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Life Cycle Assessment and Cropping Energy Audits for IREE Project RL-0016-13

2013 to 2017

Contents

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Note: This Document is part of a larger body of work examining agricultural energy in West Central Minnesota. Other information can be found at http://wcroc.cfans.umn.edu. Though this document is submitted as part of a final report for funding from IREE, the work is ongoing and due to the nature of energy auditing and life cycle assessment, significant updates are likely in the future.

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I. Introduction:

Energy is an important input in the modern agricultural throughout the world. In the United States, agriculture uses roughly 1.7 quadrillion BTUs of energy each year. This includes fuels for tractors, vehicles for transportation, electricity for handling grains, and energy used to make agricultural chemicals and fertilizers. This dependence on energy has significant economic and environmental impacts on farms and farm communities.

Economically, the cost of energy is the single largest input needed for modern agricultural systems. Often, energy is used in producing the feeds, seeds, and chemicals needed on the farm. Because much of this energy is fossil based, there can be significant economic impacts when crude oil prices change. In the mid-2000s, high energy prices increased the cost of chemical fertilizers and forced farmers to make critical decisions on how much fertilizer they could afford to apply to their crops. The rapid changes of fossil energy prices demonstrated the economic vulnerability of farmers to energy market changes. With the variability of both energy costs and crop prices, farmers struggle to maintain consistent profitability.

Another important consideration for agriculture's dependence on energy is the environmental impacts of using fossil fuels. Though not a universally accepted belief in the agricultural sector, global climate change due to fossil fuel use is an important consideration to food manufacturing companies and, ultimately, consumers purchasing making decisions on buying agricultural products.

In order to reduce the dependence of agriculture on fossil fuels, it is first important to understand where these energy resources are being used and precisely how much energy is being used by agriculture. Though there are some estimates of energy use on farms, much of the data comes from surveys conducted every few years by the United States Department of Agriculture (USDA). USDA data provides a good starting point for examining any energy issues. However, survey data will only provide a rough estimate of what happens on the farm. Many of the farmers completing these survey will be growing multiple crops and using multiple chemical and fertilizer inputs, which may not get accurately categorized for the specific crops they are reporting on surveys. In addition, the surveys depend on farmers having accurate records and remembering to include all fuel/energy used on the survey. A more accurate understanding how energy is used at the individual farm level can help in developing changes to farming practices, equipment, and energy sources, which will reduce farming's dependence on fossil fuels.

The work done as part of this report analyzed farm energy use and assessed how technology improvements, energy conservation, and the addition of renewable energy sources could reduce fossil energy use and improve the environmental impacts of farming activities. The work was done at the West Central Research and Outreach Center (WCROC), an agricultural research facility located in Morris Minnesota. The WCROC is a research farm that conducts cropping, dairy, swine, horticultural, and renewable energy research on an 1100 acre campus on the northern edge of the corn belt. In addition to conventional agricultural systems, the farm has organic cropping and organic dairy systems, as well as alternative swine housing systems. With a number of research scientist and agricultural research technicians, the facility provides an ideal location to analyze the intersection of energy and agriculture issues.

This report and the work behind it is part of a larger examination of energy uses on many of the systems at WCROC. Specifically, this report focuses on energy use in the cropping system and the environmental impacts of energy use in the cropping system and dairy systems. The specific research questions, methods, and finding are discussed in the individual sections.

WCROC's research into agricultural energy issues is an ongoing effort. This report documents our efforts to date. However, many of the systems described are continuing to be updated as research efforts continue.

II. Cropping System Energy Auditing

Energy use for production of commodity crops is a cornerstone for energy in all of US agriculture. As the primary source for animal feeds and cash income, commodity crops are the basis for most other agricultural systems. In the Midwest, corn and soybeans are by far the largest crops being produced. These are used directly as food, processed into animal feed, and used for biofuels. Therefore, it is important have accurate data on energy use in cropping systems. This allows for a better calculation of energy use in many different agricultural systems.

There are two different areas where energy is used in crop production, direct energy use and indirect energy use. Direct energy uses include on-farm use of liquid fuels, electricity, and propane or natural gas. These are directly used by the farmer to power equipment, move products, or further process them. An equally important area is indirect energy use, when farmers use materials that have been made using energy or fossil fuels. For example, most nitrogen fertilizers are made using natural gas. Similarly, many pesticides are produced using crude oil. Though the typical farmer does not recognize these as energy containing products, they form a significant portion of the energy used in the production of crops.

For this research project, we examined energy use in the cropping systems at the West Central Research and Outreach Center. Our goals were to document the energy used in production of crops, focusing especially on common crops for Minnesota. On its own, this data will help inform regional farmers about the amounts and types of energy that they are using on the farm. However, the broader goal with this information is to examine how changes can be made to production systems to reduce their dependence on fossil energy. The next sections (III. Cropping LCA and IV. Dairy System LCA) use the data to calculate lifecycle energy and environmental impacts of crop system energy use.

A. WCROC Cropping Systems

The work described here was conducted using the agricultural systems of the West Central research and outreach center (WCROC). Cropping system at WCROC support two different needs. The first is an on-going need for animal feed for dairy and swine operations at the research center. The second goal is to research the agronomics and soil science of a wide variety of common and potential crops for the region.

WCROC has a specific need for organic forages and grains to supply the organic dairy herd, which is being studied alongside a conventional dairy herd. An organic rotational cropping system is used for producing the organic dairy rations that are cost prohibitive to purchase on the open market. A smaller amount of land is used for a conventional corn-soybean rotation. These crops are used for non-organic animal feed or sold on a cash basis. Non-organic land is also used as needed to research on non-organic research crops.

WCROC Cropping Systems Overview

The cropping systems at the WCROC are designed to supply the research facilities' dairy and swine operations with feed. An additional constraint on the operation is the need to produce as much of the more expensive organic feed needed for the organic dairy research as possible. Conventionally produced feeds for the traditional dairy and swine systems can be purchased as needed on the open market. The added complexity in the organic system reflect both the need for more organic forage and changes to the system to help contain weeds.

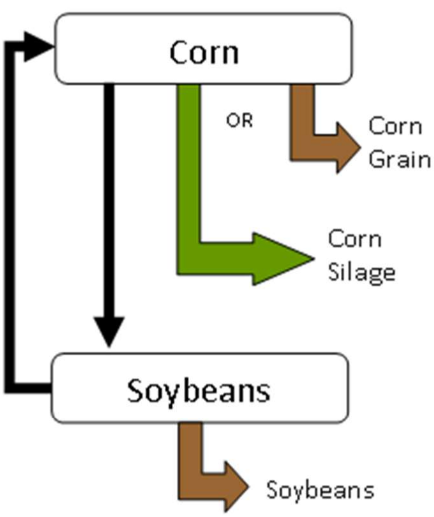
Conventional Systems

Products:

Corn grain

Soybean grain

Corn Silage



Organic Systems

Products:

Corn grain

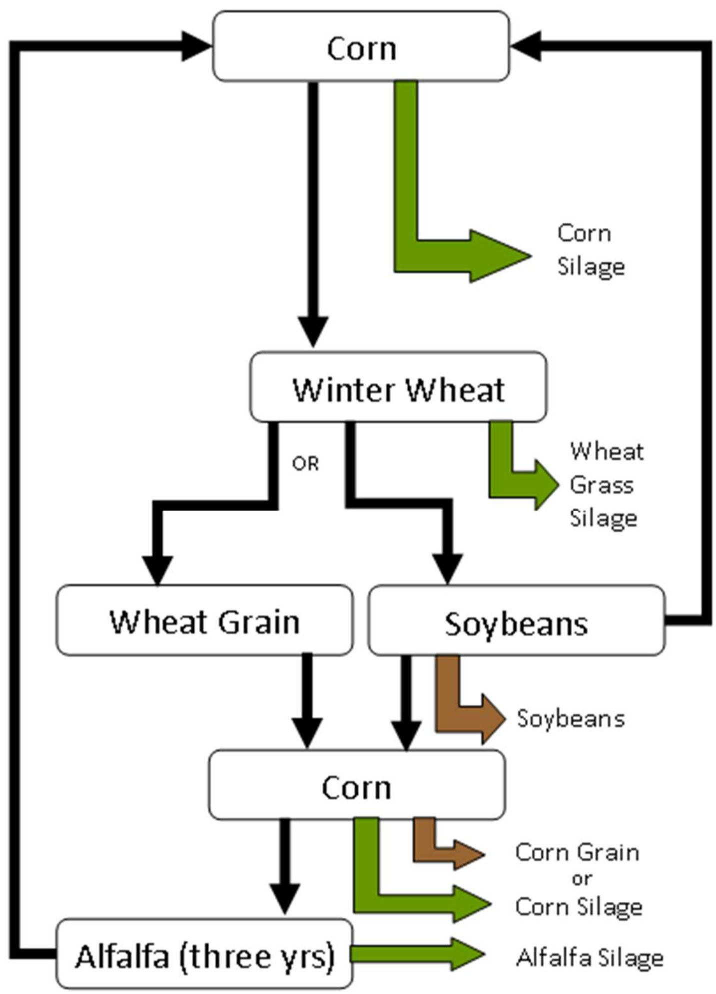
Soybean grain

Corn Silage

Wheat Grain

Wheat Forage

Alfalfa Forage



B. Cropping Energy Use Research Methodology

The primary method for analyzing cropping energy use was the direct measurement of fuel or energy consumption in producing crops at WCROC. This involved documenting fuel added to tractors, chemical and fertilizer applied to fields, and natural gas use in grain drying. In cases where data was not easily available, literature or database values were used.

Data was collected for each activity conducted on the farm; for example, tillage with a 15' chisel plow. Then all activities needed for a given crop were added together to calculated the fuel use for tractors and field work. In the LCA section, external data on indirect energy for other inputs is added to arrive at the total energy for production of a given crop.

In order to make comparisons between organic and conventional cropping systems, conventional crops not grown at WCROC were modeled using on farm cultivation method data from and chemical input data from the University of Minnesota and other regional extension services. The model crops are noted in the section discussing individual crops below.

1. Study Data and Collection Methods

a. Location and Timing

This study was conducted at the WCROC (45°35'6"N 95°54'36"W), located outside of Morris, MN. Soils in the region are productive loamy soils consistent with the norther edge of the corn belt.

Fuel use for tillage and field operations was collected from 4 seasons worth of cropping (2013 to 2016). 2016 data has not yet been analyzed or added to the information below.

b. Data Quality and Replication

In examining energy use in WCROC cropping, it was decided that commonly grown crops on fields that were larger than 10 acres (4.05 ha) would be analyzed. The commonly grown crops such as corn and soybeans, were analyzed with several replicates over multiple years.

Replicate data from measuring the fuel use of performing the same agronomic activities over the three-year period were averaged for a final energy use value. The number of observations for most of agronomic methods described here was three or greater. However, for some of the methods there is only one observation or an estimate based on the equipment operator's observation of similar tasks.

The standard deviation was also provided to provide some indication of the variability of the readings. In addition, the sample size was provided. In a few cases, outliers that were ± 3X the standard deviation were removed. In addition, a few outliers were removed when the crop scientist supervising the work advised that the conditions were atypical and that the data was not representative of the work typically performed.

c. Tractor Liquid Fuel Use

West Central research and outreach center primarily used four tractors for field operations, a John Deere 6400 (85 PTO HP), a john Deere 7330 (125 PTO HP) a John Deere 8230 (200 PTO HP) and the John Deere 7700 (126 PTO HP). For forage harvesting and storage operations, the case 2090 (108 PTO HP) was used. These tractors were used fairly consistently for each field operation based on the amount of power needed for pulling implements or tilling soil. In order to determine how much fuel was used for each operation, the tractor was filled at a dedicated diesel fuel pump located at WCROC prior to its use and then refilled after the operation was complete. The amount of fuel used was recorded on a clipboard in the tractor and later transcribed to a database. Therefore, fuel use for each activity included transport of the tractor and implement to the field and back, typically between 0 and 5 miles from the research farm and any idling time for the tractor.

Similarly, data was collected for trucks (gas and diesel) used for transportation of grain and forages. A John Deere 9500 combine (212/228 boost HP) was used for collection of all grains reported in this study.

d. Cropping Records

Inputs of chemical fertilizers, manures, and pesticides were tracked by the project agronomists, who recorded the volumes and dates of application. In the case of manures, WCROC uses solid manures, slurry, and very dilute solution from cleaning the dairy parlor. Each is applied in a different fashion, with only the solid manure being applied by WCROC staff using in-house equipment.

e. Utility Bills

For natural gas and electricity usage, utility bills were used when available. WCROC has multiple meters that help identify energy use in particular operations. For example, the grain dryer has a specific meter for natural gas use that can be read at the end of each season.

f. Literature and Databases

In some cases, data had to be obtained from scientific literature or technical databases to determine energy use for production of chemicals or quantities of materials needed for specific crops. These are noted below where were used for calculating energy associated with an activity.

g. Items Not Considered

There were some energy uses that were not included in the study. One is the use of fuel for transportation around the farm. Typically, farmers will use a four-wheel-drive pickup truck for both work-related and personal transportation. At the WCROC, the same trucks are used for many different purposes and tracking mileage becomes almost impossible for these situations. For example, many of the trips taken in the University owned vehicles were for research activities that would not be typical of farmer's use of the vehicle. Also these vehicles were used for farm activities other than cropping. Therefore, farm related personal transportation vehicle use was not included.

Energy from offices and support facilities was also not included. The agronomy staff have offices and equipment located in a building heated by natural gas that houses computers and other loads using electricity. Because these offices were used for research and non-cropping uses, this overhead energy for staff space was not included. Similarly, WCROC has a maintenance shop that serves all the different agricultural operations run out of WCROC.

Due to the inability to separate out where electricity and natural gas were used in a given activity or for given cropping system, energy from the maintenance shop was not included

C. Cropping Practices Tracked And Resulting Energy Use

a. Tillage

Soil tillage at WCROC is done using different implements to achieve a number of agronomic goals. Tillage is often used to gently or more aggressively loosen the soil to prepare a proper seedbed and allow for proper aeration. It is also used to mix soil to incorporate plant residues on the surface with sub-surface soils. Another key use is to kill weeds growing or disturb weed seed.

Implement/Practice	Tractor	Gal/Ac	St.Dev	n=
12.5' Disk Chisel	JD8230	1.838	0.401	9
17' Chisel Plow	JD8230	1.164	0.339	4
30.5' Field Cultivator	JD3200	0.674	0.126	17
8 Row Stalk Chopper	JD7700	1.102	0.17	4
6 Bottom Moldboard Plow	JD8230	3.009	0.86	4

Energy use for tillage varies greatly depending on the implement used, the tractor used, and the aggressiveness of the tillage. Also, most implements can be adjusted to till/cut at different depths, which changes the energy use profile.

