Energetics of a Sustainable Crop-Livestock System

by

James D. Kern

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APPROVED:

David H. Vaughan

David H. Vaughan, Chairman

Lori S. Marsh

Lori S. Marsh

Vivien G. Allen

John V. Perumpal, Dept. Chairman

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David H. Vaughan, Chairman

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(ABSTRACT)

This study compares the energy utilization of two systems for producing cattle of desirable slaughter weight and grade from weanlings. Both systems produce beef cattle as a primary output; various types of baled hay are produced as a secondary output. One system uses generally accepted, "best management practices" while the other uses experimental, sustainable agriculture techniques. Since the adoption of new practices in agriculture often hinges on economics, an economic comparison is also presented.

Beef produced in the sustainable system required 32% less energy per kilogram than that produced in the conventional system. However, baled alfalfa produced in the sustainable system required 8% more energy per kilogram than the alfalfa grown in the conventional system. When all types of hay were considered, the sustainable system used 7% more energy to produce one kilogram of baled hay. To compare the energetics of the two systems on a whole farm basis, the amount of energy required to produce one dollar of return was calculated. The sustainable system required 12.4 megajoules to produce one dollar of return, while the conventional system required 17.1 megajoules to produce the same return. Although economic returns on beef and alfalfa production were comparable in the two systems studied, the conventional system showed greater returns on the whole farm, due to a greater export of baled hay.

Acknowledgments

> "If flying-saucer creatures or angels or whatever were to come here in a hundred years, say, and find us gone like the dinosaurs, what might be a good message for humanity to leave for them, maybe carved in great big letters on a Grand Canyon wall?
>
> "Here is this old poop's suggestion:
>
> WE PROBABLY COULD HAVE SAVED OURSELVES,
> BUT WE WERE TOO DAMNED LAZY TO TRY VERY HARD.
>
> "We might well add this:
>
> AND TOO DAMN CHEAP."
>
> \- Kurt Vonnegut -

I am forever grateful to everyone who helps me to keep from being "too damned lazy to try very hard." Only now, do I begin to realize how many people have done just that, and in doing so, have helped be to complete this thesis.

Thanks to Mom and Dad. I would never have completed this work without your unconditional love and support. Thanks to my seven brothers and sisters, and all of my friends, old and new. Thanks to all of my teachers through the years, particularly my committee members. Without your guidance, I never could have accomplished this goal. And, a very special thank you to Carol. It looks like your kind words of encouragement have paid off.

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1.0 Introduction

Fossil energy inputs to U.S. agriculture represent a relatively small percentage of the nations energy consumption, accounting for 4.2% in 1972 and 5.0% in 1982 (Faidley, 1992). Nevertheless, agriculture is dependent on these energy inputs. Because of agriculture's energy dependence, the energy consumption of a given agricultural system plays a key role in determining that system's sustainability (Crew et al., 1991).

The energy efficiency of an agricultural system can affect the sustainability of that system in three ways. First, fossil fuel inputs are available in limited supply. Thus, energy is a limiting factor in determining the sustainability of any practice or system. Second, the cost and availability of fossil energy inputs depend on foreign oil supply, which could be interrupted at any time, as history has shown. Thus, practices that are considered sustainable today may not be sustainable tomorrow if the cost or availability of the required energy input precludes its use. Finally, an agricultural practice cannot be considered sustainable unless farmers are willing to practice it. The more energy efficient an agricultural system is, the less vulnerable it is to uncontrollable market fluctuations that are driven by the shifting winds of politics, regional conflicts on the other side of the globe and a limited supply of fossil fuel in a supply and demand economy. Decreased economic vulnerability may make a given agricultural system more attractive to the farmer.

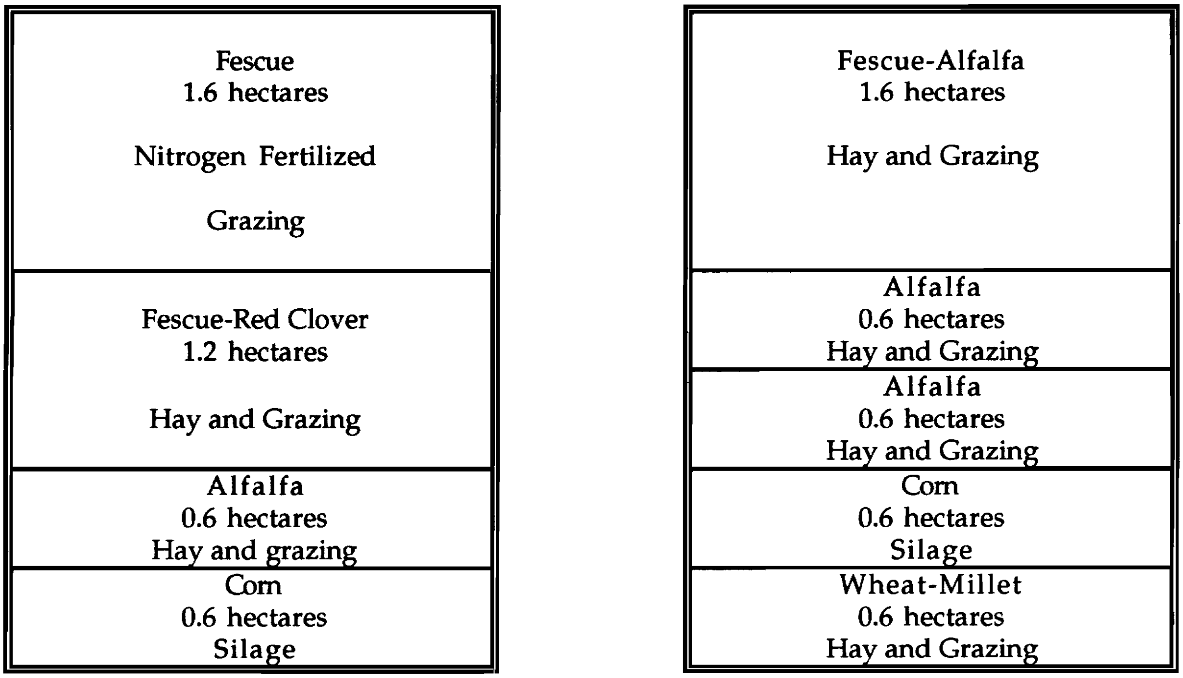
1.1 The Crop-Livestock, Whole Farm Experiment

The Crop-Livestock System located at the Whitethorne-Kentland Farm, McCoy, Virginia (Luna et al., 1991a; Luna et al., 1991b) is a farm-scale experiment that is designed to compare two systems for producing cattle of desirable slaughter weight and grade from weanlings. Both systems produce beef cattle using pastures for grazing from November through October and corn silage raised on the farm and fed during the feedlot finishing period at the end of the grazing cycle. One system uses generally accepted, best management practices while the other uses experimental sustainable agriculture techniques. These sustainable agriculture techniques include the use of conservation tillage systems, crop rotations, grazing management for improved nutrient utilization and pest control, winter annual cover crops, and integrated pest management practices for weeds and insect pests. The goals of this system are to reduce inputs of non-renewable resources and potential pollutants, to improve nutrient management, and to slow soil erosion, while maintaining an acceptable profit margin.

As information is gained and techniques improve, the procedures for both systems are altered to reflect their improvements. During the period of the current study the respective systems were designed as follows:

Each system was replicated four times. Each replicate consisted of four hectares and six Angus steers (*Bos tarus*). Each crop or pasture block was located on a uniform soil landscape with a uniform cropping and cover history. An extensive soil survey was conducted to ensure uniformity within experimental blocks (Luna et al., 1991b). Steers were divided into six blocks based on weight, and were allotted at random within blocks to form replicates of the two system treatments (Luna et al., 1991a).

The "conventional" land was divided into four areas as follows: 1.6 hectares of nitrogen fertilized fescue (*Festuca arrundinacea*), 1.2 hectares of a fescue-red clover (*Trifolium pratense*) mix, 0.6 hectares of alfalfa (*Medicago sativa*), and 0.6 hectares of corn (*Zea mays*) for silage. The sustainable land was divided into five areas as follows: 1.6 hectares of fescue-alfalfa mix, 0.6 hectares of first year alfalfa, 0.6 hectares of second year alfalfa, 0.6 hectares of corn for silage, and 0.6 hectares of wheat (*Triticum aestivum*) followed by foxtail millet (*Setaria italica*). Figure 1 shows a graphical representation of these divisions.



Conventional System
4.0 hectares
6 Angus Steers

Sustainable System
4.0 hectares
6 Angus Steers

Figure 1. **Conventional and sustainable forage/crop/livestock systems.**

Both systems allowed for some flexibility in scheduling grazing and hay harvest operations. The sustainable system was particularly flexible in this regard. This quality proved valuable in the first two years of cattle production when weather conditions hampered hay harvest operations. The brief schedule of operations outlined in the following paragraphs is considered to be an average situation, and reflects the operations as modeled in this analysis. A more thorough schedule of operations for each system is given in Appendix A.

In the conventional system, alfalfa, which was in a five-year rotation with corn, was harvested in three cuttings per year and sold. Some grazing was allowed on the alfalfa after the last cutting. A winter cover crop of rye was grown on the corn land and killed chemically before planting in the spring.

In the sustainable system, a four-year rotation was implemented in which corn followed two years of alfalfa. After the corn was harvested, the land was planted with wheat followed by millet. The wheat was grazed and the millet was partially grazed, with the remainder being harvested for hay. The millet also served as a smother crop to reduce weeds. Following millet, the land was planted with alfalfa again. The first-year alfalfa was harvested in three cuttings during the summer and sold. After the third cutting of alfalfa, this area was available for grazing. The following winter, the alfalfa crop was over-seeded with wheat and rye to provide additional grazing. This second-year alfalfa was over-seeded with rye in October, after being thoroughly grazed. The rye was planted as a winter cover crop in preparation for planting with corn in the spring. The rye and any residual alfalfa were then killed with one application of glyphosate. While the cover crop was still green, it was rolled down with a roller packer to form a thick mat of biomass (Vaughan et al., 1992). Corn was planted directly into this rolled down mat of rye and alfalfa.

In the conventional system, nitrogen-fertilized fescue was stockpiled by applying 80 kg/ha of nitrogen in early August in preparation for the introduction of cattle in November. This pasture was grazed and not harvested. Fescue/red clover was harvested once in early summer, then grazed as needed. Baled fescue/red clover was fed as needed throughout the year, and any excess was sold. All of the baled alfalfa was also sold.

In the sustainable system, weanling cattle grazed stockpiled fescue/alfalfa. Steers were then rotated among the available paddocks as needed. One cutting of fescue/alfalfa was taken in late spring. Baled fescue/alfalfa was then fed as needed throughout the year, with the excess being sold. All of the baled millet and alfalfa were sold as well.

When the grazing cycle was completed in October, steers were moved to the feedlot where they were fed corn silage supplemented with soybean meal in the conventional system and poultry litter in the sustainable system. Manure was collected separately from the sustainable and conventional systems during the feedlot finishing period. This manure was then analyzed for nutrient content and applied to the corn land for the respective treatments prior to planting. Synthetic fertilizer was applied according to soil test recommendations.

1.2 Energy Analysis

This energy analysis compared the energy efficiency of the two systems. This comparison was made on the basis of individual outputs where appropriate. Both systems produced beef cattle as a primary output and baled hay as a secondary output. With the exception of alfalfa, the hay produced in each system differed in content and was therefore difficult to compare. To compare the energetics of the whole farming systems, a ratio of energy input to economic return was used.

1.3 Economic Analysis

Since new production methods in agriculture are generally not adopted without adequate economic justification, a brief economic analysis is presented here. This analysis considered annual costs as well as the capital costs attributable to the required equipment. It did not consider the capital cost attributable to land. The hope is that the analysis will serve as a means of comparing of the two systems, rather than a definitive determination of the profitability of either.

2.0 Review of Literature

2.1 Crop-Livestock Production and Sustainability

According to a recent study conducted at the Leopold Center for Sustainable Agriculture, Iowa State University, Ames, Iowa, the incorporation of livestock into a cropping system can enhance that system's sustainability through improving profitability, and energy efficiency (Duffy, 1992). This study examined incorporating swine production into a corn/soybean production system. While this addition increased labor requirements, it also increased farm returns due to both the addition of a high quality output and the replacement of synthetic fertilizers with manure. The replacement of synthetic fertilizers accounted for the energy savings that were observed.

Crop-livestock production also improves sustainability by increasing diversification of the farm, converting more erodable lands to rangeland or pasture land and allowing for greater use of forage crops in crop rotations. This result is illustrated by five crop-livestock case studies reviewed in **Alternative Agriculture** (National Research Council, 1989). These case studies showed five instances in which farm owners incorporated livestock production into an alternative farming system and achieved acceptable results.

2.2 Energy Analysis of Sustainable Beef Production

Lockeretz et al. (1977) performed an energy analysis on 28 Corn Belt farms, 14 of which were conventional farms, the remaining 14 were considered organic farms. All 28 farms included some type of livestock; however, the analysis only examined crop production. The organic farms produced slightly lower yields than the conventional farms, but the two types of systems showed comparable profitability. The organic farms consumed appreciably less energy.

The Crop-Livestock, Whole Farm Experiment at Virginia Tech (Luna et al., 1991a; Luna et al., 1991b) has produced one energy analysis thus far. This analysis (Ess, 1990) examined corn silage production using leguminous winter cover crops. Substantial energy savings were achieved through this practice by replacing synthetic nitrogen inputs with biologically-fixed nitrogen.

Little work has been done in examining the energy efficiency of sustainable beef production systems. However, energy analysis of conventional beef production has been performed for both pasture and feedlot production (Cook et al., 1980; Hoveland, 1980).

2.3 Energy in Seed

Fluck and Baird (1980) and Leach (1976) both listed the energy accountable to seed as a minor input to the overall crop energy budget. Fluck and Baird (1980) suggested accounting for seed based on the ratio of national energy consumption to GNP or input-output analysis coefficients. Leach (1976) accounted for the energy in edible seed by deducting the weight of seeds planted from the crop output. Non-edible seed was given an energy value based on 80% of the ratio of one unit of primary energy to one unit of Gross Domestic Product. Leach stated that the 80% reduction agrees closely with a process analysis of grass seed production.

Heichel (1980) presented four methods for quantifying the energy attributable to seed. Those methods are outlined here.

Method 1: Fossil energy costs of crop propagation are represented by a multiple of the enthalpy or the digestible energy content of the seed. Use of this method was not advised.

Method 2: Similar to the method suggested by Leach (1976) for accounting for the energy in edible seed, the crop yield is reduced by the amount of seed that was planted. This method assumes that the energy required for seed production is comparable to the energy required for feed or food grain production. Also, it assumes that the material harvested is anatomically identical to the material planted, and is therefore useless in the energy analysis of vegetative or fruit crops.

Method 3: In the absence of a detailed input-output analysis for every crop, this method estimates energy costs of producing seed based on the economic cost of the seed and the ratio of national energy consumption to GNP (kilocalorie per dollar). Fluck and Baird (1980) and Leach (1976) advocated variations on this idea. The assumption is made that the seeds or other materials of crop reproduction are comparable in energy intensity to other goods and services in the economy. Heichel (1980) showed that use of this method attributed an energy value to seed that was anywhere from 200% to 800% greater than the energy value calculated by Method 1.

Method 4: Rather than make an approximation based on one of the first three methods, a detailed energy budget of seed production is determined. This is an ideal situation. Unfortunately, information on inputs for seed production is often of a proprietary nature, and thus unavailable to the energy analyst. Heichel (1980) used Method 4 to calculate the energy requirements of alfalfa-seed production, and observed that Method 3 overestimated the energy intensity by 28% compared to Method 4. However, it was pointed out that Heichel's analysis using Method 4 was limited to information from only two seed producers and did not take into account the energy sequestered in irrigation and seed processing equipment. Heichel concluded that Method 3 is adequate in the absence of detailed seed production information, and published a list of energy costs for 24 propagation materials based on Method 3.

Ess (1990) compared the results of Methods 3 and 4 in analyzing the energy required to produce four types of seed: hairy vetch, bigflower vetch, rye and corn. His analysis showed that the estimation of energy cost based on the economic cost of production (Method 3) produces results that range from 27% to 270% of that which results from a detailed energy analysis (Method 4).

2.4 Energy in Fertilizers

Synthetic fertilizer accounts for 40% of the commercial energy used in agricultural production in developed countries and 68% in developing countries (Mudahar and Hignett, 1987b). Although fertilizer accounts for a large part of the energy inputs to agricultural production, it also increases yields substantially and therefore improves the energy productivity of other inputs. Because of fertilizers' effect on yields, Mudahar and Hignett (1987b) stated that it is neither feasible nor advisable to reduce fertilizer use in the agricultural sector; however, the energy efficiency of fertilizer can be enhanced by improving the energy efficiency of fertilizer production, improving the energy efficiency of transporting fertilizer and improving fertilizer use efficiency at the farm level.

