay loam soils than for one application of 65% and 56%, respectively, of the herbicides used in western Canadian crop production (Nagy, 1999).

Clements et al. (1995) studied energy expenditure of tillage and herbicide inputs in alternative weed management systems in Ontario. The authors examined 12 farms and found that eliminating tillage improved energy use efficiency more than eliminating herbicide use. In addition, the two farms that used only herbicides had the lowest energy budgets for weed control (Clements et al. 1995). These findings suggest that energy use of cropping systems can be effectively decreased by reducing the number of tillage operations.

2.5.2 Tillage effects on soil porosity

Tillage management systems can substantially affect soil porosity, which has a profound influence on water movement and potential soil productivity. Numerous studies have found, with the exception of fine-textured soils, that bulk soil density is decreased in a zero-tillage management system (Blevins et al. 1985). As bulk soil density decreases, soil porosity increases. For a given soil texture, the higher the degree of soil porosity, the greater water infiltration will be, resulting in soils that are able to store more water for use during drier periods (Blevins et al. 1985; Allmaras et al. 1991). Efficient use of soil water is an especially important consideration on the Canadian Prairies, as moisture is the factor that is generally the most limiting to crop production (Campbell et al. 1990). This is important for energy efficiency of cropping systems, for as crop yields are increased, so to can energy efficiency, if the factor that is changed does not require large amounts of energy.

2.5.3 Tillage effects on soil nitrogen

One area of interest that has arisen with regards to tillage effects on legumes is how nitrogen fixation by the legumes is affected. In one of the few studies to consider tillage effects on nitrogen fixation by legumes on the Prairies, Matus et al. (1997) observed that nitrogen fixation by lentil and pea in a zero-tillage system was 10% and 31% greater, respectively, than when grown in a conventional tillage system. The authors speculated that higher nitrogen fixation under zero-tillage was due to three main factors related to nitrate availability in the soil. Firstly, soil cultivation stimulates mineralization of soil organic matter, which results in higher concentrations of nitrate in tilled soils as compared to zero-tillage soils; this accumulated nitrate represses nitrogen fixation. High concentrations of inorganic nitrogen in soil can inhibit root-hair infection, nodule growth and development, as well as nitrogen fixation itself (Ledgard and Giller, 1995). Therefore, lower levels of inorganic soil nitrogen associated with zero-tillage systems are more favourable for higher levels of nitrogen fixation by legumes. Secondly, under zero-tillage, the populations of aerobic microorganisms in the rooting zone are lower than in conventional tillage systems (Power and Doran, 1988). Lower populations of microorganisms in the rooting zone result in slower turnover of organic matter, which results in lower levels of soil nitrates. Thirdly, zero-tillage retains crop residues on the soil surface, often resulting in lower levels of available soil nitrogen in the rooting zone as compared to conventional tillage (Power and Doran, 1988; Matus et al. 1997).

Tillage can also affect the availability of legume nitrogen to subsequent crops. It has been well documented for many years that legumes contribute fixed nitrogen to subsequent crops, but it is only recently that researchers have examined the effects that tillage systems may have on that legume nitrogen. Soil organic nitrogen levels are enhanced by returning crop residues to the soil (Power and Doran, 1988), especially from the residues of terminated legumes (Mohr et al. 1998). In western Canada, forage legumes are terminated using tillage, herbicides, or a combination of the two (Entz et al. 1995). It is known that tillage speeds up decomposition of legume residues and mineralization of nitrogen contained in the residue (Frye et al. 1988). In one controlled environment study, soil-incorporation of vetch residues resulted in mineralization of 51% of residue N after 35 days, while only 36% of residue nitrogen was mineralized over the same time period where vetch residues were surface-applied (Aulakh et al. 1991). However, a number of studies have found that differences in nitrogen mineralization tend to be greatest within 30 days of residue application, and decline afterwards (Mohr, 1997; Varco et al. 1989; Wilson and Hargrove, 1986). As a result, studies have been undertaken to determine the effect of tillage on nitrogen availability from legume residues to subsequent crops. One such laboratory study examined the fate of symbiotically-fixed $^{15}N_2$ in alfalfa as influenced by method of crop termination (Mohr et al. 1998). Thirty-three days after alfalfa termination, 1% of ^{15}N present was recovered in the aboveground biomass of succeeding barley plants, 8% in the soil and 91% in alfalfa residues in the herbicide (zero-tillage) treatments, while 10% of ^{15}N present was recovered in barley aboveground biomass, 52% in soil and 38% in alfalfa residues in the tillage treatments (Mohr et al. 1998).

In follow-up field experiments, Mohr et al. (1999) examined plant-available nitrogen supply as affected by method of alfalfa termination. Alfalfa was terminated using either tillage or herbicide (glyphosate) and no tillage; wheat was established after termination. In three of the four experiments, plant-available nitrogen in the spring after termination was higher in the tilled treatments than in the treatments receiving only herbicides, but by the fall of the second growing season after termination, differences in cumulative plant-available nitrogen supply between treatments were no longer observed. Wheat yields in the herbicide treatments were similar to or greater than those in the tillage treatments, despite lower levels of plant-available nitrogen in the spring. Tillage accelerates mineralization of alfalfa residues, resulting in a larger soil inorganic nitrogen pool the following spring. However, there was still sufficient mineralization of legume residues to provide enough nitrogen to the subsequent wheat crop to allow for similar yields, as compared to the treatments where tillage was the termination method (Mohr et al. 1998, 1999). The results suggest that more nitrogen is lost from the system when tillage is the termination method, as opposed to using herbicides, and that nitrogen release from alfalfa residues and nitrogen requirements of a wheat crop are more closely matched when using herbicides to terminate alfalfa, thereby reducing nitrogen losses and improving nitrogen use efficiency, and improving energy use efficiency (Mohr et al. 1999).

2.5.4 Tillage effects on soil water

In addition to affecting nitrogen fixation and nitrogen availability from legume residues to subsequent crops, tillage may also affect water availability to subsequent crops. A study conducted by Bullied and Entz (1999) in south-central Manitoba examined the effect of alfalfa stand termination method on soil water recharge, as well as on the establishment, growth and water use efficiency (WUE) of a succeeding spring wheat crop. The alfalfa termination treatments consisted of herbicide (glyphosate), tillage (four chisel plow and two tandem disc operations), and herbicide plus delayed tillage (glyphosate followed approximately 30 days later with two passes with a tandem disc) at a number of times throughout the season. Results showed that the herbicide treatments had greater late season soil water recharge and conservation, as compared to both the tillage and herbicide plus tillage treatments in the period of time from stand termination to late fall of the first season. The authors also found that overwinter soil water recharge was greater in the herbicide treatments. With respect to the subsequent spring wheat crop, treatments where the alfalfa was terminated with herbicide resulted in higher water use efficiency of the wheat and higher grain yields, as compared with treatments involving tillage.

While the benefits of growing perennial forage legumes in a zero-tillage management system have been well documented, their termination may be more difficult than in a conventional tillage system. It is important to achieve proper termination, in order that yields of the succeeding crop does not suffer as a result of competition from remaining legume plants. Bullied et al. (1999) examined no-till alfalfa termination strategies in southern Manitoba and found that herbicide could be used successfully for termination. However, the only herbicide treatment that consistently provided similar alfalfa suppression to tillage was a high rate of glyphosate. The high rate of glyphosate used in this study was four times the recommended rate (Manitoba Agriculture, 1998) for normal weed control, indicating that termination of perennial forage legume stands may prove to be a challenge in no-till systems.

These results suggest that using herbicide as a method of forage legume stand termination can further extend the benefits of including forage legumes in a crop rotation, as well as maintaining soil water levels and soil quality. This, in turn, will increase crop yields, which will also increase energy production and energy efficiency of cropping systems.

2.6 Redesign of Cropping Systems to match Farm and Economic Structures

While tillage regime and environmental conditions will factor into the decision of how to incorporate legumes into a crop rotation, it is the ability of a legume to fit into the farming system, and economic factors that will be the deciding factors. For example, if a producer does not have access to forage cutting and baling equipment (Higgs et al. 1990), or a viable market for selling harvested forage crops, then it may prove too difficult to produce perennial forage legumes. In fact, the single most likely reason for why producers accept or reject a particular crop rotation is the price margin. The low cost of purchased inputs tends to favour their use, replacing more traditional methods, such as including legumes in rotation (Clark and Poincelot, 1996). However, as prices of energy and nitrogen fertilizer continue to increase, crop rotations containing legumes may once again become cost effective (Heichel, 1978). The realized net income of Canadian producers as a percentage of farm cash receipts declined by approximately 60% from 1974 to 1990 (Clark and Poincelot, 1996), which has led to increased interest in agriculture that is less dependent on non-renewable energy, such as including legumes in rotation. In addition, certain market forces (i.e. increasing market for organic foods) have provided another incentive to include legumes in a crop rotation. In the past, it was easier, more profitable, and more convenient to replace the services provided by legumes (i.e. nitrogen benefit; breaking of disease, insect, and weed cycles, etc.) with biocides and fertilizers. However, as problems associated with these technology-based inputs came under increasing scrutiny, and as profit margins narrowed, producers began searching for alternatives. For increasing numbers of producers, crop rotations containing forage, green manure or multiple cropped legumes provide a way to not only increase profitability but to achieve greater harmony with the surrounding environment (Clark and Poincelot, 1996).

2.7 Conclusions

After reviewing the relevant literature on the subject, it is quite clear that the inclusion of legumes in a crop rotation can decrease total rotational non-renewable energy use, and maintain or increase rotational energy efficiency, as compared to continuous grain cropping. The production of inorganic nitrogen fertilizer requires more energy to be expended than for any other aspect of crop production. Legumes fix nitrogen, reducing or negating the need for addition of inorganic nitrogen fertilizers in years they are present in a rotation. Legumes, especially those that are grown as perennial forages, green manures, and multiple crops, can provide substantial amounts of nitrogen to the soil for subsequent non-legume crops to utilize, further reducing the need for inorganic nitrogen fertilizers in the cropping system. Including legumes in a cropping system appears to decrease energy use and increase energy efficiency. However, there remain a number of outstanding issues.

Firstly, while there has been research conducted on non-renewable energy use and efficiency of cropping systems, little of it is current. The majority of the relevant research into energy use and efficiency of crop production was conducted during the energy crisis of the late 1970's and early 1980's, and the majority of that work was conducted in the United States. More research on energy in grain production needs to be conducted, especially in western Canada. Perhaps if oil and gas prices continue to rise as they have during the recent past year, more energy research in agriculture will be conducted, as was the case during the last energy crisis.

Secondly, more research which examines the effect of climate and soil zone on legume performance is needed. If legumes are to play an important role in decreasing non-renewable energy use and increasing energy efficiency in crop production on the Canadian Prairies, more work on how climate and soil type affect legume performance is required.

Thirdly, more research needs to be conducted with novel legume systems, in order to encourage more producers to include legumes in crop rotations. In particular, legumes suited to multiple cropping on the Prairies need to be examined, what regions are best suited to these systems, and how these systems affect non-renewable energy use and efficiency, in Western Canada. As cropping systems have changed on the Prairies, so to must the legumes utilized in order to compliment these cropping systems.

3. Effects of Green Manure and Perennial Forage Legumes on Non-Renewable Energy Use Efficiency In Western Canadian Crop Rotations

3.1 ABSTRACT

Inputs such as machinery, fuel, pesticides and fertilizers contribute to energy expended in cropping systems. Reducing non-renewable energy use (EU) and increasing energy use efficiency (EUE) can make cropping systems more sustainable. Nitrogen benefits of legumes to succeeding non-leguminous crops are well documented. This study examined the effect of green manure and perennial forage legumes on energy efficiency of crop production for four western Canadian crop rotation studies: Lethbridge, AB; Swift Current, SK; Indian Head, SK; Glenlea, MB. Relative to continuous grain rotations, rotations containing 50% perennial forage legumes decreased EU by up to 85% and increased EUE by up to 438%. Relative to cereal, pulse and oilseed rotations, they reduced EU by up to 28% and increased EUE by up to 294%. Unfertilized rotations containing green manure legumes decreased EU by up to 65%, and increased EUE by up to 196%. Fertilized rotations containing green manure legumes, while decreasing EU by 26%, did not affect EUE. The contribution of legumes to decreased levels of energy use was nitrogen addition to the soil. Economic performance of rotations containing green manure legumes were comparable to rotations containing fallow, but were not as profitable as annual grain rotations at Lethbridge, AB and Swift Current, SK. Economic performance of rotations containing perennial forage legumes were not as profitable as fertilized continuous grain rotations at Indian Head, SK, but were more profitable when compared to continuous cropping rotations in south-central Manitoba.

3.2 INTRODUCTION

During the latter part of the 20th century, there has been much discussion and interest with respect to the environment, and the impact of humans upon it. Throughout recent history, human activity has had a great impact, often detrimental, on the environment. This detrimental impact has occurred especially with regard to the use of non-renewable energy sources, particularly fossil fuels. The burning of fossil fuels has resulted in large amounts of pollutants being released into the atmosphere, while the fossil fuel shortages of the early 1970's forced people to examine modern industrialized systems. Agriculture was criticized for being 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 the energy use efficiency of agricultural production.

An energy budget calculates how much energy is being produced and consumed by the farm. The energy requirements to produce machinery, fertilizers, and pesticides have been determined, as well as how much fuel energy is required to carry out the various field operations. In addition, researchers have calculated feed energy content for the different crops. These energy coefficients can be used to calculate the energy use efficiencies of different agricultural production systems.

Mineral fertilizer accounts for largest proportion of energy expended in crop production (up to 70%), while the amount of commercial energy devoted to mineral fertilizer accounted for by nitrogen is nearly 90% (Stout, 1990). When considering 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; Tran and Giroux, 1998), it is apparent that a great deal of energy expended in crop production is lost through the inefficiency of nitrogen fertilizer.

Including legumes in a crop rotation has been shown to reduce energy requirements of the cropping system in a variety of ways. Firstly, and most importantly, legumes fix atmospheric nitrogen, so they do not require inorganic nitrogen fertilizers. Legume residue 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); this management practice was commonplace for the replacement of nitrogen in cropping systems until the arrival of commercial nitrogen fertilizers (Heichel and Barnes, 1984), which led to a dramatic decrease in the utilization of legumes in rotation. Secondly, including 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 (Higgs et al. 1990), and weeds such as wild oats that are problems in monocultures are much better controlled in rotations containing forage legumes (Ominski et al. 1999). The objective of this study was to examine the effectiveness of green manure and perennial forage legume crops in reducing the use of non-renewable energy inputs in rotation, and increasing energy use efficiency of cropping systems, as a result of decreased nitrogen fertilizer requirements.

3.3 MATERIALS AND METHODS

3.3.1 Background

A series of crop rotation experiments were utilized to study the effect of perennial forage and green manure legumes on the overall energy use and energy efficiency of western Canadian cropping systems. Field experiments from four sites were used: Agriculture and Agri-Food Canada research centres located at Lethbridge, Alberta, Swift Current, Saskatchewan, and Indian Head, Saskatchewan, and at the University of Manitoba research station situated at Glenlea, Manitoba.

3.3.1.1 Green Manure Legume Experiments

A crop rotation experiment was initiated in 1951 at the Agriculture and Agri-Food Canada research station at Lethbridge, AB (49° 42'N, 112° 50'W) on a Lethbridge clay loam soil (Orthic Dark Brown Chernozem). Four crop rotations from this study were examined: a three-year fallow-wheat-wheat rotation that did not receive nitrogen fertilizer [F-W-W(-N)], a three-year fertilized fallow-wheat-wheat rotation (F-W-W), a fertilized continuous wheat rotation (contW), and a three-year green manure-wheat-wheat rotation [GM-W-W (-N)]. The green manure crop sown was 'Indianhead' lentil, and 'Katepwa' was the variety of wheat sown. The GM-W-W (-N) rotation was added to the experiment in 1985. The treatments were arranged in randomized complete block design with all rotational phases present every year in each of four replicates. Plot size was 3.2 m × 36.6 m (Bremer et al. 1994). Six years of data, from 1989 through 1994, were examined in this study.

Phosphorous fertilizer was applied as mono-ammonium phosphate (11-52-0) at 50 kg P_2O_5 ha^{-1} to wheat with the seed in all treatments since 1985, with the exception of 1993, when 30 kg P_2O_5 ha^{-1} was applied. Nitrogen fertilizer was applied as ammonium nitrate (34-0-0) at 80 kg N ha^{-1} to wheat in the contW and F-W-W rotations with the seed since 1985, with the exceptions of 1989, when 90 kg N ha^{-1} was applied, and 1994, when 50 kg N ha^{-1} was applied. The F-W-W (-N) and GM-W-W (-N) rotations did not receive nitrogen fertilizer, other than the 5 kg N ha^{-1} or less contained in the phosphorous fertilizer (Bremer et al., 1994).

In 1989 and 1990, plots were sprayed two weeks prior to seeding to control weeds with 1.5 L ha^{-1} of 2,4-D and 2.2 L ha^{-1} of paraquat, respectively. Weed control in fallow treatments was achieved with a combination of tillage and a variety of herbicides. All field operations were performed using small commercial farm equipment (Bremer et al., 1994).

Wheat and lentil crops were seeded in late April or early May, into a prepared seedbed, which had been cultivated or disced the day of seeding, or a few days beforehand. Wheat was seeded at 60 kg ha^{-1} using a hoe drill seeder, while lentil was seeded at 40 kg ha^{-1} using a disc drill seeder. Wheat crops were sprayed in late May to mid-June in 1989 to 1992 and 1994 to control weeds using a variety of herbicides; no in-crop spraying occurred in 1993. Wheat crops were also hand-weeded in 1994. The lentil crop was terminated with tillage or herbicides in June or July, depending on when the legumes had reached the flowering stage. Grain yields of wheat were determined each year by harvesting a portion of each plot with a small combine (Bremer et al. 1994).

A crop rotation experiment was initiated at the Agriculture and Agri-Food Canada research station at Swift Current, SK (50° 16'N, 107° 44'W) in 1987. This study is situated on a Swinton silt loam soil (Orthic Brown Chernozem) (Biederbeck et al. 1996). Three crop rotations from this study were examined: a continuous wheat rotation (contW), a three-year fallow-wheat-wheat rotation (F-W-W), and a three-year green manure-wheat-wheat rotation (GM-W-W). The green manure crop was 'Indianhead' lentil, and 'Leader' was the variety of wheat sown. The treatments were arranged in a randomized complete block design with all rotational phases were present every year in each of three replicates . Plot size was 6.75 m ×18 m (Biederbeck et al. 1993). Nine years of data, from 1987 through 1995, were examined in this study.

Phosphorous fertilizer was applied as mono-ammonium phosphate (11-52-0) at 15 kg P_2O_5 ha^{-1} to 23 kg P_2O_5 ha^{-1}, depending on soil test recommendations, to wheat and legume treatments with the seed in all treatments. Nitrogen fertilizer was applied as ammonium nitrate (34-0-0) to wheat in all rotations with the seed at rates of 0 kg N ha^{-1} to 66 kg N ha^{-1}. Weed control in fallow treatments was achieved with a combination of tillage and a variety of herbicides. All field operations were preformed using small commercial farm equipment.

Crops were seeded in late April or early May using a disc drill. Crops were seeded into a prepared seedbed, which had been cultivated or disced a few days beforehand. Wheat was seeded at 60 kg ha^{-1}, and lentil was seeded at 40 kg ha^{-1}. Herbicides were applied as required for in-crop weed control. The lentil crop was terminated by herbicides and tillage in June or July, depending on when the legumes had reached the flowering stage. Grain yields of wheat were determined each year by harvesting a portion of each plot with a small combine.

3.3.1.2 Perennial Forage Legume Experiments

A crop rotation study was initiated in 1958 at the Agriculture and Agri-Food Canada experimental farm at Indian Head, SK (50° 53'N, 103° 66'W) on an Indian Head heavy clay soil (Rego Black Chernozem) (Zentner et al. 1987). Three crop rotations from this study were examined: a fertilized continuous wheat (cultivars of hard red spring wheat changed periodically to correspond to recommended cultivars that were used in the area) rotation (contW), an unfertilized continuous wheat rotation [contW(-f)], and a 6-year unfertilized fallow-wheat-wheat-hay-hay-hay [F-W-W-H-H-H (-f)], or perennial, rotation, where the hay crop was a mixture of alfalfa (cv. common) and bromegrass (cv. common) in 1993 and 1994, and alfalfa in 1995 through 1998. The treatments were arranged in randomized complete block design with all rotational phases present every year in each of four replicates. Plot size was 4.5 m × 33.5 m. Six years of data, from 1993 through 1998, were examined in this study (Zentner et al. 1987; Campbell et al. 1990).

Phosphorous fertilizer was applied as mono-ammonium phosphate to the fertilized wheat treatment with the seed, with application rates ranging from 23 kg P_2O_5 ha^{-1} to 28 kg P_2O_5 ha^{-1}. Nitrogen fertilizer was applied as urea (46-0-0) to the fertilized wheat treatment with the seed, with application rates ranging from 50 kg N ha^{-1} to 100 kg N ha^{-1}. Fertilizers were applied according to soil test recommendations. Weed control in all treatments was achieved with a wide variety of herbicides, as the experiment was managed under a zero-tillage system. All field operations were performed using small commercial farm equipment (Zentner et al. 1987; Campbell et al. 1990).

Wheat and forage crops were seeded in late April to late May ha^{-1}, using a disc drill seeder. Wheat was seeded at 134 kg ha^{-1} to 145 kg ha^{-1}, while the alfalfa was seeded alone at 9 kg ha^{-1} to 11 kg ha^{-1} from 1995 and on. Prior to 1995, alfalfa was seeded at 2 kg ha^{-1} to 4 kg ha^{-1} in a mixture with bromegrass, which was seeded at 8 kg ha^{-1}. The forages were seeded in the spring of the fourth year of the rotation, and harvested during the fourth, fifth, and sixth years of the rotation. The forage crop was terminated with herbicides. Grain yields of wheat were determined each year by harvesting each plot with a small combine. Forage plots were cut once per year, field-dried and baled, and the hay weighed to determine forage yields (Zentner et al. 1987; Campbell et al. 1990).

A crop rotation experiment was initiated in 1992 at the University of Manitoba Faculty of Agricultural and Food Sciences research station at Glenlea, MB (49° 63'N, 97° 13'W) on a Scanterbury clay soil (Gleyed Black Chernozem). Two four-year rotations from the study were examined: a wheat (cv. Katepwa)-pea (cv. Grande)-wheat-flax (cv. AC McDuff) rotation (W-P-W-Fx) and a wheat-alfalfa (cv. OAC Minto)-alfalfa-flax rotation (W-A-A-Fx). Each rotation contained four crop-input treatments, consisting of a factorial of two fertilization (fertilizer applied according to soil test recommendations, no fertilizer applied) and two pest control schemes (pesticides applied as required, no pesticides applied). The treatments were arranged in a randomized complete block design in a factorial arrangement with one rotational phase present every year in each of three replicates. Plot size was 75 m × 90 m. Eight years of data, from 1992 through 1999, were analyzed in this study.

Phosphorous fertilizer was applied to fertilized treatments as mono-ammonium phosphate with the seed at 24 kg P_2O_5 ha^{-1} to 57 kg P_2O_5 ha^{-1}. The phosphorous fertilizer was applied with the seed, except in the case of established alfalfa, where a broadcast application was used. Nitrogen fertilizer was applied to fertilized treatments as ammonium nitrate at 18 kg N ha^{-1} to 75 kg N ha^{-1}. The nitrogen fertilizer was broadcast applied to the crops. Weed control in treatments that received pesticides was achieved with a variety of pesticides and tillage, and tillage only in treatments that did not receive pesticides. All field operations were performed with small commercial farm equipment.

All crops were seeded in late April to late May using a disc drill seeder. Crops were seeded into a prepared seedbed, which had been cultivated the day of seeding, or a few days beforehand. Wheat, pea, flax and alfalfa were seeded at 100 kg ha^{-1}, 150 kg ha^{-1}, 40 kg ha^{-1}, and 10 kg ha^{-1}, respectively. The alfalfa in the W-A-A-Fx rotation was underseeded to wheat in the first year of the rotation, and was harvested in the second and third years of the rotation. Alfalfa termination was accomplished by spraying 3 L glyphosate ha^{-1} and 1 L 2,4-D ha^{-1} to the forage, and then cultivated twice. Grain yields of wheat, pea and flax were determined each year by harvesting each plot with a small combine. Alfalfa dry matter production was determined each year by cutting three 1 m^2 samples out of each plot, and then oven-drying and weighing the samples.

3.3.2 Statistical analysis of rotational energy use efficiency

Data collected from each of the aforementioned sites included levels of all crop inputs, such as seed (including inoculants), fuel, machinery, fertilizers, and pesticides, all field operations (i.e. seeding, tillage, water hauling, spraying, harvesting, truck transport of seed and harvested grain between the farm and elevator, etc.), and crop yields from each treatment. This information was then converted to energy values (MJ ha^{-1}) using energy coefficients assigned for each crop input, field operation, and crop harvested (Nagy, 1999);

a record of the field operation data is located in appendix Tables A-1 to A-38. Rotational energy use was calculated by adding the energy coefficients of all the field operations and crop inputs. Rotational energy production was calculated using energy coefficients assigned to the different crops through laboratory bomb calorimeter tests (Nagy, 1999). An average farm size of 729 hectares (1800 acres) was assumed in calculating the coefficients. This was done so that equipment size assumed for each site would be equal, ensuring consistency in energy calculations between the different rotations. An energy efficiency rating was then calculated for each cycle of a crop rotation. This was accomplished by dividing total energy production of the rotation (in terms of feed energy embodied in the harvested grain and forage as calculated through laboratory bomb calorimeter tests) by total energy use in a crop rotation (in terms of inputs and field operations).

Energy use and energy efficiency values within each location were analyzed using analysis of variance (SAS Institute, Inc., 1985), where variation within a rotation occurred. In rotations where no variation existed in input levels or field operations between replicates of identical treatments in a rotation, an analysis of variance was not performed for energy use. Wheat yields from all sites, as well as flax, pea, and alfalfa yields from the Glenlea site, were also analyzed using analysis of variance. Where a significant F value was observed for energy use, energy efficiency, and crop yields among the different rotations at each site, Tukey's *w* Procedure Least Significant Difference test (LSD) was used to measure significance of the differences (Steel et al. 1997).

3.3.3 Economic analysis

A simple economic analysis was performed on the combined crop input and grain

Table 3-1 Crop prices used in economic analysis (in 1996 dollars)

Crop	Output Price ($ tonne^{-1})		
	– Alberta –	– Saskatchewan –	– Manitoba –
wheat	216.54	216.54	216.54
alfalfa	-	77.00	69.00
bromegrass	-	63.00	-
pea	-	-	215.00
flax	-	-	326.76

yield data for all of the aforementioned locations and rotations. Grain prices (Table 3-1) and crop input cost were based on 1996 data (Nagy, 1999). In order to calculate total rotational economic cost, the crop input data used for the energy analysis was converted to economic values ($ ha^{-1}) using economic coefficients assigned for each crop input and field operation (Nagy, 1999). Net economic return ($ ha^{-1}) was calculated by subtracting the total cost of the rotation from the gross economic return of the grain and forage crops harvested within a rotation during one crop rotation cycle. An economic analysis was also conducted where the price of nitrogen fertilizers was doubled, but prices of all other inputs remained the same.

3.4 RESULTS

3.4.1 Green Manure Legume Experiments

3.4.1.1 Lethbridge, AB

3.4.1.1.1 Energy Use There was an approximately three-fold difference in non-renewable energy consumption between the rotations that used the highest and lowest amounts of energy at Lethbridge, AB between 1989 and 1994 (Table 3-2). The GM-W-W (-N) and F-W-W (-N) rotations consumed the least amount of energy of the four rotations. Slightly higher energy use in the GM-W-W (-N) rotation was attributed to the energy required for seed production embodied in the lentil seed, as well as the fuel and machinery energy required to seed and terminate the green manure crop. In the F-W-W (-N) rotation, between 1 and 5 tillage operations were used to control weeds compared with between 1 and 4 tillage operations for green manure incorporation in the GM-W-W rotation (Appendix Tables A-2 through A-5).

The GM-W-W (-N) and F-W-W(-N) rotations used less than half the energy of the fertilized fallow-wheat-wheat (F-W-W) rotation. The difference in energy use was accounted for by the presence of nitrogen fertilizer in the F-W-W rotation, as the remainder of the crop inputs and field operations remained unchanged between the rotations.

The fertilized continuous wheat consumed the largest amount of non-renewable energy of all the rotations examined at Lethbridge (Table 3-2). This rotation used nearly three times as much energy as the GM-W-W (-N) and F-W-W (-N) rotations. Higher energy use was due to use of nitrogen fertilizer, as well as increases in crop inputs and the number of field operations carried out. Nitrogen fertilizer accounted for 68% of the energy consumed by the continuous wheat rotation, while the GM-W-W (-N) and F-W-W (-N) rotations used only 17% and 11% of the fertilizer energy used by the continuous wheat rotation, respectively. The continuous wheat rotation had greater fuel and machinery energy expenditures than the other rotations due to an extra year of crop production per rotation

Table 3-2 **Energy use of crop rotations per rotation cycle at Lethbridge, AB (1989-1994)**

Input	F-W-W (-N)[z]	Cont. W	F-W-W	GM-W-W (-N)
	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –
seed	970	1450	970	1120
machinery	940	1150	990	800
fuel	4240	4840	4470	3620
pesticides	2210	2160	2090	1720
fertilizers	2280	20660	13770	3420
Total	10640	30260	22290	10680

[z] F = fallow; W = wheat; GM = green manure; -N = no nitrogen fertilizer applied to crops

cycle compared to the other systems. The F-W-W (-N) rotation used 87% of the seed, fuel, machinery, and herbicide energy that the continuous wheat rotation did, while the GM-W-W (-N) rotation used 76% of the seed, fuel, machinery, and herbicide energy that the continuous wheat rotation did .