The residue and root structures from the previous crop can also influence the amount of energy used during the tillage process. For example, data indicated that using the field cultivator on soil that had previously grown corn required more energy than when on soil previously growing soybeans. Corn has considerably more mass and requires more power when tilling. Unfortunately, for most tillage processes analyzed, there was not sufficient data to compare energy use with prior cropping history.

b. Planting

Planting crops tended to use a fairly small amount of energy, which was fairly consistent when using either the 12 Row Planter or 14 foot seed drill to plant corn, soybeans, or small grains. For some crops the 20 foot drum roller was used to level the ground for easier harvest and to pack soil for better soil to seed contact

Implement/Practice	Tractor	Gal/Ac	St.Dev	n=
12 Row Planter	JD 7330	0.405	0.030	7
14' drill	JD7700	0.521	0.147	4
20' Roller	Varied	0.239	0.047	6

c. Chemical Inputs

Conventional manufactured pesticides, herbicides, and fertilizers are used exclusively in the conventional production systems. Although many different chemical inputs are used on farms nationwide, WCROC uses a fairly small number of synthetic chemicals in its regular operations. The specific amounts of each are documented below for individual crops. In general, chemical use is for weed control. As the conventional crops are roundup ready™, glyphosate (RoundUp™) is used extensively on the two primary crops, corn and soybean. The increasing resistance of some weeds to glyphosate has necessitated additional herbicides. The next most common herbicide is acetochlor, which is used in several brand name chemicals. Species specific chemicals form the balance of herbicides. During the data collection period, insecticide was only applied during one year to control aphids on soybeans. Specific chemical inputs for each crop are listed below in under the discussion of individual crops.

d. Weeding and Chemical Application

Weeding of crops is done using a number of different techniques that work to selectively remove weeds, while leaving the crops unharmed. Currently, most conventional crops planted at WCROC are roundup ready and mostly require the application of herbicides to control weed problems. Whereas organic crops need a variety of weed control treatments used depending on size of the growing crops.

Implement/Practice	Gal/Ac	St.Dev	n=
12 Row Cultivator	0.304	0.092	7
20' Rotary Hoe	0.260	NA	1
30' Weed Harrowing	0.165	0.028	8
45' Herbicide Spraying	0.159	0.00	6

e. Conventional Fertilizer Application

A couple of important items not included on this list are the application of solid fertilizer via large commercial application equipment and the soil incorporation of anhydrous ammonia fertilizer. Currently WCROC contracts the application of solid fertilizers to local farmers co-op, which has specialized equipment needed for application. Anhydrous ammonia fertilization was also applied by the local coop during the study period. Information for these processes is further discussed in the cropping LCA section, where literature references and other information were used to energy determine values.

f. Manure Application

Spreading of manure on fields was done via different methods depending on the type of manure applied. WCROC staff and equipment was used for spreading a portion of the solid manures with a traditional manure wagon pulled behind a medium horsepower tractor. However, custom contractors with larger tracked equipment are being used more frequently as the number of animals and volume of solid manure has increased. The manure slurry from the swine barn manure pits required specialized equipment which WCROC does not have. A contractor was hired for removal of manure from the swine barns and application onto the field. A very dilute liquid manure from the dairy barn was also spread using the same equipment.

g. Harvesting

Crop harvesting methodology varies considerably, but generally falls into two groups – grains and forages. Most grains are harvested using a combine that separates the grain from the cobs, leaves, and stems after it has been given time to dry in the field. Transport of the grain to the farm is discussed below. Depending on the type of grain and how it was planted, different harvesting heads are used on the combine. The combine unloads grain into transport trucks or trailers (discussed below) for transport to the farm.

Forages require multiple harvesting steps to first cut the fibrous material from the roots and then collect it for transportation to a storage bag. WCROC typically collects its forage when it is still green and can be ensiled for use as cattle feed. Forage materials are transported from the field to the farm site where they are put in a large plastic covered silage piles or in silage bags where they are stored until needed. This process requires several different implements and tractors.

Implement/Practice	Gal/Ac	St.Dev	n=
14.5' Haybine	0.612	0.054	3
6 Row Head on Combine	1.626	0.338	6
20' Head on Combine	1.079	0.095	3
Wheel Rake	0.139	0.021	2
7.5' Forage Harvester	1.407	0.36	3
9' Bagger	0.554	0.11	2
Forage Wagons (2 wagons used)	0.548	0.177	3
Grain Swather	0.556	NA	1

h. Transport and Processing

After harvest, grains need transport to the farm or grain elevator and/or processing to prepare them for storage or use on the farm, all of which requires energy.

Grain Transport

Transportation of grain at WCROC is typically done using trucks and gravity box wagons. The two trucks available are a gasoline powered single axle truck and dual axle diesel powered truck. In addition, a gravity box wagon pulled by a tractor is used to move grain from the field to the farm. Because of the differing uses of these vehicles an accurate calculation of energy used was somewhat difficult. The estimates in the table below are the best approximations that could be made with the data. The gasoline used in the single axle truck was converted to an equivalent amount of diesel fuel based the amount of chemical energy each contains. Because of the significantly different volumes of grain collected from each acre of corn and soybeans, each was analyzed sperately for transporation energy use. Based on similar yields, small grains would be assumed to be similar to soybeans. Because of the challenge of working with transport data, the accuracy of these estimates is likely to be

Crop Transport	Gal/AC	sd
Corn	0.584655	NA
Soybean	0.5847	NA

somewhat questionable. These results are also likely to be different from many regional farmers, who have purchased much larger grain hauling trucks due to limited labor, much larger fields, and greater transport distances.

Grain Drying

Grain at WCROC is dried in a natural gas fired continuous flow grain dryer. The dryer uses natural gas for heat generation and electricity to power fans, augers, and conveyers. In our case, only corn (conventional and organic) is dried; other crops are sufficiently dry for storage Typically, grain is quickly dried to less than 15% moisture so that it can be stored. Natural gas measurements were taken from a dedicated meter on the grain dryer. Unfortunately, electricity use was not measure for WCROC's drier. Data from an Iowa State Extension publication was used to estimate electricity use (Edwards 2014). Units used for energy estimates were cubic meters of natural gas and kilowatt hours of electricity per bushel point of moisture removed (one percent of moisture for one bushel of grain). In 2014 and 2015, corn moisture readings were 23 and 22% respectively.

Corn Drying Energy		
Moisture Removed	7.63%	Average
Natural gas Used	0.01866	Therm/bu per % pt
Electricity Used	0.0105	kWhr/bu per % pt

Because of differences in the structure and composition of grains of different crops, it is likely that there would be minor differences in energy needed to dry other grains. These would likely be less significant than the overall percentage of moisture being removed. Most common models of grain dryers are similar in their ability to remove water from seeds. Grain drying is one of the largest uses of energy in corn cropping systems. Therefore, this is a likely where energy reductions could impact both the economics of cropping as well as the final energy and carbon footprint.

D. Specific Crop Results

2. Conventional Crops

The conventional crop land at WCROC is mostly planted in a corn-corn-soybean rotation. The rotation is designed to provide ingredients for animal feed and allow research on conventional crops. Typical practices include the use of pesticides and synthetic fertilizer. Seeding is also done with roundup ready seed; resulting in less tillage use, but more chemicals applied.

a. Conventional Corn

Data for conventional corn cropping is primarily derived from dataset from 2013 to 2015.

Yield

Using an average yield weighted based on acreage, WCROC conventional yields were 154 bu/acre between 2011 and 2015.

Tillage and field operations

In general tillage for corn involves field preparation using a field cultivator, planting the seed, application of fertilizers and chemicals, harvesting with the combine and transporting material with trucks and grain wagons. After harvest, corn stocks are chopped and a final tillage is done to incorporate surface material into the soil.

Field Operations
30.5' Field Cultivate
Planting 12 row
45' Herbicide Spraying
Fertilizer application
15' Combining
8-row Stalk Chopping
12.5' Disk-Chisel

Seed

Seed used for conventional corn production is genetically modified (roundup ready, BT) corn. Seeding rate is 35,000 seeds per acre. Unfortunately, little data exists from seed producers to speculate the amount of energy used/emissions produced for crops in the United States. This is discussed more in the LCA section.

Fertilizer Type	lbs/acre
NH3 (anhydrous ammonia)	113.8
Mono Ammonium Phosphate	37.5
Triple Super Phosphate	3.3
Di ammonium phosphate	8.3
Muriate of Potash	11.5

Fertilizer Use

Fertilizer inputs for the conventional system include a variety of synthetic fertilizers. The chief nitrogen source is anhydrous ammonia. The fertilizers listed for this study were approxiamated based on the amount of nutrients reported to be applied, specific formulations were not available. It should be noted that WCROC has high soil nutrients relative to many regional farms due to past use of manures on all fields. Therefore, nutrient application rates were lower for our fields.

Active Ingredient	lbs/acre
Acetochlor	0.8203
Clopyralid	0.0831
Flumetsulam	0.0263
glyphosate	0.7500

Transport and non-field Operations

Transportation energy was calculated based on the use of fuel for several vehicles employed for moving grain from the field to the farm.

Chemicals

Active ingredients for chemicals applied to corn are shown in the table. Energy use for chemicals manufacture is estimated in section III.

Drying

Corn grain drying energy is as described above.

b. Conventional Corn Silage

Conventional corn silage begins production essentially along the same pathway as corn grain described above. However, before it begins to senesce (die-off and dry) the entire plant is harvested by a chopper that cuts all the leaves, stalks, and ears of corn into small pieces. This material is moved in large trucks from the field to storage piles/silage bags on the farm. The storage piles are covered with plastic to maintain an anaerobic environment. In this environment, the plant material will undergo biochemical changes that inhibit decay. The material can then be stored wet for over a year before it decays too extensively and loses its value as animal feed.

Field Activity
30.5' Field Cultivate
12-row planter
45' Herbicide Spraying
Fertilizer Application
Silage Harvest chopper/truck
12.5' Disk-chisel

Average Yields

The average yield of all corn silage at the WCROC was 18.16 tons per acre at roughly 65-70% moisture. Unfortunately, silage harvest energy and yield data was not consistently seperated out between conventional and organic at the beginning of the study. Additional data is being collected.

Fertilizer and Chemical Use

Fertilizer and chemical use are as described for production of corn grain.

Tillage and Field Operations

The main differences between tillage of grain corn and silage corn are in the harvesting steps. Silage is chopped when the corn is green and at high moisture; therefore, there is much more mass removed from the field. This literally requires a fleet of vehicles removing material. Following harvest, the field can simply be tilled once.

Silage Harvest Energy	
3.46	Gal/Acre
0.191	Gal/Ton
5.25	Tons/Gal

Harvest and Storage Operations

A number of different transport vehicles, tractors, and loaders are needed for moving and storing silage. As some of the equipment vehicles were contracted services, obtaining fuel use for all of these was some what complicated and some fuel use was estimated.

Variability of Data

In reviewing data for silage harvest, there was some variation observed. Some of this was likely impacted by inconsistent yields. However transportation distances or other factors may have influenced harvest data. For the three years analyzed, the gallons of fuel per acre varied between 2.97 and 4.35.

c. Conventional Soybeans

Average Yield

The five-year average for conventional soybeans was 37.97 bu/acre based on an average weighted for the number of acres planted.

Tillage and Field Activities

Tillage and field activities are similar for corn and soybeans. Differences include an extra step to pack the seedbed with a roller is typical of soybeans. Post crop tillage is less intense as soybeans leave less material on the soil surface and have less root mass to complicate seeding during the following season. Depending on weed pressures, a second chemical application is often needed.

Field Activity
30.5' Field Cultivate corn residue
12-row seeding
Soybean rolling, 20' Roller
45' Herbicide Spraying 1st Pass
45' Herbicide Spraying 2st Pass
20' Combining
17' Chisel Plowing

Fertilizers Use

Soybeans are legumes and are able to aquire nitrogen through the air in combination with symbiotic micro-organisms. Therefore, fertilizers are not generally used for soybeans. In fact, legumes are often used to build soil nitrogen levels.

Chemical Use

Conventional Soybeans grown at WCROC and throughout much of West central Minnesota are roundup ready and often have resistance to other herbicides. Therefore, much of the weed control for conventional soybeans is through the use of a number of chemicals. In addition to herbicides, insecticides are occasionally used for control of soybean aphids. An estimated volume of the chemicals used during the study period is in the table on the right.

Chemicals Applied	
Active Ingredient	**lbs/Acre**
acetochlor	0.140624
glyphosate	1.374721
lamda-cyhalothrin	0.003516
lactofen	0.024414
clethodium	0.023437

Harvesting, Transportation, and Storage

Hauling of soybeans from farm fields to WCROC facility required 0.5847 gallons of fuel per acre. Post-harvest drying of soybeans is not required as they are typically below the maximum moisture allowed for safe storage. The WCROC typically sells soybeans rather than stores them, most soy materials used on-site require further processing before being added to feed.

d. Conventional Haylage (alfalfa)

Conventional alfalfa haylage is not typically grown at WCROC. However it was decided to model what this crop might look like if it were grown in our conventional system. In general, chemical and fertilizer application rates are based on desired yields. The timing and number of harvests is an approximation that averages two different harvest regimes set up by the former and current WCROC agronomists. Harvests are set at 2 in year one and 4 in years two and three, for a total of 10 harvests over the 3 years of an alfalfa rotation.

Yield

Yield data for conventional alfalfa is not available due to it's limited production at WCROC. Results indicate that the first seasons harvest is considerably smaller than the following two seasons. Based on our organic data it appears that over the three-year of alpha rotation, yields are roughly 30 tons (wet basis). This leads to an average of roughly 10 tons per year.

Tillage and Field Operation

Most tillage operations for alfalfa haylage are done during the first season, when it is seed. Application of roundup or moldboard plowing is used to kill the alfalfa at the end of the 3 year roation.

Field Activity for 3 Year Rotation	
Activity	**# of Operations**
Planting	
Seed Drill	**1**
30.5' Field Cultivate	**1**
20' roller	**1**
Harvest*	
10.5' Haybine	**10**
30' Wheel rake	**10**
Forage Wagons	**10**
7.5' Forage Harvester	**10**
9' Bagger	**By ton**
Final Tillage	
Moldboard Plow	**1**
*2,4,4 Harvests in Years 1,2,3 respectively	

Fertilizer

Alfalfa is a legume and can meet its nitrogen needs via nitrogen fixation using symbiotic micro-organisms. However, potassium and phosphorus are suggested depending on yield goals and background fertility levels.

Chemical Use

In Minnesota, companion crops can be used to help with weed control. These annuals companion crops will outcompete weeds, remove nutrients, and thus, reduce weed pressure. However, chemical weed control is also commonly used.

Transportation, and Storage

A significant use of energy in haylage production is the transportation and storage of material from the field to storage piles. This is similar to silage is discussed above, and often includes an extra tractor to put the material into silage bags.