2.4.1 Nitrogen

Production of nitrogen fertilizers accounts for almost three quarters of the total energy expended by the fertilizer sector (Mudahar and Hignett, 1987a). Nitrogen fertilizers are produced almost exclusively from ammonia, which is synthesized from nitrogen and hydrogen. The required nitrogen is available from the atmosphere; however, the hydrogen required is obtained through the processing of a hydrocarbon, generally through steam reformation of natural gas. Mudahar and Hignett estimated that 80% of ammonia production is from natural gas. Thus, nitrogen production requires both a high quality energy source as a feedstock and significant energy inputs for the production process.

The nitrogen fertilizer applied in the two crop/livestock systems being analyzed was in the form of urea-ammonium nitrate (UAN) solution and prilled ammonium nitrate. Urea-ammonium nitrate solution is formed by combining urea and ammonium nitrate solutions and adding water to achieve the desired grade (30% N in this case). The production of urea requires ammonia and carbon dioxide. The carbon dioxide is readily available from the ammonia production process. Ammonium nitrate solution is produced in two steps: production of nitric acid and neutralization of acid with ammonia. The prilling process converts the ammonium nitrate solution to a solid product which contains 34% nitrogen.

Mudahar and Hignett (1987a) estimated the energy required for the production of UAN solution to be 65.27 MJ/kg N. Fluck and Baird (1980) listed energy requirements for the production of urea that range from 50.1 to 77.7 MJ/kg N, and energy requirements for the production of ammonium nitrate that range from 51.5 to 76.7 MJ/kg N. Since the combination of these two components to form UAN solution requires less than 1.0 MJ/kg N, the estimates seem to be in general agreement.

The energy required to produce prilled ammonium nitrate was estimated by Mudahar and Hignett (1987a) to be 66.59 MJ/kg N. This estimate is on the same order as those listed by Fluck and Baird (1980).

2.4.2 Phosphorus

Leach (1976) suggested that a rough estimate of the energy cost of phosphorus fertilizers is adequate since they have low energy inputs compared to nitrogen fertilizers. The energy cost of producing phosphorus fertilizers varies widely depending on the processes used and the end product desired. Fluck and Baird (1980) listed energy requirements for phosphate fertilizers that range from 0.8 to 33.8 MJ/kg of product.

In this study, it was assumed that triple superphosphate (TSP) is used since it is most popular as an unmixed granular fertilizer. A dihydrate, dry rock feed process is assumed for production of phosphoric acid as this is the most common practice world-wide (Mudahar and Hignett, 1987a). A slurry process for production of granular TSP is most common (Mudahar and Hignett, 1987a), and is therefore assumed. The resulting energy intensity of TSP, according to Mudahar and Hignett (1987a), is 3.81 MJ/kg, which corresponds to an energy intensity of 8.28 MJ/kg P_2O_5.

2.4.3 Potassium

As with phosphorus, Leach (1976) suggested that potassium fertilizers have low energy inputs as compared with nitrogen fertilizers and thus rough estimates of the energy required for their production are adequate. According to Mudahar and Hignett (1987a), over 95% of potassium fertilizers are produced from fertilizer grade potassium chloride (KCl or muriate of potash). The energy cost of obtaining KCl varies with the method used, the grade of the ore and the source location. Fluck and Baird (1980) list energy requirements for potassium fertilizers that range from 1.6 to 14.4 MJ/kg of product.

Shaft mining is the most common method for obtaining KCl (Mudahar and Hignett, 1987a). Mudahar and Hignett (1987a) reported a world average for KCl production of 3.80 MJ/kg. To produce granular potash, an additional 0.5 MJ/kg is required for roll compaction. The resulting energy requirement on a nutrient basis is 7.24 MJ/kg K_2O.

2.4.4 Boron

Boron (B) is a micronutrient commonly used in alfalfa production. As a micronutrient, it does not add much to the overall energy requirements of crop production and has been largely ignored as an energy input in the literature. Mudahar and Hignett (1987a) reported energy requirements for producing boron from two ores, borax and colemanite, with respective energy requirements of 18.18 MJ/kg B and 12.50 MJ/kg B.

2.4.5 Packaging , Transportation and Application

In the case of nitrogen fertilizers, 90% of the total energy requirement is for production. However, in the case of phosphorus and potassium, over 50% of the energy requirement is due to packaging, transportation and application (Mudahar and Hignett, 1987b). Packaging, transportation and application energy for nitrogen, phosphorus and potassium, courtesy of

Mudahar and Hignett (1987a), are outlined in Table 1. Energy requirements are given in terms of megajoules per kilogram of product, based on an analysis of 45% nutrients.

Table 1. Energy in packaging, transportation, and application of fertilizer.

Activity	N	P_2O_5	K_2O
Packaging (MJ/kg)	2.58	2.65	1.75
Transportation (MJ/kg)	4.47	5.68	4.60
Application (MJ/kg)	1.55	1.47	0.95

2.5 Energy in Manure

Due to the bulkiness of organic materials, such as manure, as well as the low cost, availability and effectiveness of chemical fertilizers, the use of organic materials as a nutrient source has been largely replaced in modern agriculture by the use of chemical fertilizers (Parr and Colaccio, 1987). However, the importance of organic materials as a soil amendment should not be overlooked. According to Hauck (1981), reintroduction and utilization of organic wastes to improve soil productivity in developing countries could contribute more than 50% of the increased food production that is needed worldwide. Organic materials as a soil amendment provide improved tilth, fertility, and productivity. There are opportunities to improve on the use of these materials to minimize energy usage and maintain soil productivity (Parr and Colaccio, 1987).

In addition to its value as a soil amendment, manure also has value as a source of protein for livestock. Poultry manure has been observed to be an acceptable protein supplement for cattle

(Smith and Wheeler, 1979; Chester-Jones et al., 1984). Taking full advantage of this resource requires a thorough understanding of the energy flows involved in its use.

2.5.1 Energy Cost of Manure

The energy cost of manure is a measure of how much energy is spent in using manure as an input to the system. Coble and Lepori (1974) estimated an energy usage of 0.14 MJ/kg for collecting, transporting 16.1 km and spreading cattle manure. Cook et al. (1980) reported a tractor use of 0.24 h/head for steer manure removal during a 190-day feedlot period, which corresponds to a fuel use of 1.74 L/head.

The energy cost of poultry litter as a feed supplement has not been explored thoroughly. Processing poultry litter for use as a feed supplement entails collection, deep stacking, and transporting to the point of use. Deep stacking is a process in which poultry litter is allowed to anaerobically ferment. Coliforms are thus eliminated by the resulting temperature increase (Dana et al., 1979; Hovatter et al., 1979). The dominant energy input required in utilizing poultry litter as a feed supplement is transportation.

2.5.2 Energy Value of Manure

The energy value of manure is a measure of how much energy the manure is replacing in the system. Parr and Colacicco (1987) suggested a technique for determining the energy value of manure. Their technique involves analyzing the nutrient content of the manure and assigning an energy value equal to the energy content of the amount of synthetic fertilizers that would be required to replace these nutrients. This method does not take into account less quantifiable benefits of manure application, such as improved soil tilth, increased moisture holding capacity and the increased efficiency of chemical fertilizers that is due to improved soil characteristics. Stout (1990) advocated this method, but also suggested using anaerobic digestion to produce methane from the manure, thereby making use of manure's energy content while maintaining its nutrient value.

The potential for producing methane gas through anaerobic digestion suggests that manure also has value as an energy source. According to Hill (1984), it is reasonable to expect that 196.7 m^3 of methane are available from 1 Mg (dry weight) of steer manure, and 249.3 m^3 of methane are available from 1 Mg (dry weight) of poultry manure. These values assume that the digester is kept at 35°C, and the hydraulic retention time is greater than 14 days. Assuming a heating value for methane of 33.9 MJ/m^3, Hill's reported yields correspond to an energy content of 6.67 MJ/kg (dry weight) for steer manure and 8.45 MJ/kg (dry weight) for poultry manure. Assuming 15% solids in steer manure and 25% solids in poultry manure, the amount of energy available from the respective manure types is 1.00 MJ/kg and 2.11 MJ/kg.

Fischer et al. (1983) reported that the energy required to produce methane from manure at 35°C ranges from 7.20 to 16.88 MJ/m^3-d. Using the greatest of these values and assuming a hydraulic retention time of 15 days, the energy cost of producing methane is 253 MJ/m^3 of influent to the digester. Assuming that water is mixed in a 1:1 ratio with the fresh steer manure and in a 7:3 ratio with fresh poultry manure in order to reduce the dry matter content to 7.5% before entering the digester, the resulting energy cost is 0.51 MJ/kg and 0.84 MJ/kg for fresh steer and poultry manure, respectively.

Subtracting the energy cost of methane production from the energy content of the manure yields net energy values of 0.49 MJ/kg and 1.27 MJ/kg of fresh steer and poultry manure. The poultry litter used in this experiment consisted of approximately 33% bedding and 67% manure. A net energy value of the poultry litter was taken as 0.85 MJ/kg of poultry litter to conservatively account for the corresponding decrease in methane production.

2.6 Energy in Field Operations

The energy inputs, both direct and indirect, represented by field operations, are second in magnitude only to the energy inputs of fertilizers in U.S. agriculture, accounting for as much as one fifth of the total energy requirement (Bowers, 1992). The energy inputs of agricultural field operations come in the form of direct inputs (gasoline, diesel, oil) and indirect inputs (raw materials, manufacturing, transportation, repairs). Of these two types of inputs, direct inputs account for the major share.

2.6.1 Manufacturing, Transportation and Repair

Agricultural machinery sequesters energy through manufacturing, transportation and necessary repairs. There has been some dispute over whether or not to include the energy required to obtain raw materials in the total manufacturing energy, since much of this material is recyclable (Bowers, 1992; Leach, 1976). However, accounting for the energy in raw materials seems to be an accepted practice because only a small percentage of material is recovered from scrapped farm equipment and any energy savings can be accounted for at the point of recycling.

Leach (1976) presented a method of accounting for manufacturing energy based on the energy required to produce one English pound (£) worth of farm machinery in 1968 (200 MJ/£). This value of energy intensity was applied to a straight line depreciation of the purchase price as well as the cost of repairs. Using this analysis method, Leach estimated that the energy cost of manufacturing small-to-medium-sized tractors is near 90 MJ/kg.

Pimentel et al. (1973) used information, provided by Berry et al. (1973) regarding the energy required for automobile production, to estimate the energy required for the production of agricultural machinery at 86.77 MJ/kg. Pimentel attached an additional 6% of the manufacturing energy to account for repairs. Loewer et al. (1977) suggested adding 8.8 MJ/kg to account for transportation. In related work, Bridges and Smith used this information to estimate a total energy requirement for manufacturing, transportation and repair of 100.7 MJ/kg.

Doering (1980) presented a method for calculating the energy embodied in farm equipment that was based on the energy in materials, fabrication and repairs. Energy in materials was given as 85.8 MJ/kg, 62.8 MJ/kg, 49.5 MJ/kg and 50.3 MJ/kg for tires, steel, tractors and combines respectively. Energy requirements for fabrication ranged from 6.27 MJ/kg to 14.6 MJ/kg for seven different categories of farm machinery. Energy for repair was determined based on total accumulated repair (TAR) equations, which estimate repair costs as a fraction of the original machine cost.

Fluck (1985) analyzed the energy in repair and maintenance of farm machinery by examining the sales volume of manufactured machines, parts and repair services. He also included energy for travel in his analysis. Fluck determined the average repair energy to be 55% of the energy in the purchased machine. He listed 14 different agricultural machines, with their corresponding ratio of repair energy to energy in the purchased machine. These ranged from 24% for self-propelled combines to 144% for cutterbar mowers.

Bowers (1992) reviewed these approaches and found Pimentel's estimate of 86.77 MJ/kg to be in acceptable agreement with Doering's estimates, with the added convenience of combining the various material and fabrication coefficients into a single coefficient. Bower's suggested that a simplified method for determining the total energy embodied in farm equipment would be to apply Pimentel's manufacturing coefficient of 86.77 MJ/kg along with Loewer's transportation coefficient of 8.8 MJ/kg and the appropriate repair ratio from the list supplied by Fluck.

2.6.2 Fuel Consumption

ASAE Standards (ASAE, 1992) present equations for determining tractor fuel consumption based on the percentage of maximum PTO power being used by a specific field operation. These equations were designed to model a 15% increase in fuel consumption over typical Nebraska Tractor Test data. The 15% adjustment accounts for increased fuel consumption which would be expected from older equipment used in the field, as opposed to the new equipment which is actually tested.

Leach (1976) presented the percentage of engine loading for various farm operations and the predicted fuel consumption based on field trials made by the U.K. National Agricultural Advisory Service. Leach noted that the figures given were averages. Actual fuel consumption can vary widely due to terrain, soil moisture and other field conditions. Draft and power requirements were determined for field operations in reduced tillage corn and soybean production by Vaughan et al. (1977).

Bowers (1992) compiled average fuel consumption estimates for thirty-eight different field operations. This information was based on data from eleven states in the United States and other countries (Kramer et al., 1978; Bowers, 1981; Stout et al., 1981). Bowers reaffirmed Leach's statement that actual fuel consumption can vary widely due to differences in field conditions, but accepted the compiled data as adequate for making estimates.

The total energy sequestered in diesel fuel includes the energy content of the fuel and the energy necessary for recovering, refining, transporting and storing the fuel. Bullard et al. (1976) determined a coefficient of 1.2227 for petroleum refinery products to account for these added energy expenditures. The heating value of diesel fuel was given as 45.5 MJ/kg by Goering (1989). Goering also supplied a fuel density of 834 kg/m^3. Applying Bullard's coefficient to these values yields an energy total for diesel fuel equal to 46.4 MJ/L.

2.7 Energy in Pesticides

According to Green et al. (1987), the use of pesticides in U.S. agriculture accounts for 1.6% of agriculture's total energy requirements. Although pesticides make up a seemingly insignificant portion of the total energy inputs to agriculture, the use of pesticides can represent a very important and efficient use of energy. Green et al. (1987) pointed out that a pesticide input to corn production that requires an additional 410 MJ/ha can prevent a 10% crop loss. The energy required to produce the lost 10% would equal 3,280 MJ/ha. Thus, the use of the pesticides, in this case, resulted in an energy savings of 2,870 MJ/ha.

Pesticides require indirect as well as direct energy inputs. Indirect energy inputs represent the energy sequestered by all the materials that are derived from petroleum products. Direct energy inputs represent the energy used in heating, stirring, distilling, filtering, drying and related processes. In addition to these inputs is the energy required for building and maintaining manufacturing plants, feeding and transporting labor, etc. Calculating all of the energy inputs described here is possible, though it can be a formidable task, provided that accurate descriptions of the manufacturing processes are available. However, this information is often unavailable as it is of a proprietary nature (Green, 1987).

Green (1987) calculated production energy requirements for many commonly used pesticides that range from 58 MJ/kg to 580 MJ/kg. Pimentel (1980) reported that the average energy requirements for the production of herbicides, insecticides, and fungicides were 239 MJ/kg, 184 MJ/kg and 92 MJ/kg, respectively.

In addition to production energy, pesticides require energy inputs to accomplish the processes of formulation, packaging and distribution. Energy requirements for formulation of emulsifiable oils, wettable powders and granules are not more than 20 MJ/kg, 30 MJ/kg and 10 MJ/kg, respectively. Packaging of pesticides amounts to about 2 MJ/kg. Distribution uses 5-8% of the production energy, and transportation from the retailer to the farm requires about 1 MJ/kg (Green, 1987).

Pimentel (1980) reported energy requirements for formulation of miscible oils, wettable powders and granules as 139 MJ/kg, 11 MJ/kg and 15 MJ/kg, respectively. Energy requirements for packaging of miscible oils, wettable powders and granules were reported as 36 MJ/kg, 11 MJ/kg and 84 MJ/kg, respectively. The total transportation energy requirement was listed as 4.7 MJ/kg, 2.8 MJ/kg and 28.1 MJ/kg for miscible oils, wettable powders and granules, respectively. Transportation energy was calculated based on energy requirements of truck and rail equal to 2.22 kJ/kg/km, and a mean distance of 640 km. All calculations were based on formulations of 30% active ingredient (A.I.), 50% A.I., and 5% A.I. for miscible oils, wettable powders and granules, respectively.

2.8 Energy in Labor

The first International Federation of Advanced Study energy analysis workshop (IFIAS, 1974) recommended determining the gross energy requirement of an individual worker rather than determining the energy required for life-support; that is, the total energy required to furnish a life-support system should be considered rather than merely the thermodynamic energy required to keep a worker alive. This decision places a higher value on human labor.

Fluck (1992a) reviewed and summarized the literature and presented nine different methods for determining the energy cost of agricultural labor. These methods are reviewed here. The first five methods deal with the energy cost of agricultural labor from a thermodynamic perspective. The remaining four consider the overall energy sequestered by the worker.

