This is to certify that the
dissertation entitled

MODELING AND ANALYSIS OF THE BIOREFINERY
INTEGRATED WITH THE AGRICULTURAL LANDSCAPE

presented by

ELIZABETH DIANE SENDICH

has been accepted towards fulfillment
of the requirements for the

Doctoral degree in Chemical Engineering

Bruce T. Dale

Major Professor's Signature

Oct. 14, 2008

Date

MODELING AND ANALYSIS OF THE BIOREFINERY INTEGRATED WITH THE AGRICULTURAL LANDSCAPE

By

Elizabeth Diane Sendich

A DISSERTATION

Submitted to
Michigan State University
In partial fulfillment of the requirements
For the degree of

DOCTOR OF PHILOSOPHY

Chemical Engineering

2008

ABSTRACT

MODELING AND ANALYSIS OF THE BIOREFINERY INTEGRATED WITH THE AGRICULTURAL LANDSCAPE

By

Elizabeth Diane Sendich

The current energy crisis has drawn much attention to cellulosic ethanol, but the chemical engineering system that produces this alternative fuel, called the biorefinery, has not yet been modeled with one of its primary feedstock suppliers, the agricultural system. Combining cropping and animal systems with the biorefinery in a single integrated model will allow environmental and economic analysis of biomass, bioenergy, co-product, and fertilizer production.

This study focuses on the integration of the NREL biorefinery model with the Integrated Farm System Model (IFSM), which is shown here to be the best choice for work with this biorefinery model. With these selected models, the biorefinery system is simulated within realistic agricultural landscapes, which include animal and crop production, across various US regions using the new research tool Biorefinery and Farm Integration Tool (BFIT). This combined modeling approach allows analysis of regional variability, economic profitability, and development pathways with little environmental impact. Preliminary results from this model development study indicate that the Midwest, already a center for grain ethanol production, is ideal for the cellulosic ethanol industry. This study also underscores the need for continued research on the use of biorefinery co-products, specifically pretreated grasses, as animal feed.

Although validation of the research tool developed in this work can only occur when commercial scale biorefineries and biomass markets are operational, a sensitivity analysis and verification are presented at this time. The sensitivity analyses reveal three variables having notable effects on overall system outcomes: biorefinery size, biomass farm gate price, and switchgrass yields. These analyses stress the need for care with model input assumptions and continued research on these variables.

The verification tests performed at the conclusion of this study highlight this model's potential for "expert users" as a decision-making tool. The outcomes of these tests lay the ground work for future studies using this research tool, while also pointing to areas that would benefit from further expansion and validation. Specifically, future research should investigate the effects of combined changes in precipitation and temperature, biomass choice, and land use, as defined by the farm management distribution in the landscape.

DEDICATION

Dedicated to my parents, Dick and Deborah Newton, and to my husband, Marc Sendich, your love and support kept me going.

ACKNOWLEDGEMENTS

I would like to thank my advisor, Bruce Dale, for his guidance and support. Special thanks also go to my guidance committee Dr. Seungdo Kim, Dr. Dennis Miller, Dr. Jon Sticklen, Dr. Timothy Harrigan, and Dr. William Northcott.

I am grateful to my many collaborators, especially Dr. C Alan Rotz, Dr. Mark S Laser, Bryan Bals, and Pragnya Eranki.

I wish to acknowledge financial support from the Great Lakes Bioenergy Research Center, Grant #DE-FC02-07ER64494, and the Office of Biobased Technology at Michigan State University. I also wish to thank the helpful staff in the Department of Chemical Engineering and Material Science and my co-workers in the Biomass Conversion Research Laboratory.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO SYMBOLS AND ABBREVIATIONS

AFEX = Ammonia Fiber Expansion

BFIT = Biorefinery and Farm Integration Tool

CBP = Consolidated Bio-Processing

DM = Dry Matter

DML = Dry Matter Loss

GHG = Greenhouse Gas

IFSM = Integrated Farm System Model

IRR = Internal Rate of Return

ISBAL = Integrated Biomass Supply Analysis and Logistics

LCA = Life Cycle Assessment/Analysis

MACRS = Modified Accelerated Cost Recovery System

MESP = Minimum Ethanol Selling Price

NREL = National Renewable Energy Laboratory

SHF = Separate Hydrolysis and Fermentation

SSCF = Simultaneous Sacharification and Co-Fermentation

TIC = Total Investment Capital

TPD = US Ton Per Day

TPI = Total Project Investment

USD ($) = United States Dollar

CHAPTER 1: INTRODUCTION

The world has recently been gripped by an energy crisis, and rapidly rising oil prices have encouraged the need for alternative fuels. A shift to alternative energy sources has also been hastened by the increasing awareness of global environmental issues [1,2]. The development of a diversified and environmentally sound energy portfolio requires a full understanding of the many energy options currently available and those still in development.

Biological-based alternative fuels are often referred to as "biofuels". The production of select liquid biofuels, including ethanol, is performed in a facility similar to an oil refinery and has thus become known as the "biorefinery". The biorefinery is the combination of a number of chemical engineering unit operations, many of which have recently become the center of heated debate. As a result, there has been more research and development attention for all elements of this industrial process concept, including its feedstock supply chain, which involves crop and forest sources [3,4,5].

The use of ethanol, traditionally made from corn grain, as an alternative liquid transportation fuel is well accepted [6]. The use of cellulosic biomass feedstocks for the biorefinery, however, is still in the stages of research and development. The need to study a system for which we do not have a full-scale commercial example or market requires the use of modeling tools to move us forward.

According to Carolan et al., the risk for the biorefinery lies with both the farmer and the biorefinery investor, which creates a "chicken and egg" situation for the development of the biorefinery [7]. Modeling tools allow projection of economic and environmental expectations for this system and can determine the affect of changes for potential designs and commercialization.

The growing life cycle assessment (LCA) and sustainable development disciplines corroborate the need for both environmental and economic impact assessments to understand the feasibility and practicality of the biorefinery system [8,9]. Researchers in these areas have emphasized the need for new analyses to fill previous data gaps for the study of cellulosic ethanol [10].

Tools like the one developed here and the simulation results produced can provide baseline expectations for the cellulosic ethanol biorefinery and the surrounding farm system allowing further understanding of biorefinery system feasibility. In addition, a research tool like the one presented here has great potential for future modification and validation as real systems come online. By de-risking investment in biorefinery technology and the feedstock supply chain, investors and farmers alike can confidently become part of the US alternative energy future.

Because of interaction between the biorefinery and its feedstock suppliers, particularly the agricultural system, the assessment tool here must account for the biorefinery, the crop production unit, and the animal production unit. The interaction between the crop and animal units occurs by way of feed and manure fertilizer exchange, and between these two systems and the biorefinery by way of the biomass feedstock and pretreated biomass, which is used as a ruminant feed. This study is a first attempt to directly simulate the biorefinery set into a realistic landscape with both these agricultural units included. The proposed integrated system boundary can be seen in Figure 1.1.

