ENVIRONMENTAL ASSESSMENT OF PASTURE-BASED AND CONFINED DAIRY FARMS IN GEORGIA

by

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(Under the Direction of Mark Risse)

ABSTRACT

Information on the environmental impacts and resource consumption resulting from milk production in the southeastern U.S. is limited. The biological and physical processes of an intensively managed rotational pasture-based dairy and a confined dairy feeding mixed rations were modeled, and the greenhouse gas emissions, carbon footprint, erosion, nitrate leaching, phosphorus runoff, phosphorus accumulation in the soil, ammonia volatilization, and soil carbon sequestration were estimated for each farm. The results of this study were compared to measured and modeled data. Potential changes in management on each farm were modeled and the resulting changes in environmental impacts were quantified. The total water and electricity consumption and the primary components of each were measured. Water and electricity consumption per cow and per unit of milk produced were reported. The waste management system on the pasture-based dairy was monitored, and design parameters for future systems were developed.

INDEX WORDS: Dairy, Grazing, Pasture-based, Confined, Environmental impact, Carbon footprint, Life cycle assessment, LCA, Greenhouse gas emission, Water consumption, Electricity Consumption, Waste Management

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B.S.A.E., University of Georgia, 2009

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2010

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December 2010

DEDICATION

To my Mom, Dad, and Sister. Thank you for the love and support.

ACKNOWLEDGEMENTS

I would like to thank everyone whose time and knowledge contributed to my research. First and foremost is my major professor, Mark Risse. Thank you for all of your help, guidance, and support. I could not have asked for a better major professor. I would also like to thank the rest of my committee; I greatly appreciate all of your advice and help. I appreciate the education on water supply and electricity in agriculture from Everett Williams. I am also grateful for all of the help and advice given to me by Jason Perry, Brad Chandler, Cavel King, Tom Lawrence, Nick Hill, Cathy Felton, Hillary Tanner, Miguel Cabrera, Bobby Smith, Julia Gaskin, Melony Wilson, John Worley, Harvey Klaer, Vic Harrison, Kevin Samples, Matt London, and Heath Vinson. Thank you to my friends for all of the fun. Last but not least, I would like to thank my family and Annie for their love.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

Dairy farming in the United States has evolved towards confining cattle and feeding imported rations in order to achieve higher and more predictable milk production rates (Winsten and Petrucci, 2003). In contrast, pasture-based dairies feed cattle by growing grasses on the farm and rotating grazing cattle through carefully managed paddocks. The warm climate and soils in Georgia are conducive to pasture-based dairying. This combined with the state's milk deficit, meaning that it consumes more milk than it produces, has led many to consider the viability of pasture-based dairies in Georgia and the Southeast (Hill et al., 2008).

When considering each method of feeding dairy cattle, it seems that conventional dairies are trading quite a bit in exchange for higher milk production. For example, conventional dairies rely on intensive fossil-fuel usage during feed production (petroleum based fertilizers and pesticides), and during the transport of feed to the farm and waste away from the farm (Saunders and Barber, 2007). Alternatively, on a pasture-based dairy farm, cattle passively fertilize their food source and recycle their waste at the same time when cattle are allowed to graze and defecate on pasture.

Recent reports such as "Livestock's Long Shadow" (FAO, 2006) have concluded that environmental impacts must be considered in order to gain public and or regulatory approval for any large scale agricultural operation. Therefore, it is worthwhile for the Georgia and the

Southeast dairy industry to utilize and evaluate existing tools for determining the impacts that their farms have on the environment.

Even though feeding confined dairy cattle grain will likely continue to result in higher milk production per cow (White et al., 2002), pasturing cattle on grass might consume less resources and reduce environmental impacts per unit of milk produced. Quantifying the environmental impacts associated with different dairy production methods in Georgia will improve the understanding of how various choices in the management of a dairy will impact the environment. This understanding could inform decisions by the dairy industry to reduce the impact that the production of milk has on the environment.

Objectives

It would be difficult, if not impossible, to directly measure all of the environmental impacts on any dairy (Rotz et al., 2009). This project focused on modeling a wide spectrum of environmental impacts, and conducting small scale on-farm monitoring to obtain data to address specific knowledge gaps. More specifically, a life cycle assessment of pasture-based and confined dairies analyzed the sustainability of both systems by quantifying environmental impact categories such as erosion, nutrient runoff, carbon footprint, and greenhouse gas emissions that result from each production system. Also, on-farm monitoring efforts provided data on electricity and water usage for both types of dairies. Finally, a general analysis of the waste management system on the pasture-based dairy was conducted in order to develop general design parameters and suggestions for future systems.

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Chapter 2

LITERATURE REVIEW

Environmental Impact Assessment of Dairies Using Life Cycle Assessment

The agricultural community in the Southeastern United States currently lacks an accurate quantitative assessment of the environmental repercussions of pasture-based and conventional dairy farming. Life cycle assessments (LCAs) of dairy production methods performed in Sweden (Cederberg and Mattsson, 2000), Finland (Grönroos et al., 2006), Japan (Masuda, 2007), New Zealand (Basset-Mens, 2009), and Pennsylvania and California (Rotz et al., 2010) provide examples of cradle to farm gate life cycle assessments to determine environmental impacts of dairy production systems, but an adaptation of these studies to local conditions is necessary in order to make definitive conclusions about another region.

The Economic Input Output Life Cycle Assessment model (EIO-LCA), developed by Carnegie Mellon University, calculates the greenhouse gas production that occurs during the milk production process using economic and environmental data for the dairy and related industries. Figure 2.1 shows the components of greenhouse gas emissions by the United States dairy industry as predicted by the EIO-LCA model (Carnegie Mellon, 2010)

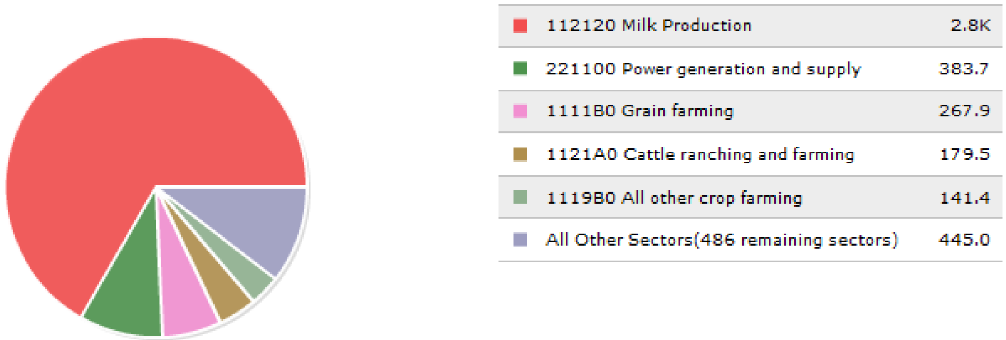

Figure 2.1: Annual greenhouse gas emissions by the United States dairy industry in metric tons of CO_2 equivalent (Carnegie Mellon, 2010).

Shifting dairy production methods from confinement to pasture-based has been shown to benefit society on several accounts (Winsten and Petrucci, 2003). For example, past research has shown that grass-fed cattle produce healthier milk as measured by a more favorable fatty acid profile and a greater presence of cardio-protective fatty acids (Hauswirth et al. 2004) and (White et al., 2001a). Cattle evolved as grazing animals, and claims that unconfined, grass-fed, cattle are healthier than their confined, grain-fed, counterparts are supported by a study which observed fewer cases of diseases, such as mastitis, in pasture-based dairy cattle than confined cattle (Washburn et al., 2002). Also, acidosis is common in cattle whose rumens are not provided with adequate amounts of forage (White et al., 2002).

In addition to the health benefits that grazing can provide to both cattle and the humans that consume their milk, pasture-based dairies have also been shown to be more environmentally friendly than confined operations. In Sweden, life cycle assessments comparing dairy production methods showed that a “low-input” agricultural system utilizing a grazing feeding strategy has environmental benefits over a “high-input” agricultural system that confines cattle (Cederberg and Mattsson, 2000). On a per unit milk production basis, the energy intensity of the confined farm was significantly higher than that of the organic farm. A more thorough study of energy consumption on dairies in Finland achieved similar results (Grönroos et al., 2006). Also, the pasture-based farms required less intensive pesticide application, had lower nutrient surpluses, and generated fewer emissions than their conventional counterparts (Cederberg and Mattsson, 2000). A life cycle assessment of varying land use intensities in Germany (Haas et al., 2001) showed similar results to the Cederberg and Mattsson study. The Haas et al. study showed that systems focused on grazing have a smaller environmental footprint (measured by nearly the same parameters as in the Cederberg and Mattson study) than systems that confine animals for a significant portion of their lives.

Most recently, USDA-ARS scientists used the Integrated Farm System Model (IFSM) to simulate the major biological and physical processes on four types of dairy farms in Pennsylvania, and presented their results as a comprehensive environmental assessment of each farming method. The study modeled a pasture-based dairy, a confined dairy, and two farms that combined elements of both. The pasture-based dairy was deemed to be more environmentally sustainable in terms of reduced erosion, sediment-bound and soluble phosphorus runoff, and greenhouse gas emissions. Also, the pasture-based dairy had a smaller carbon footprint. The paper stated that, “The environmental benefits of grass-based dairy production should be used to encourage greater adoption of managed rotational grazing in regions where this technology is well adapted” (Rotz et al., 2009).

However, the literature on this subject is far from unanimous. In fact, several papers could be cited to make a convincing case for the superior environmental sustainability of confined dairies utilizing intensive production. For example, an environmental impact assessment of the 1944 (i.e. grazing) and the 2007 (i.e. confined) dairy industries in the United States showed that modern production practices reduce resource consumption, environmental impacts, and waste outputs. This paper makes a concerted effort to ensure that readers understand that cows were predominately put on pasture to graze in 1944 and confined in 2007. However, grazing methods in 1944 were drastically different and less efficient than grazing methods in 2007. Capper cites efficiency, as determined by milk production per cow, to be the most important characteristic when assessing the environmental friendliness of a certain dairy production system (Capper et al., 2009).

In fact, scientific literature claiming that agricultural intensification is the most effective way to decrease animal agriculture's impact on the environment is readily available. For example, an analysis of the environmental impacts of the increased productivity obtained through agricultural intensification showed that the scientific advances made in the agriculture industry have saved a massive amount of carbon emissions since the 1960s (Burney et al., 2010). This paper claims that investing in productivity research is the most effective strategy to mitigate greenhouse gas emissions. Also, the Food and Agriculture Organization (FAO) of the United Nations released a study showing that developed regions that predominately practice confined dairy production strategies have much lower carbon footprints per unit of milk produced than less developed regions that typically practice pasture-based dairy production strategies (FAO, 2010).

Simulations using the Dairy Greenhouse Gas Model (DairyGHG), which was created in the same USDA-ARS research lab as the Integrated Farm System Model mentioned earlier, showed that the carbon footprint of a dairy production system was decreased if production was intensified and cattle were confined (USDA-ARS, 2010). However, the largest pasture-based dairy simulated in this study contained 60 cattle, and confined scenarios with 500 and 2000 cows were not compared to a grazing scenario of a similar size. The 60 cow pasture-based dairy had a smaller carbon footprint than the 60 cow confined dairy simulated in the study (Rotz et al., 2010).

Clearly, a thorough review of peer reviewed literature regarding the environmental impacts of pasture-based and confined dairy production systems does not lead to any clear conclusions as to which dairy production system might be coined “more sustainable”. This study is not intended to provide an answer to this question. Rather, this study of actual farms in the Southeastern U.S. that practice pasture-based and confined dairy production techniques will provide insight on how existing models can be used to study this previously unaddressed region, and how both confined and pasture-based dairy farmers might alter their management strategies to reduce the impact their respective farms have on the environment.

Waste Management on Pasture-based dairies

Waste and nutrient management processes and design methodologies for confined dairies have been studied thoroughly, and design information for new management systems is readily available from University extension specialists, standards from engineering professional organizations, and standards from the Natural Resource Conservation Service (NRCS). For example, the ANSI/ASAE EP403.3, ASAE EP393.3, and ASAE D384.2 standards released by the American Society of Agricultural and Biological Engineers (ASABE) provide a wealth of design parameters for a waste management system design on a confined dairy (ASABE, 2009a), (ASABE, 2009b), and (ASABE, 2010). However, there is little information in these standards on how to adapt design parameters to a system that is drastically different from a conventional confined dairy, such as an intensively managed rotational pasture-based dairy.

The novelty of pasture-based dairies in Georgia has presented problems to farmers who attempt to implement management intensive grazing on their farms (Washburn, 2009). For example, regulatory agencies apply existing standards for waste management systems on conventional, or confined, dairies to pasture-based dairies. Moreover, as mentioned earlier, sufficient efficacy data and general design principles are not available to the consulting engineers contracted to develop waste management plans for pasture-based dairies (Hill et al., 2008).

Limited efforts have been made to understand how waste management systems on a rotational pasture-based dairy will differ from the traditional systems found on confined dairies. For example, studies have cited the passive application of manure on pasture by grazing cattle as a possible waste management alternative to the complicated and somewhat risky waste management systems often required by large confined dairies (Rotz et al., 2009 and Winsten and Petrucci, 2003).

Little preceding work addresses the technical aspects of a waste management system on a rotational pasture-based dairy in the Southeastern USA. The spatial distribution of cattle manure and the amount of time that cattle spent in all components (paddock, milking parlor, holding area, etc.) was measured on an intensively managed rotational pasture-based dairy. This study showed that the volume of manure production in a certain area was directly correlated to the amount of time that cattle spent in that specific area, and that cattle on a rotational pasture-based dairy spend an average of 10 percent of their time on areas that drain into the waste management system (i.e. holding area and milking parlor) (White et al., 2001b). Although a complete waste characterization of manure from a pasture-based dairy cow could not be found, a complete phosphorus analysis of manure from pasture-based dairy cattle stated that the phosphorus content of pasture-based dairy cattle manure was generally lower than the phosphorus content of manure from confined dairy cattle. Also, this study showed that available phosphorus increases as manure dries on pastures (McDowell and Stewart, 2005).

Water and Electricity Usage on Pasture-Based and Confined Dairies

Electricity

The EIO-LCA model developed by Carnegie Mellon University, calculates the energy use that occurs during the milk production process using economic and environmental data for the dairy and related industries. Figure 1.2 shows the components of energy consumption by the United States dairy industry.

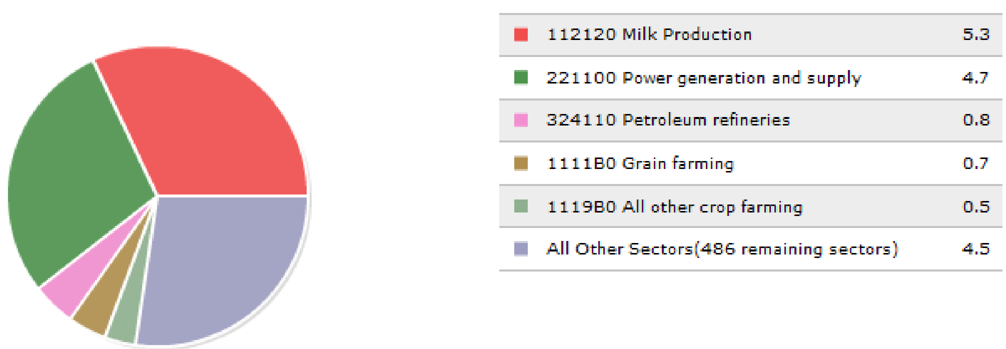

Figure 2.2: Annual energy usage by the United States dairy industry in millions of kilowatt-hours (MkWh) (Carnegie Mellon, 2010).

In the Integrated Farm System Model (IFSM) developed by USDA, electricity usage on a dairy is estimated as the total of that used for milking-related activities, lighting, and ventilation (USDA-ARS, 2009). Electricity usage during milking activities was estimated as 0.06 kWh/kg of milk produced based on an energy audit of 32 dairies in New York (Ludington and Johnson, 2003). Annual electricity use for lighting was 0 kWh for a drylot and 120 kWh per cow for all other facilities, and electricity used for ventilation was 0, 75, and 175 kWh/cow for drylots, naturally ventilated barns, and mechanically ventilated barns, respectively as determined by the aforementioned energy audit (Ludington and Johnson, 2003). When grazing is specified in the IFSM, electrical consumption for lighting and ventilation is set proportional to the amount of time that animals spend in a barn (USDA-ARS, 2009). Ludington and Johnson thoroughly cover the electricity consumption that occurs because of milking or animal housing, but did not address the electricity consumption taking place when water is pumped for cropland irrigation or animal drinking water. This electricity consumption will vary widely from farm to farm because farmers can choose to pump water with either diesel or electric pumps, but electricity usage for water supply will likely form a large portion of a typical dairy farm’s electricity consumption.

Several studies have provided estimates of the entire electricity consumption of a dairy based on the number of cattle on the farm. In Wisconsin, a study that evaluated the electricity consumption of the entire dairy system on an ‘efficient’ farm estimated electricity consumption to be 262 kWh/cow/year for a 400 cow dairy (Mehta, 2002). In Sweden, electricity usage was measured to be much higher, and was stated to be an average of approximately 1400 kWh/cow/year (Cederberg and Flysjö, 2004). This study included water consumption by both the dairy cow and its replacement animal in their estimates. The Mehta study did not specify whether or not replacement heifers or electricity consumption during the pumping of water were included in the electrical usage predictions made in the study. These reports provide useful data on expected electrical usage by dairies, but the considerable differences in climate and production practices between the dairies in these studies and dairies in the Southeastern USA reduce the applicability of the data in these studies to dairies in the Southeast.

Water

Water usage throughout all sectors of society has become particularly important in Georgia in light of US District Court Judge Paul Magnuson's ruling that Lake Lanier, Atlanta's main source of water supply, is not authorized to be used for drinking water. Only the power production industry consumes more water than agriculture in Georgia, and as the state's second largest water consumer the agricultural sector is under pressure to document and potentially allocate their water usage (Lathrop, 2009 and Fanning, 2003).

The EIO-LCA developed by Carnegie Mellon University calculated water usage that occurs during the milk production process using economic and environmental data for the dairy and related industries. According to this model the processes of grain farming, power generation and supply, and milk production are the top three water consumers in the United States dairy industry (Carnegie Mellon, 2010).

Even though the irrigation of row crops accounts for the vast majority of the agricultural sector's water use in Georgia, water usage by all components of the agriculture industry, including the dairy industry, is being scrutinized by scientists and policy makers. In fact, water usage by the major components of animal production in Georgia was compiled in a report by Albany State University's Flint River Water Policy Center (Masters, 2010). The Georgia Milk

Producers, Inc. worked in coordination with local dairy producers throughout Georgia to estimate water usage by the various components of a dairy. Their estimates are as follows:

- Cow Drinking – 40 gpd/head (gpd = gallon per day)
- Cow Cooling – 33 gpd/head
- Milk Equipment Washing – 5 gpd/head
- Parlor Flushing (freshwater portion) – 30 gpd/head
- Feed Equipment Cleaning – 3 gpd/head
- Total Use – 111 gpd/head

Additionally, water use per head for heifers was estimated to be 15 gpd/head, and the total number of heifers was assumed to be 90% of the total number of cows (Masters, 2010). This report is more complete than the water usage data concerning dairies that is published in scientific literature.

A dairy cow's consumption of drinking water will vary widely by temperature, level of milk production, stage of lactation, etc. An average yearly consumption of about 25-30 gallons per day per head is reported by Brugger and Dorsey, and this value is consistent with those that appear consistently in scientific literature (Brugger and Dorsey, 2006).

While drinking water usage data on dairy cows is readily available, data on water consumption by the rest of the dairy farm is sparse. This is likely because water usage and how it is allocated among its components will vary widely from farm to farm. Bulletins and publications by dairy extension specialists in a certain geographic region will likely provide the most useful information on the consumption of water by dairies in that region. The University of Florida extension service reports the following breakdown for water use by dairies in their state (Bray et al., 2008):

- Cow Drinking – 25 gpd/head
- Cow Cooling – 25 gpd/head
- Milk Equipment Washing – 3 gpd/head
- Parlor Flushing (freshwater portion) – 90 gpd/head
- Cow Cleaning – 32 gpd/ head
- Total Use – 175 gpd/head

Water usage during the irrigation of crops grown by dairy farmers for their cattle will be dependent on the type and amount crops grown, precipitation, temperature, and the volume of water available for irrigation throughout the year. As such, it is not realistic to provide one number to describe a dairy farm's water usage during irrigation. Water usage during the irrigation of crops is best estimated with a model designed to balance the water needs of a particular crop with expected precipitation, available irrigation, and evapotranspiration (Bray et al., 2008). The University of Florida extension service provides estimates of water usage by various triple cropping scenarios typically used by dairy farms (Bray et al., 2008). Also, the Georgia Automated Environmental Monitoring Network provides an online tool that is capable of predicting the amount of irrigation that is needed for a certain crop under historical weather conditions (UGA, 2010).

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Chapter 3

ENVIRONMENTAL ASSESSMENT OF PASTURE-BASED AND CONFINED DAIRY FARMS

Introduction

Multiple life cycle assessments have been performed to evaluate the environmental impacts that result from various types of dairy production in regions throughout the United States (Rotz et al., 2009), (Rotz et al., 2010), (FAO, 2010). However, to-date, no published literature has reported a life cycle or environmental impact assessment of an individual farm in the Southeastern United States. While seasonal grazing has been examined to determine this practice's impact on the environment (Rotz et al., 2009), this type of analysis has not been performed on an intensively managed large-scale and year-round rotational pasture-based dairy.

The Integrated Farm System Model (IFSM) was utilized to conduct a life cycle assessment of a pasture-based and a confined dairy in Georgia, and thereby analyzed the sustainability of both processes by quantifying environmental impacts such as erosion, nutrient runoff, and greenhouse gas emissions that resulted from each production process. Comparing the model's outputs to data measured in field studies provided an indication of the ability of the model to assess conditions in the Southeast. Also, an examination of how various shifts in management strategies affected the modeled environmental impact outputs gives farm managers an idea of how a change in the management of their farm could positively or negatively impact the environment.

Materials and Methods

Life Cycle Assessment

A life cycle assessment (LCA) quantifies the environmental impacts of a given product or process by accounting for all materials used, directly or indirectly, during the process. This is also referred to as cradle-to-grave analysis for materials that are not recycled in the system and cradle-to-cradle analysis for materials that are reincorporated in the system's overall process (Owens, 1997). LCAs of agricultural processes typically stop at the farm gate, and do not look at what happens to the product once it leaves the farm. This type of life cycle assessment is generally referred to as a 'partial life cycle assessment' and is also called 'cradle to farm gate' when an agricultural process is being examined (Rotz et al., 2010).

It is critical to follow LCA standards when attempting to quantify the environmental impacts of a given product or process because LCA methodology requires all materials used directly or indirectly in the process to be included in the analysis (Owens, 1997). This "cradle-to-grave" approach is essential when analyzing livestock systems that often purchase inputs that were produced on distant farms. In order to determine energy consumption per unit of milk produced on confined and pasture-based farms, Swedish scientists included energy consumption during the production and transportation of feed to each dairy (Cederberg and Mattsson, 2000). The pasture-based dairies in the study predominately utilized pasture to feed their cattle. The confined dairies imported over half of their feed from off the farm, and also use much more feed, and therefore incur more environmental impacts during the production and transportation of feed. Figures 3.1 and 3.2 depict how production methods affect the relative size and importance of material flows on confined and pasture-based dairies.