The continuous wheat rotation also used approximately one-third more non-renewable energy than did the F-W-W rotation. This was attributed to the extra year of grain cropping per rotation cycle in the continuous wheat rotation, which resulted in an increased number of field operations and increased levels of crop inputs, especially nitrogen fertilizer.

3.4.1.1.2 Crop Yields and Energy Production in Harvested Grain While average annual wheat production between the rotations did not differ significantly (Table 3-3) at Lethbridge, there were substantial differences in average rotational energy production (Table 3-4). For

Table 3-3 Average annual wheat yields at Lethbridge, AB (1989-1994)

Rotation	Wheat yield
	– kg ha^{-1} –
GM-W-W (-N)[z]	2200
F-W-W (-N)	2000
F-W-W	2500
Cont.W	2000
C.V.	50.9
Significance (Pr>F)	
Rotation	0.1232[y] NS[x]

[z] F = fallow; W = wheat; GM = green manure; -N = no nitrogen fertilizer applied to crops
[y] The df for effect of rotation is 3
[x] NS = not significant at the 0.05 level

Table 3-4 Energy production in harvested grain of crop rotations per rotation cycle at Lethbridge, AB (1989-1994)

Rotation	Energy production
	– MJ ha^{-1} –
GM-W-W (-N)[z]	83000
F-W-W (-N)	79000
F-W-W	97000
Cont.W	120000

[z] F = fallow; W = wheat; GM = green manure; -N = no nitrogen fertilizer applied to crops

example, the continuous wheat rotation produced approximately 40% more energy than the average energy production of the other three rotations. This was attributed to the fact that the continuous wheat rotation had three years of grain production per crop rotation cycle, as opposed to two years of grain production per cycle in the green manure rotation or either of the fallow-containing rotations.

3.4.1.1.3 Energy Use Efficiency There were substantial differences in rotational energy use efficiency between a number of the Lethbridge rotations. One the basis of energy efficiency, the Lethbridge rotations fell into two groups which were statistically different at $p<0.05$ (Table 3-5). The first group contained the GM-W-W (-N) and F-W-W (-N) rotations, which did not use nitrogen fertilizer. The other group contained the continuous wheat and F-W-W rotations, which did include nitrogen fertilizer. In fact, the rotations that did not use nitrogen fertilizer were nearly twice as energy-efficient as rotations where nitrogen fertilizer was used.

No apparent differences in energy use efficiency were observed between the two rotations that did not use nitrogen fertilizer, F-W-W (-N) and GM-W-W. This was due to similar levels of energy production and consumption between the two rotations. While there was similarity in energy use efficiency values between these two rotations, nitrogen and organic matter are being added to the soil by the green manure legume crop. A number of studies examining the role of legumes as green manures in Canadian Prairie dryland conditions have shown that over 3000 kg ha^{-1} of dry matter and upwards of 70 kg N ha^{-1} could be supplied by a legume crop grown as a green manure (Biederbeck et al. 1993; 1996). This results in additional benefits being realized in the GM-W-W (-N) rotation, with no apparent decrease in energy use efficiency.

Table 3-5 Energy use efficiency of crop rotations at Lethbridge, AB (1989-1994)

Rotation	Energy efficiency
	– output energy input energy $^{-1}$ –
GM-W-W (-N)[z]	8.0 a[y]
F-W-W (-N)	7.6 a
F-W-W	4.4 b
Cont.W	4.1 b
LSD	0.728
Significance (Pr>F)	
Rotation	0.0234[x] *[w]

[z] F = fallow; W = wheat; GM = green manure; -N = no nitrogen fertilizer applied to crops
[y] Means followed by the same letter are not significantly different
[x] The df for effect of rotation is 3
[w] * = significant at the 0.05 level

When comparing the two rotations that did contain nitrogen fertilizer, the continuous wheat and F-W-W rotations, there was also no apparent difference in energy use efficiency. While the continuous wheat rotation consumed more energy than the F-W-W rotation, the continuous wheat rotation had one more year of grain production per crop rotation cycle. The increase in energy production balanced out the increase in energy use in the continuous wheat rotation, resulting in a similar energy efficiency value as the F-W-W rotation.

3.4.1.2 Swift Current, SK

3.4.1.2.1 Energy Use There was an approximately 35% difference in non-renewable energy consumption between the highest and lowest energy-consuming rotations at Swift Current,

Table 3-6 Energy use of crop rotations per rotation cycle at Swift Current, SK (1987-1995)

Input	F-W-W[z]	GM-W-W	Cont. W
	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –
seed	860	1000	1300
machinery	620	600	690
fuel	2960	2840	3080
pesticides	1400	1100	1420
fertilizers	5650	6080	9190
Total	11490	11620	15680

[z] F = fallow; W = wheat; GM = green manure

SK between 1987 and 1995 (Table 3-6). The fallow-wheat-wheat (F-W-W) and green manure-wheat-wheat (GM-W-W) rotations consumed the least amounts of energy of the three rotations. While they did not differ significantly in terms of energy consumption, the F-W-W rotation used slightly less energy than the GM-W-W rotation, due to the added energy associated with legume seed production, and the operational energy required to seed and terminate the legume stand in the green manure year of the rotation. The fallow year of the F-W-W rotation required only the energy used to control weeds.

The continuous wheat rotation consumed the largest amount of non-renewable energy of any of the Swift Current rotations examined here. This rotation used approximately 35% more energy than did the GM-W-W and F-W-W rotations. This increase in energy consumption was attributed to the extra year of grain production.

3.4.1.2.2 Crop Yields and Energy Production in Harvested Grain Similar to trends for the Lethbridge trial, there were no significant differences in average annual wheat production between the three rotations at Swift Current (Table 3-7). Therefore, it would appear that nitrogen was sufficient in all cases, though it may have derived from different sources: indigenous soil nitrogen for the F-W-W rotation, legume nitrogen for the GM-W-W rotation, and inorganic fertilizer nitrogen for the continuous wheat rotation. However, there were differences in average rotational energy production (Table 3-8). The continuous wheat rotation produced approximately 40% more energy than the average rotation production of the F-W-W and GM-W-W rotations. This was attributed to the extra year of grain

Table 3-7 Average annual wheat yields at Swift Current, SK (1987-1995)

Rotation	Wheat yield
	– kg ha^{-1} –
GM-W-W[z]	1800
F-W-W	1900
Cont.W	1800
C.V.	42.6
Significance (Pr>F)	
Rotation	0.7218[y] NS[x]

[z] F = fallow; W = wheat; GM = green manure
[y] The df for effect of rotation is 2
[x] NS = not significant at the 0.05 level

Table 3-8 **Energy production of crop rotations per rotation cycle at Swift Current, SK (1987-1995)**

Rotation	Energy production
	– kg ha^{-1} –
GM-W-W[z]	68000
F-W-W	75000
Cont.W	100000

[z] F = fallow; W = wheat; GM = green manure

production in the continuous wheat rotation.

3.4.1.2.3 Energy Use Efficiency There were no significant differences in rotational energy use efficiency between the three Swift Current rotations (Table 3-9). When comparing the GM-W-W and F-W-W rotations, the lack of a significant difference in energy use efficiency was due to the fact that there were no significant differences in either rotational energy use or grain production.

When comparing the continuous wheat rotation to the F-W-W and GM-W-W rotations, the lack of significant differences in rotational energy use efficiencies is due to another reason. The continuous wheat rotation produced more energy, due to one more year of grain cropping per three-year rotation cycle than the other two rotations. However, this extra year of grain production also used more energy than did a year of fallow or green manure. In the continuous wheat rotation at Swift Current, the increase in energy production was offset by the increase in energy use, which resulted in a similar rotational energy use efficiency to the F-W-W and GM-W-W rotations.

Table 3-9 Energy use efficiency of crop rotations at Swift Current, SK (1987-1995)

Rotation	Energy efficiency
	– output energy input energy $^{-1}$ –
GM-W-W[z]	5.9
F-W-W	6.5
Cont.W	6.3
C.V.	13.3
Significance (Pr>F)	
Rotation	0.451[x] NS[w]

[z] F = fallow; W = wheat; GM = green manure
[y] Means followed by the same letter are not significantly different
[x] The df for effect of rotation is 2
[w] NS = not significant at the 0.05 level

3.4.1.3 Results Summary of Green Manure Legume Experiments

At both Lethbridge, AB and Swift Current, SK, energy expended in the continuous wheat rotations was higher than in the rotations containing a year of fallow or green manure. This was due to decreased energy requirements to maintain land in fallow, which requires energy inputs only in terms of tillage and/or herbicides for weed control, or green manure, which requires energy inputs only in terms of seeding a legume and tillage and/or herbicides for weed control and/or legume termination. By way of comparison, production of a wheat crop requires energy inputs in terms of tillage and/or herbicides for weed control, and for field operations such as seeding, fertilizer, harvest, and hauling of grain. In a previous study by Zentner et al. (1989), it was found that a fallow-wheat-wheat (F-W-W) rotation consumed approximately one-third less energy than did a continuous wheat rotation.

Energy consumption in the rotations with similar fertilizer treatments containing green manure was slightly higher than in the rotations containing fallow at both sites. This was due to the added energy costs of producing a green manure, which includes the production energy embodied in the legume seed, the act of seeding, and tillage and/or herbicides to terminate the stand. By way of comparison, the fallow phase requires only the energy needed to control weeds through herbicide and/or tillage. This corresponds to previous work conducted on the Prairies. Rice and Biederbeck (1983) found that a green manure-wheat-fallow-wheat rotation used slightly more energy than a fallow-wheat-fallow-wheat rotation in the Brown soil zone, if wheat crops in each rotation were fertilized with the same rate of nitrogen.

Similar rotations at Lethbridge consumed more energy than at Swift Current, and all facets of energy consumption in the fertilized F-W-W and continuous wheat rotations were greater at Lethbridge. However, the majority of the differences were accounted for with regard to fertilizers, as energy related to fertilizers accounted for 49% to 68% of total rotational energy use at each site. However, at Lethbridge, energy expenditures related to fertilizers was more than twice as great than at Swift Current. A previous study by Rice and Biederbeck (1983) compared similar crop rotations with two years of cereal cropping. The rotations were located in the Brown and Dark Brown soil zones, where Swift Current and Lethbridge are located, respectively. The authors found that the rotation in the Dark Brown soil zone had energy expenditures for fertilizer that were almost three times higher that the rotation in the Brown soil zone. The annual moisture deficit, which is 395 mm at Swift

Current compared to 268 mm at Lethbridge (Campbell et al. 1990), leads to an increased risk of drought and of crop failure at Swift Current. In addition, the use of nitrogen fertilizers in drier climates is risky due to uncertain weather conditions (Biederbeck et al. 1996). Taking these factors into consideration, producers in drier areas generally decrease the amount of inputs for crop production, in order to limit financial risks.

Average annual wheat yields were higher at Lethbridge than at Swift Current for all crop rotations. The lower moisture deficit at Lethbridge results in more water available for crop growth (127 mm more water available at Lethbridge), which led to higher wheat yields. The higher wheat yields at Lethbridge also resulted in corresponding increases in energy production, compared to the Swift Current rotations.

Energy efficiency tended to be higher at Swift Current than at Lethbridge. The continuous wheat and fallow-wheat-wheat rotations at Swift Current had energy efficiencies that were approximately 47% and 55% higher than at Lethbridge, respectively. However, the green manure-wheat-wheat rotation at Lethbridge was 34% more energy efficient. The major contributing factor to higher levels of energy efficiency for the continuous wheat and F-W-W rotations at Swift Current related to levels of energy consumption by the rotations at the two sites. While energy production levels for the continuous wheat and F-W-W rotations at Lethbridge were 21% and 30% higher, respectively, than at Swift Current, energy consumption levels for these rotations were approximately twice those at Swift Current, resulting in lower energy efficiencies at Lethbridge. On the other hand, energy production for the GM-W-W rotation at Lethbridge was greater, while energy consumption was lower than at Swift Current, resulting in a higher energy efficiency rating.

3.4.2 Perennial Forage Legume Experiments

3.4.2.1 Indian Head, SK

3.4.2.1.1 Energy Use There was a greater than six-fold difference in non-renewable energy consumption between the highest and lowest energy-consuming rotations at Indian Head, SK between 1993 and 1998. The fertilized continuous wheat rotation used nearly four times as much energy as did the unfertilized continuous wheat rotation (-f) (Table 3-10). The difference in energy consumption was due almost entirely to the non-renewable energy embodied in the nitrogen fertilizer, with the remainder accounted for by the energy required to apply the fertilizer.

The perennial rotation used the least non-renewable energy of any of the Indian Head rotations examined here, using only approximately 60% of the non-renewable energy consumed by continuous wheat (-f) rotation over the six-year cycle. As both rotations did not use nitrogen fertilizer, this difference was attributed to differing levels of other inputs and increased numbers of field operations. The continuous wheat (-f) rotation had six years of grain crop production, whereas the perennial rotation only had two years of grain production. The other four years of the rotation were comprised of fallow or forage crops, both of which require much lower levels of crop inputs and field operations than a grain crop.

The perennial rotation used only 15% of the energy required by the continuous wheat rotation over the six-year cycle. A portion of the difference in energy consumption was accounted for by field operations and crop inputs other than nitrogen fertilizer, as was discussed in the previous paragraph. However, the majority of the difference in non-renewable energy consumption between the two rotations was accounted for by the use of

Table 3-10 Energy use of crop rotations at Indian Head, SK (1993-1998)

Input	Cont. W (-f)[z]	Cont. W	F-W-W-H-H-H (-f)
	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –
seed	5910	5910	2020
machinery	810	1430	830
fuel	3210	5920	3260
pesticides	4760	4960	2590
fertilizers	0	38440	0
Six-year total	14690	56660	8700
Annual average	2448	9443	1450

[z] Cont. W = continuous wheat; -f = no fertilizers applied to crops; F = fallow; H = alfalfa or alfalfa/bromegrass mixture

nitrogen fertilizer in the continuous wheat rotation, as nitrogen fertilizer use by the continuous wheat rotation was more that 4 times greater than the total energy consumption of the perennial rotation.

3.4.2.1.2 Crop Yields and Energy Production in Harvested Grain There were significant differences in average annual wheat yields between the three rotations at Indian Head (Table 3-11). The continuous wheat (-f) rotation produced the lowest wheat yields, at approximately 700 kg ha^{-1}. The perennial rotation averaged annual wheat yields of 1400 kg ha^{-1}, or an increase of 104% over the continuous wheat (-f) rotation. The continuous wheat rotation produced average wheat yields of 2200 kg ha^{-1}, or an increase of 214% over the continuous wheat (-f) rotation and 57% over the perennial rotation. Wheat yields in the continuous wheat rotation were greater than those in the perennial rotation likely because of

Table 3-11 Average annual wheat yields at Indian Head, SK (1993-1998)

Rotation	Crop yield
	– kg ha^{-1} –
F-W-W-H-H-H (-f)[z]	1400 b[y]
Cont.W (-f)	700 c
Cont.W	2200 a
LSD	316.8
Significance (Pr>F)	
Rotation	0.0001[x] **[w]

[z] Cont. W = continuous wheat; -f = no fertilizers applied to crops; F = fallow; H = alfalfa or alfalfa/bromegrass mixture
[y] Means followed by the same letter are not significantly different
[x] The df for effect of rotation is 2
[w] ** = significant at the 0.01 level

the addition of nitrogen fertilizer that occurred every year in the continuous wheat rotation would be greater than the nitrogen added to the soil from the alfalfa after a 3-year alfalfa/bromegrass stand, which would have been used by two subsequent wheat crops. In addition, the wheat crops in the perennial rotation received no phosphorous, potassium, or sulphur fertilizers, while the wheat crops in the fertilized continuous wheat rotation did. Wheat yields in the F-W-W-H-H-H (-f) rotation were greater than those in the continuous wheat (-f) rotation likely because of the nitrogen that was added to the system by the alfalfa in the perennial rotation, whereas the continuous wheat (-f) was relying solely on the nitrogen mineralized from the soil organic matter during the year of fallow for two years of wheat cropping. Other rotational yield enhancing benefits of the forage crop (Forster, 1999) would also have played a role.

Average rotational energy production (Table 3-12) also differed between the rotations. The continuous wheat rotation produced just over two times more energy than did the continuous wheat (-f) rotation, which corresponds directly to the difference in wheat yields between the two rotations. The continuous wheat rotation produced 48% more energy than the perennial rotation. The proportional difference between these two rotations for rotational energy production was less than it was for annual average wheat production. This was due to only two years of wheat production present in the perennial rotation and three years of forage production. With forages, all the aboveground biomass is harvested, as compared to grain production, where only the grain is harvested. Hence, more energy is harvested on a per hectare basis in the forage-containing rotation.

Table 3-12 Energy production of crop rotations at Indian Head, SK (1993-1998)

Rotation	Energy production	
	Six-year total – MJ ha^{-1} –	Annual average – MJ ha^{-1} –
F-W-W-H-H-H (-f)[z]	177600	29600
Cont.W (-f)	80000	13330
Cont.W	263500	43920

[z] Cont. W = continuous wheat; -f = no fertilizers applied to crops; F = fallow; H = alfalfa or alfalfa/bromegrass mixture

3.4.2.1.3 Energy Use Efficiency There was no significant difference in energy use efficiency between the continuous wheat and continuous wheat (-f) rotations at Indian Head (Table 3-13). This was due to the fact that the increase in energy production by the continuous wheat rotation was offset by a corresponding increase in energy consumption.

When comparing the two continuous wheat rotations with the perennial rotation, there was a large significant difference in energy use efficiency. The perennial rotation had an energy efficiency rating that was between 374% and 438% greater than either of the continuous wheat rotations. This was because the perennial rotation produced approximately

Table 3-13 Energy use efficiency of crop rotations at Indian Head, SK (1993-1998)

Rotation	Energy efficiency
	– output energy input energy $^{-1}$ –
F-W-W-H-H-H (-f)[z]	20.4 a[y]
Cont.W (-f)	5.4 b
Cont.W	4.7 b
LSD	3.6
Significance (Pr>F)	
Rotation	0.0001[x] **[w]

[z] Cont. W = continuous wheat; -f = no fertilizers applied to crops; F = fallow; H = alfalfa or alfalfa/bromegrass mixture
[y] Means followed by the same letter are not significantly different
[x] The df for effect of rotation is 1
[w] ** = significant at the 0.01 level

two times as much energy and used only 60% as much energy as the continuous wheat (-f) rotation. In comparison to the continuous wheat rotation, the perennial rotation produced approximately two-thirds of the energy but used approximately only 15% as much energy as the continuous wheat rotation, resulting in a much higher energy use efficiency.

3.4.2.2 Glenlea, MB

3.4.2.2.1 Energy Use There was an approximate 3.5-fold difference in non-renewable energy consumption between the highest and lowest energy-consuming rotations at Glenlea, MB between 1992 and 1999 (Tables 3-14 and 3-15). When comparing the same fertilizer and pesticide treatments between rotations, the wheat-pea-wheat-flax (W-P-W-Fx) rotation used between 26% and 49% more energy than the wheat-alfalfa-alfalfa-flax (W-A-A-Fx) rotation. This difference was due to the fact that the second and third crops of the W-P-W-Fx rotation, peas and wheat, are produced as grain crops, while the middle two years of the W-A-A-Fx rotation consist of a two-year alfalfa stand. Grain crops require more substantial amounts of energy to produce than a forage crop.

When comparing different fertilizer treatments within rotations, the rotation treatments that received nitrogen fertilizer consumed approximately between 2 and 2.5 times as much non-renewable energy as those rotation treatments not receiving nitrogen fertilizer. When comparing different pesticide treatments within rotations, the rotation treatments that received pesticides consumed approximately between 7% and 29% more non-renewable energy than those rotation treatments not receiving pesticides.

3.4.2.2.2 Crop Yields and Energy Production in Harvested Grain There were no significant effects of fertilizer, pesticide, rotation and their interactions. However, there was

Table 3-14 Energy use of the wheat-pea-wheat-flax rotation at Glenlea, MB (1992-1999)

Input	+f+p[z]	+f-p	-f+p	-f-p
	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –
seed	2500	2500	2500	2500
machinery	1100	1050	990	960
fuel	5440	6200	4740	5370
pesticides	3150	0	3150	0
fertilizers	12690	12750	0	0
Four-year total	24880	22500	11380	8830
Annual average	6220	5625	2845	2208

[z] f = fertilizers; p = pesticides

Table 3-15 Energy use of the wheat-alfalfa-alfalfa-flax rotation at Glenlea, MB (1992-1999)

Input	+f+p[z]	+f-p	-f+p	-f-p
	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –	– MJ ha^{-1} –
seed	1350	1350	1350	1350
machinery	910	900	860	870
fuel	4780	5150	4320	4750
pesticides	1510	0	1510	0
fertilizers	8120	8120	0	0
Four-year total	16670	15520	8040	6970
Annual average	4168	3880	2010	1743

[z] f = fertilizers; p = pesticides

a substantial amount of variation in average annual wheat yields in 1996 following a previous crop of flax among the four fertilizer/pesticide treatments at Glenlea (Table 3-16) within each of the rotations. There were no significant differences in wheat yields when comparing similar treatments between the two rotations, however, large differences between the two rotations were evident. The large value for the least significant difference was likely due to a degree of experimental error, due to the large amount of variation during the one year that data was available. The +f+p and +f-p treatments in each of the rotations had significantly higher annual average wheat yields than the -f-p treatments, but not the -f+p treatments.

There was little statistical variation in flax yields between the two rotations and among the four fertilizer/pesticide treatments, but large differences were evident, as the LSD was approximately 40% of the highest average annual flax yield (Table 3-17). There were no significant differences within the W-A-A-Fx rotation, while the +f-p and -f-p treatments in the W-P-W-Fx rotation produced significantly lower flax yields than the +f+p and +f-p treatments. There were no significant differences in flax yields when comparing the same fertilizer/pesticide treatments between the rotations. There was a significant difference in flax yields between the +f+p and +f-p treatments in the W-P-W-Fx rotation. Flax is considered a relatively uncompetitive crop with weeds (Manitoba Agriculture, 1998) so it is likely that weeds took advantage of the combination of available fertilizer nitrogen and lack of herbicides, and caused significant yield loss to the flax. This was not the case in the W-A-A-Fx rotation. Alfalfa is known to be an effective competitor against weeds (Ominski et al. 1999), so it is likely that weed populations were suppressed somewhat in the flax where alfalfa was grown the previous two years. Table

3-16 Average annual wheat yields (after flax) at Glenlea, MB (1996)

Rotation	Treatment	Wheat yield
		– kg ha^{-1} –
W-P-W-Fx	f-p-[z]	1100 e[y]
	f-p+	1500 de
	f+p-	2300 bcd
	f+p+	3300 ab
W-A-A-Fx	f-p-	2000 cde
	f-p+	2500 abcd
	f+p-	2900 ab
	f+p+	3500 a
LSD		1127.2
Significance (Pr>F)		
Rotation (R)		0.1147[x] NS[w]
Fertilizer (F)		0.0674 NS
R*F		0.2663 NS
Pesticides (P)		0.1263 NS
R*P		0.7775 NS
F*P		0.3708 NS
R*F*P		0.5000 NS

[z] W = wheat; P = pea; Fx = flax; A = alfalfa; f = fertilizers; p = pesticides
[y] Means followed by the same letter are not significantly different
[x] The df for effects of R, F, R*F, P, R*P, F*P, and R*F*P are 1, 1, 1, 1, 1, 1, and 1, respectively
[w] NS = not significant at the 0.05 level

Table 3-17 **Average annual flax yields at Glenlea, MB (1992-1999)**

Rotation	Treatment	Flax yield
		– kg ha^{-1} –
W-P-W-Fx	f-p-[z]	1000 b[y]
	f-p+	1500 ab
	f+p-	900 b
	f+p+	1700 a
W-A-A-Fx	f-p-	1100 ab
	f-p+	1300 ab
	f+p-	1100 ab
	f+p+	1500 ab
LSD		672.3
Significance (Pr>F)		
Rotation (R)		0.2322[x] NS[w]
Fertilizer (F)		0.1281 NS
R*F		0.2798 NS
Pesticides (P)		0.0243 *
R*P		0.0671 NS
F*P		0.0768 NS
R*F*P		0.5000 NS

[z] W = wheat; P = pea; Fx = flax; A = alfalfa; f = fertilizers; p = pesticides
[y] Means followed by the same letter are not significantly different
[x] The df for effect of R, F, R*F, P, R*P, F*P, and R*F*P is 1, 1, 1, 1, 1, 1, and 1, respectively
[w] NS = not significant at the 0.05 level; * = significant at the 0.05 level

No significant differences in pea yields (Table 3-18) existed within the W-P-W-Fx rotation when comparing fertilizer/pesticide treatments, although large differences were evident. The C.V. for the pea yields was quite high, indicating a high degree of variation, likely due to high levels of experimental error, as the pea crop in 1993 was adversely affected by localized flooding. The lowest average annual pea yield, achieved in the +f-p treatment, was less than 30% of the highest average annual pea yield, achieved in the -f+p treatment When comparing alfalfa yields between fertilizer/pesticide treatments in the W-A-A-Fx rotation, there were also no significant differences (Table 3-19). Unlike what was observed

Table 3-18 Average annual pea yields at Glenlea, MB (1992-1999)

Rotation	Treatment	Pea yield
		– kg ha^{-1} –
W-P-W-Fx	f-p-[z]	700
	f-p+	1300
	f+p-	400
	f+p+	800
C.V.		117.3
Significance (Pr>F)		
Fertilizer (F)		0.1081[y] NS[x]
Pesticides (P)		0.0828 NS
F*P		0.5000 NS

[z] W = wheat; P = pea; Fx = flax; f = fertilizers; p = pesticides
[y] The df for effect of F, P, and F*P is 1, 1, and 1, respectively
[x] NS = not significant at the 0.05 level

with the pea yields, the lowest average annual alfalfa yield, achieved with the treatment that received no fertilizers or pesticides, was only approximately 10% lower than the highest average annual alfalfa yield, which was achieved with fertilizers and pesticides.

While significant differences for average annual wheat yields were limited to only certain treatment/rotation combinations, large differences for average rotational energy production were observed (Table 3-20). Within the W-P-W-Fx rotation, rotational energy

Table 3-19 Average annual alfalfa yields at Glenlea, MB (1992-1999)

Rotation	Treatment	Alfalfa yield
		– kg ha^{-1} –
W-A-A-Fx	f-p-[z]	5600
	f-p+	6100
	f+p-	5900
	f+p+	6200
C.V.		32.6
Significance (Pr>F)		
Fertilizer (F)		0.3314[y] NS[x]
Pesticides (P)		0.1526 NS
F*P		0.5000 NS

[z] W = wheat; A = alfalfa; Fx = flax; f = fertilizers; p = pesticides
[y] The df for effect of F, P, and F*P is 1, 1, and 1, respectively
[x] NS = not significant at the 0.05 level

Table 3-20 **Energy production of crop rotations at Glenlea, MB (1992-1999)**

Rotation	Treatment	Energy production	
		Four-year total – MJ ha^{-1} –	Annual average – MJ ha^{-1} –
W-P-W-Fx	f-p-[z]	116100	29030
	f-p+	154900	38730
	f+p-	132900	33230
	f+p+	172500	43130
W-A-A-Fx	f-p-	271200	67800
	f-p+	299000	74750
	f+p-	288700	72180
	f+p+	316900	79230

[z] W = wheat; P = pea; Fx = flax; A = alfalfa; f = fertilizers; p = pesticides

production varied by almost 50%, while rotation energy production in the W-A-A-Fx rotation varied by approximately 17%. Generally, the level of rotational energy output decreased with decreasing input level. Rotation-treatment combinations in the W-A-A-Fx treatments had levels of rotational energy production that were approximately 84% to 134% greater than those rotation-treatment combinations in the W-P-W-Fx rotation. This increase in energy production was due to the presence of a forage crop during the second and third years of the W-A-A-Fx rotation, as opposed to grain crops being harvested in the W-P-W-Fx rotation. With forage crops, all of the aboveground biomass is harvested, as compared to grain crop production, where only the grain is harvested. The result is higher levels of energy being produced on an area basis by the forages.

Variation in energy production within treatments at Glenlea was less in the perennial rotation than in the annual rotation. This was likely due to a two-year alfalfa stand providing substantially more nitrogen than a pea crop to subsequent non-legume crops (Beckie and Brandt, 1997; Kelner et al. 1997), which helped to offset the lack of nitrogen in the unfertilized perennial treatments. Secondly, forage legumes are effective competitors against weeds (Ominski et al. 1999), which visibly lowered weed pressure in the perennial rotation.