3. Organic Crops

The organic rotation is designed to provide feed for dairy cows; therefore, it has more forage crops that would be typical of Midwestern farm. An organic corn soybean rotation would require a fairly large amount of mechanical weeding and fertility treatments to maintain adequate nutrients and soil health. Therefore, the rotational system is much larger and more complex. In addition to the typical corn and soybeans (grains), the rotation has wheat (grain) and wheatlage (wheat harvested as silage) as well as alfalfa. Oats can also be used in place of wheat. Another part of the organic system is the use of cover crops. At WCROC, this includes tillage radishes, legumes, and small grains. This combination was designed by the crop scientist to be sustainable with no non-organic inputs. It maintains soil health, retains nitrogen, and presents erosion. By using different crops, disease and pests can be minimized and soil health and fertility improved, while supplying a good mix of grains and forages for the dairy operation. An important consideration when comparing organic and non-organic systems is the difficulty in directly comparing the same crop grown under different systems. For example, an organic corn crop is greatly benefited by the use of a cover crop or the rotation of alfalfa to help maintain soil health and control pests and diseases. Whereas the conventional crop requires only additional synthetic fertilizers and herbicides. This is discussed further below in the LCA section.

The major differences between the specific organic crops and their conventional counterparts are the use of animal manures as fertilizer and additional mechanical weed removal. Where the conventional crop is described above, the descriptions in this section mainly describes the differences between the organic and conventional system.

i. Mechanical Weeding

In order to eliminate weeds without synthetic chemicals, crops at WCROC are mechanically weeded using a number of different implements. These implements are able to remove weed seeds at several different stages. Typically this involves multiple passes at different times the growing season. Thus, it does require additional energy.

Implement/Practice	Gal/Ac	St.Dev	n=
12 Row Cultivator	0.304	0.092	7
20' Rotary Hoe	0.260	NA	1
30' Weed Harrowing	0.165	0.028	8

ii. Manure Application

Application of manure at WCROC serves two important goals. First is the removal of waste from the animal production systems. Second is maintaining the fertility of soil for organic crops. WCROC has three forms of animal wastes that are applied to its cropping land. One is the manure slurry concentrate from the swine barns, which is pumped into large tanks pulled by tractors with applicators that inject the manure into the soil surface. A second liquid manure is from a lagoon near the dairy parlor that contains the diluted manure and wash water used to clean the dairy facility. The third manure source is solid mentors from both the dairy and swine buildings that is typically mixed with straw and other bedding. This manure is distributed using a conventional manure spreader pulled behind a tractor. Because of the cost of equipment and limited need, WCROC does not have a truck-mounted liquid manure applicator and contracts the service out. Therefore, the only manure that WCROC applies is the solid manures.

Records of manure application are an important component of state mandated pollution control requirements. WCROC carefully tracks which manures are applied and the concentrations of nutrients added to each field. Typically, in the organic system, manure is applied to corn crops either in the fall preceding or early spring before the crop. Manure application rates are determined by the amount of nutrients in the manure. So, the dilute dairy wastes are applied at a higher concentration than the swine manure or solid manures.

Average Percentage of Corn Land Receiving Each form of manure		
Lagoon	**Solid**	**Pit**
11.59%	63.26%	25.15%

Overview of Manures Applied to Crops Grown 2013-2015						
		Analysis				
Manure Source	**N**	**P**	**K**	**Amount**	**Rate**	**Primary Crops**
Dairy Effluent	11.1	3.3	8.4	10844	Gal/Acre	Alfalfa, Pasture
Swine Slurry	27.0	10.3	20.3	6289	Gal/Acre	Corn
Solid Manure	15.1	6.1	16.4	16.2	Tons/ Acre	Corn, Small grain

a. Organic Corn

Organic corn production is only slightly different from conventional production. One observed difference is that yields are typically somewhat less for organic corn production (148.7 bu/acre) compared with conventional corn (154 bu/acre).

Field Activity
30.5' Field Cultivate (sometimes X2)
12-Row planter
30' Weed Harrowing (sometimes X2 or 3)
12-Row Row Cultivating (sometimes X2 or 3)
15' Combining
8-Row Stalk Chopping
12.5' Disk-chisel

Tillage and Field Operation

In terms of field operations, weed control is the largest difference between organic and conventional systems. In order to remove weeds without using herbicides, additional operations are needed. In this case, a weed harrowing step is done early in the year after planting and cultivating with a 12 row cultivator is done later during midseason. In combination with good rotational planting and weed control during other crops, corn can be successfully produced without synthetic herbicides. Though it is important to acknowledge that poor weather and other conditions can limit mechanical weed control and makes organic production more variable.

Fertilizer

Corn has a high demand for nutrients and needs to have sufficient animal manures applied in order to be productive. As described above, WCROC uses three different types of manure. Much of WCROC's manure is applied to the organic corn production system. The corn crop will use most of the nitrogen during the season and leave some phosphorus and potassium for the following seasons crops.

Average Corn Crop Manure Application Rate		
(Only One Manure Type Per Field Per Year)		
Manure Type	**Application Rate**	
Dairy Effluent	13,975	Gal/Acre
Swine Slurry	20.5	Ton/Acre
Solid Manure	5,700	Gal/Acre

Drying

It was noted during the study that because organic corn at WCROC is harvested earlier, it was more moist and needed more drying. Thus, there was more energy used for drying organic corn. Starting with 2016 data, more information is being collected to help quantify the differences between organic and conventional corn drying.

b. Organic Corn Silage

From an agronomic standpoint, organic corn grain and silage production is identical until the silage harvest stage. It utilizes the same weed control steps and similarly does not use synthetic chemicals as for organic grain discussed above. As noted in the conventional corn silage description above, yields for both organic and conventional corn silage average roughly 18.16 tons per acre.

c. Organic Soybean

Typically grown as a cash crop and part of a healthy crop rotation, organic soybeans are not typically used directly by WCROC and are sold. Though WCROC does purchase organic meal and oil from processors who have the equipment to refine soybeans into these products.

Activity
30.5' Field Cultivate corn residue
12-row seeding
Soybean rolling, 20' Roller
Harrowing
12 Row Cultivating
20' Combining
17' Chisel Plowing

Yield

WCROC does not plant large amounts of soybeans as other crops can be grown as part of the organic rotation and the beans are not directly needed for feed. The few crops that have been produced during the study averaged 37.66 bushels per acre.

Tillage and Field Operation

as with organic corn, the largest change in field operations is the additional mechanical weeding steps needed to replace chemical herbicide application. For soybeans this included harrowing and cultivating.

d. Organic Haylage (alfalfa)

In many ways, the production of organic alfalfa hay is similar to the conventional system described above. The carryover of phosphorus and potassium from manure application on other crops is sufficient for production of alfalfa. However, manures can be used for added production. Dairy lagoon effluent is occasionally added, but this is done more as a way to empty the dairy lagoon rather than as a fertilizer. Harvesting organic alfalfa haylage is identical to conventional alfalfa haylage as described above.

4. Other Crops

A number of other commodity and cover crops were produced, but collection of data on their inputs and production was not complete. An effort is being made to model these using outside data. More data on these crops is needed for the ongoing work in evaluating the dairy and swine systems. For example, wheat and hay are both used as dairy feed. Initial models of these were developed for supplying these ingredients to the dairy system. Cover crops are also an important component of a proper organic rotation. Therefore, it is important to fully understand the energy use in crops such as tillage radishes and turnips. These crops are being analyzed using tillage data from WCROC and typical agronomic practices as described in University Extension publications.

E. Summary

The efforts of this phase of the overall project were meant to allow farmers to calculate how much fuel the field operations they use will require and whether it may be more economical to change their cropping systems. Few other recent studies have looked at actual measured data for agriculture. Data from 1989 (Helsel 2007) appears to be the most complete set of on farm fuel use measurements. Fuel use data from this current study appeared to be within the range established by Helsel. However, crop productivity is significantly higher than when the study was conducted in 1989. A number of other studies have examined fuel use, but they focus on estimates of fuel use based on tractor size and load (Downs and Hansen 1998, Helsel 2007, Hana and Schweitzer 2013). Single issue studies that are relevant to this projects' fuel use data include work done on plowing (Hana and Schweitzer 2013) and sugar beets (Fitts and D.D. 1981).

Future work for crop energy auditing includes revising estimates with data from 2016 and further work to look at cover crops and crops for which we currently have limited data. As this data is collected, it will be disseminated to producers and used in life cycle assessment work.

III. Cropping System LCA

In the previous section (I. Cropping System Energy Audits), energy inputs from many of the cropping systems used at WCROC were collected and described. However, a complete energy estimate for crop production was not provided. This section describes how that data was used to model energy use in these cropping systems.

Life cycle assessment (LCA) is a method of looking at the impacts of different activities in a production system. It is traditionally used for large systems that have a number of different steps to carry out an activity or produce an item. At its heart, LCA is an auditing process that tracks inputs and outputs in a system and then creates a list of impacts of the system based on characterizations of system inputs and outputs (Figure II-1). There are a number of different impacts that are commonly tracked using LCA methodology. In agriculture, the two most common are fossil energy use and greenhouse gas emissions. Those are the two impacts that are being tracked in this study of cropping systems at WCROC.

Advantage of LCA methodology is that it allows you to model changes in systems to determine how the changes will influence the impacts of the system. In studying cropping systems, this might be how a decrease in tillage reduces energy usage for the system. The work described here is an effort to build life cycle models for cropping systems in West central Minnesota.

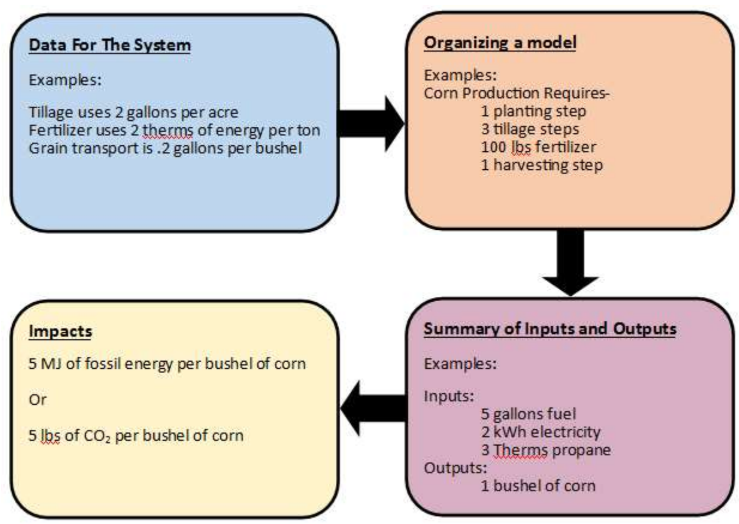


Figure II-1 Life Cycle Methodology. This schematic represents a generalized approach to how life cycle assessment work is conducted.

In addition to the general goal of building LCA models of our cropping system, specifically we were interested in where fossil energy use in these systems could be reduced and where potential greenhouse gas emissions could be mitigated. Another area of interest was the different impacts of organic versus conventional cropping systems.

F. WCROC Crop System LCA Modeling

Life cycle assessment modeling typically involves a data collection stage, a modeling stage, a input/output summary and an impact analysis stage (figure II-1).

1. Life Cycle Assessment Data Sources

A number of data sources were used for this work. In addition to data collected at WCROC, technical literature and databases were used to fill in gaps where data could not be collected.

a. WCROC Farm Cropping Energy Audits

The primary source of data for this project was the energy auditing of crop production systems (section I above). For each of the field operations and inputs identified in the auditing process, the energy and emissions from the inputs were calculated. This included each step of crop production from pre-planting tillage to post-harvest tillage.

b. WCROC Based Calculations

Some data describing WCROC cropping operations were calculated using reference standards with WCROC information because direct on farm measurements are not feasible. Manure emissions were one of these and are described here because of the significant impact they have on the cropping system.

Manure Emissions

Manure use and emissions in a cropping system LCA can be a fairly complex issues. It can be difficult to allocate emissions and fertilizer replacement values to the components of the animal systems and manure use in cropping system. Additionally, manure calculations in LCA work typically involved a simple closed-loop single animal - single crop system. The manure component of the LCA analysis at WCROC has added complexities because manure from multiple swine and dairy husbandry systems is combined and stored before being added to croplands.

For basic analysis in this system, manure management is divided between those activities in the crop and animal systems (dairy and swine). The approach taken was to assign GHG emission to animal systems until manure is removed from the storage location (pit, pile, or feedlot). Removal operations are part of animal systems, while transport/application at field sites are part of cropping systems. The replacement nutrient value is kept as a credit to the animal system. Energy is similarly assigned in the removal/collection and application steps.

Calculations of emissions were based on both WCROC data and standard animal waste reference data (Lorimor, Powers et al. 2004, IPCC 2006, IPCC 2013). Individual crop emissions calculations and data are described below.

Ammonia emissions were calculated as a percentage of total nitrogen in the fertilizer applied. A search of literature found that the emission factor for vary greatly based on several factors, including temperatures, rainfall/soil moisture, and soil incorporation.

Direct N_2O emissions are based on the amount of nitrogen in all sources applied to a landscape. These are added together and an emission factor is used to estimate the amount of the total nitrogen released from the system.

$$N_2O\text{–}N_{N\,inputs} = \begin{bmatrix} \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM} \right) \bullet EF_1 \right] + \\ \left[\left(F_{SN} + F_{ON} + F_{CR} + F_{SOM} \right)_{FR} \bullet EF_{1FR} \right] \end{bmatrix}$$

Adapted from IPCC 2006 equation 11.1

EF_1 = emissions factor (0.01)

Fsn = synthetic nitrogen added

Fcr = organic fertilizers nitrogen added

Fsom = soil organic matter nitrogen

c. Data From Literature and Databases

Literature and database references were primarily used in the background systems for this LCA. These are mainly components of the cropping system that were manufactured off-site and outside WCROC's control.

Seed Production and Treatments

data for the production and treatment of seeds with fungicides and other chemicals was not found for US seed sources. Therefore as an interim measure, the seed material for cropping was set to the current crop being grown. For example, corn seed referred back to the corn grain kernels grown in the WCROC corn production process. This does underestimate of the amount of energy needed for seed production, but is an initial value that can be reviewed and updated over time.

Pesticides

Energy and emissions for farm chemicals were based on database values for the active ingredient in the chemicals. In some cases, data base values could not be found and a general farm pesticide value was used.

Energy sources

Information on electricity use at WCROC was calculated using energy data from the energy information agency (EIA) and public utility records. This data was used in conjunction with database information on different types of electricity generation to determine greenhouse gas and fossil fuel impacts for energy in the region. Data on diesel fuel, natural gas, and propane was found in LCA reference databases and was specific to the United States.

Fertilizers

Fertilizers, particularly nitrogen, are an important part of most conventional farming systems. Nitrogen fertilizer production is very energy intense and in the United States, is typically made using natural gas. Depending on the form of nitrogen fertilizer needed, it must then be transformed from anhydrous ammonia into other solid or liquid fertilizers. These are then transported across the country via pipeline and rail. Phosphorus and potassium fertilizers are typically mined using heavy equipment and transported via train to the Midwest.