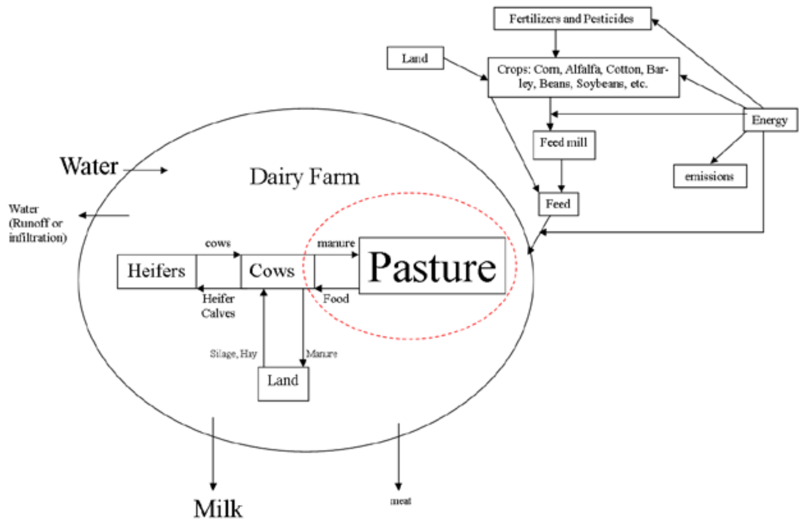

Figure 3.1: Material flows on a pasture-based dairy. The red circle highlights the critical process required to feed cattle on this dairy.

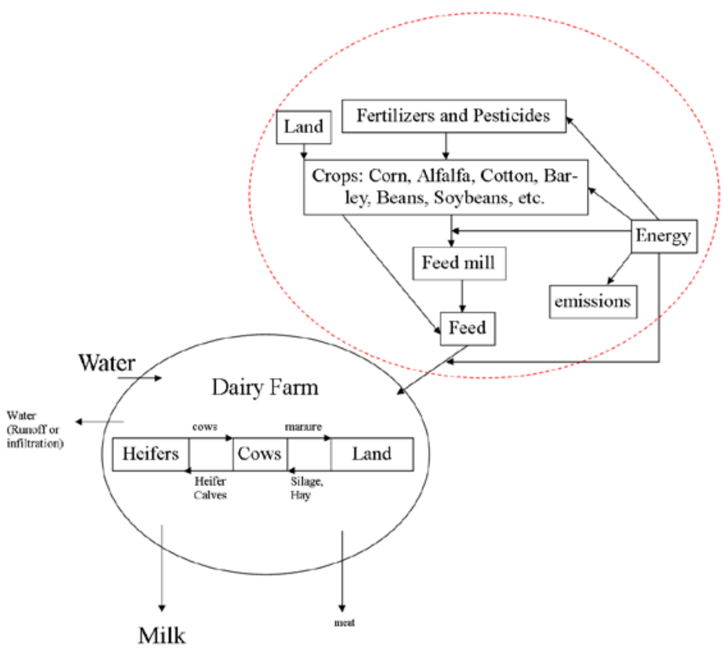

Figure 3.2: Material flows on a confined dairy. The red circle highlights the critical process required to feed cattle on this dairy.

As concerns about the impact of anthropogenic greenhouse gas emissions mount, it has become increasingly important to be able to define the amount of emissions resulting from a particular process. In order to accomplish this goal, life cycle assessment can be used to determine the 'carbon footprint' of a process. By definition, the carbon footprint of a process is the total greenhouse gas emission, expressed in carbon dioxide equivalent units, associated with that process or product (USDA-ARS, 2010). The three greenhouse gases emitted by dairy farms in substantial amounts are carbon dioxide (CO_2), nitrous oxide (NO_2), and methane (CH_4). Carbon dioxide emissions or sequestration on a dairy farm result from carbon fixation in plant growth, soil respiration, plant respiration, engine exhaust, animal respiration, manure respiration on the barn floor, and manure respiration in storage. Nitrous oxide emissions on a dairy farm result from nitrification and denitrification processes in cropland, the manure storage surface, and the manure in bedded packs or dry lots. Methane emissions on a dairy farm result from enteric fermentation, manure on the barn floor, manure storage, losses following manure application, and feces from grazing animals (Chianese et al., 2009D).

The Integrated Farm System Model (IFSM)

This study utilized the IFSM, which follows LCA methodology to ensure that the embedded environmental costs of purchased inputs were included in the results. As mentioned in the literature review, the IFSM has been utilized to perform partial life cycle assessments of various dairy farming methods (Rotz et al., 2009) and (Rotz et al., 2010).

These studies were a simulation of theoretical farms designed to be characteristic of the Pennsylvania and California dairy industries. The LCAs proposed here will address a new geographic region by adapting the IFSM to local climatic conditions and agricultural practices in

Georgia, and will model the characteristics of existing farms to compare actual, instead of theoretical, production techniques. The IFSM provided a framework to guide monitoring and research efforts toward meaningful results in the form of an environmental impact assessment of two dairy farms.

As quoted from the IFSM user's manual, "The IFSM simulates all major farm components on a process level. This enables the integration and linking of components in a manner that adequately represents the major interactions among the many biological and physical processes on the farm. This provides a robust research and teaching tool for exploring the whole farm impact of changes in management and technology" (USDA-ARS, 2010). Figure 3.3 portrays the major processes that the IFSM simulates throughout the dairy production system.

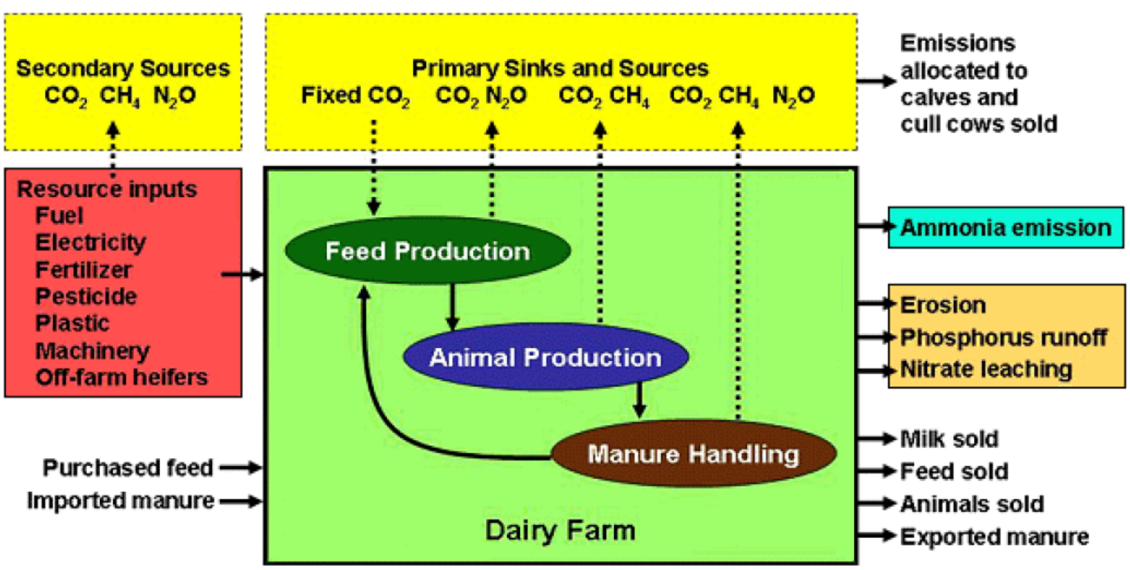

Figure 3.3: Processes on a dairy farm and their resulting environmental impacts as simulated by the IFSM (Rotz et al., 2010).

Farm Characteristics

Two dairy farms, one confined and one pasture-based, were selected for this study. Each farm was chosen based on the willingness of farm managers and owners to cooperate, and the dairy's ability to reasonably represent other dairies with the same type of production method.

The dairies in this study were promised anonymity. As such, the farms are described so that one can understand the general characteristics of each system, but details that pinpoint the exact location or identity of the farm are omitted.

The management intensive rotational pasture-based dairy in this study maintained a herd size of about 500 dairy cattle. The breed composition of the herd was approximately 40% small framed Holstein or Friesian and 60% Holstein and Jersey cross-breeds. The average mature cow weight of the herd was 1,100 pounds. Milk production was about 11,000 pounds per cow per year, and the milk fat concentration averaged about 3.6 percent.

Calves were maintained on the farm under a barn with sawdust bedding for 1-4 weeks at which point they were shipped to another farm. Half of the cows were bred by artificial insemination on a fall cycle, calving on approximately November 1, and the other half were bred by artificial insemination on a spring cycle, calving on approximately March 1. Therefore, the farm consistently milked close to 500 cows throughout the year, except for two dry periods when about 250 cows were milked. On this farm, cows have a 12 month calving interval with a 60 day dry period.

Cows were maintained on about 250 acres of pasture throughout the year at the pasture-based dairy in this study. The pasture consisted of two paddock systems that were irrigated with center-pivot irrigation units. The two paddock systems were divided with high-tensile electric fencing into twenty-eight and twenty-two individual paddocks that were about five acres each

(Figure 3.4). One hundred and ninety acres of this pasture were established to Tifton-85 hybrid bermudagrass, which produced forage during late spring, summer, and early fall. The remaining 60 acres were planted with pearl millet which produced forage during the summer. All 250 acres were overseeded with annual ryegrass, oats, and arrowleaf clover using a no-till drill in the fall. These cool-season annuals produced forage during the late fall, winter, and spring. The pastures were fertilized with 300 pounds of nitrogen and 1 ton of chicken litter per acre.

Figure 3.4: Aerial photograph of the pasture-based dairy.

Lactating cows were brought from one of the two paddock systems to be milked twice daily, and the holding area and milking parlor were washed down with pressurized water hoses after each milking. The milking parlor was a swing 48 herringbone parlor, and the large size of this parlor enabled the farm workers to complete the milking process quickly. All of the manure, urine, and dirt that cattle deposited in the holding area and milking parlor were washed into grate inlets with pressurized water hoses. These grate inlets carried flow into underground gravity flow PVC pipes that carried the effluent into the waste management system, which consisted of a sand-trap, 30,000 gallon storage tank, and an overflow lagoon.

During the milking process cattle were fed grain. The amount fed varied from about 6-20 pounds/head/day throughout the year, and was inversely related to the amount of energy provided by forage in the paddocks. A small amount of supplemental hay and silage were fed in the pastures, but because this was negligible and difficult to quantify, it was not included in the modeling process.

The confined dairy in this study maintained a herd size of about 700 dairy cattle. During this study, the dairy was in the process of transitioning to a cross-breed operation, and therefore the breed composition of the herd was rather complicated.

The farm began their transition to a cross-breed operation with 100 percent large frame pure-bred Holstein cattle. The pure-bred Holstein cattle were artificially inseminated to Jersey sires. These second generation Holstein Jersey crosses were then bred to Swedish Red sires. Finally, the third generation Holstein Jersey Swedish Red crosses will be bred back to pure-bred Holstein sires, resulting in cattle that are 62.5% Holstein, 25% Swedish Red, and 12.5% Jersey. The farm was a mix of first, second, and third generation cattle during the study. The average bodyweight of the herd was 1,300 pounds. Milk production was about 24,300 lbs per cow per year, and the milk fat concentration averaged about 3.8 percent. Lactating cows were milked twice daily in a Double 8 herringbone milking parlor.

Calves on the farm were maintained in calf-hutches for about five weeks and then placed on pasture. Cows were bred year round using artificial insemination. Lactating cows were maintained in two free-stall barns with sand bedding, which are the largest buildings in Figure 3.5. Dry cows and replacement heifers were maintained on 250 acres of common bermudagrass pasture. These pastures were overseeded with annual ryegrass in the fall with a no-till drill.

Figure 3.5: Aerial photograph of the confined dairy and a portion of its cropland.

Water was pumped into towers that flushed the concrete floors of the freestall barns into the waste management system. The waste management system consisted of a sand-trap, solid separator, and three lagoons in series. The water in the lagoons became progressively cleaner in each successive lagoon. Water from the bottom two lagoons was pumped back to the freestall barns to wash the lanes.

Cows on the dairy were fed a mixed ration composed of silage, hay, and grain. All of the silage and hay fed was produced on the farm. By weight, the rations for lactating cows consisted of 45% silage and 55% grain. Crops grown on the farm supplied other dairies in addition to the one in the study, which made it difficult to determine the exact acreage of crops that were used on the farm. However, this allocation was made by multiplying the total number of acres of each crop grown by 0.7, which represented the ratio of cows on the dairy studied to the total number of cows fed by the crops grown on the farm. According to these calculations, 315 acres of corn and 434 acres of annual ryegrass were grown for silage, and 175 acres of annual ryegrass was grown for hay. Also, 260 acres of soybeans were grown as a cash crop. Much of the cropland was double or triple-cropped each year. Waste water from the lagoons was pumped onto these fields through center-pivot irrigation systems to fertilize the crops. The center-pivots also irrigated the fields with fresh water from surface water and wells. In addition to the recycled manure, approximately 50 pounds of nitrogen per acre was applied to the corn, and 120 pounds of potassium per acre was applied to the annual ryegrass. During the study, 3 tons per acre of poultry litter was applied to 90 acres of the corn fields. A general summary of the characteristics of each farm are listed in Table 3.1.

Table 3.1: Summarized descriptions of the two farms that were modeled.

Farm Characterisitics	Pasture-based dairy	Confined Dairy
Number of Cattle	500	700
Breed	Holstein & Jersey Crosses	Holsteins and Holstein, Jersey, and Swedish Red Crosses
Average Body Weight (lb)	1100	1300
Housing	Young calves: bedded barn All other animals on pasture	Lactating cows: two freestall barns Dry cows and older heifers: pasture
Milk production		
Total (lb/cow/year)	11,000	23,637
Milk fat concentration (%)	3.6	3.8
ECM (lb/year)	5,589,540	17,352,347
Feed production and utilization		
Harvested silage (ton DM)	0	3367
Grazed forage (ton DM)	1103	655*
Purchased grain (ton DM)	805	3335

* Dry cows and heifers were placed on pasture to graze on the confined dairy.

Modeling with the IFSM

The characteristics listed above for each of these farms were just a small portion of the inputs into the IFSM. The IFSM provided a printout of inputs into the model, and these printouts for the pasture-based and confined dairies can be viewed in Appendices A and B respectively. The majority of the inputs into the model were determined during personal interviews with the manager of each farm. All other inputs were determined by on-farm measurements (e.g. lagoon dimensions, soil tests, silo dimensions) or computer analysis (e.g. NRCS web soil survey, GIS analysis to determine land areas, online databases of curve numbers and forage characteristics).

The IFSM provided weather files for each state, and a file for Macon was provided for Georgia. This weather file was used for both farms for consistency and because Macon was approximately equidistant from each farm.

It was not possible to accurately describe exactly how the animals on each farm live and eat. Therefore, it was necessary to calibrate the model to attempt to match certain model outputs with known conditions on the farm. This calibration was done by forcing the model to predict as accurately as possible the amount of milk production per cow and the quantities and composition of feed consumed.

When modeling the pasture-based dairy, the model could not be forced to predict that cattle on the farm consumed a certain amount of grazed forage throughout the year because the model will always import forage during the winter months to account for a perceived forage deficit that does not actually exist. This is because the model was designed for Pennsylvania, and therefore lacks input options that accurately represent pasture-based dairy systems in the Southeast. For instance, it was impossible to lower the amount of purchased forages to zero because the model assumes that forages stop producing in winter months. Therefore, the model was calibrated to approximate the amount of grain fed to cattle in the milking parlor on a yearly basis. The yearly average of the amount of grain fed to cattle was 8 pounds/cow/day and the model was calibrated to predict that cows on the farm actually consumed 8.7 lbs/cow/day.

The crops grown on the confined dairy were difficult to model accurately. For instance, there was no way to separate multiple types of harvest of the same crop. On the confined dairy in the study, 175 acres of annual ryegrass are grown for hay and 434 acres are grown for silage. As there is no way to identify separate fields of the same crop, one of these farming practices could not be represented by the model. Also, although the farm had multiple corn silage fields that were all managed separately, the corn crop had to be treated as a single unit. Furthermore, although much of the cropland on the confined dairy was double or triple-cropped each year, there was no way to represent this cropland management in the model. The confined dairy was calibrated by attempting to force the model output to mimic the relative presence of silage grown on the farm and imported grain as constituents of the mixed ration fed to lactating cattle. By weight, the farm fed approximately 45% silage and 55% percent grain in mixed rations for lactating cattle. The model predicted that all cattle were fed 50% silage and grain in their rations on a yearly basis. There was no way to distinguish between lactating and non-lactating animals in the model's output and the higher forage ratio predicted by the model accounts for the smaller amount of grain fed to non-lactating animals.

Given the input descriptions of each farm modeled, the major processes of feed allocation, animal intake and production, and manure production and handling were simulated over 25 years of historical weather from the Macon, GA weather file to predict daily and annual emissions and other environmental impacts (USDA-ARS, 2009).

Soil carbon sequestration was not included in the IFSM, but it can have a major effect on the carbon footprint of a dairy farm during transition periods following a reduction in the tillage of cropland. Therefore, the Comet-VR model was utilized to predict carbon sequestration in soils given the historical and current farming practices on each farm (USDA-NRCS, 2009). It is important to note that carbon sequestration levels decrease with time for 20 to 50 years following a change in production practices as the soil approaches a new level of carbon equilibrium (Rotz et al., 2010). The farmland on the pasture-based dairy was converted from row crops to perennial pasture about three years ago, and therefore has at least a decade before carbon equilibrium on the soils of the farm is reached.

When comparing different farming production processes with LCA, it is integral to scale the environmental impacts produced by the LCA to the amount of commodity produced by the farm (Capper et al., 2009). Therefore, the environmental impacts predicted by the model were scaled to the amount of milk production on each farm. In order to account for the differences in the fat content of milk produced by each dairy, milk production was corrected to 3.5 percent milk fat and 3.1 percent milk protein, denoted as Energy Corrected Milk (ECM), as defined in the IFSM User's Manual (USDA-ARS, 2009). This definition was selected for consistency with the outputs generated by the IFSM that were scaled to ECM production.

Results and Discussion

Environmental Impacts Predicted by the Model

Tables 3.2 thru 3.8 summarize the environmental impacts predicted by the model. It is important to realize that the term 'impact' encompasses both the positive and negative effects that agriculture has on the environment. Food production is integral to the survival of civilization, and thoughtfully performed agriculture can beautify the landscape and protect surrounding natural resources (Cederberg and Mattsson., 2000).

Table 3.2 lists the impacts that both dairies had on soil and water resources.

Table 3.2: Modeled outputs of water and soil environmental impacts.

Environmental Impact Category (Yearly Results)	Pasture-based dairy Model	Confined Dairy Model
Erosion sediment loss (lb/acre)	7.00	3540.00
Erosion sediment loss (lb/ton ECM)	0.61	285.82
Sediment-bound P runoff (lb/acre)	0.0041	1.75
Sediment-bound P runoff (lb/ton ECM)	0.00036	0.19
Soluble P runoff (lb/acre)	0.010	0.51
Soluble P runoff (lb/ton ECM)	0.00089	0.056
Soil P accumulation (depletion) (lb/acre)	31.60	41.39
Soil P accumulation (depletion) (lb/ton ECM)	2.75	3.34
Nitrate N leaching (lb/acre)	147.40	52.39
Nitrate N leaching (lb/ton ECM)	12.82	4.23

The variations in the model's predictions of soil and water resource impacts on the two dairies, shown in Table 3.2, result largely from differences in management practices and farm characteristics. For instance, erosion was predicted to be greater on the confined dairy because of soil types and tillage. The clay soils present on the site were predicted to generate more runoff than the sandy soils of the pasture-based dairy, and this runoff resulted in a prediction of increased erosion. Also, tillage for silage production on the confined dairy was predicted to contribute to substantially higher erosion rates than the perennial grass cover on the pasture-based dairy. Phosphorus runoff was predicted to be higher on the confined dairy because of the greater volume of runoff as well as greater nutrient application rates. Phosphorus accumulation in the soil was likely predicted to be greater on the confined dairy because of greater nutrient application rates. Nitrate leaching was predicted to be greater on the pasture-based dairy because nitrate and water infiltrate and leach more readily through sandy soil than clay soil. Also, on the pasture-based dairy urine was deposited directly onto pasture instead of undergoing treatment and nitrogen volatilization in a lagoon beforehand.

Table 3.3 shows the modeled ammonia volatilization on both dairies.

Table 3.3: Modeled outputs of ammonia emissions.

Environmental Impact Category (Yearly Results)	Pasture-based dairy Model	Confined Dairy Model
Total Ammonia N volatilization (lb/acre)	204.84	392.23
Volatilization in housing facility	32.93	226.59
Volatilization in manure storage (lb/acre)	0	103.74
Volatilization during field application (lb/acre)	29.73	40.31
Volatilization during grazing (lb/acre)	142.18	21.59
Ammonia N volatilization (lb/ton ECM)	17.81	31.65

Ammonia volatilization on the confined dairy was predicted to be greater than that on the pasture-based dairy because of the larger volume of wastewater that undergoes nitrogen volatilization in lagoons. Also, the confined dairy applies more poultry litter and dairy manure onto fields, and ammonia will volatilize following each application.

Table 3.4 depicts the flow of nutrients through each farm. Variations in nutrient flows result largely from the differences in the quantity of imported nutrients, exported milk, and crops produced on each farm.

Table 3.4: Annual nutrient balances predicted by the model.

Nutrients Available, Used, and Lost	Unit	Pasture-based dairy Mean	Standard Deviation	Confined Dairy Mean	Standard Deviation
Nitrogen imported to farm	lb/ac	782.7	33.0	625.5	124.1
Nitrogen exported from farm	lb/ac	131.8	0.0	208.8	7.9
Nitrogen Import/Export	lb/ac	5.9	NA	3.0	NA
Nitrogen available on farm	lb/ac	1023.5	33.8	769.9	129.5
Nitrogen lost by volatilization	lb/ac	168.4	7.2	322.6	7.2
Nitrogen lost by leaching	lb/ac	147.4	82.7	38.6	24.3
Nitrogen lost by denitrification	lb/ac	171.8	105.6	240.4	689.3
Nitrogen concentration in leachate	ppm	109.3	153.0	21.2	11.5
Crop removal over that available on farm	%	35.0	1.0	36.0	4.0
Phosphorous imported to farm	lb/ac	54.5	0.2	65.9	1.4
Phosphorous exported from farm	lb/ac	22.8	0.0	32.3	0.8
Phosphorus Import/Export	lb/ac	2.4	NA	2.0	NA
Phosphorous available on farm	lb/ac	54.3	3.8	65.1	10.4
Phosphorous loss in runoff and leachate	lb/ac	0.1	0.1	3.1	1.8
Soil phosphorous build up	lb/ac	31.6	0.1	30.5	1.7
Crop removal over that available on farm	%	59.0	6.0	57.0	37.0
Potassium imported to farm	lb/ac	169.5	0.3	219.8	7.4
Potassium exported from farm	lb/ac	34.6	0.0	52.9	2.9
Potassium Import/Export	lb/ac	4.9	NA	4.2	NA
Potassium available on farm	lb/ac	350.6	24.6	339.0	44.5
Potassium loss through runoff	lb/ac	17.5	1.2	17.0	2.2
Soil potassium build up	lb/ac	117.4	1.2	150.0	8.9
Crop removal over that available on farm	%	78.0	8.0	55.0	21.0
Carbon imported to farm	lb/ac	49854.1	2234.3	22631.6	1142.3
Carbon exported from farm	lb/ac	1550.4	0.0	2199.5	114.0
Carbon loss as carbon dioxide	lb/ac	47881.5	2233.5	20051.6	1129.7
Carbon loss as methane	lb/ac	422.2	1.1	365.1	5.1
Carbon loss through runoff	lb/ac	0.0	0.0	15.4	8.8

The IFSM modeled all of the greenhouse gas emitting processes on each farm to develop predictions of the emissions of nitrous oxide, carbon dioxide, and methane resulting from the production of milk on each farm. Also, the IFSM predicted secondary emissions that occurred off the farm as a result of the production of inputs that the farm purchased. These secondary emissions were emitted during the production of fuel, electricity, machinery, fertilizer, pesticides, seed, plastic, and replacement animals that the farms purchased (USDA-ARS, 2009).