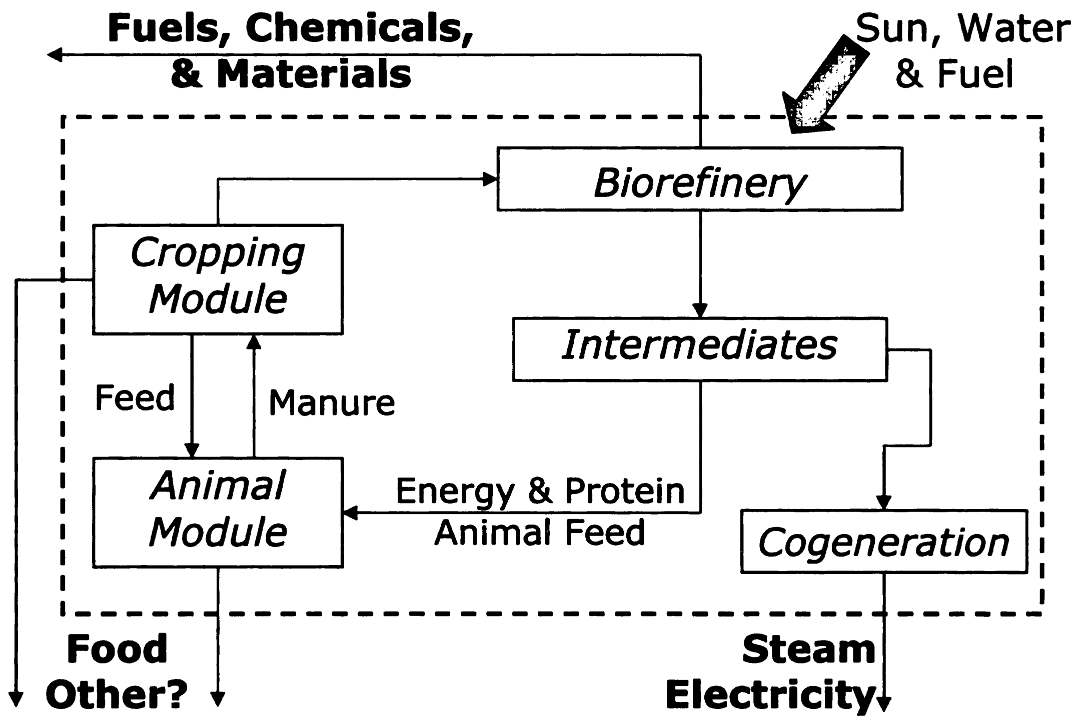

Figure 1.1: System boundary for integrated biorefinery system concept.

Using an integration scheme to combine a previously developed biorefinery model with a whole farm agricultural model, a new research tool called Biorefinery and Farm Integration Tool (BFIT) was developed. BFIT will allow expert users to analyze the environmentally relevant mass flows and economics of a fully integrated US biorefinery producing cellulosic ethanol and other secondary products over varying locations and farm types, which can direct the future of renewable energy.

The use of pretreated grasses as an animal feed is currently under investigation at Michigan State University, and a study of its feasibility is not included in the research presented here. Instead this research uses historical data about ammoniation of forage feeds, preliminary feedstock pretreatment analysis, and related information on ruminant digestibility. Deeper investigation into the viability of the feeds used in the animal production strategies included here are already under way by others [11].

For this initial study used for BFIT development, a biorefinery receiving 2000 TPD of biomass is simulated in nine agriculturally relevant states within the continental US under various farm production practices. Analysis of BFIT biorefinery and landscape results will allow, for the first time, a baseline projection of the economic feasibility and environmental impacts of cellulosic ethanol. Moreover, the simulations presented here will allow side-by-side comparison of similar biorefineries across the US, which can project regional variance trends. The study here is concluded with a series of basic scenario tests, which verify this tool and reveal potential future uses for estimating the consequences of biorefinery system changes.

1.1 Objectives

The primary goal of this work is to develop a research modeling tool to study the biorefinery and its surrounding landscape. This first study of the system will identify trends and build a foundation for future decision-making research, which will identify winners and losers in the system. To achieve this objective and address some of the issues described in this chapter, the specific research phase objectives are as follows:

- Alter the leading biorefinery model for integration and confirm model simulation results are consistent with previous publications
- Test leading agricultural models through simulation and select a model for use with the biorefinery model
- Design a research tool around the two previous model selections with long-term viability by using programs that are readily available to expert users
- Integrate the pieces of the system and fully develop a tool that enables cradle-to-gate assessment/analysis of the "whole biorefinery system"
- Perform basic simulations and a sensitivity analysis, and analyze independent verification results to assess the research tool function
- Evaluate model results trends and their significance
- Suggest way to elaborate on the findings presented here
- Write a trained users' guide to aid future users in installation and operation of the research tool
- Automate this unique tool to limit required user engagement and thereby improve "user-friendliness"

1.2 Limitations

The limitations for the scope of this research are as follows:

- Geographical locations are limited to the nine locations within the contiguous US selected for this initial study

- Agricultural management limitations are defined by the existing model selection's limits
- The landscape design and calculation are based on the user selected feedstock intake rate of the biorefinery, making the biorefinery intake the functional unit
- Biomass sources are limited to agricultural sources, specifically corn stover and switchgrass
- The temporal setting chosen for final development is the year 2006 to give full and reliable input data sets, which maintains consistency in development

CHAPTER 2: REVIEW OF LITERATURE

2.1 The Biorefinery

The combination of unit operations used to derive the liquid transportation fuel ethanol is commonly referred to as a biorefinery [12,13]. A diagram outlining the stages of the biorefinery can be seen in Figure 2.1 [14].

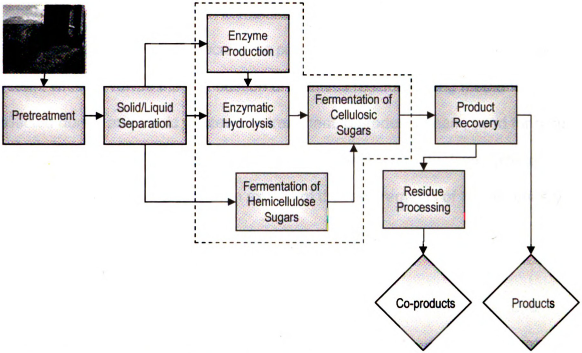

Figure 2.1: Stages of the cellulosic ethanol biorefinery (adapted from DOE diagram) [14].

Many of the stages in the biorefinery follow well developed industrial processes, but some are still the subject of research. The first stage, pretreatment, and the steps boxed together, biological processing, are of particular interest in research and have thus been highlighted in sections 2.1.1 and 2.1.2.

The remaining stages in the biorefinery are ethanol (product) recovery, wastewater treatment, and on-site utilities, which includes residue processing.

Ethanol recovery aims to use as little energy as possible while still maintaining high ethanol purity. This is achieved through distillation followed by molecular sieves [15]. Water treatment and utilities refers to the cleanup of water to be re-used in the system and its subsequent heating or cooling for use in the biorefinery unit operations. Wastewater treatment systems may include a suspended sludge system or an immobilized film anaerobic digester [16]. Heating of the returned water occurs as part of a steam and electricity production system, which involves the combustion of biomass residues using methane collected during anaerobic wastewater treatment to produce steam, used for heat in the biorefinery, and the subsequent use of that steam in a Rankine cycle to produce electricity, all equal to or in excess of the requirements of the biorefinery [4].