3.4.2.2.3 Energy Use Efficiency There were significant differences in energy use efficiency within and between the two rotations at Glenlea (Table 3-21). Within each rotation, the two treatments that were not fertilized were more energy efficient than the two treatments that were fertilized. This was primarily due to the substantially higher levels of input energy in the fertilized treatments, which more than negated any increases in output energy, in terms of rotational energy efficiency. These results were similar to those at Swift Current.

The W-A-A-Fx rotation treatments had energy efficiency ratings that were between 270% and 328% higher than the W-P-W-Fx rotation treatments. This was due to higher levels of energy production, largely due to high levels of energy produced by the alfalfa, and lower levels of input energy in the W-A-A-Fx rotation.

3.4.2.3 Results Summary of Perennial Forage Legume Experiments

At both Indian Head and Glenlea, the rotations containing perennial forage legumes consumed less non-renewable energy than the continuous cropping rotations, with much of the difference attributed to reductions in nitrogen fertilizer use. A number of previous studies support these findings. Heichel (1980) compared a year of corn silage production to a year of alfalfa production, during the year of alfalfa establishment, in southeastern Minnesota. The results of his study showed that production of the alfalfa used only 63% of the energy required for corn silage production, and that most of this difference was accounted

Table 3-21 Energy use efficiency of crop rotations at Glenlea, MB (1992-1999)

Rotation	Treatment	Energy efficiency
		– output energy input energy $^{-1}$ –
W-P-W-Fx	f-p-[z]	13.0 c[y]
	f-p+	13.8 c
	f+p-	5.9 d
	f+p+	7.1 d
W-A-A-Fx	f-p-	38.9 a
	f-p+	37.2 a
	f+p-	19.2 b
	f+p+	19.8 b
LSD		5.0
Significance (Pr>F)		
Rotation (R)		< 0.0001[x] **[w]
Fertilizer (F)		0.0003 **
R*F		0.0209 *
Pesticides (P)		0.9143 NS
R*P		0.7002 NS
F*P		0.7494 NS
R*F*P		0.8226 NS

[z] W = wheat; P = pea; Fx = flax; A = alfalfa; f = fertilizers; p = pesticides
[y] Means followed by the same letter are not significantly different
[x] The df for effects of R, F, R*F, P, R*P, F*P, and R*F*P are 1, 1, 1, 1, 1, 1, and 1, respectively
[w] NS = not significant; * = significant at the 0.05 level; ** = significant at the 0.01 level

for by nitrogen fertilizers. A previous study by Spedding and Walsingham (1976) found that the energy required for production of alfalfa was approximately one-third of what was required in barley production, while in another study, a corn-corn-oats-alfalfa-alfalfa rotation consumed only 61% of the energy required in a 5-year continuous corn rotation (Heichel, 1978).

Annual energy use in the continuous wheat rotation at Indian Head was greater than in the W-P-W-Fx rotation at Glenlea. The majority of this difference was accounted for by higher nitrogen fertilizer use at Indian Head. On the other hand, the continuous wheat (-f) rotation at Indian Head used only 14% less energy on an annual basis than did the W-P-W-Fx treatment that received pesticides, but no fertilizers. This indicates that, other than nitrogen fertilizer use, energy use between these rotations was quite similar.

The F-W-W-H-H-H rotation at Indian Head used 72% of the energy consumed on an annual basis in the W-A-A-Fx treatment that received pesticides, but no fertilizers, as was the case with the F-W-W-H-H-H rotation. Both rotations were in perennial forages for half of their cycles. However, the F-W-W-H-H-H rotation contained one year of fallow, which requires very few inputs, whereas the W-A-A-Fx rotation did not. The W-A-A-Fx rotation also used more than twice as much energy allocated to fuel and machinery expenditures as the F-W-W-H-H-H rotation. This difference was due to the Indian Head rotations being managed under a zero-tillage management system, while the Glenlea rotations were managed under a conventional tillage system, as tillage adds extra energy costs, in terms of equipment, repairs, and fuel. As well, herbicide energy costs were higher at Glenlea.

Differences in average annual wheat yields occurred between the Glenlea and Indian

Head rotations. In Glenlea, wheat yields for the W-P-W-Fx rotation ranged from 1873 kg ha^{-1} to 2762 kg ha^{-1}, while wheat yields for the W-A-A-Fx rotation ranged from 2511 kg ha^{-1} to 3257 kg ha^{-1} . The average annual wheat yields at Indian Head were 2182 kg ha^{-1}, 712 kg ha^{-1}, and 1431 kg ha^{-1} for the continuous wheat, continuous wheat (-f), and F-W-W-H-H-H, respectively. These differences were likely due to greater moisture levels at Glenlea (Environment Canada, 1999), beneficial effects of rotating crops at Glenlea, and the fact that the unfertilized rotations at Indian Head were started 34 years prior to the Glenlea rotations, likely resulting in greater soil nutrient deficiencies.

The average annual energy production for the continuous wheat rotation at Indian Head was similar to that of the W-P-W-Fx treatment at Glenlea that received fertilizers and pesticides. On the other hand, the average annual energy production for the continuous wheat (-f) rotation at Indian Head was only approximately one-third that of the W-P-W-Fx -f+p treatment at Glenlea. The W-A-A-Fx rotation produced 79220 MJ ha^{-1} and 72179 MJ ha^{-1} annually, for the +f+p and +f-p treatments, respectively. The W-A-A-Fx rotation produced 74741 MJ ha^{-1} and 67793 MJ ha^{-1} annually, for the -f+p and -f-p treatments, respectively. At Indian Head, energy production for the F-W-W-H-H-H rotation was 29589 MJ ha^{-1} annually, which is less than half of the energy that was produced in the W-A-A-Fx -f+p treatment. When comparing similar rotations and treatments between Glenlea and Indian Head, the fertilized continuous wheat rotation at Indian Head produced similar levels of energy expenditures to the +f+p W-P-W-Fx rotation at Glenlea. On the other hand, energy production for the unfertilized continuous wheat and F-W-W-H-H-H rotations at Indian Head was less than half that of the -f+p W-P-W-Fx and W-A-A-Fx rotations at Glenlea, respectively.

There were differences in energy efficiency between the rotations at Glenlea and Indian Head. The W-P-W-Fx rotation at Glenlea had energy efficiency ratings of 7.064 and 5.861 for the +f+p and +f-p treatments, respectively. These energy efficiency values were comparable to that of the fertilized continuous wheat rotation at Indian Head, which was 4.65. The W-P-W-Fx rotation at Glenlea had energy efficiency ratings of 13.788 and 12.967 for the -f+p and -f-p treatments, respectively. These energy efficiency values were more than 2 times greater than those for either the fertilized continuous wheat rotation, or the unfertilized continuous wheat rotation at Indian Head, which had an energy efficiency value of 5.45. These results also show little additional benefit of adding pesticides, with regards to rotational energy efficiency. There were also differences in energy efficiency ratings between the perennial forage-containing rotations at Glenlea and Indian Head. The W-A-A-Fx rotation at Glenlea had energy efficiency ratings of 19.752 and 19.211 for the +f+p and +f-p treatments, respectively. The W-A-A-Fx rotation at Glenlea had energy efficiency ratings of 37.211 and 38.890 for the -f+p and -f-p treatments, respectively. By way of comparison, the unfertilized F-W-W-H-H-H rotation at Indian Head had an energy efficiency rating of 20.38.

3.4.3 Economics of Legumes in Rotation

3.4.3.1 Green Manure Legumes

When examining the data from the Lethbridge rotations, the continuous wheat (+N) rotation had the greatest net return per year, at \$146.29 ha^{-1} (Table 3-22). This was due to greater gross income, which more than offset an increase in production costs, relative to the

Table 3-22 Economic performance of crop rotations at Lethbridge, AB on a per-year basis (1989-1994)

Rotation	Gross income	Costs	Net Income
	– $ ha^{-1} yr^{-1} –	– $ ha^{-1} yr^{-1} –	– $ ha^{-1} yr^{-1} –
GM-W-W (-N)[z]	321.71	197.04	124.67
F-W-W (-N)	294.23	181.42	112.81
F-W-W	360.71	237.35	123.36
Cont.W	435.51	289.22	146.29

[z] F = fallow; W = wheat; GM = green manure; -N = no nitrogen fertilizer applied to crops

other Lethbridge rotations. Production costs for the continuous wheat rotation were $289.22 ha^{-1} during the crop production cycle, as opposed to $237.35 ha^{-1}, $181.42 ha^{-1}, and $197.04 ha^{-1} for the F-W-W, GM-W-W (-N), and F-W-W (-N) rotations, respectively. On an annual basis, the net returns of the F-W-W and GM-W-W (-N) rotations were over $20 ha^{-1} less than that of the continuous wheat rotation, and were very similar to each other, varying by less than $2 ha^{-1}. The F-W-W rotation had a gross return that was $39 ha^{-1} higher than the GM-W-W rotation over the 3-year crop rotation cycle, but this was offset by higher production costs. The F-W-W (-N) rotation had the lowest net return per crop rotation cycle. This rotation had the lowest production costs of any of the Lethbridge rotations.

At Swift Current, the continuous wheat rotation also had the greatest net return per year at $198.56 ha^{-1}, followed by the F-W-W and the GM-W-W rotations at $119.60 ha^{-1} and $110.65 ha^{-1}, respectively (Table 3-23). The continuous wheat rotation also had the highest production costs at $385.77 ha^{-1}, compared to $274.40 ha^{-1} and $262.88 ha^{-1} for the F-W-W

Table 3-23 Economic performance of crop rotations at Swift Current, SK on a per-year basis (1987-1995)

Rotation	Gross Income	Costs	Net Income
	– \$ ha^{-1} yr^{-1} –	– \$ ha^{-1} yr^{-1} –	– \$ ha^{-1} yr^{-1} –
GM-W-W[z]	262.88	152.23	110.65
F-W-W	274.40	154.80	119.60
Cont. W	385.77	187.21	198.56

[z] F = fallow; W = wheat; GM = green manure

and GM-W-W rotations, respectively. The net returns of the F-W-W and GM-W-W rotations were quite similar, but were both substantially less than that of the continuous wheat rotation. This was due in to higher gross returns in the continuous wheat rotation, which more than offset the higher production costs, relative to the other rotations.

At both Lethbridge and Swift Current, the green manure-containing rotations produced a similar amount of net income to the fallow rotations and substantially less income than the continuous wheat treatments, although these differences were less pronounced at Lethbridge. The likely reason for this was that the green manure rotation at Lethbridge did not receive any nitrogen fertilizers, while the green manure rotation at Swift Current did.

The addition of nitrogen fertilizer can add substantially to production costs. At Lethbridge, the green manure rotation had input costs that were over \$40 ha^{-1} and \$92 ha^{-1} less than the fertilized fallow and continuous wheat rotations, respectively, on an annual basis. At Swift Current, by comparison, the fertilized green manure rotation had input costs that were less than \$3 ha^{-1} and \$35 ha^{-1} lower than the fertilized fallow and continuous wheat rotations, respectively.

At Lethbridge and Swift Current, the green manure rotations had the lowest or second-lowest production costs. These lower costs of production help to decrease financial risk to producers.

3.4.3.2 Perennial Forage Legumes

At Indian Head, the continuous wheat rotation had the highest annual net return, by far, of the three rotations at \$261.32 ha^{-1}, as compared to \$81.85 ha^{-1} and \$19.37 ha^{-1} for the F-W-W-H-H-H (-f) and continuous wheat (-f) rotations, respectively (Table 3-24). Net return for the F-W-W-H-H-H (-f) rotation was approximately one-third that of the continuous wheat rotation while the net return of the continuous wheat (-f) rotation was less than one-tenth that of the continuous wheat rotation. The cost of production associated with the continuous wheat rotation, \$484.92 ha^{-1}, was much higher than for the F-W-W-H-H-H (-f) and continuous wheat (-f) rotations, which were \$173.31 ha^{-1} and \$152.25 ha^{-1}, respectively. However, the difference in the gross return was high enough that it more than offset the higher level of production costs, and so the net return of the F-W-W-H-H-H (-f) rotation was over four times higher than that of the continuous wheat (-f) rotation.

With the rotations at Indian Head, the continuous wheat rotation was approximately three times more profitable than the F-W-W-H-H-H (-f) rotation, which was approximately four times more profitable than the continuous wheat (-f) rotation. This was largely due to the income in these rotations being based largely or totally on wheat production. It was discussed in section 3.5.2.2 how the wheat yields of the two unfertilized treatment were substantially lower than wheat yields in the continuous wheat treatment, due to over 30 years

Table 3-24 **Economic performance of crop rotations at Indian Head, SK on a per-year basis (1993-1998)**

Rotation	Gross Income	Costs	Net Income
	– $ ha^{-1} yr^{-1} –	– $ ha^{-1} yr^{-1} –	– $ ha^{-1} yr^{-1} –
F-W-W-H-H-H (-f)[z]	173.31	91.46	81.85
Cont.W (-f)	152.25	132.88	19.37
Cont.W	484.92	223.60	261.32

[z] Cont. W = continuous wheat; -f = no fertilizers applied to crops; F = fallow; H = alfalfa or alfalfa/bromegrass mixture

of continuous cropping to the same crop, and soil nutrient depletion. These lower wheat yields translated into lower net incomes, despite the fact that costs in the F-W-W-H-H-H (-f) and continuous wheat (-f) rotations were only 41% and 59%, respectively, of what they were in the continuous wheat treatment.

The W-A-A-Fx rotation at Glenlea had higher net returns per crop rotation cycle as compared to the W-P-W-Fx rotation, regardless of fertilizer/pesticide treatment (Table 3-25). The higher net returns were generally due to higher gross income levels and, more importantly, lower costs associated with the perennial forages in rotation. Within each rotation, the net return varied much less with fertilizer/pesticide treatment than between rotations, indicating that crop rotation had more of an effect on economic return than the level of crop inputs used. Generally, while gross income decreased with decreasing levels of inputs, so too did the associated costs.

The W-A-A-Fx rotation at Glenlea had annual net income levels that were $93.17 ha^{-1}

Table 3-25 Economic performance of crop rotations at Glenlea, MB (1992-1999) on a per-year basis

Rotation	Treatment	Gross Income	Costs	Net Income
		– \$ ha^{-1} yr^{-1} –	– \$ ha^{-1} yr^{-1} –	– \$ ha^{-1} yr^{-1} –
W-P-W-Fx	f-p-[z]	342.45	107.31	235.14
	f-p+	457.47	191.41	266.06
	f+p-	390.17	176.31	213.86
	f+p+	509.84	258.07	251.77
W-A-A-Fx	f-p-	439.45	89.14	350.31
	f-p+	487.53	128.30	359.23
	f+p-	472.94	138.13	334.81
	f+p+	537.35	177.05	360.30

[z] W = wheat; P = pea; Fx = flax; A = alfalfa; f = fertilizers; p = pesticides

to \$120.95 ha^{-1} higher than the W-P-W-Fx rotation, depending on treatment. This was due to both higher gross income levels and lower production costs in the W-A-A-Fx rotations. Higher gross income levels were largely a result of high alfalfa yields in the W-A-A-Fx rotation and lower wheat yields in the W-P-W-Fx rotation. Lower production costs in the W-A-A-Fx rotation were largely a result of having two years of alfalfa in the rotation. Other than seeding in the year of establishment, most of the production costs of alfalfa are allocated to harvesting, whereas pea and wheat crops normally involve numerous spraying operations, seeding costs each year, and more tillage operations to prepare the land for the next crop.

3.4.3.3 Doubling of Nitrogen Fertilizer Costs

When the price of nitrogen fertilizer was doubled in the economic analysis of the rotations in question (Table 3-26), the majority of the comparisons between the different rotations at a given site remained similar, although a number of changes were observed. At

Table 3-26 Economic performance of crop rotations on a per-year basis if nitrogen fertilizer prices double from 1996 prices

Location	Rotation	Gross Income	Costs	Net Income
		– \$ ha^{-1} yr^{-1} –	– \$ ha^{-1} yr^{-1} –	– \$ ha^{-1} yr^{-1} –
Lethbridge	GM-W-W (-N)[z]	321.71	197.04	124.67
	F-W-W (-N)	294.23	181.42	112.81
	F-W-W	360.71	291.86	68.85
	Cont.W	435.51	370.99	64.52
Swift Current	GM-W-W	262.88	189.22	73.66
	F-W-W	274.40	176.34	98.06
	Cont.W	385.77	222.43	163.34
Indian Head	F-W-W-H-H-H (-f)	173.31	91.46	81.85
	Cont.W (-f)	152.25	132.88	19.37
	Cont.W	484.92	286.15	198.77
Glenlea	W-P-W-Fx (-f-p)	342.45	107.31	235.14
	W-P-W-Fx (-f+p)	457.47	191.41	266.06
	W-P-W-Fx (+f-p)	390.17	210.39	179.78
	W-P-W-Fx (+f+p)	509.84	292.15	217.69
	W-A-A-Fx (-f-p)	439.45	89.14	350.31
	W-A-A-Fx (-f+p)	487.53	128.30	359.23
	W-A-A-Fx (+f-p)	472.94	156.53	316.41
	W-A-A-Fx (+f+p)	537.35	195.45	341.90

[z] F = fallow; W = wheat; GM = green manure; -N = no nitrogen fertilizer applied to crops; H = alfalfa or alfalfa/bromegrass mixture; P = pea; Fx = flax; A = alfalfa; f = fertilizers; p = pesticides

Lethbridge, the two rotations that did not use nitrogen fertilizer had higher net income levels than the two rotations that did use nitrogen fertilizer; this is a direct reversal of the original economic analysis conducted when all economic coefficients remained at 1996 levels. The net income levels of the F-W-W and Cont. W rotations dropped by approximately \$55 ha^{-1} yr^{-1} and \$82 ha^{-1} yr^{-1}, respectively. At Swift Current, net income dropped for each of the rotations, as nitrogen fertilizer was applied to wheat crops in all three rotations. As a result, there was no change in the order of profitability, although the difference in net income between the GM-W-W rotation and the F-W-W rotation grew from just under \$9 ha^{-1} yr^{-1} to just under \$ 25 ha^{-1} yr^{-1}, while the difference in net income between the F-W-W rotation and the Cont. W rotation dropped from approximately \$79 ha^{-1} yr^{-1} to approximately \$65 ha^{-1} yr^{-1}. In addition, the difference in net income between the GM-W-W and Cont. W rotations remained relatively unchanged. At Indian Head, the fertilized continuous wheat treatment remained the most profitable, despite a drop in net income of more than \$ 60 ha^{-1} yr^{-1}. The low yields in the unfertilized treatments were not enough to offset the increase in production costs in the fertilized continuous wheat treatment. At Glenlea, the rotation containing alfalfa remained more profitable than the annual cropping rotation. While the net income of each fertilized treatment dropped, the fertilizer treatments in the W-A-A-Fx rotation experienced a decline in net income of approximately \$ 18 ha^{-1} yr^{-1}, while net income in the fertilizer treatments in the W-P-W-Fx rotation declined by approximately \$34 ha^{-1} yr^{-1}. The difference between the rotations in net income decline was due to the fact that the fertilized treatments in the W-A-A-Fx rotation used less fertilizer than in the W-P-W-Fx rotation.

Although the calculation of rotational net income using fertilizer costs that are doubled, while all other input costs remained constant, is a rather simplistic exercise, it does illustrate an important point. As oil and gas prices increase, so does the price of crop inputs. However, this is especially true with respect to the production of nitrogen fertilizer, which is dependent on large amounts of fossil fuel energy to produce. As energy prices continue to rise, so too will the cost of nitrogen fertilizer. As a result, cropping systems containing green manure or perennial forage legumes could become more economically attractive to producers.

3.5 DISCUSSION

It was shown in the previous section that western Canadian crop rotations containing legumes had energy efficiency ratings that were equal to or greater than those rotations not containing legumes. When comparing similar three-year rotations, one containing a year of fallow and the other containing a green manure legume (e.g. F-W-W vs. GM-W-W), from the perspective of grain harvest, the comparison is quite logical. Both rotations contain two years during which a crop is harvested and energy is harvested, and one year during which no crop is harvested and no energy is harvested. As a result, comparisons between the two rotations, in terms of energy efficiency, can be easily made, though one rotation is introducing long-term soil fertility benefits into the system while the other is not.

However, comparing energy efficiency between rotations with and without forage legumes proves to be more difficult when comparing the output energy of alfalfa to that of grain crops, such as wheat or pea, there is very little difference on a per kilogram basis (Nagy, 1999). However, unlike grain crops, where only seed is harvested, the majority of aboveground biomass of alfalfa is harvested, resulting in greater amounts of biomass being included in energy calculation.

While energy efficiency can be used as a measure of environmental sustainability more often that not, it does not always tell the whole story. For example, at both Lethbridge and Swift Current, the rotations containing similarly fertilized fallow and green manure legume treatments had energy efficiencies that were not statistically different from each other. However, a long-term study conducted in Saskatchewan found that while a fallow-containing rotation experienced a steady and continuous decrease in soil nitrogen levels, a green manure-containing rotation maintained soil nitrogen levels (Campbell et al. 1991). In addition, including a year of fallow in a rotation results in a loss of soil quality, as a result of soil erosion, whereas using a green manure legume as a fallow replacement can reduce soil erosion (Biederbeck et al. 1996). All of this evidence points to fallow as being detrimental to soil quality, whereas the data in this paper showed that the fallow-containing rotations in relatively short-term studies were just as energy efficient as similarly-fertilized green manure-containing rotations. So, while the measure of the energy efficiency of a crop rotation is a very useful tool, other factors, such as time, should be used to assess the sustainability of a cropping system.

Another issue that complicates the comparisons between perennial forage legumes and annual grain rotations is the end use of the harvested products. Grain is consumed by humans and livestock, while forage legumes, such as alfalfa, are generally consumed by livestock only, specifically cattle. When taking into consideration that nine kilograms of feed are required to produced one kilogram of beef (Ensminger, 1987), one might quickly determine that any gain in energy efficiency from including perennial forage legumes in a crop rotation would be lost due to the inefficiency of feed utilization of cattle. However, manure that is produced by cattle can be used to add nutrients, including nitrogen, to the soil for subsequent crops to use. In addition, the issue is clouded further when considering one-third of the grain produced in the world is fed to livestock, mostly cattle, while in the United States, over 70 % of grain produced is fed to livestock, mostly cattle (Rifkin, 1992). Suddenly, the issue of discounting energy efficiency of forage legume-containing cropping systems due to the inefficiency of feed utilization of cattle is not as obvious as one might have originally thought.

Climatic conditions vary greatly across the Prairies, as was discussed earlier in this paper. For example, Swift Current receives approximately 180 mm less precipitation annually than Winnipeg, while having an annual average temperature that is more than 1^0C higher than Winnipeg (Campbell et al. 1990; Environment Canada, 1999). Growing perennial forage legumes in a hot, dry environment like southwestern Saskatchewan would most likely have a detrimental effect on the performance of a rotation, both in terms of economics and energy. This is because the alfalfa will generally produce low levels of herbage, and will fix limited amounts of nitrogen, in addition to depleting soil water for subsequent cereal crops (Janzen, 1987).

On the other hand, including a green manure legume in a cropping system in the drier areas of the Prairies makes much more sense. Studies have shown greater subsoil water recharge following green manures than wheat (Biederbeck and Bouman, 1994). In most years, yields of subsequent cereal crops should not be adversely affected by green manure legumes in the rotation, resulting in the maintenance or enhancement of economic performance and energy efficiency of rotations in drier regions of the Prairies.

By designing crop rotations that make the best use of the available resources in a region, rotational economic performance and energy efficiency can be improved through decreased levels of inputs, in addition to increased yields. Including perennial forage legumes in a crop rotation in south-central Manitoba would likely provide a benefit to subsequent grain yields. Part of this yield benefit is due to the nitrogen fixed by those legumes. Kelner et al. (1997) found that three-year stands of alfalfa provided nearly 140 kg N ha^{-1} to the soil for a subsequent crop to use, which would result in a dramatic reduction in the nitrogen fertilizer requirement for a subsequent crop. This reduction in the amount of fertilizer required would result in lower input costs and lower levels of input energy, while at the same time, maintaining crop yields. The end result would be an improvement in economic and energy efficiency of the cropping system.

4. Relay Intercropping and Double Cropping Green Manure Legume Cover Crops with Winter Cereals in Southern Manitoba

4.1 ABSTRACT

When relay intercropping and double cropping green manure legumes with winter cereals, nitrogen benefits of the legumes can be realized within a continuous crop rotation. The rotational benefits of relay intercropped and double cropped green manure legumes in continuous grain systems in Manitoba were investigated. Relay intercrops were seeded into winter cereals, and double crops were seeded within four days of winter cereal harvest at Winnipeg and Carman, MB. Relay intercrops included alfalfa and red clover, while double crops included chickling vetch and black lentil. Winter cereals included winter wheat and fall rye. Fertilizer replacement values (FRV) of the relay intercropped and double cropped legumes to a succeeding oat crop at Winnipeg ranged from 23 kg N ha^{-1} to 62 kg N ha^{-1}, while legume FRV at Carman ranged from -27 kg N ha^{-1} to 22 kg N ha^{-1}. Reduced legume growth at Carman, due to drought conditions, resulted in negative yield responses from the relay intercropped legumes and small yield benefits from the double cropped legumes. Including relay intercropped and double cropped green manure legumes in continuous grain rotations reduced energy use by up to 39%, and increased energy use efficiency by up to 28%. Increasing the frequence of legumes in cropping systems shows promise to enhance agricultural sustainability.

4.2 INTRODUCTION

It has long been recognized that including a green manure or forage legume in a crop rotation can enhance the productivity of a succeeding non-legume crop (Hesterman, 1988). However, including legumes in a crop rotation as green manures or perennial forages results in a lack of grain harvest from the land during those years. Through multiple cropping with legumes, the benefits of a legume in rotation can be attained while maintaining continuous grain production. In a multiple cropping system, the forage legume is a secondary crop that is put in place once the primary crop of the growing season is well-established or harvested. Two primary types of multiple cropping with legumes is relay intercropping and double cropping. Relay intercropping is a system in which there are two crops in the field at the same time for a portion of the growing season (Moomaw et al. 1991a). The relay crop is no-till planted or broadcast seeded into the winter cereal in early spring. Double cropping is a multiple cropping system in which there are two crops grown in succession in the same field in the same season; there is no overlap between the two crops as there is with relay intercropping (Moomaw et al. 1991b). In Canada and the United States, the first crop in relay intercropping and double cropping has typically been a winter cereal. Winter cereals are harvested approximately two weeks to one month earlier than spring cereals, allowing for a greater window of opportunity for a second crop to make use of available resources remaining in the growing season.

Previous work in the United States has shown the benefits of relay intercropping and double cropping with legumes. In a Michigan study, FRV's of alfalfa and red clover relay intercropped into winter wheat in spring ranged from 32 to 51 kg N ha^{-1} for alfalfa and from 50 to 108 kg N ha^{-1} for red clover, to a succeeding corn crop (Hesterman et al. 1992). The authors of a New Mexico study which examined the effect of relay intercropping hairy vetch, barrel medic, alfalfa, black lentil and red clover with corn found that FRV's to a succeeding sorghum crop from alfalfa and hairy vetch ranged from 78 kg N ha^{-1} to 140 kg N ha^{-1}, and ranged from 10 kg N ha^{-1} to 72 kg N ha^{-1} for the barrel medic, red clover and black lentil (Guldan et al. 1997). In a Kentucky study, hairy vetch, and bigflower vetch were broadcast seeded into a standing corn crop shortly before harvest, closely approximating a true double cropping system (Blevins et al. 1990). The FRV's for hairy vetch and bigflower vetch to a succeeding corn crop were 75 kg N ha^{-1} and 65 kg N ha^{-1}, respectively, and 125 kg N ha^{-1} and 135 kg N ha^{-1} in a succeeding sorghum crop, respectively (Blevins et al. 1990). The authors of a study conducted in North Carolina which examined the effect of double cropping crimson clover and hairy vetch after corn found that the FRVs to a succeeding corn crop were 40 kg N ha^{-1} to 45 kg N ha^{-1} for the crimson clover and hairy vetch, respectively (Wagger, 1989). A study conducted in Maine examined the effect of double cropping a mixture of hairy vetch and winter rye after barley. The nitrogen FRV to a subsequent corn crop ranged from 120 kg N ha^{-1} to 151 kg N ha^{-1} (Griffin et al. 2000). While the values described here may be higher than what could be expected on the Canadian Prairies due to the shorter growing season, double cropping forage legumes on the Canadian Prairies should still add nitrogen to the soil for subsequent non-legume crops to use

Prior work has been done to show the nitrogen benefits of shorter-term legume stands on the Canadian Prairies. Kelner and Vessey (1995) examined nitrogen fixation and growth of one-year stands of non-dormant alfalfa in Manitoba and found that the variety "Nitro" contributed an average of 121.4 kg N/ha to the soil after only one season of growth. An experiment conducted by Biederbeck et al. (1996) examined the nitrogen benefits from a number of green manure legumes, grown for a six-to-seven week period, to a succeeding spring wheat crop. The average amount of nitrogen fixed was 18, 16, 49, and 40 kg N/ha for black lentil, Tangier flatpea, chickling vetch, and pea, respectively (Biederbeck et al. 1996). These results show that a shorter-term stands of legumes can be a viable option to green manure on the Prairies, in areas with sufficient precipitation. The advantage of multiple cropping with legumes is that a producer does not have to sacrifice a year of grain cropping, while achieving the same goals as with a green manure crop, with respect to factors such as nitrogen addition and weed control. By utilizing the nitrogen provided by multiple cropping with legumes, nitrogen fertilizer use could be decreased, thereby decreasing commercial energy use within such rotations.