Various greenhouse gases have different abilities to trap heat in the atmosphere, or global warming potentials. Therefore, when discussing the production of greenhouse gases during a specific process, it is useful to convert all greenhouse gases to the same metric. Typically, this is done by multiplying each gas by its global warming potential in terms of carbon dioxide (CO_2 equivalents). Each unit of nitrous oxide is equivalent to 298 units of CO_2, and each unit of methane is equivalent to 25 units of CO_2 in trapping heat in the atmosphere (IPCC, 2007).

The results of the greenhouse gas emission modeling performed by the IFSM are shown in Tables 3.5 and 3.6.

Table 3.5: Modeled outputs of greenhouse gas emissions on each dairy.

Environmental Impact Category (Yearly Results)	Pasture-based dairy Model	Confined Dairy Model
Nitrous oxide emissions (lb N_2O/Cow)	2.80	16.45
Nitrous oxide emissions (lb CO_2 equiv.)	416604	3431172
Nitrous oxide emissions (lb CO_2 equiv./ton ECM)	149	395
Methane emissions (lb CH_4/Cow)	274	487
Methane emissions (lb CO_2 equiv.)	3419982	8519363
Methane emissions (lb CO_2 equiv./ton ECM)	1224	982
Carbon dioxide emissions (lb CO_2/Cow)	6202	7045
Carbon dioxide emissions (lb CO_2 equiv.)	3100949	4931500
Carbon dioxide emissions (lb CO_2 equiv./ton ECM)	1110	568.4

Table 3.6: Summary of total greenhouse gas emissions.

Greenhouse Gas Emission or Sequestration	Pasture-based dairy lb CO_2 equiv.	Confined Dairy lb CO_2 equiv.
Methane	3,419,875	8,519,425
Nitrous oxide	416,604	3,430,278
Carbon dioxide	3,100,949	4,931,669
Secondary sources	571,718	325,104
Assimilation during feed production	-4,101,466	-8,458,287
Not allocated to milk	-243,530	-533,333
Sum	3,164,150	8,214,856

The results of the modeling efforts on both farms provide valuable insight into the interaction of management variables with the resulting emissions and carbon footprint of each farm.

Nitrous oxide emissions per unit of ECM production were greater on the confined dairy because more animal manure and inorganic nitrogen fertilizer were applied to cropland and more nitrogen was fed to cattle. Also, nitrous oxide emissions increase as the volume and residence time of effluent in the waste management system increase (Chianese et al., 2009C), and both the volume and residence time of effluent were greater on the confined dairy as compared to the pasture-based dairy.

Methane emissions per cow increase with the percentage of indigestible fiber that is fed to the cow. Cattle that consume diets high in forage consume more indigestible fiber and emit more methane (Chianese et al., 2009B). Therefore, methane emissions per unit of ECM production were greater on the pasture-based dairy because the forage to grain ratio of the diets consumed by cattle on this farm was much higher than this ratio in the diets fed to cattle on the confined dairy.

The pasture-based dairy imported significantly less feed than the confined dairy, and consequently less farmland for row-crops was required to feed the cattle on the pasture-based dairy. Engine emissions increase as the amount of farmland in row-crops increases, but the biogenic assimilation of CO_2 by crops overcompensates for this increase in emissions. In effect, carbon is transported to the farm in imported feed. Therefore, carbon dioxide emissions were higher per unit of ECM on the pasture-based dairy. While carbon dioxide is emitted from other sources on a dairy, such as animal respiration and manure respiration during storage, the emission and assimilation of CO_2 that occurs during the production of feed heavily influences the total emissions of CO_2 on each farm (Chianese et al., 2009A).

Secondary emissions were lower on the confined dairy because of one distinction in the two farms: the confined dairy raised replacement heifers on-site, while the pasture-based dairy exported replacement heifers to a neighboring farm. Even though more secondary emission contributors such as fertilizers, pesticides, and energy were imported into the confined dairy, the contribution of emissions by purchased replacement heifers to the pasture-based dairy overpowered all of the other secondary emission sources. Also, the confined dairy raised replacement heifers faster than the replacement rate of lactating animals on the farm, and the IFSM accounted for this by using an emission factor to subtract a certain amount of emissions for each excess replacement heifer grown and sold from the farm from the sum of secondary emissions.

In order to visualize the relative contributions of greenhouse gases to the total carbon footprint of each dairy, Figures 3.6 and 3.7 depict these contributions as a percentage of the total amount of emissions produced or sequestered.

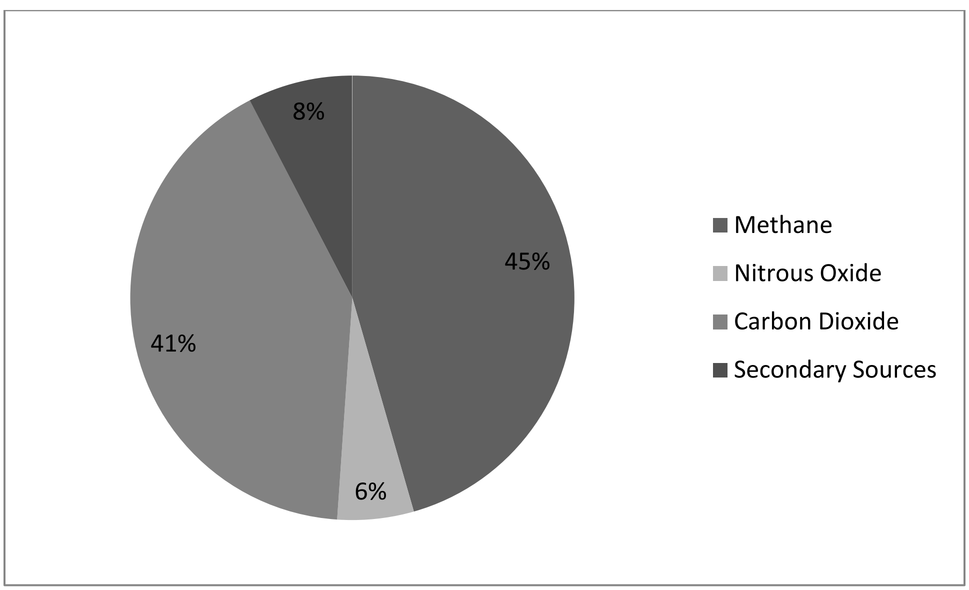

Figure 3.6: Animal and manure emission components on the pasture-based dairy.

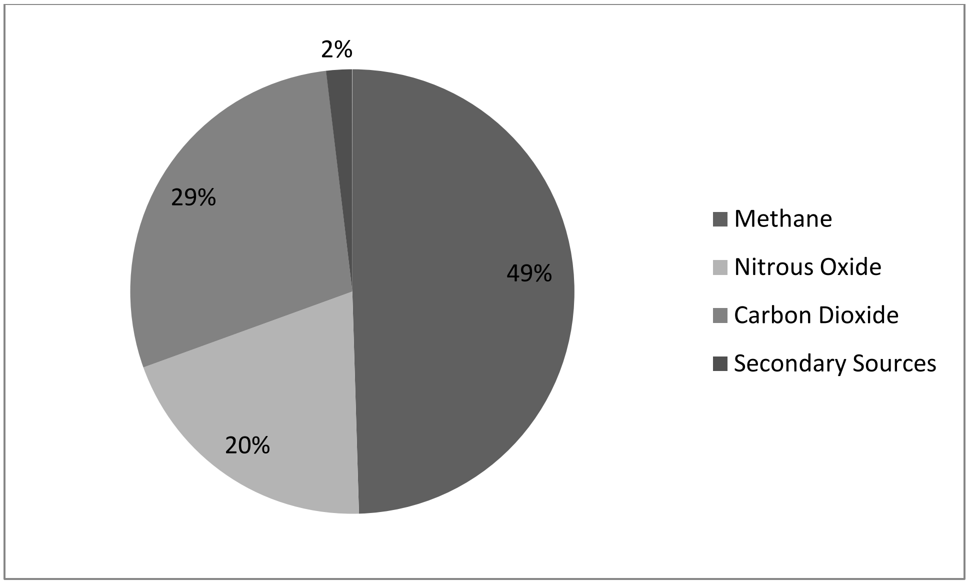

Figure 3.7: Animal and manure emission components on the confined dairy.

The variation between the two dairies in the percentage contribution of each emission to the total in Figures 3.6 and 3.7 resulted from many interrelated and complicated factors. However, each can be understood by considering the sources of each emission. It is important to remember that the sum of the pie chart in Figure 3.7 is much greater than the sum of Figure 3.6. However, as shown below, this did not result in a greater carbon footprint for the confined dairy because it produced much more milk per cow.

The IFSM calculates the carbon footprint of a farm with two methodologies commonly used during LCAs. The first method includes biogenic CO_2, which accounts for the carbon dioxide sequestered during the life of crops on each farm. The USDA-ARS scientists who created the IFSM believe that the principles of LCA lead one to include biogenic CO_2 in a partial LCA that stops at the farm gate (Rotz, 2010). However, it is common for LCAs of the dairy industry to exclude biogenic CO_2 in their analysis of emissions and carbon footprints, and this methodology will increase the carbon footprint of dairy farms (USDA-ARS, 2009).

Table 3.7 incorporates biogenic sources and sinks into the calculation of the carbon footprint of each dairy, while Table 3.8 excludes biogenic CO_2.

Table 3.7: Carbon footprints of the two dairies.

Farm Characteristic	Pasture-based dairy	Confined Dairy
Energy Corrected Milk Production (ECM) (lb)	5,589,540	17,352,347
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	3,164,150	8,214,856
Carbon Footprint (lb. CO_2 equiv. / lb ECM)	0.56	0.47
Carbon Sequestration* (lb CO_2 / lb ECM)	0.09	0.00
Carbon Footprint With Sequestration (lb. CO_2 equiv. / lb ECM)	0.47	0.47

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table 3.8: Carbon footprints of the two dairies excluding biogenic CO_2 sources and sinks.

Farm Characteristic	Pasture-based dairy	Confined Dairy
Carbon Footprint (lb. CO2 equiv. / lb ECM)	0.67	0.64
Carbon Sequestration* (lb CO2 / lb ECM)	0.09	0.00
Carbon Footprint With Sequestration (lb. CO2 equiv. / lb ECM)	0.58	0.64

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table 3.7 shows the impact that milk production had on the carbon footprint of each dairy. While greenhouse emissions were 2.6 times higher on the confined dairy, energy corrected milk production was 3.1 times greater, which resulted in a lower carbon footprint for the confined dairy before soil carbon sequestration was taken into account.

As mentioned earlier, the conversion of land from annual tillage to perennial grass allows the soil to sequester carbon. The Comet-VR model (USDA-NRCS, 2009) showed that soil carbon sequestration resulting from the conversion of farmland from row-crops to perennial pasture decreased the carbon footprint of the pasture-based dairy by about 16 percent. The Comet-VR model was also utilized to analyze the carbon dynamics in the soils of the confined dairy, and predicted that carbon was not sequestered but released from the soil because of the large amount of land that was intensively tilled each year. Since the Comet-VR model was employed to determine the potential for carbon sequestration in the soils of each farm, and the confined dairy showed no potential, the carbon dynamics of cropland at the confined dairy were depicted as if cropland was in carbon equilibrium in all carbon footprint calculations.

Once this potential for sequestration was taken into account, the modeled carbon footprints of each dairy were approximately equal. Carbon sequestration by soil on the pasture-based dairy will slow over time as the soil reaches a new level of equilibrium.

Table 3.8 shows that the carbon footprint of each dairy increased, and that the confined dairy's carbon footprint increased more relative to the pasture-based dairy, when biogenic CO_2 was taken out of the equation. The carbon footprint of the confined dairy increased more because cattle on this dairy consume much more feed. Therefore this dairy lost more credit for carbon assimilated during feed production when this parameter was removed from carbon footprint calculations.

Comparison of Modeled Environmental Impacts to Modeled Data from Literature

The complexity and costliness of measuring emissions throughout the life cycle of milk production yields this process extremely difficult, if not impossible. Therefore, scientists rely on models to predict the emissions resulting from milk production (USDA-ARS, 2010). Two published studies have assessed the emissions resulting from dairy production using the IFSM or the Dairy Greenhouse Gas model (DairyGHG), a similar model developed by the same research group (Rotz et al., 2009) and (Rotz et al., 2010). Although several other studies have conducted life cycle assessments to determine emissions resulting from milk production, these studies rely on IPCC emission factors to estimate emissions (IPCC, 2007), (Cederberg and Mattsson, 2000), (Basset-Mens et al., 2009), (FAO, 2010), (Verge et al., 2007), and (Masuda, 2007). This approach is quite different from the process based approach used by the IFSM, and consequently results from these studies were not used for comparison. A comparison of the findings of a previous IFSM study to emissions and other selected environmental impacts from this study are shown in Figure 3.8.

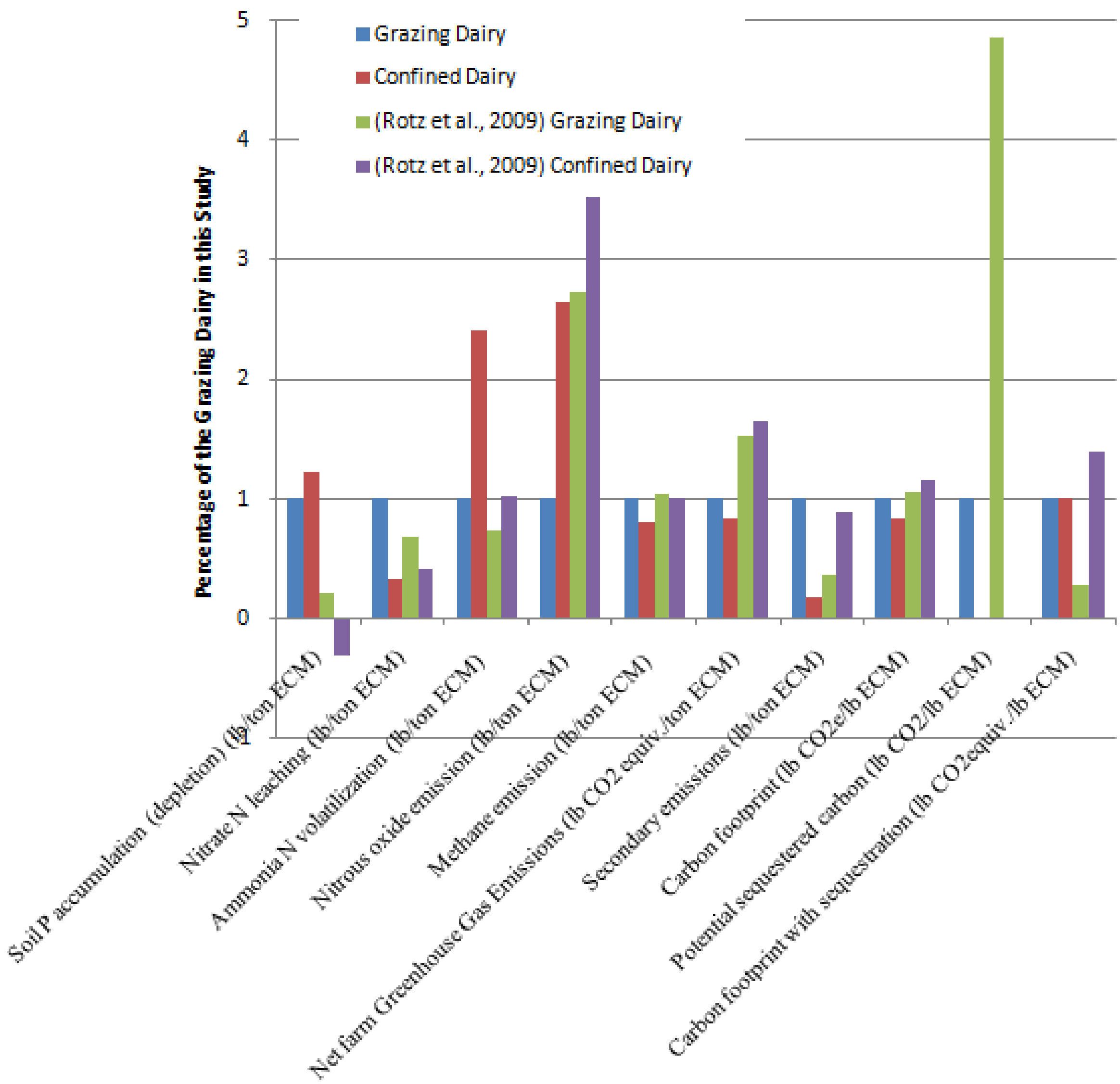

Figure 3.8: Comparison of selected environmental impacts to results from Rotz et al., 2009.

Also, erosion and phosphorus runoff were predicted to be about 100 and 2 times greater respectively under the pasture-based and confined scenarios modeled by Rotz et al., 2009 than in both the pasture-based and confined scenarios modeled in this study.

The consistency between the greenhouse gas results from this study and from Rotz et al., 2009 show the ability of the IFSM to adapt to the Southeast. The emission categories with large variations between the studies highlight the regional climate and agricultural differences between Georgia and Pennsylvania. For instance, nitrous oxide emissions, soil carbon sequestration, and erosion on the pasture-based dairy in the Rotz et al., 2009 study were much greater than in this study. This results from the inability to feed and house lactating cattle on pasture year-round in Pennsylvania, and different soil types. More crops are grown to feed cattle in the winter and more manure is treated by the waste management system, both of which result in increased nitrous oxide emissions. The increase in tillage required to produce row crops results in greater amounts of erosion. Also, soil types and temperature differences give Pennsylvania dairies a greater potential to sequester carbon in the soil when row crop land is converted to perennial pasture.

Comparison of Modeled Environmental Impacts to Measured Data from Literature

While measured values of greenhouse gas emissions from dairy farms were not widely available, other environmental impacts resulting from dairy production have been measured. Therefore, effort was made to find measured values of environmental impacts from studies on dairies similar to the pasture-based and confined dairies in this study. Table 3.9 compares environmental impact outputs predicted by the IFSM to measured values from a variety of sources.

Table 3.9: Comparison of modeled to measured or empirical environmental impacts.

Environmental Impact Category (Yearly Results)	Pasture-based dairy Model	Measured Values	Confined Dairy Model	Measured Values
Erosion sediment loss (lb/acre)	7.00	48.0 [A]	3540.00	14000 [A]
Sediment-bound P runoff (lb/acre)	0.0041	NMF*	1.75	NMF
Soluble P runoff (lb/acre)	0.010	NMF	0.51	NMF
Total P runoff (lb/acre)	0.0014	0.006 - 11.7 [B]	2.26	NMF
Soil P accumulation (depletion) (lb/acre)	31.60	NMF	41.39	-4.1 [C]
Nitrate N leaching (lb/acre)	147.40	1.5 - 34 [D]	52.39	NMF
Ammonia N volatilization (lb/acre)	168.40	6 - 166 [D]	437.81	NMF
Potential sequestered carbon (lb CO_2/acre)**	2178	10696 [E]	0.00	Negative [F]

*NMF = No measurement found

[A] The Universal Soil Loss Equation (USLE)

[B] (Romeis, 2008)

[C] (Confined Dairy Farm Manager. Personal Communication. September 1, 2010)

[D] (Eason, 2010)

[E] (Dr. Nicholas Hill, University of Georgia. Personal Communication. September 8, 2010)

[F] (Franzluebbers and Follett, 2005)

While Table 3.9 may point out areas where the IFSM or the Comet-VR models do not adequately predict environmental impacts in the southeast, it also hints at the considerable difficulty in determining the environmental impacts on the farm scale. While the IFSM might provide somewhat inaccurate environmental impact data, relative comparisons of this data between management strategies were correct in almost every instance. For instance, the USLE predicted greater erosion on both the confined and the pasture-based dairy than the IFSM , but agreed with the IFSM's assertion that erosion would be greater on the confined dairy.

Table 3.9 shows a potential sequestered carbon level about five times higher than that predicted by the Comet-VR model. This measured sequestration would approximately offset the carbon footprint of the pasture-based dairy shown in Table 3.7. However, it is important to remember that sequestration decreases as the soil on the dairy reaches a new level of carbon equilibrium.

Alterations in Management Strategies and the Resulting Impact on the Environment

Previous studies have conducted sensitivity analyses of farm input parameters to emission outputs and used the results to suggest ways to reduce the carbon footprint of dairies (Chianese et al., 2009A), (Chianese et al., 2009B), (Chianese et al., 2009C), (Chianese et al., 2009D), and (Rotz, 2010). Suggested improvements in management included: increase production per animal, include more grain and higher quality forage in rations, reduce or eliminate manure storage time, cover manure storage and flare biogas, incorporate managed rotational grazing into confinement operations, and reduce the amount of inputs to the farm.

The IFSM was used to analyze four potential changes in management on both the pasture-based and confined dairy to see how these changes affected the dairies' impacts on the environment, particularly through changes in greenhouse gas emissions. On the pasture-based dairy, the following four adjustments were modeled:

- Milk production per cow was increased from approximately 11,000 pounds per cow per year to 13,500 pounds per cow per year. It was assumed that this change could be made by incorporating cattle that perform better on grass into the herd and thereby by improving the genetics on the farm.

- Decreased the inorganic Nitrogen fertilizer application rate on paddocks from 300 pounds per acre to 150 pounds per acre.
- All replacement heifers were grown on the farm instead of being raised on a nearby farm.
- More corn silage and grain were incorporated into the diets of cattle on the farm under the assumption that this change would result in an increase in productivity to 13,500 pounds of milk per cow per year.

On the confined dairy, the following four adjustments were made:

- Eliminated the effects of the cross-breeding program that the farm is currently undertaking by increasing the average body weight, decreasing the percent milk fat, and increasing the milk production per cow per year to levels representative of pure-bred large frame Holstein cattle.
- Reduced the land areas that the farm currently produces silage on by fifty percent, thereby forcing the farm to import more forage and grain.
- Covered the manure storage area on the farm and flared the resulting biogas.
- Eliminated the freestall barns on the farm and placed all cattle on pasture. In addition to the 250 acres that are currently being used for grazing, an additional 250 acres of land currently used for annual ryegrass and corn silage production was converted to perennial pastures. The existing common bermudagrass base was maintained, although it was assumed that clover and annual ryegrass were no-tilled into the existing forage mix each fall. Milk production was decreased to 18,000 pounds per cow per year.

The impacts that these changes in management had on the carbon footprint of each dairy are shown in Figure 3.9. Also, Tables C.1 thru C.8, in Appendix C, show the changes in components of total greenhouse gas emissions, as well as the changes in milk production and the total carbon footprint of every management scenario.