2.1.1 Pretreatment

AFEX is mild pretreatment that uses concentrated ammonia, heat, and rapid pressure release to increase digestibility of biomass feedstocks. It is fairly unique because it is a dry-to-dry process and requires no detoxification steps following pretreatment, both of which tend to make it a highly desirable pretreatment. AFEX has been studied for some time and continues to improve with development [17,18,19].

The approach for recovering and recycling ammonia for use in pretreatment has seen improvement as well. The biorefinery model designed by NREL in 2003 used evaporation, distillation, and vapor compression to recover and recycle ammonia, whereas current work uses an innovative quench system

[19, 20,21]. In this quench system, the pretreated slurry is flashed, stripped with steam, and then resulting ammonia vapor from these two steps is condensed by a combination of direct water quenching and indirect cooling with both cooling and chilled water. This system is envisioned as using processing equipment that is similar to that used for direct steam drying of solids [22,23]. The process flow diagram for each of these two recover systems can be seen in Figures 2.2 and 2.3.

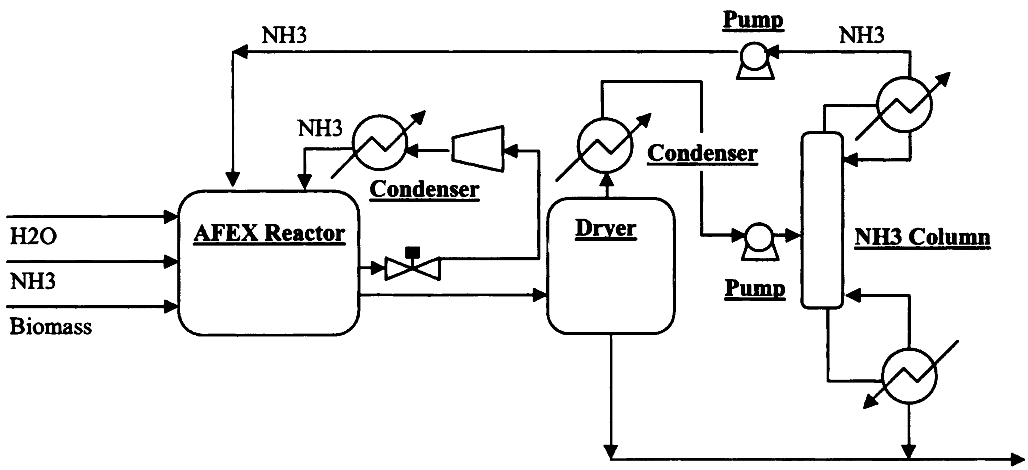

Figure 2.2: Process diagram of the pretreatment stage of the biorefinery with the older NREL recompression ammonia recovery approach.

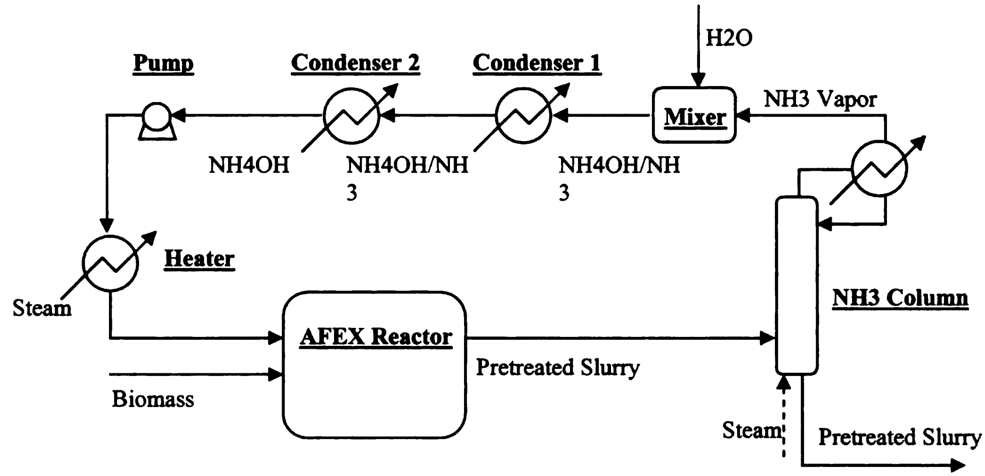

Figure 2.3: Process diagram of the pretreatment stage of the biorefinery using new quench ammonia recovery approach.

2.1.2 Biological Processing

Biological processing refers to a system that uses saccharolytic enzymes to hydrolyze structural carbohydrates (cellulose and hemicellulose) to oligomers. These oligomers are then further hydrolyzed to monomers and dimers. Finally these five and six carbon simple sugars are fermented to ethanol or other products such as lactic acid [24]. SHF is a biological processing system that performs all the steps mentioned above separately. SSCF performs the four biologically-mediated events mentioned above in two separate process steps, first enzyme production and then hydrolysis and simultaneous 5 and 6 carbon sugar fermentation. CBP performs all four steps of enzymatic hydrolysis and fermentation in a single vessel and is currently under study in various laboratories, though it has not yet been perfected. For CBP to become viable, microorganisms capable of utilizing all the appropriate components of biomass to produce ethanol at high yields and concentrations must be developed. Such a development would be a breakthrough that would ultimately reduce the cost of ethanol biorefining well below the current biological processing method, SSCF [25].

2.2 Biomass Feedstocks

The Department of Energy defines biomass as "all plants and plant-derived material" [26]. Examples of current biomass usage include oil crops for biodiesel, starch crops for fuel alcohols, and forest and agricultural residues for combustion or, as presented in this work, alcohol production [3]. For the work in question, the biomass used is a combination of corn stover and switchgrass. Corn stover refers to the portion of the corn plant *Zea mays* that is currently unused (residue), which includes the cob, stalk, leaves, and husks [26]. Switchgrass refers to the prairie grass *Panicum virgatum*, which is a US native, perennial grass [4].

The benefits of using corn stover as a feedstock come primarily from its availability, due to the large amount of corn cropping currently practiced in the US, and its low cost, because it is a residue [26]. Switchgrass provides value to the agro-fuel system because it is highly productive (tons per acre), requires little input (fertilizer and irrigation) to achieve these yields, and is native to the US posing little threat to the natural ecosystem, in fact potentially providing increased habitat for some species [4].

2.3 Crop Modeling

The area of crop modeling has produced a limited number of crop farming models, which simulate multiple farming activities by combining a number of submodels. IFSM, for example, combines plant growth submodels, such as

ALSIM, an alfalfa only growth model, and CERES-Maize, a corn growth model, with hydrological and soil submodels, and management related submodels, simulating items such as machinery and farm economics [27]. Unfortunately, a number of model focus only on farm economics, such as the IBSAL model and BIOCOST [28,29,30].