4.3 MATERIALS AND METHODS

4.3.1 Experimental Design

Relay intercropping and double cropping trials were conducted at two sites, the University of Manitoba research station situated at Winnipeg, Manitoba (49° 88'N, 97° 14'W) on a Black Lake clay soil (Cumulic Regosol), and the University of Manitoba research station located at Carman, Manitoba (49° 49'N, 98° 00'W), on a Hochfeld fine sandy loam soil (Orthic Black Chernozem). Trials were conducted in a split-plot design with four replications.

Main plots were one of two winter cereals, either winter wheat (cv. CDC Kestral) or fall rye (cv. Puma), seeded in late summer of 1997. Three 2-year crop rotations were examined: a winter cereal-oat (cv. OT288). rotation, a winter cereal-oat rotation containing a legume relay crop, and a winter cereal-oat rotation with a legume double crop. Sub-plots were relay- or double- cropped legumes, seeded either into the winter cereals in the spring or immediately after cereal grain harvest. Spring seeded legumes included alfalfa (cv. Nitro) and red clover (cv. common). Double-cropped legumes included black lentil (cv. Indianhead) and chickling vetch (cv. AC Greenfix). Subplots were 2m × 6m. A number of blank treatments (winter cereal-oat) were also included as sub-plots, for the purpose of carrying out a fertilizer replacement value study in 1999.

4.3.2 Field Management

All crops in the experiment were seeded using a Fabro (Swift Machinery Co., Swift Current, SK) no-till offset disc drill. In preparation for the trial, winter cereals were planted in Winnipeg on 4 September, 1997, and in Carman on September 8, 1997. The winter wheat was seeded at a rate of 98 kg ha^{-1}, while the fall rye was seeded at a rate of 93 kg ha^{-1}. Mono-ammonium phosphate fertilizer (11-52-0) was placed with the seed in all winter cereal plots at a rate of 20 kg P_2O_5 ha^{-1}.

Ammonium nitrate fertilizer (34-0-0) was broadcast applied to main crops at a rate of 80 kg N ha^{-1} at Carman on April 27, 1998, and 82 kg N ha^{-1} at Winnipeg on April 29. All fertilizer applications were based on soil test recommendations, analyzed by Norwest Labs (Winnipeg, MB). In the relay cropping system, the legumes were direct seeded into the winter cereals on May 1 at Winnipeg, and May 8 in Carman. The alfalfa was seeded at a rate of 10 kg ha^{-1}, and a seeding rate of 12 kg ha^{-1} was used for the red clover. Nitragin Gold *Rhizobium* inoculants (LiphaTech, Milwaukee, WI) were used to inoculate the alfalfa at time of seeding and pre-inoculate the red cover. On June 8, propiconazole was applied to the winter wheat at Winnipeg at the recommended rate of 0.5 L ha^{-1} in order to control tanspot leaf disease.

Grain yield was determined by threshing a 1.8m × 4m area in each plot using a small plot combine. Fall rye was harvested at Carman with a Wintersteiger plot combine (Wintersteiger Inc., Salt Lake City, UT) and Winnipeg with a Hege plot combine (Hege Equipment Inc., Colwich, KS) on July 27. Winter wheat was harvested on August 5 at Carman and Winnipeg. Cereal cutting height was approximately 20 cm, and straw was removed from the plot immediately after harvest. After threshing, samples were cleaned and weighed and yield per hectare was calculated.

The legume double crops (black lentil and chickling vetch) were the direct seeded into the harvested fall rye plots in Carman on July 29 and in Winnipeg on July 31, and into harvested winter wheat plots on August 6. The chickling vetch was seeded at a rate of 93 kg ha^{-1}, and a seeding rate of 43 kg ha^{-1} was used for the black lentil. The legume double crops were inoculated at time of seeding with Soil Implant+ *Rhizobium* inoculants (LiphaTech, Milwaukee, WI). The double crop plots in Carman and Winnipeg were sprayed with 5 L ha^{-1} of glyphosate to control weeds on July 31. On September 15, all legume relay and double crop plots at Carman were sprayed with 2.7 L ha^{-1} of sethoxydim to control grassy weeds.

In 1999, oats were seeded into the plots at a rate of 91.6 kg ha^{-1} at Carman on May 26, and at Winnipeg on May 28. Triple super phosphate fertilizer (0-46-0) was placed with the seed at a rate of 55 kg P_2O_5 ha^{-1}. The plots were sprayed with 5 L ha^{-1} glyphosate and 1 L ha^{-1} 2,4-D to control grassy and broadleaf weeds, as well as volunteer cereals. Plots not containing legumes during the previous growing season received broadcast fertilizer applications of ammonium nitrate (34-0-0) at rates of 0, 40, 80 and 120 kg N ha^{-1} on June 7 at Carman and June 8 at Winnipeg. The oats at the Carman site were sprayed with 0.5 kg ha^{-1} propanil and 0.02 kg ha^{-1} thiensulfuron/tribenuron to control broadleaf weeds on 17 June.

Grain yield was determined by threshing 1.8m × 4m area in each plot using a small plot combine. The oats were harvested with a Wintersteiger plot combine at Carman on September 17, and with a Hege plot combine at Winnipeg on September 19. After threshing, samples were cleaned and weighed and yield per hectare was calculated.

4.3.3 Plant sampling procedures

Measurements taken included legume plant population density and dry matter production. Legume plant density was measured on two × 1 m lengths of row within each plot. Measurements were taken on July 13.

Legume dry matter was measured by hand-clipping (at ground level) three × 1 m lengths of row at cereal harvest (late July/early August), and on October 16 (Winnipeg) and October 24 and 26 (Carman), corresponding approximately to the end of the growing season, or freeze-up.

4.3.4 Statistical analysis

Main crop yields within each location were analyzed using analysis of variance (SAS Institute, Inc., 1985). Winter cereal yields were analyzed in a split-plot design with winter cereal grown (winter wheat or fall rye) as the main plot effect and relay crop legume (red clover, alfalfa, or no legume) as the subplot effect. Where significant differences in winter cereal yields at each site were observed, Tukey's *w* Procedure Least Significant Difference test (LSD) was used to measure differences (Steel et al. 1997).

Oat yields within each location were analyzed using analysis of variance (SAS Institute, Inc., 1985). Oat yields were analyzed in a split-plot design with winter cereal grown the previous year (winter wheat or fall rye) as the main plot effect and nitrogen source (inorganic nitrogen fertilizer or legume relay/double crop) as the subplot effect. Where significant differences in energy use and energy use efficiency among the different rotations at each site were observed, Tukey's *w* Procedure LSD test was used to measure differences (Steel et al. 1997).

4.3.4 Fertilizer replacement values of legumes

Fertilizer replacement values were calculated in order to approximate nitrogen benefits to succeeding non-legume crops from the relay intercropped legumes and double cropped legumes. Fertilizer response curves were generated by running quadratic regressions for each site using oat yield data from the treatments receiving 0, 40, 80, and 120 kg N ha^{-1} of inorganic nitrogen fertilizer. Oat yields from the relay intercropped and doublecropped legumes were then plotted on the fertilizer response curve, using the equation generated by the slope of the curve, in order to calculate the fertilizer replacement values of the different legumes (Lory et al. 1995).

4.4 RESULTS

4.4.1 Legume Relay Intercrop Densities

Legume relay intercrop densities were analyzed for each site (Table 4-1). At both Carman and Winnipeg, there were no significant differences in relay intercrop legume densities as affected by winter cereal type.

Table 4-1 **Legume cover crop densities by main crop and cover crop at winter cereal harvest at Carman (July 29) and Winnipeg, MB (July 31)**

Rotation	Legume density	
	– plants m^{-2} –	
	Carman	Winnipeg
Main crop		
winter wheat	75	198
fall rye	69	164
Cover crop		
control	-	-
red clover (relay crop)	89	250 a[z]
alfalfa (relay crop)	55	112 b
LSD	-	66
C.V.	42.1	29.8
Significance (Pr>F)		
Block (B)	0.0804[y] NS[x]	0.2593 NS
Main Crop (MC)	0.7371 NS	0.2594 NS
B*MC	0.2888 NS	0.1657 NS
Cover Crop (CC)	0.0659 NS	0.0022 **
MC*CC	0.5906 NS	0.6241 NS

[z] Main crop and cover crop means followed by different letters at the same site are significantly different

[y] The df for effects of B, MC, B*MC, CC and MC*CC are 3, 1, 3, 1 and 1, respectively

[x] NS = not significant; ** = Significant at the 0.01 level

Overall, the densities of relay intercropped legumes at Winnipeg were more than two times greater than at Carman. A possible reason for the difference between sites was that the heavy clay soil at Winnipeg allowed for greater water holding capacity than the sandy soil at Carman. Also, spring precipitation levels were greater at Winnipeg (appendix Table B-2) providing more water to the legumes at emergence. Alfalfa and red clover are legumes that use relatively large amounts of water (Zentner et al. 1996; Clark, 1998).

Red clover densities were approximately 223% and 62% greater than that of alfalfa at Winnipeg and Carman, respectively (Table 4-1), but were significantly different from alfalfa densities at Winnipeg only. Hesterman et al. (1992) examined the dynamics of a number of legumes intercropped with small grains, and found that "Nitro" alfalfa, used in this trial, had a lower plant density than red clover at all experimental sites. It has also been noted that when seeded together as a legume mixture, red clover can become the predominant species, and in addition, red clover tends to be more shade tolerant than alfalfa (Smith, 1978). All of these factors suggest that red clover may be more competitive in a relay intercropping system.

4.4.2 Winter Cereal Yields

There were significant differences in grain yield between the two winter cereals (Table 4-2). At both the Carman and Winnipeg sites, fall rye yielded significantly higher than winter wheat. Yields for both winter wheat and fall rye were higher at the Carman site.

Winter cereal yields were also analyzed to examine the influence of legume cover crops. At both sites, there were no significant differences in cereal yields whether either legume cover crop was present in the cereal stand or not, though small yield reductions due

Table 4-2 **Winter cereal yields by main crop and cover crop at winter cereal harvest at Carman (July 29) and Winnipeg, MB (July 31)**

Rotation	winter cereal yield	
	– kg ha^{-1} –	
	Carman	Winnipeg
Main crop		
winter wheat	3200 b[z]	2300 b
fall rye	5300 a	4000 a
LSD	954	500
Cover crop		
control	4400	3300
red clover (relay crop)	4200	3100
alfalfa (relay crop)	4100	3000
C.V.	20.6	12.0
Significance (Pr>F)		
Block (B)	0.2185[y] NS[x]	0.0089 **
Main Crop (MC)	0.0001 **	0.0001 **
B*MC	0.5657 NS	0.3784 NS
Cover Crop (CC)	0.7278 NS	0.3023 NS
MC*CC	0.2480 NS	0.9467 NS

[z] Main crop and cover crop means followed by different letters at the same site are significantly different
[y] The df for effects of B, MC, B*MC, CC and MC*CC are 3, 1, 3, 1 and 1, respectively
[x] NS = not significant; ** = Significant at the 0.01 level

to the presence of the underseeded legumes were observed in most instances.

4.4.3 Legume dry matter production at cereal harvest

Legume relay intercrop dry matter production at time of main crop winter cereal harvest was analyzed for each site (Table 4-3). Legume dry matter production did not differ significantly between the main crops at either site.

At the time of winter cereal harvests, the dry matter production of the red clover was significantly higher than that of the alfalfa at Carman. However, no significant differences in legume dry matter production were evident at Winnipeg. As was previously discussed in section 4.4.1, "Nitro" alfalfa did not perform as well under relay intercropping competition conditions as red clover did (Hesterman et al. 1992), and that red clover tends to be more shade tolerant than alfalfa (Smith, 1978). These factors may have caused lower dry matter yields of alfalfa at the time of winter cereal harvest.

4.4.4 Legume dry matter production at fall freeze-up

Legume dry matter production at the end of the growing season was analyzed for each site (Table 4-4). There was no significant difference between main crop type for legume dry matter at either site. Overall, legume dry matter production at the end of the growing season at Winnipeg was more than three times greater than at Carman, and this difference was attributed to greater water availability.

Dry matter production of the two relay intercropped legumes, red clover and alfalfa, and the two double cropped legumes, chickling vetch and lentil, were analyzed for each site. At both Carman and Winnipeg, red clover had significantly higher dry matter production than all other legumes. At both sites, there were no significant differences in dry matter

Table 4-3 **Legume cover crop dry matter production by main crop and cover crop at winter cereal harvest at Carman (July 29) and Winnipeg, MB (July 31)**

Rotation	legume dry matter	
	– kg ha^{-1} –	
	Carman	Winnipeg
Main crop		
winter wheat	140	820
fall rye	30	160
Cover crop		
red clover (relay crop)	120 a[z]	600
alfalfa (relay crop)	50 b	300
LSD	2.0	-
C.V.	60.4	95.1
Significance (Pr>F)		
Block (B)	0.5695[y] NS[x]	0.4934 NS
Main Crop (MC)	0.1071 NS	0.1388 NS
B*MC	0.0711 NS	0.2162 NS
Cover Crop (CC)	0.0298 *	0.1962 NS
MC*RC	0.0642 NS	0.3204 NS

[z] Main crop and cover crop means followed by different letters at the same site are significantly different

[y] The df for effects of B, MC, B*MC, CC and MC*CC are 3, 1, 3, 1 and 1, respectively

[x] NS = not significant; * = Significant at the 0.05 level

Table 4-4 **Legume cover crop dry matter production by main crop and cover crop at Carman (October 24 and 26) and Winnipeg, MB (October 16)**

Rotation	legume dry matter	
	– kg ha^{-1} –	
	Carman	Winnipeg
Main crop		
winter wheat	1000	3100
fall rye	900	3700
Cover crop		
red clover (relay crop)	1800 a[z]	4600 a
alfalfa (relay crop)	600 b	3100 b
chickling vetch (double crop)	1100 b	3000 b
lentil (double crop)	600 b	3000 b
LSD	600	1300
C.V.	44.8	25.7
Significance (Pr>F)		
Block (B)	0.3414[y] NS[x]	0.3527 NS
Main Crop (MC)	0.7248 NS	0.0613 NS
B*MC	0.1539 NS	0.3099 NS
Cover Crop (CC)	0.0001 **	0.0039 **
MC*CC	0.6878 NS	0.1746 NS

[z] Main crop and cover crop means followed by different letters at the same site are significantly different

[y] The df for effects of B, MC, B*MC, CC and MC*CC are 3, 1, 3, 1 and 1, respectively

[x] NS = not significant; ** = Significant at the 0.01 level

production between the remaining three legumes: alfalfa, chickling vetch, and lentil.

4.4.5 Oat yields

Yields of oats grown on fall rye stubble were slightly higher than for oats grown on winter wheat stubble, although the difference was significant at Winnipeg only (Table 4-5). This difference may be due to the fact that the fall rye was harvested approximately one week prior to the winter wheat. This extra week of legume growth would have resulted in extra nitrogen fixation that would not have occurred in the winter wheat plots, thereby providing extra nitrogen to the succeeding oat crop in the fall rye plots, which resulted in higher yields. Another reason for this difference may relate to nutrient levels in the soil. Winter wheat

Table 4-5 Effect of previous winter cereal crop on oat yield (1999)

Previous cereal	Oat yield	
	– kg ha^{-1} –	
	Carman	Winnipeg
winter wheat	4500	2900 b[z]
fall rye	4500	3200 a
C.V.	11.0	-
LSD	-	200
Significance (Pr>F)		
Previous cereal	0.4789[y] ns[x]	0.0003 **

[z] Means followed by different letters at the same site are significantly different
[y] The df for effect of Previous Cereal is 1
[x] NS = not significant; ** = Significant at the 0.01 level

requires higher rates of nitrogen fertilizer for adequate production than fall rye does (Manitoba Agriculture, 1998), therefore, the winter wheat plots would likely be more depleted of nitrogen than the fall rye plots, leading to lower oat yields in the following growing season.

Oat yields varied between the treatments at each site. However, the range was much greater at Winnipeg than at Carman (Table 4-6). The average oat yield in Manitoba from 1990 to 1997 was 2477 kg ha^{-1} (Manitoba Agriculture, 1997). At both sites, the highest and second-highest oat yields occurred where 120 kg ha^{-1} and 80 kg ha^{-1} of fertilizer nitrogen were applied, respectively. At both sites, the lowest oat yields occurred in the control treatment and where red clover had been present the previous year. However, at Winnipeg, the red clover treatment out- yielded the control treatment, while the control treatment out-yielded the red clover at Carman. When comparing oat yields of the different treatments, the plots that received 120 kg N ha^{-1} or 80 kg N ha^{-1} had higher yields than the legume treatments, while the 40 kg N ha^{-1} treatment had higher yields than the legumes in all instances, with the exception of the alfalfa treatment at Winnipeg. These differences are likely due to nitrogen. Kelner et al. (1997) found that a one-year stand of alfalfa could add 84 kg N ha^{-1} to the soil in Manitoba, while Biederbeck et al. (1996) found that green manure crops of lentil and chickling vetch added 18 kg N ha^{-1} and 49 kg N ha^{-1}, respectively, to the soil. Therefore, it is not entirely unexpected that yields of oats where legumes were actively growing for the last 3 months of the growing season would, for the most part, be somewhere in between those yields where 0 kg N ha^{-1} and 40 kg N ha^{-1} were applied.

There were large differences in oat yields between the two sites, with yields for all

Table 4-6 Effect of nitrogen source (legume cover crop or fertilizer) on oat yield

Nitrogen source (for oats)	Oat yield	
	– $kg\ ha^{-1}$ –	
	Carman	Winnipeg
Cover crop		
red clover (relay crop)	3600	2500
alfalfa (relay crop)	4100	3200
chickling vetch (double crop)	4500	2900
lentil (double crop)	4300	2700
Fertilizer		
0 $kgN\ ha^{-1}$	4100	1600
40 $kgN\ ha^{-1}$	5000	3000
80 $kgN\ ha^{-1}$	5100	3900
120 $kgN\ ha^{-1}$	5300	4500

treatments substantially larger at Carman than at Winnipeg. Soil tests done in April 1998 found almost identical levels of available soil nitrogen at the two sites. However, alfalfa was grown at Carman a number of years previous to this experiment, so organic soil nitrogen, which is not accounted for in available soil nitrogen tests, may have contributed to the higher yields at Carman. Forster (1999) and Hoyt (1990) found that yield benefits to wheat crops from alfalfa occurred up to 6 and 13 years, respectively, after alfalfa.

When contrasting oat yields as influenced by legume nitrogen source to oat yield as influenced by application 40 kg N ha^{-1} of fertilizer, significant differences were observed at

Table 4-7 **Contrast comparison of oat yields from fertilizer treatments against oat yields from legume nitrogen sources at Winnipeg, MB (1998)**

Contrast	F-value	Pr>F
0 kg N ha^{-1} vs. red clover	51.11	<.0001 **[z]
0 kg N ha^{-1} vs. alfalfa	98.92	<.0001 **
0 kg N ha^{-1} vs. chickling vetch	65.48	<.0001 **
0 kg N ha^{-1} vs. lentil	35.21	<.0001 **
40 kg N ha^{-1} vs. red clover	128.70	0.0001 **
40 kg N ha^{-1} vs. alfalfa	73.07	0.0001 **
40 kg N ha^{-1} vs. chickling vetch	108.21	0.0001 **
40 kg N ha^{-1} vs. lentil	157.77	0.0001 **
80 kg N ha^{-1} vs. red clover	4.47	0.0401 *
80 kg N ha^{-1} vs. alfalfa	0.47	0.4982 NS
80 kg N ha^{-1} vs. chickling vetch	1.37	0.2477 NS
80 kg N ha^{-1} vs. lentil	11.08	0.0017 **
120 kg N ha^{-1} vs. red clover	55.33	0.0001 **
120 kg N ha^{-1} vs. alfalfa	21.55	0.0001 **
120 kg N ha^{-1} vs. chickling vetch	42.20	0.0001 **
120 kg N ha^{-1} vs. lentil	74.90	0.0001 **

[z] NS = not significant; * = significant at the 0.05 level; ** = significant at the 0.01 level

both Winnipeg (Table 4-7) and Carman (Table 4-8). At Winnipeg, all yields from the legume treatments were significantly different from the yields of the treatments that were fertilized with 0, 40, and 120 kg N ha^{-1}. However, the oat yields from the alfalfa and chickling vetch legume treatments at Winnipeg were not significantly different from the yields of oats fertilized with 80 kg N ha^{-1}, indicating that the alfalfa and chickling vetch provided similar yield enhancement as 80 kg N ha^{-1} of nitrogen fertilizer. At Carman, yields from the legume treatments did not differ significantly from the 0 kg N ha^{-1} treatment, and were significantly different from the yields of the treatments that were fertilized with 40 and

Table 4-8 Contrast comparison of oat yields from fertilizer treatments against oat yields from legume nitrogen sources at Carman, MB (1998)

Contrast	F-value	Pr>F
0 kg N ha^{-1} vs. red clover	0.72	0.3992 NS[z]
0 kg N ha^{-1} vs. alfalfa	0.03	0.8550 NS
0 kg N ha^{-1} vs. chickling vetch	2.84	0.0988 NS
0 kg N ha^{-1} vs. lentil	3.17	0.0819 NS
40 kg N ha^{-1} vs. red clover	15.82	0.0003 **
40 kg N ha^{-1} vs. alfalfa	21.57	<.0001 **
40 kg N ha^{-1} vs. chickling vetch	9.87	0.0030 **
40 kg N ha^{-1} vs. lentil	43.66	<.0001 **
80 kg N ha^{-1} vs. red clover	7.41	0.0092 **
80 kg N ha^{-1} vs. alfalfa	11.49	0.0015 **
80 kg N ha^{-1} vs. chickling vetch	3.56	0.0655 NS
80 kg N ha^{-1} vs. lentil	28.66	<.0001 **
120 kg N ha^{-1} vs. red clover	11.16	0.0017 **
120 kg N ha^{-1} vs. alfalfa	16.07	0.0002 **
120 kg N ha^{-1} vs. chickling vetch	6.28	0.0159 *
120 kg N ha^{-1} vs. lentil	35.66	<.0001 **

[z] NS = not significant; * = significant at the 0.05 level; ** = significant at the 0.01 level

120 kg N ha^{-1}. Therefore, legumes provided limited yield benefits to subsequent oat crops at this site. Yields from the chickling vetch treatment also did not differ significantly from oat yields of the treatment that received 80 kg N ha^{-1}. However, the level of non-significance (P = 0.0655) was lower than for the comparison with the 0 kg N ha^{-1} treatment (P = 0.0988), indicating a stronger relationship between chickling vetch and the 0 kg N ha^{-1} treatment.

4.4.6 Energy use, production and efficiency

4.4.6.1 Energy use Energy use varied by 3% or less between the winter wheat and fall rye systems at Winnipeg and Carman (Tables 4-9; 4-10). When the various nitrogen treatments

Table 4-9 Energy use (MJ ha^{-1}) of the fertilizer and legume cover crop treatments in the winter wheat-oat rotation at Winnipeg and Carman, MB (1997-1999)

	Nitrogen fertilizer treatments (kg N ha^{-1})				Relay intercrops and double crops			
	0	40	80	120	A[z]	RC	IH	CV
seed	1380	1380	1380	1380	1451	1466	1523	2034
machinery	531	531	531	531	568	568	580	580
fuel	2188	2188	2188	2188	2313	2313	2361	2361
pesticides	1524	1524	1524	1524	1524	1524	2429	2429
fertilizers	6553	9242	11908	14598	6553	6553	6553	6553
total	12176	14865	17531	20221	12409	12424	13446	13957

[z] A - alfalfa; RC - red clover; IH - lentil; CV - chickling vetch

Table 4-10 Energy use (MJ ha^{-1}) of the fertilizer and legume cover crop treatments in the fall rye-oat rotation at Winnipeg and Carman, MB (1997-1999)

	Nitrogen fertilizer treatments (kg N ha^{-1})				Relay intercrops and double crops			
	0	40	80	120	A[z]	RC	IH	CV
seed	1396	1396	1396	1396	1467	1482	1539	2050
machinery	519	519	519	519	556	556	568	568
fuel	2141	2141	2141	2141	2266	2266	2313	2313
pesticides	1214	1214	1214	1214	1214	1214	2120	2120
fertilizers	6553	9242	11908	14598	6553	6553	6553	6553
total	12174	14864	17530	20219	12056	12071	13093	13604

[z] A - alfalfa; RC - red clover; IH - lentil; CV - chickling vetch

are compared, the treatment that was fertilized with 120 kg N ha^{-1} consumed the most energy, while the control treatment consumed the least energy. The legume treatments used between 61% and 68% of the energy that the 120 kg N ha^{-1} treatment used, respectively. The two 40 kg N ha^{-1} and 80 kg N ha^{-1} treatments used 74% and 87% of the energy that the 120 kg N ha^{-1} treatment used, respectively. Energy use of the treatments did not differ greatly, except where nitrogen fertilizer rates varied. Fertilizers accounted for 62% to 73% of total rotational energy use, where nitrogen fertilizer was added to the oats. Fertilizers accounted for between 47% and 55% of the total rotational energy requirement in the treatments where the oats were not fertilized, because the winter wheat and fall rye received nitrogen fertilizer in all of the treatments.

Energy costs for the alfalfa and red clover treatments were approximately 90% of the lentil and chickling vetch treatments. Higher energy use by double crops is because they require more energy to produce seed than alfalfa or red clover. In addition, plots where lentil and chickling vetch were double cropped received an extra herbicide application immediately prior to legume seeding, thereby increasing energy consumption.

4.4.6.2 Energy Production in Harvested Grain There were significant differences in energy production when comparing the various nitrogen source treatments at both sites (Table 4-11). At Winnipeg, energy production by the treatments receiving 120 kg N ha^{-1} and 80 kg N ha^{-1} were significantly higher than the other treatments. The 40 kg N ha^{-1} treatment, along with the four legume treatments, did not differ significantly from each other in terms of energy production. The control treatment produced significantly less energy than any other treatment at Winnipeg. At Carman, there were fewer significant differences between

Table 4-11 **Total energy production of harvested grain of fall rye/winter wheat-oat rotation by nitrogen source and previous cereal (1998-1999)**

Main effect	– MJ ha^{-1} –	
Nitrogen source (for oats)	Carman	Winnipeg
red clover (relay crop)	148400 c[z]	105500 b
alfalfa (relay crop)	155100 c	116400 b
chickling vetch (double crop)	168900 abc	116100 b
lentil (double crop)	164800 abc	113200 b
0 kgN ha^{-1}	160700 bc	90900 c
40 kgN ha^{-1}	178000 ab	119800 b
80 kgN ha^{-1}	180900 ab	136400 a
120 kgN ha^{-1}	184000 a	148500 a
LSD	22300	14300
Previous cereal		
winter wheat	146400 b	100300 b
fall rye	188800 a	136300 a
LSD	7100	4500
Significance (Pr>F)		
Block	0.0018[y] **[x]	0.0001 **
Previous cereal (Pc)	0.0001 **	0.0001 **
Nitrogen source (Ns)	0.0001 **	0.0001 **
Pc*Ns	0.3762 ns	0.8488 ns

[z] Means followed by different letters at the same site are significantly different

[y] The df for effect of Block, Pc, Ns and Pc*Ns are 3, 1, 7, and 7, respectively

[x] ** = Significant at 0.01 level

the treatments. Once again, the 120 kg N ha^{-1} treatment produced the most energy, but differed significantly only from the alfalfa, red clover, and control treatments.

Energy production did not vary by more than 20% at Carman and, with the exception of the treatment where the oats were not fertilized, did not vary by more than 29% at Winnipeg. This was because the winter cereals that were grown during the previous season were fertilized the same across treatments, so energy production from the first year of the system was similar for each treatment. Differences occurred in the second year, when varying rates of nitrogen and legume nitrogen were used by the oats.

At both Carman and Winnipeg, the system containing fall rye produced significantly more energy that the winter wheat system averaged over all the treatments. This observation was attributed to two factors. Firstly, rye and wheat seed contain almost identical amounts of energy per unit weight (Nagy, 1999), yet fall rye yields were higher than winter wheat yields in the first year of the system. Secondly, oat yields in the second year of the system were higher where fall rye had been grown previously.