Thermodynamic Methods

1) Muscular Energy - This method only considers the physical work that one adult male can provide in one day. Values ranging from 0.49 (Makhijani, 1975) to 1.42 MJ/day (Smil, 1979) have been used. This method considers neither the energy consumed in food nor the energy required for food production. Also, it does not consider energy used in management tasks.

2) Partial Energy of Food Metabolized - This approach includes only the energy metabolized by a human while working, less the basal energy requirement. Deleague et al. (1979) used 0.7 MJ/h, while Norman(1978) used 0.75 MJ/h. Depending on the number of hours worked, the daily energy requirement could range from 3 to 10 MJ/day .

3) Total Energy of Food Metabolized - This technique considers the energy metabolized by a human while working including the basal energy requirement. Stanhill (1980) reported 0.7 MJ/h and Revelle (1976) reported 1.05 MJ/h for Indian men and 0.84 MJ/h for Indian women. Use of this method yields values that are from 1 to 2 MJ/day higher than the previous method. Thus, the daily energy requirement using this method ranges from 4 to 12 MJ/day.

4) Total Energy Content of Food Consumed - This method measures the energy content of all food consumed. Pimentel et al. (1973) used 2.28 MJ/h, which was based on an assumed 91.1 MJ/week and 40 h per week. Values for this method range from 10 to 15 MJ/day.

5) Energy Sequestered in Food - This approach multiplies the energy value based on the previous method by a factor of 6.8 in order to account for energy sequestered through the food chain (Wells, 1984). An energy value of 68 to 102 MJ/day results. There is little justification given for this approach.

Sequestered Energy Methods

1) Farm Family Support Energy - Williams et al. (1975) determined a value of 607.8 MJ/day, while USDA (1974) determined a value of 414.6 MJ/day to account for the direct energy usage of a farm family. These values are given solely for comparison to the two following methods.

2) Marginal Substitution Ratio - This method does not measure the energy sequestered by agricultural labor, rather it measures the energy necessary to replace labor with mechanization and maintain equivalent yields. De Wit (1975) determined the marginal substitution ratio for one example of Dutch agriculture to be 826 MJ/day. Later, De Wit and Van Heemst (1976) gave the ratio as 543 MJ/day.

3) Life-style Support Energy - This technique measures the total energy sequestered in goods and services used by the farm laborer. The energy values produced by this method vary with the standard of living of the worker. Fluck (1992a) gave a value of 1850 MJ/day for U.S. laborers in 1983.

4) Net Energy Analysis - Fluck (1981) performed a net energy analysis on U.S. production to determine the energy sequestered in those goods and services which are required to enable productive employment of labor. Fluck (1981) determined the energy sequestered by labor to be 594 MJ/day. Fluck (1985) revised this figure to reflect more recent economic information. The updated information showed that the average American laborer would sequester 80.5 MJ/hr, assuming he worked 230 8-hour days annually.

For the analysis of industrialized agriculture systems, the Net Energy Analysis method appears to be the most applicable since it includes only the energy sequestered for the support of labor.

3.0 Analytical Methods

3.1 Energy Analysis

The **goal** of this analysis was to compare the energy utilization of the two crop-livestock production systems currently in operation at the Whitethorne-Kentland Farm. A sequestered energy approach was used. All significant energy inputs (direct and indirect) to each crop and to the cattle production operation were determined. Each crop-livestock system was analyzed in four parts: corn silage production, pasture production, baled hay production, and beef production. The systems are divided in this way to ease the analysis procedure. However, it should be noted that the sub-systems within the sustainable system are heavily interdependent and cannot be operated autonomously.

The sustainable system is designed to be flexible, offering the farmer alternatives in dealing with unpredictable circumstances such as poor stands or crop loss due to weather. The field operations analyzed reflected an 'ideal' situation in which all harvests were completed in a timely manner.

Crop yield data from the cropping year of 1993 is used in this analysis. The first group of steers was introduced to the system in November of 1990, and the first full year of research was completed in 1991. However, data from the first two years was not representative of the system for a number of reasons, some of which will be detailed here.

First, since no steer manure was available from the previous year's operation, dairy manure was substituted. The amount of manure applied (6.7 Mg/ha) was based on an estimate of future manure production within the system. This estimate of manure production was far less than the actual output in 1991 (27 to 31 Mg/ha).

Secondly, the first year's corn production in the sustainable plots was hampered by poor weed control along with unfavorable weather conditions during seedling emergence and plant establishment, resulting in an unsatisfactory yield (Table 2). In response to this situation, a new production system was introduced in the sustainable plots. This system involved seeding the corn into a rolled-down cover crop with an innovative strip tillage planter (Vaughan et al., 1992). The new planting method improved weed control.

Table 2. **Mean corn silage yields for 1991 and 1992.**

Crop Year	SUST	CONV
1991 Yield (kg-dry matter/ha)	5,035 ^{a}	10,671 ^{b}
1992 Yield (kg-dry matter/ha)	12,790 ^{a}	12,892 ^{a}

a, b Means in the same row with different superscripts are significantly different ($P < 0.05$).

Finally, during the 1991 and 1992 cropping years, inadequate fencing made it impossible to establish the intensive grazing management that the sustainable system requires, which resulted in excessive hay feedings and altered forage harvesting operations. With improved fencing now in place, grazing patterns are being practiced as were initially planned.

Due to these situations, it is not reasonable to include the first two years of data in this energy analysis. The Crop-Livestock System was established with the philosophy that the system should be dynamic, incorporating innovative technologies, and making improvements to the system as needed. While this approach makes a traditional analysis difficult, it stimulates creative thought and inspires innovative solutions to difficult problems.

3.1.1 Corn Silage Production

Energy inputs to corn silage production, from the planting of the winter cover crop to the bagging of the corn silage, were calculated. The inputs were reported on a 'per kilogram of silage' basis. All silage was considered to be used for finishing the cattle. Corn silage yields for 1993 are reported in Table 3.

Table 3. Mean corn silage yield for 1993.

Corn Silage Yield (kg-dry matter/ha)	Mean
Sustainable System	11,562 ^{a}
Conventional System	12,421 ^{a}

a, b Means in the same column with different superscripts are significantly different ($P < 0.05$).

3.1.2 Grazed Forage Production

Grazed forage production includes crops that were used strictly for grazing, such as: nitrogen fertilized fescue in the conventional system, second-year alfalfa and wheat in the sustainable system; as well as crops that were both grazed and harvested: fescue/red clover and alfalfa in the conventional system and fescue/alfalfa and millet in the sustainable system. Energy inputs were reported on a 'per kilogram of dry matter' basis for each grazed forage crop and for total grazed forage production in each system.

Grazed forage production was calculated based on the dry matter requirement of medium frame steer calves as reported by National Research Council (1984). Table 4 shows the results of this calculation and the percentage of each crop that was grazed. All energy inputs to crops that were both harvested and grazed were divided between the harvested and grazed production based on the percentage of total output, with the exception of energy inputs that were accountable to harvesting.

Table 4. Per hectare production of grazed forage and percentage of crop that was grazed for 1993 based on feed requirements.

Product	Estimated Yield (Mg -dry matter/ha)	Amount of Crop Grazed
Sustainable:		
Wheat	6.23	100%
Millet	1.64	37%
Second-Year Alfalfa	15.74	100%
Fescue/Alfalfa	11.38	80%
Conventional:		
Alfalfa	4.53	38%
Fescue/Red Clover	5.42	57%
Fescue	9.06	100%

3.1.3 Baled Hay Production

The analysis of baled hay production included both crops that were grown strictly for hay and crops that were grazed and harvested. The crops analyzed in this section are outlined in Table 5. All energy inputs from planting to removal of bales from the field were calculated. Energy inputs were reported on a 'per kilogram of dry matter' basis for each crop and for total baled hay production in each system. The total energy cost of each type of baled hay was also determined on a 'per kilogram of dry matter basis'.

Hay harvest data from 1993 are reported in Table 5 along with the percentage of each crop that was harvested. Non-harvest energy inputs were divided between grazed and baled forage production, where necessary, based on the percentage of total production.

Table 5. **Per hectare production of baled hay for 1993 and percentage of crop that was harvested.**

Crop	Yield (Mg -dry matter/ha)	Amount of Crop Harvested
Sustainable		
Millet	2.85	63%
First Year Alfalfa	8.37	100%
Fescue/Alfalfa	2.78	20%
Conventional		
Alfalfa	7.85	62%
Fescue/Red Clover	3.99	43%

3.1.4 Beef Production

All significant energy inputs to beef cattle production, from the introduction of weanlings to the removal of finished cattle, were calculated on both a per head and a per kilogram of cattle gain basis. Energy inputs included: all energy inputs to corn silage production, all energy inputs to pasture production, and energy that was accountable to the baled hay that was fed. In addition to cultural inputs, the energy represented by the respective protein supplements in each system was calculated. Fuel, labor and machinery inputs, which were required for feeding, manure handling and moving the herd, were computed as well. Minor inputs that were not treated differently in the two systems, were disregarded. Production of cattle that were introduced in November of 1992 and finished in April 1994 is outlined in Table 6.

Table 6. Mean weight gain of beef in each system from November 1991 to April 1993.

Item	SUST	CONV
Mean Initial Weight (kg/head)	213 ^{a}	214 ^{a}
Mean Final Weight (kg/head)	607 ^{a}	585 ^{a}
Mean Total Gain (kg/head)	394^{a}	371 ^{a}
Standard Deviation	41.0	42.2

a, b Means in the same row with different superscripts are significantly different ($P < 0.05$).

3.1.5 Energy Analysis of Whole Farm

The primary output of both systems is beef. Baled hay is produced in each system for use on the farm and as a secondary output. Energy productivities were calculated for each output in both systems. Energy productivity is the ratio of product output to energy input (Fluck and Baird, 1980). It is a measure of the crop/beef production per unit of energy. In this study, energy productivity was measured in terms of kilograms of dry matter output per megajoule of energy input for the crops being grown, and kilograms of steer weight gain per megajoule of energy input for the two beef production systems. Because the crops being considered are not energy crops, energy ratios (energy value of output/ sum of energy inputs) were considered to have little meaning and were not calculated for these systems.

The only energy productivities that are readily comparable between systems are those that measure beef and alfalfa energy productivity. The other baled hay produced by the two systems is very different in consistency. Comparing the energy efficiency of the two entire farming systems is difficult due to the differences in crops produced. However, one method for achieving this is to look at the ratio of energy input to financial return. Combining the results of energy and economic analyses, the ratio of megajoules input to dollars of return was computed for both systems.

3.2 Farm Size and Machinery Complement

According to **Virginia Agricultural Statistics 1992**, the average cattle-producing farm in Virginia had 59 head of cattle. Each of the systems modeled here would require approximately 40 hectares of land to support 59 steers. To make the results of this analysis applicable on farms in Virginia and the southeastern United States, a 40 hectare farm raising 59 head of cattle was modeled where economies of scale were a consideration.

The machinery complement (Appendix D) was determined based on a 40 hectare farm and tractor preferences in Virginia. According to Ess (1990), the most commonly used tractor in Virginia is in the 60- to 66-kW range. Ess outlined an entire machinery complement for corn silage production on 17 hectares based on the use of a 63-kW tractor. Many of the implements that he chose have been included in the machinery complement that was modeled in this study and implements have been added as necessary.

3.3 Accounting for the Energy in Seed

Based on the research of Ess (1990) and Heichel (1980), it was decided to use a process analysis approach to determine the energy cost of seed production. Where available, previously determined energy costs were used. The energy cost of alfalfa seed production was based on a process analysis of seed production performed by Heichel (1980). Values of seed energy calculated by Ess (1990) for corn and rye were used. Additionally, a process analysis was performed to determine the energy value of millet, wheat and red clover. These analyses are detailed in Appendix B.

In analyzing the energy inputs to millet and red clover seed, methods used were identical to those described for the overall energy analysis. The analysis of millet seed production is based on the suggested field operations and seed yields reported by Chopra (1982) and Seetharam et al. (1989). The field operations and yields used in the analysis of red clover seed production were taken from Rincker and Rampton (1985). Briggle (1980) reported an energy analysis for winter wheat grain that was grown in Ohio. The inputs that Briggle listed were used in the analysis of wheat seed production energy.

Once seed production energy was calculated, energy requirements for seed cleaning, packaging and transportation were added. Energy requirement for seed cleaning was based on the analysis of Ess (1990), who calculated a value of 3.10 MJ/kg. Berry and Makino (1974) determined the energy cost of paper packaging to be 363 MJ/m^3. Adjusting this value by a factor taken from Leach (1976) to account for the total energy sequestered in the packaging yields a total energy cost of 922 MJ/m^3. Transportation energy was calculated based on an energy intensity for trucking of 3.475 MJ/Mg-km. reported by Pimentel (1980). Transportation distances between primary seed producing areas and southwestern Virginia were estimated. The results of this analysis is shown in Table 7.

Values for energy cost were applied to the seeding rates in each system (Appendix E) to determine the total energy sequestered in the seed. In cases where perennial crops were left in place for more than one season, total seed energy was divided over the full life of the crop.

Table 7. **Energy cost of seed based on process analysis.**

Seed Energy	Rye	Corn	Wheat	Millet	Alfalfa	Red Clover
Crop Production (MJ/kg)	3.83	5.47	4.51	20.10	94.10	77.90
Seed Cleaning (MJ/kg)	3.10	3.10	3.10	3.10	3.10	3.10
Packaging (MJ/kg)	1.28	1.28	1.19	1.46	1.19	1.19
Transportation (MJ/kg)	8.40	5.62	1.74	6.05	10.43	3.82
Energy Value (MJ/kg)	**16.61**	**15.47**	**10.54**	**30.71**	**108.82**	**86.01**

3.4 Accounting for the Energy in Fertilizers

In this experiment, nitrogen was applied in two forms: urea-ammonium nitrate (UAN) solution and prilled ammonium nitrate (AN). Phosphorus and potassium were applied in the form of triple super phosphate (TSP) and fertilizer-grade potassium chloride (KCl). Boron was assumed to be supplied in the form of borax. Energy values for the production, packaging, and distribution of these fertilizers were based on the analysis of Mudahar and Hignett (1987a). The results are shown in Table 7. Packaging and transportation energy, reported by Mudahar and Hignett (1987a) and shown in Table 1, were adjusted based on the percentage of nutrient in the actual product used.

The energy cost of applying the fertilizer is not reported here since it is accounted for in the energy analysis of field operations. The application rates for each nutrient are listed in Appendix F.

Table 8. Energy in production, packaging, and transportation of fertilizer.

Energy in Fertilizer	AN[1] (N)	UAN[2] (N)	TSP[3] (P_2O_5)	KCl[4] (K_2O)	Borax (B)
Percentage of Nutrient (%)	32	30	46	60	11
Production Energy (MJ/kg)	66.59	65.27	8.28	6.40	18.18
Packaging Energy (MJ/kg)	3.63	3.87	2.59	1.31	18.82
Transportation Energy (MJ/kg)	6.29	6.71	5.56	3.45	3.89
Energy Value (MJ/kg)	**76.51**	**75.85**	**16.43**	**11.16**	**40.89**

[1] Prilled Ammonium Nitrate
[2] Urea-Amonium Nitrate
[3] Triple Super Phosphate
[4] Potassium Chloride

3.5 Accounting for the Energy in Manure

The direct energy cost of utilizing manure in this experiment was determined in order to compare the energy usage of the two systems. A further study of the energy flows involved in using the manure and the potential energy value of the manure was also conducted.

3.5.1 Energy Cost of Manure

The energy cost of manure is a measure of how much energy is spent in using manure as an input to the system. For the steer manure used in this study, the energy inputs included manure handling and spreading. The energy involved in spreading the manure was accounted for in the field operations analysis, and totaled to 20.6 MJ/Mg for machinery, fuel and labor inputs. The energy required for manure handling was included in the machinery, fuel and labor inputs to the beef production system. Fuel and time requirements, reported by Cook et al. (1980), were combined with average beef cattle manure production, reported in **ASAE Standards 1992** (Manure Production and Characteristics, ASAE D384.1), to determine the energy requirement on a per Mg of manure basis (26.7 MJ/Mg). Energy inputs to manure handling were then calculated based on the amount of manure produced in each system.

The only significant energy investment in the use of poultry litter as a feed supplement is the energy required to transport the litter to the cattle farm. Pimentel (1980) supplied a coefficient for truck transport of 3.475 MJ/Mg-km. Assuming a maximum travel distance in Virginia from poultry farm to cattle feedlot of 400 km yields an energy cost of 1.39 MJ/kg of poultry litter.

3.5.2 Energy Analysis of Manure Use

An energy analysis of manure use appears in appendix C. The analysis compares the energy value of steer manure as a fertilizer and as a source of methane with the energy cost of collection and application. The energy value of poultry litter as a fertilizer, as a feed supplement and as a source of methane is compared with the energy cost of transporting the poultry litter 400 km to the farm. For both types of manure, average nutrient contents were used in determining the manures' value as fertilizer. The energy value of poultry litter as a feed supplement was determined based on the rate at which it replaces soybean meal in this experiment.