Development of user-friendly interfaces is another hurdle facing crop model progress. Farm models that use languages like FORTRAN and C++ without a user-interface can hinder users from making changes easily and allow those changes made to introduce error into the code [31]. Having a program environment that is not easy to use may limit the audience of a model, particularly the rural farmer.

Another limitation in current crop models is simulation of interaction with animal systems, such as grazing by animals or application of animal manure as fertilizer [32]. Some models allow simulation of effects of animal systems, such as DAYCENT that allows grazing, but only account in a limited way for these interactions between plant/soil and animal systems [33].

2.4 Animal Modeling

As with crop modeling, modeling of livestock typically focuses on management and economics. It is now desirable to simulate gaseous emissions, as a result of the environmental movement, or empirical production, because it is directly related to farm economics [34,35,36]. Those models that do simulate livestock systems focus mostly on cattle because they are the predominant livestock in the US [37].

As pointed out in section 2.3 limited work has been dedicated to animals in a whole farm system, but researchers have begun to recognize the importance of integration of livestock systems with cropping systems [32]. For livestock models that do currently simulate some crop activities, such as DairyWise dairy farm model, there remain limitations, such as simulation of only popular feed crops like grazed grasses or corn [34]. Whole farm simulation models having both crop and animal management flexibility are uncommon, which helps to highlight leading models for simulation of crop and animal combinations along with associated soils, emissions, and economics, as described later in this work [27,38,39,40].

2.5 Sustainable Development

The continually growing area of sustainable development calls for assessment of both environmental and economic impacts, which are critical to understand the feasibility of the system or process, such as the biorefinery [8,9]. Growing concern for human effects on the planet drives a movement to improve the environmental characteristics of existing systems and design new ones with the potential environmental impact in mind. More over, sustainable development also calls for this environmental awareness to be combined with a mind for the maintenance of human standards of living, thus encouraging clean, socially conscious behaviors that do not cripple economies with costly technologies or programs [9].

One method for assessment of these impacts is LCA. LCA has recently been accepted by many organizations and governments, and now has agreed upon standards for assessment and analysis, which have been published by the International Standards Organization [41]. Adherence to these standards is difficult for the study of the biorefinery system due to the lack of measured data and limited availability of reliable and comparable emissions data for the surrounding landscape. Following a framework for assessment similar to LCA, it is possible to collect and report individual outputs that indicate environmental performance instead of reporting LCA impact categories that would encompass that output, for example reporting nitrogen leached rather than eutrophication.

CHAPTER 3: SELECTION OF A BIOREFINERY MODEL

3.1 Background

In an effort to demonstrate the biorefinery model as it has been updated for use at Michigan State University and to reveal economic advantages of improvements in the AFEX process, simulation work was done using the latest iteration of the biorefinery model developed at NREL.

The biorefinery model developed at the NREL was used to produce cost estimates of pretreatment options as embedded in the overall biorefinery using the chemical engineering modeling software ASPEN PLUS, along with an economics workbook in Microsoft Excel [21]. This model has since been updated to allow for possible technology developments by researchers at Dartmouth College with input from collaborators at Michigan State University [20]. These alterations include eliminating feedstock washing, including an innovative ammonia recovery approach, and raising the feedstock feed rate to 5,000 TPD.

The initial economic analysis at NREL compared dilute acid, hot water, ammonia recycle percolation, AFEX, and lime pretreatments on corn stover [20]. This study found that the MESP of ethanol fuel produced using AFEX pretreatment was approximately $1.41/gallon using data available in late 2003. The results of this economic comparison of pretreatments are summarized in Figure 3.1. The MESP is the lowest price at which ethanol produced in the biorefinery can be sold to maintain a set IRR, while accounting for feedstock costs, capital and operating costs, and secondary products sold at market value.

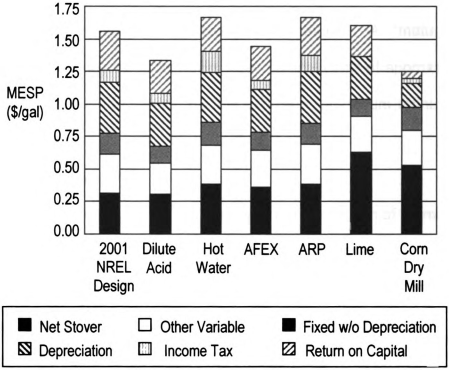

Figure 3.1: Economic comparison of various pretreatments made by Eggeman and Elander in 2003 [20].

Important advances in the AFEX pretreatment, and other parts of the system, have occurred since NREL's initial economic comparison [20]. The work presented here reveals the economic impacts of these AFEX process advances in the context of SSCF to produce and ferment sugars from AFEX treated corn stover. Furthermore, this work reveals the reductions in MESP that can be realized by pairing this improved AFEX pretreatment system with CBP. These biological processing options have already been outlined in Section 2.1.2.

It can be seen in Figure 3.1 that feedstock cost is a relatively small fraction of the cost for most of the pretreatment options, while processing costs are the largest portion. This is characteristic of an immature process. Reduction of these processing costs is necessary to make cellulosic ethanol more competitive with petroleum-derived fuels. The AFEX process and the entire cellulosic ethanol production system are clearly not mature. A "mature" process technology can be described as having raw material costs of approximately 70% of the total manufacturing cost. By this definition, petroleum refining and corn wet milling industries are both mature [42].

3.2 Materials and Methods

The specific changes to AFEX process were reduction of ammonia loading and recycle concentration (using concentrated aqueous ammonia in AFEX rather than anhydrous), updating the ammonia recovery approach, and reduction of enzyme loading in hydrolysis. Ammonia loading refers to the ratio of ammonia to dry biomass fed to the AFEX reactor, and in model simulations ammonia loading was varied from 0.8 to 0.2 g NH_3: g dry biomass. Ammonia recycle concentration refers to the concentration of ammonia by mass in the recycle stream, which is combined with the fresh ammonia make-up stream and then fed to the AFEX reactor. In simulations, this parameter was varied between 70-99% by mass (ammonia in water). Enzyme loading refers to the ratio of cellulase enzyme to glucan fed to the AFEX reactor, where glucan fed is calculated as the dry biomass feed rate multiplied by its glucan content. This parameter was modeled at 7, 15, and 60 FPU/g glucan, where FPU, filter paper units, is a measure of the enzyme activity. An enzyme loading of 15 FPU was found to be the economic optimum, and was thus fixed at this value for all subsequent simulations [43].

For calculation of MESP, assumptions use for the current work vary somewhat from the previous model work at NREL, but the calculations are performed using the same equations [20,21]. Assumptions for the previous work at NREL include a corn stover feedstock cost of $35/dry ton, an IRR of 10%, and additional feedstock costs for cellulase and corn steep liquor [20]. Assumptions for the current work include a corn stover feedstock cost of $40/dry ton, an IRR of 12%, and no requirement of corn steep liquor or cellulase as feedstock when implemented with CBP. As a result of increased feedstock cost and IRR assumptions, the current results require a higher MESP to meet performance objectives and thus represent a more stringent test of profitability than the previous simulations. An outline of all key financial parameters used in the economic analysis of the simulations for this work can be seen in Table 3.1.