4.4.6.3 Energy Use Efficiency There were few significant differences in energy use efficiency (Table 4-12). This is because energy use and energy production did not vary greatly between treatments, as the winter cereal crops were treated similarly in all treatments. However, there were some differences of note. At Carman, the alfalfa, chickling vetch and lentil treatments all had higher energy efficiencies than where nitrogen fertilizer was applied at either 80 kg N ha^{-1} or 120 kg N ha^{-1}. At Winnipeg, the alfalfa system was more energy efficient than any of the treatments with nitrogen fertilizer applied, while the red clover treatment was more energy efficient than the treatment that received 120 kg N ha^{-1}. This

Table 4-12 **Energy use efficiency of fall rye/winter wheat-oat rotation by nitrogen source and previous cereal (1998-1999)**

Main effect	– Energy output energy input $^{-1}$ –	
Nitrogen source (for oats)	Carman	Winnipeg
alfalfa (relay crop)	12.6 a[z]	9.5 a
red clover (relay crop)	12.1 ab	8.6 ab
chickling vetch (double crop)	12.2 a	8.4 abc
lentil (double crop)	12.4 a	8.5 abc
0 kgN ha^{-1}	13.4 a	7.6 bc
40 kgN ha^{-1}	12.1 ab	8.1 bc
80 kgN ha^{-1}	10.4 bc	7.8 bc
120 kgN ha^{-1}	9.2 c	7.4 c
LSD	1.7	1.1
Previous cereal		
winter wheat	10.5 b	7.1 b
fall rye	13.2 a	9.4 a
LSD	0.6	0.4
Significance (Pr>F)		
Block	0.0059[y] **[x]	0.0001 **
Previous cereal (Pc)	0.0001 **	0.0001 **
Nitrogen source (Ns)	0.0001 **	0.0001 **
Pc*Ns	0.2555 ns	0.2395 ns

[z] Means followed by different letters at the same site are not significantly different

[y] The df for effect of Block, Pc, Ns and Pc*Ns are 3, 1, 7, and 7, respectively

[x] ** = Significant at 0.01 level

corresponds to findings in the previous paper, in which it was found that having green manure legumes in rotation maintained or increased energy use efficiency in western Canadian cropping systems. The legumes provided similar yields to some of the fertilized treatments, while increasing energy use efficiency.

There were few significant differences in energy use efficiency between treatments at either site. At both sites, the 120 kg N ha^{-1} treatment had the lowest energy use efficiency. At Carman, the 120 kg N ha^{-1} treatment differed significantly from all others except the 80 kg N ha^{-1} treatment, while differing significantly from only the alfalfa and red clover treatments at Winnipeg. The alfalfa treatment had a significantly higher energy use efficiency rating than the 40 kg N ha^{-1} treatment at Winnipeg, however, the difference was not significant at Carman.

At both sites, the fall rye system had a significantly higher energy use efficiency than the winter wheat system. Both the fall rye and winter wheat systems at Carman were more energy efficient than they were at Winnipeg, and this increase was once again attributed to higher grain yields at Carman.

4.4.7 Fertilizer Replacement Values of the Legumes

The legume fertilizer replacement values (FRV) at Winnipeg were substantially higher than at Carman (Table 4-13). For example, at Winnipeg, the FRV of the alfalfa was 51 kg N ha^{-1} and 62 kg N ha^{-1} in the fall rye and winter wheat systems, respectively, while in Carman, the FRV of the alfalfa was 5 kg N ha^{-1} and -3 kg N ha^{-1} in the fall rye and winter wheat systems, respectively. The FRV's for double crops in the winter wheat system at Winnipeg ranged from a low of 23 kg N ha^{-1} for lentil to a high of 62 kg N ha^{-1} for alfalfa.

Table 4-13 Fertilizer replacement values of the legumes to a succeeding oat crop by winter cereal type at Winnipeg and Carman, MB (1999)

Nitrogen source (for oats)	Winnipeg		Carman	
	winter wheat	fall rye	winter wheat	fall rye
red clover	24	26	-13	-27
alfalfa	62	51	-3	5
chickling vetch	29	43	22	14
lentil	23	39	18	-3

winter wheat (Winnipeg) $y = 1439.067 + 46.392675x - 0.187691x^2$
winter wheat (Carman) $y = 3999.584 + 25.652975x - 0.134916x^2$
fall rye (Winnipeg) $y = 1755.1615 + 38.371788x - 0.117667x^2$
fall rye (Carman) $y = 4226.698 + 20.4517x - 0.093025x^2$

At Carman, the FRV's in the winter wheat system ranged from a low of -27 kg N ha^{-1} for red clover in the fall rye system to a high of 22 kg N ha^{-1} for chickling vetch.

There were also differences in FRV ranking among legumes at each site. At Winnipeg, alfalfa in both the winter wheat and fall rye systems had the highest FRV, at 51 kg N ha^{-1} and 62 kg N ha^{-1}, respectively. Hesterman et al. (1992) found that the FRV for relay intercropped alfalfa was as high as 55 kg N. Kelner et al. (1997) found that a one-year stand of "Nitro" alfalfa provided 84 kg N ha^{-1} to the soil in Manitoba, so the above values for a 3-month growth period of growth are quite comparable. The FRV from chickling vetch and lentil ranged between 23 kg N ha^{-1} and 43 kg N ha^{-1} at Winnipeg, similar to the results of Biederbeck et al. (1996), who used these legumes as green manure fallow substitutes. The FRV from red clover at Winnipeg reached up to 26 kg N ha^{-1}, which is somewhat lower than values in other studies. Hesterman et al. (1992) found the FRV from relay intercropped red clover reached as high as 127 kg N ha^{-1}. However, red clover is adversely affected by exposure to low soil moisture (Smith, 1978), and precipitation levels after winter cereal harvest were low at Winnipeg, so this may have inhibited nitrogen fixation in the red clover.

Low FRV for alfalfa and red clover at Carman were again attributed to low soil moisture levels. Alfalfa requires relatively large amounts of water (Zentner et al. 1996), while red clover generally performs poorly on light-textured soils (Smith, 1978), like those at Carman. Considering the drought conditions that ensued at Carman after the winter cereal harvest (appendix Table B-2), it is not surprising that these two legumes provided the lowest FRV at Carman.

Chickling vetch and lentil performed much better than either alfalfa or red clover at Carman, with FRV's up to 22 kg N ha^{-1} (Table 4-15). Chickling vetch and lentil are legumes that are used as green manure fallow substitutes in drier areas of the Prairies, because of their ability to use water efficiently and, especially in the case of chickling vetch, their ability to fix nitrogen (Bellido, 1994; Biederbeck et al. 1996; Cocks, 1999). It is not surprising, then, that these more drought-tolerant legumes outperformed alfalfa and red clover under the drought conditions at the Carman site.

4.5 DISCUSSION

Results of this study showed that the double crops performed best at Carman, while the relay intercrops performed best at Winnipeg. There are likely two main causes for this outcome, both relating to water use. Firstly, the relay intercrops were present on the plots for the whole growing season, while the double crops were seeded approximately three months later, after the winter cereals were harvested. Where water was not a limiting factor in Winnipeg, this did not appear to be a problem. However, in Carman, where the sandy soil and lower levels of precipitation (appendix Table B-2) resulted in drought-like conditions, the length of time that the legumes were present in the field may have played a factor in the overall performance of the cropping system. The oat yields where the relay intercrops had been grown the previous year were generally much lower than where the doublecrops had been grown the previous year, an indication that perhaps the oat crops following the relay crops were suffering from a moisture deficiency, partially caused by the length of time that the legumes were present in the plots. Secondly, the chickling vetch and lentils originated in the Near East/Mediterranean (Bellido, 1994; Cocks, 1999; Oplinger et al. 1990), while alfalfa and red clover originated in southwestern Asia/southern Europe, areas which are generally not as dry as the Near East/Mediterranean (Sheaffer, 1993). It is not surprising then that the legumes that originated in the drier climates performed better at Carman, where water was a limiting factor, and that the legumes that originated in the wetter climates performed better at Winnipeg, where water was more plentiful.

Taking what was observed at the two sites in this experiment, one could extrapolate from the data and make some recommendations for western Canada. Based on the performance of the doublecrops at the dry Carman site, plus previous research on green manure legumes in dry regions of the Prairies (Biederbeck et al. 1996; Biederbeck and Bouman, 1994), it appears that using green manure legumes as doublecrops in the drier areas of the Prairies (i.e. southern Saskatchewan and southeastern Alberta) could be a viable option. On the other hand, the performance of the relay intercrops at the wetter Winnipeg site, in addition to prior work done on the use of short-term perennial forage legume stands in south-central Manitoba (Kelner and Vessey, 1995), suggests that perennial legumes could be used as relay intercrops in the wetter regions of the Prairies (i.e. south-central Manitoba and northern Alberta). Use of a properly adapted legume with winter cereals could be a viable option to provide legume benefits to continuous cropping systems across the Prairies.

The results of this study showed that including legume relay intercrops and double crops in a winter cereal-oat rotation maintained or increased energy use efficiency relative to the treatments which only used inorganic nitrogen fertilizer. The primary reason for the maintenance or increase in energy use efficiency was decreased energy use, as a result of substituting the nitrogen provided by the legumes for inorganic nitrogen fertilizer. The alfalfa treatment used approximately the same amount of energy as the control treatment, and up to 39% less energy than the other fertilizer treatments. Often, producers do not include a green manure or forage legume in a crop rotation, because of the resulting loss of one or more years of grain cropping. These results show that including legume relay intercrops and/or double crops in a crop rotation can increase energy use efficiency, while maintaining a continuous crop production system.

The benefits to a cropping system from including legumes in rotation are well documented (Spratt, 1966; Hoyt and Leitch, 1983; Badaruddin and Meyer, 1989; Entz et al. 1995). However, many producers are wary to include legumes as green manures or perennial forages, as to not sacrifice a year or more of grain production in order to receive the benefits of a legume in rotation. One of the advantages of relay intercropping and doublecropping with legumes is that the benefits provided by a legume in rotation can be achieved without sacrificing a year of grain production. All that is required is that a winter cereal be included in the rotation, in order that the relay intercrops and doublecrops are provided with a sufficient amount of heat and light resources at the end of the growing season. This is so that legume growth can be maximized, thereby providing the nitrogen and other resulting benefits to subsequent non-legume crops in sufficient amounts.

The primary additional cost in a multiple cropping system with legumes is the cost of the seed. The price (in 1996 dollars) for the alfalfa and lentil seed used in this experiment was approximately \$ 40 ha^{-1} and \$ 30 ha^{-1}, respectively (Nagy, 1999). The fertilizer replacement values for these legumes were up to, approximately, 60 kg N ha^{-1} and 40 kg N ha^{-1}. The approximate cost (in 1996 dollars) to provide the equivalent amount of nitrogen using urea (46-0-0) fertilizer would be \$ 48 ha^{-1} and \$ 32 ha^{-1}, respectively (Nagy, 1999). Looking at these figures, one can see that in instances where conditions allow for excellent legume performance, the nitrogen available from a subsequent crop provided by relay-intercropped or doublecropped legumes may be worth more than the seed costs of the legumes. In other instances, the where conditions are less than ideal, such as Carman in 1999, the value of the nitrogen from the multiple-cropped legumes may be worth less than the seed costs of those legumes. However, this does not take into account the additional benefits provided by the legume crop to subsequent non-legume crops, such as higher protein levels, higher yields, weed control, and improved soil physical properties (Spratt, 1966; Hoyt and Leitch, 1983; Badaruddin and Meyer, 1989; Entz et al. 1995).

There are numerous advantages and disadvantages to including legume relay intercrops and double crops in a cropping system. Many of the advantages and disadvantages would depend on the appropriateness of the legume system chose for a particular region of the Prairies. However, if legumes that are well adapted to a region are chosen, the advantages of relay intercropping and double cropping legumes with winter cereals would appear to outweigh the disadvantages.

5. GENERAL DISCUSSION

Including legumes in a cropping system, whether as green manures, perennial forages, or as relay intercrops and double crops, can add substantial amounts of nitrogen to the soil for subsequent non-legume crops to use. Some producers may not want to include legumes in a rotation, holding the belief that as long as the amount of inorganic nitrogen fertilizer applied to a non-legume crop is increased to match the approximate nitrogen contribution that a previous legume crop would have made, the cropping system will perform no differently. However, this may not be the case. There are a number of reasons why it would be preferable to use legumes as a nitrogen source, as opposed to inorganic nitrogen fertilizers.

Firstly, inorganic nitrogen fertilizers are very inefficient to use. In order to synthesize ammonia, nitrogen and hydrogen gases must be combined at a pressure of 200 atm and a temperature of 500 °C (Smil, 1997), which requires large amounts of energy. In fact, the present study determined that approximately 60% of the total commercial energy used in agricultural crop production is accounted for by the production of nitrogen fertilizers. In addition, other studies have shown that approximately 50% of nitrogen that is applied as inorganic nitrogen fertilizer is lost through denitrification, volatilization, or leaching below the root zone (Karlen et al. 1996; Tran and Giroux, 1998).

By way of comparison, including a legume in a crop rotation requires only the legume seed, light, heat, water, and perhaps some fertilizer phosphorous, potassium, sulphur, and micronutrients, all of which require far less energy to produce than nitrogen fertilizers (Stout, 1990). Therefore, using legumes as a nitrogen source requires far fewer energy expenditures than using inorganic nitrogen fertilizer as a nitrogen source.

A second advantage to using legumes as a nitrogen source instead of inorganic nitrogen fertilizers is that rotations with legumes generally have lower input costs than continuous cropping rotations. Just as applying inorganic nitrogen fertilizer adds significantly to the amount of energy required for grain production, it also adds significantly to the cost of grain production (Clark and Poincelot, 1996). Large amounts of inorganic nitrogen fertilizers are generally used in Prairie agriculture, making fertilizer one of the primary costs of grain production. By including legumes in a crop rotation, nitrogen fertilizer requirements for non-legume grain crops can be decreased, which will decrease the cost of grain production (Clark and Poincelot, 1996). When examining data from the first paper, it was shown that including legumes in a crop rotation lowered the costs of production, regardless of location or whether the legumes were used as green manures or perennial forages. As the costs of production are lowered, so to is the financial risk. The higher the costs of production are, the higher the crop yields need to be to provide a return on investment, and the more susceptible the cropping system is to financial losses. This will become even more of a reality as fuel prices continue to rise, causing nitrogen fertilizer prices to follow suit. The realized net income of Canadian producers as a percentage of farm cash receipts dropped from 36% in 1974 to 14% in 1990 (Clark and Poincelot, 1996), which has led to increased interest in agriculture that is less dependent on purchased inputs. Including legumes in a crop rotation can assist in achieving this.

The third advantage to using legumes as a nitrogen source is that legumes provide rotation benefits that cannot be realized by adding inorganic nitrogen fertilizers. As was discussed previously, including legumes in a crop rotation can provide subsequent grain crops with numerous benefits above and beyond that of nitrogen addition, such as higher protein levels, higher yields, weed control, and improved soil physical properties (Spratt, 1966; Hoyt and Leitch, 1983; Badaruddin and Meyer, 1989; Entz et al. 1995; Forster, 1999). Evidence of these benefits to subsequent grain crops was seen at the Lethbridge and Swift Current sites, where the non-significant trend was that wheat yields in the rotations with green manure legumes were slightly higher than wheat yields in the continuous grain rotations. Evidence of these benefits from legumes to subsequent grain crops was also seen at Glenlea, where wheat yields in the rotations with perennial forage legumes were between 238 kg ha^{-1} and 900 kg ha^{-1} greater than wheat yields for the same treatment in the continuous grain rotations (although these differences were not significant, due to a large degree of variation resulting from a small sample size at harvest). If it were possible to improve the grain yields of the continuous grain rotations to match those of the rotations with legumes, the improvement would likely be achieved through greater levels of crop inputs, such as fertilizers and pesticides. Increasing the levels of crop inputs used would increase the cost of crop production, once again demonstrating how including legumes in a crop rotation can minimize input costs. Legumes provide benefits to subsequent grain crops that cannot be achieved by simply replacing legumes as a nitrogen source with inorganic nitrogen fertilizer. Therefore, findings from the present study may begin to convince more producers to include legumes in crop rotations.

It has been established in this thesis that including legumes in crop rotations as green manures, perennial forages, or cover crops can maintain or enhance the energy efficiency of cropping systems. However, some people may question the importance of energy efficiency ratings for cropping systems, concluding that energy efficiency is just a number on a piece of paper that does not hold a great deal of relevance; in fact, just the opposite is true. Energy efficiency in agricultural cropping systems is important for a number of reasons. The first of these reasons relates to the use of fossil fuels. The vast majority of commercial energy used in crop production is in the form of fossil fuels (Fluck and Baird, 1980). When fossil fuels are burned, they release carbon dioxide, a greenhouse gas that is linked to global climate change. It has been estimated that approximately two-thirds of potential global warming will be accounted for by carbon dioxide emissions (Herzog et al. 2000). The threat of global warming has become so prevalent, researchers have begun to investigate carbon sequestration methods which include pumping carbon dioxide underground into coal beds, depleted oil and gas reservoirs, and mined salt domes, as well as depositing carbon dioxide deep in the ocean as dry ice, or pumping it to the bottom of the ocean. In addition, some countries such as Norway have implemented taxes on the amount of carbon dioxide released into the air by industry (Herzog et al. 2000). By decreasing reliance on fossil fuel-based nitrogen fertilizers, through the use of legumes, carbon dioxide emissions into the atmosphere could be reduced. The threat of global warming, along with the possibility of a Canadian carbon tax, may eventually factor into the decision of whether or not to include legumes as green manure, perennial forages, or relay intercrops and doublecrops in a Prairie crop rotation.

The second reason why energy efficiency of cropping systems should be important concerns the availability of fossil fuels. Fossil fuels are considered a non-renewable resource, as they require millions of years to form. Concerns regarding diminishing supplies of fossil fuels have surfaced periodically during the past century, although experts have stated that there should be enough fossil fuels remaining to satisfy world demand well into this century, and possible the next (Herzog et al. 2000). However, the fact remains that supplies of fossil fuels are finite, and will inevitably grow more scarce someday in the future, and hence become more expensive (Smil, 1997). By reducing inputs that depend on fossil fuels for their production, a cropping system will become less dependent on non-renewable resources. In the future, when the availability of fossil fuels comes into question, using legumes as a nitrogen source to supplement inorganic nitrogen fertilizer use may become a more common practice.

The third reason why energy efficiency of cropping systems is important concerns the level of economic risk in a cropping system. As the energy efficiency of a cropping system increases, the amount of energy consumed by the system decreases in proportion to the amount of energy produced by the system. Energy inputs for a cropping system, whether in the form of seed, pesticides, herbicides, machinery, or fuel, are all items that must be purchased, so the fewer energy inputs incurred by a cropping system, the fewer costs incurred by the system. The first chapter in this thesis showed that, while not always having the highest returns, the rotations with legumes had the lowest levels of input costs in almost every situation. The higher the energy use efficiency of a cropping system, the lower (proportionally) the amount of energy inputs, and hence, the lower the input costs. The lower the costs of production are, the lower the economic risk of production. Legumes can reduce the economic risk of crop production by enhancing the energy use efficiency of cropping systems.

This thesis has demonstrated the importance of enhancing the energy efficiency of cropping systems. Whether in relation to the consumption of fossil fuels and the production of greenhouse gases, the depletion of non-renewable fossil fuel resources, or economic risk of crop production, increasing the energy use efficiency of cropping systems should improve the environmental and economic stability of those cropping systems.

6. CONCLUSIONS

It was found that including legumes in a number of western Canadian crop rotations could decrease energy use and maintain or increase energy use efficiency of crop production. Three legume systems were examined: green manure legumes, perennial forage legumes, and relay intercropped and double cropped legumes.

It was found that green manure legumes maintained or increased the energy use efficiency of western Canadian cropping systems by up to 196%, as a result of decreases in energy use of up to 65%. The decreases in energy use were primarily through reductions in nitrogen fertilizer requirements. Green manure legumes could be used as a fallow replacement to improve the energy use efficiency of cropping systems in drier areas of the Prairies.

It was found that perennial forage legumes increased energy use efficiency of western Canadian cropping systems by up to 500%, as a result of decreases in energy use and increases in energy production. Decreases in energy use of up to 86% were primarily through reductions in nitrogen fertilizer requirements. Increases in energy production of up to 134% were primarily due to the harvest of all aboveground biomass from forage crops, as opposed to grain harvest only from grain crops. Perennial forage legumes could be used as hay crops to improve the energy use efficiency of cropping systems in wetter areas of the Prairies.

It was found that relay intercropping and double cropping green manure legume cover crops with winter cereals in southern Manitoba increased yields of a subsequent oat crop by the equivalent of up to 62 kg ha^{-1} of fertilizer nitrogen. It was also found that the legumes increased energy use efficiency of the system by up to 28%, as a result of decreases in energy use by up to 39% in the legume treatments. The decreases in energy use were primarily due to reductions in nitrogen fertilizer requirements. Relay intercropped and double cropped legume cover crops could add legume benefits to a crop rotation and improve the energy use efficiency of continuous cropping systems in areas of the Prairies with adequate heat and water resources remaining after the harvest of a winter cereal.

The findings of this thesis point to the importance of including legumes in cropping systems in order to improve energy use efficiency. The vast majority of energy used in crop production is in the form of fossil fuels. When burned, these fossil fuels release carbon dioxide, a greenhouse gas, into the atmosphere. With ever-increasing concern over global warming as a result of greenhouse gases, any steps taken to improve the energy use efficiency of agriculture should be welcome steps indeed.

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8. APPENDICES

Appendix A

Table A-1. Seed energy use of Lethbridge, AB rotations (1989-1994)

1989	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	482.40	482.40	482.40	0.00	482.40	482.40	0.00	482.40	482.40
lentil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.39	0.00	0.00
total	0.00	482.40	482.40	482.40	0.00	482.40	482.40	150.39	482.40	482.40

1990	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	482.40	482.40	482.40	0.00	482.40	482.40	0.00	482.40	482.40
lentil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.39	0.00	0.00
total	0.00	482.40	482.40	482.40	0.00	482.40	482.40	150.39	482.40	482.40

1991	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	482.40	482.40	482.40	0.00	482.40	482.40	0.00	482.40	482.40
lentil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.39	0.00	0.00
total	0.00	482.40	482.40	482.40	0.00	482.40	482.40	150.39	482.40	482.40

1992	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	482.40	482.40	482.40	0.00	482.40	482.40	0.00	482.40	482.40
lentil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.39	0.00	0.00
total	0.00	482.40	482.40	482.40	0.00	482.40	482.40	150.39	482.40	482.40

1993	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	482.40	482.40	482.40	0.00	482.40	482.40	0.00	482.40	482.40
lentil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.39	0.00	0.00
total	0.00	482.40	482.40	482.40	0.00	482.40	482.40	150.39	482.40	482.40

1994	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	482.40	482.40	482.40	0.00	482.40	482.40	0.00	482.40	482.40
lentil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	150.39	0.00	0.00
total	0.00	482.40	482.40	482.40	0.00	482.40	482.40	150.39	482.40	482.40

Table A-2. Fuel energy use of Lethbridge, AB rotations (1989-1991)

1989	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	0.00	9.04	9.04	9.04	0.00	9.04
water truck	44.70	44.70	44.70	44.70	44.70	44.70	44.70	0.00	134.10	134.10
sprayer	97.50	97.50	97.50	97.50	97.50	97.50	97.50	0.00	292.50	292.50
fertilizer spreader	0.00	85.90	85.90	85.90	0.00	85.90	85.90	0.00	0.00	85.90
cultivator	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80
harrow packers	0.00	76.60	76.60	76.60	0.00	76.60	76.60	0.00	0.00	76.60
rodweeder	0.00	92.40	92.40	92.40	0.00	92.40	92.40	0.00	0.00	92.40
blade cultvator	860.70	0.00	0.00	0.00	860.70	0.00	0.00	0.00	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	798.90	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	0.00	116.10	116.10	0.00	0.00	116.10
swather	0.00	132.10	132.10	132.10	0.00	132.10	132.10	0.00	0.00	132.10
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1231.01	882.45	882.45	882.45	1231.01	882.45	882.45	1036.05	654.71	1166.85

1990	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	0.00	9.04	9.04	9.04	0.00	9.04
water truck	29.80	29.80	29.80	29.80	29.80	29.80	29.80	14.90	59.60	59.60
sprayer	65.00	65.00	65.00	65.00	65.00	65.00	65.00	32.50	130.00	130.00
fertilizer spreader	0.00	85.90	85.90	85.90	0.00	85.90	85.90	0.00	0.00	85.90
cultivator	0.00	128.80	128.80	128.80	0.00	128.80	128.80	0.00	0.00	128.80
harrow packers	0.00	153.20	153.20	153.20	0.00	153.20	153.20	0.00	0.00	306.40
blade cultvator	860.70	0.00	0.00	0.00	860.70	0.00	0.00	0.00	0.00	0.00
tandem disc	0.00	532.60	532.60	532.60	0.00	532.60	532.60	798.90	0.00	1065.20
disc drill	0.00	116.10	116.10	116.10	0.00	116.10	116.10	0.00	0.00	116.10
swather	0.00	132.10	132.10	132.10	0.00	132.10	132.10	0.00	0.00	132.10
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1054.81	1351.85	1351.85	1351.85	1054.81	1351.85	1351.85	954.65	288.91	2132.45

1991	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	0.00	9.04	9.04	9.04	0.00	9.04
water truck	29.80	29.80	29.80	29.80	29.80	29.80	29.80	14.90	59.60	59.60
sprayer	65.00	65.00	65.00	65.00	65.00	65.00	65.00	32.50	130.00	130.00
fertilizer spreader	0.00	85.90	85.90	85.90	0.00	85.90	85.90	0.00	0.00	85.90
cultivator	128.80	0.00	0.00	0.00	128.80	0.00	0.00	0.00	0.00	0.00
harrow packers	0.00	76.60	76.60	76.60	0.00	76.60	76.60	0.00	0.00	0.00
blade cultvator	860.70	0.00	0.00	0.00	860.70	0.00	0.00	286.90	0.00	0.00
tandem disc	0.00	532.60	532.60	532.60	0.00	532.60	532.60	798.90	0.00	532.60
disc drill	0.00	116.10	116.10	116.10	0.00	116.10	116.10	0.00	0.00	116.10
swather	0.00	132.10	132.10	132.10	0.00	132.10	132.10	0.00	0.00	132.10
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1183.61	1146.45	1146.45	1146.45	1183.61	1146.45	1146.45	1241.55	288.91	1164.65

Table A-3. Fuel energy use of Lethbridge, AB rotations (1992-1994)

1992	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	0.00	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	0.00	9.04	9.04	9.04	0.00	9.04
water truck	44.70	29.80	29.80	29.80	29.80	29.80	29.80	14.90	89.40	59.60
sprayer	97.50	65.00	65.00	65.00	65.00	65.00	65.00	32.50	195.00	130.00
fertilizer spreader	0.00	85.90	85.90	85.90	0.00	85.90	85.90	0.00	0.00	85.90
cultivator	0.00	128.80	128.80	128.80	0.00	128.80	128.80	0.00	0.00	0.00
harrow packers	0.00	76.60	76.60	76.60	0.00	76.60	76.60	0.00	0.00	0.00
rodweeder	0.00	92.40	92.40	92.40	0.00	92.40	92.40	0.00	0.00	0.00
blade cultvator	286.90	286.90	286.90	286.90	286.90	286.90	286.90	0.00	286.90	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	266.30	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	0.00	116.10	116.10	0.00	0.00	116.10
swather	0.00	132.10	132.10	132.10	0.00	132.10	132.10	0.00	0.00	132.10
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	528.41	1121.95	1121.95	1121.95	381.70	1121.95	1121.95	422.05	670.61	632.05

1993	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	0.00	9.04	9.04	9.04	0.00	9.04
water truck	44.70	29.80	29.80	29.80	29.80	29.80	29.80	14.90	89.40	59.60
sprayer	97.50	65.00	65.00	65.00	65.00	65.00	65.00	32.50	195.00	130.00
fertilizer spreader	0.00	85.90	85.90	85.90	0.00	85.90	85.90	0.00	0.00	85.90
cultivator	128.80	128.80	128.80	128.80	128.80	128.80	128.80	0.00	128.80	128.80
harrow packers	0.00	76.60	76.60	76.60	0.00	76.60	76.60	0.00	0.00	76.60
rodweeder	0.00	92.40	92.40	92.40	0.00	92.40	92.40	0.00	0.00	92.40
blade cultvator	860.70	0.00	0.00	0.00	860.70	0.00	0.00	0.00	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	532.60	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	0.00	116.10	116.10	0.00	0.00	116.10
swather	0.00	132.10	132.10	132.10	0.00	132.10	132.10	0.00	0.00	132.10
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1231.01	835.05	835.05	835.05	1183.61	835.05	835.05	688.35	512.51	929.85

1994	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	0.00	9.04	9.04	9.04	0.00	9.04
water truck	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90	14.90
sprayer	32.50	32.50	32.50	32.50	32.50	32.50	32.50	32.50	32.50	32.50
fertilizer spreader	0.00	85.90	85.90	85.90	0.00	85.90	85.90	0.00	0.00	85.90
HD cultivator	0.00	207.70	207.70	207.70	0.00	207.70	207.70	0.00	0.00	0.00
cultivator	128.80	0.00	0.00	0.00	128.80	0.00	0.00	128.80	0.00	0.00
harrow packers	153.20	76.60	76.60	76.60	153.20	76.60	76.60	0.00	153.20	0.00
blade cultvator	573.80	0.00	0.00	0.00	573.80	0.00	0.00	0.00	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	532.60	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	0.00	116.10	116.10	0.00	0.00	116.10
swather	0.00	132.10	132.10	132.10	0.00	132.10	132.10	0.00	0.00	132.10
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	1002.51	774.15	774.15	774.15	1002.51	774.15	774.15	817.15	299.91	489.85

Table A-4. Machinery energy use of Lethbridge, AB rotations (1989-1991)