2. Model Building

Using the data described above, a model was built for each crop to examine the fossil energy and greenhouse gas impacts. As shown in figure II-2, all of these pieces of data are linked in the model. The individual steps, called processes, contain the inputs and outputs for the activities of the process. These processes are linked together to form the model. The figure shows how fossil energy is used in the production of soybeans. Each red line is fossil energy moving between the different processes. You can see from the soybean example that many of the processes link back to diesel fuel consumption. Diesel fuel is the largest energy sink for soybeans, which don't require fertilizer.

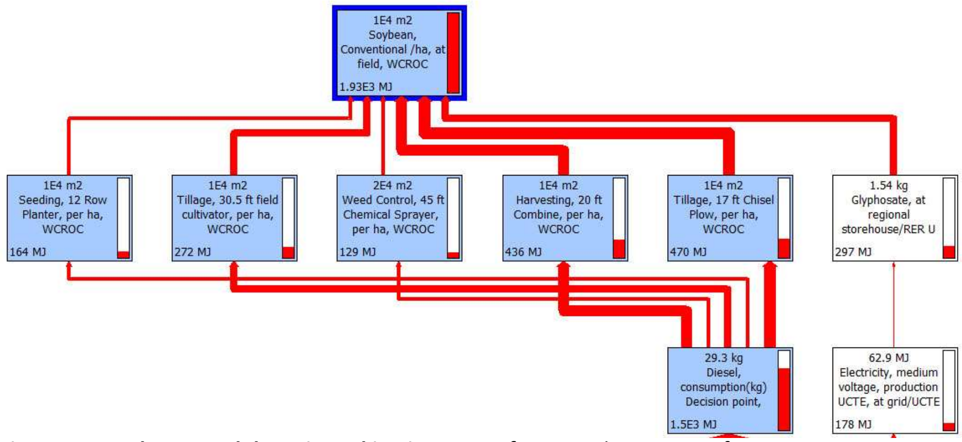


Figure II-2 Soybean Model as Viewed in SimaPro Software. This printout from SimaPro LCA software shows how individual activities in the model are linked together to create a model. In this screenshot, you can see that producing conventional soybeans requires several activities- seeding, tillage, weed control, harvesting. It also requires inputs such as glyphosate (roundup). These individual pieces are assembled into a model to make a production system.

G. Findings

After entering all production data and data on inputs associated with the different crops. Each crop was analyzed for fossil energy use and greenhouse gases. Fossil energy use data was expressed in terms of the megajoules of fossil energy that was required to produce 1 kilogram (kg) of a particular crop. For most crops the data was expressed as 1 kg of the crop after being transported and processed for storage at the farm site. Greenhouse gas emissions were similarly measured per kg of crop transported and processed at the farm. As has been noted above these models undergo fairly regular revisions as new information becomes available.

III-1 Preliminary Energy and Emissions By Crop		
Crop	GHG CO_2 Equiv. kg	Fossil Energy MJ
Conventional Corn	0.199	1.61
Conventional Hay	0.12	1.67
Conventional Silage	0.0922	0.646
Conventional Wheat	0.145	1.81
Organic Corn Grain	0.155	1.16
Organic Corn Silage	0.066	0.359
Organic Hay	0.061	0.375
Organic Haylage	0.0295	1.59
Organic Soybean	0.055	0.364
Organic Wheat	0.0388	0.464
Pasture Grass	0.0129	0.154
Per kg grain or dry matter		

H. Further Work

There are a number of areas where revisions to this work will be occurring over the next several months. These changes are expected to both improve the accuracy of the data and provide a better perspective on how agricultural practices can be improved.

1. comparing organic and conventional crops

Although this project was begun with the goal of directly comparing individual organic and conventional crops. The interactions between the organic crops suggest that this is not an accurate way to analyze individual organic crops. For example, in conventional corn production systems, herbicides and chemicals are used to eliminate many of the limitations of production. These inputs can easily be assigned to producing corn during a given season. The organic system is considerably more complex. Different crops are rotated to provide different benefits for soil health and pest control to make the conventional corn crop possible. Figure II-3 shows graphically how the different crops rotating through the production system impact soil health and reductions weed pressure. The organic rotation has cover crops that don't provide an economic or production benefit, but are needed to maintain the system. Thus, these benefits and the inputs needed to maintain them must be considered on the whole rotation rather than an individual crop. For example, a tillage radish cover crop will help retain nitrogen in the soil and add organic matter. This benefit may translate most to the next crop being planted, but also remains a benefit to the system as a whole for multiple crops. Therefore, future work will examine conventional and organic cropping as systems. Possible ways to compare them include on the basis of calories produced, dollar value of crops, or protein production.

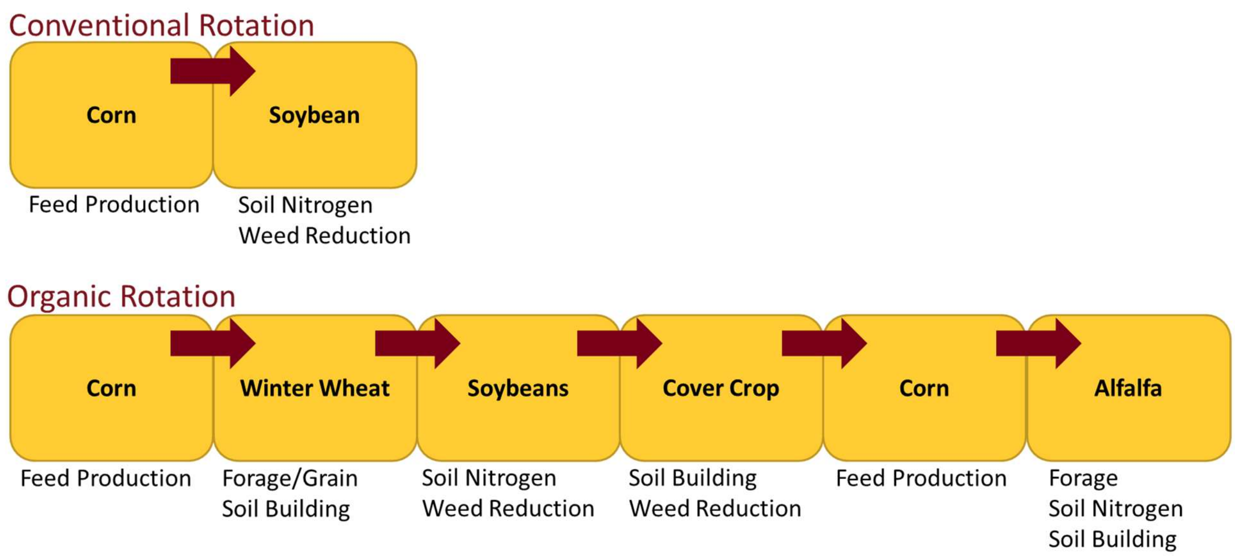


Figure III-3 Comparison of Conventional and Organic Rotations. Important benefits for each crop are listed under each crops segment in the rotation.

2. Improving Model Accuracy

Several changes and additions are planned to help improve model accuracy over the next year. More information is being collected on manure application and nutrients that accompany manure. Another area of concern that was brought up by agronomy staff was the use of different soil types and qualities for production of organic versus conventional materials. In general, organic crops are grown on some of the most fertile at WCROC. By comparing past cropping records, may be able to make some observations about potential differences between crops grown on these lands.

IV. Dairy System LCA

This work examines the lifecycle of milk production at the West Central Research and Outreach Center (WCROC). It is a cradle to gate analysis set in West Central Minnesota Region, but more specifically reflects the unique dairy systems being studied as part of the Universities' dairy research. Important aspects of the system include a low maintenance organic grazing dairy herd being co-located with a more conventional confinement herd. The midsize scale of the operation is in contrast to the trend towards larger (5000+ head) dairies in the region. An important driving factor in conducting life cycle assessment (LCA) at this facility was the opportunity to observe how planned improvements in the facilities energy infrastructure would impact fossil energy and greenhouse gas, 'carbon', footprints. These ongoing improvements include new equipment for renewable energy generation, replacement of existing inefficient milking system equipment, and addition of energy recapture equipment. The LCA work is being used to both compare environmental impacts difference between the organic and conventional herds, and how inclusion of different energy technologies can influence these impacts.

This study relies heavily on the work done to assess environmental impacts of crop production at WCROC. The cropping system analysis in Sections I & II were used as the background data for feed inputs in the dairy system. The fossil energy use and greenhouse gas emissions for the feed ingredients are a significant part of dairy energy and emissions impacts.

In conducting the dairy portion of this study, many different dairy and agricultural LCA efforts were reviewed. (Dalgaard, Schmidt et al. 2014). Many of the studies that focused on a single dairy, but were in areas of the world with the ability to graze cows for much more of the summer. They also tended to farms whose only activities were dairy production. The studies could be considered enterprise specific and looked much more broadly at total inputs and outputs for the farm. Thoma *et al* (Thoma, Popp et al. 2010) conducted a high level study of dairy production in the United States. It examined the greenhouse gas emissions from production and use of fluid milk in the United States. For data, it used surveys from dairy farms across the country and national statistics. This study is much more focused on a single dairy and looks at the specific activities that are used in the dairy production system rather than a more broad dairy farm enterprise analysis.

A. General LCA Methodology

The study was designed specifically to evaluate the dairy operation at WCROC, located in West Central Minnesota (43°N 93°W). The region is characterized by a large amount of fairly flat farmland along with some rolling hills. Soils in the area are varied with much of it being glacial till interspersed with more sandy soils. Historically, dairies and beef production used much of the rolling hills for pasture grazing. The dairy system at WCROC has maintained its pasture dairy operation using a combination of rolling hills and low production sandy soils for pasture, along with feed from row crop land. While this is no longer typical of dairies in the region, it has allowed the dairy at the research and outreach center to maintain sufficient pasture opportunities to host an organic dairy alongside a conventional operation.

The work documented here should be considered an investigatory LCA, as some factors are still being added to the project in order to make it more complete. The Inventory of data collected for this project (Life Cycle Inventory [LCI]) includes only impacts of interest, primarily items that influence greenhouse gas emission and fossil energy use (resource depletion) categories of life cycle impacts. For example, water usage is tracked in operations where energy is used to move it or heat it, but not irrigation or groundwater used for producing crops. Inventory items were assembled into processes that describe different steps in the dairy in crop production systems. Over 100 unique processes were created to represent the major steps in the crop and dairy system modeling. SimaPro software is used as the primary process storage database and calculation tool used for analysis of the data set.

1. Data Sources

A number of different sources of data are used for this dairy LCA work. Priority was given to data generated at WCROC or data that was calculated based on WCROC operations. However, some background data was found in databases or literature.

a. WCROC Data

WCROC's conventional and organic crop production systems was used to model feed ingredients. The majority crops produced by WCROC are forages used in livestock production. The greatest use of energy was for diesel fuel to power tractors. However, it also includes nitrogen fertilizers and energy needed to dry grain, which are important for conventional corn grain and silage.

Energy audits conducted by WCROC researchers were another important source of information. By incorporating sensors and monitoring utility bills, staff was able to document multiple years' worth of energy use in the dairy production system.

The dairy system data was assembled into a fairly comprehensive model with information from WCROC dairy researchers. This included data concerning diets, growth stages, milk production, and how cows interacted with facilities and pastures.

b. Databases and Literature

When data collection from WCROC did not include a piece of information that was needed for modeling, databases and background literature were consulted to add information to the model. This was typically the case in areas where materials or energy were brought into WCROC's dairy system (background items). A case in point is the energy and greenhouse gas impacts of the energy electricity used in the model. A search of literature and databases was used to find information about the types of electrical energy being used in the Midwest and Minnesota in particular. There are number of commonly used LCA databases. They vary significantly in the breadth and depth of the information they have and the geographical regions that they are specific for. The databases used directly or as reference for this project included:

U.S. LCI-the US life cycle inventory database is maintained by NREL and contains database entries related to materials and products produced in the United States. It has LCA information from a number of different fields, but has relatively few processes. It is free to use and can be found at: https://www.lcacommons.gov/nrel/search

USDA LCA Commons- the USDA has a collection of agricultural specific data for production of many common crops in the United States. The data is updated as new information is generated by the National Agricultural Statistics Service (USDA-NASS) and other interested parties. Data includes specific information about many of the different stages of agricultural production. One area with very little coverage to date is livestock. It is free to use and can be found at : https://www.lcacommons.gov/

Ecoinvent- Ecoinvent is a large database developed primarily with European data, but does contain some North America and other worldwide data coverage. It has a broad spectrum of different industries and activities, including agriculture. It should be noted that in order to provide the huge number of processes that the database contains, accuracy of US specific information is sometimes questionable. Ecoinvent version 2.0 was used for this project. Ecoinvent is not a free database, but is part of the SimaPro package and can be purchased separately. More information on eco-invent can be found at: http://www.ecoinvent.org/.

In a number of cases, accurate information for the cropping or dairy models being used at WCROC could not be calculated based on project data or found in databases. In these cases, data from technical literature was used to develop processes to model cropping and dairy systems. This included a wide variety of documents from the federal government, specifically the EPA, USDA, EIA (Energy Information Agency), and DOE. Information for modeling Minnesota-based crops that WCROC doesn't grow came from University of Minnesota Extension publications. Commodity group and industry publications were also used to provide background or insight into developing processes.

2. Approach

The decision was made early in planning the LCA to use specific data for each operation, rather than a more generic system. As an example, rather than assign all the organic corn used to feed animals to a generic milk production process, the organic corn is assigned to specific stages of animal growth where it is used. Our goal involves being able to modify specific items/processes in the milk production system and determining impacts of the changes within the dairy system, as well as, outside the dairy system boundaries. Creation of an LCA model for this purposes involves much more specificity. Therefore, many distinct processes have been developed in this model (i.e. growth stages & feed decision points).

3. Goals and Scope

This analysis is focusing on two key areas of environmental impact, global warming potential and fossil energy resource depletion. For global warming potential (GWP), carbon dioxide equivalents are being tracked per functional unit of milk produced. Fossil energy use (resource depletion) is being tracked using individual types of fossil energy (natural gas, coal, crude oil), and as an overall fossil energy statistics.

An additional goal of the project is to develop a model that could be expanded to include other impacts; such as water use, eutrophication, or particulate emission. By adding data about these topics to the existing model, these items could conceivably be examined should the impacts become important in understanding farming in Minnesota.

4. Boundaries

Boundaries of the foreground system focus on the on-farm activities related to milk production, these activities include pastures and needed pasture maintenance, milking and milk house operations, and the preparation and mixing of feeds. The background system includes operations related to production of grain and forage crops from production agriculture (figure IV-1).