Table 3.1: Financial parameters used in simulations described in this chapter.

Parameter	NREL 2004	All Other Scenarios
Debt/Equity ratio	0/100	40/60
Loan rate (APR)	Not Applicable	7.5%
IRR	10%	12%
Federal & state tax rate	39%	39%
Economic life	20 years	25 years
Depreciation period	• 7 years for general plant • 20 years for power & steam production	• 7 years for general plant • 20 years for power & steam production
Depreciation method	MACRS	MACRS
Capital charge rate	18%	~17%
Indirect costs	48% of total installed capital	48% of total installed capital

In addition to the differences already described, the present work differs from the previous work done at NREL in many of the stages depicted in Figure 2.1. Careful consideration of these differences is necessary to provide appropriate comparisons of the systems modeled. The initial NREL model and the updated model used here differ in the approach for biological conversion, plant size, feedstock handling, product recovery, wastewater treatment, and on-site utilities.

The biological processing step differs by changing from SSCF in the NREL model to CBP or SSCF in the current model. The difference between these two biological processing options has already been outlined in Section 2.1.2. It is important to note that in the current model conversion of all sugars to ethanol is assumed to be 95% when CBP is used. Although the AFEX pretreatment meets this test for glucose with SSCF, it has not yet demonstrated this level of conversion with CBP; this assumption represents future technology and performance. SSCF is modeled to use a separate conversion for 5 carbon sugars than 6 carbon sugars, and both types of biological conversion follow the same process scheme in simulation as Eggeman and Elander [21].

Another change made for the current work was a decrease in the feedstock flow rate, from 5,000 TPD in the newer Dartmouth model back to the original NREL feed rate of 2,205 TPD to allow better comparison between current results and those from the NREL modeling exercise [20].

Other process changes are as follows. Ethanol recovery in the current model was updated from the NREL approach to reduce energy consumption, but still maintain high ethanol purity. The evaporative concentration of ethanol distillation bottoms liquid was eliminated, and replaced by a single distillation column with direct steam injection and an intermediate heat pump with optimal side-stream return followed by molecular sieving. For wastewater treatment, an immobilized film anaerobic digester system replaced a suspended sludge system in the NREL model. For the current model a chilled water system was added to the utilities section to enable full condensation of recycled ammonia in the new ammonia recovery system.

The final major change in the current model is the ammonia recovery approach used with AFEX in the pretreatment stage. Previous versions of the biorefinery model used the traditional distillation and compression ammonia recovery system outline in Figure 2.2 in Section 2.1.1, where as the updated model includes the innovative ammonia quench recovery system in Figure 2.3 of Section 2.1.1.

As part of the design of the new quench ammonia recovery approach, the AFEX process must still effectively treat biomass using ammonium hydroxide rather than pure anhydrous ammonia, due to the mixing of water and ammonia in the recycle stream. In contrast, the previous or "classical" approach to AFEX involved adding anhydrous ammonia to biomass containing various moisture levels [43]. Experiments verifying concentrated ammonium hydroxide use in AFEX with acceptable resulting enzymatic hydrolysis yields can be found in Sendich et al. [19].

3.3 Results and Discussion

The effects on MESP of changing both AFEX process parameters (ammonia loading and concentration of ammonia in the recycle stream) and the configuration of the ammonia recovery process can be seen in Figure 3.2. The abbreviations for each simulation in Figure 3.2 are spelled out in Table 3.2, highlighting the changes being made, individually or in combination [44].

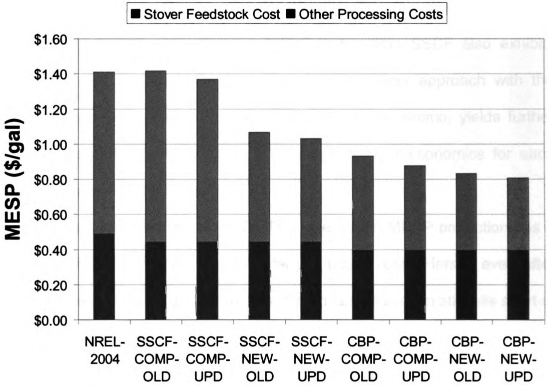

Figure 3.2: Simulation economic results as indicated by MESP. Abbreviations are outlined in Table 3.2.

Table 3.2: Abbreviations for simulation scenarios.

Abbreviation	Meaning
SSCF-COMP-OLD	SSCF, NH3 Recompression, Old AFEX parameters
SSCF-COMP-UPD	SSCF, NH3 Recompression, Updated AFEX parameters
SSCF-NEW-OLD	SSCF, New NH3 Recovery approach, Old AFEX parameters
SSCF-NEW-UPD	SSCF, New NH3 Recovery approach, Updated AFEX parameters
CBP-COMP-OLD	CBP, NH3 Recompression, Old AFEX parameters
CBP-COMP-UPD	CBP, NH3 Recompression, Updated AFEX parameters
CBP-NEW-OLD	CBP, New NH3 Recovery approach, Old AFEX parameters
CBP-NEW-UPD	CBP, New NH3 Recovery approach, Updated AFEX parameters

The results in Figure 3.2 show a reduction in MESP with the new AFEX process parameters compared to the previous result of $1.41/gallon (Figure 3.1), regardless of the ammonia recovery configuration with which they are simulated. The new ammonia recovery approach also shows reduced MESP over the previous recovery approach, regardless of which AFEX process parameters are used. A biological process change of CBP rather than SSCF also exhibits considerable cost savings. Combining the new recovery approach with the updated process parameters, an advanced technology scenario, yields further enhanced economics (lower MESP). A full summary of economics for each simulation can be found in Appendix A.

At the scale in Figure 3.2, 2,205 TPD, the lowest MESP projection has a feedstock cost that is roughly 50% of total production cost. Hence, even after inclusion of these process enhancements, the advanced system still falls short of a "mature" cellulosic ethanol industry, where costs would be 70% feedstock to 30% processing cost. Increasing plant scale to 5,000-10,000 TPD would increase the ratio of feedstock to processing costs and bringing the system closer to "maturity", but further reductions in processing costs can and should be anticipated as technologies improve.

A comparison of the TIC per annual gallon of ethanol produced for all of the simulations summarized in Table 3.2 can be seen in Figure 3.3. TIC per gallon of annual capacity for the most advanced of these cases is comparable to current TIC per gallon of annual capacity for the corn ethanol industry, which is estimated at $1.25 per annual gallon for similar plants at this scale [45].

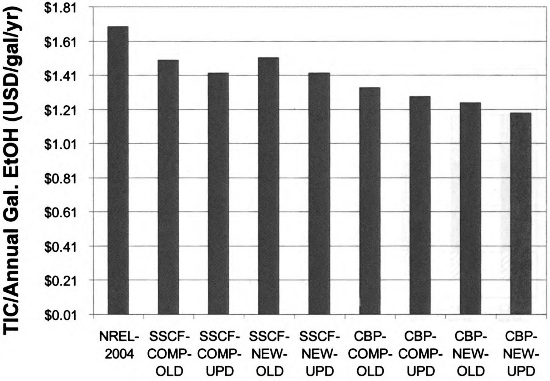

Figure 3.3: TIC per annual gallon of ethanol produced for simulations described in Table 3.2.