1989	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	0.00	2.90	2.90	2.90	0.00	2.90
water truck	8.10	8.10	8.10	8.10	8.10	8.10	8.10	0.00	24.30	24.30
sprayer	28.20	28.20	28.20	28.20	28.20	28.20	28.20	0.00	84.60	84.60
fertilizer spreader	0.00	4.90	4.90	4.90	0.00	4.90	4.90	0.00	0.00	4.90
cultivator	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
harrow packers	0.00	19.70	19.70	19.70	0.00	19.70	19.70	0.00	0.00	19.70
rodweeder	0.00	23.80	23.80	23.80	0.00	23.80	23.80	0.00	0.00	23.80
blade cultvator	121.20	0.00	0.00	0.00	121.20	0.00	0.00	121.20	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	0.00	34.30	34.30	0.00	0.00	34.30
swather	0.00	29.60	29.60	29.60	0.00	29.60	29.60	0.00	0.00	29.60
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	202.54	196.54	196.54	196.54	202.54	196.54	196.54	169.14	153.94	269.14

1990	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	0.00	2.90	2.90	2.90	0.00	2.90
water truck	5.40	5.40	5.40	5.40	5.40	5.40	5.40	2.70	10.80	10.80
sprayer	18.80	18.80	18.80	18.80	18.80	18.80	18.80	9.40	37.60	37.60
fertilizer spreader	0.00	4.90	4.90	4.90	0.00	4.90	4.90	0.00	0.00	4.90
cultivator	0.00	14.00	14.00	14.00	0.00	14.00	14.00	0.00	0.00	14.00
harrow packers	0.00	39.40	39.40	39.40	0.00	39.40	39.40	0.00	0.00	78.80
blade cultvator	121.20	0.00	0.00	0.00	121.20	0.00	0.00	0.00	0.00	0.00
tandem disc	0.00	101.80	101.80	101.80	0.00	101.80	101.80	152.70	0.00	203.60
disc drill	0.00	34.30	34.30	34.30	0.00	34.30	34.30	0.00	0.00	34.30
swather	0.00	29.60	29.60	29.60	0.00	29.60	29.60	0.00	0.00	29.60
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	176.44	282.14	282.14	282.14	176.44	282.14	282.14	198.74	79.44	447.54

1991	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	0.00	2.90	2.90	2.90	0.00	2.90
water truck	5.40	5.40	5.40	5.40	5.40	5.40	5.40	2.70	10.80	10.80
sprayer	18.80	18.80	18.80	18.80	18.80	18.80	18.80	9.40	37.60	37.60
fertilizer spreader	0.00	4.90	4.90	4.90	0.00	4.90	4.90	0.00	0.00	4.90
cultivator	14.00	0.00	0.00	0.00	14.00	0.00	0.00	0.00	0.00	0.00
harrow packers	0.00	19.70	19.70	19.70	0.00	19.70	19.70	0.00	0.00	0.00
blade cultvator	121.20	0.00	0.00	0.00	121.20	0.00	0.00	40.40	0.00	0.00
tandem disc	0.00	101.80	101.80	101.80	0.00	101.80	101.80	152.70	0.00	101.80
disc drill	0.00	34.30	34.30	34.30	0.00	34.30	34.30	0.00	0.00	34.30
swather	0.00	29.60	29.60	29.60	0.00	29.60	29.60	0.00	0.00	29.60
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	190.44	248.44	248.44	248.44	190.44	248.44	248.44	239.14	79.44	252.94

Table A-5. Machinery energy use of Lethbridge, AB rotations (1992-1994)

1992	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	0.00	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	0.00	2.90	2.90	2.90	0.00	2.90
water truck	8.10	5.40	5.40	5.40	5.40	5.40	5.40	2.70	16.20	10.80
sprayer	28.20	18.80	18.80	18.80	18.80	18.80	18.80	9.40	56.40	37.60
fertilizer spreader	0.00	4.90	4.90	4.90	0.00	4.90	4.90	0.00	0.00	4.90
cultivator	0.00	14.00	14.00	14.00	0.00	14.00	14.00	0.00	0.00	0.00
harrow packers	0.00	19.70	19.70	19.70	0.00	19.70	19.70	0.00	0.00	0.00
rodweeder	0.00	23.80	23.80	23.80	0.00	23.80	23.80	0.00	0.00	0.00
blade cultivator	40.40	40.40	40.40	40.40	40.40	40.40	40.40	0.00	40.40	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.90	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	0.00	34.30	34.30	0.00	0.00	34.30
swather	0.00	29.60	29.60	29.60	0.00	29.60	29.60	0.00	0.00	29.60
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	107.74	224.84	224.84	224.84	64.60	224.84	224.84	96.94	144.04	151.14

1993	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	0.00	2.90	2.90	2.90	0.00	2.90
water truck	8.10	5.40	5.40	5.40	5.40	5.40	5.40	2.70	16.20	10.80
sprayer	28.20	18.80	18.80	18.80	18.80	18.80	18.80	9.40	56.40	37.60
fertilizer spreader	0.00	4.90	4.90	4.90	0.00	4.90	4.90	0.00	0.00	4.90
cultivator	14.00	14.00	14.00	14.00	14.00	14.00	14.00	0.00	14.00	14.00
harrow packers	0.00	19.70	19.70	19.70	0.00	19.70	19.70	0.00	0.00	19.70
rodweeder	0.00	23.80	23.80	23.80	0.00	23.80	23.80	0.00	0.00	23.80
blade cultivator	121.20	0.00	0.00	0.00	121.20	0.00	0.00	0.00	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	101.80	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	0.00	34.30	34.30	0.00	0.00	34.30
swather	0.00	29.60	29.60	29.60	0.00	29.60	29.60	0.00	0.00	29.60
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	202.54	184.44	184.44	184.44	190.44	184.44	184.44	147.84	117.64	208.64

1994	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	0.00	2.90	2.90	2.90	0.00	2.90
water truck	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70	2.70
sprayer	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40	9.40
fertilizer spreader	0.00	4.90	4.90	4.90	0.00	4.90	4.90	0.00	0.00	4.90
HD cultivator	0.00	207.70	207.70	207.70	0.00	207.70	207.70	0.00	0.00	0.00
cultivator	14.00	0.00	0.00	0.00	14.00	0.00	0.00	14.00	0.00	0.00
harrow packers	39.40	19.70	19.70	19.70	39.40	19.70	19.70	0.00	39.40	0.00
blade cultivator	80.80	0.00	0.00	0.00	80.80	0.00	0.00	0.00	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	101.80	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	0.00	34.30	34.30	0.00	0.00	34.30
swather	0.00	29.60	29.60	29.60	0.00	29.60	29.60	0.00	0.00	29.60
grain truck (harvest)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
grain truck (market)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
combine	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	177.34	342.24	342.24	342.24	177.34	342.24	342.24	161.84	82.54	114.84

Table A-6. Herbicide energy use of Lethbridge, AB rotations (1989-1994)

1989	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat (+N)
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
2,4-D	293.22	293.22	293.22	293.22	293.22	293.22	293.22	0.00	293.22	293.22
Roundup	670.39	670.39	670.39	670.39	670.39	670.39	670.39	0.00	670.39	670.39
Total	963.61	963.61	963.61	963.61	963.61	963.61	963.61	0.00	963.61	963.61

1990	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat (+N)
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Sweep	237.94	237.94	237.94	237.94	237.94	237.94	237.94	237.94	237.94	237.94
Buctril M	185.42	185.42	185.42	185.42	185.42	185.42	185.42	0.00	185.42	185.42
Total	423.36	423.36	423.36	423.36	423.36	423.36	423.36	237.94	423.36	423.36

1991	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat (+N)
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Hoegrass II	445.21	445.21	445.21	445.21	445.21	445.21	445.21	0.00	445.21	445.21
Sweep	263.55	263.55	263.55	263.55	263.55	263.55	263.55	263.55	263.55	263.55
Total	708.76	708.76	708.76	708.76	708.76	708.76	708.76	263.55	708.76	708.76

1992	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat (+N)
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Torch	92.32	92.32	92.32	92.32	92.32	92.32	92.32	0.00	92.32	92.32
Hoegrass 284	262.16	262.16	262.16	262.16	262.16	262.16	262.16	0.00	262.16	262.16
Roundup	626.54	447.53	447.53	447.53	447.53	447.53	447.53	447.53	447.53	447.53
Buctril M	185.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1166.44	802.01	802.01	802.01	802.01	802.01	802.01	447.53	802.01	802.01

1993	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat (+N)
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Torch	92.32	92.32	92.32	92.32	92.32	92.32	92.32	0.00	92.32	92.32
Hoegrass 284	262.16	262.16	262.16	262.16	262.16	262.16	262.16	0.00	262.16	262.16
Roundup	625.54	447.53	447.53	447.53	447.53	447.53	447.53	447.53	447.53	447.53
Buctril M	185.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1074.12	709.69	709.69	709.69	709.69	709.69	709.69	447.53	709.69	709.69

1994	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat (+N)
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Rustler	261.78	0.00	0.00	0.00	261.78	0.00	0.00	261.73	0.00	0.00
Achieve X Gold	0.00	719.53	719.53	719.53	0.00	719.53	719.53	0.00	719.53	719.53
Total	261.78	719.53	719.53	719.53	261.78	719.53	719.53	261.78	719.53	719.53

Table A-7. Fertilizer energy use of Lethbridge, AB rotations (1989-1994)

1989	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	684.41	684.41	7430.31	0.00	7430.31	7430.31	684.41	684.41	684.41
P_2O_5	0.00	535.20	535.20	535.20	0.00	535.20	535.20	535.20	535.20	535.20
total fert. energy	0.00	1219.61	1219.61	7965.51	0.00	7965.51	7965.51	1219.61	1219.61	1219.61

1990	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	684.41	684.41	6678.23	0.00	6678.23	6678.23	684.41	684.41	684.41
P_2O_5	0.00	535.20	535.20	535.20	0.00	535.20	535.20	535.20	535.20	535.20
total fert. energy	0.00	1219.61	1219.61	7213.43	0.00	7213.43	7213.43	1219.61	1219.61	1219.61

1991	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	684.41	684.41	6678.23	0.00	6678.23	6678.23	684.41	684.41	684.41
P_2O_5	0.00	535.20	535.20	535.20	0.00	535.20	535.20	535.20	535.20	535.20
total fert. energy	0.00	1219.61	1219.61	7213.43	0.00	7213.43	7213.43	1219.61	1219.61	1219.61

1992	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	684.41	684.41	6678.23	0.00	6678.23	6678.23	684.41	684.41	684.41
P_2O_5	0.00	535.20	535.20	535.20	0.00	535.20	535.20	535.20	535.20	535.20
total fert. energy	0.00	1219.61	1219.61	7213.43	0.00	7213.43	7213.43	1219.61	1219.61	1219.61

1993	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	684.41	684.41	6678.23	0.00	6678.23	6678.23	684.41	684.41	684.41
P_2O_5	0.00	535.20	535.20	535.20	0.00	535.20	535.20	535.20	535.20	535.20
total fert. energy	0.00	1219.61	1219.61	7213.43	0.00	7213.43	7213.43	1219.61	1219.61	1219.61

1994	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow	wheat	wheat	wheat (+N)	fallow	wheat (+N)	wheat (+N)	lentil	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	411.91	411.91	4172.29	0.00	4172.29	4172.29	411.91	411.91	411.91
P_2O_5	0.00	322.11	322.11	322.11	0.00	322.11	322.11	322.11	322.11	322.11
total fert. energy	0.00	734.03	734.03	4494.41	0.00	4494.41	4494.41	734.03	734.03	734.03

Table A-8. Total rotational energy use of Lethbridge, AB rotations (1989-1994)

1989-1994	Rotation #3			Rotation #4	Rotation #6			Rotation #8		
	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	wheat (+N) MJ/ha	fallow MJ/ha	wheat (+N) MJ/ha	wheat (+N) MJ/ha	lentil MJ/ha	wheat MJ/ha	wheat MJ/ha
seed	0.00	2894.40	2894.40	2894.40	0.00	2894.40	2894.40	902.31	2894.40	2894.40
machinery	1057.04	2439.92	2111.91	2291.15	1001.80	2566.41	2345.68	1013.64	1591.78	2186.25
fuel	6231.36	10328.01	8889.39	9675.52	6037.25	10882.78	9914.68	5159.77	6815.30	9770.08
herbicide	4598.06	4326.95	4326.95	4326.95	3869.20	4326.95	4326.95	1658.33	4326.95	4326.95
fertilizer	0.00	6832.08	6832.08	41313.66	0.00	41313.66	41313.66	6832.08	6832.08	6832.08
total	**11886.46**	**26821.37**	**25054.73**	**60501.67**	**10908.25**	**61984.20**	**60795.37**	**15566.13**	**22460.51**	**26009.76**

1989-1994 (all phases)	Rotation #3	Rotation #4	Rotation #6	Rotation #8
	MJ/ha	MJ/ha	MJ/ha	MJ/ha
seed	5788.80	2894.40	5788.80	6691.11
machinery	5608.87	2291.15	5913.89	4791.67
fuel	25448.76	9675.52	25834.72	21745.15
herbicide	13251.96	4326.95	12523.10	10312.23
fertilizer	13664.17	41313.66	82627.31	20496.25
total	**63762.56**	**60501.67**	**133687.82**	**64036.41**

all phases per rot'n cycle	Rotation #3	Rotation #4	Rotation #6	Rotation #8
	MJ/ha	MJ/ha	MJ/ha	MJ/ha
seed	2894.40	1447.20	2894.40	3345.56
machinery	2804.44	1145.58	2956.94	2395.83
fuel	12724.38	4837.76	13417.36	10872.58
herbicide	6625.98	2163.48	6261.55	5156.12
fertilizer	6832.08	20656.83	41313.66	10248.13
total	**31881.28**	**30250.84**	**66843.91**	**32018.21**

per 3 year rotation cycle	Rotation #3	Rotation #4	Rotation #6	Rotation #8
	MJ/ha	MJ/ha	MJ/ha	MJ/ha
seed	964.80	1447.20	964.80	1115.19
machinery	934.81	1145.58	985.65	798.61
fuel	4241.46	4837.76	4472.45	3624.19
herbicide	2208.66	2163.48	2087.18	1718.71
fertilizer	2277.36	20656.83	13771.22	3416.04
total	**10627.09**	**30250.84**	**22281.30**	**10672.74**

Table A-9 Seed energy use of Swift Current, SK rotations (1987-1995)

1987	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1988	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1989	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1990	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1991	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1992	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1993	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1994	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

1995	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	0.00	432.00	432.00	0.00	432.00	432.00	432.00
lentil	0.00	0.00	0.00	133.68	0.00	0.00	0.00
total	0.00	432.00	432.00	133.68	432.00	432.00	432.00

Table A-10. Fuel energy use of Swift Current, SK rotations (1987-1989)

1987	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	14.90	44.70	44.70	14.90	44.70	44.70	44.70
sprayer	32.50	97.50	97.50	32.50	97.50	97.50	97.50
blade cultivator	573.80	0.00	0.00	286.90	286.90	286.90	286.90
disc drill	0.00	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	0.00	0.00	0.00	266.30	0.00	0.00	0.00
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	65.51	49.63	0.00	58.47	52.53	53.77
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	180.75	136.93	0.00	161.30	144.94	148.36
total	720.51	879.77	787.40	825.05	1125.68	1091.18	1098.39

1988	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	14.90	34.77	29.80	14.90	29.80	29.80	29.80
sprayer	32.50	75.83	65.00	32.50	65.00	65.00	65.00
blade cultivator	573.80	0.00	0.00	286.90	0.00	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	116.10	116.10	116.10
rod weeder	92.40	0.00	0.00	0.00	0.00	0.00	0.00
HD cultivator	0.00	0.00	0.00	207.70	0.00	0.00	0.00
harrow packers	0.00	0.00	0.00	76.60	0.00	0.00	0.00
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	55.22	19.87	0.00	33.13	19.23	20.08
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	152.36	54.81	0.00	91.40	53.05	55.40
total	812.91	809.50	628.11	843.05	696.14	631.69	637.44

1989	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	29.80	29.80	29.80	14.90	29.80	29.80	29.80
sprayer	65.00	65.00	65.00	32.50	65.00	65.00	65.00
blade cultivator	860.70	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	0.00	0.00	0.00	266.30	0.00	0.00	0.00
HD cultivator	0.00	207.70	207.70	207.70	207.70	207.70	207.70
harrow packers	0.00	76.60	76.60	0.00	76.60	76.60	76.60
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	85.84	85.84	0.00	76.91	82.23	88.07
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	236.83	236.83	0.00	212.21	226.86	242.98
total	1054.81	1193.07	1160.40	745.85	1145.03	1152.80	1177.31

Table A-11. Fuel energy use of Swift Current, SK rotations (1990-1992)

1990	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	14.90	29.80	29.80	14.90	29.80	29.80	29.80
sprayer	32.50	65.00	65.00	32.50	65.00	65.00	65.00
blade cultivator	573.80	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	0.00	0.00	0.00	266.30	0.00	0.00	0.00
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	109.79	84.12	0.00	53.74	88.87	84.67
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	302.92	232.09	0.00	148.26	245.18	233.60
total	720.51	998.83	869.65	538.15	773.61	893.46	880.23

1991	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	29.80	29.80	29.80	0.00	29.80	29.80	29.80
sprayer	65.00	65.00	65.00	0.00	65.00	65.00	65.00
blade cultivator	286.90	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	0.00	0.00	0.00	266.30	0.00	0.00	0.00
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	117.21	122.08	0.00	107.39	124.78	124.31
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	323.37	336.81	0.00	296.29	344.27	342.96
total	481.01	1026.69	1012.32	490.75	975.29	1028.46	1029.22

1992	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	74.50	44.70	44.70	14.90	29.80	44.70	44.70
sprayer	162.50	97.50	97.50	32.50	65.00	97.50	97.50
blade cultivator	286.90	0.00	0.00	286.90	0.00	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	116.10	116.10	116.10
HD cultivator	0.00	0.00	0.00	266.30	0.00	0.00	0.00
rod weeder	0.00	92.40	0.00	0.00	92.40	0.00	0.00
tandem disc	0.00	207.70	0.00	0.00	207.70	0.00	207.70
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	130.36	71.94	0.00	97.18	59.52	59.52
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	359.67	198.49	0.00	268.12	164.22	164.22
total	623.21	1423.65	871.27	825.05	1237.01	830.56	1040.81

Table A-12. Fuel energy use of Swift Current, SK rotations (1993-1995)

1993	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	59.60	44.70	44.70	44.70	44.70	44.70	44.70
sprayer	130.00	97.50	97.50	97.50	97.50	97.50	97.50
disc drill	0.00	0.00	0.00	286.90	0.00	0.00	0.00
HD cultivator	0.00	116.10	116.10	116.10	115.10	116.10	116.10
harrow drawbar	0.00	76.60	0.00	0.00	0.00	0.00	0.00
blade cultivator	0.00	207.70	0.00	0.00	0.00	0.00	0.00
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	159.01	105.56	0.00	119.81	96.04	103.81
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	438.70	291.24	0.00	330.56	264.97	286.40
total	288.91	1515.52	997.64	653.55	1069.39	967.82	999.57

1994	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	59.60	29.80	29.80	29.80	29.80	29.80	29.80
sprayer	130.00	65.00	65.00	65.00	65.00	65.00	65.00
blade cultivator	573.80	0.00	0.00	0.00	0.00	0.00	0.00
harrow packers	0.00	116.10	116.10	116.10	0.00	0.00	116.10
HD cultivator	0.00	0.00	0.00	266.30	0.00	0.00	0.00
disc drill	0.00	415.40	207.70	207.70	415.40	207.70	207.70
tandem disc	0.00	76.60	76.60	0.00	76.60	76.60	76.60
fertilizer spreader	0.00	0.00	0.00	0.00	85.90	85.90	0.00
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	94.24	73.12	0.00	85.93	99.88	98.47
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	260.01	201.73	0.00	237.07	275.58	271.67
total	862.71	1432.36	1112.58	793.25	1356.40	1188.97	1216.39

1995	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	0.00	9.04	9.04	9.04	9.04	9.04	9.04
water truck	44.70	29.80	29.80	14.90	29.80	29.80	0.00
sprayer	97.50	65.00	65.00	32.50	65.00	65.00	65.00
blade cultivator	573.80	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	0.00	0.00	0.00	266.30	0.00	0.00	0.00
HD cultivator	207.70	415.40	415.40	0.00	415.40	415.40	138.47
harrow packers	0.00	153.20	0.00	0.00	153.20	0.00	0.00
rod weeder	92.40	92.40	0.00	0.00	0.00	0.00	0.00
swather	0.00	132.10	132.10	0.00	132.10	132.10	132.10
grain truck (harvest)	0.00	146.23	127.87	0.00	151.38	126.45	125.71
grain truck (market)	0.00	134.76	102.09	0.00	120.27	108.07	110.62
combine	0.00	403.43	352.78	0.00	417.65	348.87	346.82
total	1115.41	1796.77	1449.49	538.15	1709.24	1450.13	1143.16

Table A-13. Machinery energy use of Swift Current, SK rotations (1987-1989)

1987	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	2.70	8.10	8.10	2.70	8.10	8.10	8.10
sprayer	9.40	28.20	28.20	9.40	28.20	28.20	28.20
blade cultivator	80.80	0.00	0.00	40.40	40.40	40.40	40.40
disc drill	0.00	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	0.00	0.00	0.00	50.90	0.00	0.00	0.00
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	20.84	15.79	0.00	18.60	16.72	17.11
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	29.57	22.40	0.00	26.39	23.71	24.27
total	123.94	220.98	199.93	171.64	252.04	244.18	245.82

1988	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	2.70	6.30	5.40	2.70	5.40	5.40	5.40
sprayer	9.40	21.93	18.80	9.40	18.80	18.80	18.80
blade cultivator	80.80	0.00	0.00	40.40	0.00	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	34.30	34.30	34.30
rod weeder	23.80	0.00	0.00	0.00	0.00	0.00	0.00
HD cultivator	0.00	0.00	0.00	22.40	0.00	0.00	0.00
harrow packers	0.00	0.00	0.00	19.70	0.00	0.00	0.00
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	17.57	6.32	0.00	10.54	6.12	6.39
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	24.93	8.97	0.00	14.95	8.68	9.06
total	147.74	205.00	164.92	162.84	180.04	166.05	167.39

1989	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water hauling	5.40	5.40	5.40	2.70	5.40	5.40	5.40
sprayer	18.80	18.80	18.80	9.40	18.80	18.80	18.80
blade cultivator	121.20	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	0.00	0.00	0.00	50.90	0.00	0.00	0.00
HD cultivator	0.00	22.40	22.40	22.40	22.40	22.40	22.40
harrow packers	0.00	19.70	19.70	0.00	19.70	19.70	19.70
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	27.31	27.31	0.00	24.47	26.16	28.02
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	38.75	38.75	0.00	34.72	37.11	39.75
total	176.44	266.62	257.79	153.64	255.84	256.63	261.81

Table A-14. Machinery energy use of Swift Current, SK rotations (1990-1992)

1990	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	2.70	5.40	5.40	2.70	5.40	5.40	5.40
sprayer	9.40	18.80	18.80	9.40	18.80	18.80	18.80
blade cultivator	80.80	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	0.00	0.00	0.00	50.90	0.00	0.00	0.00
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	34.93	26.77	0.00	17.10	28.28	26.94
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	49.56	37.97	0.00	24.26	40.11	38.22
total	123.94	242.96	214.37	131.24	195.90	219.64	217.10

1991	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	5.40	5.40	5.40	0.00	5.40	5.40	5.40
sprayer	18.80	18.80	18.80	0.00	18.80	18.80	18.80
blade cultivator	40.40	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	0.00	0.00	0.00	50.90	0.00	0.00	0.00
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	37.29	38.84	0.00	34.17	39.70	39.55
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	52.90	55.10	0.00	48.47	56.32	56.11
total	95.64	248.66	243.58	119.14	237.19	247.27	247.60

1992	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	13.50	8.10	8.10	2.70	5.40	8.10	8.10
sprayer	47.00	28.20	28.20	9.40	18.80	28.20	28.20
blade cultivator	40.40	0.00	0.00	40.40	0.00	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	34.30	34.30	34.30
HD cultivator	0.00	0.00	0.00	50.90	0.00	0.00	0.00
rod weeder	0.00	23.80	0.00	0.00	23.80	0.00	0.00
tandem disc	0.00	22.40	0.00	0.00	22.40	0.00	22.40
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	41.48	22.89	0.00	30.92	18.94	18.94
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	58.84	32.47	0.00	43.86	26.87	26.87
total	131.94	317.09	217.10	171.64	275.53	209.16	232.25

Table A-15. Machinery energy use of Swift Current, SK rotations (1993-1995)

1993	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	10.80	8.10	8.10	8.10	8.10	8.10	8.10
sprayer	37.60	28.20	28.20	28.20	28.20	28.20	28.20
disc drill	0.00	0.00	0.00	40.40	0.00	0.00	0.00
HD cultivator	0.00	34.30	34.30	34.30	34.30	34.30	34.30
harrow drawbar	0.00	19.70	0.00	0.00	0.00	0.00	0.00
blade cultivator	0.00	22.40	0.00	0.00	0.00	0.00	0.00
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	50.59	33.59	0.00	38.12	30.56	33.03
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	71.77	47.65	0.00	54.08	43.35	46.86
total	79.44	335.03	242.97	144.94	258.85	237.26	243.92

1994	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	10.80	5.40	5.40	5.40	5.40	5.40	5.40
sprayer	37.60	18.80	18.80	18.80	18.80	18.80	18.80
blade cultivator	80.80	0.00	0.00	0.00	0.00	0.00	0.00
harrow packers	0.00	34.30	34.30	34.30	0.00	0.00	34.30
HD cultivator	0.00	0.00	0.00	50.90	0.00	0.00	0.00
disc drill	0.00	44.80	22.40	22.40	44.80	22.40	22.40
tandem disc	0.00	19.70	19.70	0.00	19.70	19.70	19.70
fertilizer spreader	0.00	0.00	0.00	0.00	4.90	4.90	0.00
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	29.99	23.26	0.00	27.34	31.78	31.33
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	42.54	33.00	0.00	38.78	45.08	44.45
total	160.24	295.49	248.00	165.74	255.77	240.82	269.81

1995	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	0.00	2.90	2.90	2.90	2.90	2.90	2.90
water truck	8.10	5.40	5.40	2.70	5.40	5.40	0.00
sprayer	28.20	18.80	18.80	9.40	18.80	18.80	18.80
blade cultivator	80.80	0.00	0.00	0.00	0.00	0.00	0.00
disc drill	0.00	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	0.00	0.00	0.00	50.90	0.00	0.00	0.00
HD cultivator	22.40	44.80	44.80	0.00	44.80	44.80	14.93
harrow packers	0.00	39.40	0.00	0.00	39.40	0.00	0.00
rod weeder	23.80	23.80	0.00	0.00	0.00	0.00	0.00
swather	0.00	29.60	29.60	0.00	29.60	29.60	29.60
grain truck (harvest)	0.00	46.53	40.69	0.00	48.17	40.23	40.00
grain truck (market)	0.00	36.43	27.60	0.00	32.51	29.21	29.90
combine	0.00	66.00	57.72	0.00	68.33	57.08	56.74
total	194.34	378.99	292.84	131.24	355.24	293.36	258.21

Table A-16. Herbicide energy use of Swift Current, SK rotations (1989-1991)

1987	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
2,4-D ester	72.64	72.64	72.64	72.64	72.64	72.64	72.64
Decis	0.00	26.91	26.91	0.00	26.91	26.91	26.91
Hoegrass II	0.00	442.53	442.53	0.00	442.53	442.53	442.53
Total	72.64	542.07	542.07	72.64	542.07	542.07	542.07

1988	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Roundup	0.00	59.67	0.00	0.00	0.00	0.00	0.00
Hoegrass II	0.00	442.53	442.53	0.00	442.53	442.53	442.53
2,4-D ester	72.64	72.64	72.64	72.64	72.64	72.64	72.64
Total	72.64	574.84	515.17	72.64	515.17	515.17	515.17

1989	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Banvel	99.55	0.00	0.00	0.00	0.00	0.00	0.00
2,4-D ester	211.65	84.71	84.71	84.71	84.71	84.71	84.71
Hoegrass II	0.00	442.53	442.53	0.00	442.53	442.53	442.53
Total	311.20	527.23	527.23	84.71	527.23	527.23	527.23

1990	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
2,4-D ester	84.71	181.48	181.48	84.71	181.48	181.48	181.48
Torch	0.00	77.00	77.00	0.00	77.00	77.00	77.00
Total	84.71	258.48	258.48	84.71	258.48	258.48	258.48

1991	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Roundup	447.71	447.71	447.71	0.00	447.71	447.71	447.71
Banvel	99.55	99.55	99.55	0.00	99.55	99.55	99.55
2,4-D amine	60.64	60.64	60.64	0.00	60.64	60.64	60.64
Rustler	90.60	0.00	0.00	0.00	0.00	0.00	0.00
Laser	0.00	175.32	175.32	0.00	175.32	175.32	175.32
Total	698.51	783.22	783.22	0.00	783.22	783.22	783.22

Table A-17. Herbicide energy use of Swift Current, SK rotations (1992-1995)

1992	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
2,4-D ester	149.14	149.14	149.14	74.57	149.14	149.14	149.14
Roundup	447.71	0.00	0.00	0.00	0.00	0.00	0.00
Banvel	99.55	0.00	0.00	0.00	0.00	0.00	0.00
2,4-D amine	30.32	0.00	0.00	0.00	0.00	0.00	0.00
Rustler	108.73	0.00	0.00	0.00	0.00	0.00	0.00
Laser	0.00	175.32	175.32	0.00	0.00	175.32	175.32
Total	835.46	324.46	324.46	74.57	149.14	324.46	324.46