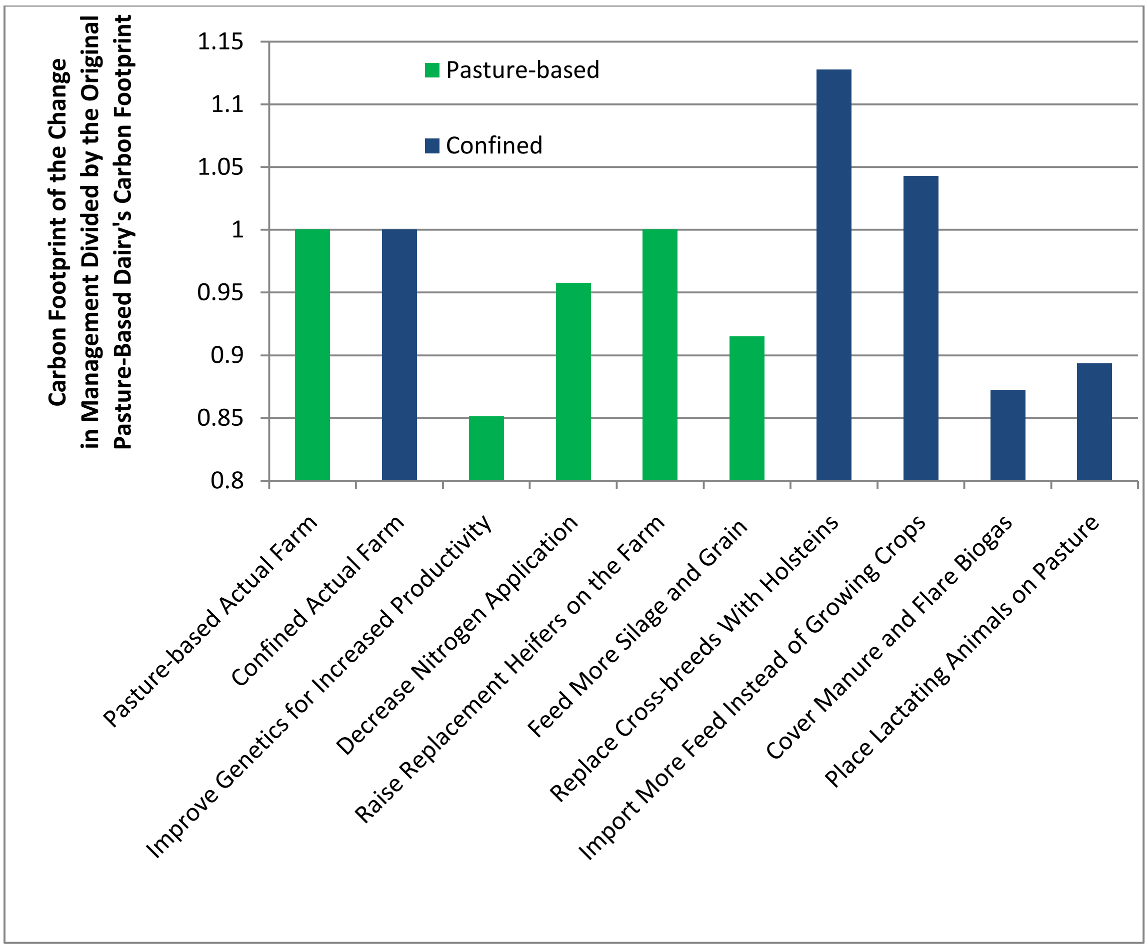

Figure 3.9: Summary of the effect of various changes in management on the carbon footprint per unit of ECM on the pasture-based and confined dairy.

The changes in the modeled carbon footprint resulting from alternative management scenarios demonstrated the potential of the IFSM to positively impact the dairy industry. While this study did not address economics, utilization of the model's economic prediction capabilities could show the potential economic impact of each of these changes in management, thereby providing dairy producers with ideas of how to decrease their carbon footprint and also improve their bottom line.

While emissions and energy consumption are an important consideration for any farmer concerned about the environment, when a change in management is considered for the purpose of decreasing negative environmental impacts, a holistic approach that considers all factors must be taken. For instance, a particular change might decrease emissions, but increase erosion and nutrient runoff. These consequences must be weighed against each other in order to determine which management decision is better for the environment.

Table 3.10 below summarizes the impacts that each change in management that was analyzed with the IFSM had on the environment relative to the original pasture-based and confined dairies.

Table 3.10: Summary of every scenario's impact on the environment.

Farm	Right: Environmental Impact Below: Change in Management	Carbon Footprint (lb CO_2 equiv./lb ECM)	Ammonia N Volatilization (lb/acre)	Erosion (lb/acre)	Phosphorus Runoff (lb/acre)	Nitrate Leaching (lb/acre)
Pasture-based	Improve Genetics for Increased Productivity	Decreased	Increased	NC*	NC	Increased
Pasture-based	Decrease Nitrogen Application	Decreased	NC	NC	NC	Decreased
Pasture-based	Raise Replacement Heifers on the Farm	NC	Increased	NC	NC	Increased
Pasture-based	Feed More Silage and Grain	Decreased	NC	NC	NC	Increased
Confined	Replace Cross-breeds With Holsteins	Increased	Decreased	NC	NC	Decreased
Confined	Import More Feed Instead of Growing Crops	Increased	Decreased	Decreased	Decreased	Decreased
Confined	Cover Manure and Flare Biogas	Decreased	Decreased	NC	NC	Decreased
Confined	Place Lactating Animals on Pasture	Decreased	Decreased	Decreased	Decreased	Decreased

*NC = No change

Table 3.10 shows that three of the eight management change scenarios decreased or did not change the level of every negative environmental impact: 1) Decreasing the level of nitrogen application on the pasture-based dairy, 2) Covering manure storage areas and flaring biogas on the confined dairy, and 3) Placing lactating animals on pasture on the confined dairy.

Again, each management scenario must be examined holistically in order to determine whether or not a particular change makes sense for an individual farm. Comparing the soil and water impacts as well as ammonia volatilization on a per acre basis, as done in Table 3.10, allows one to determine whether or not a particular change pushes a farm over an environmental threshold or regulatory standard. However, it is important to realize that changes in levels of environmental impacts should also be scrutinized on a production basis (i.e. per unit milk production).

The evaluation of a variety of changes in management at each farm helped to explain what ‘Life Cycle Assessment’ means for the IFSM. When determining emissions, LCA methodology was responsible for evaluating the whole farming system’s impact, both on the actual dairy farm and on other farms contributing replacement heifers and feed. For example, raising more feed off of the farm on the confined dairy resulted in less on-farm emissions from row-crop agriculture, but this was more than balanced by the increase in emissions from row-crop agriculture occurring off-site and the transportation of feed to the farm. However, this same holistic approach was not used to assess other environmental impacts besides emissions. For example, raising more feed off of the farm on the confined dairy resulted in the model predicting decreased ammonia volatilization, erosion, phosphorus runoff, and nitrate leaching. These predictions are misleading because, given similar soil types and farming practices, all of these environmental impacts were merely exported off of the farm onto another farm. The total impact on the environment as evaluated by these four impact categories was not decreased, just moved elsewhere. Arguably, growing more crops on the dairy farm would be better for the environment because of the decrease in transportation required to recycle nutrients from manure onto cropland and transport feed to the farm.

It is worth noting that the confined dairy in the study has a noted record of environmental stewardship, and that the farm has continually been modified throughout its approximately 40 years in operation to improve its efficiency and decrease its impact on the environment. In contrast, the pasture-based dairy has been operating for less than 5 years, and the farm managers are still learning how best to operate the farm. It is likely that the pasture-based dairy will become more efficient and have less negative impact on the environment as the farm's operators fine tune their system.

Conclusions

Surprisingly, although the contributions of individual emissions to the carbon footprint of the pasture-based and confined dairies were quite different, the total carbon footprint of each dairy was approximately the same (Tables 3.6 and 3.7). Other environmental impacts resulting from each dairy production process varied widely between each farm (Tables 3.2 and 3.3). Erosion and phosphorus runoff were much greater on the confined dairy because of soil types and the substantially larger area of land that was plowed each year to grow silage. The level of phosphorus accumulation in the soil was predicted to be greater at the confined dairy, although soil test records show that farmland on this dairy was actually losing phosphorus. Nitrate leaching per unit of milk produced was predicted to be greater on the pasture-based dairy because of soil types and the fact that urine and feces were deposited directly onto pasture instead of undergoing treatment in a lagoon before land application; however, recent on-farm observations have shown nitrate leaching to be much lower than the level predicted by the IFSM. Ammonia volatilization was greater on the concrete freestall barn floors and cropland of the confined dairy than on the pastures of the pasture-based dairy.

The comparison of the modeled characteristics of the two farms in this study to previous studies using the IFSM showed similar results (Figure 3.6), with differences that are understood by considering variations in the management and structure of the farms, climate, and physiography. The considerable discrepancy between modeled and measured environmental impacts shown in Table 3.9 largely results from the difficulty in modeling and measuring highly variable parameters. For example, the nitrate leaching measured on two seemingly similar pasture-based dairies varied 183 percent from one dairy to the other (Eason, 2010).

Modeling four adjustments in management on each farm showed how these changes would positively or negatively impact the carbon footprint of each farm (Figure 3.9). Improving the genetics of cattle on the pasture-based dairy to produce more milk and covering the manure storage and flaring the resulting biogas showed the most potential for reducing the carbon footprint of the pasture-based and confined dairies, respectively. Table 3.10 shows the relative levels of environmental impacts resulting from the potential changes in management on each farm. Three of the eight management change scenarios decreased or did not change the level of every negative environmental impact: 1) Decreasing the level of nitrogen application on the pasture-based dairy, 2) Covering manure storage areas and flaring biogas on the confined dairy, and 3) Placing lactating animals on pasture on the confined dairy.

Although adapting the IFSM to farming practices in the southeast was difficult in some instances, the model proved to be an invaluable tool for evaluating the environmental impact of dairies in the region. The amount of information gleaned from the modeling work performed would have taken many years and a multimillion dollar budget to complete through monitoring efforts.

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Chapter 4

WATER AND ELECTRICITY USAGE ON A PASTURE-BASED AND A CONFINED DAIRY IN GEORGIA

Introduction

Growing concerns about the environmental consequences of society's energy consumption should encourage all energy consumers to become cognizant of their energy use. Electricity supplies the majority of the U.S. dairy industry's energy, thereby providing a starting point for understanding the industry's energy consumption (Carnegie Mellon, 2010).

Water usage throughout all sectors of society has become particularly important in Georgia in light of U.S. District Court Judge Paul Magnuson's ruling that Lake Lanier, Atlanta's main source of water supply, is not authorized to be used as drinking water. Only the power production industry consumes more water than agriculture in Georgia, and as the state's second largest water consumer the agricultural sector is under pressure to document and potentially allocate their water usage (Lathrop, 2009) and (Fanning, 2003).

Electricity and water consumption data for the dairy industry is available on a national scale (Carnegie Mellon, 2010), and for other regions in the United States (Ludington and Johnson, 2003), (Mehta, 2002), (Masters, 2010), and (Brugger and Dorsey, 2006). A University of Florida Extension report detailed water consumption by confined dairies in their state (Bray et al., 2008), but no information was found regarding electricity consumption in the Southeast. In light of increasing concern about societal and agricultural resource consumption, more comprehensive data on electricity and water consumption by pasture-based and confined dairies in Georgia will benefit both the dairy industry and society in general.

Materials and Methods

Water Consumption Monitoring

The farm manager on both the confined and the pasture-based dairy were interviewed in order to determine the sources and flow-paths of water on the two dairies. After each water system was analyzed thoroughly, a monitoring plan that would measure the total water consumption and its main components was developed for each dairy.

The budget for this project was limited, so water consumption was measured using somewhat unorthodox, but cost-effective, methodology. Four methods were used to quantify water consumption on the two dairies: 1) direct measurement with non-invasive flow meters (PT878, GE Sensing Co., Billerica, MA); 2) measurement of a pump’s on time with a split-core AC current sensor (CTV-B, Onset Corp., Pocasset, MA) and then multiplying on-time by the pump’s average flowrate; 3) recording electricity usage over time, correlating it to a pump’s on-time using a split-core AC current sensor, and then multiplying on-time by the pumps average flowrate; and 4) directly recording water consumption measured by an existing gauge. Figure 4.1 shows an example of an installed current sensor, and Figure 4.2 is a picture of the non-invasive flowmeter used for this project. These methods are explained in more detail below.

Figure 4.1: A current sensor (top right) installed on a pump at the pasture-based dairy.

Figure 4.2: The non-invasive flowmeter used for this project.

Water Usage Measurement: Pasture-Based Dairy

On the pasture-based dairy, a current sensor was installed on the well pump that provided the farm with all of its water excluding irrigation, and the sensor was set to measure current flow to the pump every minute. Water from this well filled all of the drinking water troughs in the paddocks before it reached the milking parlor. Two non-invasive flowmeters were installed on PVC pipes near the milking parlor to measure water consumption minus cattle drinking water from the aforementioned well.

The current usage data was stored on a HOBO U12 4-Channel External Data Logger (U12-006, Onset Corp., Pocasset, MA) and manually downloaded using HOBOware Pro software from Onset Corporation. The downloaded data was used to calculate the amount of time that the pump was on throughout each period when the pump was monitored. The calculation of the on-time of the pump utilized Microsoft Excel (2007, Redmond, WA) to count the number of time increments when the current meter registered a reading greater than 1 amp. The 1 amp threshold was used to filter out the small current readings that represented electrical noise picked up by the current monitor. Multiplying the on-time of the pump during a specific time interval by the flowrate of the pump resulted in the volume of water pumped by the well.

The non-invasive flowmeters continually displayed the cumulative volume of water that traveled through the two PVC pipes where they were installed. This cumulative volume was manually recorded at a frequent interval of no longer than 30 days.

Irrigation water consumption by the two center-pivot units on the farm was manually recorded at frequent intervals no longer than 30 days from a flowmeter installed by the Georgia Environmental Protection Division (EPD).

Water Usage Measurement: Confined Dairy

On the confined dairy, the water supply system to the farm and crops was much more extensive and complicated than on the pasture-based dairy. Water usage by four well-pumps (1.5, 2, 3, and 7.5 horsepower) and three surface water pumps (10, 100, and 100 horsepower) had to be measured.

The 2 and 7.5 horsepower wells were on isolated electric meters that were read on intervals no longer than 15 days. A current sensor was installed on these wells for a two week period, and the on-time during this period was calculated as described previously. The on-time was multiplied by the flowrate of the pump, and this number was divided by the kilowatt-hours consumed during this specific time period. This ratio of gallons pumped per kilowatt-hour was used to correlate electricity consumption to gallons pumped by the well pumps during time periods when only electricity consumption was recorded.

The 1.5 and 3 horsepower wells were tied into a single electric meter that powered many other things. Therefore, current had to be measured directly by current sensors in order to calculate the on-time and the volume of water pumped by these pumps using the methodology described for the well on the pasture-based dairy.

The 10 horsepower and one of the 100 horsepower surface water pumps were on an otherwise isolated electric meter. The farm manager stated that the 10 horsepower pump ran for the same amount of time daily from May to September, the only time period during which the associated 100 horsepower pump would be turned on. Current data from a current sensor that was installed on the 10 horsepower pump for a two week period confirmed that this statement was true, at least for the two weeks monitored. The amount of power used by the 10 horsepower pump was recorded during a two week period when the 100 horsepower pump was not on. This power consumption was extrapolated to estimate the power consumed by the 10 horsepower pump from May to September, and this consumption was subtracted from the total amount of power consumption by both pumps, recorded by the electric meter, to estimate the power consumption of the 100 horsepower pump. Dividing this power consumption by the kilowatts at which the pump operates, taken from the pump's nameplate, provides an estimate of the number of hours that the 100 horsepower pump was turned on during 2010. Multiplying the on-time by the flowrate of the pump provides an estimate of the total volume of water pumped by the 100 horsepower pump.

As mentioned earlier, a current sensor was installed on the 10 horsepower pump during a two week period during which the 100 horsepower pump did not run. The on-time and the volume of water pumped by this pump were calculated using the methodology described for the well on the pasture-based dairy. The kilowatt hours (kWh) consumed by the 100 horsepower pump from May to September were subtracted from the total recorded by the meter, and the result was multiplied by the gallons pumped per kilowatt-hour consumed ratio to calculate the volume of water pumped throughout the period that was monitored.

The volume of water pumped by the remaining 100 horsepower surface water pump was recorded directly from a flowmeter installed by the Georgia Environmental Protection Division (EPD).

Electricity Consumption Monitoring

Electricity consumption on both dairies was monitored using two methods: 1) Installing a current sensor on specific pumps and 2) Recording electricity consumption directly from existing electric meters. As described earlier, electrical noise was filtered and the remaining data from each current sensor was multiplied by the operating voltage of each pump over time to calculate electricity consumption by a certain pump.

On the pasture-based dairy, the electricity consumption of a well pump that provided all of the farm water supply excluding irrigation was monitored via the installation of a current meter. Similarly, two more current meters were installed to record the energy usage of the vacuum pump and the effluent pump. Also, two existing electric meters were regularly recorded to obtain the electricity usage by the center pivot irrigation system and the main farm operation.

On the confined dairy, two current meters were installed to record the energy usage of well pumps that supply the farm with water. Another current meter was installed to record the energy usage of the vacuum pump. Four existing electric meters were regularly recorded to obtain the energy usage by a large river pump, two creek pumps, and two wells that supply the farm with water.

Time Frame of Study and Further Data Acquisition

The annual water and electricity consumption data reported by this study represents November 2009 thru October 2010 on the confined dairy and October 2009 thru September 2010 on the pasture-based dairy. On-farm monitoring was conducted from April thru October 2010 on the confined dairy and from January thru October 2010 on the pasture-based dairy. To account for the remaining portions of the annual data and for electricity consumption recorded by utility meters but not by hand, electric utility bills for a one year period were obtained for twenty one meters on the confined dairy and for three meters on the pasture-based dairy. The portions of the annual water consumption not recorded during the monitoring period were calculated based on the average ratio of kWh consumed to water pumped observed during the monitoring period.

Results and Discussion

Water Consumption

All of the water consumption data obtained by the methods described in the previous section were compiled in order to calculate total water usage and derive its main components on each dairy. In addition to the figures shown below, Tables D.1 thru D.5, in Appendix D, list the water consumption data obtained on both dairies.

Figure 4.3 shows water consumption excluding irrigation on the pasture-based dairy.

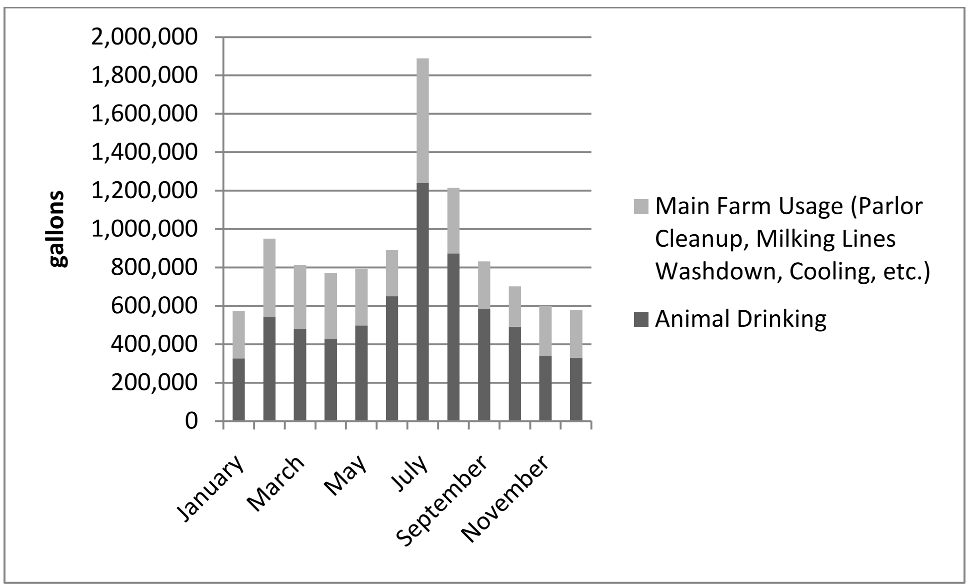

Figure 4.3: Water consumption excluding irrigation on the pasture-based dairy.

Figure 4.3 illustrates that water consumption excluding irrigation was composed of animal drinking water and consumption in the area in and around the milking parlor, and that this consumption varied from about 570,000 gallons in January to 1,900,000 gallons in July. The extremely high amount of water consumption during July might have been caused by a water leak that was observed on the farm, but there is no way to quantify the volume of water that this leak caused the farm to waste. The annual average of main farm water usage was 21 gallons per cow per day, and this average varied from 14 gallons per cow per day in October to 42 gallons per cow per day in July.

Figure 4.4 shows total water consumption, including irrigation, on the pasture-based dairy.

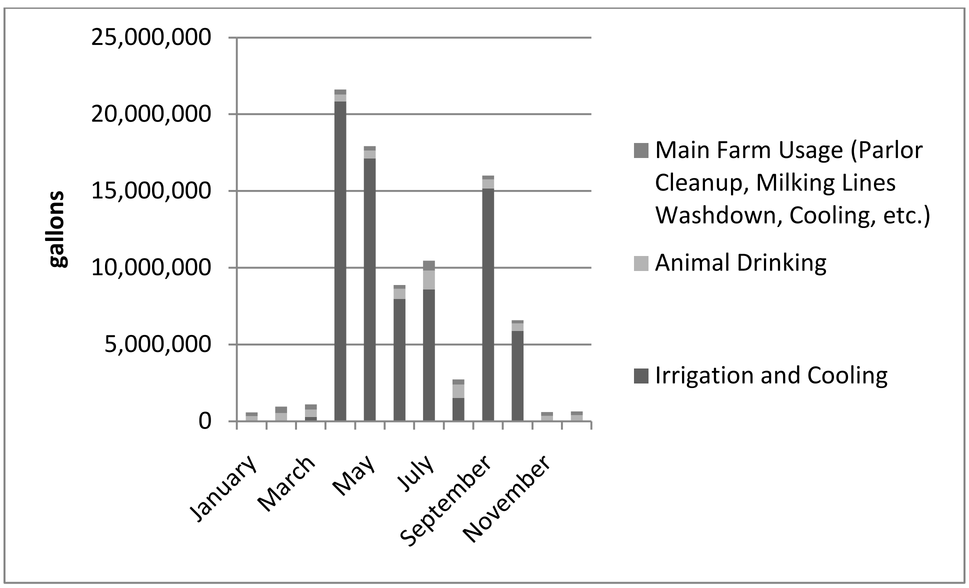

Figure 4.4: Total and component water consumption at the pasture-based dairy.

Figure 4.4 illustrates that the total water consumption on the pasture-based dairy varied from about 570,000 gallons in January to over 21,000,000 gallons in April. Eighty-eight percent of water consumption on this dairy was composed of water that was applied by the center-pivots for irrigation and cattle cooling. This consumption occurred exclusively during the warmer months from March to October. The dairy used 88,064,000 gallons of water throughout the year.

Figure 4.5 depicts the consumption of drinking water by cattle on the pasture-based dairy.

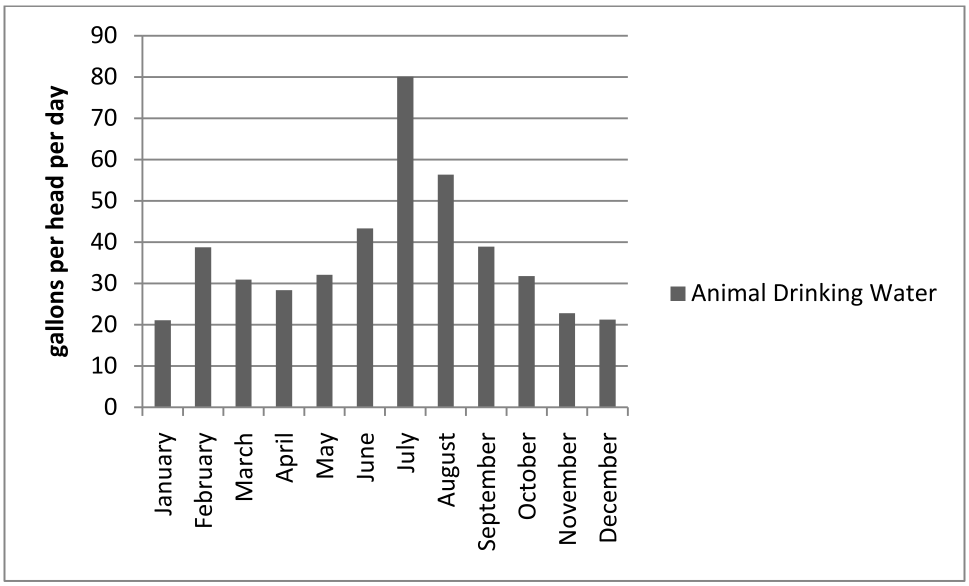

Figure 4.5: Animal drinking water consumption at the pasture-based dairy.