While it is not typical to put the cropping systems in the background system of a dairy operation (vs the foreground), the multifaceted operations of the research facility and requirements to import some feed ingredients for different animals (hogs and cattle), different herds (organic, conventional, different feed studies), and use of multiple manure sources makes including the cropping system in this LCA difficult.

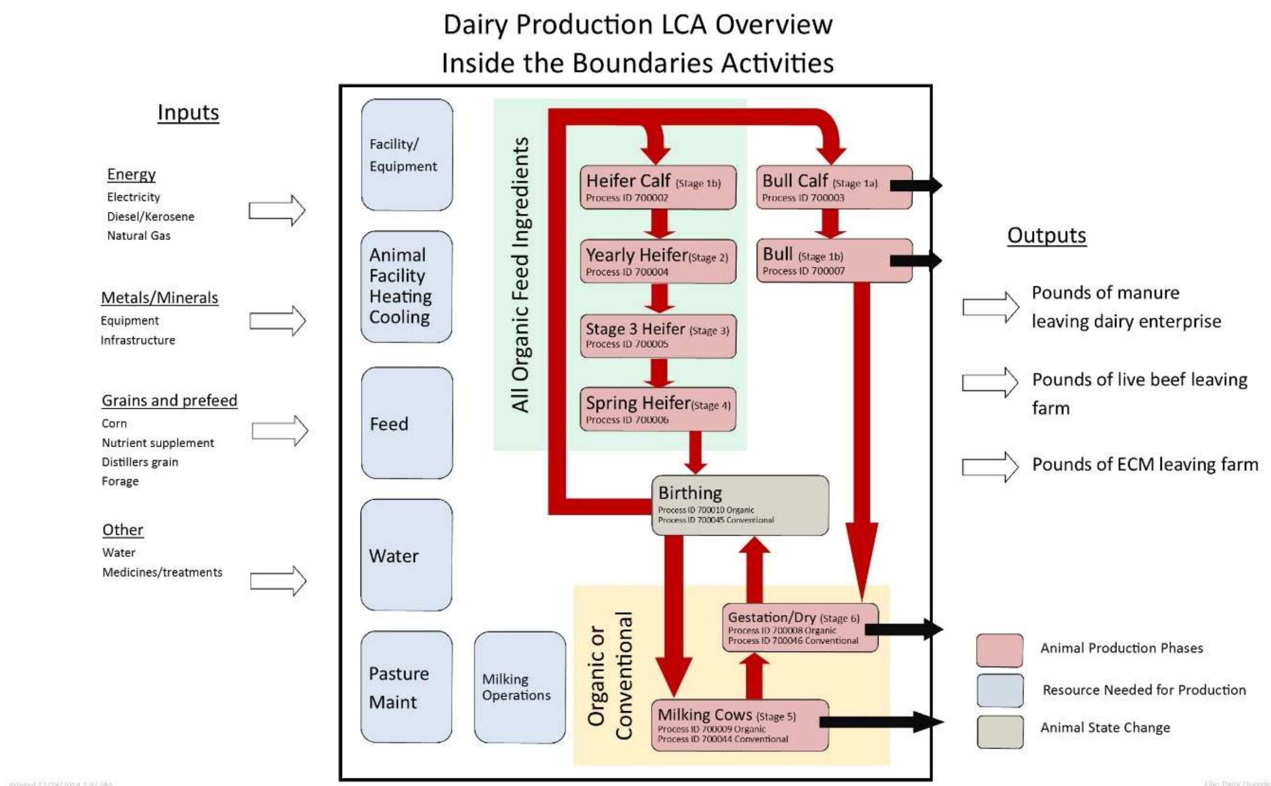


Figure IV-1 Dairy Production LCA schematic.

Whenever possible, activities relating solely to research are not included in the LCA. In some cases, allocations were made where energy use or resources for research and dairy system operations were mixed.

The study was designed to examine data for the present or very near future. In surveying the herd management strategies, we specified modelled a three-year snapshot of feed and management decisions in requesting information.

B. Dairy System Modeling

This model was designed as a 'cow centric' model, based growth stages of the cow and the inputs and outputs of each individual growth stages (table IV-1). This allow for the ability to easily change animal management strategy assumptions based on needs to model proposed system changes when testing various scenarios studies. For example, the question could be asked, "what is the impact on GWP of a 10% reduction in calories for the summer milking herd diet given it will reduce milk production 2%"? This data can easily be added to the WCROC model by simply changing a few variables for the organic milking herd cow and summer diet.

Data management and analysis of data for the project was done using SimaPro LCA software. The flow of inputs and outputs for the dairy system is divided into discrete processes or stages. Each of these processes or stages has a unique process ID, which is listed in figures and appendix data.

1. Animal Growth Stages

Overall the dairy production system has two major cycles for the dairy system (Figure IV-1); replacement animal production and milk production. The replacement animal processes involve several stages of growth from newborn calves to heifers ready to calve, plus bull calf sales and replacement bull. For simplicity, all calves at WCROC are raised as organic until they first give birth and begin milk production. Milk production stages include actively milking cows and dry/gestating (non-heifer) cows.

Table IV-1 Dairy Model Growth Stages and Stage Process ID Numbers

Stage	Conventional	Organic
Bull Calves	-	700003
Heifer Calves	-	700002
Weaned Heifers	-	700004
Yearling Heifers	-	700005
Spring Heifers	-	700006
Milking	700044	700009
Birthing	700045	700010
Dry Cows	700046	700008
Bulls	700007	-

The growth stages (Appendix B-1) equate to processes entered into the LCA software model that include diets, animal housing, and other activities that may influence energy use or GHG emissions.

These growth stages begin with the birth of animals, which happens twice per year (Spring and Fall). Therefore, there are two groups of animals that are always moving through the system. This is needed because milk production varies over the length of time that a cow has been milking. At a certain point, the cow needs to stop milking to regain weight and maintain health. Using two groups of cows at different points in the system, the periods of low production are minimized.

Breeding of animals is done using artificial insemination. This allows for selective breeding to maintain herd genetics without having a number of bulls on site. In terms of an capability, a single bull can breed well in excess of 500,000 cows using AI (20,000 used in LCA). Therefore, the resources required for a bull are almost negligible. However, this LCA does include a bull to make a more complete system.

For this system, the growth stage process is based on when animals research certain weights, give birth, or are bred. The length of each growth stage is based on the herd management plan developed by WCROC staff. From an analysis and organizational standpoint, each growth stage process includes the main inputs and outputs for the animals at a given stage for a given length of time.

As an example of a growth stage based process, the organic milking stage (700009) is described in this section (see the full stage in Appendix B-1). So for organic milking cows, the animals spend 305 days in the milking phase of the system. Each of the inputs and outputs is described in terms of that 305 day period.

Data in Growth Stages

a. Outputs (products)

Typical output products for each stage include, an animal that has progressed through the stage, loss of animals through mortality, birth of young animals, and the output products milk and meat.

All bull calves are sold after two weeks of being raised on whole organic milk. A few female calves may be sold, but most are kept as replacements. Due to the few resources these have used during their brief stay at WCROC, relatively little is energy use or emissions are create for this output. Meat output is included as culled animals from some stages. Often cows are culled if they have health or other issues in calving, or fail to breed. More description of meat production is included below. There are occasional deaths of animals to injuries or accidents. Because of rarity and unpredictability, this has not been added to the model at this time. However, it may be added later if further data indicates it warrants inclusion.

Another output of each stage is animal manures. This is handled in a slightly backward fashion due to the software setup and interpretation of results. Manure outputs are listed as manure management inputs, negative inputs so to speak. This allows for certain air emissions quantities to be set up for each unit of animal waste produced. Waste volumes are established based on data from Lorimor *et al*. (Lorimor, Powers et al. 2004). N_2O calculations are similarly negative inputs based on manure. More information on manure and manure emissions is below.

Milk, the major output of the system is produced in the Milking Stage. In this stage, outputs include the dry cows staying in the herd (95% of cows), the culled cows (5% of cows), roughly 3750 kg (Organic) or 6380 kg (conventional) of milk ready to be put in a storage tank, and a small portion of milk that is not suitable for consumption.

b. Inputs

Each stage includes an animal input from a precious stage in the LCA. For example, a cow in the milking stage came from the previous birthing stage, which had a milking cow and calf as outputs.

Feed rations for each stage are organized based number of days a ration is given to each animal (1 p [part] = 1 day's ration). One day's feed includes the mix of several ingredients that provide a balance diet. The total number of days on each feed type are an average of different feed rations that would be provided for animals in a given stage, during their time at WCROC. Cows calving in spring will have 130 days of pasture diet and 199 days of non-pasture during their milking cycle. Whereas, cows calving in fall will spend 69 days on pasture and 236 days of non-pasture rations during their milking cycle. So in combining these two sets of cows, the average organic cow will receive 100 days of ration L (pasture) and 206 days of ration M (winter).

As was noted above, infrastructure is not currently included in this study. However, pasture activities have been added so that energy used for production and maintenance of pasture grasses can be included.

Water use is inconsistently applied to the model at this time. It is included for the milking stage, but is not for other stages. During the milking stage, water and specifically hot water were in used in a building that had flow meters to measure water use. Most other animal waters on WCROC fields are direct plumbed to wells with limited ability to monitor. Vehicle data is not yet a component of the model.

2. Milking Operation

The major foreground use of energy in the dairy system is in the milking harvesting operations. This includes collection of milk from the animal, cooling of the milk, and cleaning of the facilities. Other activities are needed to support this work, includes building heating/cooling, employee shower and cleaning space, and office equipment. Data from these activities was collected during energy audits in which sensors were added to water and power systems. In addition, workers were questioned about equipment that used diesel fuel. After reviewing the data, two main patterns were seen in energy use, overhead energy use and marginal units of energy for each additional animal added to the system. All milking parlor data was divided into one of these two categories. This allows for relatively easy changes to either the overhead units or the marginal units in evaluating energy-saving technologies.

a. Milking Facility Overhead Inputs

Overhead inputs (see appendix B-5) are considered resources that are static and don't depend on the actual number of cows milked. For example, hot water for washing milking equipment following twice daily milkings doesn't change with animal numbers. Similarly, facility heating is not typically influenced by the number of animals being milked. For calculation of this data, each individual overhead energy use item was divided by an average of 192 cows to get the per cow per day energy use for each area of energy consumption.

b. Animal Dependent Marginal Units

Energy use of a number of processes in the milking parlor are dependent on the number of animals being milked daily. A good example of this is the use of energy for cooling milk. As more cows are being milked, more energy is needed in the milk cooling process. The vacuum system needed to extract milk from the cows also used energy in an animal dependent fashion. Since both cooling and vacuum extraction are fairly energy intense, these were separated out into a different calculation than the overhead inputs. In terms of the LCA effort, the energy in these processes represents what is needed to remove one days' worth of milk from one cow (roughly 21lbs for conventional cows). Because the organic and conventional herds use different types of cooling compressors, a significant energy difference was observed between the amount of energy needed to remove milk from the two different herds (organic: 0.184 kWh/animal/ day, conventional: 0.465 kWh/animal/day).

3. Dairy feed and Ingredients

There are a number of different feed mixes that correspond to the particular growth stages and seasons. A number of feed ingredients are blended to provide each stage of animal growth with the correct balance of protein, calories, and minerals for proper development. The feed ingredients vary considerably in their properties and can be mixed at different ratios depending on availability and cost. Because of the complexity of maintaining separate organic versus non-organic feed for the number of different growth stages, feed mixes for the all replacement animals are made with organic feed even if the cow will ultimately go into the conventional herd. Table IV-2 lists the feed mixes used for animals in during the different stages and seasons.

Table IV-2 Diets Used For Dairy Herd

ID #	Feed Ration Name
700011	Milk (organic)
700012	Grain Mix (total of ingredients)
700013	Summer Weaned Heifer Mix
700014	Winter Weaned Heifer Mix
700015	Summer Yearling Mix
700016	Winter Yearling Mix
700017	Summer Bred Heifers
700018	Winter Bred Heifers
700021	Organic summer 2014 Milking
700022	Organic Summer Pasture milking
700023	Winter Organic Milking
700024	Summer Conventional Milking
700025	Winter Conventional Milking Rations
700043	Spring Conventional Rations
700019	Summer Dry Cow
700020	Winter Dry Cow Diet

A number of ingredients (Appendix B-2) go into making up the different rations used for the cattle at WCROC. Between the farm and pasture land at WCROC, as much of the livestock feed as possible is produced on-site. Items such as minerals and soybean oils must be purchased from outside facilities making or marketing them. Because of the expense of purchasing organic grains and roughage, WCROC has converted much of its cropland to organic production. When needed, conventional products can be purchased at a significant cost savings compared to buying organic ingredients. The availability of ingredients can change, meaning that diets may have nonstandard ingredients at some points. A good example of this was the summer 2014 diet, which included sugar beet pulp. Because sugar beet pulp became available for short time at a competitive price, it was included in the conventional herd's diet. However, it was decided not to include this as part of the current LCA work as it was a transitory diet.

A set of selection processes for choosing the LCA data source for each feed ingredient was developed (Appendix B-2). These processes link to a number of LCA database sources for a given ingredient. For the current research, only WCROC LCA cropping data for feed ingredients was used in calculating energy and emissions. However, there are a number of other LCA data sources from national and international databases that describe ingredients needed for dairy feeds.

a. Feed Preparation and Delivery

Though energy for production of the major feed ingredients grown on the farm is included in the cropping system energy use, they are usually further processed or mixed into a blended ration. Depending on the ration and situation, this can involve grinding, shredding, or mixing materials. For the WCROC dairy, this is typically mixing forage, grain, and mineral supplements using a tractor powered ration mixing wagon. The wagon mixes feed, is driven to herd in a pen or pasture, and then dispenses feed on the ground or into a bunker. This data is currently under review and not included at this time.

b. Pastures and Grazing

WCROC has been farming the same ground for over 100 years. Essentially all land used for the dairy operation has been in agricultural production since that time. Over the last several decades, relatively little change has occurred in the overall use of crop land and pasture.

Within the last 10 years, all pasture land has changed to organic pasture. Rather than use chemicals to control weeds in the pasture and along the fence lines, staff using tractor mounted mowers (open pasture) and string line trimmers (fences) to remove weeds not grazed by cows.

4. Milk and Meat Leaving the system

a. Milk Production

Currently milk production rates for the study include only the 2014 milk production data (Table IV-3). 2015 and 16 data have been collected, but not yet integrated into the work. Milk production at WCROC varies significantly over the year, with production peaking in spring and fall after the calving season. During the production period analyzed, the organic herd averaged 89 cows and the conventional herd 104 cows.