1993	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Rustler	144.95	0.00	0.00	72.48	0.00	0.00	0.00
2,4-D ester	74.57	74.57	74.57	74.57	74.57	74.57	74.57
Roundup	447.71	447.71	447.71	447.71	447.71	447.71	447.71
Puma	0.00	27.28	27.28	0.00	27.28	27.28	27.28
Buctril M	0.00	185.42	185.42	0.00	185.42	185.42	185.42
Total	667.24	734.98	734.98	594.76	734.98	734.98	734.98

1994	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Rustler	72.48	0.00	0.00	0.00	0.00	0.00	0.00
Sweep	263.66	0.00	0.00	0.00	0.00	0.00	0.00
2,4-D amine	60.64	0.00	0.00	0.00	0.00	0.00	0.00
Roundup	447.71	0.00	0.00	447.71	0.00	0.00	0.00
2,4-D ester	74.57	74.57	74.57	74.57	74.57	74.57	74.57
Puma	0.00	27.28	27.28	0.00	27.28	27.28	27.28
Buctril M	0.00	185.42	185.42	0.00	185.42	185.42	185.42
Total	919.06	287.27	287.27	522.28	287.27	287.27	287.27

1995	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Roundup	223.76	0.00	0.00	0.00	0.00	0.00	0.00
Rustler	72.45	0.00	0.00	0.00	0.00	0.00	0.00
Puma	0.00	27.28	27.28	0.00	27.28	27.28	27.28
Buctril M	0.00	185.42	185.42	0.00	185.42	185.42	185.42
2,4-D ester	74.51	74.51	74.51	74.51	74.51	74.51	74.51
Total	370.72	287.21	287.21	74.51	287.21	287.21	287.21

Table A-18. Fertilizer energy use of Swift Current, SK rotations (1987-1991)

1987	Rotation #1			Rotation #2			Rotation #6
	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	green manure MJ/ha	wheat MJ/ha	wheat MJ/ha	wheat MJ/ha
N	0.00	4198.75	4478.93	232.36	3727.75	3856.89	3875.62
P_2O_5	0.00	218.05	181.71	181.71	218.05	218.05	181.71
total fert. energy	**0.00**	**4416.79**	**4660.64**	**414.07**	**3945.80**	**4074.94**	**4057.32**

1988	Rotation #1			Rotation #2			Rotation #6
	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	green manure MJ/ha	wheat MJ/ha	wheat MJ/ha	wheat MJ/ha
N	0.00	1371.42	1743.66	209.12	1751.26	1743.66	983.99
P_2O_5	0.00	163.53	163.53	163.53	163.53	163.53	163.53
total fert. energy	**0.00**	**1534.96**	**1907.20**	**372.66**	**1914.80**	**1907.20**	**1147.53**

1989	Rotation #1			Rotation #2			Rotation #6
	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	green manure MJ/ha	wheat MJ/ha	wheat MJ/ha	wheat MJ/ha
N	0.00	937.07	2875.58	209.12	3908.73	1941.18	1804.44
P_2O_5	0.00	109.02	163.53	163.53	163.53	163.53	163.53
total fert. energy	**0.00**	**1046.10**	**3039.11**	**372.66**	**4072.27**	**2104.71**	**1967.97**

1990	Rotation #1			Rotation #2			Rotation #6
	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	green manure MJ/ha	wheat MJ/ha	wheat MJ/ha	wheat MJ/ha
N	0.00	930.81	1166.31	183.78	680.12	1614.52	892.83
P_2O_5	0.00	163.53	163.53	143.71	163.53	163.53	163.53
total fert. energy	**0.00**	**1094.35**	**1329.85**	**327.49**	**843.66**	**1778.05**	**1056.37**

1991	Rotation #1			Rotation #2			Rotation #6
	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	green manure MJ/ha	wheat MJ/ha	wheat MJ/ha	wheat MJ/ha
N	0.00	1694.34	3061.76	0.00	2408.44	2119.76	4201.27
P_2O_5	0.00	208.14	208.14	0.00	208.14	208.14	208.14
total fert. energy	**0.00**	**1902.48**	**3269.89**	**0.00**	**2616.57**	**2327.90**	**4409.40**

Table A-19. Fertilizer energy use of Swift Current, SK rotations (1992-1995)

1992	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	2621.15	4201.27	0.00	3730.27	3965.77	3965.77
P_2O_5	0.00	208.14	208.14	0.00	208.14	208.14	208.14
total fert. energy	0.00	2829.28	4409.40	0.00	3938.40	4173.90	4173.90

1993	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	2529.98	3608.72	0.00	2362.86	3608.72	3487.17
P_2O_5	0.00	208.14	208.14	0.00	208.14	208.14	208.14
total fert. energy	0.00	2738.12	3816.86	0.00	2570.99	3816.86	3695.31

1994	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	3775.85	2902.22	266.16	3540.35	3008.58	3114.93
P_2O_5	0.00	208.14	208.14	208.14	208.14	208.14	208.14
total fert. energy	0.00	3983.98	3110.36	474.29	3748.49	3216.71	3323.07

1995	Rotation #1			Rotation #2			Rotation #6
	fallow	wheat	wheat	green manure	wheat	wheat	wheat
	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
N	0.00	3099.74	2203.33	0.00	3449.19	1869.07	3517.56
P_2O_5	0.00	208.14	208.14	0.00	208.14	208.14	208.14
total fert. energy	0.00	3307.87	2411.46	0.00	3657.32	2077.20	3725.70

Table A-20. Total rotational energy use of Swift Current, SK rotations (1987-1995)

1987-1995	Rotation #1			Rotation #2			Rotation #6
	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	green manure MJ/ha	wheat MJ/ha	wheat MJ/ha	wheat MJ/ha
seed	0.00	3888.00	3888.00	1203.12	3888.00	3888.00	3888.00
machinery	1140.54	2417.71	1988.39	1258.94	2173.29	2021.24	2053.71
fuel	6679.99	11076.15	8888.86	6252.81	10087.79	9235.07	9252.33
herbicide	4032.17	4319.77	4260.10	1580.82	4084.78	4260.10	4260.10
fertilizer	0.00	22853.94	27954.77	1961.17	27308.29	25477.48	27556.56
total	11852.70	44555.56	46980.11	12256.85	47542.16	44881.88	47010.69

1987-1995 (all phases)	F-W-W	GM-W-W	ContW
	MJ/ha	MJ/ha	MJ/ha
seed	7776.00	8979.12	3888.00
machinery	5546.64	5453.47	2053.71
fuel	26645.00	25575.67	9252.33
herbicide	12612.04	9925.70	4260.10
fertilizer	50808.70	54746.94	27556.56
total	103388.38	104680.89	47010.69

all phases per rotation cycle	F-W-W	GM-W-W	ContW
	MJ/ha	MJ/ha	MJ/ha
seed	2592.00	2993.04	3888.00
machinery	1848.88	1817.82	2053.71
fuel	8881.67	8525.22	9252.33
herbicide	4204.01	3308.57	4260.10
fertilizer	16936.23	18248.98	27556.56
total	34462.79	34893.63	47010.69

per 3 year rotation cycle	F-W-W	GM-W-W	ContW
	MJ/ha	MJ/ha	MJ/ha
seed	864.00	997.68	1296.00
machinery	616.29	605.94	684.57
fuel	2960.56	2841.74	3084.11
herbicide	1401.34	1102.86	1420.03
fertilizer	5645.41	6082.99	9185.52
total	11487.60	11631.21	15670.23

Table A-21. Seed energy use of Indian Head, SK rotations (1993-1998)

1991	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	967.68	967.68	0.00	967.68	725.76	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	14.35	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	199.20	0.00	0.00
total	**967.68**	**967.68**	**0.00**	**967.68**	**725.76**	**213.55**	**0.00**	**0.00**

1992	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	1000.08	1000.08	0.00	1000.08	725.76	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	14.35	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	199.20	0.00	0.00
total	**1000.08**	**1000.08**	**0.00**	**1000.08**	**725.76**	**213.55**	**0.00**	**0.00**

1993	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	967.68	967.68	0.00	967.68	720.00	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	28.71	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	199.20	0.00	0.00
total	**967.68**	**967.68**	**0.00**	**967.68**	**720.00**	**227.91**	**0.00**	**0.00**

1994	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	993.60	993.60	0.00	993.60	820.80	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	28.71	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	199.20	0.00	0.00
total	**993.60**	**993.60**	**0.00**	**993.60**	**820.80**	**227.91**	**0.00**	**0.00**

1995	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	967.68	967.68	0.00	967.68	967.68	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	64.59	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	**967.68**	**967.68**	**0.00**	**967.68**	**967.68**	**64.59**	**0.00**	**0.00**

1996	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	1044.00	1044.00	0.00	1044.00	1044.00	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	64.59	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	**1044.00**	**1044.00**	**0.00**	**1044.00**	**1044.00**	**64.59**	**0.00**	**0.00**

1997	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	967.68	967.68	0.00	967.68	967.68	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	64.59	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	**967.68**	**967.68**	**0.00**	**967.68**	**967.68**	**64.59**	**0.00**	**0.00**

1998	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	967.68	967.68	0.00	967.68	967.68	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	0.00	77.51	0.00	0.00
bromegrass	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
total	**967.68**	**967.68**	**0.00**	**967.68**	**967.68**	**77.51**	**0.00**	**0.00**

Table A-22. Fuel energy use of Indian Head, SK rotations (1993-1995)

1993	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	0.00	9.04	9.04	9.04	0.00	0.00
water truck	29.80	29.80	29.80	14.90	0.00	0.00	0.00	14.90
sprayer	65.00	65.00	65.00	32.50	0.00	0.00	0.00	32.50
disc drill	116.10	116.10	0.00	116.10	116.10	116.10	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	167.10	167.10	167.10
baler	0.00	0.00	0.00	0.00	0.00	72.30	109.80	99.90
swather	132.10	132.10	0.00	132.10	132.10	0.00	0.00	0.00
grain truck (harvest)	15.11	92.93	0.00	50.34	31.62	72.73	110.42	100.51
grain truck (market)	31.08	191.17	0.00	103.56	65.05	149.62	227.14	206.76
combine	41.65	256.20	0.00	138.78	87.19	0.00	0.00	0.00
total	401.04	853.49	65.00	573.38	432.06	577.85	614.45	608.78

1994	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	0.00	9.04	9.04	9.04	0.00	0.00
water truck	29.80	29.80	44.70	29.80	0.00	0.00	0.00	14.90
sprayer	65.00	65.00	97.50	65.00	0.00	0.00	0.00	32.50
disc drill	116.10	116.10	0.00	116.10	116.10	116.10	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	167.10	167.10	167.10
baler	0.00	0.00	0.00	0.00	0.00	91.60	110.10	89.30
swather	132.10	132.10	0.00	132.10	132.10	0.00	0.00	0.00
grain truck (harvest)	23.56	94.41	0.00	93.84	29.66	92.24	110.73	89.82
grain truck (market)	48.46	194.21	0.00	193.04	61.01	189.74	227.78	184.77
combine	64.94	260.28	0.00	258.71	81.76	0.00	0.00	0.00
total	450.15	862.10	97.50	858.80	420.63	656.77	615.71	563.50

1995	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	0.00	9.04	9.04	9.04	0.00	0.00
water truck	74.50	59.60	44.70	74.50	44.70	0.00	0.00	0.00
sprayer	162.50	130.00	97.50	162.50	97.50	0.00	0.00	0.00
disc drill	116.10	116.10	0.00	116.10	116.10	116.10	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	167.10	167.10	167.10
baler	0.00	0.00	0.00	0.00	0.00	98.50	97.40	72.50
swather	132.10	132.10	0.00	132.10	132.10	0.00	0.00	0.00
grain truck (harvest)	54.24	145.33	0.00	110.16	96.35	0.00	0.00	0.00
grain truck (market)	111.57	298.95	0.00	226.60	198.20	0.00	0.00	0.00
combine	149.53	400.65	0.00	303.69	265.62	0.00	0.00	0.00
total	726.04	1223.14	97.50	1051.15	905.88	381.70	264.50	239.60

Table A-23. Fuel energy use of Indian Head, SK rotations (1996-1998)

1996	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	0.00	9.04	9.04	9.04	0.00	0.00
water truck	59.60	59.60	29.80	29.80	29.80	0.00	0.00	14.90
sprayer	130.00	130.00	65.00	65.00	65.00	0.00	0.00	32.50
disc drill	116.10	116.10	0.00	116.10	116.10	116.10	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	167.10	167.10	167.10
baler	0.00	0.00	0.00	0.00	0.00	129.50	194.20	155.20
swather	132.10	132.10	0.00	132.10	132.10	0.00	0.00	0.00
grain truck (harvest)	55.34	138.08	0.00	121.14	95.67	130.25	195.43	156.13
grain truck (market)	113.83	284.05	0.00	249.20	195.80	267.93	402.01	321.17
combine	152.55	380.68	0.00	333.98	263.75	0.00	0.00	0.00
total	689.92	1181.01	65.00	1017.53	868.42	810.87	958.74	832.10

1997	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	0.00	9.04	9.04	9.04	0.00	0.00
water truck	44.70	44.70	59.60	14.90	14.90	0.00	0.00	0.00
sprayer	97.50	97.50	130.00	32.50	32.50	0.00	0.00	0.00
disc drill	116.10	116.10	0.00	116.10	116.10	116.10	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	167.10	167.10	167.10
baler	0.00	0.00	0.00	0.00	0.00	51.40	62.70	47.80
swather	132.10	132.10	0.00	132.10	132.10	0.00	0.00	0.00
grain truck (harvest)	25.64	84.58	0.00	64.60	45.91	51.64	63.13	48.10
grain truck (market)	52.75	173.98	0.00	132.88	94.45	106.23	129.86	98.95
combine	70.69	233.17	0.00	178.09	126.58	0.00	0.00	0.00
total	494.78	837.43	130.00	656.27	547.64	492.47	422.78	361.96

1998	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	0.00	9.04	9.04	9.04	0.00	0.00
water truck	29.80	29.80	59.60	44.70	44.70	0.00	0.00	14.90
sprayer	65.00	65.00	130.00	97.50	97.50	0.00	0.00	32.50
disc drill	116.10	116.10	0.00	116.10	116.10	116.10	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	167.10	167.10	167.10
baler	0.00	0.00	0.00	0.00	0.00	43.40	167.10	140.50
swather	132.10	132.10	0.00	132.10	132.10	0.00	0.00	0.00
grain truck (harvest)	21.50	110.88	0.00	26.30	58.55	43.69	168.09	141.32
grain truck (market)	44.22	228.08	0.00	54.11	120.44	89.88	345.78	290.71
combine	59.27	305.67	0.00	72.52	161.41	0.00	0.00	0.00
total	438.19	957.83	130.00	498.63	686.10	460.17	848.08	772.14

Table A-24. Machinery energy use of Indian Head, SK rotations (1993-1995)

1993	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	0.00	2.90	2.90	2.90	0.00	0.00
water truck	5.40	5.40	5.40	2.70	0.00	0.00	0.00	2.70
sprayer	18.80	18.80	18.80	9.40	0.00	0.00	0.00	9.40
disc drill	34.30	34.30	0.00	34.30	34.30	34.30	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	28.20	28.20	28.20
baler	0.00	0.00	0.00	0.00	0.00	15.00	22.80	20.70
swather	29.60	29.60	0.00	29.60	29.60	0.00	0.00	0.00
grain truck (harvest)	4.81	29.57	0.00	16.02	10.06	23.14	35.13	31.98
grain truck (market)	8.40	51.67	0.00	27.99	17.58	40.44	61.39	55.89
combine	6.82	41.95	0.00	22.72	14.27	0.00	0.00	0.00
total	102.73	205.89	18.80	140.03	105.82	141.08	147.53	146.17

1994	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	0.00	2.90	2.90	2.90	0.00	0.00
water truck	5.40	5.40	8.10	5.40	0.00	0.00	0.00	2.70
sprayer	18.80	18.80	28.20	18.80	0.00	0.00	0.00	9.40
disc drill	34.30	34.30	0.00	34.30	34.30	34.30	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	28.20	28.20	28.20
baler	0.00	0.00	0.00	0.00	0.00	19.00	22.80	18.50
swather	29.60	29.60	0.00	29.60	29.60	0.00	0.00	0.00
grain truck (harvest)	7.49	30.04	0.00	29.86	9.44	29.35	35.23	28.58
grain truck (market)	13.10	52.49	0.00	52.18	16.49	51.29	61.57	49.94
combine	10.63	42.61	0.00	42.36	13.39	0.00	0.00	0.00
total	113.92	207.85	28.20	207.10	103.21	162.13	147.80	134.62

1995	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	0.00	2.90	2.90	2.90	0.00	0.00
water truck	13.50	10.80	8.10	13.50	8.10	0.00	0.00	0.00
sprayer	47.00	37.60	28.20	47.00	28.20	0.00	0.00	0.00
disc drill	34.30	34.30	0.00	34.30	34.30	34.30	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	28.20	28.20	28.20
baler	0.00	0.00	0.00	0.00	0.00	20.40	20.20	15.00
swather	29.60	29.60	0.00	29.60	29.60	0.00	0.00	0.00
grain truck (harvest)	17.26	46.24	0.00	35.05	30.66	31.51	31.16	23.20
grain truck (market)	30.16	80.81	0.00	61.25	53.57	55.07	54.46	40.54
combine	24.48	65.60	0.00	49.72	43.49	0.00	0.00	0.00
total	182.80	294.15	28.20	256.92	219.82	169.49	134.02	106.94

Table A-25. Machinery energy use of Indian Head, SK rotations (1996-1998)

1996	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	0.00	2.90	2.90	2.90	0.00	0.00
water truck	10.80	10.80	5.40	5.40	5.40	0.00	0.00	2.70
sprayer	37.60	37.60	18.80	18.80	18.80	0.00	0.00	9.40
disc drill	34.30	34.30	0.00	34.30	34.30	34.30	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	28.20	28.20	28.20
baler	0.00	0.00	0.00	0.00	0.00	26.80	40.30	32.20
swather	29.60	29.60	0.00	29.60	29.60	0.00	0.00	0.00
grain truck (harvest)	17.61	43.94	0.00	38.55	30.44	41.44	62.18	49.68
grain truck (market)	30.77	76.78	0.00	67.36	53.19	72.42	108.66	86.81
combine	24.98	62.33	0.00	54.68	43.18	0.00	0.00	0.00
total	174.85	284.54	18.80	243.29	209.52	203.16	239.35	206.29

1997	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	0.00	2.90	2.90	2.90	0.00	0.00
water truck	8.10	8.10	10.80	2.70	2.70	0.00	0.00	0.00
sprayer	28.20	28.20	37.60	9.40	9.40	0.00	0.00	0.00
disc drill	34.30	34.30	0.00	34.30	34.30	34.30	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	28.20	28.20	28.20
baler	0.00	0.00	0.00	0.00	0.00	10.60	13.00	9.90
swather	29.60	29.60	0.00	29.60	29.50	0.00	0.00	0.00
grain truck (harvest)	8.16	26.91	0.00	20.55	14.61	16.43	20.09	15.31
grain truck (market)	14.26	47.03	0.00	35.92	25.53	28.71	35.10	26.75
combine	11.57	38.18	0.00	29.16	20.72	0.00	0.00	0.00
total	126.09	204.21	37.60	158.93	134.16	118.25	96.39	80.15

1998	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	0.00	2.90	2.90	2.90	0.00	0.00
water truck	5.40	5.40	10.80	8.10	8.10	0.00	0.00	2.70
sprayer	18.80	18.80	37.60	28.20	28.20	0.00	0.00	9.40
disc drill	34.30	34.30	0.00	34.30	34.30	34.30	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	0.00	28.20	28.20	28.20
baler	0.00	0.00	0.00	0.00	0.00	9.00	34.60	29.10
swather	29.60	29.60	0.00	29.60	29.60	0.00	0.00	0.00
grain truck (harvest)	6.84	35.28	0.00	8.37	18.63	13.90	53.48	44.97
grain truck (market)	11.95	61.65	0.00	14.63	32.55	24.29	93.46	78.58
combine	9.70	50.05	0.00	11.87	26.43	0.00	0.00	0.00
total	111.20	229.68	37.60	126.97	169.71	109.69	209.75	190.25

Table A-26. Herbicide energy use of Indian Head, SK rotations (1993-1998)

1993	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Target	97.17	97.17	0.00	121.46	0.00	0.00	0.00	0.00
Fortress	568.44	568.44	0.00	568.44	0.00	0.00	0.00	0.00
Rustler	0.00	0.00	259.56	0.00	0.00	0.00	0.00	0.00
Roundup	0.00	0.00	0.00	0.00	0.00	0.00	0.00	452.96
Banvel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	40.27
Total	665.61	665.61	259.56	689.90	0.00	0.00	0.00	493.24

1994	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Banvel	86.99	86.99	0.00	86.99	0.00	0.00	0.00	49.94
2,4-D amine	83.41	83.41	0.00	83.41	0.00	0.00	0.00	0.00
2,4-D ester	0.00	0.00	72.40	0.00	0.00	0.00	0.00	0.00
Rustler	0.00	0.00	584.54	0.00	0.00	0.00	0.00	0.00
Roundup	0.00	0.00	0.00	0.00	0.00	0.00	0.00	452.96
Express	0.00	0.00	82.01	0.00	0.00	0.00	0.00	0.00
Total	170.39	170.39	738.95	170.39	0.00	0.00	0.00	502.90

1995	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Buctril M	187.67	187.67	0.00	187.67	187.67	0.00	0.00	0.00
Rustler	129.78	0.00	233.61	195.19	65.41	0.00	0.00	0.00
Roundup	567.11	905.93	452.96	452.96	793.59	0.00	0.00	0.00
2,4-D	41.70	41.70	0.00	41.70	41.70	0.00	0.00	0.00
Banvel	40.27	40.27	50.26	49.94	40.27	0.00	0.00	0.00
Fortress	568.44	568.44	0.00	568.44	568.44	0.00	0.00	0.00
Lorsban	104.16	104.16	0.00	104.16	104.16	0.00	0.00	0.00
Total	1639.14	1848.17	736.83	1600.07	1801.25	0.00	0.00	0.00

1996	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Touchdown	317.07	317.07	398.61	317.07	317.07	0.00	0.00	0.00
2,4-D	171.72	171.72	122.66	171.72	171.72	0.00	0.00	0.00
Banvel	40.27	40.27	0.00	40.27	40.27	0.00	0.00	0.00
Fortress	568.44	568.44	0.00	568.44	568.44	0.00	0.00	0.00
Rustler	0.00	0.00	259.56	0.00	0.00	0.00	0.00	0.00
Poast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	56.75
Total	1097.51	1097.51	780.83	1097.51	1097.51	0.00	0.00	56.75

1997	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
Buctril M	187.67	187.67	0.00	187.67	187.67	0.00	0.00	0.00
2,4-D	122.66	122.66	171.72	122.66	122.66	0.00	0.00	0.00
Fortress	568.44	568.44	0.00	568.44	568.44	0.00	0.00	0.00
Roundup	0.00	0.00	1358.89	0.00	0.00	0.00	0.00	0.00
Total	878.77	878.77	1530.61	878.77	878.77	0.00	0.00	0.00

1998	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f)	wheat (+f)	fallow	wheat	wheat	hay	hay	hay
Herbicide	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
2,4-D LV600	256.42	256.42	120.67	256.42	256.42	0.00	0.00	0.00
Banvel	47.12	47.12	0.00	47.12	47.12	0.00	0.00	0.00
Poast	0.00	0.00	0.00	0.00	0.00	0.00	0.00	156.06
Roundup	0.00	0.00	1358.89	0.00	0.00	0.00	0.00	0.00
Pursuit	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.93
Total	303.53	303.53	1479.56	303.53	303.53	0.00	0.00	164.98

Table A-27. Fertilizer energy use of Indian Head, SK rotations (1993-1998)

1993	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f) MJ/ha	wheat (+f) MJ/ha	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	hay MJ/ha	hay MJ/ha	hay MJ/ha
N	0.00	5669.35	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.00	216.56	0.00	0.00	0.00	0.00	0.00	0.00
total fert. energy	0.00	5885.91	0.00	0.00	0.00	0.00	0.00	0.00

1994	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f) MJ/ha	wheat (+f) MJ/ha	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	hay MJ/ha	hay MJ/ha	hay MJ/ha
N	0.00	6795.38	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.00	259.18	0.00	0.00	0.00	0.00	0.00	0.00
total fert. energy	0.00	7054.55	0.00	0.00	0.00	0.00	0.00	0.00

1995	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f) MJ/ha	wheat (+f) MJ/ha	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	hay MJ/ha	hay MJ/ha	hay MJ/ha
N	0.00	6936.73	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.00	252.74	0.00	0.00	0.00	0.00	0.00	0.00
total fert. energy	0.00	7189.47	0.00	0.00	0.00	0.00	0.00	0.00

1996	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f) MJ/ha	wheat (+f) MJ/ha	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	hay MJ/ha	hay MJ/ha	hay MJ/ha
N	0.00	7720.81	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.00	270.08	0.00	0.00	0.00	0.00	0.00	0.00
total fert. energy	0.00	7990.89	0.00	0.00	0.00	0.00	0.00	0.00

1997	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f) MJ/ha	wheat (+f) MJ/ha	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	hay MJ/ha	hay MJ/ha	hay MJ/ha
N	0.00	5748.78	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.00	237.87	0.00	0.00	0.00	0.00	0.00	0.00
total fert. energy	0.00	5986.65	0.00	0.00	0.00	0.00	0.00	0.00

1998	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f) MJ/ha	wheat (+f) MJ/ha	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	hay MJ/ha	hay MJ/ha	hay MJ/ha
N	0.00	4116.15	0.00	0.00	0.00	0.00	0.00	0.00
P_2O_5	0.00	218.05	0.00	0.00	0.00	0.00	0.00	0.00
total fert. energy	0.00	4334.19	0.00	0.00	0.00	0.00	0.00	0.00

Table A-28. Total rotational energy use of Indian Head, SK rotations (1993-1998)

1993-1998 (all phases)	Rotation #1	Rotation #2	Rotation #8					
	wheat (-f) MJ/ha	wheat (+f) MJ/ha	fallow MJ/ha	wheat MJ/ha	wheat MJ/ha	hay MJ/ha	hay MJ/ha	hay MJ/ha
seed	5908.32	5908.32	0.00	5908.32	5487.84	727.12	0.00	0.00
machinery	811.59	1426.31	169.20	1133.23	942.24	475.80	322.90	332.20
fuel	3210.12	5914.99	585.00	4655.76	3861.72	2185.90	1743.90	1737.80
herbicide	4754.95	4963.99	5526.35	4740.17	4081.06	0.00	0.00	1217.87
fertilizer	0.00	38441.67	0.00	0.00	0.00	0.00	0.00	0.00
total	**14684.97**	**56655.28**	**6280.55**	**16437.48**	**14372.86**	**3388.82**	**2066.80**	**3287.87**

1993-1998 (all phases)	Rotation #1	Rotation #2	Rotation #8
	MJ/ha	MJ/ha	MJ/ha
seed	5908.32	5908.32	12123.28
machinery	811.59	1426.31	3375.58
fuel	3210.12	5914.99	14770.07
herbicide	4754.95	4963.99	15565.45
fertilizer	0.00	38441.67	0.00
total	**14684.97**	**56655.28**	**45834.37**

1993-1998 (1 rot'n cycle)	Rotation #1	Rotation #2	Rotation #8
	MJ/ha	MJ/ha	MJ/ha
seed	5908.32	5908.32	2020.55
machinery	811.59	1426.31	562.60
fuel	3210.12	5914.99	2461.68
herbicide	4754.95	4963.99	2594.24
fertilizer	0.00	38441.67	0.00
total	**14684.97**	**56655.28**	**7639.06**

Table A-29. Seed energy use of Glenlea, MB rotations (1992-1999)

1992	Wheat				Wheat			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	720.00	720.00	720.00	720.00	720.00	720.00	720.00	720.00

1993	Pea				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pea	501.29	501.29	501.29	501.29	0.00	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	71.77	71.77	71.77	71.77
total	501.29	501.29	501.29	501.29	71.77	71.77	71.77	71.77

1994	Wheat				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	720.00	720.00	720.00	720.00	0.00	0.00	0.00	0.00

1995	Flax				Flax			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
flax	560.00	560.00	560.00	560.00	560.00	560.00	560.00	560.00

1996	Wheat				Wheat			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	720.00	720.00	720.00	720.00	720.00	720.00	720.00	720.00

1997	Pea				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pea	501.29	501.29	501.29	501.29	0.00	0.00	0.00	0.00
alfalfa	0.00	0.00	0.00	0.00	71.77	71.77	71.77	71.77
total	501.29	501.29	501.29	501.29	71.77	71.77	71.77	71.77

1998	Wheat				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
wheat	720.00	720.00	720.00	720.00	0.00	0.00	0.00	0.00

1999	Flax				Flax			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
seed	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
flax	560.00	560.00	560.00	560.00	560.00	560.00	560.00	560.00

Table A-30. Fuel energy use of Glenlea, MB rotations (1992-1994)