While much data regarding drinking water consumption by cattle on confined dairies is accessible in peer-reviewed literature, little, if any, is available for pasture-based dairies. On this dairy, no shade was available for cattle in any of the paddocks. Cooling was provided by misters installed on the center-pivot irrigation systems, which generally were maintained in the same paddock as the cattle during the warm summer months. During the study multiple leaks and malfunctions, including overflowing water troughs and busted pipes, in the animal drinking water system were observed. Under these conditions, the consumption of drinking water by cattle varied seasonally, peaking in July at 80 gallons per head per day and bottoming out in December and January at 21 gallons per head per day. Annually, cattle on the dairy consumed an average of 37 gallons per head per day.

The water supply system of the confined dairy was much more extensive than the system on the pasture-based dairy. Therefore, additional graphs depicting this consumption were developed in order to more accurately show the contribution of each component pump to the total consumption.

Figure 4.6 below shows the water consumption by the four wells on the confined dairy.

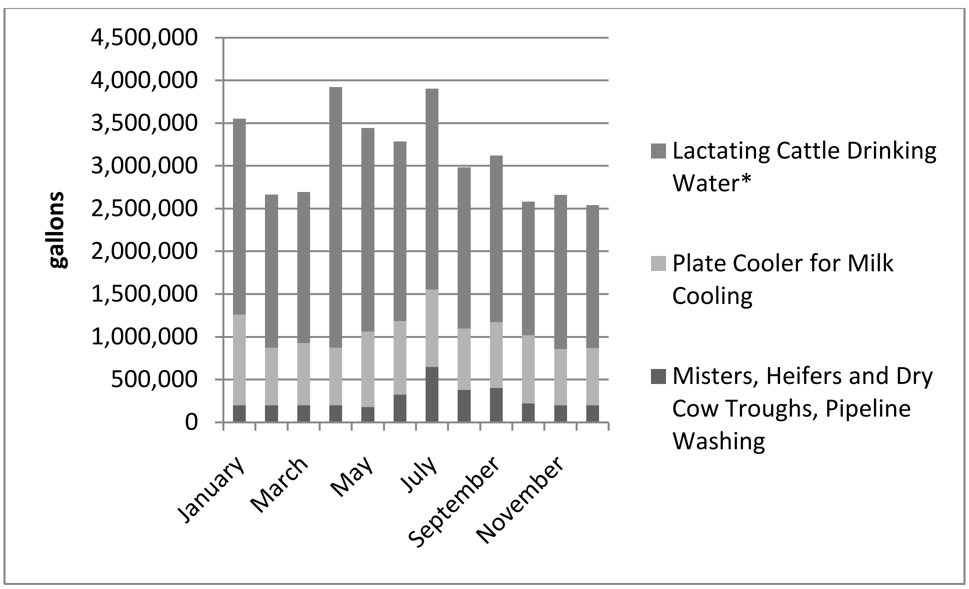

Figure 4.6: Total and component usage of well water by the confined dairy.

*Lactating cattle drinking water was estimated, not measured

Figure 4.6 illustrates that well water consumption varied from about 2,500,000 gallons in December to 4,000,000 gallons in April, and that the majority of this consumption provided lactating cattle with drinking water. The annual consumption of well water on this dairy was 37,352,658 gallons.

Figure 4.7 shows the water consumption by the three surface water pumps on the confined dairy.

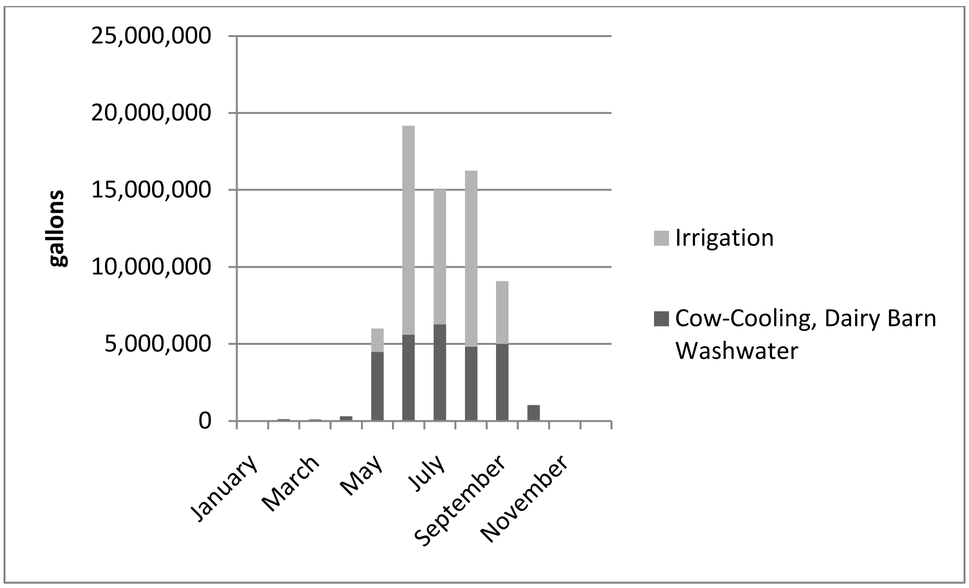

Figure 4.7: Total and component usage of surface water at the confined dairy.

Figure 4.7 illustrates that the confined dairy only consumed surface water from April to October, and that this consumption varied from about 90,000 gallons in March to 19,000,000 gallons in June. The majority of surface water consumption was for irrigation. The annual consumption of surface water on this dairy was 67,123,223 gallons.

Figure 4.8 shows the total water consumption, including surface and well water, on the confined dairy.

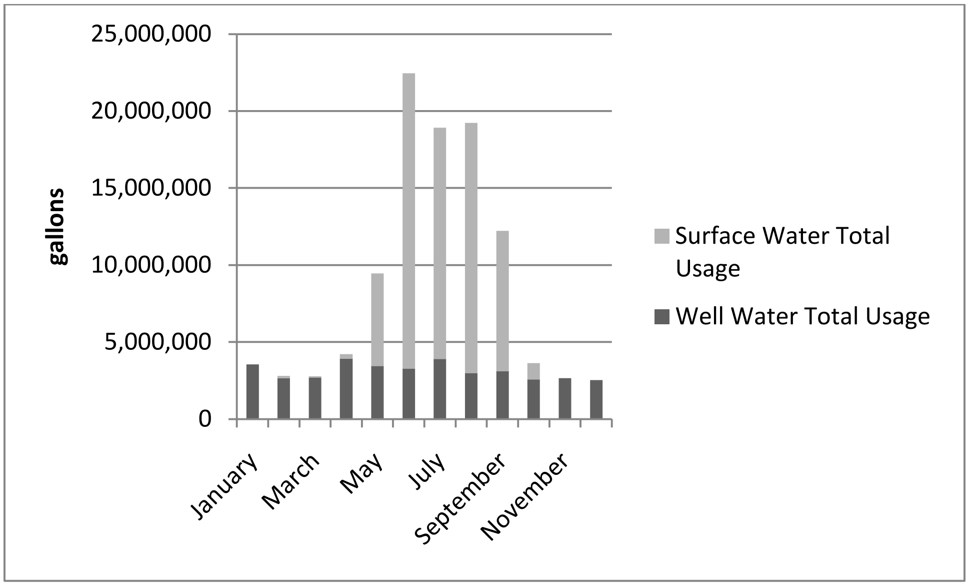

Figure 4.8: Well, surface, and total water usage at the confined dairy.

Figure 4.8 illustrates that the consumption of water varied from 2,500,000 gallons in December to 22,500,000 gallons in June. The majority of the total water consumption was from surface water. The annual consumption of water on this dairy was 104,475,881 gallons.

Electricity Consumption

All of the electricity consumption data obtained by the methodology described in the materials and methods section were compiled in order to calculate total electricity consumption and derive its main components on each dairy. Electricity consumption was divided into two subcategories, electricity consumption to pump water and all other consumption, for clarity when graphing. In addition to the figures shown below, Tables D.6 thru D.9, in Appendix D, list the electricity consumption data obtained on both dairies.

Figure 4.9 shows the electricity consumed by well pumps on the pasture-based dairy.

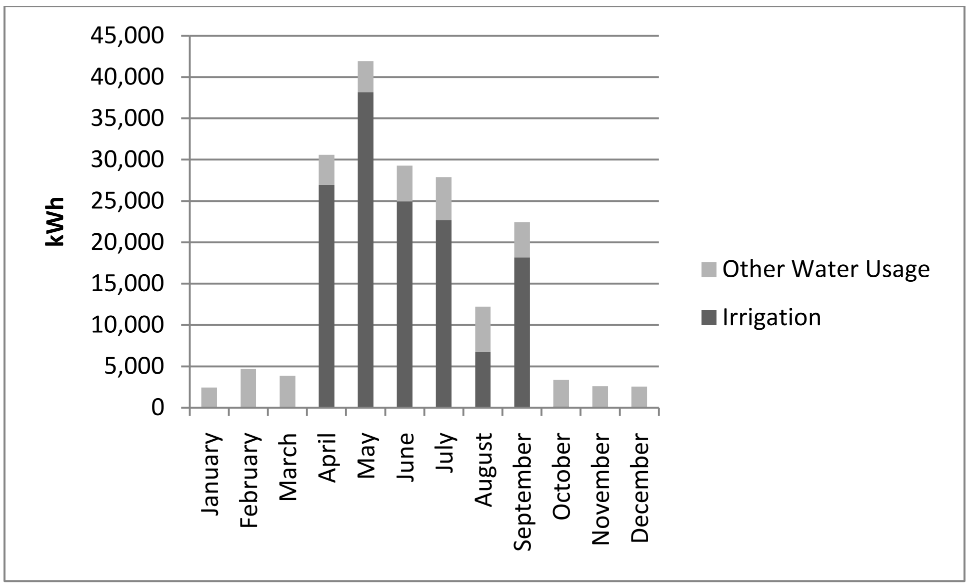

Figure 4.9: Electricity usage resulting from the consumption of water on the pasture-based dairy.

Figure 4.9 illustrates that electricity usage due to water consumption on the pasture-based dairy varied from 2,400 kWh in January to 42,000 kWh in May, and that the majority of electricity consumption was for irrigation. The dairy used 183,828 kWh to pump water throughout the year. Assuming electricity costs $0.10 per kWh, the pasture-based dairy spent about $18,400 to pump water during the year that was monitored.

Figure 4.10 shows the electricity consumption outside that consumed by water pumps on the pasture-based dairy.

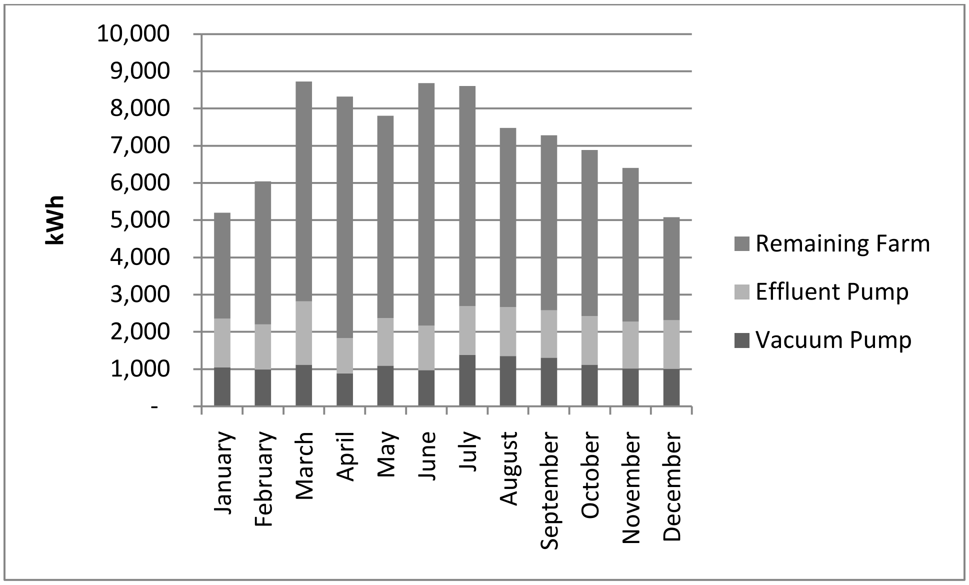

Figure 4.10: Electricity usage apart from water consumption on the pasture-based dairy.

Figure 4.10 illustrates that electricity usage on the pasture-based dairy, apart from that consumed during water consumption, was fairly constant throughout the year, with a slight peak occurring at about 8700 kWh in June. The increase during the summer months likely resulted from an increase in both the operation of fans in the milking parlor and the cooling load required to cool milk.

Figure 4.11 shows the total electricity consumption on the pasture-based dairy.

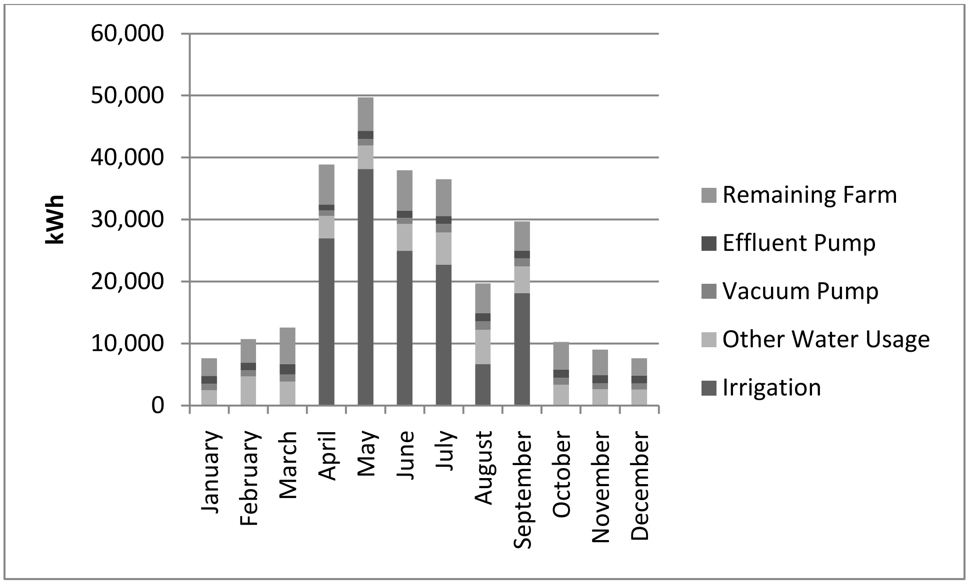

Figure 4.11: Total electricity usage on the pasture-based dairy.

Figure 4.11 shows that electricity consumption varied from about 7,600 kWh in December to 50,000 kWh in May, and that irrigation accounted for the majority of the total electricity consumption. The dairy consumed 270,308 kWh throughout the year.

Figure 4.12 shows the electricity consumed by well and surface water pumps on the confined dairy.

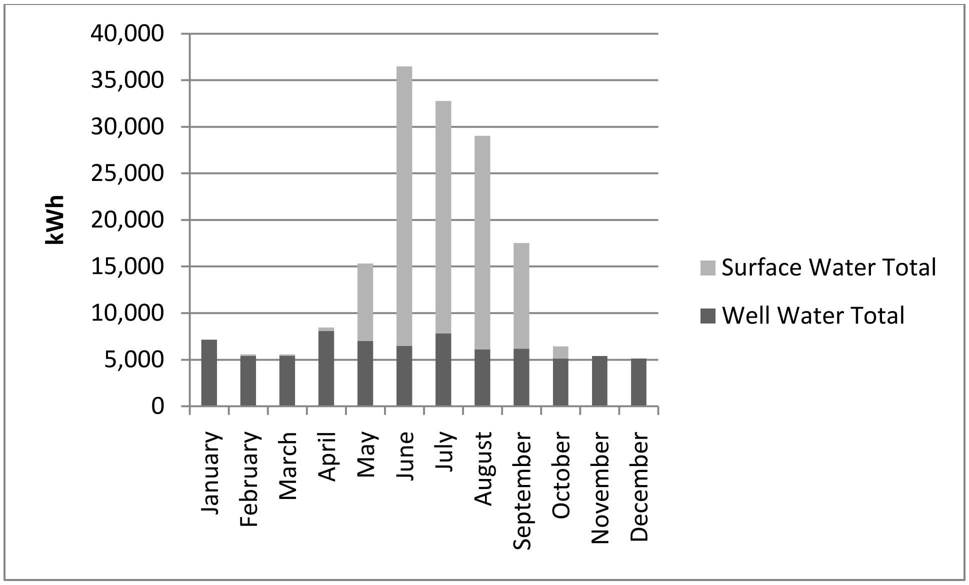

Figure 4.12: Electricity usage resulting from the consumption of water on the confined dairy.

Figure 4.12 illustrates that electricity usage due to water consumption on the confined dairy varied from 5,000 kWh in December to 36,000 kWh in May, and that the majority of this electricity consumption was for irrigation. The dairy used 174,830 kWh to pump water throughout the year. Assuming electricity costs $0.10 per kWh, the confined dairy spent about $17,500 to pump water throughout the year.

Figure 4.13 shows electricity consumption outside that consumed to pump water on the confined dairy.

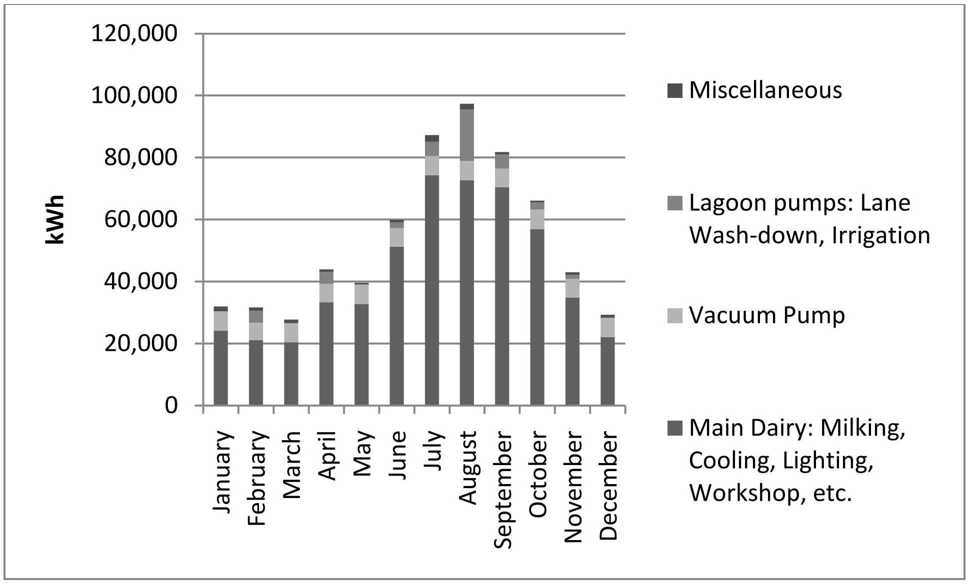

Figure 4.13: Electricity usage apart from water consumption on the confined dairy.

Figure 4.13 illustrates that electricity usage on the confined dairy apart from that consumed during water consumption varied from about 28,000 kWh in March to 100,000 kWh in August. The large increase in the electricity consumed during the summer months is in large part due to the operation of fans in the freestall barns.

Figure 4.14 shows the total electricity consumption on the confined dairy.

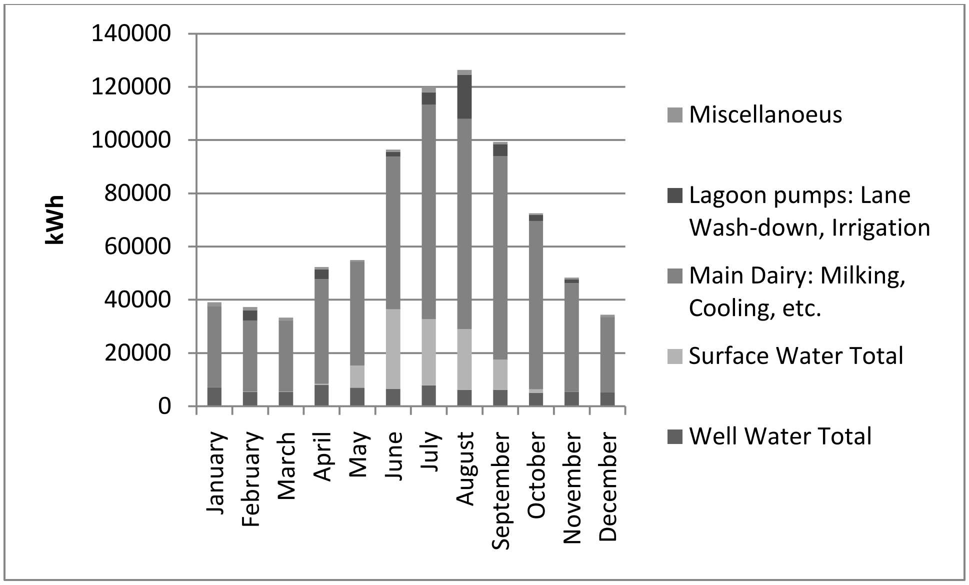

Figure 4.14: Total electricity usage on the confined dairy.

Figure 4.14 shows that electricity consumption varied from about 33,000 kWh in March to 126,000 kWh in August, and that the main dairy operation accounted for the majority of the total electricity consumption. The dairy consumed 814,376 kWh throughout the year.

In addition to the dairy's 100 horsepower electric lagoon pump, the dairy utilized a 150 horsepower diesel lagoon pump to pump water from the lagoons. Electricity consumption by the dairy would have been greater if both of the pumps had been electric.

Water and Electricity Consumption Scaled to Farm Characteristics

The differences in the number of cattle maintained and the amount of milk produced on the two dairies makes a direct comparison of the energy or electricity consumption on the two dairies irrelevant. Therefore, electricity and water consumption were divided by the pounds of energy corrected milk produced and the number of cattle on each farm in order to compare the electricity and water consumption of each dairy. It is worth noting that the confined dairy raised all of it replacement heifers on the farm, while the pasture-based dairy exported its heifers to a neighboring farm. However, the vast majority of water and electricity consumption on each dairy was directly related to milk production, and it is likely that raising replacement heifers had a negligible contribution to water and electricity consumption on the confined dairy. In addition to the figures shown below, Tables D.10 and D.11, in Appendix D, list electricity and water consumption data scaled per unit of milk production and the number of cows on each dairy.

Table 4.1 lists the total water and electricity consumption on each dairy divided by the number of cattle and the pounds of energy corrected milk produced.

Table 4.1: Annual water and electricity usage scaled per cow and per unit of milk production.

Dairy	Annual Water Usage (gallon / lb ECM)	Annual Water Usage (gallon / cow)	Annual Electricity Usage (kWh / lb ECM)	Annual Electricity Usage (kWh / cow)
Confined	6.0	149251	0.047	1163
Pasture-based	15.8	176128	0.048	541

The confined dairy annually produced about 17,350,000 pounds of energy corrected milk, or about 24,000 pounds per cow per year at 3.8 percent milk fat, and the pasture-based dairy produced about 5,590,000 pounds of energy corrected milk, or about 11,000 pounds per cow per year at 3.6 percent milk fat. Table 4.2 demonstrates that while the confined dairy used more water and electricity than the pasture-based dairy, when the resource consumptions were divided by the amount of milk produced on each dairy, the confined dairy used less than half the water and almost the same amount of electricity as the pasture-based dairy. Also, on a per cow basis the pasture-based dairy used 18 percent more water and about half the amount of electricity as the confined dairy.

Figures 4.15 thru 4.18 show the distribution of these annual values throughout each year. Figure 4.15 shows the electricity consumption divided by the energy corrected milk production on each dairy.