A summary of the operating costs for the simulations listed in Table 3.2 can be found in Figure 3.4. This figure shows the gradual reduction of operating cost as process improvements are made.

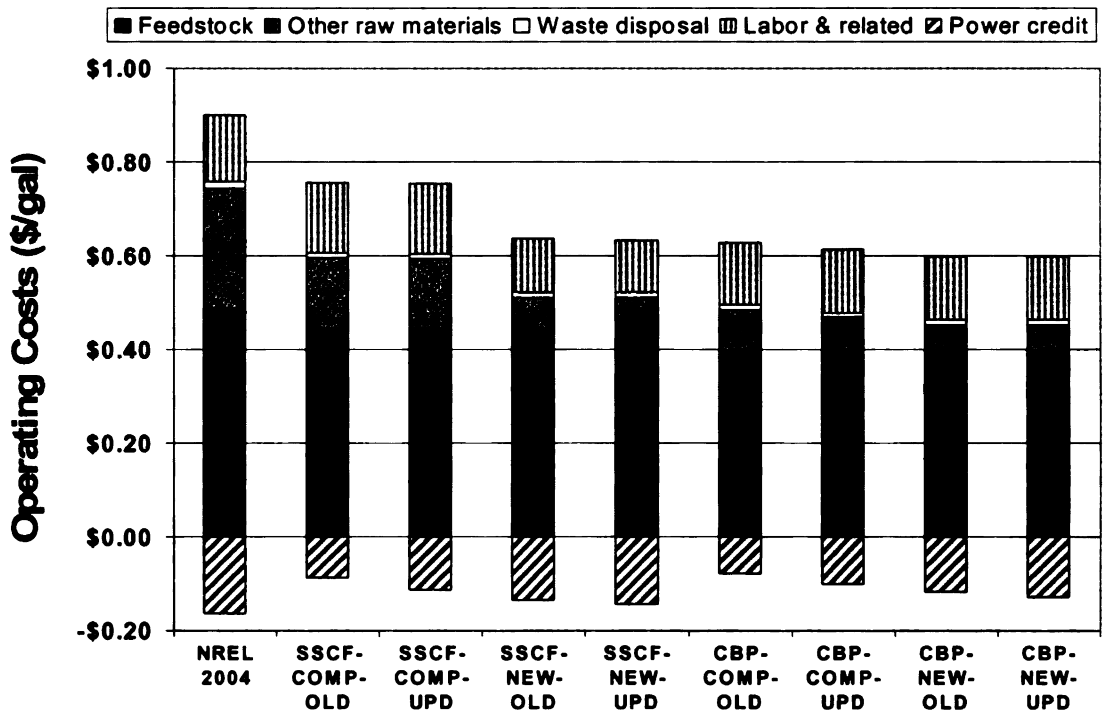

Figure 3.4: Break down of operating costs for simulations listed in Table 3.2.

The ethanol yields that were assumed for each simulation of the biorefinery are given in Table 3.3. These yields are reasonably conservative and will increase with improved technologies.

Table 3.3: Ethanol production for various simulations presented in this chapter.

Scenario	Ethanol Production (MM gal/yr)
NREL 2004	70.5
SSCF-COMP-OLD	69.7
SSCF-COMP-UPD	69.7
SSCF-NEW-OLD	69.6
SSCF-NEW-UPD	69.6
CBP-COMP-OLD	78.1
CBP-COMP-UPD	78.1
CBP-NEW-OLD	78.0
CBP-NEW-UPD	77.9

3.4 Conclusions

This work has shown that the updated biorefinery model is capable of reproducing the NREL results using similar technologies, and it is therefore effective for economic comparisons, here and in future work.

This work points to elements that are critical to biorefinery design including pretreatment, ammonia recovery, biological process choice, and biorefinery size. Historically the processing industries use improved technologies and techniques to decrease processing costs thus increasing the ratio of feedstock cost to processing cost. By minimizing the amount of water and ammonia used in the AFEX process, and efficiently recovering and recycling ammonia, processing costs are shown here to be greatly reduced over estimates that are only a few years old. Decreasing ammonia loading and lowering ammonia recycle concentrations results in less total ammonia that must be recovered and concentrated for each gallon of ethanol produced, ultimately driving down capital and operating costs. The new ammonia recovery process significantly reduces operating costs by using cool water rather than mechanical energy to recover aqueous ammonia. The capital cost for pretreatment, however, is not greatly affected by this new ammonia recovery approach.

This work shows that while SSCF provides attractive ethanol prices, even better economic performance can be expected if CBP can be realized. It is important to note that the feedstock cost per gallon of ethanol produced in all the cases is approximately equal. Any cost reductions seen in the simulations studied here are a direct result of processing developments. As mentioned previously, using petroleum refining as a classical example of a mature processing industry, process maturity is achieved when raw material costs are approximately 70% of the manufacturing costs, and the remaining 30% is processing costs. Given the present feedstock cost assumption of $40/ton, process maturity for cellulosic ethanol will be achieved at an MESP of about $0.56/gallon. Therefore even with the progress described here, process maturity is still some distance in the future.

CHAPTER 4: SELECTION OF AN AGRICULTURAL MODEL

4.1 Background

In consideration of the biorefinery system as described in Section 2.1, an analysis of available simulation programs was completed to evaluate which cropping and/or animal (agricultural) production model would be best suited for integration with the biorefinery simulation program selected for future simulations in Chapter 3.

In modeling it is often difficult to select the most appropriate model for a specific application, thus the model that is most familiar to the user is often chosen [31]. In an effort to make the best and most rational model selection, this evaluation was performed with leading applicable crop and/or animal system models, including DAYCENT, IFSM, and I-FARM. The task of evaluating simulation programs is not a simple one. Each model is a combination of several sub-models, which contain complex algorithms. Each model considered in this evaluation is described in detail in later sections.

4.1.1 Crop and Animal Modeling

The difficulty in assessing the many varied approaches for modeling crop or animal systems is that there is no right or wrong approach, and often times "model validity is in the eyes of the user" [46]. Many users find that their needs would be met best if they could pick and chose capabilities from a variety of existing models to achieve their purposes. Using a model without any alteration is particularly difficult given that a single improperly estimated sub-process can result in general error, which may produce a result that fits within experimental deviation, but is nonetheless wrong in a specific detail [31]. Evidence of this can be seen in the work of Marchetti, et al. [47]; using a simple sensitivity analysis they showed comparable algorithms can still lead to dissimilar results.

Ideally a user would select the most desirable pieces of different models and combine them, but many sub-models are difficult or impossible to extract from the model in which they are imbedded. This occurs because the method of handling carbon and nitrogen often interacts with other processes in the agricultural system, such as water movement, chemical transport, plant growth, and management practices, and this coupling makes sub-model division difficult. Modeling of organic matter and surface residues also creates integration incompatibilities. Separating organic matter and residue into "pools", and assigning conversion rates to these "pools", is intricate and varies among programs [46]. Recently, two of the models being studied in this work were used in combination, but it should be noted that the models were used for two very different purposes, IFSM for farm machinery and DAYCENT for biogeochemical cycling [48].