1992	Wheat				Wheat			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	9.04	9.04	9.04	9.04
water truck	29.80	29.80	0.00	0.00	14.90	14.90	0.00	0.00
sprayer	65.00	65.00	0.00	0.00	32.50	32.50	0.00	0.00
fertilizer spreader	85.90	0.00	85.90	0.00	0.00	0.00	0.00	0.00
HD cultivator	519.20	519.20	519.20	519.20	0.00	0.00	0.00	0.00
disc drill	116.10	116.10	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	266.30	266.30	266.30	266.30	266.30	266.30	266.30	266.30
harrow packers	153.20	153.20	153.20	153.20	153.20	153.20	153.20	153.20
swather	132.10	132.10	132.10	132.10	132.10	132.10	132.10	132.10
combine	391.50	391.50	391.50	391.50	391.50	391.50	391.50	391.50
grain truck (harvest)	141.90	141.90	141.90	141.90	141.90	141.90	141.90	141.90
grain truck (market)	291.90	291.90	291.90	291.90	291.90	291.90	291.90	291.90
total	2163.10	2077.20	2098.10	2012.20	1525.50	1525.50	1493.00	1493.00

1993	Pea				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	9.04	9.04	9.04	9.04
water truck	29.80	29.80	0.00	0.00	0.00	0.00	0.00	0.00
sprayer	65.00	65.00	0.00	0.00	0.00	0.00	0.00	0.00
fertilizer spreader	0.00	0.00	0.00	0.00	85.90	0.00	85.90	0.00
cultivator	257.60	257.60	128.80	128.80	0.00	0.00	0.00	0.00
disc drill	116.10	116.10	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	532.60	532.60	532.60	532.60	0.00	0.00	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	167.10	167.10	167.10	167.10
baler	0.00	0.00	0.00	0.00	142.50	151.30	142.50	151.30
swather	132.10	132.10	132.10	132.10	0.00	0.00	0.00	0.00
combine	53.43	70.66	261.00	75.10	0.00	0.00	0.00	0.00
grain truck (harvest)	19.37	25.61	94.60	27.22	143.39	152.07	94.60	152.07
grain truck (market)	39.84	52.68	194.60	55.99	294.97	312.83	194.60	312.83
total	1216.04	1252.35	1459.80	1067.91	949.96	899.40	800.80	899.40

1994	Wheat				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	0.00	0.00	0.00	0.00
water truck	29.80	29.80	0.00	0.00	14.90	14.90	0.00	0.00
sprayer	65.00	65.00	0.00	0.00	32.50	32.50	0.00	0.00
fertilizer spreader	85.90	0.00	85.90	0.00	85.90	0.00	85.90	0.00
HD cultivator	0.00	0.00	519.20	519.20	259.60	259.60	778.80	778.80
cultivator	128.80	128.80	128.80	128.80	0.00	0.00	0.00	0.00
harrow packers	0.00	0.00	153.20	153.20	0.00	0.00	0.00	0.00
disc drill	116.10	116.10	116.10	116.10	0.00	0.00	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	334.20	334.20	334.20	334.20
baler	0.00	0.00	0.00	0.00	284.90	280.60	299.50	284.90
swather	132.10	132.10	132.10	132.10	0.00	0.00	0.00	0.00
combine	347.71	290.64	495.42	377.58	0.00	0.00	0.00	0.00
grain truck (harvest)	126.03	105.34	179.56	136.85	286.67	282.26	301.14	286.75
grain truck (market)	259.25	216.70	369.38	281.52	589.70	580.62	619.46	589.88
total	1260.88	1054.67	2179.66	1845.35	1873.47	1769.78	2419.00	2274.53

Table A-31. Fuel energy use of Glenlea, MB rotations (1995-1997)

1995	Flax				Flax			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	9.04	9.04	9.04	9.04
water truck	29.80	29.80	0.00	0.00	14.90	14.90	0.00	0.00
sprayer	65.00	65.00	0.00	0.00	32.50	32.50	0.00	0.00
fertilizer spreader	171.80	0.00	171.80	0.00	171.80	0.00	171.80	0.00
HD cultivator	0.00	0.00	519.20	519.20	519.20	519.20	519.20	519.20
cultivator	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80
harrow packers	0.00	0.00	76.60	76.60	0.00	0.00	76.60	76.60
disc drill	116.10	116.10	116.10	116.10	116.10	116.10	116.10	116.10
swather	132.10	132.10	132.10	132.10	132.10	132.10	132.10	132.10
combine	244.92	171.25	127.24	125.40	223.45	202.32	168.58	179.21
grain truck (harvest)	88.77	62.07	46.12	45.45	80.99	73.33	61.10	64.96
grain truck (market)	182.61	127.68	94.87	93.50	166.60	150.85	125.69	133.62
total	1130.10	803.00	1412.84	1237.14	1571.54	1355.21	1499.98	1350.58

1996	Wheat				Wheat			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	9.04	9.04	9.04	9.04
water truck	59.60	59.60	0.00	0.00	14.90	14.90	0.00	0.00
sprayer	130.00	130.00	0.00	0.00	32.50	32.50	0.00	0.00
fertilizer spreader	85.90	0.00	85.90	0.00	85.90	0.00	85.90	0.00
HD cultivator	0.00	0.00	519.20	519.20	0.00	0.00	0.00	0.00
cultivator	0.00	0.00	128.80	128.80	128.80	128.80	128.80	128.80
harrow packers	0.00	0.00	76.60	76.60	76.60	76.60	76.60	76.60
disc drill	116.10	116.10	116.10	116.10	116.10	116.10	116.10	116.10
swather	132.10	132.10	132.10	132.10	132.10	132.10	132.10	132.10
combine	427.51	193.04	297.64	146.43	458.53	331.49	373.78	263.88
grain truck (harvest)	154.95	69.97	107.88	53.08	166.20	120.15	135.48	95.64
grain truck (market)	318.75	143.93	221.92	109.18	341.88	247.16	278.69	196.75
total	1365.31	785.13	1686.14	1281.49	1538.60	1184.91	1327.44	1009.87

1997	Pea				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	9.04	9.04	9.04	9.04
water truck	29.80	29.80	0.00	0.00	0.00	0.00	0.00	0.00
sprayer	65.00	65.00	0.00	0.00	0.00	0.00	0.00	0.00
fertilizer spreader	0.00	0.00	0.00	0.00	85.90	0.00	85.90	0.00
cultivator	0.00	0.00	128.80	128.80	0.00	0.00	0.00	0.00
harrow packers	76.60	76.60	76.60	76.60	0.00	0.00	0.00	0.00
disc drill	116.10	116.10	116.10	116.10	116.10	116.10	116.10	116.10
tandem disc	266.30	266.30	266.30	266.30	0.00	0.00	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	334.20	334.20	334.20	334.20
baler	0.00	0.00	0.00	0.00	365.70	396.30	292.90	326.30
swather	132.10	132.10	132.10	132.10	0.00	0.00	0.00	0.00
combine	147.53	250.12	85.54	100.64	0.00	0.00	0.00	0.00
grain truck (harvest)	53.47	90.66	31.01	36.48	367.82	398.66	294.54	328.14
grain truck (market)	110.00	186.49	63.78	75.03	756.63	820.07	605.90	675.02
total	967.11	1183.36	900.23	932.05	2026.35	2065.32	1729.54	1779.76

Table A-32. Fuel energy use of Glenlea, MB rotations (1998-1999)

1998	Wheat				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	0.00	0.00	0.00	0.00
water truck	14.90	14.90	0.00	0.00	14.90	14.90	0.00	0.00
sprayer	32.50	32.50	0.00	0.00	32.50	32.50	0.00	0.00
fertilizer spreader	85.90	0.00	85.90	0.00	85.90	0.00	85.90	0.00
HD cultivator	519.20	519.20	519.20	519.20	519.20	519.20	778.80	778.80
cultivator	257.60	257.60	257.60	257.60	0.00	0.00	0.00	0.00
harrow packers	76.60	76.60	76.60	76.60	0.00	0.00	0.00	0.00
disc drill	116.10	116.10	116.10	116.10	0.00	0.00	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	266.30	266.30	266.30	266.30
mower/conditioner	0.00	0.00	0.00	0.00	334.20	334.20	334.20	334.20
baler	0.00	0.00	0.00	0.00	268.50	295.20	262.30	232.20
swather	132.10	132.10	132.10	132.10	0.00	0.00	0.00	0.00
combine	274.82	181.92	115.79	62.11	0.00	0.00	0.00	0.00
grain truck (harvest)	99.61	65.94	41.97	22.51	270.13	296.95	264.04	233.85
grain truck (market)	204.90	135.64	86.33	46.31	555.68	610.85	543.16	481.05
total	1799.32	1517.60	1431.59	1232.54	2332.41	2355.20	2534.70	2326.40

1999	Flax				Flax			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	99.31	99.31	99.31	99.31	99.31	99.31	99.31	99.31
grain truck (seeding)	9.04	9.04	9.04	9.04	9.04	9.04	9.04	9.04
water truck	29.80	29.80	0.00	0.00	29.80	29.80	0.00	0.00
sprayer	65.00	65.00	0.00	0.00	65.00	65.00	0.00	0.00
fertilizer spreader	85.90	0.00	85.90	0.00	85.90	0.00	85.90	0.00
HD cultivator	0.00	0.00	519.20	519.20	0.00	0.00	519.20	519.20
cultivator	128.80	128.80	128.80	128.80	128.80	128.80	128.80	128.80
harrow packers	76.60	76.60	76.60	76.60	76.60	76.60	153.20	153.20
disc drill	116.10	116.10	116.10	116.10	116.10	116.10	116.10	116.10
swather	132.10	132.10	132.10	132.10	132.10	132.10	132.10	132.10
combine	179.83	137.03	78.17	78.95	189.62	199.80	130.24	179.83
grain truck (harvest)	65.18	49.67	28.33	28.62	68.73	72.42	47.21	65.18
grain truck (market)	134.08	102.17	58.28	58.87	141.38	148.97	97.11	134.08
total	983.59	807.46	1223.48	1139.24	1004.22	939.78	1409.85	1428.49

Table A-33. Machinery energy use of Glenlea, MB rotations (1992-1994)

1992	Wheat				Wheat			
machinery	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
water truck	5.40	5.40	0.00	0.00	2.70	2.70	0.00	0.00
sprayer	18.80	18.80	0.00	0.00	9.40	9.40	0.00	0.00
fertilizer spreader	4.90	0.00	4.90	0.00	0.00	0.00	0.00	0.00
HD cultivator	44.80	44.80	44.80	44.80	0.00	0.00	0.00	0.00
disc drill	34.30	34.30	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	50.90	50.90	50.90	50.90	50.90	50.90	50.90	50.90
harrow packers	39.40	39.40	39.40	39.40	39.40	39.40	39.40	39.40
swather	44.40	44.40	44.40	44.40	44.40	44.40	44.40	44.40
combine	64.05	64.05	64.05	64.05	64.05	64.05	64.05	64.05
grain truck (harvest)	45.15	45.15	45.15	45.15	45.15	45.15	45.15	45.15
grain truck (market)	78.90	78.90	78.90	78.90	78.90	78.90	78.90	78.90
total	425.60	420.70	406.80	401.90	366.50	366.50	357.10	357.10

1993	Pea				Alfalfa			
machinery	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
water truck	5.40	5.40	0.00	0.00	0.00	0.00	0.00	0.00
sprayer	18.80	18.80	0.00	0.00	0.00	0.00	0.00	0.00
fertilizer spreader	0.00	0.00	0.00	0.00	4.90	0.00	4.90	0.00
cultivator	28.00	28.00	14.00	14.00	0.00	0.00	0.00	0.00
disc drill	34.30	34.30	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	101.80	101.80	101.80	101.80	0.00	0.00	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	28.20	28.20	28.20	28.20
baler	0.00	0.00	0.00	0.00	29.50	31.40	29.50	31.40
swather	29.60	29.60	29.60	29.60	0.00	0.00	0.00	0.00
combine	8.74	11.56	8.24	12.29	0.00	0.00	0.00	0.00
grain truck (harvest)	6.16	8.15	5.81	8.66	45.62	48.39	45.62	48.39
grain truck (market)	10.77	14.24	10.16	15.13	79.73	84.56	79.73	84.56
total	238.17	246.45	203.91	215.78	222.25	226.84	222.25	226.84

1994	Wheat				Alfalfa			
machinery	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	0.00	0.00	0.00	0.00
water truck	5.40	5.40	0.00	0.00	2.70	2.70	0.00	0.00
sprayer	18.80	18.80	0.00	0.00	9.40	9.40	0.00	0.00
fertilizer spreader	4.90	0.00	4.90	0.00	4.90	0.00	4.90	0.00
HD cultivator	0.00	0.00	44.80	44.80	22.40	22.40	67.20	67.20
cultivator	14.00	14.00	14.00	14.00	0.00	0.00	0.00	0.00
harrow packers	0.00	0.00	39.40	39.40	0.00	0.00	0.00	0.00
disc drill	34.30	34.30	34.30	34.30	0.00	0.00	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	56.40	56.40	56.40	56.40
baler	0.00	0.00	0.00	0.00	59.10	38.20	62.10	59.10
swather	29.60	29.60	29.60	29.60	0.00	0.00	0.00	0.00
combine	56.89	47.55	81.05	61.77	0.00	0.00	0.00	0.00
grain truck (harvest)	40.10	33.52	57.13	43.54	91.21	89.81	95.82	91.24
grain truck (market)	70.07	58.57	99.84	76.09	159.40	156.94	167.44	159.44
total	268.66	236.34	405.03	343.51	402.81	373.15	453.86	433.38

Table A-34. Machinery energy use of Glenlea, MB rotations (1995-1997)

1995	Flax				Flax			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
water truck	5.40	5.40	0.00	0.00	2.70	2.70	0.00	0.00
sprayer	18.80	18.80	0.00	0.00	9.40	9.40	0.00	0.00
fertilizer spreader	9.80	0.00	9.80	0.00	9.80	0.00	9.80	0.00
HD cultivator	0.00	0.00	44.80	44.80	44.80	44.80	44.80	44.80
cultivator	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
harrow packers	0.00	0.00	19.70	19.70	0.00	0.00	19.70	19.70
disc drill	34.30	34.30	34.30	34.30	34.30	34.30	34.30	34.30
swather	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60
combine	40.07	28.02	20.82	20.52	36.56	33.10	27.58	29.32
grain truck (harvest)	28.25	19.75	14.67	14.46	25.77	23.33	19.44	20.67
grain truck (market)	49.36	34.51	25.64	25.27	45.03	40.77	33.97	36.12
total	224.17	178.98	213.34	202.65	249.26	229.31	233.20	228.50

1996	Wheat				Wheat			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
water truck	10.80	10.80	0.00	0.00	2.70	2.70	0.00	0.00
sprayer	37.60	37.60	0.00	0.00	9.40	9.40	0.00	0.00
fertilizer spreader	4.90	0.00	4.90	0.00	4.90	0.00	4.90	0.00
HD cultivator	0.00	0.00	44.80	44.80	0.00	0.00	0.00	0.00
cultivator	0.00	0.00	14.00	14.00	14.00	14.00	14.00	14.00
harrow packers	0.00	0.00	19.70	19.70	19.70	19.70	19.70	19.70
disc drill	34.30	34.30	34.30	34.30	34.30	34.30	34.30	34.30
swather	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60
combine	69.94	31.58	48.69	23.96	75.02	54.23	61.15	43.17
grain truck (harvest)	49.30	22.26	34.33	16.89	52.88	38.23	43.11	30.43
grain truck (market)	86.16	38.90	59.98	29.51	92.41	66.81	75.33	53.18
total	311.80	194.25	290.30	212.76	332.21	266.27	282.09	224.38

1997	Pea				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
water truck	5.40	5.40	0.00	0.00	0.00	0.00	0.00	0.00
sprayer	18.80	18.80	0.00	0.00	0.00	0.00	0.00	0.00
fertilizer spreader	0.00	0.00	0.00	0.00	4.90	0.00	4.90	0.00
cultivator	0.00	0.00	14.00	14.00	0.00	0.00	0.00	0.00
harrow packers	19.70	19.70	19.70	19.70	0.00	0.00	0.00	0.00
disc drill	34.30	34.30	34.30	34.30	34.30	34.30	34.30	34.30
tandem disc	50.90	50.90	50.90	50.90	0.00	0.00	0.00	0.00
mower/conditioner	0.00	0.00	0.00	0.00	56.40	56.40	56.40	56.40
baler	0.00	0.00	0.00	0.00	75.80	82.20	60.70	67.70
swather	29.60	29.60	29.60	29.60	0.00	0.00	0.00	0.00
combine	24.14	40.92	13.99	16.46	0.00	0.00	0.00	0.00
grain truck (harvest)	17.01	28.85	9.87	11.61	117.03	126.84	93.72	104.41
grain truck (market)	29.73	50.41	17.24	20.28	204.52	221.66	163.77	182.46
total	224.18	273.47	189.60	196.85	492.95	521.41	413.79	445.26

Table A-35. Machinery energy use of Glenlea, MB rotations (1998-1999)

1998	Wheat				Alfalfa			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	0.00	0.00	0.00	0.00
water truck	2.70	2.70	0.00	0.00	2.70	2.70	0.00	0.00
sprayer	9.40	9.40	0.00	0.00	9.40	9.40	0.00	0.00
fertilizer spreader	4.90	0.00	4.90	0.00	4.90	0.00	4.90	0.00
HD cultivator	44.80	44.80	44.80	44.60	44.80	44.80	67.20	67.20
cultivator	28.00	28.00	28.00	28.00	0.00	0.00	0.00	0.00
harrow packers	19.70	19.70	19.70	19.70	0.00	0.00	0.00	0.00
disc drill	34.30	34.30	34.30	34.30	0.00	0.00	0.00	0.00
tandem disc	0.00	0.00	0.00	0.00	50.90	50.90	50.90	50.90
mower/conditioner	0.00	0.00	0.00	0.00	56.40	56.40	56.40	56.40
baler	0.00	0.00	0.00	0.00	55.70	61.20	54.40	48.20
swather	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60
combine	44.96	29.76	18.94	10.16	0.00	0.00	0.00	0.00
grain truck (harvest)	31.69	20.98	13.35	7.16	85.95	94.48	84.01	74.41
grain truck (market)	55.38	36.66	23.34	12.52	150.20	165.11	146.82	130.03
total	**302.74**	**253.21**	**216.93**	**186.24**	**487.85**	**511.90**	**494.23**	**456.73**

1999	Flax				Flax			
	1 f+p+	1 f-p+	1 f+p-	1 f-p-	3 f+p+	3 f-p+	3 f+p-	3 f-p-
machinery	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha	MJ/ha
pickup truck	31.04	31.04	31.04	31.04	31.04	31.04	31.04	31.04
grain truck (seeding)	2.90	2.90	2.90	2.90	2.90	2.90	2.90	2.90
water truck	5.40	5.40	0.00	0.00	5.40	5.40	0.00	0.00
sprayer	18.80	18.80	0.00	0.00	18.80	18.80	0.00	0.00
fertilizer spreader	4.90	0.00	4.90	0.00	4.90	0.00	4.90	0.00
HD cultivator	0.00	0.00	44.80	44.80	0.00	0.00	44.80	44.80
cultivator	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
harrow packers	19.70	19.70	19.70	19.70	19.70	19.70	39.40	39.40
disc drill	34.30	34.30	34.30	34.30	34.30	34.30	34.30	34.30
swather	20.39	15.54	8.87	8.95	21.50	22.66	14.77	20.39
combine	29.42	22.42	12.79	12.92	31.02	32.69	21.31	29.42
grain truck (harvest)	20.74	15.80	9.01	9.11	21.87	23.04	15.02	20.74
grain truck (market)	36.24	27.62	15.75	15.91	38.21	40.27	26.25	36.24
total	**198.50**	**168.18**	**164.12**	**159.69**	**204.31**	**205.45**	**214.75**	**239.30**

Table A-36. Herbicide energy use of Glenlea, MB rotations (1992-1999)

1992	Wheat				Wheat			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Achieve 40G	62.00	62.00	0.00	0.00	62.00	62.00	0.00	0.00
Refine Extra	5.05	5.05	0.00	0.00	0.00	0.00	0.00	0.00
MCPA	80.58	80.58	0.00	0.00	0.00	0.00	0.00	0.00
Total	147.63	147.63	0.00	0.00	62.00	62.00	0.00	0.00

1993	Pea				Alfalfa			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Roundup	452.96	452.96	0.00	0.00	0.00	0.00	0.00	0.00
Edge 5G	429.83	429.83	0.00	0.00	0.00	0.00	0.00	0.00
Basagran	415.00	415.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1297.79	1297.79	0.00	0.00	0.00	0.00	0.00	0.00

1994	Wheat				Alfalfa			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Hoegrass II	449.05	449.05	0.00	0.00	0.00	0.00	0.00	0.00
Roundup	452.96	452.96	0.00	0.00	905.93	905.93	0.00	0.00
MCPA	80.58	80.58	0.00	0.00	0.00	0.00	0.00	0.00
Total	982.59	982.59	0.00	0.00	905.93	905.93	0.00	0.00

1995	Flax				Flax			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Poast	62.99	62.99	0.00	0.00	62.99	62.99	0.00	0.00
Roundup	634.15	634.15	0.00	0.00	452.96	452.96	0.00	0.00
2,4-D	49.06	49.06	0.00	0.00	0.00	0.00	0.00	0.00
Buctril M	187.67	187.67	0.00	0.00	187.67	187.67	0.00	0.00
Refine Extra	5.05	5.05	0.00	0.00	5.05	5.05	0.00	0.00
Total	938.92	938.92	0.00	0.00	708.67	708.67	0.00	0.00

1996	Wheat				Wheat			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Achieve 40G	62.00	62.00	0.00	0.00	62.00	62.00	0.00	0.00
Refine Extra	5.05	5.05	0.00	0.00	0.00	0.00	0.00	0.00
Roundup	1087.11	1087.11	0.00	0.00	0.00	0.00	0.00	0.00
MCPA	80.58	80.58	0.00	0.00	0.00	0.00	0.00	0.00
Total	1234.74	1234.74	0.00	0.00	62.00	62.00	0.00	0.00

1997	Pea				Alfalfa			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Roundup	452.96	452.96	0.00	0.00	0.00	0.00	0.00	0.00
Odyssey	305.06	305.06	0.00	0.00	0.00	0.00	0.00	0.00
Total	758.02	758.02	0.00	0.00	0.00	0.00	0.00	0.00

1998	Wheat				Alfalfa			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Achieve 40G	62.75	62.75	0.00	0.00	0.00	0.00	0.00	0.00
Buctril M	187.67	187.67	0.00	0.00	0.00	0.00	0.00	0.00
Roundup	0.00	0.00	0.00	0.00	543.56	543.56	0.00	0.00
2,4-D	0.00	0.00	0.00	0.00	49.06	49.06	0.00	0.00
Total	250.42	250.42	0.00	0.00	592.62	592.62	0.00	0.00

1999	Flax				Flax			
Herbicide	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
Poast Flax Max	468.19	468.19	0.00	0.00	468.19	468.19	0.00	0.00
Roundup	224.67	224.67	0.00	0.00	224.67	224.67	0.00	0.00
Total	692.86	692.86	0.00	0.00	692.86	692.86	0.00	0.00

Table A-37. Fertilizer energy use of Glenlea, MB rotations (1992-1999)

1992	Wheat				Wheat			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	5318.02	-	5318.02	-	5318.02	-	5318.02	-
P_2O_5	237.87	-	237.87	-	237.87	-	237.87	-
total fert. energy	5555.89	0.00	5555.89	0.00	5555.89	0.00	5555.89	0.00

1993	Pea				Alfalfa			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	304.18	-	367.55	-	506.97	-	506.97	-
P_2O_5	237.87	-	287.42	-	396.45	-	396.45	-
total fert. energy	542.05	0.00	654.98	0.00	903.42	0.00	903.42	0.00

1994	Wheat				Alfalfa			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	3312.49	-	3312.49	-	487.96	-	487.96	-
P_2O_5	237.87	-	237.87	-	381.58	-	381.58	-
total fert. energy	3550.36	0.00	3550.36	0.00	869.54	0.00	869.54	0.00

1995	Flax				Flax			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	4857.22	-	4857.22	-	2646.57	-	2646.57	-
P_2O_5	287.42	-	287.42	-	287.42	-	287.42	-
total fert. energy	5144.65	0.00	5144.65	0.00	2934.00	0.00	2934.00	0.00

1996	Wheat				Wheat			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	4165.84	-	4165.84	-	1499.39	-	1499.39	-
P_2O_5	227.96	-	227.96	-	227.96	-	227.96	-
total fert. energy	4393.80	0.00	4393.80	0.00	1727.34	0.00	1727.34	0.00

1997	Pea				Alfalfa			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	266.16	-	266.16	-	475.28	-	475.28	-
P_2O_5	208.14	-	208.14	-	371.67	-	371.67	-
total fert. energy	474.29	0.00	474.29	0.00	846.95	0.00	846.95	0.00

1998	Wheat				Alfalfa			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	2224.02	-	2224.02	-	367.55	-	367.55	-
P_2O_5	545.12	-	545.12	-	287.42	-	287.42	-
total fert. energy	2769.14	0.00	2769.14	0.00	654.98	0.00	654.98	0.00

1999	Flax				Flax			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
N	2769.24	-	2769.24	-	2655.18	-	2655.18	-
P_2O_5	178.40	-	178.40	-	89.20	-	89.20	-
total fert. energy	2947.64	0.00	2947.64	0.00	2744.38	0.00	2744.38	0.00

Table A-38. Total rotational energy use of Glenlea, MB rotations (1992-1999)

1992-1999	W-P-W-Fx				W-A-A-Fx			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
seed	5002.57	5002.57	5002.57	5002.57	2703.54	2703.54	2703.54	2703.54
machinery	2193.82	1971.57	2090.03	1919.38	2758.13	2700.83	2671.26	2611.51
fuel	10885.45	9480.78	12391.84	10747.91	12822.06	12095.10	13214.32	12562.04
herbicide	6302.99	6302.99	0.00	0.00	3024.08	3024.08	0.00	0.00
fertilizer	25377.82	0.00	25490.75	0.00	16236.49	0.00	16236.49	0.00
total	**49762.66**	**22757.91**	**44975.19**	**17669.86**	**37544.32**	**20523.55**	**34825.61**	**17877.09**

per 4 year rotation cycle	W-P-W-Fx				W-A-A-Fx			
	1 f+p+ MJ/ha	1 f-p+ MJ/ha	1 f+p- MJ/ha	1 f-p- MJ/ha	3 f+p+ MJ/ha	3 f-p+ MJ/ha	3 f+p- MJ/ha	3 f-p- MJ/ha
seed	2501.29	2501.29	2501.29	2501.29	1351.77	1351.77	1351.77	1351.77
machinery	1096.91	985.78	1045.02	959.69	1379.07	1350.41	1335.63	1305.75
fuel	5442.73	4740.39	6195.92	5373.96	6411.03	6047.55	6607.16	6281.02
herbicide	3151.50	3151.50	0.00	0.00	1512.04	1512.04	0.00	0.00
fertilizer	12688.91	0.00	12745.37	0.00	8118.25	0.00	8118.25	0.00
total	**24881.33**	**11378.96**	**22487.59**	**8834.93**	**18772.16**	**10261.77**	**17412.81**	**8938.55**

Appendix B

Table B-1. Average temperatures for growing season months at Carman and Winnipeg.

Month	Temperature			
	1997	1998	1999	Avg.†
	°C			
		Carman		
April	-0.5	8.3	5.8	4.2
May	9.0	12.9	11.8	12.5
June	18.6	15.1	16.0	16.9
July	19.0	18.7	18.8	19.4
August	18.1	20.2	18.1	18.2
September	14.4	14.4	11.3	12.2
October	5.2	6.4	5.0	5.5
Avg/Total	12.0	13.7	12.4	12.7
		Winnipeg		
Apr.	0.4	9.0	7.5	3.9
May	9.8	14.0	13.0	11.9
June	20.3	16.7	17.5	17.0
July	20.8	21.0	20.8	19.5
Aug.	19.4	21.6	19.5	18.5
Sept.	15.1	15.6	12.4	12.4
Oct.	5.9	6.6	5.4	5.2
Avg/Total	13.1	14.9	13.7	12.6

†30-year average.

Table B-2. Average precipitation for growing season months at Carman and Winnipeg.

	Precipitation						
Month	1997		1998		1999		Avg.†
	mm	%‡	mm	%	mm	%	mm
				Carman			
April	67.8	250	53.4	197	15.4	57	27.1
May	25.0	47	43.2	81	142.0	266	53.4
June	59.0	71	94.6	114	74.0	89	82.8
July	117.8	159	33.4	45	83.2	112	74.1
August	50.4	80	45.4	72	31.0	49	62.8
September	32.6	65	13.3	27	36.6	73	49.9
October	48.4	130	55.6	149	15.4	41	37.2
Avg/Total	401	104	338.9	88	397.6	103	387.3
				Winnipeg			
Aprril	35.1	129	36.3	134	29.2	108	23.5
May	36.3	68	118.6	222	102.9	193	57.8
June	53.1	64	71.2	86	95.5	115	89.0
July	93.2	126	67.8	92	72.4	98	71.6
August	73.4	117	15.0	24	35.3	56	75.0
September	50.5	101	14.2	29	58.4	117	55.6
October	74.4	200	59.2	159	22.9	61	28.5
Avg/Total	416.1	107	382.4	99	416.5	108	401

‡Percent relative to 30-year average.