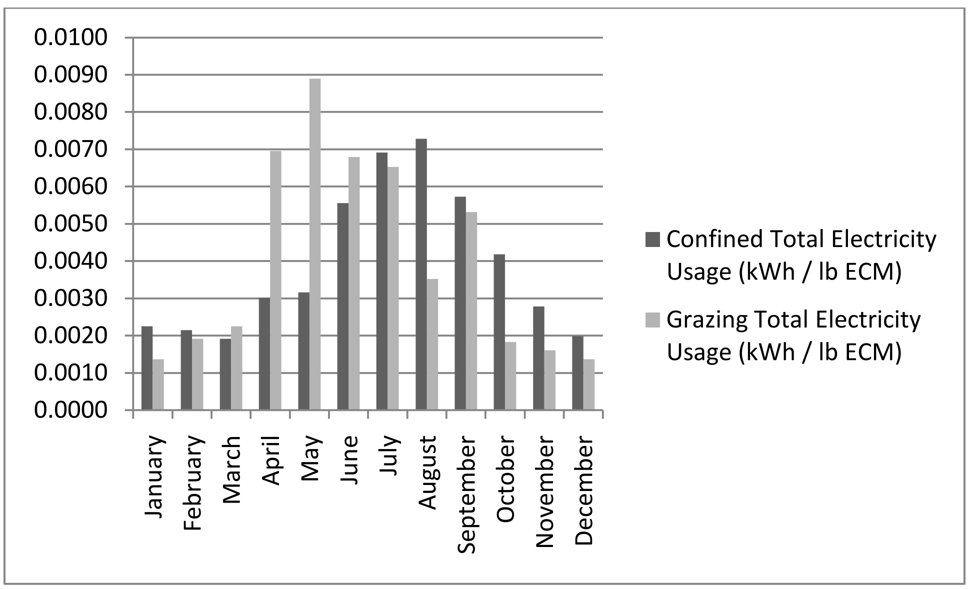

Figure 4.15: Electricity usage per pound of energy corrected milk production on each dairy.

Figure 4.15 illustrates that electricity consumption per unit of ECM was fairly similar on each dairy throughout the year, with the largest gaps occurring in April and May, when the pasture-based dairy irrigated heavily.

Figure 4.16 shows the electricity consumption divided by the number of cows on each dairy.

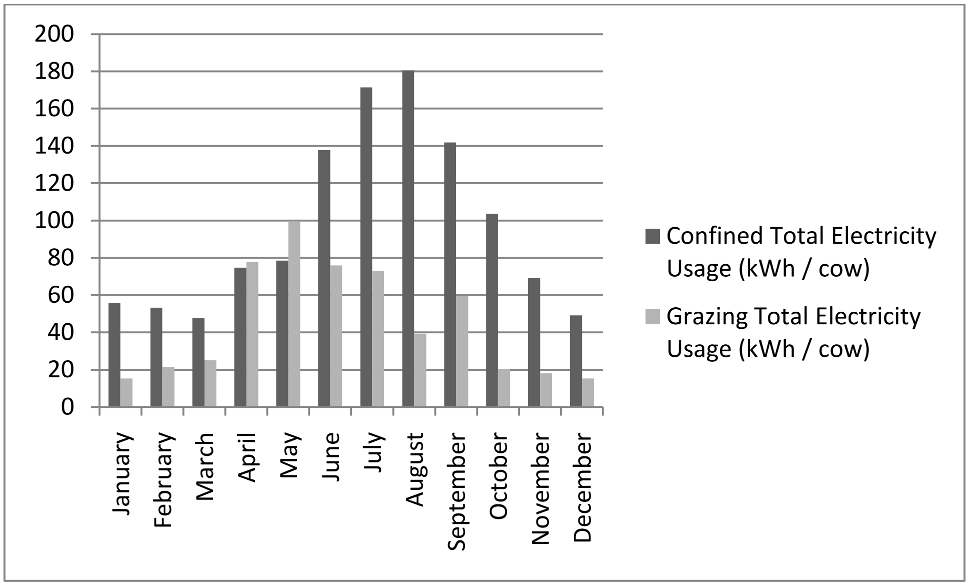

Figure 4.16: Electricity usage per cow on each dairy.

Figure 4.16 illustrates that, when scaled per cow, the confined dairy used much more electricity than the pasture-based dairy. This difference was the most significant in August, when the confined dairy irrigated significantly and the pasture-based dairy did not. In the winter months of December, January, and February, the electricity consumption scaled per cow remained fairly constant on each dairy, at an average of 53 kWh per cow on the confined dairy and 17 kWh per cow on the pasture-based dairy. This represents the baseline electricity consumption on each dairy throughout the year, once irrigation and cattle cooling were removed from the total.

Figure 4.17 shows the water consumption divided by the energy corrected milk production on each dairy.

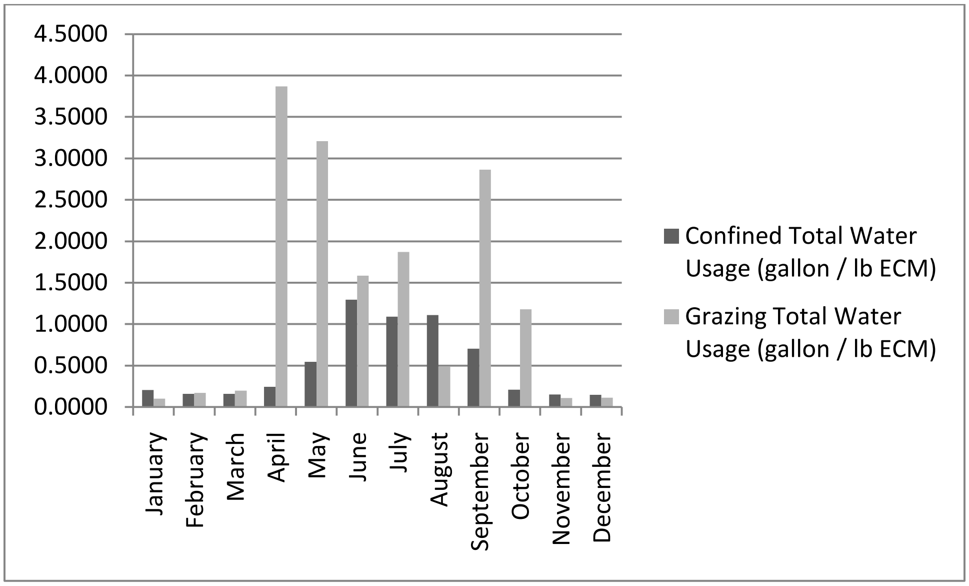

Figure 4.17: Water usage per pound of energy corrected milk production on each dairy.

Figure 4.17 exemplifies that the pasture-based dairy consumed much more water per unit of milk production for irrigation during the growing season than the confined dairy. The confined dairy consumed more water per unit of milk production during November, December, and January, but the large discrepancy in water consumption during the growing season easily outweighed the wintertime water use.

Figure 4.18 shows the water consumption divided by the number of cows on each dairy.

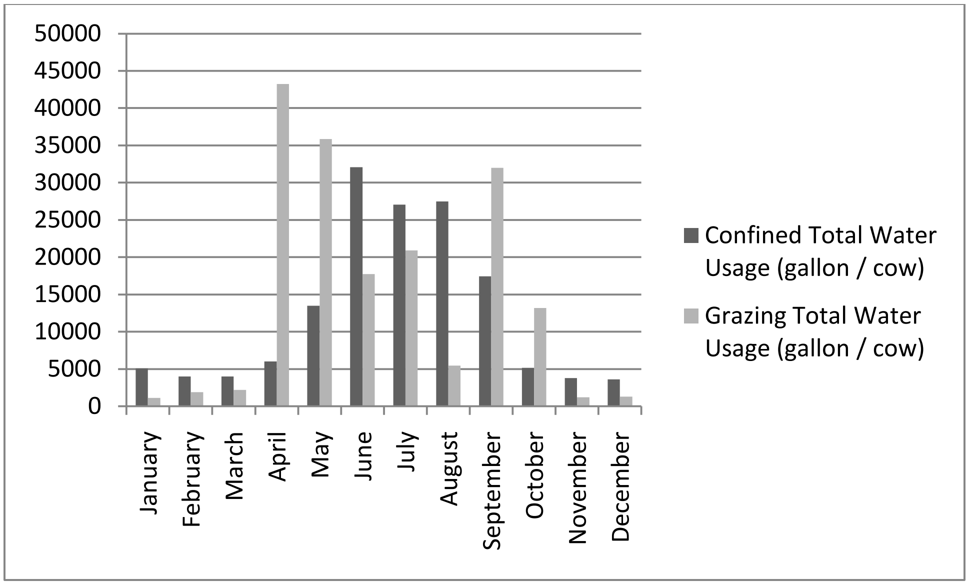

Figure 4.18: Water usage per cow on each dairy.

Analyzing water consumption on each dairy on a per cow basis, as shown in Figure 4.18, reveals less discrepancy between the pasture-based and confined dairy than water consumption on a milk production basis. However, Table 4.1 shows that the pasture-based dairy also consumes more water on a per cow basis than the confined dairy. This is almost exclusively the result of irrigation on the pasture-based dairy, as the confined dairy used an average of 3 times the water per cow during November, December, January, and February.

Table 4.2 lists the total water and electricity consumption excluding irrigation on each dairy divided by the number of cattle and the pounds of energy corrected milk produced.

Table 4.2: Annual water and electricity usage on each dairy excluding irrigation scaled per cow and per unit of milk production.

Dairy	Annual Water Usage Excluding Irrigation (gallon / lb ECM)	Annual Water Usage Excluding Irrigation (gallon / cow)	Annual Electricity Usage Excluding Irrigation (kWh / lb ECM)	Annual Electricity Usage Excluding Irrigation (kWh / cow)
Confined	3.8	93,067	0.043	1,073
Pasture-based	1.9	21,199	0.024	265

Table 4.2 shows that excluding water and electricity consumed for the purpose of irrigation results in the confined dairy consuming significantly more water and electricity per cow and per unit of energy corrected milk produced. While removing irrigation from the total water and electricity consumption of the pasture-based dairy was straightforward, the confined dairy presented a series of challenges because of the interconnectedness of its water supply system. Simplifying assumptions regarding the uses of specific wells and pumps on the confined dairy were made in order to obtain the data presented in Table 4.2.

The confined dairy maintained three progressively cleaner lagoons in series that allowed the dairy to recycle freestall barn flush water and to easily access effluent for irrigation and fertility. A significant portion of the water used to flush the freestall barns was pumped from one of these lagoons. Also, the effluent water was used to irrigate and fertilize a significant portion of the farm’s corn silage crop. During the summer months when irrigation demand was heavy, water from a creek was pumped to the bottom lagoon to refill it. This intensive water management program resulted in considerable water recycling. For the purposes of this study, water was ‘consumed’ only when it was initially taken from a well or from surface water. The water conservation taking place on the confined dairy significantly decreased the total water consumption of the farm.

Comparison of Measured Water and Electricity Consumption to Data from Literature

An extensive literature review revealed surprisingly little data on water and electricity consumption by dairies. However, several studies were found, and these studies were cited in Chapter 2. Tables 4.3 and 4.4 compare previous water and electricity consumption data to the data presented in this study.

Table 4.3: Comparison of measured water consumption on each dairy to data from literature.

<table>
<tr><th>Water Consumption Component (gallon/head/day)</th><th>Masters, 2010</th><th>Bray et al., 2008</th><th>Pasture-based dairy</th><th>Confined dairy</th></tr>
<tr><td>Cow Drinking</td><td>40</td><td>25</td><td>37</td><td>96*</td></tr>
<tr><td>Cow Cooling</td><td>33</td><td>25</td><td>- **</td><td rowspan="2">109</td></tr>
<tr><td>Parlor Flushing (freshwater portion)</td><td>30</td><td>90</td><td>7***</td></tr>
<tr><td>Milk Equipment Washing</td><td>5</td><td>3</td><td>7***</td><td rowspan="2">13</td></tr>
<tr><td>Feed Equipment Cleaning</td><td>3</td><td>-</td><td>-</td></tr>
<tr><td>Plate Cooler to Cool Milk</td><td>-</td><td>-</td><td>7***</td><td>37</td></tr>
<tr><td>Cow Cleaning</td><td>-</td><td>32</td><td>-</td><td>-</td></tr>
<tr><td>Total</td><td>111</td><td>143</td><td>58</td><td>255</td></tr>
</table>

* Water from the well designated for lactating cattle drinking water could have been used for other purposes

** Water was consumed for the purpose of cattle cooling on this dairy, but there was no way to distinguish between the water consumed for cooling and that used for irrigation

*** Water consumption for parlor flushing, milk equipment washing, and the milk cooling totaled 21 gallons per head per day on this dairy

The Masters, 2010 and the Bray et al., 2008 provide estimates of water consumption on confined dairies in Georgia and Florida respectively. Table 4.3 demonstrates that the water consumption on the pasture-based dairy was significantly less than that estimated by the two studies from literature. However, water consumption for cow cooling was grouped with irrigation water consumption on the pasture-based dairy, and data for this component was omitted from the total presented here because of the inability to separate consumption for irrigation from consumption for cooling. Water consumption on the confined dairy in this study was significantly higher than the water consumption estimated by the two studies from literature. This increase was a result of the inclusion of water consumption during milk cooling, higher water demands by lactating cattle, and an increase in water consumed to clean equipment on the farm.

Table 4.4 compares the electricity consumption data given by this study to data presented in previous studies.

Table 4.4: Comparison of measured electricity consumption on each dairy to data from literature.

Dairy	kWh/cow/year
Pasture-based (includes irrigation)	541
Confined (includes irrigation)	1,163
Cederberg and Flysjö, 2004 (includes irrigation)	1,400
Pasture-based (excludes irrigation)	265
Confined (excludes irrigation)	1,073
Mehta, 2002 (excludes irrigation)	262

The Mehta, 2002 data was gathered on a small confined dairy in Wisconsin that has implemented numerous management strategies and equipment that improved the efficiency of the farm. The Cederberg and Flysjö, 2004 study represents the average electricity consumption by several organic and conventional dairy farms in Sweden. As shown in Table 4.4, electricity consumption on the pasture-based dairy was 40 percent of and electricity consumption on the confined dairy was comparable to that estimated by Cederberg and Flysjö, 2004. This likely results from the relatively small amount of infrastructure present on the pasture-based dairy compared to that present on the confined dairy and the dairies in Sweden. Electricity consumption on the pasture-based dairy was approximately equal to and electricity consumption on the confined dairy was about 4 times higher than that estimated by Mehta, 2004. The Mehta study did not specify which components of the confined dairy were included in their estimate of electricity consumption by the dairy, and the drastic difference between the two dairies likely results from the inclusion of more components in this study. Also, the Mehta, 2002 study stated that the monitored dairy used less electricity per cow than a typical confined dairy in Wisconsin.

Conclusions

As shown in Figures 4.4 and 4.8, the largest component of water consumption on each dairy was irrigation. The confined dairy used a total of 104,475,881 gallons of water per year, or 6.0 gallons per pound of energy corrected milk production and 149,251 gallons per cow. The pasture-based dairy used a total of 88,064,029 gallons of water per year, or 15.8 gallons per pound of energy corrected milk production and 176,128 gallons per cow. Water conservation and recycling efforts on the confined dairy significantly reduced the total water consumption of the farm.

The largest component of electricity consumption on the pasture-based dairy was irrigation, while the area in and around the freestall barns and milking parlor consumed more than any other component on the confined dairy. The confined dairy used a total of 814,376 kWh of electricity per year, or 0.047 kWh per pound of energy corrected milk production and 1163 kWh per cow. The pasture-based dairy used a total of 270,308 kWh of electricity per year, or 0.048 kWh per pound of energy corrected milk production and 541 kWh per cow.

The water and electricity consumption data from each dairy scaled per cow provides standards to predict the water and electricity consumption of similar dairies based on the number of cattle on the farm in question.

The data in this study contributes to the available literature that lists the total water and electricity consumption of dairies. The data gathered in this study compares reasonably to data presented in previous studies, with differences that resulted from variations in the methodology of each study and regional variations in milk production and climate.

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Chapter 5

ANALYSIS OF THE WASTE MANAGEMENT SYSTEM ON AN OPERATING GRAZING DAIRY IN GEORGIA

Introduction

On a confined dairy farm lactating cattle spend the vast majority of their time on artificial surfaces, typically concrete, and virtually all of their waste must be handled by the farm's waste management system. In contrast, on a grazing dairy farm the waste management system only has to handle the manure produced immediately prior to and during the milking process (White et al., 2001).

In Georgia, regulatory agencies apply existing standards for waste management systems on confined dairies to grazing dairies. Moreover, sufficient efficacy data and general design standards are not available to the consulting engineers contracted to develop waste management plans for grazing dairies (Hill et al., 2008). To address this gap, on-farm monitoring of the waste management process on a grazing dairy in Georgia provided data to better inform the design of waste management systems on grazing dairies in the future. The monitoring data resulting from this effort builds on previous efforts to address the differences in waste management for confined and grazing dairies and provides scientific data that could assist in standardizing the permitting process for future grazing dairies in Georgia.

Materials and Methods

Farm and Waste Management System Characteristics

The grazing dairy in this study was promised anonymity. As such, the farm and the waste management system are described in enough detail so that one can understand the general characteristics of the farm, but details that pinpoint the exact location or identity of the farm are omitted. The management intensive rotational grazing dairy in this study maintained a herd size of about 500 dairy cattle during the study. The breed composition of the herd was approximately 40% small framed Holstein or Friesian and 60% Holstein and Jersey cross-breeds. Half of the cows were bred on a fall cycle, calving on approximately November 1, and the other half were bred on a spring cycle, calving on approximately March 1. Therefore, the farm consistently milked close to 500 cows throughout the year, except for two dry periods when about 250 cows were milked. On this farm, most cows have a 12 month calving interval with a 60 day dry period. Therefore, approximately 250, 500, 250, and 500 cows were milked between January 1 and March 1, March 1 and September 1, September 1 and November 1, and November 1 and December 1, respectively.

Lactating cows were brought from one of two paddock systems to be milked twice daily, and the holding area and milking parlor were washed down with pressurized water hoses after each milking. The volume of water used to wash the holding area and milking parlor remains roughly the same regardless of how many cows are milked. However, the volume of manure and urine flushed during this process changes according to the number of cows moved through the milking parlor. The system was monitored from January 25 – June 24, which spanned approximately one month when the farm had 250 dry cows and four months when all 500 cows were milking.

All of the manure, urine, and dirt that cattle deposited in the holding area and milking parlor were washed into grate inlets with pressurized water hoses. These grate inlets carried flow into underground gravity flow PVC pipes that carried the effluent into the waste management system, which consists of a sand-trap, 30,000 gallon storage tank, and an overflow lagoon (Figure 5.1). The storage tank had an overflow pipe approximately 1 foot below the level of full capacity that drained into the overflow lagoon. Also, the storage tank contained an effluent pump (Yardmaster Ltd, Matamata, New Zealand), which floated on plastic barrels acting as pontoons (Figure 5.1). Typically, the pump was utilized after each milking (twice per day) to pump the storage tank down to the level it was before the influx of effluent that occurred as the milking parlor and holding area were washed down. The effluent was pumped to a 'slurry slinger' that land applied the waste onto pasture (Figure 5.2). Figure 5.3 shows an aerial schematic of this entire system excluding the land application system.

Figure 5.1: From the foreground: the sand-trap, storage tank and pump, and overflow lagoon.

Figure 5.2: The land application system, or 'slurry slinger', connected to the storage tank.

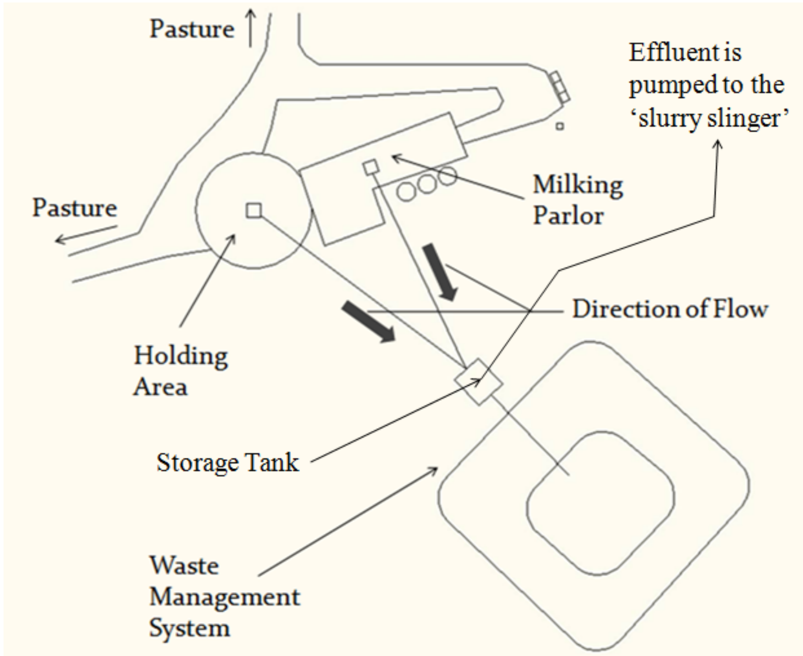

Figure 5.3: Plan view schematic drawing of the waste management system, holding area, milking parlor, and travel lanes.

Spatial Distribution of Cattle Locations

As mentioned previously, cattle on a rotational grazing dairy spend a large percentage of their time on pasture, and the waste management system for the dairy only has to treat the waste generated by cattle while they are on artificial surfaces. In order to design waste management systems for this type of grazing dairy, it is necessary to know how much time cattle actually spend in areas where waste will be flushed into the waste management system. Previous studies determined that the percentage of time that cattle spent in an area of the farm has a high correlation to the percentage of waste production (0.94 for manure and 0.99 for urine) deposited in that area (White et al., 2001). Therefore, by measuring the percentage of time that cattle spend in a particular area of a dairy, the percentage of the manure and urine that will be deposited in that area can be estimated.

Three livestock Geographical Positioning System (GPS) Collars (Lotek Wireless Inc., Ontario, Canada) were installed on lactating cattle of differing breeds, ages, and sizes to account for the potential variability in movement across these variables. The collars were set to record the coordinates of the cattle every 5 minutes for a two week period during the fall of 2009. After the collars were removed, approximately 5,000 points were downloaded from each collar using software from Lotek Wireless Inc. Differential correction was performed on the points using data from a Continuously Operating Reference Station (CORS) base station near Augusta, GA (NOAA, 2009) and N4, a proprietary software program from Lotek Wireless Inc. These corrected points were then converted into WGS 84 decimal degrees (latitude, longitude) using Microsoft Excel so that the points could easily be imported into ArcMap (Figure 5.4), a Geographical Information System (GIS) software program (ESRI Inc., Redlands, CA). A geographically referenced aerial photograph of the farm created by the National Agriculture Imagery Program (NAIP) was downloaded from the Georgia GIS Clearinghouse (GASDI, 2009) and imported into ArcMap.