A final challenge in selecting and implementing a crop and/or animal model is the interface. As described in section 2.3, older models using programming languages without user-friendly interfaces hinder the addition of new elements, or require substantial alteration to the source code to make changes, which can introduce error in the program [31]. This is certainly the case for DAYCENT.

4.1.1.1 Nitrogen Sub-models

In any plant growth model with a soil sub-model the simulation of nitrogen species is the most difficult because of the complexity of interactions and the lack of accurate field data [31]. Nitrogen sub-models typically simulate a nitrogen budget using four major processes: crop nitrogen uptake, soil nitrogen mineralization, denitrification, and leaching, and are therefore easily influenced by nitrogen application rates and soil characteristics entered by the user [47]. To simulate these four processes nitrogen sub-models consists of either empirical models, also called functional models, or mechanistic models.

Empirical models are effective, but they are not as robust or easily adjusted to accommodate new conditions, locations, and crops. In contrast, mechanistic models are more robust because they use algorithms to simulate the actual physical and biological process that occur in natural systems. The disadvantage of mechanistic models is their complexity, which makes them more difficult to operate because of additional required inputs and validation can be difficult. Unfortunately, even if the model outputs agree with field measurements it does not necessarily indicate that the processes in the model are properly simulated. For these reasons simpler functional models may perform better than their complex mechanistic counterparts simply because they do not require as many input parameters that are difficult to measure [31].

4.1.1.2 Denitrification/Nitrification

Of the four parts of the nitrogen sub-model, nitrification and denitrification are the most difficult to measure in the field and to simulate. The direct measurement of nitrification and denitrification is difficult because of the spatial and temporal variability of anaerobic and aerobic zones in the soil profile. The difficulty in simulating these processes is a result of the lack of complete understanding of nitrification and denitrification. Because of these difficulties, many nitrification and denitrification models are empirical in design [46].

In agricultural soils, the aerobic process of nitrification and the anaerobic process of denitrification are constantly and simultaneously occurring. The conditions that affect these processes in the soil include the concentration of ammonium and nitrate ion, for nitrification and denitrification respectively, soil water content, water filled pore space (WFPS), temperature, carbon availability for denitrification, and soil physical properties [49].

4.1.2 CENTURY/DAYCENT

The CENTURY model is one of the leading models for estimating long-term environmental impact of crop systems and managed forests. The need for short-term calculations, for which this long-term model is not appropriate, was recently adjusted to simulate daily time steps and renamed DAYCENT.

The DAYCENT model is of intermediate complexity, using a mechanistic approach for important processes and empirically derived equations for other processes. It contains sub-models for plant productivity, decomposition of dead plant material and soil organic matter, soil water and temperature dynamics, and trace gas fluxes. While the plant production sub-model of DAYCENT can simulate a variety of crops, trees, and grasses, it is limited to simulation of only one plant type (crop or grass) and one tree type at one time [33]. In a study by

Del Grosso, et al., DAYCENT was shown to simulate the outputs for gaseous nitrogen emissions calculation well, but under high spatial or temporal variation the output values do not match well to observed data [33].

One feature of DAYCENT that was convenient for this work is its ability to simulate both air and soil emissions and losses of nitrogen, carbon, and phosphorus, which are included because it was designed as a biogeochemical cycle model. A drawback to working with DAYCENT is the extensive requirements for input data and the undeveloped, DOS based data entry format. A publication by the authors of the software indicates that input parameters required by DAYCENT are "often available for many regions" [33].

4.1.3 IFSM

The whole farm simulation model IFSM is a USDA program that was developed from expansion of the dairy forage system model, DAFOSYM. The major sub-models included in IFSM are crop growth, harvest, storage, beef or dairy cattle feed utilization, manure handling, nutrient flows, crop establishment, and economic analysis. Each individual crop growth sub-model is based on a specific species using previously published models, such as CERES-Maize for corn or ALSIM1 for alfalfa. All the various sub-models combine empirical and mechanistic modeling to produce model results [27,40].

One advantage IFSM has over models like DAYCENT is the ability to simulate a whole farm system with a variety of crop and cattle options, including simulation of crop storage and nutrient losses locally and on the field [27,40]. Also, the well developed, user-friendly interface of IFSM allows easier use and reduces the likelihood of user-introduced error in the system. One limitation of this interface, however, is that for some items the user is confined to the selections available in a drop-down list of options.

4.1.4 I-FARM

I-FARM is an online, database-driven whole farm simulation model developed at Iowa State University. It allows simulation of a variety of crops and crop rotations, including associated practices such as tillage, fertilization, planting, weed control, harvesting, and removal of residue. The crop yields in I-FARM are location, thus soil type, dependent and representative yields are internally referenced for simulation from the integrated SSURGO soil database. The model carbon balance is estimated using the integrated SCI-index, and soil erosion is calculated by the integrated RUSLE soil erosion model [38]. The livestock production model uses feed intake, growth rate, grazing, and confinement options, and contains a manure management system. Economic analysis is performed on all systems after initial simulation. Output tables from the model include: livestock import/export and carcasses processed; crop, forage, and biomass import/export; manure and fertilizer import/export; nutrient balance of N, P, and K at the field and farm scale; soil water erosion and soil conditioning index; energy requirements for field operations at the farm scale; labor requirements at the farm scale; and economic impacts at the farm/enterprise scale [39].

As with IFSM, I-FARM has the advantage of simulating the whole farm, with the added benefit of offering multiple livestock types, not just cattle. The user-friendly, online interface of I-FARM makes it easy to use and accessible to anyone with an internet connection, while preventing users from introducing error, just as with IFSM. A major disadvantage of I-FARM is the limitation of simulation locations. I-FARM only allows simulation of a portion of states, because of the limited weather and soils database [38].

4.2 Materials and Methods

The work presented here began with an investigation of the outputs modeled by DAYCENT and IFSM, and which of the comparable variables of the two programs were of most interest for potential future work. It was then determined which locations simulated by both models had available soil and weather information. The five locations chosen were: Lancaster, PA; Roanoke, VA; Black Hawk County, IA; Sangamon County, IL; Branch County, MI. The six variables chosen were: crop yield, crop nitrogen removal, nitrate leaching, denitrified nitrogen, evapotranspiration, and soil erosion. As a way to further assess the flexibility and usefulness of these models, simulations were run for two different crop systems with different management systems. The first crop arrangement was a 1000 acre corn farm using no-till management with a nitrogen fertilizer application according to model suggestions. The second crop system was a 1000 acre switchgrass farm using no-till management with two harvest dates, May 21 and July 10, and late fall grazing (Sept.-Oct.). The I-FARM model is unable to simulate grazing on switchgrass at present, and was therefore only included in the simulations done for corn production.