Table IV-3 Average kgs of Milk per Cow per Day

Month	Conventional	Organic
JAN	19	14
FEB	20	14
MAR	22	13
APR	22	13
MAY	27	12
JUN	23	14
JUL	21	12
AUG	20	12
SEP	17	12
OCT	18	11
NOV	19	9
DEC	24	13
Average	**20.91**	**12.28**

The amount of energy, fat, and protein, in milk vary depending on a number of factors including feed and animal breed. In order to more clearly compare milk production from different dairy farms and farming systems, formulas have been developed to relate milk properties to one standard. The international dairy Federation formula ((IDF) 2010) was used for this study:

$$\text{FPCM (kg/yr)} = \text{Production (kg/yr)} \times [0.1226 \times \text{Fat\%} + 0.0776 \times \text{True Protein\%} + 0.2534]$$

Using this calculation and the WCROC dairy data, organic milk had a correction factor of 97.01% and conventional milk had a correction factor of 96.83%.

b. Meat

Meat is also a measurable output in the dairy production process. For this work, meat production focused on dairy cows sold after the their productivity or health were not sufficient to stay in the herd. Typically this decision is made at the end of their milking cycle. In order to fairly place some of the energy and emissions burdens on the meat output at the end of the milking phase, an allocation factor is calculated that assigns environmental impacts to milk and meat.

The allocation factor used for this study is suggested by the International Dairy Federation ((IDF) 2010) and uses a physical ratio based on the mass of beef and milk leaving the system. These were calculated for the organic and conventional systems and were 96% and 97% allocation to milk system for organic and conventional respectively. The balance was allocated to meat. This ratio was applied to culled animals leaving the milking process. Though some bull calves and sometimes heifer calves are sold shortly after birth, the small amount of meat leaving the system was not included at this time. Similarly, there are occasional sales of animals at different stages. However these are irregular, and not part of the overall dairy system.

IDF Formula for the allocation factor (AF) of milk and meat:

$$AF = 1 - 5.7717 \times (\text{Mass of Meat}/\text{Mass of Milk})$$

Occasionally animals succumb to injury or disease and pass away, thus leaving the system. This is not currently included in this analysis because of the low overall frequency of occurrence. Additionally, the animals most susceptible to health issues are calves whose body weight is fairly small.

5. Manure and Enteric Emissions

Manure and enteric emissions are a significant component of the greenhouse gas emissions from the dairy process. Enteric emissions refer to gases generated in the digestive process. Ruminants, such as cows, have much larger digestive systems they can process fibrous grasses. During the digestive process, a portion of the fibrous diet is converted to methane. This methane is a potent greenhouse gas and is included in the LCA assessment.

Dairy manures at WCROC are generated in two main manure management systems, pastures/dry lots and confinement (deep bedding packs/scrap lots/Stock piles) systems. A small amount of waste is present in wash water for the dairy parlor. Swine manure and bedding from deep bed swine housing system are combined with dairy manure in stockpiles. This along with other factors, discussed below, makes direct sampling of emissions from dairy manure difficult. Decomposition of manure releases greenhouse gases and depending on the handling and storage of manure, different greenhouse gases are released in different quantities. Factors such as temperature, oxygen, and the nutrients present in the manure all affect which gases are released and how much is omitted.

Manures collected at WCROC are spread on agricultural fields in spring and fall. The majority of manure is used for WCROC's organic cropping systems. The most common gases are released as either methane or N_2O and are created during storage period between applications. Methane is typically released when the manure decomposes without oxygen. This occurs in storage pits and piles where oxygen cannot penetrate into the material. N_2O is formed when decomposition occurs in the presence of oxygen. Therefore, two separate calculations are used to determine the amount of emissions from manure at WCROC.

Actual manure emissions are extremely difficult and expensive to track. Therefore, calculations of emissions are used to estimate the amount of greenhouse gases being emitted. In this system, emissions were calculated from the point of leaving the animal until they leave the storage piles and are moved to fields. Emissions from manure that is applied to fields are a component of the cropping system assessment and are discussed above.

Table IV-4 Enteric Emissions Based on Diet

Diet		kg/day /animal
1B	Grain Mix (total of ingredients)	0.0090
2C	Summer Weaned Heifer Mix	0.0861
2D	Winter Weaned Hiefer Mix	0.1560
3E	Summer Yearling Mix	0.1102
3F	Winter Yearling Mix	0.2195
4G	Summer Spring Heifers	0.1515
4H	Winter Spring(Bred) Heifers	0.2930
5K	Organic summer 2014 Milking	0.1644
5L	Organic Summer Pasture milking	0.2612
5M	Winter Organic Milking	0.3804
5N	Summer Conventional Milking	0.3896
5O	Winter Conventional Milking	0.3852
5P	Spring Conventional Rations	0.3872
6I	Summer Dry Cow	0.1928
6J	Winter Dry Cow Diet	0.2930

a. Enteric Emissions Calculations

The main factors impacting enteric emissions are the nutrient concentrations of the animal's diet and the amount of material that the animal is consuming. WCROC nutrient levels and diets were used to calculate enteric emissions.

The calculations are based mostly on the dry matter intake of the animal and animal size. The formula used for calculating enteric emissions was equation 10.21 from IPCC (IPCC 2006).

b. Calculations for Manure Volume In LCA

Estimation of manure volumes and solids were done data found using ASAE Manure Characteristics Publication (ASAE 2005). Body mass, dry mater intake, Milk volumes, and milk are to calculate total manure for animals in different stages.

c. Calculations of Emissions

Methane emissions estimates use manure and volatile solid calculations from the ASAE manure characteristics guidebook and IPCC tier 1 calculations from the IPCC report (vol. 4, chapt. 10 (IPCC 2006). These calculations also involve other factors that influence the decomposition of manure, such whether the manure is in an anaerobic environment and the temperature of manure in storage.

Nitrous Oxide (N_20) calculations for this work used ASAE Manure characteristics formulas (Section 5 equation 14) for nitrogen excretion of animals in the milking stage. IPCC tier 1 estimates were used for N_2O nitrogen excretions from other stages. Final emissions of N_2O

from the soil. IPCC 2006 Chapter 11 (IPCC 2006) equations for N_2O emissions on agricultural soils and pastures.

d. Integration of Enteric and Manure Related Emissions in LCA

Manure emissions are added to each growth stage as three separate inputs, each a 'negative input' to the system. Since different diets can influence the amount of emissions of each greenhouse gas, each diet has separate N_20, Manure Methane, and enteric emission outputs. Therefore, some calculation are based on known diet properties and others based on historic emission formulas. For each growth stage (Appendix B-1), 1p is 1 daily unit of a given emission type. Therefore, the organic milking phase has 100 days (100p) of emissions from feed L and 205 days (205p) from feed M.

Table IV-5 Methane Emissions From Dairy Manure

Diet	CH3 kg/day
Summer Weaned Heifer Mix	0.0120
Winter Weaned Hiefer Mix	0.0177
Summer Yearling Mix	0.0143
Winter Yearling Mix	0.0252
Summer Spring Heifers	0.0165
Winter Spring(Bred) Heifers	0.0330
Organic summer 2014 Milking	0.0176
Organic Summer Pasture milking	0.0251
Winter Organic Milking	0.0343
Summer Conventional Milking	0.0310
Winter Conventional Milking	0.0307
Spring Conventional	0.0309
Summer Dry Cow	0.0232
Winter Dry Cow Diet	0.0340

Table IV-6 N_2O Emissions from Dairy Manure

Diet		Kg/day
2*	Heifer	0.001397
3*	Yearling	0.002595
4*	Bred Heifer	0.003793
5K	Organic Summer 2014	0.01934
5L	Organic Summer Typical	0.017615
5M	Organic Winter	0.008808
5N	Conventional Summer	0.020097
5O	Conventional Winter	0.009186
5P	Conventional Spring	0.009186
6I	Organic	0.004893
6J	Conventional	0.005687

C. Dairy System Energy and Emissions Findings

Using the data collected about all the activities occurring and materials being brought into and out of the dairy system, a model was developed to assess fossil fuel use and greenhouse gas emissions. It should be specifically noted that this model is continuing to evolve as additional data is still being collected and entered. Therefore, these results will likely change as new data is added. The most current information on the project will be available at: http://wcroc.cfans.umn.edu/research-programs/renewable-energy.

Before discussing specific results of the system, it is important to note the limitations of the current model. It was noted in the cropping section of this document (sections I and II) that analyzing individual crops in an organic rotation is problematic due to the beneficial interactions between different crops and cover crops needed to successfully produce organic feed ingredients. The cropping system used to supply feed for the dairy operation is an important part of the dairy system model. In the current model, dairy energy and greenhouse gas results rely upon the individual cropping results discussed above. It is expected that when organic cropping as is evaluated as a system, the organic crop results will change significantly. These changes will be brought into the dairy system and it is likely that the organic dairy will have higher fossil energy use and greater

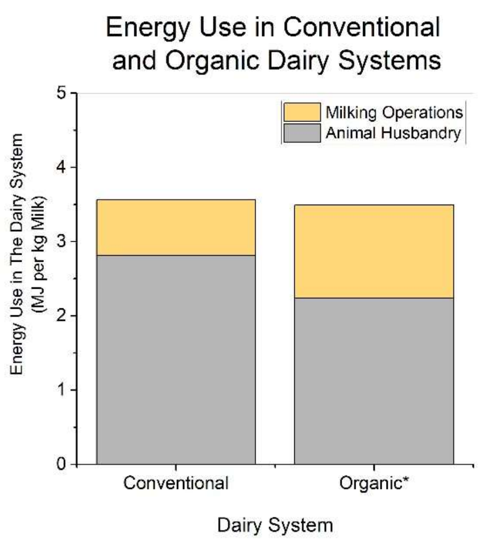


Figure IV-2 Fossil Energy Use in Conventional and Organic Dairy Systems. Fossil energy use as determined by cumulative energy demand method (SimaPro 8.1, CED 1.0.8). The data is graphed as megajoules of fossil energy per kilogram of fat and protein corrected milk. *Organic results likely to experience change as cropping systems are reanalyzed.

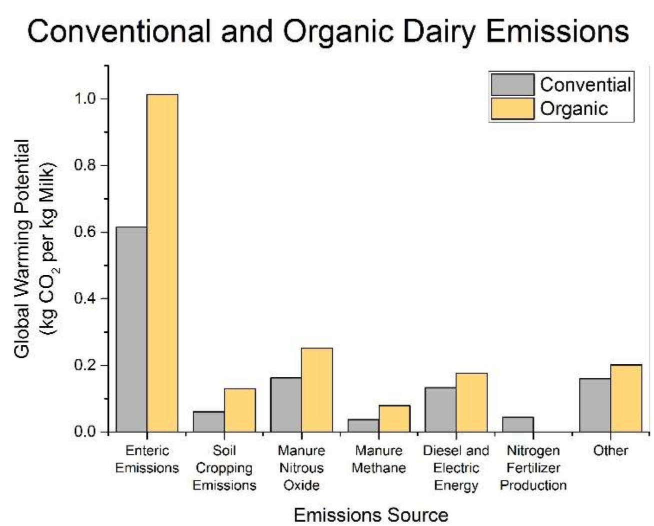


Figure IV-3 Dairy Greenhouse Gas Emissions in Conventional and Organic Dairy Systems. Greenhouse gases emissions were calculated using the GWP 100A method (IPCC 2013, in SimaPro). Greenhouse gas emissions were measured as CO2 equivalents per kilogram of fat and protein corrected milk.

greenhouse gas emissions. However, the extent of these changes can only be determined when both organic and conventional cropping systems undergo this more holistic analysis.

Fossil energy use in the dairy system is shown in figure IV-2. In both the conventional and organic dairy, milking operation energy use (milk extraction, cooling, and related activities) was significantly less than the energy needed to produce livestock feed. Because of greater milk production by conventional cows with a the same facility overhead energy use, the fossil energy use in milking operations for conventional milk was much lower than organic the animal husbandry category is used to describe all the activities related to production and delivery of crops to the dairy herd. In terms of animal husbandry, fossil energy is currently higher in the conventional herd. This may change as a broader analysis of organic cropping is completed.

Greenhouse gas emissions (GHG) were analyzed using the GWP 100A (IPCC 2013) method in SimaPro. Total greenhouse gas emissions were 1.21 and 1.85 kg CO_2 Eq. per kg of milk for conventional and organic milk respectively. Information for GHG data, shown in figure IV-3, was grouped into categories of emission sources. Enteric emissions was the single largest contributor to global warming potential. Results indicate that the organic system had higher emissions than the conventional system. This is probably due to the increased amount of feed organic animals require to produce 1 kg of milk. Daily feed intake is a large component of enteric emissions. Emissions from manure management were also fairly significant. Again, the higher feed intake per kg of milk produced likely resulted in higher emissions in the organic system. Similarly, cropping emissions were higher for the organic system. Direct energy use, as measured by diesel fuel and electricity was also greater in organic systems. Although nitrogen fertilizer emissions were higher in the conventional systems, the increase was fairly small relative to the higher enteric, soil, and manure methane emissions in the organic system related to lower productivity.

D. Dairy System Energy Enhancements

As is discussed in other sections of this report, enhancements are being made to the WCROC dairy to add renewable energy production technologies, replace fossil energy use with different equipment, and add energy conservation measures. Figure IV-3 has a rough schematic of the changes being implemented in the system.

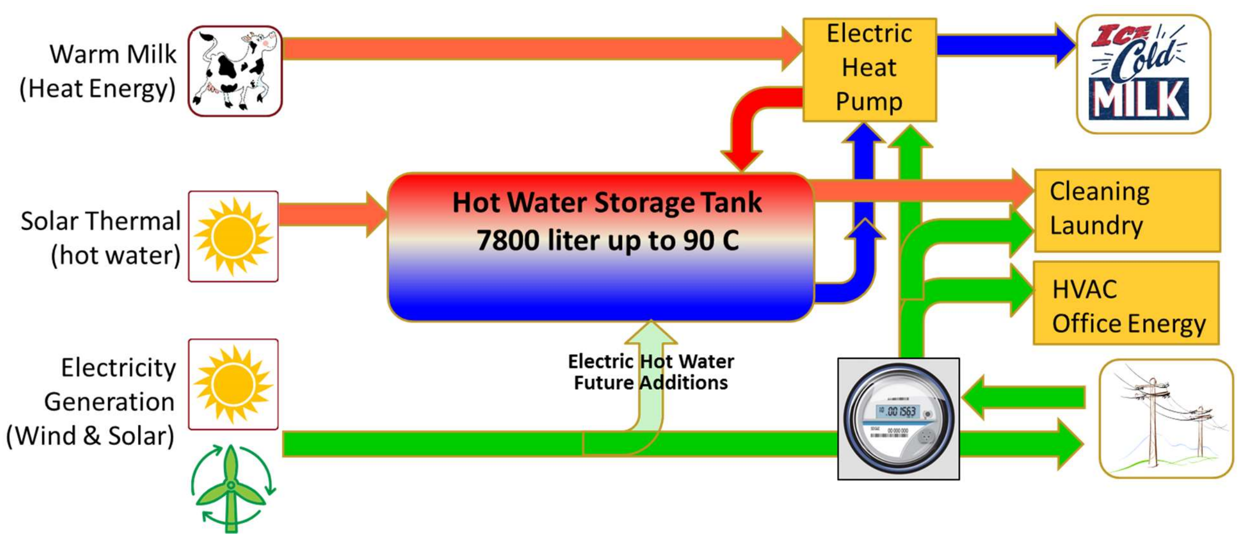


Figure IV-4 Schematic Of The Renewable Energy And Conservation Integrations In The Renewable Dairy System

As part of the LCA efforts for the dairy system, the fossil energy and greenhouse gas differences between the baseline dairy system and the energy enhance system were analyzed. The comparison used the conventional dairy and preliminary data on potential energy savings. Renewable electric and hot-water energy were the two types of additional energy available. The enhanced system was designed to use them to replace kerosene, natural gas, and fossil-based electricity. The additional energy available to the system was calculated (Table IV-7) based on engineering data and the model was analyzed to determine where this energy would replace existing fossil energy.