The use of steer manure as a soil amendment and poultry litter as a feed supplement are both justified from an energetics viewpoint. However, it should be noted that both manures have significant value as a source of methane. Once digested for methane, manure maintains much of its value as a fertilizer and a feed supplement (Stout, 1990). At the current time, economics have prevented the adoption of on-farm methane production in the United States. So, the 'potential' energy value of manure for methane generation was not accounted for in the energy analysis of the whole farm.

3.6 Accounting for the Energy in Field Operations

Calculation of the energy sequestered in field operations was divided into two sections. First, the indirect energy inputs of manufacturing, transportation and repair of field equipment were calculated. Next, the energy sequestered by fuel consumption was calculated. Time requirements, determined by equipment capacity and average field speeds for each operation, were used to determine the energy inputs for each operation and to determine labor requirements.

3.6.1 Manufacturing, Transportation and Repair

Doering's (1980) method for calculating manufacturing energy was used in this analysis. The method is based on the weight of the machinery, and accounts for the energy in materials, manufacture and repair. Doering supplied coefficients for the energy embodied in one kilogram of tires, steel, tractor and combine. Energy embodied in materials is calculated by multiplying the weight of the given material by its corresponding coefficient. Next, the energy required for fabrication is calculated by multiplying the weight of the implement, excluding tires, by the appropriate coefficient for fabrication energy. The amount of energy in repairs was based on total accumulated repair equations that predict repair costs.

Fluck (1985) analyzed the energy in repair and maintenance of farm machinery by examining the sales volume of manufactured machines, parts and repair services. He included energy for travel in his analysis. Since Fluck's analysis seems more thorough, his repair energy coefficients were used in this analysis. Transportation of equipment to the farm was accounted for by including 8.8 MJ/kg, as suggested by Loewer et al. (1977)

An example of calculating the energy sequestered by a 4,581 kg tractor is shown here. The net weight of the tractor, excluding tires, was assumed to be 82.1% of the total weight, as suggested by Doering.

Example of the Method Used for Calculating the Energy Sequestered by Machinery

Energy in Materials:

Embodied Energy = (4,581 kg)(49.46 MJ/kg) = **226,576 MJ**

Fabrication Energy:

Fabrication Energy = (0.821)(4,581 kg)(14.63 MJ/kg) = **55,023 MJ**

Energy in Repairs:

Repair Energy = (0.49)(226,576 MJ + 55,023 MJ) = **137,984 MJ**

Energy in Transportation:

Transportation Energy = (4581 kg)(8.8 MJ/kg) = **40,313 MJ**

Total Energy Content = 459,896 MJ

Once the total energy content of each implement was established, it was divided by the estimated machine lifetime, in hours, to give an hourly energy cost. For the tractor example, the machine lifetime was 10,000 hours, and the energy cost was 45.99 MJ/h. This energy cost was then multiplied by the annual usage, in hours, to yield an annual energy expense (Ess, 1990).

Machinery weights and operating characteristics were drawn from the 1993 *Implement and Tractor* **Red Book**, the Spring 1993 *NAEDA Official Guide - Tractors and Farm Equipment*, as well as from discussion with farm equipment dealers and manufacturers. Machine life listed in **ASAE Standards 1992** (Agricultural Machinery Management Data, ASAE D497) was used to calculate the energy expense of each implement. Typical field speed and efficiency estimates from the same publication were used to determine required operating time. The machinery complement is outlined in Appendix D.

3.6.2 Fuel Consumption

The methods outlined in **ASAE Standards 1992** (Agricultural Machinery Management Data, ASAE D497; Agricultural Machinery Management, ASAE EP496) were used to determine fuel consumption for each operation. The equations given for determining tractor fuel consumption are based on the percentage of maximum PTO power being used by a specific field operation.

These equations are designed to model a 15% increase in fuel consumption over typical Nebraska Tractor Test data. The 15% adjustment accounts for increased fuel consumption due to field use.

The equation for calculating fuel consumption is given as:

$$FC = 2.64X + 3.91 - 0.203\sqrt{738X + 173}$$

Where,

FC = Tractor Fuel Consumption (L/kWh); and

X = The ratio of equivalent PTO power required for the given operation to the maximum PTO power available.

The actual fuel consumption, in liters per hour, for a specific operation is then calculated as:

$$FC_{spec} = FC \times PTOkW_{equiv}$$

Where,

FC_{spec} = Fuel Consumption for a specific operation (L/h); and

$PTOkW_{equiv}$= The equivalent PTO power required for the given operation (kW).

Power requirements were calculated from implement draft values and PTO requirements listed by Bowers (1989), Ess (1990), Vaughan (1977) and **ASAE Standards 1992.** Values for the percentage of maximum power for various operations were supplied by Leach (1976).

The energy sequestered by diesel fuel was determined by using a heating value of 45.5 MJ/kg and a fuel density of 834 kg/m^3 (Goering, 1989). Bullard et al. (1976) determined a coefficient of

1.2227 for petroleum refinery products to account for the total energy sequestered by a given product. Applying Bullard's coefficient yields an energy cost for diesel fuel equal to 46.4 MJ/L.

3.7 Energy in Pesticides

Following integrated pest management guidelines (Virginia Cooperative Extension Service, 1992), pesticides have been applied to both systems on an as-needed basis. In addition, as part of the conventional system, a number of standard preventative pesticides were applied at planting (Appendix H).

Green (1987) reported production, formulation, packaging, distribution, and transportation energy requirements for many commonly used pesticides, including many of those used in this study. Pimentel (1980) reported average energy requirements for the production of herbicides, insecticides and fungicides. Where more accurate information was unavailable, the average value was applied. Table 8 lists the energy inputs of the pesticides used in this analysis, including those used in the analysis of seed energy.

Table 9. Energy cost of various pesticides.

Trade Name[1]	Active Ingredient	A.I.[2] (kg/L)	Energy[3] Content (MJ/kg)	Form[4]	Formulation Energy (MJ/kg)	Package Energy (MJ/kg)	Distribution Energy (MJ/kg)	Transport Energy (MJ/kg)	Total Energy (MJ/kg)
Aatrex C	Atrazine	0.479	190	L	20	2	15.20	1	228
Accent S	Nicosulfuron	0.719	239*	WDG	20	2	19.12	1	281
Banvel C	Dicamba	0.479	295	L	20	2	23.60	1	342
Bladex C	Cyanazine	0.479	201	L	20	2	16.08	1	240
Eptam E	EPTC	0.211	160	EC	20	2	12.80	1	196
Gramoxone Extra C,S	Paraquat	0.300	460	L	20	2	36.80	1	520
Lasso C	Alachlor	0.479	278	EC	20	2	22.24	1	323
Princep C	Simazine	0.479	239*	L	20	2	19.12	1	281
Round-up S	Glyphosate	0.479	454	L	20	2	36.32	1	513
Agrox-DL C,S	Diazinon	15%	184*	P	30	2	14.72	1	232
	Lindane	25%	58	P	30	2	4.64	1	96
Ambush C,S	Permethrin	0.240	580	EC	20	2	46.40	1	649
Asana C	Esfenvalerate	0.079	184*	EC	20	2	14.72	1	222
Cygon S	Dimethoate	0.825	184*	EC	20	2	14.72	1	222
Cythion E	Malathion	0.599	229	EC	20	2	18.32	1	270
Force C	Tefluthrin	20%	184*	G	10	2	14.72	1	212
Surface Active	Surfactant	100%	41.5	N/A	N/A	2	3.32	1	48
Agents C,S	Phytobland Oil	100%	45	N/A	N/A	2	3.60	1	52

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[1] The letter 'C', following a trade name indicates that the pesticide was used in the conventional system. The letter 'S' indicates that the pesticide was used in the sustainable system. The letter 'E' indicates that the energy value for this pesticide was required for the energy analysis of seed inputs.

[2] The amount of active ingredient in the product is reported as kg/L for liquid products and as a percentage by weight for solid products.

[3] Energy Content is based on the analysis of Green (1987), except where marked by an asterisk (*), in which case the energy content of the active ingredient was unavailable and the average value reported by Pimentel (1980) was used.

[4] L = Liquid, EC = Emulsifiable Concentrate, WDG = Water Dispersible Granule, G = Granular, P = Powder, N/A = Not Applicable.

3.8 Energy in Labor

The sustainable system being studied required a greater degree of management due to the added crop rotations, intensive cattle grazing and scouting for insect pests. Because of this, it is important to apply an energy coefficient to labor that accurately reflects the value of human endeavors. For the analysis of industrialized agriculture systems, the Net Energy Analysis method appears to be the most applicable since it includes the energy sequestered for the support of labor.

The energy value of labor was determined based on the energy coefficient for labor developed by Fluck (1981, 1985), and adjusted for agricultural labor based on the work of Herendeen and Tanaka (1975). The coefficient determined was 57.1 MJ/h. This value was multiplied by the total number of hours of field operations to determine the annual energy use attributable to labor.

In addition to field operations, the energy coefficient for labor was applied to time spent in the following operations: scouting for insects in the sustainable system, cattle feeding, cattle movement, and manure handling. According to Laub (1993), scouting for insect pests requires approximately 0.42 h/ha. Time required for cattle feeding and cattle movement was determined based on the methods described in the following section. The time required for manure handling, as a function of the amount of manure handled, was calculated as described in the analysis of the energy costs of manure.

3.9 Accounting for the Energy Inputs to Beef Production

In addition to the cultural requirements of producing feed for cattle, maintenance of the herd requires energy inputs to achieve the following tasks: feed preparation, feeding, movement of the herd and manure handling. In general, fuel, farm machinery and labor inputs were calculated in the manner described in preceding sections. Specifics are given here.

3.9.1 Hay Feeding

An average energy expenditure for hay feeding was calculated based on the method Bridges and Smith (1979) outlined for transporting hay. The model for hay feeding was based on the use of a tractor and wagon to deliver hay to the appropriate field on a 40 hectare farm producing 59 steers. The tractor was assumed to travel 8.05 km/h. The average total distance traveled was taken as 3.2 km. The average weight of hay fed was calculated to be 6 kg/hd based on actual hay feedings during 1993, resulting in a total weight of hay delivered equal to 354 kg for the hypothetical 59 head herd.

Table 10. Energy required for hay feeding.

Item	Energy Required per Feeding (MJ/hd)
Machinery	0.286
Fuel	0.681
Labor	0.388
Total	1.355

Energy embodied in the required machinery, fuel consumption and labor requirements were calculated in the manner described in the previous sections. The resulting energy usage per feeding was 1.36 MJ/hd. This total energy requirement is broken down in Table 9.

The energy cost of baled hay fed in each system included the energy cost of production plus the energy cost of storage. Calculation of the energy cost of production has been outlined throughout this report. Calculation of the energy cost of storage was based on Doering's (1980) report of 14.78 MJ/m^2 as the energy sequestered in service buildings. Assuming that square bales (0.36m x 0.46m x 1.17 m) weighed 31.7 kg and were stacked six bales high and that the service life of the building was 20 years, the energy cost of hay storage was calculated as 0.358 MJ/kg-dry matter. The total energy cost of baled fescue/red clover in the conventional system and baled fescue/alfalfa in the sustainable system was applied to the total amount of hay fed in each system to determine the energy sequestered in hay fed (Table 10).

Table 11. **Energy cost of hay fed.**

System	Type of Hay Fed	Amount Fed (kg/head)	Energy Cost (MJ/kg)	Total Energy (MJ/head)
Sustainable	Fescue/Alfalfa	652	0.683	445
Conventional	Fescue/Red Clover	227	1.100	249

3.9.2 Feeding in Feedlot

Once the cattle in the two systems reached the feedlot, they were fed a mixture of hay, corn silage and a protein supplement. Hay was gradually removed from the diet leaving corn silage and a protein supplement. The protein supplement in the sustainable system was poultry litter.

The energy cost of poultry litter was determined previously based on transportation energy. The resulting energy cost was 1.39 MJ/kg.

Cattle in the conventional system were given a protein supplement of soybean meal. Cook et al. (1980) listed the average cultural energy expended in the production of various cattle feed sources. A value of 6.12 MJ/kg was given for soybeans. Ward et al. (1977) enumerated the energy required for processing various cattle feedstuffs. An energy requirement of 3.18 MJ/kg for processing soybean meal was given. Summing these values yielded a total energy value of 9.30 MJ/kg for soybean meal.

Corn silage feeding also required energy inputs in the form of fuel, machinery and labor. Since these inputs are relatively small in comparison to the other inputs to beef production, and since the inputs are equal in both systems, a crude estimate will suffice for the purposes of this comparison. The time requirement for mixing the feed and feeding the 24 cattle in each system was estimated at ten minutes by the farm manager. The power requirement was based on a 25% engine loading given by Leach (1976) for ensiling. The methods described previously for determining the energy cost of fuel, machinery and labor were used to determine the total energy cost of feeding silage.

3.9.3 Movement of Herd

The sustainable beef production system was designed to incorporate intensively managed grazing patterns so that alternative crop rotations could be utilized. To account for this difference in management practices, an average time requirement for moving the herd was predicted based on time-and-motion observations and discussion with the farm manager. If the herd walks at 6.4 km/h, it takes 30 minutes to travel 3.2 km, which should be an adequate distance to travel between any two pastures on a 40 hectare farm. Thirty minutes would overestimate travel time in most cases, but the extra time allocation allows for related activities, such as traveling to and from pastures and opening gates. The resulting travel time requirement was 0.0085 h/head.

Total time required for moving the herd was computed based on the number of herd relocations and added to the total labor requirement. A simple sensitivity analysis showed that doubling the time estimate decreased the energy productivity of the system by less than 0.5%. Due to the insensitivity of the analysis to this labor input, the estimate was considered adequate.

3.9.4 Minor Inputs

Minor energy inputs to beef production that were not different for the two systems (i.e. veterinary care, insecticides, farm buildings, etc.) were not considered in this analysis since they were considered insignificant in the comparison of the two systems. Two minor inputs that were examined were the energy in fencing and the energy in bloat-prevention blocks.

Fencing requirements in the sustainable system were larger due to the division of land in the cropping system (Figure 1). The energy intensity of fencing was given by Cook et al. (1980) as 1840 MJ/km. A hypothetical length of fencing was calculated for a 40-hectare farm with 59 head of cattle, based on an assumption that all fields were square and all fields were fenced to allow for grazing. Total energy was depreciated over a 20-year lifetime. The results are shown in Table 12. The difference in the energy required for fencing is small and the total energy required is inconsequential in comparison to the other energy inputs in the system.

Table 12. **Energy cost of fencing.**

System	Fence Length (km/farm)	Energy Cost (MJ/farm)	Energy Cost (MJ/hd)
Sustainable	5.52	508	8.61
Conventional	4.95	455	7.71

Bloat-prevention blocks are medicated mineral blocks that are supplied to prevent bloating in steer being fed leguminous forage crops. Manufacturers recommend that blocks be supplied to cattle at the daily rate of 0.5 kg/Mg live weight. In the absence of specific energy requirement information for the production of the blocks, a statistical analysis method supplied by Fluck (1992b) was used. Fluck reported the average energy intensity of U.S. products as 16.51 MJ/$ in 1989, based on the gross national product and the total national primary energy consumption. The cost of bloat blocks is $0.86/kg. Applying the energy intensity figure supplied by Fluck yielded an energy cost for bloat-prevention blocks of 14.19 MJ/kg.

3.10 Economic Analysis

Since new production methods in agriculture are generally not adopted without adequate economic justification, a brief economic analysis was performed to compare the two systems. This analysis considers annual costs, as well as the capital costs attributable to the required equipment. It does not consider the capital cost attributable to land. The hope is that the analysis will serve as a means of comparing of the two systems, rather than a definitive determination of the profitability of each.

Fixed costs were calculated using straight line depreciation with no salvage value. Operating costs included repair and maintenance costs and were calculated using ASAE total machine life repair cost estimates (ASAE, 1992).

3.10.1 Input Prices

For the purpose of this economic analysis, input prices were obtained from **Virginia Agricultural Statistics 1992**, **Agricultural Statistics 1992**, the Spring 1993 *NAEDA Official Guide - Tractors and Farm Equipment* and local retailers.

Where available, seed prices were taken from **Agricultural Statistics 1992** and reflected the average price paid by farmers in Virginia. Prices for foxtail millet and hairy vetch were obtained from a local retailer, Southern States Cooperative, Christiansburg. A list of the seed prices used in this analysis is as follows:

Alfalfa	\$5.56/kg
Corn	\$2.57/kg
Foxtail Millet	\$0.93/kg
Hairy Vetch	\$1.98/kg
Red Clover	\$2.69/kg
Rye	\$0.97/kg
Winter Wheat	\$0.27/kg

Prices for urea ammonium nitrate (UAN) solution and prilled ammonium nitrate were taken from **Virginia Agricultural Statistics 1992**. These prices did not include application costs and reflected average prices paid in the southeast region of the United States during 1992. A local fertilizer supplier (Mitchell Fertilizer Company, Christiansburg) was consulted for the price of triple super phosphate (TSP), fertilizer-grade potassium chloride and borax. Following is a list of prices used, given on a per kilogram of nutrient basis:

UAN Solution (N)	\$0.51/kg
Prilled Ammonium Nitrate (N)	\$0.65/kg
TSP (P_2O_5)	\$0.43/kg
KCl (K_2O)	\$0.26/kg
Borax (B)	\$4.59/kg

The prices of pesticides listed below were obtained from a local supplier (Southern States Cooperative, Christiansburg) and represent the price paid by farmers for the most popular sizes of containers.