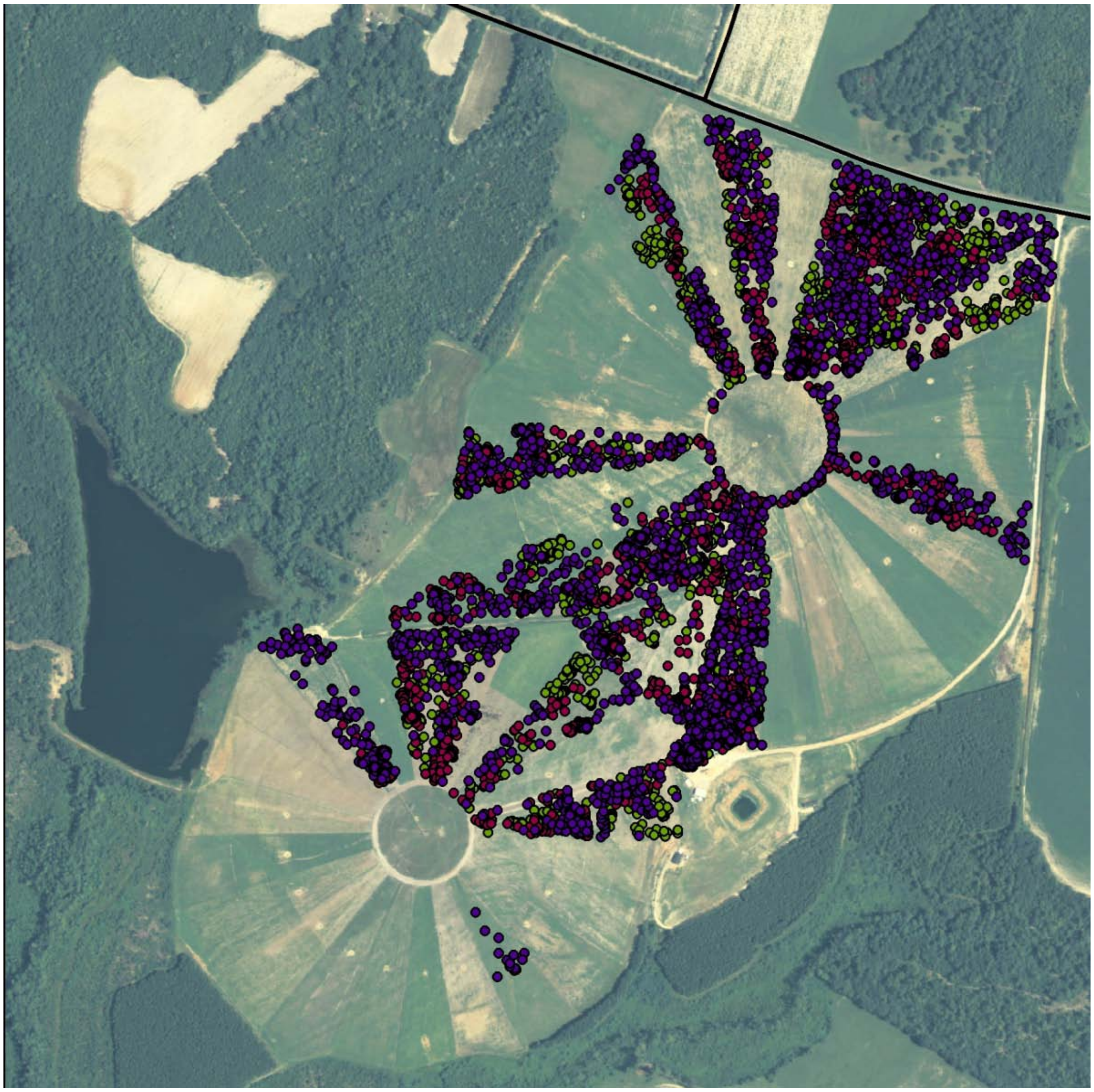

Figure 5.4: All of the corrected points overlaid on top of an aerial photograph in ArcMap.

The percentage of time that cattle spent in areas draining into the waste management system was calculated in ArcMap by drawing a polygon around the area that drains into the waste management system (Figure 5.5) and then clipping the point layers so that only the points inside of the polygon remained (Figure 5.6).

Figure 5.5: The polygon delineating the areas draining into the waste management system.

The polygon that represents the drainage area of waste into the waste management system was delineated based on the geographically referenced aerial photograph and knowledge of the site.

Figure 5.6: The point layers after points outside of the polygon were clipped.

Dividing the number of clipped points by the total number of points and multiplying by 100 percent yielded the percentage of time spent by each cow in an area that drains into the waste management system.

Measurement of the Volume of Effluent Land Applied

A 0 - 50 Amp split-core AC current sensor (CTV-B, Onset Corp., Pocasset, MA) was installed on the effluent pump and set to measure the amperage flowing to the pump every minute. The current usage data was stored on a HOBO U12 4-Channel External Data Logger (U12-006, Onset Corp., Pocasset, MA) and downloaded using HOBOware Pro software from Onset Corporation. Data was collected from this data logger for a five month period (January 25

– June 24, 2010) and was used to calculate the amount of time that the pump was on during this period. The calculation of the on-time of the pump utilized Microsoft Excel to count the number of time increments when the current meter registered a reading greater than 5 amps. The 5 amp threshold was used to filter out the small current readings that represented electrical noise picked up by the current monitor.

The flowrate of the pump was calculated by measuring both the depth that the water level of the storage tank dropped and the amount of time that the effluent pump ran during a typical pumping session. The distance that the water level dropped multiplied by the the plan-view area of the storage tank equals the volume of effluent pumped, and dividing this number by the time that the pump was on provided an estimation of the volumetric flowrate of the pump.

Multiplying the on-time of the pump during a specific time interval by the flowrate of the pump resulted in the volume of effluent that was land applied during this time period.

Stormwater Runoff and its Effect on the Waste Management System

Poor grading and site layout at the farm in this study allowed stormwater runoff and eroded soil to flow into the waste management system (Figure 5.7).

Figure 5.7: Erosion directly uphill of the waste management system.

To demonstrate the differences that simple changes in management could make, the contribution of runoff to the amount of effluent that was treated and land applied was calculated over the time-frame that the effluent pump was monitored.

The curve number method was utilized to estimate runoff given land use, soil type, topography, and precipitation information at the farm. Precipitation data was obtained from the Georgia Automated Environmental Monitoring Network for two locations near the dairy (UGA, 2010). The precipitation records during January 25 – June 24, 2010 were summed for each location, and the average of these two totals was used as the approximate amount of precipitation received at the farm during this time period. The watershed draining into the waste management system was delineated and determined to be 1.3 acres.

Results and Discussion

Spatial Distribution of Cattle Locations

The percentage of time that cattle spent in areas draining into the waste management system varied from 8.2 to 14.6 percent among the three cows monitored (Table 5.1).

Table 5.1: Percentage of time spent by cattle in areas that drain into the waste management system.

Collar	Clipped Points	Total Points	Percentage of Points Inside Polygon
1	545	4920	11.1%
2	696	4757	14.6%
3	403	4913	8.2%

The average percentage of time that the three cattle spent inside an area draining into the waste management system was 11.3 percent.

Measurement of the Volume of Effluent Land Applied

Figure 5.8 provides a graph of a 10 day period that was representative of the current data collected on the effluent pump during the 5 month monitoring period.

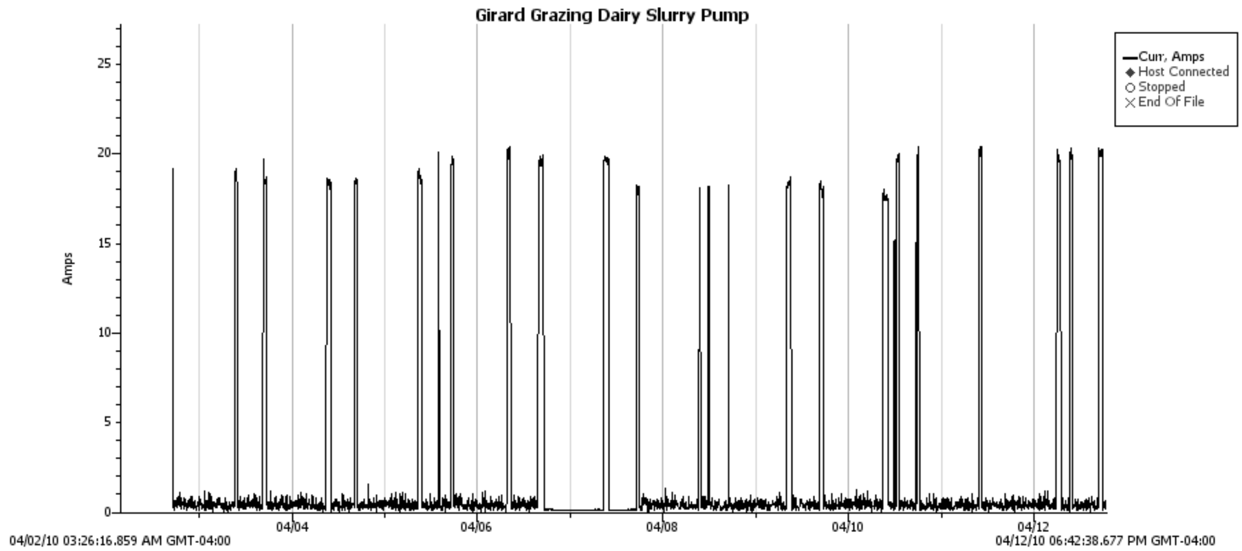

Figure 5.8: The recorded electrical current in amps flowing to the effluent pump during a typical nine day period.

The effluent pump was turned on for about 2.6 hours per day, which resulted in approximately 17,370 gallons of effluent being land applied per day. Dividing the volume pumped daily by the number of head maintained on the farm yields 34.7 gallons, which represents the volume of effluent pumped per cow per day (Table 5.2).

Table 5.2: Results from monitoring the activity of the effluent pump.

Total Time Monitored (days)	150
Total On Time (minutes)	23,613
On Time Per Day (minutes)	157
Volume Pumped Per Day (gallons)	17,370
Volume Pumped Per Month (gallons)	521,093
Volume per Cow per day (gallons)	**34.7**

Stormwater Runoff and its Effect on the Waste Management System

The total amount of runoff that flowed into the waste management system from January 25 – June 24, 2010 was estimated to be 585,243 gallons. Therefore, the percentage of the volume of effluent pumped that was attributable to stormwater runoff was 22.5 percent. Of this total, the percentage of the volume of effluent pumped that was attributable to runoff from the holding area was 2.6 percent. According to the electricity consumption monitoring results presented in Chapter 4, the effluent pump used about 15,400 kWh annually. If 22.5 percent of this annual electricity consumption was attributable to stormwater runoff, then this runoff forced the effluent pump to consume about 3,470 kWh. If electricity costs 10 cents per kWh, then the grazing dairy spent about 347 dollars during one year to pump stormwater runoff out of the waste management system.

Conclusions

The results of the research conducted during this study contribute design parameters to engineers who are developing waste management plans and designing waste management systems for future intensively managed rotational grazing dairies in the Southeast.

GIS analysis of the data gathered during GPS monitoring of the location of cattle on the dairy provided a measurement of the time that cattle spent on artificial surfaces on this type of dairy. During future permitting processes, this estimate will allow potential owners of comparable dairies to justify a smaller waste management system design than what would be necessary for a confined dairy with similar cattle numbers. As shown in Table 5.1, cattle were measured to spend between 8.2 and 14.6 percent of each day on artificial surfaces and other areas that drained into the waste management system on the farm. Therefore, a conservative estimate of the amount of manure and urine that a waste management system must treat on an intensively managed rotational grazing dairy is 15 percent of the total manure and urine produced by dairy cattle on the farm.

Monitoring the volume of effluent spread on pastures by the land application system showed that 34.7 gallons of effluent per cow were land applied on pastures each day. This number provides the scientific community with a simple design parameter that allows engineers to estimate the amount of effluent land applied on a similar system based on the number of cattle on that farm.

Quantifying stormwater runoff into the waste management system provides justification for several changes that could easily be implemented on this grazing dairy: 1) Grade diversions above the effluent tank to eliminate the runoff that comprises 22.5 percent of the effluent pumped out of the storage tank; 2) Cover the holding area to eliminate this area's contribution of runoff to the waste management system, thereby eliminating 2.6 percent of the volume that is currently being land applied and increasing cattle comfort during hot weather; 3) Implement a rainwater harvesting system at the covered holding area to provide cattle with drinking water while they are waiting to be milked. These suggested management changes also provide design considerations for engineers and farmers who are planning future grazing dairies.

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Chapter 6

SUMMARY AND CONCLUSIONS

In Georgia, a sharp increase has been observed in the number of dairies utilizing rotational grazing during the past decade. However, even with this increase, milk production in Georgia is still dominated by confined dairies, which typically feed mixed rations to cattle in freestall barns (Hill et al., 2008). The objectives of this project were to quantify environmental impacts and resource consumption on a pasture-based and a confined dairy in Georgia, as well as to address a specific barrier, waste management system design, confronting pasture-based dairies during initial permitting processes. To accomplish this, a wide spectrum of environmental impacts resulting from each production process, including erosion, nutrient runoff, carbon footprint, and greenhouse gas emissions, were modeled using the Integrated Farm System Model (IFSM), a life cycle assessment software package (USDA-ARS, 2009). Also, electricity and water consumption were measured on each dairy through on-farm monitoring efforts. Finally, a thorough analysis of the waste management system on the pasture-based dairy yielded design parameters that could inform future design and permitting processes.

Summing the modeled nitrous oxide, methane, and carbon dioxide emissions, the three predominant greenhouse gas emissions on dairies, and then dividing this sum by energy corrected milk production on each dairy resulted in approximately equal total carbon footprints for the pasture-based and the confined dairy in this study (Tables 3.6 and 3.7). Other environmental impacts resulting from each dairy production process varied widely between each farm (Tables 3.2 and 3.3). For example, erosion and phosphorus runoff were much greater on the confined dairy because of soil types and the substantially larger area of land that was plowed each year to grow silage, while nitrate leaching per unit of milk produced was predicted to be higher on the pasture-based dairy because of soil types and the fact that urine and feces were deposited directly onto pasture instead of undergoing treatment in a lagoon before land application.

The modeled environmental impact results for the two farms were similar to results from previous studies using the IFSM (Figure 3.6), with differences that are understood by considering variations in the management and structure of the farms, climate, and physiography. Modeled environmental impacts were compared to measured or empirical values, if available, in Table 3.9. The considerable discrepancy between the modeled and measured environmental impacts largely results from the difficulty in modeling highly variable parameters. For example, the nitrate leaching measured on two otherwise similar pasture-based dairies varied 183 percent from one dairy to the other (Eason, 2010).

Modeling four adjustments in management on each farm showed how these changes would positively or negatively impact the carbon footprint of each farm (Figure 3.9). Improving the genetics of cattle on the pasture-based dairy to produce more milk and covering the manure storage and flaring the resulting biogas showed the most potential for improving the carbon footprint of the pasture-based and the confined dairy respectively. Table 3.10 shows the relative levels of environmental impacts resulting from the potential changes in management on each farm. Three of the eight management change scenarios decreased or did not change the level of every negative environmental impact: 1) Decreasing the level of nitrogen application on the pasture-based dairy, 2) Covering manure storage areas and flaring biogas on the confined dairy, and 3) Placing lactating animals on pasture on the confined dairy.

Although adapting the IFSM to farming practices in the southeast was difficult in some instances, the model proved to be an invaluable tool for evaluating the environmental impact of dairies in the region. The amount of information gleaned from the modeling work performed would have taken many years and a multimillion dollar budget to complete through monitoring efforts.

Water and electricity consumption monitoring quantified the major components of this consumption and the total amount used on each of the dairies. As depicted in Figures 4.4 and 4.8, the largest component of water consumption on each dairy was irrigation. The confined dairy used a total of 104,475,881 gallons of water per year, or 6.0 gallons per pound of energy corrected milk production and 149,251 gallons per cow. The pasture-based dairy used a total of 88,064,029 gallons of water per year, or 15.8 gallons per pound of energy corrected milk production and 176,128 gallons per cow. Water conservation and recycling efforts on the confined dairy significantly reduced the total water consumption of the farm.

The largest component of electricity consumption on the pasture-based dairy was irrigation, while the area in and around the freestall barns and milking parlor consumed more than any other component on the confined dairy. The confined dairy used a total of 814,376 kWh of electricity per year, or 0.047 kWh per pound of energy corrected milk production and 1163 kWh per cow. The pasture-based dairy used a total of 270,308 kWh of electricity per year, or 0.048 kWh per pound of energy corrected milk production and 541 kWh per cow.

Water and electricity consumption data given by this study were compared to data given by previous studies. The comparisons were mostly reasonable, with differences that resulted from variations in the methodology of each study and regional variations in milk production and climate.

The water and electricity consumption data from each dairy scaled per cow provides standards to predict the water and electricity consumption of similar dairies based on the number of cattle on the farm in question.

The analysis of the operation of the waste management system on the pasture-based dairy yielded three design parameters: the amount of time that cattle spend on artificial surfaces and therefore the percentage of waste that must be treated by the waste management system, the volume of waste land applied per cow per day, and the contribution of stormwater runoff to the volume of effluent handled by the waste management system.

GIS analysis of the data gathered during GPS monitoring of the location of cattle on the dairy provided a measurement of the time that cattle spent on artificial surfaces on this type of dairy. During future permitting processes, this estimate will allow potential owners of comparable dairies to justify a smaller waste management system design than what would be necessary for a confined dairy with similar cattle numbers. As shown in Table 5.1, cattle were measured to spend between 8.2 and 14.6 percent of each day on artificial surfaces and other areas that drained into the waste management system on the farm. Therefore, a conservative estimate of the amount of manure and urine that a waste management system must treat on an intensively managed rotational pasture-based dairy is 15 percent of the total manure and urine produced by dairy cattle on the farm.

Monitoring the volume of effluent spread on pastures by the land application system showed that 34.7 gallons of effluent per cow were land applied on pastures each day. This number provides the scientific community with a simple design parameter that allows engineers to estimate the amount of effluent land applied on a similar system based on the number of cattle on that farm.

An analysis of stormwater runoff on the dairy resulted in the estimation that 22.5 percent of the volume of effluent pumped could be attributed to stormwater runoff. This analysis resulted in the identification of several changes that could easily be implemented on this pasture-based dairy to reduce the volume of runoff flowing into the waste management system: 1) Grade diversions above the effluent tank to eliminate the runoff that comprises 22.5 percent of the effluent pumped out of the storage tank; 2) Cover the holding area to eliminate this area's contribution of runoff to the waste management system, thereby eliminating 2.6 percent of the volume that is currently being land applied and increasing cattle comfort during hot weather; 3) Implement a rainwater harvesting system at the covered holding area to provide cattle with drinking water while they are waiting to be milked.

The results of this research contribute design parameters to engineers who are developing waste management plans and designing waste management systems for future intensively managed rotational pasture-based dairies in the southeast.

As summarized above, this study contributes several pieces of knowledge to the general body of existing information on dairies in the southeastern U.S. The capability of the IFSM to adapt to conditions in Georgia was demonstrated, and the model was used to predict a wide range of environmental impacts on a pasture-based and a confined dairy. Also, the IFSM was used to predict the changes in environmental impacts that would result from four changes in management on each dairy. Electricity and water consumption on each dairy were measured and listed. The waste management processes on a pasture-based dairy in Georgia were analyzed and design parameters for similar systems were developed.

Rotational pasture-based dairies are still a relatively new concept in Georgia and the southeast, and much room is available for improvements in efficiency, both in milk production per cow and in the consumption of resources. In contrast, the resources and research of land grant universities and the ingenuity of farmers have led to the continuous improvement in the efficiency of confined dairies during the past half-century (Burney et al, 2010).

The results of this research demonstrate that while decreasing the resource and material consumption of a dairy can provide reductions in environmental impacts, these reductions should be weighed against their impact on milk production. If milk is sold to a co-op, and is considered a uniform commodity defined only by volume and milk fat concentration, then environmental impacts must be scaled to energy corrected milk production to compare the sustainability of various production systems. For instance, in this study the annual energy corrected milk production per cow on the confined dairy was about 3 times that of the pasture-based dairy. Therefore, the confined dairy could generate three times the amount of a certain negative environmental impact as the pasture-based dairy and the amount of the environmental impact per unit of milk production would be approximately equal on each dairy.

Studies have claimed that grass-fed milk is healthier, and that if given a choice consumers prefer this milk over milk produced by confined dairies (Hauswirth et al., 2004), (Winsten et al., 2003), and (Conner and Campbell-Arvai, 2009). If milk produced by a pasture-based cow is actually superior to milk produced by a confined cow, additional research is needed to develop a new standard for milk production that accounts for parameters such as omega-3 fatty acids, taste, animal welfare, and consumer attitudes. These parameters could then be considered in addition to milk production volume and fat content when scaling environmental impacts and resource consumption to the production of milk on a dairy.

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Appendix A

IFSM PRINTOUT OF INPUT PARAMETERS FOR THE PASTURE-BASED DAIRY MODEL

Date: 10/08/2010 FRI Time: 04:52:18 PM

CROP AND SOIL PARAMETERS

Land and crop	Value
Owned land	243 acres
Rented land	0 acres
Grass	243 acres
Life of grass stand	10 years
Yield adjustment factor	200 %
Legume portion in sward	5 %
Maximum annual irrigation	20.0 inches
Nitrogen	300.00 lb N/ac
Phosphate	0.00 lb P2O5/ac
Potash	0.00 lb K2O/ac
Manure	15 % of that collected

Soil Characteristics Value

Predominant soil type	Deep Loamy Sand
Available water holding capacity	6.299 inches
Fraction of available water when stress begins	0.500
Bare soil albedo	0.150
Soil evaporation coefficient	0.157 inches
Moist bulk density	106.138 lb/ft3
Organic carbon concentration	0.300 %
Silt content	6.000 %
Clay content	5.000 %
Sand content	89.000 %
Runoff curve number	65.000
Whole profile drainage rate coefficient	0.300
Soil pH	6.500

Tractability coefficients

Spring tillage and planting, upper soil	1.000
Fall tillage and planting, upper soil	1.040
Fall harvest and planting, upper soil	1.080
Spring tillage and planting, lower soil	1.000
Fall tillage and planting, lower soil	1.040
Fall harvest and planting, lower soil	1.060

TILLAGE AND PLANTING PARAMETERS

Operation	Starting Date

Grass

Operation #1 Grass seeding 20 September

Maximum operations performed simultaneously: 2

Time available for tillage and planting operations 24.0 hrs/day

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GRAZING PARAMETERS

Parameter	Value
Spring grazing area	243 acre
Summer grazing area	243 acre
Fall grazing area	243 acre
Investment in perimeter fence	0 $
Investment in temporary fence	0 $
Investment in watering system	0 $
Annual cost for seed, fertilizer and chemicals	0 $/acre
Grazed forage yield adjustment factor	250 percent
Labor for grazing management	0 h/week
Grazing strategy	All animals, year around (outwintered)

STORAGE AND PRESERVATION PARAMETERS

Forage Type	Storage Type	Capacity (ton DM)	Initial Cost ($)	Annual Cost ($/ton DM)
High quality forage (1)	No storage	0	0	1.50
High quality forage (2)	No storage	0	0	0.00
Low quality forage (1)	No storage	0	0	0.00
Low quality forage (2)	No storage	0	0	0.00
Grain crop silage (1)	No storage	0	0	1.50
Grain crop silage (2)	No storage	0	0	0.00
High moisture grain	Sealed silo	92	23133	0.00
Dry Hay	Inside a shed	150	10000	0.00
Dry grain storage	----	----	----	8.99

HERD, FEEDING AND MANURE PARAMETERS

Herd/Facility Parameters	Value
Animal type	Small Holstein
Target milk production	11000 lb/cow/year
First lactation animals	10 %
Number of lactating animals	500
Number of young stock (over 1 year)	0
Number of young stock (under 1 year)	100

Feeding Method

Grain	Loader and mixer wagon
Silage	No silage fed
Hay	No hay fed

Ration constituents

Minimum dry hay in rations	0.0% of forage
Relative forage to grain ratio	Low
Crude protein supplement	Soybean meal, 44%
Undegradable protein supplement	Cotton seed
Energy supplement	Grain only
Phosphorus feeding level in rations	100.0% of NRC recommendation

Manure Parameters	Value
Manure collection method	Flush system
Manure type	Liquid slurry (5 - 7% DM)
Average hauling distance	0.00 mile

Manure storage

Method	No storage (Daily haul)
Type	Concrete tank
Loading Position	Top
Storage capacity	221 ton

Bedding

Type	None
Amount of bedding per mature animal	0.00 lb/day

Imported manure

Quantity	121 ton
Type	Poultry
Dry matter content	25.00 %
Nitrogen content	3.00 % DM
Organic nitrogen content	60.00 % DM
Phosphorus content	3.00 % DM
Potassium content	3.00 % DM