Table IV-7 Additional Energy Inputs

System	Yearly (MJ)	Daily (MJ)
Wind Electric	181,400	495
Solar Electric	266,400	730
Solar Thermal	18,615	100
Milk Heat Energy via Heat Pump	243,200	400
Total	**629,625**	**1725**

After reviewing the engineering plans and expected energy production from the renewable dairy system, it was decided that in the absence of measured energy production and consumption data there was not enough information to completely model the new system. The total amount of renewable energy additions were examined and found to be greater than the amount of likely energy being used. Therefore, it appeared that simply substituting renewable energy for many of the fossil based energy systems being used now would be the easiest way to implement the energy changes. Once energy production and consumption data is available for the renewable energy additions, the model can be revised to directly look at each individual piece of equipment.

Initial findings for energy reduction were that improvements to the milking parlor in the renewable energy dairy would reduce fossil energy use by roughly 77% (Table IV-8). A large amount of this was the replacement of electricity and natural gas. The total reduction for the system was 16%

Table IV-8 Fossil Energy Reduction in Renewable Dairy System

Area of Fossil Energy Use	Base System	Renewable System	Percent Savings
Feed Production/Husbandry	2.86	2.86	0%
Milking Parlor	0.743	0.171	77%
Total	**3.603**	**3.031**	**16%**
MJ per kg of energy and fat corrected milk			

In terms of global warming potential (CO_2 emissions), the renewable energy dairy parlor had a reduction of 93% of CO_2 emissions (Table IV-9). Overall, this reduce fossil energy use in the dairy system by around 2%.

Table IV-9 Global Warming Potential Reduction in the Renewable Dairy System			
Area of Fossil Energy Use	**Base System**	**Renewable System**	**Percent Savings**
Feed Production/Husbandry	1.18	1.18	0%
Milking Parlor	0.0317	0.0021	93%
Total	**1.217**	**1.182**	**2%**
Units are kg CO_2 per kg energy and fat corrected milk			

This data indicates that the renewable energy changes to the dairy parlor can reduce the environmental impacts of the dairy on fossil energy depletion and greenhouse gas emissions. They also show the important impacts of the feed production system and that to greatly reduce impacts, the feed and manure systems should be addressed as well.

E. Future Work On the Dairy System

As new data is available from the energy auditing team and crop production team, the dairy system LCA will be updated. Additional work is also planned on comparing the organic and conventional system after work is done to better analyze the organic cropping rotation system. The current analysis relies on individual organic crops outside of the rotation. As discussed in section 2, it is critical to understand how an individual crop functions with in the rotation and how the inputs the rotation is a whole influence the fossil energy and greenhouse gases for an individual crop.

Appendix A: Individual Crop Processes

These are the working tables used for developing cropping processes and are designed to provide background on information used in developing the cropping models. Though they do not include the full LCA data being used to describe production of a particular crop, they offer and explanation for many of the major components analyzed.

Notes:

- Crops data here is as the product is at harvest in the field- no transportation, no drying.
- Units have been changed to metric to prepare for entry into modeling software

Common Conversions Used

base on https://www.extension.iastate.edu/agdm/wholefarm/html/c6-80.html

1 acre = .4045 Hectares

1 kg = 2.204lbs

1 Bushel/Acre = 62.77 kg/hectare (CORN)

1 Bushel/Acre = 67.25 kg/hectare (WHEAT & SOYBEANS)

1 pound/acre = 1.121 (1.1) kilograms/hectare

1 ton/acre = 2.242 MG/hectare

Conventional Crops

Table 1 Conventional Corn Production Process

	kg/ha
Conventional Corn Yield =	10152.7

Summary of Tillage

Activity	HA
30.5' Field Cultivate	1.00
Planting 12 row	1.00
45' Herbicide Spraying	1.00
Fertilzer application	0.00
15' Combining	1.00
Corn Transport	1.00
8-row Stalk Chopping	1.00
12.5' Disk-Chisel	1.00

Seed Input

24.5186 kg/ha

Summary of Chemical Use

	lbs/acre	kg/acre	kg/ha
Acetochlor	0.8203	0.3722	**0.9199**
Clopyralid	0.0831	0.0377	**0.0932**
Flumetsulam	0.0263	0.0119	**0.0294**
glyphosate	0.7500	0.3403	**0.8411**

Summary of Fertilizer Use

Fertilizer	kg/ha
NH3 (anhydrous ammonia)	127.59009
Mono ammonium Nitrate	42.031875
Triple Super Phosphate	3.7361667
Di ammonium phosphate	9.3404167
potassium chloride	12.932885

For these inputs, see file: Corn, Conv Fertilizer.xlsx

Other Activities

Drying

Drying is calculated based on the amount of water that needs to be removed.

Table 2 Conventional Silage

Yield

	tons/ac	Tonnes/HA
Corn Silage	18.16	40.72

Field Operations

Activity	HA
30.5' Field Cultivate (1st Pass)	1
12-row planter	1
45' Herbicide Spraying	1
Fertilizer Application	1
Silage Harvest chopper/truck	1
12.5' Disk-chisel	1

Seed Input

24.5186 kg/ha

	lbs/acre	kg/acre	kg/ha
Acetochlor	0.8203	0.3722	**0.9199**
Clopyralid	0.0831	0.0377	**0.0932**
Flumetsulam	0.0263	0.0119	**0.0294**
glyphosate	0.7500	0.3403	**0.8411**

Fertilizer Use

Fertilizer (lbs element)	kg/ha
NH3 (anhydrous ammonia)	**127.590**
Mono ammonium Nitrate	**42.032**
Triple Super Phosphate	**3.736**
Di ammonium phosphate	**9.340**
muriate of potash	**12.933**

Other Activities

The process ends with silage on farm.
Silage then needs to be piled/bagged.

Table 3 Conventional Alfalfa Haylage

Yeilds

	Tons/Ac	Mg/ha	Mosture average
Haylage Yield	30	67.2677	67%

Field Operations

***2,4,4 Harvests in Years 1,2,3 respectively**

	HA
Seeding	
Seed Drill	1
30.5' Field Cultivate	1
20' roller	1
3 Years of Harvest	
10.5' Haybine	10
30' Wheel rake	10
Forage Wagons	10
7.5' Forage Harvester	10
9' Bagger	tons
Final Tillage	
Moldboard Plow	1

Seed

	kg/HA
Alfalfa	16.815
Wheat	100.89

Summary of Fertilizer Use

Anhydrous Ammonia	162.07
Rock Phosphate	164.85
Potassium Chloride	93.42

Table 4 Conventional Soybeans

Yield

bushel/acre	43.4	**kg/ha**	**2918.65**

Yields based on all conventional soybean fields 10 acres or greater.

Summary of Tillage

Process ID	Activity	Ha
	30.5' Field Cultivate corn residue	1
	12-row seeding	1
	Soybean rolling, 20' Roller	1
	45' Herbicide Spraying 1st Pass	1
	45' Herbicide Spraying 2st Pass	1
	20' Combining	1
	17' Chisel Plowing	1

Summary of Chemical Use

	g/ha	kg/ha
acetochlor	157.6187	0.1576
glyphosate	1540.8551	1.5409
lamda-cyhalothrin	3.9405	0.0039
lactofen	27.3644	0.0274
clethodium	26.2698	0.0263

For these inputs, see file: Soybean, Conv Chemical 2013 to 2015.xlsx

Seeding

kg/ha	**44.836**

Summary of Fertilizer Use

Not Regularly Used

Organic Crops

Table 5 Organic Corn

Yield

	bu/acre	Mg/ha
Organic Corn Yield =	148.7	10811.5

Summary of Tillage

Activity	Hectares
30.5' Field Cultivate (1st Pass)	1
30.5' Field Cultivate (2st Pass)	1
12-row planter	1
30' Weed Harrowing	1
12-row Row Cultivating	1
15' Combining	1
8-row Stalk Chopping	1
12.5' Disk-chisel	1

Seed 24.52 kg/ha

Summary of Chemical Use

No chemicals, this is organic

Summary of Fertilizer Use

Manure is used. Data not shown here.

Table 6 Organic Silage

Yield

	MG/HA	tons/ac
Corn Silage	40.72	18.16388

Summary of Tillage

Activity	HA
30.5' Field Cultivate (1st Pass)	1
30.5' Field Cultivate (2nd Pass)	1
12-row planter	1
30' Weed Harrowing	1
12-row Row Cultivating	1
Silage Harvest chopper/truck	1
12.5' Disk-chisel	1

Seed

24.5186 kg/ha

Summary of Chemical Use

No chemicals, this is organic

Summary of Fertilizer Use

For manure applications, there is an extra file
refer to organic corn grain

Table 7 Organic Alfalfa Haylage

Yeilds

	Tons/Ac	Mg/ha	Mosture average
Haylage Yield	30	67.2677	67%

Field Operations

***2,4,4 Harvests in Years 1,2,3 respectively**

	HA
Seeding	
Seed Drill	1
30.5' Field Cultivate	1
20' roller	1
3 Years of Harvest	
10.5' Haybine	10
30' Wheel rake	10
Forage Wagons	10
7.5' Forage Harvester	10
9' Bagger	tons
Final Tillage	
Moldboard Plow	1

Seed

	kg/HA
Alfalfa	16.815
Wheat	100.89

Summary of Fertilizer Use

Manure use varies considerably

Table 8 Organic Soybean

Yield

kg/ha	2690	bu/acre	40

Yields based on all conventional soybean fields 10 acres or greater.

Field Operations

Activity	HA
30.5' Field Cultivate corn residue	1
12-row seeding	1
Soybean rolling, 20' Roller	1
Harrowing	1
Cultivating	1
20' Combining	1
17' Chisel Plowing	1

Seeding

	kg/ha
Soybean seed	44.836

Chemical Use

No Chemicals Used

Fertilizer Use

Fertilizer Not Used in This Phase of Rotations

Appendix B: Dairy LCA Tables

Appendix B-1 Animal Growth Stages

700003 Bull Calves – This process follows newborn bull calves through the first 15 days of development until they are able to be sold. These calves will be fed a milk diet. They are typically sold before being transitioned to a grain-based diet. Initial Housing is provided in enclosed build with minimal heat. Beginning weight is 36.3 kg and ending late weight 40.8 kg.

700002 Heifer Calves – heifer calves are taken from birth to transitioning through the weaning stage (60 Days). Initially they are fed a milk diet, which for simplicity reasons is organic milk in WCROC's dairy system. During this process, they transition to an organic grain diet. Housing is provided in an enclosed building fort the first few days, then calf huts with several other animals of the same stage. Beginning weight is 36.3 kg and ending weight is 90.7 kg.

70004 Weaned heifers – These animals are between 60 days and 13 months old (329 days). Depending on the season they would be fed with one of two diets, the summer diet or the winter diet. All feed would be organic at this point. Generally these animals are kept in pasture during this stage, in both winter and summer. Starting weight is 90.7 kg and ending weight is 226.8 kg

70005 Yearling Heifers- Yearling heifers are between 14 and 18 Months (149 Days). They have a summer and a winter diet, which is organic. They are kept in pasture at this stage. Yearling heifers start at 226.8 kg and finish the stage at 363.0 kg.

70006 Spring (Bred) Heifers- These animals are provided a summer and a winter diet, which is organic. They are kept in pasture at this stage. Spring heifers start out weighing 363 kg and in that of 499kg

700007 Bulls- this process takes the bull from the newborn to mature stage. It is not based on WCROC data, but is more a generalized process to include the presence of the bull in the process. Output of Semen is currently set at 20,000 units.

700009/700045 Milking Cows- In this stage, the cows have previously given birth to the calves and are actively producing milk. Organic cows will be grazing on the pasture in summer, with a supplement. In winter, they will be held in a paddock closer to the milking parlor. Conventional cows will remain in feedlots. This stage lasts 305 days.

700008/700046 Dry Cows- the dry cow stage is set up for cows who have finished producing milk and are gestating a new calf. They enter the stage at lower weights (521.5 kg Organic, 612.25 conventional) due to calving and milk production in the previous stage. During this stage, they will gain weight (590 kg Organic, 680 kg Conventional) until they are ready to begin milking again.