Aatrex (Atrazine)	\$3.80/L
Accent (Nicosulfuron)	\$998.25/kg
Banvel (Dicamba)	\$21.66/L
Bladex (Cyanazine)	\$6.76/L
Gramoxone Extra (Paraquat)	\$7.60/L
Lasso (Alachlor)	\$7.08/L
Princep (Simazine)	\$4.33/L
Round-up (Glyphosate)	\$12.15/L
Agrox-DL (Diazinon & Lindane)	\$4.54/kg
Ambush (Permethrin)	\$31.69/L
Asana (Esfenvalerate)	\$39.62/L
Cygon (Dimethoate)	\$8.77/L
Force (Tefluthrin)	\$4.32/kg

Purchase prices for tractors, hay harvesting equipment, forage harvesting equipment and manure spreaders were taken from the Spring 1993 *NAEDA Official Guide - Tractors and Farm*

Equipment , where possible. Local equipment dealers were consulted for the prices of the remaining machinery.

Tractor	$32,140
Grain Drill	$4,930
Roller Packer	$6,100
Manure Spreader	$9,740
Broadcaster	$1,690
Sprayer	$2,110
Planter (no-till)	$10,940
Forage Harvester	$20,280
Forage Wagon	$9,200
Rotary Mower	$5,120
Disc Harrow	$5,380
Mower Conditioner	$11,400
Side Delivery Rake	$2,950
Baler	$11,660
Silage Bagger	$19,000
Silage Feeder	$12,260
Front Loader	$3,180
Wagon	$830

Of the remaining input prices, all but the prices of poultry litter and bloat-prevention blocks were obtained from **Virginia Agricultural Statistics 1992**. The price of diesel fuel represents the price paid in 1992 by farmers in the Appalachian Region for bulk diesel fuel with farm delivery. The price of labor represents the average hourly wage paid by farmers in Virginia and North Carolina during 1992. The price paid for weanlings is based on the price received by Virginia farmers for calves during 1992. The price of soybean meal reflects the average price paid by farmers in the Appalachian Region in 1992. A representative of the Virginia Cooperative Extension Service (Roller, 1993) quoted the price of poultry litter delivered to

Blacksburg, VA from the Harrisonburg, VA area. A local supplier (Southern States Cooperative, Christiansburg) quoted the price of bloat-prevention blocks.

Diesel	\$0.22/L
Labor	\$5.78/L
Weanlings	\$1.78/kg
Soybean Meal	\$0.30/kg
Poultry Litter	\$33.08/Mg
Bloat Prevention Blocks	\$0.86/kg

3.10.2 Machinery Costs

Machinery costs include both fixed and operating costs. Fixed costs represent the cost of owning machinery, which include depreciation, interest and taxes. The method developed by Chen and Bateman (1988) for determining fixed costs of machinery was used in this analysis, since it represents a straightforward accounting of the fixed costs without regard to the present value of machinery. No salvage value is assigned to the equipment being evaluated. Costs are computed based on the amount of hourly use.

Ess (1990) presented a compelling argument for assigning a high annual use to deflate the fixed costs of new equipment. His argument was based on the high purchase price of new equipment in comparison to the average value of the entire machinery complement on a Virginia farm. Following his example, the equipment was assigned a useful life of 10 years. Annual use was then calculated by dividing the expected life in hours, as reported by ASAE (1990), by the 10-year useful life.

The equation for calculating fixed costs was given as:

$$FCH = \left[\left(PP/L\right) + \left(PP/2\right)(IR + TSI)\right]/HR$$

Where,

FCH = Fixed Costs ($/h);

PP = Purchase Price ($);

L = Useful Life (years);

HR = Annual Use (h);

IR = Interest Rate at 10%; and

TSI = Tax Shelter at 4%.

Operating costs include the costs of repair and maintenance, as well as fuel consumption. The methods outlined in **ASAE Standards 1992** (Agricultural Machinery Management Data, ASAE D497) were used to calculate the operating costs of each operation.

Operating costs were calculated as:

$$OCH = \frac{(PP \times RPP)}{(L \times HR)} + FCT \times FU$$

Where,

OCH = Operating Costs excluding Labor ($/h);

RPP = Repair Costs (percentage of purchase price);

FCT = Fuel Cost ($/L); and

FU = Fuel Use (L/h).

3.10.3 Output Prices

Prices paid for outputs from the farm were compiled from **Virginia Agricultural Statistics 1992** and conversations with local hay sellers. The price listed for beef steer represents the average price received by Virginia Farmers in 1992. **Virginia Agricultural Statistics 1992** reported the price received by farmers for baled alfalfa hay and all other hay. Local hay sellers were contacted to determine a selling price for each type of baled hay, since the various types of hay have different values. All hay was assumed to have a 15% moisture content.

Beef Steer	$1.64/kg
Baled Alfalfa Hay	$130.00/Mg
Baled Fescue/Alfalfa Hay	$125.00/Mg
Baled Fescue/Red Clover Hay	$120.00/Mg
Baled Millet Hay	$110.00/Mg

4.0 Results and Discussion

The results of the energy analysis are divided based on the type of production. Following the analysis of each area of production, the whole farm systems are compared. Implications of the analysis are discussed and an alternative system is suggested. Finally, economic analyses of the two current systems and a suggested alternative system are presented.

4.1 Corn Silage Production

Figure 2 shows the energy inputs to corn silage production per kilogram of dry matter produced. As would be expected, synthetic fertilizer represented the largest energy input to corn silage production in both systems. Sustainable corn silage production used less energy than conventional corn silage production in the form of synthetic fertilizer; the difference in energy use is attributable to the nitrogen supplied by legumes in the sustainable system. Sustainable corn silage production also used significantly less energy in the form of pesticides than conventional corn silage production. The remaining differences in energy usage are fairly insignificant and are mainly the result of differences in corn yield. It is important to note that, while corn silage production has been analyzed as an autonomous unit, sustainable corn production received the benefit of an annual rotation system and cannot be reproduced outside of that system.

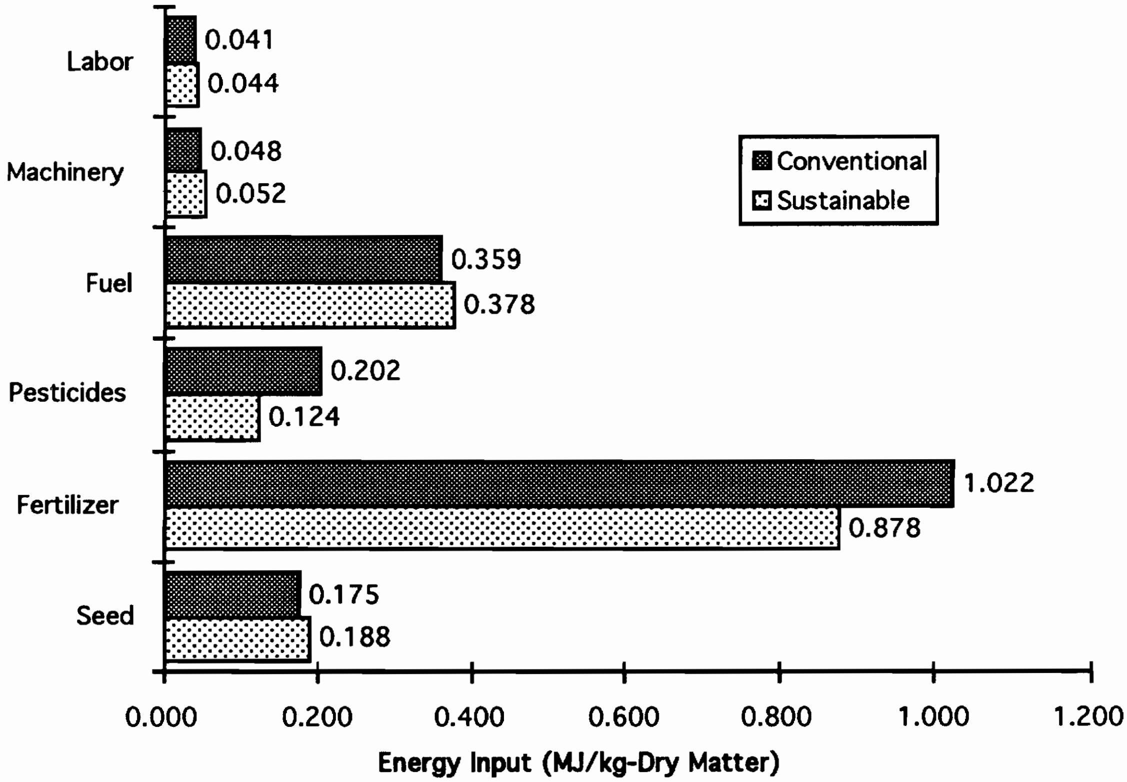

Figure 2. **Energy inputs to corn silage production in sustainable and conventional system.**

4.2 Grazed Forage Production

Figure 3 shows the energy inputs per kg-dry matter for each type of grazed forage employed. As in the case of corn silage production, synthetic fertilizer is the most significant energy input. The conventional fescue pasture received all of its nitrogen in the form of synthetic fertilizer; the result is that the fertilizer input to conventional fescue dominates the energy inputs to grazed forage production. A significant amount of energy was used in the sustainable system to supply synthetic nitrogen to the millet and wheat pasture.

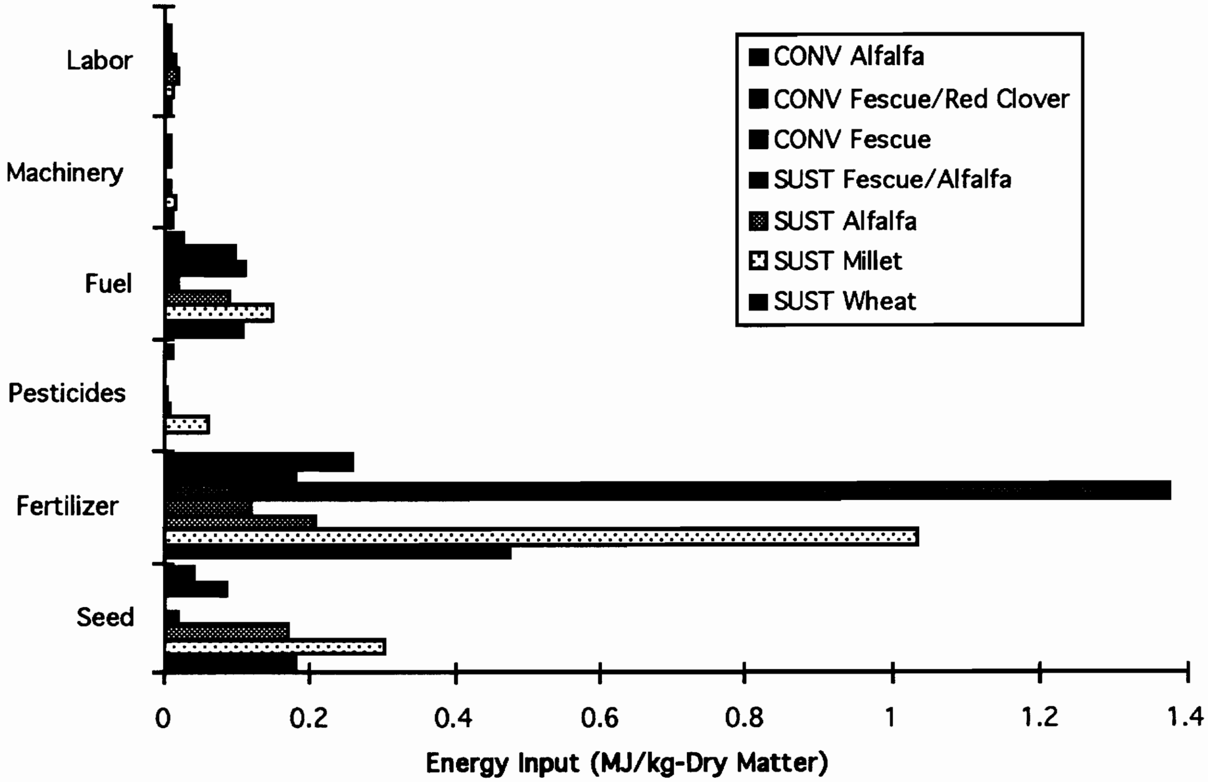

Figure 3. **Energy inputs to each type of grazed forage production in sustainable and conventional system.**

When pasture types are grouped in the sustainable and conventional systems and energy inputs are measured based on total dry matter output (Figure 4), it becomes evident that the sustainable system performs better than the conventional system, which is due in large part to the differences in fertilizer usage, but is also a result of higher yields in the sustainable system. The high energy requirement for seed inputs in the sustainable system is a result of annual plantings of wheat, millet and alfalfa.

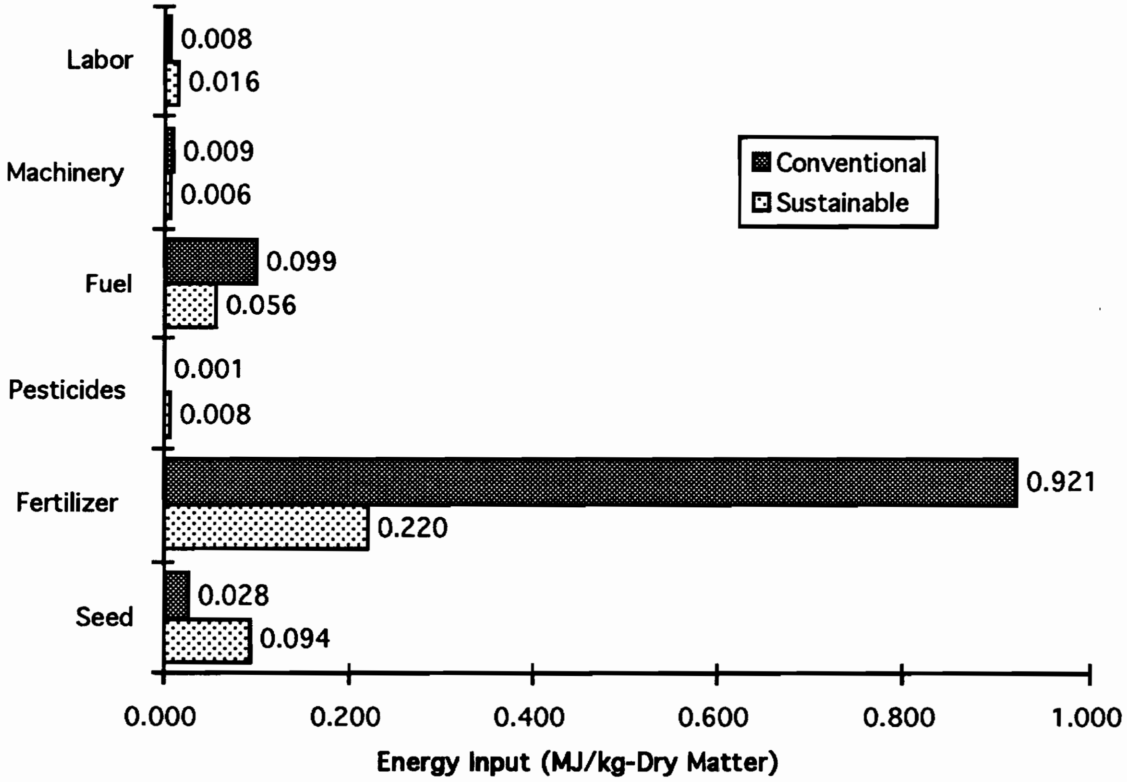

Figure 4. **Energy inputs to all grazed forage production in sustainable and conventional system.**

4.3 Baled Hay Production

Baled hay production represents the most interesting part of the energy analysis. Table 13 shows that, while production of baled fescue/alfalfa in the sustainable system was the most energy efficient form of baled hay production in either system, production of baled millet in the sustainable system was the most energy intensive form of baled hay production in either system. A closer look reveals that the energy intensity of millet is due, not only to the small yield which results from the relatively short growing season, but to increased energy inputs that are required by the millet crop. Figure 5 shows that the energy input per kilogram of dry

Table 13. Energy cost of baled hay in sustainable and conventional system.