Exported manure

Quantity	0 % of that collected
Form	Fresh manure

Appendix B

IFSM PRINTOUT OF INPUT PARAMETERS FOR THE CONFINED DAIRY MODEL

Date: 10/08/2010 FRI Time: 05:53:31 PM

CROP AND SOIL PARAMETERS

Land and crop	Value
Owned land	700 acres
Rented land	0 acres
Grass	450 acres
Life of grass stand	3 years
Yield adjustment factor	150 %
Legume portion in sward	0 %
Maximum annual irrigation	10.0 inches
Nitrogen	100.00 lb N/ac
Phosphate	0.00 lb P2O5/ac
Potash	120.00 lb K2O/ac
Manure	20 % of that collected
Corn	400 acres
Relative maturity index	120 days
Grain yield adjustment factor	50 %
Silage yield adjustment factor	90 %

Maximum annual irrigation	25.0 inches
Preplanting Nitrogen	120.00 lb N/ac
Postplanting Ammonia	0.00 lb N/ac
Phosphate	50.00 lb P2O5/ac
Potash	100.00 lb K2O/ac
Manure	70 % of that collected

Soybean 400 acres

Yield adjustment factor	100 %
Maximum annual irrigation	10.0 inches
Nitrogen	0.00 lb N/ac
Phosphate	0.00 lb P2O5/ac
Potash	0.00 lb K2O/ac
Manure	10 % of that collected

Soil Characteristics	Value
Predominant soil type	Medium Clay Loam
Available water holding capacity	5.906 inches
Fraction of available water when stress begins	0.500
Bare soil albedo	0.110
Soil evaporation coefficient	0.236 inches
Moist bulk density	74.921 lb/ft3
Organic carbon concentration	1.800 %
Silt content	45.000 %
Clay content	45.000 %
Sand content	10.000 %
Runoff curve number	85.000
Whole profile drainage rate coefficient	0.350
Soil pH	6.500

Tractability coefficients

Spring tillage and planting, upper soil	0.920
Fall tillage and planting, upper soil	0.990
Fall harvest and planting, upper soil	1.030
Spring tillage and planting, lower soil	0.940
Fall tillage and planting, lower soil	1.000
Fall harvest and planting, lower soil	1.010

TILLAGE AND PLANTING PARAMETERS

Operation	Starting Date
Grass	
Operation #1 Grass seeding	01 November
Corn	
Operation #1 Moldboard/chisel plow	25 May
Operation #2 Row crop planting	01 June
Soybean	
Operation #1 Moldboard/chisel plow	20 May
Operation #2 Row crop planting	01 June

Maximum operations performed simultaneously: 3

Time available for tillage and planting operations 16.0 hrs/day

GRAZING PARAMETERS

Parameter	Value
Spring grazing area	250 acre
Summer grazing area	250 acre
Fall grazing area	250 acre
Investment in perimeter fence	0 $
Investment in temporary fence	0 $
Investment in watering system	0 $
Annual cost for seed, fertilizer and chemicals	0 $/acre
Grazed forage yield adjustment factor	60 percent
Labor for grazing management	0 h/week
Grazing strategy	Older heifers and dry cows

HARVEST, FEEDING, TILLAGE AND PLANTING MACHINE PARAMETERS

Machine	Num	Type and Size(Initial Cost)	Tractor(Initial Cost)

Mowing 2 SP mow-conditioner,16 ft (4.9 m)($ 90000) None

Tedding 0 None None

Raking 0 None None

Baling 0 None None

Bale wrapping 0 None None

Forage chopping 2 SP forage harvester($ 157500) None

Grain Harvesting 2 Large corn combine, 12 row($ 209700) 245 hp (164 kW) tractor($ 142200)

Feed mixing 2 Medium mixer (9 ton, 8.5 t)($ 28530) 134 hp (100 kW) tractor($ 81900)

Silo filling 8 Small silage bagger (8-9 ft)($ 27000) 134 hp (100 kW) tractor($ 81900)

Manure handling 2 Manure pump/agitator($ 15300) 134 hp (100 kW) tractor($ 81900)

Plowing 2 Coulter-chisel plow, 20 ft (6.1 m)($ 29700) 245 hp (164 kW) tractor($ 142200)

Disking 0 None None

Field Cultivation 0 None None

Hoeing 0 None None

Aeration 0 None None

Row crop planting 2 Corn planter, 12-row (9.1 m)($ 47700) 245 hp (164 kW) tractor($ 142200)

Drill seeding 2 134 hp (100 kW) tractor($ 81900) 245 hp (164 kW) tractor($ 142200)

Subsoiling 0 None None

MISCELLANEOUS MACHINE PARAMETERS

Machine Type	Number	Tractor
Transport tractors	1	108 hp (80 kW) tractor
Feed /manure loader	1	Medium skid-steer loader
Manure nurse tankers	0	
Round bale loader		134 hp (100 kW) tractor
Manure Agitator		134 hp (100 kW) tractor
Auxiliary manure pump		108 hp (80 kW) tractor

Feed transport	Machine	Number	Haul distance
Hay	Square bale wagons	1	0.62 miles
Hay crop silage	Dump trucks	5	0.50 miles
Grain crop silage	Dump trucks	5	0.50 miles
Grain	No grain harvest	2	25.00 miles

GRASS HARVEST PARAMETERS

Preferred harvest schedule: 1 Cutting - early head

Harvest	Type	Earliest Harvest Date	Drying Treatment

First Wilted silage harvest by chopping 5 April Mechanical conditioning, narrow swath

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Corn Harvest Parameters

Starting dates

Corn silage	15 August
High moisture corn	1 October
Dried grain	21 October

Maximum silage moisture content at harvest 67 %

Corn silage processing Rolled at chopper

Corn silage cutting height 6.0 in

High moisture corn type w/ Little or no cob & husk

Soybean Harvest Parameters

Starting date of harvest 1 November

Primary use of soybean Cash crop

Soybean roasting cost 35.00

STORAGE AND PRESERVATION PARAMETERS

Forage Type	Storage Type	Capacity (ton DM)	Initial Cost ($)	Annual Cost ($/ton DM)
High quality forage (1)	Bunker silo	2247	146265	1.50
High quality forage (2)	Bunker silo	2247	146265	0.00
Low quality forage (1)	Bunker silo	2247	146265	0.00
Low quality forage (2)	Bunker silo	2247	146265	0.00
Grain crop silage (1)	Bunker silo	4214	221161	1.50
Grain crop silage (2)	Bunker silo	4214	221161	0.00
High moisture grain	Stave silo	1026	44690	0.00
Dry Hay	Inside a shed	150	10000	0.00
Dry grain storage	----	----	----	8.99

Preservation Treatments	Value
High moisture hay drying type	None
Dryer capacity	0.00 ton DM
Additional labor	0.00 man h/ton DM
Hay preservation procedure	No preservation used
Hay preservation treatment	Buffered/ dilute acid solution
Hay preservation application rate	0.00 %DM
Hay preservation equipment cost	0.00 $

Hay crop silage:

Treatment	Bacterial inoculant (inactive)
Application rate	3.00 %DM
Equipment cost	0.00 $

Grain crop silage:

Treatment	Anhydrous ammonia
Application rate	1.50 %DM
Equipment cost	0.00 $

HERD, FEEDING AND MANURE PARAMETERS

Herd/Facility Parameters	Value
Animal type	Holstein
Target milk production	24000 lb/cow/year
First lactation animals	33 %
Number of lactating animals	700
Number of young stock (over 1 year)	370
Number of young stock (under 1 year)	380
Animal facilities	
Milking center structure: Double eight parlor	111000 $/cow
Milking and milk handling equipment	152000 $/cow
Cow housing: Free stall barn, mechanically ventilated	840000 $/cow
Heifer housing: Calf hutches and dry lot	177900 $/head
Feed facility: Commodity shed	177900 $/cow
Labor for milking and animal handling	3.5 minutes/cow/day

Feeding Method

Grain	Loader and mixer wagon
Silage	Loader and mixer wagon
Hay	No hay fed

Ration constituents

Minimum dry hay in rations	0.0% of forage
Relative forage to grain ratio	Low
Crude protein supplement	Soybean meal, 44%
Undegradable protein supplement	Cotton seed
Energy supplement	Grain only
Phosphorus feeding level in rations	100.0% of NRC recommendation

Manure Parameters	Value
Manure collection method	Flush system
Manure type	Liquid slurry (5 - 7% DM)
Average hauling distance	0.00 mile
Average time between manure spreading and incorporation	4 day(s)

Manure storage

Method	4 month storage
Type	clay lined pit
Loading Position	Top
Storage capacity	119115 ton

Bedding

Type	Sand

Amount of bedding per mature animal	50.00 lb/day

Imported manure

Quantity	270 ton
Type	Poultry
Dry matter content	25.00 %
Nitrogen content	3.00 % DM
Organic nitrogen content	60.00 % DM
Phosphorus content	3.00 % DM
Potassium content	3.00 % DM

Exported manure

Quantity	0 % of that collected
Form	Fresh manure

Appendix C

CHANGES IN INDIVIDUAL EMISSIONS RESULTING FROM CHANGES IN MANAGEMENT ON EACH FARM

Table C.1: Changes in greenhouse gas emissions on the pasture-based dairy as a result of modeling increased milk production per cow.

Greenhouse Gas Emission or Sequestration	Pasture-based Dairy lb CO_2 equiv.	New Pasture-based Dairy lb CO2 equiv.
Methane	3419875	3819750
Nitrous Oxide	416604	446404
Carbon Dioxide	3100949	3217664
Secondary Sources	571718	626111
Sequestration During Feed Production	-4101466	-4499825
Not Allocated to Milk	-243530	-213340
Sum	3164150	3396764
Farm Characteristic	**Pasture-based Dairy**	**New Pasture-based Dairy**
Energy Corrected Milk Production (ECM) (lb)	5589540	6859944
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	3164150	3396764
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.56	0.49
Carbon Sequestration* (lb CO_2/ton ECM)	0.09	0.09
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.40

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table C.2: Changes in greenhouse gas emissions on the pasture-based dairy as a result of modeling decreased nitrogen application on pastures.

Greenhouse Gas Emission or Sequestration	Pasture-based Dairy lb CO_2 equiv.	New Pasture-based Dairy lb CO2 equiv.
Methane	3419875	3419875
Nitrous Oxide	416604	412432
Carbon Dioxide	3100949	3100949
Secondary Sources	571718	451177
Sequestration During Feed Production	-4101466	-4101462
Not Allocated to Milk	-243530	-234618
Sum	3164150	3048353
Farm Characteristic	Pasture-based Dairy	New Pasture-based Dairy
Energy Corrected Milk Production (ECM) (lb)	5589540	5589540
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	3164150	3048353
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.56	0.54
Carbon Sequestration* (lb CO_2/ton ECM)	0.09	0.09
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.45

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table C.3: Changes in greenhouse gas emissions on the pasture-based dairy as a result of raising replacement heifers on the farm.

Greenhouse Gas Emission or Sequestration	Pasture-based Dairy lb CO_2 equiv.	New Pasture-based Dairy lb CO2 equiv.
Methane	3419875	3940575
Nitrous Oxide	416604	469648
Carbon Dioxide	3100949	3440551
Secondary Sources	571718	3382
Sequestration During Feed Production	-4101466	-4482430
Not Allocated to Milk	-243530	-235999
Sum	3164150	3135727
Farm Characteristic	Pasture-based Dairy	New Pasture-based Dairy
Energy Corrected Milk Production (ECM) (lb)	5589540	5589540
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	3164150	3135727
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.56	0.56
Carbon Sequestration* (lb CO_2/ton ECM)	0.09	0.09
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.47

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table C.4: Changes in greenhouse gas emissions on the pasture-based dairy as a result of modeling corn silage grown and fed to cattle on the farm.

Greenhouse Gas Emission or Sequestration	Pasture-based Dairy lb CO_2 equiv.	New Pasture-based Dairy lb CO2 equiv.
Methane	3419875	3763275
Nitrous Oxide	416604	442828
Carbon Dioxide	3100949	5208480
Secondary Sources	571718	626564
Sequestration During Feed Production	-4101466	-6214275
Not Allocated to Milk	-243530	-225832
Sum	3164150	3601040
Farm Characteristic	Pasture-based Dairy	New Pasture-based Dairy
Energy Corrected Milk Production (ECM) (lb)	5589540	6859944
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	3164150	3601040
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.56	0.52
Carbon Sequestration* (lb CO_2/ton ECM)	0.09	0.09
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.43

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table C.5: Changes in greenhouse gas emissions on the confined dairy as a result of modeling the elimination of the cross-breeding program on the farm.

Greenhouse Gas Emission or Sequestration	Confined Dairy lb CO_2 equiv.	New Confined Dairy lb CO2 equiv.
Methane	8519425	9300800
Nitrous Oxide	3430278	3400776
Carbon Dioxide	4931669	6064511
Secondary Sources	325104	62815
Sequestration During Feed Production	-8458287	-9394731
Not Allocated to Milk	-533333	-655577
Sum	8214856	8778594
Farm Characteristic	Confined Dairy	New Confined Dairy
Energy Corrected Milk Production (ECM) (lb)	17352347	16589429
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	8214856	8778594
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.47	0.53
Carbon Sequestration* (lb CO_2/ton ECM)	0.00	0.00
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.53

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table C.6: Changes in greenhouse gas emissions on the confined dairy as a result of modeling an increased reliance on imported feed.

Greenhouse Gas Emission or Sequestration	Confined Dairy lb CO_2 equiv.	New Confined Dairy lb CO2 equiv.
Methane	8519425	9349950
Nitrous Oxide	3430278	2733554
Carbon Dioxide	4931669	11020734
Secondary Sources	325104	78821
Sequestration During Feed Production	-8458287	-14052870
Not Allocated to Milk	-533333	-556328
Sum	8214856	8573861
Farm Characteristic	Confined Dairy	New Confined Dairy
Energy Corrected Milk Production (ECM) (lb)	17352347	17352347
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	8214856	8573861
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.47	0.49
Carbon Sequestration* (lb CO_2/ton ECM)	0.00	0.00
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.49

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table C.7: Changes in greenhouse gas emissions on the confined dairy as a result of modeling a covered manure storage and the flaring of biogas.

Greenhouse Gas Emission or Sequestration	Confined Dairy lb CO_2 equiv.	New Confined Dairy lb CO2 equiv.
Methane	8519425	7196825
Nitrous Oxide	3430278	3493454
Carbon Dioxide	4931669	5035444
Secondary Sources	325104	324958
Sequestration During Feed Production	-8458287	-8429642
Not Allocated to Milk	-533333	-464611
Sum	8214856	7156428
Farm Characteristic	Confined Dairy	New Confined Dairy
Energy Corrected Milk Production (ECM) (lb)	17352347	17352347
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	8214856	7156428
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.47	0.41
Carbon Sequestration* (lb CO_2/ton ECM)	0.00	0.00
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.41

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Table C.8: Changes in greenhouse gas emissions on the confined dairy as a result of converting silage land to perennial pastures in order to graze lactating animals.

Greenhouse Gas Emission or Sequestration	Confined Dairy lb CO_2 equiv.	New Confined Dairy lb CO2 equiv.
Methane	8519425	6831425
Nitrous Oxide	3430278	2300560
Carbon Dioxide	4931669	752222
Secondary Sources	325104	289973
Sequestration During Feed Production	-8458287	-4191956
Not Allocated to Milk	-533333	-484868
Sum	8214856	5497356
Farm Characteristic	Confined Dairy	New Confined Dairy
Energy Corrected Milk Production (ECM) (lb)	17352347	13214124
Sum of Greenhouse Gas Emissions (lb CO_2 equiv.)	8214856	5497356
Carbon Footprint (lb. CO_2 equiv. / ton ECM)	0.47	0.42
Carbon Sequestration* (lb CO_2/ton ECM)	0.00	0.00
Carbon Footprint With Sequestration (lb. CO_2 equiv. / ton ECM)	0.47	0.42

* Estimated using the Comet-VR model (USDA-NRCS, 2009).

Appendix D

WATER AND ELECTRICITY CONSUMPTION MONITORING DATA

Table D.1: Total and component water usage on the pasture-based dairy.

Month	Total Water Usage (gallons)	Irrigation (gallons)	Cattle Drinking (gallons)	Main Farm Usage (gallons)
January	572,851	0	327,074	245,777
February	949,659	0	542,215	407,443
March	1,102,421	290,729	479,523	332,169
April	21,615,829	20,845,259	425,688	344,882
May	17,927,095	17,135,712	497,740	293,643
June	8,869,776	7,980,373	649,327	240,076
July	10,465,183	8,576,817	1,241,163	647,203
August	2,729,880	1,513,987	873,365	342,528
September	16,002,398	15,170,557	583,865	247,976
October	6,587,872	5,886,621	492,204	209,047
November	599,202	0	342,119	257,083
December	641,863	64,480	329,661	247,721

Table D.2: Consumption of drinking water by cattle on the pasture-based dairy.

Month	Cattle Drinking (gallons)	Gallons per head per day
January	327,074	21
February	542,215	39
March	479,523	31
April	425,688	28
May	497,740	32
June	649,327	43
July	1,241,163	80
August	873,365	56
September	583,865	39
October	492,204	32
November	342,119	23
December	329,661	21

Table D.3: Summary of well water usage on the confined dairy.

Month	1.5 HP* Well (gallons)	3 HP Well (gallons)	3-Phase, 2HP Well (gallons)	7.5 HP Well (gallons)	Total (gallons)
January	109,405	91,797	1,059,109	2,289,723	3,550,034
February	109,405	91,797	670,003	1,793,781	2,664,986
March	109,405	91,797	727,192	1,766,910	2,695,303
April	109,405	91,797	671,685	3,049,664	3,922,551
May	87,271	91,150	884,309	2,378,787	3,441,517
June	252,886	73,713	855,632	2,104,295	3,286,525
July	384,769	265,389	902,201	2,350,032	3,902,391
August	296,433	83,900	713,759	1,887,784	2,981,875
September	303,035	100,723	766,885	1,952,055	3,122,698
October	131,538	92,443	792,447	1,566,811	2,583,239
November	109,405	91,797	655,426	1,805,567	2,662,194
December	109,405	91,797	665,518	1,672,625	2,539,344

Table D.4: Summary of surface water usage on the confined dairy.

Month	10 HP Submersible Creek Pump (gallons)	100 HP Creek Pump (gallons)	100 HP River Pump (gallons)	Total (gallons)
January	0	0	0	0
February	128,413	0	0	128,413
March	93,902	0	0	93,902
April	304,178	0	0	304,178
May	4,490,744	0	1,521,315	6,012,059
June	5,617,392	4,608,000	8,950,200	19,175,592
July	6,281,909	493,714	8,246,529	15,022,152
August	4,822,222	3,686,400	7,743,580	16,252,202
September	5,011,096	2,304,000	1,775,400	9,090,496
October	1,044,230	0	0	1,044,230
November	0	0	0	0
December	0	0	0	0

Table D.5: Total water usage on the confined dairy.

Month	Well Water Total Usage (gallons)	Surface Water Total Usage (gallons)	Total Water Consumption (gallons)
January	3,550,034	0	3,550,034
February	2,664,986	128,413	2,793,399
March	2,695,303	93,902	2,789,205
April	3,922,551	304,178	4,226,728
May	3,441,517	6,012,059	9,453,576
June	3,286,525	19,175,592	22,462,117
July	3,902,391	15,022,152	18,924,543
August	2,981,875	16,252,202	19,234,077
September	3,122,698	9,090,496	12,213,194
October	2,583,239	1,044,230	3,627,469
November	2,662,194	0	2,662,194
December	2,539,344	0	2,539,344

Table D.6: Total and component electricity usage on the pasture-based dairy.

Month	Total Electricity Consumption (kWh)	Irrigation (kWh)	Other Water Usage (kWh)	Vacuum Pump (kWh)	Effluent Pump (kWh)	Remaining Farm (kWh)
January	7,645	0	2,445	1,046	1,308	2,846
February	10,730	0	4,690	989	1,209	3,843
March	12,588	0	3,868	1,117	1,702	5,901
April	38,903	26,960	3,623	884	946	6,490
May	49,707	38,160	3,747	1,086	1,283	5,431
June	37,971	24,960	4,331	969	1,199	6,512
July	36,484	22,720	5,164	1,383	1,308	5,910
August	19,694	6,720	5,494	1,352	1,308	4,820
September	29,702	18,160	4,262	1,309	1,265	4,706
October	10,250	160	3,210	1,117	1,308	4,455
November	9,002	0	2,602	1,012	1,265	4,122
December	7,632	80	2,472	1,002	1,308	2,771

Table D.7: Electricity usage resulting from the consumption of water on the confined dairy.

Month	1.5 HP Well Electricity Usage (kWh)	3 HP Well Electricity Usage (kWh)	3-Phase, 2HP Water Usage (kWh)	7.5 HP Well Water Usage (kWh)	10 and 100 HP Creek Pumps (kWh)	100 HP River Pump (kWh)
January	133	271	1,889	4,857	0	0
February	133	271	1,195	3,805	160	0
March	133	271	1,297	3,748	117	0
April	133	271	1,198	6,469	379	0
May	106	269	1,577	5,046	5,595	2,729
June	307	218	1,526	4,464	14,159	15,817
July	467	784	1,609	4,985	10,384	14,546
August	359	248	1,501	4,004	9,588	13,320
September	368	297	1,368	4,141	8,034	3,320
October	160	273	1,368	3,324	1,301	0
November	133	271	1,169	3,830	0	0
December	133	271	1,187	3,548	0	0

Figure D.8: Electricity usage apart from water consumption on the confined dairy.

Month	Main Dairy: Milking, Cooling, etc. (kWh)	Lagoon pumps: Lane Wash-down, Irrigation (kWh)	Miscellaneous (kWh)
January	30,396	15	1557
February	26,716	3,776	1197
March	26,596	12	1109
April	39,316	3,745	851
May	39,025	10	562
June	57,275	1,773	856
July	80,469	4,646	2091
August	78,913	16,640	1796
September	76,455	4,514	854
October	63,167	2,301	670
November	40,876	1,305	794
December	28,316	12	936

Table D.9: Total electricity usage on the confined dairy.

Month	Water Electricity Usage (kWh)	Other Electricity Usage (kWh)	Total (kWh)
January	7,150	31,968	39,118
February	5,564	31,689	37,253
March	5,566	27,717	33,283
April	8,450	43,912	52,362
May	15,322	39,597	54,920
June	36,490	59,904	96,395
July	32,775	87,206	119,981
August	29,021	97,349	126,370
September	17,528	81,823	99,350
October	6,425	66,138	72,563
November	5,403	42,975	48,378
December	5,139	29,264	34,403

Table D.10: Water usage divided by the number of cattle and milk production on each dairy.

Month	Confined Total Water Usage (gallon / lb ECM)	Confined Total Water Usage (gallon / cow)	Pasture-based Total Water Usage (gallon / lb ECM)	Pasture-based Total Water Usage (gallon / cow)
January	0.2046	5071	0.1025	1146
February	0.1610	3991	0.1699	1899
March	0.1607	3985	0.1972	2205
April	0.2436	6038	3.8672	43232
May	0.5448	13505	3.2073	35854
June	1.2945	32089	1.5869	17740
July	1.0906	27035	1.8723	20930
August	1.1084	27477	0.4884	5460
September	0.7038	17447	2.8629	32005
October	0.2090	5182	1.1786	13176
November	0.1534	3803	0.1072	1198
December	0.1463	3628	0.1148	1284
sum	6.0	149251	15.8	176128

Table D.11: Electricity usage divided by the number of cattle and milk production on each dairy.

Month	Confined Total Electricity Usage (kWh / lb ECM)	Confined Total Electricity Usage (kWh / cow)	Pasture-based Total Electricity Usage (kWh / lb ECM)	Pasture-based Total Electricity Usage (kWh / cow)
January	0.0023	56	0.0014	15
February	0.0021	53	0.0019	21
March	0.0019	48	0.0023	25
April	0.0030	75	0.0070	78
May	0.0032	78	0.0089	99
June	0.0056	138	0.0068	76
July	0.0069	171	0.0065	73
August	0.0073	181	0.0035	39
September	0.0057	142	0.0053	59
October	0.0042	104	0.0018	21
November	0.0028	69	0.0016	18
December	0.0020	49	0.0014	15
sum	0.047	1163	0.048	541