Main inputs and outputs for each growth stage

Process: Calves, Bull (700003)	Quantity	Unit
Output Products		
Bull calf at 1 week 35 kg (WCROC 700003), US-MN, U	0.95	p
Input Materials/Fuels		
Organic Newborn bull calf (700010b), WCROC, US-MN, U	1	p
Feed Ingredient, Organic Milk for Calf Feed, Source Selection, 700042, WCROC,	75	l

Process: Calves, Heifer (700002)		
Output Products		
Mature Heifer Calf at 91 kg (WCROC 700002), US-MN, U	1	p
Input Materials/Fuels		
Newborn heifer calf (700045c), WCROC, US-MN, U	1	p
Dairy Diet 1A, Organic Milk, 700011, WCROC, US- MN, U	60	p
Dairy Diet 1B, Calf Grain Mix, 700012, WCROC, US- MN, U	45	p
Enteric Emissions for [1AB] Heifer Calf Diet, WCROC, (700051), US-MN, U	60	p
housing, shed, WCROC (700067), WCROC, US- MN, U	14	p
Housing, calves, Huts, WCROC (700069), WCROC, US- MN, U	46	p

Process: Weaned Heifer (700004)		
Output Products		
Mature weaned heifer at 227kg (WCROC 700004), US-MN, U	1	p
Input Materials/Fuels		
Dairy Diet 2C, Summer Yearling Heifer, 700013, WCROC, US- MN, U	130	p
Dairy Diet 2D, Winter Yearling Heifer, 700014, WCROC, US- MN, U	199	p
Enteric Emissions for [2C] summer weaned heifer diet, WCROC, (700052), US-MN, U	130	p
Enteric Emissions for Winter Weaned Hiefer Mix [2D] (700053), WCROC, US-MN, U	199	p
Housing, pasture, WCROC, 700073, US-MN, U	50	m2
Housing, Weaned heiffer, Shed, WCROC (700070), WCROC, US- MN, U	50	p
Manure man.for diet [2C] Summer Weaned Heifer, WCROC, 700095, US-MN, U	0	p
Manure man.for diet [2D] winter weaned heifer, WCROC, 700096, US-MN, U	199	p
Mature Hiefer Calf at 91 kg (WCROC 700002), US-MN, U	1	p
N_2O Emissions for [2C] summer weaned heifer diet, WCROC, 700108, US-MN, U	130	p
N_2O Emissions for [2D] Winter Weaned Heifer diet, WCROC, 700109, US-MN, U	199	p
Water in winterized animal waterer (WCROC), 700071, US-MN, U	4000	l

Process: Yearling Heifer (700005)	Quantity	Unit
Output Products		
Yearling heifer end at 362.9 kg (WCROC 700005), US-MN, U	1	p
Input Materials/Fuels		
Dairy Diet 3E, Summer Stage 3 Mix, 700015, WCROC, US- MN, U	49	p
Dairy Diet 3F, Winter Stage 3 Mix, 700016, WCROC, US- MN, U	100	p
Mature weaned heifer at 227kg (WCROC 700004), US-MN, U	1	p
Enteric Emissions for Summer Yearling Hiefer Mix [3E] (700054), WCROC, US-MN, U	49	p
Enteric Emissions for Winter Yearling Hiefer Mix [3F] (700055), WCROC, US-MN, U	100	p
Housing, pasture, WCROC, 700073, US-MN, U	30	m2
N_2O Emissions for [3E] Summer Yearling diet, WCROC, 700110, US-MN, U	49	p
N_2O Emissions for [3F] Winter Yearling diet, WCROC, 700111, US-MN, U	100	p
Manure man.for diet [3E] Summer yearling mix, WCROC, 700097, US-MN, U	49	p
Manure man.for diet [3F] Winter Yearling Mix, WCROC, 700098, US-MN, U	100	p

Process: Spring Bred Heifers (700006)		
Output Products		
Spring (Bred) Heifers end at 498.95 kg WCROC (700006), US-MN, U	1	p
Input Materials/Fuels		
Yearling heifer end at 362.9 kg (WCROC 700005), US-MN, U	1	p
AI Semen Unit (700007b)	1	p
Dairy Diet 4G, Summer Spring Heifer, 700017, WCROC, US- MN, U	71	p
Dairy Diet 4H, Winter spring Hiefers, 700018, WCROC, US- MN, U	122	p
Enteric Emissions for Winter Bred Hiefer Mix [4H] (700057), WCROC, US-MN, U	122	p
Enteric Emissions for Summer Bred Hiefer Mix [4G] (700056), WCROC, US-MN, U	71	p
N_2O Emissions for [4H] Winter Bred Heifer diet, WCROC, 700113, US-MN, U	122	p
N_2O Emissions for [4G] Summer Bred Hiefer diet, WCROC, 700112, US-MN, U	71	p
Manure man.for diet [4G] Summer Sprint Heifers, WCROC, 700099, US-MN, U	71	p
Manure man.for diet [4H] Winter Bred Heifers, WCROC, 700100, US-MN, U	122	p

Process: Calf Birthing, (7000010)	Quantity	Unit
Output Products		
Organic Milking Cows, (7000010a) WCROC, US-MN, U	1	p
Organic Newborn bull calf (700010b), WCROC, US-MN, U	0.5	p
Organic Newborn heifer calf (700010c), WCROC, US-MN, U	0.5	p
Input Materials/Fuels		
Spring (Bred) Heifers end at 498.95 kg WCROC (700006), US-MN, U	0.333	p
Organic Dry/Gestating Cows, (700008) WCROC, US-MN, U	0.666	p

Process: Organic Milking (700009)		
Output Products		
Organic Drying Milking Cow, (700009a) WCROC, US-MN, U	0.95	p
Organic Milk (700009b) WCROC, US-MN, U	5535	kg
Organic Culled Dry Milking Cow (700009c) WCROC, US-MN, U	0.05	p
Organic Milk not for human consumption, (700009d), WCROC, US-MN, U	0.001	kg
Inputs: Materials/fuels		
Organic Milking Cows, (7000010a) WCROC, US-MN, U	1	p
Dairy Diet K, Organic Summer 2014 Milking, 700021, WCROC, US- MN, U	0	p
Dairy Diet L, Oganic Summer Pasture Milking, 700022, WCROC, US- MN, U	100	p
Dairy Diet M, Winter Organic Milking, 700023, WCROC, US- MN, U	206	p
Enteric Emissions for [5L] Organic Summer Milking, (700059), WCROC, US-MN, U	100	p
Enteric Emissions for Organic Winter Milking [5M] (700060), WCROC, US-MN, U	206	p
N_2O Emissions for [5K] Organic Milking Summer 2014 diet, WCROC, 700114, US-MN, U	0	p
N_2O Emissions for [5L] Organic Summer Pasture Milking Diet, WCROC, 700115, US-MN, U	100	p
N_2O Emissions for [5M] Winter Organic Milking diet, WCROC, 700116, US-MN, U	206	p
Manure man.for diet [5K] Organic Summer 2014 Milk, WCROC, 700101, US-MN, U	0	p
Manure man.for diet [5L] Organic Summer Pasture, WCROC, 700102, US-MN, U	100	p
Manure man.for diet [5M] Winter Organic Milking, WCROC, 700103, US-MN, U	206	p

Process: Organic Dry Cows, (700008)	Quantity	Unit
Output Products		
Organic Dry/Gestating Cows, (700008) WCROC, US-MN, U	1	p
Input Materials/Fuels		
AI Semen Unit (700007b)	1	p
Organic Drying Milking Cow, (700009a) WCROC, US-MN, U	1	p
Enteric Emissions for Winter Dry [6J] (700065), WCROC, US-MN, U	30.5	p
Enteric Emissions for Summer Dry [6I] (700064), WCROC, US-MN, U	30.5	p
Dairy Diet 6J, Organic Winter Dry/gestating Cow, 700020, WCROC, US- MN, U	30.5	p
Dairy Diet 6I, Summer Dry/gestating Cow, 700019, WCROC, US- MN, U	30.5	p
Manure man.for diet [6I] Summer Dry Cow, WCROC, 700121, US-MN, U	30.5	p
Manure man.for diet [6J] Winter Dry Cow, WCROC, 700107, US-MN, U	30.5	p
N_2O Emissions for [6I] Summer Dry Cow diet, WCROC, 700122, US-MN, U	30.5	p
N_2O Emissions for [6J] Winter Dry Cow diet, WCROC, 700120, US-MN, U	30.5	p

Process: Conventional Calf Birthing (7000045)		
Output Products		
Conventional Milking Cows, (7000045a) WCROC, US-MN, U	1	p
Newborn bull calf (700045b), WCROC, US-MN, U	0.5	p
Newborn heifer calf (700045c), WCROC, US-MN, U	0.5	p
Input Materials/Fuels		
Spring (Bred) Heifers end at 498.95 kg WCROC (700006), US-MN, U	0.333	p
Conventional Dry/gestasting Cows, (7000046) WCROC, US-MN, U	0.666	p

Process: Conventional Milking (700044)	Quantity	Unit
Output Products		
Conventional Drying Milking Cow, (700044a) WCROC, US-MN, U	0.95	p
Conventional Milk (700044b) WCROC, US-MN, U	8600	kg
Conventional Culled Dry Milking Cow (700044c) WCROC, US-MN, U	0.5	p
Input Materials/Fuels		
Conventional Milking Cows, (7000045a) WCROC, US-MN, U	1	p
Dairy Diet N, Summer Conventional Milking, 700024, WCROC, US- MN, U	99.5	p
Dairy Diet O, Winter Conventional Milking, 700025, WCROC, US- MN, U	205.5	p
Dairy Diet P, Spring Conventional Milking, 700043, WCROC, US- MN, U	0	p
Enteric Emissions for Summer Conv Milking [5N] (700061), WCROC, US-MN, U	99.5	p
Enteric Emissions for Winter Conv Milking [5O] (700062), WCROC, US-MN, U	205.5	p
Enteric Emissions for Spring Conv Milking [5P] (700063), WCROC, US-MN, U	0	p

Process: Conventional Dry Cows, (700046)		
Output Products		
Conventional Dry/gestasting Cows, (7000046) WCROC, US-MN, U	1	p
Input Materials/Fuels		
AI Semen Unit (700007b)	1	p
Conventional Drying Milking Cow, (700044a) WCROC, US-MN, U	1	p
Dairy Diet 4G, Summer Spring Heifer, 700017, WCROC, US- MN, U	40	p
Dairy Diet 4H, Winter spring Hiefers, 700018, WCROC, US- MN, U	40	p

Process: Bull (700007)		
Output Products		
Bull 498.95 kg WCROC (700007a), US-MN, U	1	p
AI Semen Unit (700007b)	20000	p
Input Materials/Fuels		
Bull calf at 1 week 35 kg (WCROC 700003), US-MN, U	1	p
Dairy Diet 3E, Summer Stage 3 Mix, 700015, WCROC, US- MN, U	365	p

Appendix B-2 Feed Ingredients

A number of different ingredients are needed to provide a balanced diet needed for cows at different stages of growth. The list below includes those used in WCROC's feed mixes.

Ingredient	ID #
Conventional Corn grain	700026
Conventional Corn Silage	700027
Conventional Hay	700028
Conventional Soybean Meal	700029
Distillers Grain	700030
Mineral	700031
Oil or mineral oil? Soybean oil	700032
Organic Corn Grain	700033
Organic Corn Silage	700034
Organic Hay	700035
Organic Hay Silage/haylage	700036
Organic Soybean meal	700037
Organic Wheat	700038
Pasture mix	700039
Beet Pulp (conv?)	700040
Urea	700041
Organic Milk*	700042
Pasture grass	700049
wheat conv	700050

* milk used for feeding calves is often milked that is not high enough quality for human consumption. However, additional milk from health cows may be needed to be diverted to the feed supply chain to meet the needs of the young calves.

Appendix B-3 Milking Parlor Energy and Water Data

Description	Measured Units	Sensitivity	Daily Average	Total Liters Per Day	Units Per Cow Based On Herd of 192	Units Per Cow Independent of Herd Size
Building Cold Water Main	Gallons/day	Cow number	1269.8			
Water heater outlet flow	Gallons/day	Not Tested	363.9			
Pressure washer flow	Gallon/day	Not Tested	189.3	716.58	3.73	
Milk sink hot water flow	Gallon/day	Not Tested	174.2	659.42	3.43	
Milk sink cold water inlet flow	Gallon/day	Not Tested	67.3	254.76	1.33	
Tankwash HOT	Gallon/day	Not Tested	75.6	286.18	1.49	
Washing machine hot inlet	Gallon/day	Not Tested	54.1	204.79	1.07	
Washing machine cold inlet	Gallon/day	Not Tested	107.2	405.80	2.11	
Bathroom cold temp & flow	Gallon/day	Not Tested	22.3	84.41	0.44	
Bathroom hot temp & flow	Gallon/day	Not Tested	19.1	72.30	0.38	
Tankwash COLD	Gallon/day					
HVAC Electricity						
Furnace	kWh/day	Weather	9.6		0.0500	
Portable heaters	kWh/day	Weather	17	No Conversion Factor Needed	0.0885	
Utility room fan	kWh/day	Weather	5.3		0.0276	
Parlor fans NW	kWh/day	Weather	7.3		0.0380	
East fans (4/30/14)	kWh/day	?	5.1		0.0266	
Milking systems						
compressor & condenser 1 conv	kWh/day	cow# weather	48.4			0.465 kWh/anim
compressor & condenser 2 org	kWh/day	cow# weather	16.3			0.184 kWh/anim
Vacuum pump	kWh/day	Cow #	14.6			0.0760
Pressure washer	kWh/day	Not seen	5.1		0.0266	
Pressure washer ex fan	kWh/day	Weather	2.2		0.0115	
Milk line cleaning machine	kWh/day	Cow #	2.9			0.0151
Org. wash controller & agitator	kWh/day	Compr 2	0.7		0.0036	
Support Systems Electric						
Barn cleaner (4/22/14)	kWh/day	Not Tested	0.1		0.0005	
East side lights (4/22/14)	kWh/day	Not Tested	2.3		0.0120	
Cow stall receptacles (5/1/14)	kWh/day	Not Tested	3.5		0.0182	
Milk rm lights (5/1/14)	kWh/day	Not Tested	11.3		0.0589	
Lift pump	kWh/day	Not Tested	0		0.0000	
Washing machine	kWh/day	Not Tested	1.8		0.0094	
Dryer	kWh/day	Not Tested	23.5		0.1224	
Office receptacles (5/1/14)	kWh/day	Not Tested	4.4		0.0229	

V. References

(IDF), I. D. F. (2010). A common carbon footprint approach for dairy The IDF guide to standard lifecycle assessment methodology for the dairy sector. Brussels, Belgium, International Dairy Federation (IDF).

ASAE (2005). Manure Production and Characteristics. St. Joseph, MI, American Society for Agricultural Engineering.

Dalgaard, R., J. Schmidt, A. Flysjö, R. Dalgaard, J. Schmidt and A. Flysjö (2014). "Generic model for calculating carbon footprint of milk using four different life cycle assessment modelling approaches." Journal of Cleaner Production **73**: 146-153.

Downs, H. W. and R. W. Hansen (1998). Estimating Farm Fuel Requirements, Colorado State University. **Fact Sheet No 5.006**.

Edwards, W. (2014). Estimating the Cost for Drying Corn. Iowa, Iowa State University. **A2-31**.

Fitts, J. B. and H. D.D. (1981). Fuel Use for Sugarbeet Operations, Sugarbeet Research and Extension Reports. **Volume 12:177-182**.

Hana, M. and D. Schweitzer (2013). Diesel Fuel Consumption During Field Operations. Iowa State Research Farm Progress Reports, Iowa State University.

Helsel, Z. R. (2007). Fuel Requirements and Energy Savings Tips for Field Operations. Rutgers University, Rutgers, NJ, Rutgers University.

IPCC (2006). Emissions from Manure and Manure Livestock. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, IPCC. **Volume 4 Agriculture, Forestry and Other Land Use**.

IPCC (2006). GHG guidelines Volume 4 Chapter 11 Soil Emissions.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lorimor, J., W. Powers and A. Sutton (2004). Manure Characteristics, MWPS. **MWPS-18 Section 1**.

Thoma, G., J. Popp, D. Shonnard, D. Nutter, R. Ulrich, M. Matlock, D. S. Kim, Z. Neiderman, C. East, F. Adom, N. Kemper and A. Mayes (2010). Greenhouse Gas Emissions from Production of Fluid Milk in the US, University of Arkansas, Michigan Tech.