Crop	Energy Cost (MJ/kg)
Sustainable	
Millet	1.99
Alfalfa	0.84
Fescue/Alfalfa	0.33
Conventional	
Alfalfa	0.78
Fescue/Red Clover	0.74

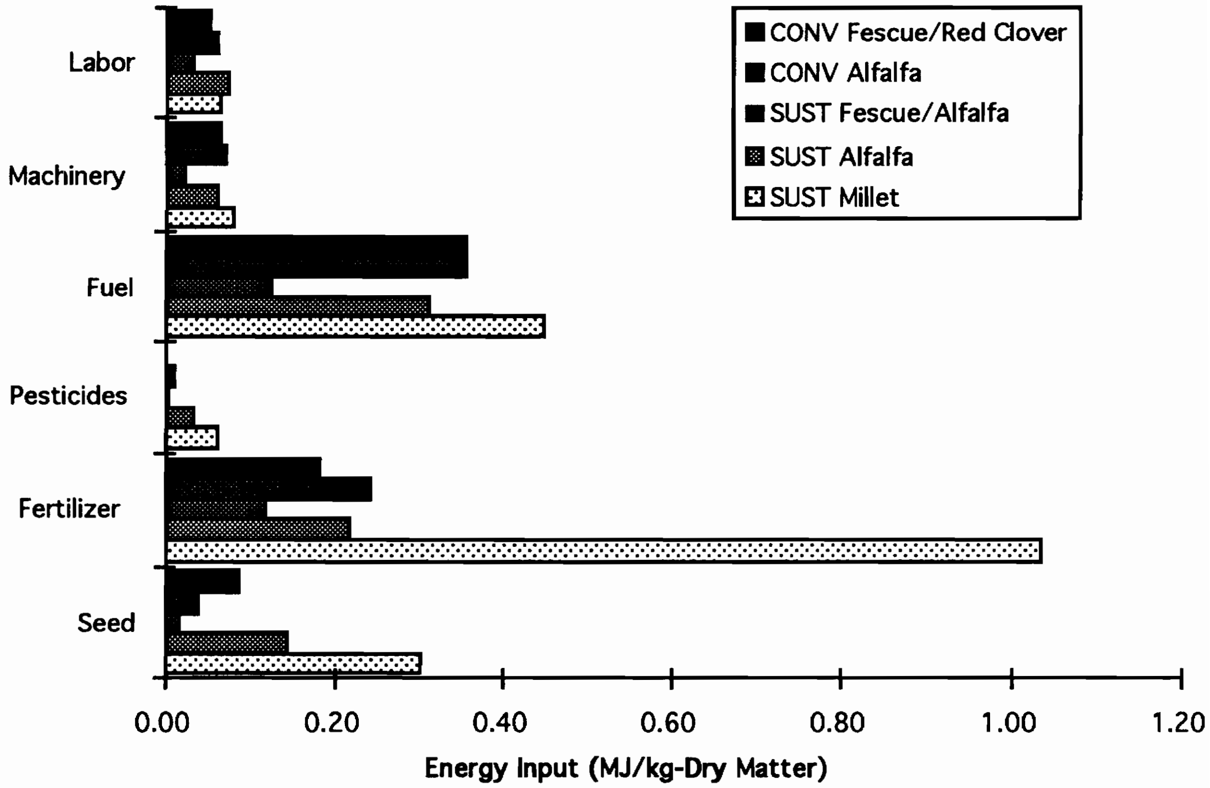

Figure 5. Energy inputs to each type of baled hay production in sustainable and conventional system.

matter output, represented by nitrogen applied to the millet crop, was the most significant energy input to all of the baled hay crops. Additionally, baled alfalfa grown in the sustainable system required more energy than baled alfalfa grown in the conventional system, due mainly to additional seed inputs.

Figure 6 combines all baled hay production in each system. The energy required in the form of synthetic fertilizers, pesticides, and seed is significantly higher in the sustainable system. The elevated use of synthetic fertilizer in the sustainable system is due entirely to the nitrogen input required by the millet crop. The high use of energy in the form of seed and pesticides is attributable to the annual plantings and related herbicide application.

The wheat and millet crops were introduced into the sustainable system to increase diversity and add flexibility to the system. It was presumed that the wheat could be alternatively harvested for grain, grazed or harvested for hay. The millet could be grazed or harvested, acts as a smoother crop to reduce weed encroachment prior to planting alfalfa, and allows for a decrease in the herbicide application that is necessary prior to alfalfa planting. However, it has become apparent that the wheat crop is needed for grazing, and the millet crop is destined to be baled. While the millet crop reduces the herbicide requirement for alfalfa planting, an additional herbicide application is required prior to planting millet. These reduced herbicide applications still exceed the herbicide application for conventional alfalfa when it is considered that the conventional alfalfa is planted only once every five years.

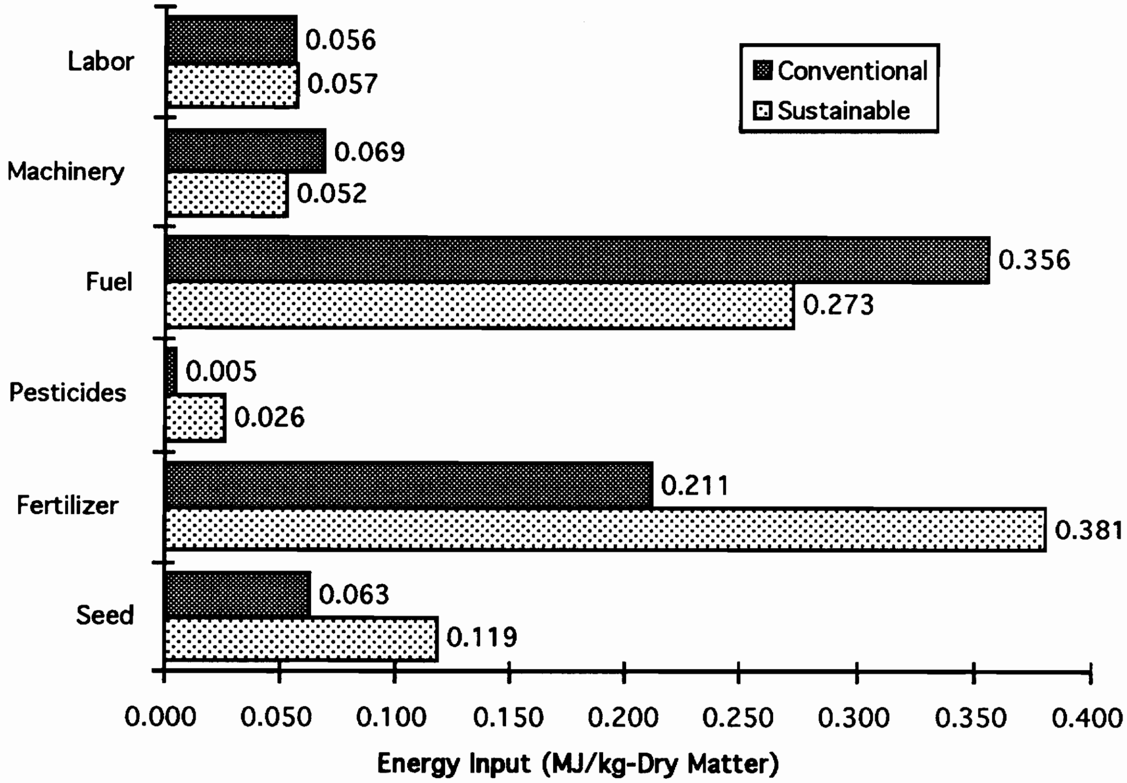

Figure 6. **Energy inputs to all baled hay production in sustainable and conventional system.**

4.4 Beef Production

Energy inputs to beef production per kilogram of beef produced are itemized in Figure 7. The most significant differences are in the energy represented by grazed forage inputs, bloat-prevention blocks and feed supplements. An energy analysis of grazed forage production and use of poultry litter as a feed supplement have each been presented and it is therefore no surprise that the sustainable system is more energy efficient in these areas. The steers in the sustainable system spend more time feeding on legumes and therefore require more bloat-prevention blocks than steers in the conventional system. The increased energy input that the bloat-prevention blocks represent is compensated for by energy savings in other areas, such as feed supplements and grazed forage production. In the case of beef production, the sustainable system outperformed the conventional system in energy utilization.

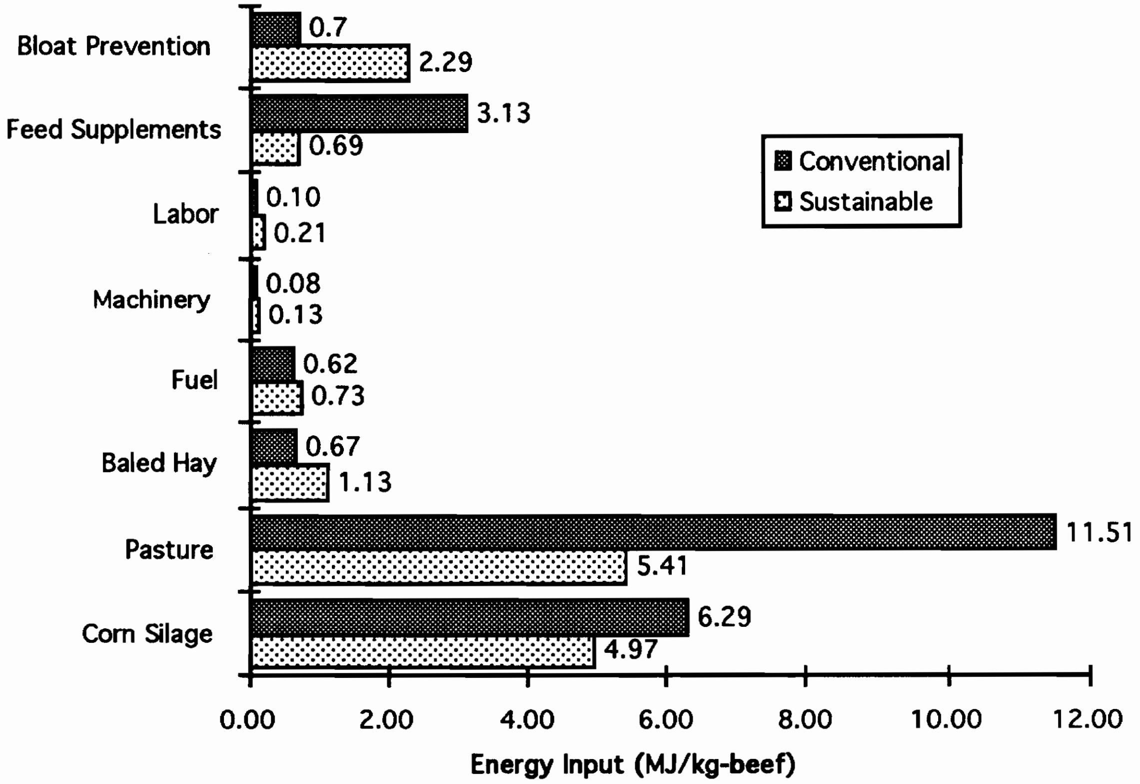

Figure 7. **Energy inputs to beef production in sustainable and conventional system.**

4.5 Whole Farm Production

The comparison of the two whole farm systems is difficult since the outputs from the two systems are not identical. With the caveat that any comparison of individual outputs from the two systems is questionable due to the interdependence of individual components within each system, the primary output of beef and the secondary output of baled alfalfa hay are comparable. However, the remaining baled hay outputs vary in consistency and are not readily comparable.

Beef production was more energy efficient in the sustainable system, as is apparent from the listing of energy productivities in Table 14. Baled alfalfa production, on the other hand, was slightly less energy efficient in the sustainable system than in the conventional system. In an attempt to further compare the energy usage of the two whole systems, the energy productivity of all baled hay is presented. The conventional system actually produced more baled hay per megajoule of energy input (1.32 kg/MJ) than the sustainable system (1.23 kg/MJ). This difference in energy productivity is due largely to the inefficiency of millet hay production that was discussed earlier.

Table 14. Energy productivity of outputs from sustainable and conventional system.

Product	Energy Productivity (kg/MJ)
Sustainable:	
Baled Millet	0.50
Baled Alfalfa	1.19
Baled Fescue/Alfalfa	3.08
All Baled Hay	1.23
Beef	0.0642
Conventional:	
Baled Alfalfa	1.29
Baled Fescue/Red Clover	1.35
All Baled Hay	1.32
Beef	0.0433

To determine if the inefficiencies of millet and alfalfa production outweigh the advantage that the sustainable system has shown in beef production, financial return was used as a common measure of productivity. The net returns of each system were calculated as part of the economic analysis. The selling price of beef steer and the various types of hay were considered in the economic analysis. Therefore this method of comparison takes into consideration the disparate values of beef and the various types of hay produced in the two systems.

The ratio of energy input to financial return was calculated for each system. The sustainable system required 12.39 megajoules of input to produce one dollar's worth of net returns. The conventional system required 17.10 megajoules of input to produce the same return. These results suggest that the sustainable system is more energy efficient than the conventional system on a whole farm scale.

4.6 Energy Analysis Implications

The strongest implication of this energy analysis is that the wheat and millet production in the sustainable system may be a detriment to the system. As seasons have passed and the advantages of the added diversity offered by wheat and millet production have not been realized, the continued use of these crops in the sustainable system has been questioned. This analysis only confirms suspicions that have already existed.

To further examine the situation, a hypothetical, alternative system was analyzed. In the alternative system, alfalfa follows the corn crop directly. Four cuttings are taken from the first-year alfalfa. The alfalfa is cropped for two more years, before the winter cover crop is planted, in preparation for the next corn crop. Figure 8 shows the hypothetical schedule of operations for the alternative system.

In modeling the alternative system, the following assumptions were made. Operations in the third-year alfalfa duplicated those in the second-year alfalfa. Alfalfa yields were based on 1990 harvest data in which four cuttings of alfalfa were taken. The cattle-related operations were not changed from those modeled in the sustainable system, except that additional bloat-prevention blocks were required because all grazed forage in the alternative system contained legumes.

Month	Past. Treat.. #3 Alfalfa/Fescue	Crop Treat. #3 Corn	Crop Treat. #4 1st Year Alfalfa	Crop Treat. #5 2nd Year Alfalfa	Crop Treat. #6 3rd Year Alfalfa
Oct	**Drill:** Alfalfa Every 7th Year	▨	**Spray Pesticide:** Gramoxone Extra	▨	▨
	▨	▨	Surfactant **Drill:** Alfalfa	**Drill:** Rye Wheat	**Drill:** Rye Wheat
Nov		**Drill:** Rye			
Dec					
Jan					
Feb					
Mar					
Apr	**Broadcast Fert:** P-K	**Spread:** Manure		**Broadcast Fert:** P-K-B	**Broadcast Fert:** P-K-B
May		**Spray Pesticide:** Round-up **Roll Down** **Plant:** Corn ***Pesticide:*** Agrox-DL			
Jun	**Mow** **Tedder** **Rake** **Bale** **Stack** **Spray Pesticide:** Ambush	**Spray Fertilizer:** N **Spray Pesticide:** Accent Surfactant	**Mow** **Tedder** **Rake** **Bale** **Stack**		
Jul			**Mow** **Tedder** **Rake** **Bale** **Stack**	**Spray Pesticide:** Cygon Surfactant	**Spray Pesticide:** Cygon Surfactant
Aug			**Mow** **Tedder** **Rake** **Bale** **Stack**		
Sep		**Chop Silage** **Bag Silage** **Rotary Mow** **Disc**	**Mow** **Tedder** **Rake** **Bale** **Stack**		
Oct		▨	▨	▨	

Figure 8. **Alternative schedule of operations.**

Grazed forage production, baled hay production and beef production were analyzed. Corn silage production was not analyzed, since the operations in that system would not be changed. Nitrogen inputs to corn production may be reduced due to the extra year of alfalfa in the crop rotation; however, the size of this reduction is difficult to quantify. This analysis considered only quantifiable changes in energy inputs that were directly related to the altered field operations.

Figure 9 compares the energy inputs to pasture production in the alternative system to those in the sustainable and conventional system. Decreased fertilizer and seed inputs reflect the removal of the wheat and millet crops from the system.

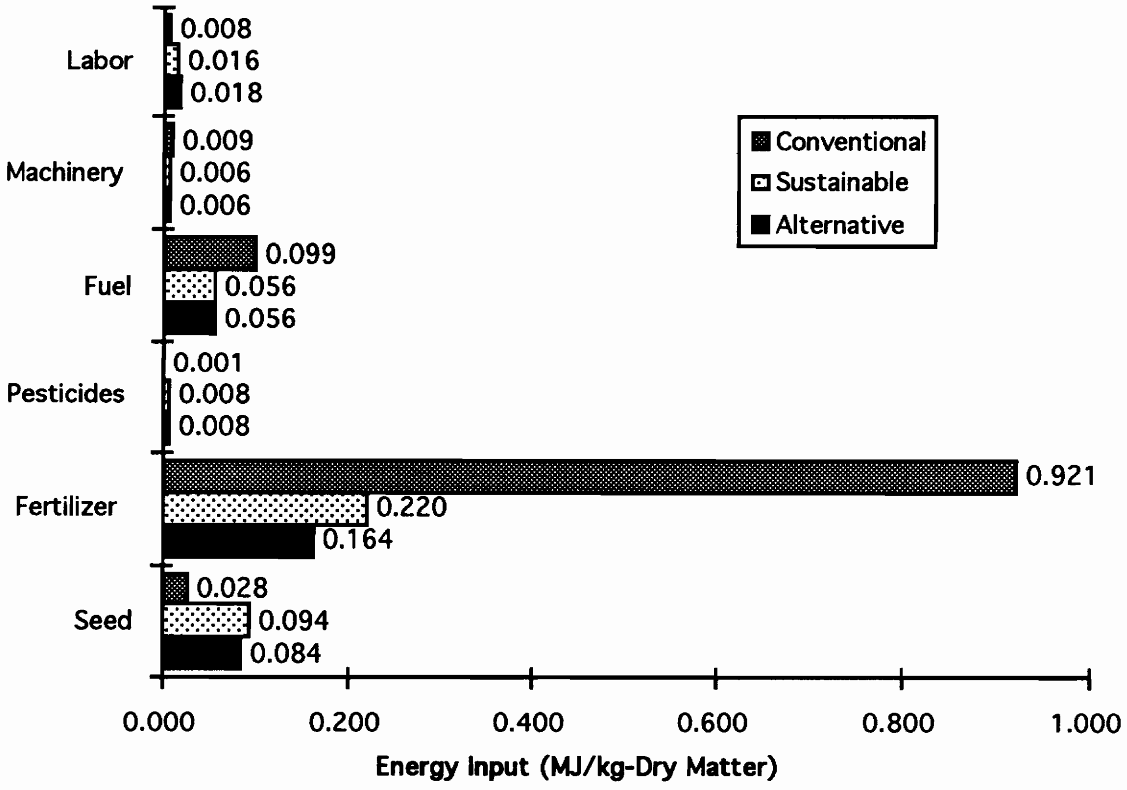

Figure 9. **Energy inputs to all grazed forage production in sustainable, conventional and alternative system.**

The most notable improvements are visible in Figure 10, which illustrates the inputs to baled hay production. Energy inputs in each category are reduced. The most dramatic reduction is in the fertilizer input. The removal of millet from the system eliminates the need for nitrogen entirely. Seed and pesticide inputs are also reduced considerably, due to the reduction in planting operations. Fuel and machinery inputs are reduced in both the baled hay and pasture production systems, due to the reduced number of field operations. It is clear that both baled hay and grazed forage production in the alternative system are more energy efficient than those in either the sustainable or the conventional system.

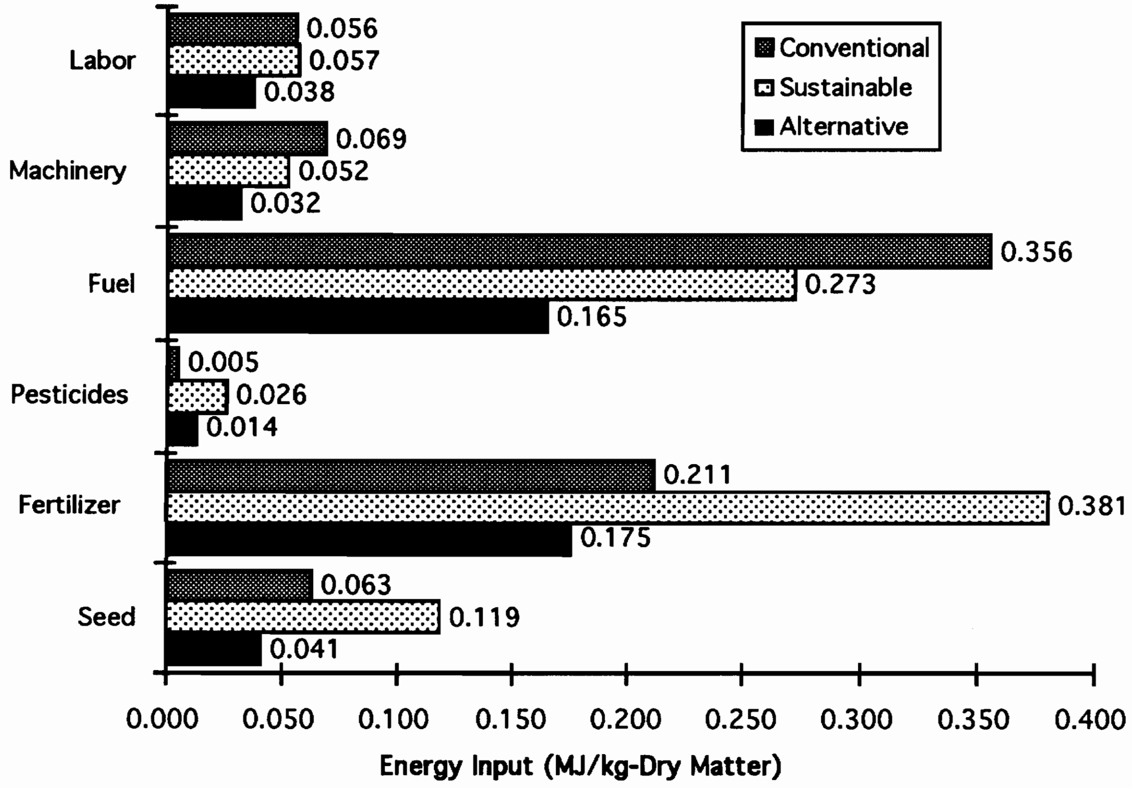

Figure 10. Energy inputs to all baled hay production in sustainable, conventional and alternative system.

The analyzed alternative system is most effective in reducing energy inputs to baled hay production. However, the slight improvement in grazed forage production is visible in the analysis of beef production (Figure 11). Since all grazed forage crops in the alternative system contain legumes, steers in this system would require more bloat-prevention blocks. The only baled hay fed to the cattle, fescue/alfalfa, was not effected by the change in operations. Therefore, the energy sequestered by the beef in baled hay was unaffected.

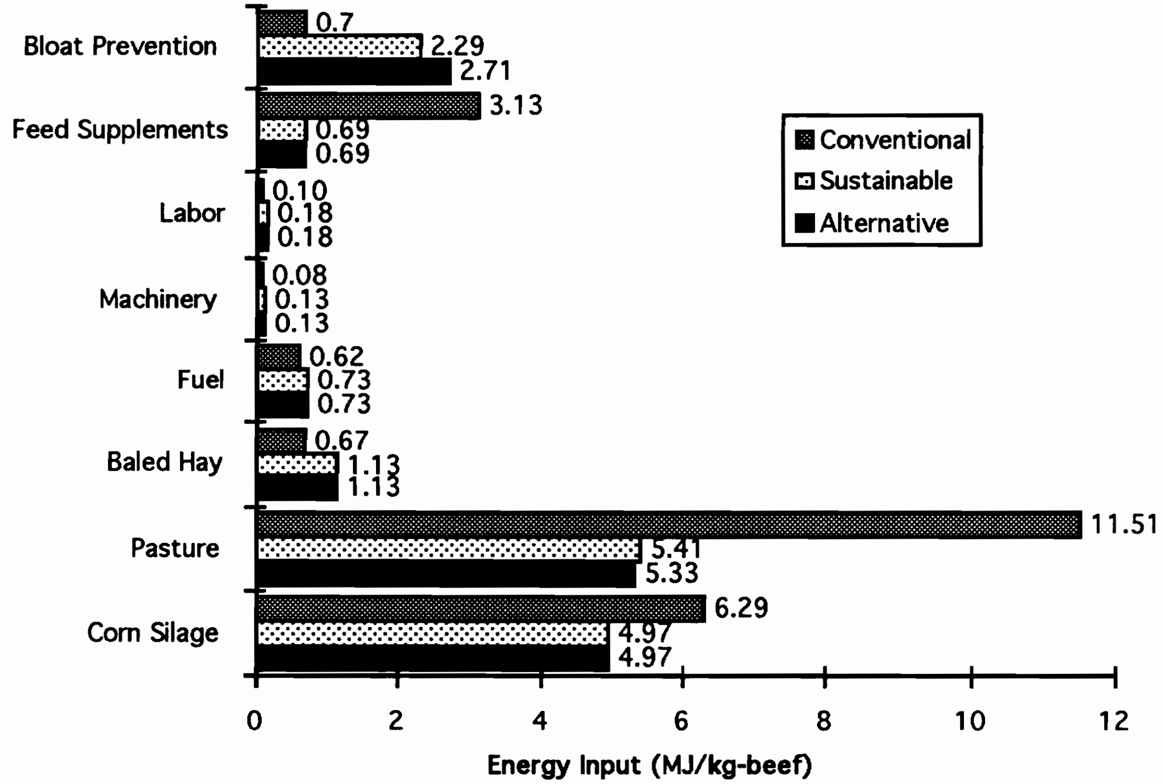

Figure 11. Energy inputs to beef production in sustainable, conventional and alternative system.

Although the alternative production system presented here has been analyzed on the basis of assumed yields, it is apparent that the overall effect of the proposed changes would be positive. The resulting reduction in synthetic fertilizer and pesticide inputs is in accordance with the desired goal of sustainability.

Sustainability is difficult to measure, and often can only be measured in retrospect. The whole farm experiment was designed with this understanding. While there may be preferable alternatives to those presented here, implementation of changes, such as those suggested, are essential to the further understanding of sustainability in agriculture.

4.7 Economic Analysis

The economic analysis compared all three systems. Costs for each system were calculated based on models that were developed. The returns on beef in the alternative system are assumed to be equal to the returns on beef in the sustainable system. The returns on baled hay in the alternative system are modeled on four cuttings of alfalfa and one cutting of fescue/alfalfa. A

Table 15. Costs and returns of beef production in the sustainable, conventional and alternative systems.

Production Costs and Returns ($/head)	Alternative	Sustainable	Conventional
Seed Costs	41.67	37.18	20.45
Fertilizer Costs	32.90	30.94	46.57
Pesticide Costs	14.34	14.05	16.95
Fuel Costs	5.39	5.02	5.12
Machinery: Fixed Costs & Operating Costs	39.94	39.31	34.82
Labor Costs	23.54	22.48	12.26
Cost of Weanlings	378.98	378.98	380.77
Feed Supplement Costs	13.57	13.57	37.25
Bloat Prevention Blocks	64.69	54.60	15.63
Hay Costs	13.18	13.18	3.07
Total Costs	628.21	609.91	572.89
Return	992.86	992.86	956.58
Net Return	364.65	382.95	383.69

detailed analysis of beef and hay production is presented in Tables 15 and 16, respectively. The results of these analyses are then combined to determine the economic performance of each whole farm system.

The costs and returns per head of beef production are outlined in Table 15. The net return per head in the sustainable and conventional systems were comparable. The net return of the alternative system is less than that of either the sustainable or conventional system, due mainly to the increased cost associated with bloat-prevention blocks.

Table 16. **Costs and returns of baled hay production in the sustainable, conventional and alternative systems.**

Production Costs and Returns ($/ha-farm)	Alternative	Sustainable	Conventional
Seed Costs	7.24	14.27	5.75
Fertilizer Costs	14.94	14.57	13.03
Pesticide Costs	3.15	4.41	1.62
Fuel Costs	2.53	3.44	4.02
Machinery: Fixed Costs & Operating Costs	26.20	33.05	38.55
Labor Costs	13.32	15.85	13.54
Total Costs	67.38	85.59	76.51
Return	278.59	263.90	302.87
Net Return	211.21	178.31	226.36

Baled hay costs and returns are detailed in Table 16 in terms of cost per hectare of the whole farm. Various types of hay are not separated in this analysis; however, returns were calculated based on hay type. The conventional system performed slightly better than the sustainable system. However, the alternative model showed that the removal of millet hay from the sustainable system can make baled hay production in the sustainable system nearly as profitable as that in the conventional system, by reducing inputs and adding an extra cutting of alfalfa.

Table 17. **Economic analysis of the whole farm for each system.**

Product	Net Return ($/ha-farm)
Conventional:	
Baled Alfalfa	140.06
Baled Fescue/Red Clover	96.42
Beef	568.86
Whole Farm	805.34
Sustainable:	
Baled Millet	30.59
Baled Alfalfa	144.09
Baled Fescue/Alfalfa	19.30
Beef	568.64
Whole Farm	762.62
Alternative:	
Baled Alfalfa	207.74
Baled Fescue/Alfalfa	19.30
Beef	540.62
Whole Farm	767.66

An economic analysis of the entire farm (Table 17) indicated that the net return per hectare of farm reflected the net return on baled hay. The net return on baled alfalfa in the sustainable and conventional systems were almost equal. The increased net return on alfalfa in the alternative system reflects the fact that an extra cutting was assumed. However, this increase in net returns does not make up the difference between the conventional and sustainable systems. Although the conventional system shows a greater net return this year, the sustainable system could be economically competitive with the conventional system particularly if greater use of grazed forage could be accomplished thus allowing more baled hay to be sold.

5.0 Conclusions

- The Sustainable System uses less energy than the Conventional System per kilogram of beef produced but slightly more energy per kilogram of alfalfa produced.

- The Sustainable System uses slightly more energy than the Conventional System per kilogram of all baled hay produced, due predominantly to the energy intensity of millet hay production.

- The Sustainable System uses less energy than the Conventional System per dollar of return on the whole farm production.

- The Alternative System presented should perform better than both the current Sustainable System and the Conventional System from an energetics viewpoint in all areas of production.

- Although economic returns on beef and alfalfa production were comparable in the two systems studied, the conventional system showed greater returns on the whole farm, due to a greater export of baled hay.

6.0 Summary

The sustainable system studied has proven to be more energy efficient than the conventional system. This is due largely to the effective recycling of nutrients in the sustainable system. The two crops within the sustainable system with the worst performance, from an energetics point of view, did so because of their need for synthetic fertilizer. While the intensive management of the sustainable system required greater inputs of labor, fuel and machinery, these extra inputs were dwarfed by the energy savings that were attained through nutrient recycling.

The economic comparison showed that the returns on beef and alfalfa production were comparable in the two systems examined. However, the conventional system produced a greater overall return. The greater return in the conventional system is accountable to a greater total amount of baled hay that is exported.

The alternative system, that was proposed as a result of this study, makes greater use of alfalfa, a leguminous, perennial crop. As a result, the number of operations are reduced, pesticide inputs are reduced, and greater nutrient recycling leads to reduced fertilizer inputs. While many factors must be considered in determining the sustainability of any endeavor, the focus of this study was energetics and the alternative system that was suggested shows promise from this point of view.

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Appendix A. Schedules of Operation

Month	Past. Treat.. #1 Fescue	Past. Treat. #2 Fescue/Red Clover	Crop Treat. #1 Corn	Crop Treat. #2 Alfalfa
Oct	▨	▨	**Drill:** Rye **Spray Fertilizer:** N	**Spray Pesticide:** Gramoxone Extra Surfactant **Drill:** Alfalfa Every 5th Year ▨
Nov				
Dec				
Jan				
Feb		**Drill:** Red Clover		
Mar				
Apr	**Broadcast Fert:** N-P-K	**Broadcast Fert:** P-K	**Spread:** Manure **Spray Pesticide:** Lasso Aatrex Princep Gramoxone Extra Bladex Asana Comp. Agent Surfactant	**Broadcast Fert:** P-K-B
May		**Mow** **Tedder** **Rake** **Bale** **Stack**	**Spray Pesticide:** Banvel **Plant::** Corn ***Pesticide:*** Agrox-DL Force	**Spray Pesticide:** Ambush
Jun	**Rotary Mow** **(Weed Control)**		**Spray Fertilizer:** N	**Mow** **Tedder** **Rake** **Bale** **Stack**
Jul		**Rotary Mow** **(Weed Control)**		**Mow** **Tedder** **Rake** **Bale** **Stack**
Aug	**Rotary Mow** **Spray Fertilizer:** N **(Begin Stockpiling)**			**Mow** **Tedder** **Rake** **Bale** **Stack**
Sep			**Chop Silage** **Bag Silage** **Rotary Mow** **Disc**	
Oct			▨	

Figure 12. Conventional schedule of operations

Month	Past. Treat.. #3 Alfalfa/Fescue	Crop Treat. #3 Corn	Crop Treat. #4 Wheat & Millet	Crop Treat. #5 1st Year Alfalfa	Crop Treat. #6 2nd Year Alfalfa
Aug	**Drill:** Alfalfa Every 7th Year	▨	▨	**Spray Pesticide:** Gramoxone Extra Surfactant **Drill:** Alfalfa	▨
Sep	▨	▨	▨		▨
Oct			**Drill:** Wheat **Spray Fertilizer:** N		**Drill:** Rye Wheat
Nov		**Drill:** Rye Hairy Vetch			
Dec					
Jan					
Feb					
Mar			**Spray Fertilizer:** N		
Apr	**Broadcast Fert:** P-K	**Spread:** Manure			**Broadcast Fert:** P-K-B
May		**Spray Pesticide:** Round-up **Roll Down** **Plant::** Corn ***Pesticide:*** Agrox-DL			
Jun	**Mow** **Tedder** **Rake** **Bale** **Stack** **Spray Pesticide:** Ambush	**Spray Fertilizer:** N **Spray Pesticide:** Accent Surfactant	**Drill:** Millet **Spray Fertilizer:** N **Spray Pesticide:** Gramoxone Extra Surfactant		
Jul				**Mow** **Tedder** **Rake** **Bale** **Stack**	**Rotary Mow** **Drill:** Millet **Spray Pesticide:** Cygon Surfactant
Aug			**Mow** **Tedder** **Rake** **Bale** **Stack**	**Mow** **Tedder** **Rake** **Bale** **Stack**	
Sep		**Chop Silage** **Bag Silage** **Rotary Mow** **Disc**	▨	**Mow** **Tedder** **Rake** **Bale** **Stack**	

Figure 13. Sustainable schedule of operations

Appendix B. Process Analysis of Seed Production

Table 18. Process energy analysis of millet seed production.

Input	Quantity (-/ha)	Energy Value (MJ/-)	Energy Cost (MJ/ha)
Labor	4.9 h	57.1 /h	280
Machinery	N/A	N/A	794
Diesel	60.5 L	46.4 /L	2807
Seed	3.0 kg	30.53 /kg	92
Carbaryl	1.68 kg	188 /kg	316
Atrazine	2.69 kg	228 /kg	613
Nitrogen (N)	125 kg	75.9 /kg	9488
Phosphorus (P_2O_5)	75 kg	16.4 /kg	1230
Potassium (K_2O)	38 kg	11.2 /kg	426
Crop Production Total			**16,046**
Crop Yield	**800 kg**		
Seed Production Cost		**20.1**	

Table 19. Process energy analysis of red clover seed production.

Input	Quantity (-/ha)	Energy Value (MJ/-)	Energy Cost (MJ/ha)
Labor	4.58 h	57.1 /h	262
Machinery	N/A	N/A	809
Diesel	58.9 L	46.4 /L	2733
Seed	13 kg	86.1 /kg	1119
Malathion	1.4 kg	435 /kg	609
Permethrin	0.22 kg	1067/kg	239
EPTC	4.5 kg	311 /kg	1400
Crop Production Total			**7,171**
Seed Yield	**92 kg**		
Seed Production Cost		**77.9**	

Table 20. Process energy analysis of winter wheat seed production.

Input	Quantity (-/ha)	Energy Value (MJ/-)	Energy Cost (MJ/ha)
Labor	5.93 h	57.1 /h	339
Machinery	25.94 kg	75.35 /kg	1955
Gasoline	52.42 L	42.8 /L	2244
Diesel	20.88 L	46.4 /L	969
Seed	168.21 kg	10.63 /kg	1788
Electricity	12.60 kWh	13.93 /kWh	176
Nitrogen	56.07 kg	75.9 /kg	4256
Phosphorus	61.68 kg	12.56/kg	775
Potassium	61.68 kg	6.70 /kg	413
Lime	112.14 kg	1.32 /kg	148
Crop Production Total			**13,063**
Seed Yield	**2,896 kg**		
Seed Production Cost		**4.51**	

Appendix C. Energy Analysis of Manure Utilization

Table 21. Energy value of steer manure.

Item	Value
% Dry Matter	15.0
% N	0.59
% P_2O_5	0.37
% K_2O	0.43
Energy Value as Fertilizer (MJ/kg-fresh)	0.56
Energy Value as a Source of Methane (MJ/kg-fresh)	0.49

Table 22. Energy value of poultry litter.

Item	Value
% Dry Matter	75.0
% N	2.80
% P_2O_5	2.25
% K_2O	1.70
Energy Value as Fertilizer (MJ/kg-fresh)	2.68
Energy Value as Feed (MJ/kg-fresh)	3.90
Energy Value as a Source of Methane (MJ/kg-fresh)	0.85

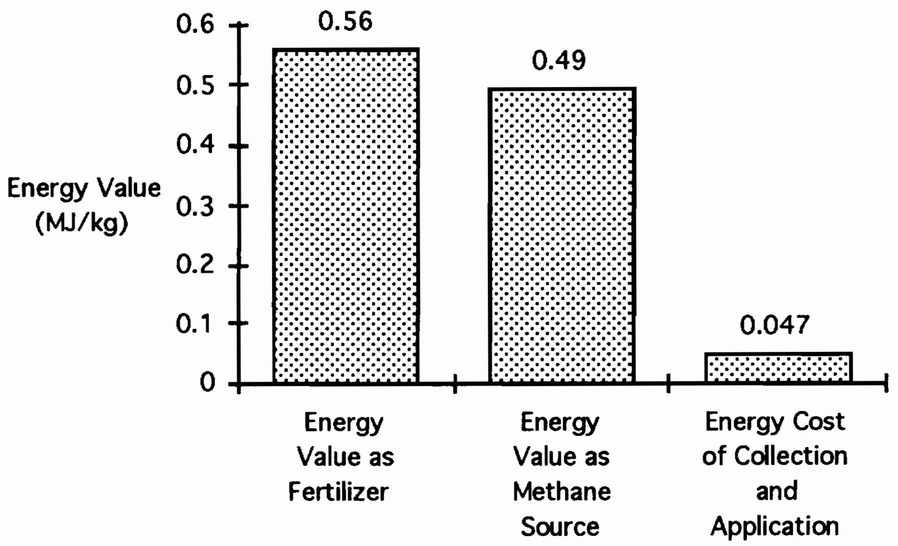

Figure 14. Comparison of energy value and energy cost of steer manure.

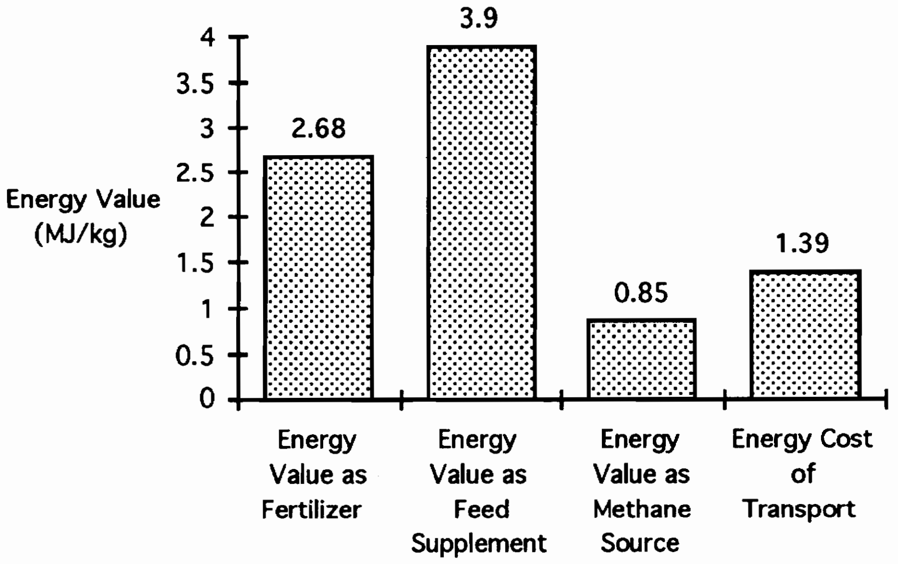

Figure 15. Comparison of energy value and energy cost of poultry litter

Appendix D. Machinery Complement

Table 23. Energy in machinery compliment.

Machine	Weight (kg)	Energy in Material (MJ)	Energy in Manufacturing (MJ)	Energy in Repair (MJ)	Total Energy (MJ)	Machine Life (h)	Energy Cost (MJ/h)
Tractor	4581	226,438	54,982	45,919	281,612	10000	28.16
Grain Drill	1043	66,034	7,513	10,531	71,962	1200	59.97
Roller Packer	1123	71,062	9,166	14,694	81,689	2000	40.84
Manure Spreader	1361	85,979	9,859	17,553	97,604	2000	48.80
Broadcaster	880	55,229	6,495	11,305	62,865	1200	52.39
Sprayer	318	19,958	2,347	2,748	21,380	1500	14.25
Planter (no-till)	1334	84,297	11,288	13,687	93,502	1200	77.92
Forage Harvester	1860	116,738	24,185	18,302	135,860	2000	67.93
Forage Wagon	924	59,154	6,452	12,016	66,807	3000	22.27
Rotary Mower	1019	63,939	7,519	7,853	67,544	2000	33.77
Disk Harrow	1470	92,257	12,676	21,315	108,942	2000	54.47
Mower Conditioner	1374	86,808	9,957	46,401	127,226	2000	63.61
Tedder	1165	73,691	7,150	14,806	82,349	2000	41.17
Rake	1165	73,691	7,150	14,806	82,349	2000	41.17
Baler	1486	93,849	9,164	13,378	99,448	2000	49.72
Silage Bagger	2028	127,252	14,965	26,047	144,846	2000	72.42
Silage Feeder	1587	100,746	11,343	20,529	114,150	10000	11.41
Front Loader	566	35,542	4,180	7,275	40,456	2000	20.23
Wagon	583	37,740	3,343	7,524	41,839	3000	13.95

Appendix E. Seeding Rates

Table 24. Seeding rates (kg/ha).

Crop	Rye	Corn	Wheat	Millet	Alfalfa	Red Clover
Sustainable:						
Corn	112.1	20.7				
Wheat			112.1			
Millet				33.6		
1st Year Alfalfa					22.4	
2ndYear Alfalfa	89.7		22.4			
Fescue/Alfalfa					2.40[1]	
Conventional:						
Corn	112.1	20.7				
Alfalfa					4.48[2]	
Fescue						
Fescue/Red Clover						8.97
Alternative:						
Corn	112.1	20.7				
1st Year Alfalfa					22.4	
2nd Year Alfalfa	89.7		22.4			
3rd Year Alfalfa	89.7		22.4			
Fescue/Alfalfa					2.40[1]	

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[1] This value represents a seeding rate of 16.8 kg/ha applied every seventh year.

[2] This value represents a seeding rate of 22.4 kg/ha applied every fifth year.

Appendix F. Fertilizer Application Rates

Table 25. Fertilizer application rates.[1]

	Nitrogen	Nitrogen	P_2O_5	K_2O	Boron
Crop	UAN 30%	Prilled AN	TSP	KCL	Borax
Sustainable:					
Corn	134.5				
Wheat	39.2				
Millet	61.7				
1st Year Alfalfa			97.5	141.2	2.2
2ndYear Alfalfa			97.5	141.2	2.2
Fescue/Alfalfa			52.7	72.9	
Conventional:					
Corn	168.2				
Alfalfa			67.3	168.2	2.2
Fescue	89.7	59.4	61.7	16.8	
Fescue/Red Clover			61.7	61.7	
Alternative:					
Corn	134.5				
1st Year Alfalfa			97.5	141.2	2.2
2nd Year Alfalfa			97.5	141.2	2.2
3rd Year Alfalfa			97.5	141.2	2.2
Fescue/Alfalfa			52.7	72.9	

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[1] All data is reported in kilograms of nutrient per hectare.

Appendix G. Machinery, Fuel and Labor

Table 26. Machinery, fuel and labor requirements.

Crop	Machinery (MJ/-)	Diesel Fuel (L/-)	Labor (h/-)
Sustainable:			
Corn	607 /ha	93.4 /ha	8.93 /ha
Wheat	70.5 /ha	14.8 /ha	1.00 /ha
Millet	252 /ha	32.8 /ha	3.67 /ha
1st Year Alfalfa	562 /ha	62.3 /ha	11.1 /ha
2ndYear Alfalfa	159 /ha	31.1 /ha	5.43 /ha
Fescue/Alfalfa	91.6 /ha	12.3 /ha	4.66 /ha
Cattle Production	53.2 /head	6.33 /head	1.30 /head
Conventional:			
Corn	597 /ha	96.7 /ha	8.90 /ha
Alfalfa	582 /ha	62.3 /ha	8.57 /ha
Fescue	84.2 /ha	22.1 /ha	1.38 /ha
Fescue/Red Clover	222 /ha	41.0 /ha	4.34 /ha
Cattle Production	40.2 /head	5.5 /head	0.93 /head
Alternative:			
Corn	607 /ha	93.4 /ha	8.93 /ha
1st Year Alfalfa	562 /ha	62.3 /ha	11.1 /ha
2nd Year Alfalfa	159 /ha	31.1 /ha	5.43 /ha
3rd Year Alfalfa	159 /ha	31.1 /ha	5.43 /ha
Fescue/Alfalfa	91.6 /ha	12.3 /ha	4.66 /ha
Cattle Production	53.2 /head	6.33 /head	1.30 /head

Appendix H. Pesticide Applications

Table 27. Pesticide application rates.[1]

Crop	Atrazine	Alachlor	Cyanazine	Dicamba	Glyphosate
	Aatrex	Lasso MT	Bladex	Banvel	Round-up
Sustainable:					
Corn					2.80
Wheat					
Millet					
1st Year Alfalfa					
2ndYear Alfalfa					
Fescue/Alfalfa					
Conventional:					
Corn	1.57[2]	3.25[2]	0.224[2]	0.280	
Alfalfa					
Fescue					
Fescue/Red Clover					
Alternative:					
Corn					2.80
1st Year Alfalfa					
2nd Year Alfalfa					
3rd Year Alfalfa					
Fescue/Alfalfa					

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[1] All data reported in kilograms of Active Ingredient per hectare.

[2] Value is adjusted to reflect the average application rate during the five year rotation.

Table 27. (Cont.) Pesticide application rates.[1]

Crop	Nicosulfuron	Paraquat	Simazine	Diazinon	Lindane
	Accent	Gramoxone	Princep	Agrox-DL	
Sustainable:					
Corn	0.009[2]			0.007	0.012
Wheat		0.525			
Millet		0.525			
1st Year Alfalfa					
2ndYear Alfalfa					
Fescue/Alfalfa					
Conventional:					
Corn		0.665[3]	0.900[3]	0.007	0.012
Alfalfa		0.105[3]			
Fescue					
Fescue/Red Clover					
Alternative:					
Corn	0.009[2]			0.007	0.012
1st Year Alfalfa					
2nd Year Alfalfa					
3rd Year Alfalfa					
Fescue/Alfalfa					

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[1] All data reported in kilograms of Active Ingredient per hectare.

[2] This value represents an application rate of 0.018 kg/ha applied to half of the corn crop.

[3] Value is adjusted to reflect the average application rate during the five year rotation.

Table 27. (Cont.) Pesticide application rates. [1]

Crop	Dimethoate Cygon	Esfenvalerate Asana	Permethrin Ambush	Tefluthrin Force
Sustainable:				
Corn				
Wheat				
Millet				
1st Year Alfalfa				
2ndYear Alfalfa	0.723			
Fescue/Alfalfa			0.112	
Conventional:				
Corn		0.050		1.68
Alfalfa			0.112	
Fescue				
Fescue/Red Clover				
Alternative:				
Corn				
1st Year Alfalfa				
2nd Year Alfalfa	0.723			
3rd Year Alfalfa	0.723			
Fescue/Alfalfa			0.112	

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[1] All data reported in kilograms of Active Ingredient per hectare.

Vita

Jim was born on September 1, 1963 in West Covina, California, a small city about forty miles east of Los Angeles on I-10. (It's important to reference a freeway when speaking about location in Los Angeles, and difficult not to.) He is the son of John and Marcella Kern and the youngest of their eight children. Being the youngest of eight, he was convinced that it took his parents eight tries to finally get it right. Being the youngest of eight, it was important for him to develop a sense of humor to deal with the realities of life.

He enjoyed school and did well in his classes, graduating high school with highest honors. Uncertain of what he wanted to do with his life, but sure that college was the next logical step, he enrolled at the University of California, Irvine. Two years and $5,000.00 in student loans later, he transferred to the California State Polytechnic University, Pomona to study Mechanical Engineering. When Mechanical Engineering failed to spark much interest, he decided to leave school and explore the world.

He got as far as San Diego, where he found an unchallenging job that didn't pay much, but allowed him to sit on the beach and ponder his future. He finally decided that his life needed more challenge and purpose. So, he returned to school at the California State Polytechnic University, Pomona, this time, to explore Agricultural Engineering, which he found to be very interesting in its diversity and complexity. He graduated from Cal Poly with a Bachelor of Science degree in Agricultural Engineering.

Having reestablished himself as a scholar, he moved on to graduate school at Virginia Polytechnic Institute and State University, where he has completed a Master of Science degree in Agricultural Engineering and will pursue his Doctor of Philosophy degree in Biological Systems Engineering. People often ask him how he got to Virginia after living in California for so long. He took I-10 east, to I-20 east, left at Fort Worth, I-30 to Little Rock, I-40 past Knoxville, and up I-81 to the New River Valley, Blacksburg, and Virginia Tech. (You can take the boy out of L.A., but it's hard to take the L.A. out of the boy.)

(He never could get used to speaking about himself in the third person.)

James D.