To ensure that each model was used properly according to design, the creators of each model were involved in preparing the simulations for this comparison of model performance. For preparing DAYCENT location, weather, and field condition data, and debugging run code errors, Cindy Keough, the point of contact programmer, was contacted [50]. For preparing run conditions for IFSM, Dr. Al Rotz, program author, was contacted [51]. For preparing run conditions for I-FARM and deciding to exclude this model from switchgrass simulations, Ed van Ouwerkerk, program author, was contacted [52].

Using the conditions and locations described, simulations were run with each model accordingly. The simulation results are also compared with available published field data for conditions as close to the simulated scenarios as possible when field data were available. It should be noted that much of the available field data are published data from research and demonstration plots with the inherent limitations of such data. The raw output comparison graphs can be seen in Appendix B Figures B.1–B.12, and a listing of field data sources by application can be seen in Appendix B Table B.1. Values in these graphs are annual averages taken over multiple years and error bars represent standard deviation. Deviations are a result of differences that result primarily from changes in weather patterns from year to year.

To clarify the results seen in Appendix B, a "grading" system was developed to evaluate each model's performance across the different conditions, locations, and outputs. Those simulations performing within the standard deviation of the other models and the field data (when available) received higher scores than those that did not. The two parts of the grading system are outlined in Tables 4.1 and 4.2. The need for two grading systems is the result of excluding the I-FARM model in the switchgrass simulations and the lack of field data available for strict comparison.

The first grading system, Table 4.1, uses plus signs (+) to indicate positive performance, which corresponds to more agreement with other models and available field data, and minus signs (-) to indicate negative performance, which corresponds to less agreement with other models and available field data.

The second grading system, Table 4.2, is used for switchgrass simulations only and accounts for the lack of a third model by scoring the two remaining models based on agreement with each other and agreement with the field data available. The first metric, agreement with each other, is assessed using the same scale in Table 4.1. The second metric, agreement with available field data, is found in the third and fourth rows of Tables 4.5 and 4.6, is assessed using the grading system in Table 4.2, which credits the models for matching the available field data without penalizing for any gaps in these data.

Tables 4.1: Grading system used for evaluation of all the three models and the available field data for simulation of corn grain farms. Plus signs (+) indicate agreement with other models and available field data in either individual variables or separate states. Minus signs (-) indicate less agreement with other models and available field data in either individual variables or separate states.

Grade	--	-	+	++
Variables Matched	**0-1**	**2-3**	**4-5**	**6**
States Matched	**0**	**1-2**	**3**	**4-5**

Table 4.2: Evaluation system used in addition to Table 4.1 for comparison of models to the available field data for simulations of switchgrass only.

Grade	--	-	+	++
% of Available Field Data Matched	0-25	26-50	51-75	76-100

4.3 Results and Discussion

The overall performance results for each individual state for corn grain farms are found in Table 4.3. Single variable (sub-model) performance over all geographic areas for corn grain farms can be seen in Table 4.4. Both of these evaluations were done using the grading system given in Table 4.1.

Table 4.3: Assessment of model performance in simulations of corn grain production for individual states over all outcomes for that state using the evaluation system in Table 4.1.

Model	PA	VA	IA	IL	MI
DAYCENT	++	+	+	+	-
IFSM	+	+	+	+	+
I-FARM	-	N/A	+	-	-

Table 4.4: Assessment of model performance in simulations of corn grain production for each output variable across all geographic areas using the evaluation system in Table 4.1.

Model	Grain Yield	Grain Nitrogen Removal	Nitrogen Leaching	Denitrified Nitrogen	Evapotrans -piration	Soil Erosion
DAYCENT	++	++	++	-	++	-
IFSM	+	++	++	-	++	+
I-FARM	+	-	-	-	N/A	-

It is notable in Table 4.3 that both IFSM and DAYCENT have positive scores across multiple states, indicating that they were able to accurately simulate conditions in a variety of ecosystems, not just for the location in which they were developed.

The scores in Table 4.4 indicate that the sub-models for grain yield in all three models were quite consistent with each other, while the soil erosion and nitrogen sub-models contained more deviation. Also, there were significant negative marks for the I-FARM model, which points to multiple sub-model deficiencies.

The overall performance results for each individual state for switchgrass farms are found in Table 4.5. Single variable (sub-model) performance over all geographic areas for switchgrass farms are found in Table 4.6. Both of these evaluations were done using the altered rating system in Table 4.2.

Table 4.5: Evaluation of model performance in simulations of switchgrass production for individual states over all output for that state. The second row uses the grading system in Table 4.1, and the third and fourth rows were evaluated using the grading system in Table 4.2.

Comparison	PA	VA	IA	IL	MI
DAYCENT-IFSM	-	-	--	-	-
Field Data-DAYCENT	--	-	+	--	--
Field Data-IFSM	+	+	+	-	++

Table 4.6: Evaluation of model performance in simulations of switchgrass production for each output variable across all geographic areas. The second row was evaluated using the grading system in Table 4.1, and the third and fourth rows were evaluated using the grading system in Table 4.2.

Comparison	Biomass Yield	Biomass Nitrogen Removal	Nitrogen Leaching	Denitrified Nitrogen	Evapotrans -piration	Soil Erosion
DAYCENT-IFSM	-	-	--	--	++	--
Field Data-DAYCENT	--	-	--	--	+	--
Field Data-IFSM	+	-	-	--	++	++

The results in Table 4.5 indicate that IFSM is in agreement with the published field data for switchgrass in the various states, while DAYCENT is not, which in turn causes the two models to disagree with each other. It is also shown that IFSM has some difficulty for switchgrass simulations in Illinois, due to its low score for this state. For situations where the two models are not in agreement with each other, but are both in agreement with field data, the two models are on opposite extremes (high and low) of field data standard deviation.

The scores in Table 4.6 indicate that IFSM has better agreement with available field data for switchgrass farms than DAYCENT. However, these results are not particularly favorable for IFSM, because, although the IFSM score is relatively higher, its absolute score is nonetheless low. The negative marks for the three nitrogen output variables may be a sign of a serious deficiency in the nitrogen sub-model in IFSM as related to switchgrass. This table does show that both models have well performing water sub-models.

It is important to note, for the results presented here, a number of small modifications or adjustments can be made to these models on a case-by-case basis to improve performance. Each model presented here has a number of parameters and specifications that could not be fully explored for this study, and a more experienced user could likely produce even more accurate outcomes.

4.4 Conclusion

Integration of the biorefinery model with agricultural systems will allow full economic and environmental analysis of ethanol fuel production along with other products of the biorefinery, crop production for biomass and feed, and fertilizer production from animals for use on crops. To allow selection of the most appropriate agricultural model to integrate with the biorefinery model the crop and animal simulation models DAYCENT, IFSM, and IFARM are compared here. This study shows that IFSM has the most consistent, positive performance and therefore is best suited for future integrated biorefinery simulations.

Unfortunately, all three models have short comings in either specific sub-models or for specific geographic areas. Improvements are constantly being made on these three models and with time these models will improve their ability to model more locations and variables, more accurately [48,53]. The results here highlight the need for further research on whole farm modeling and, more specifically, on nitrogen sub-models. It is important to note, however, that models of this type often perform best in the state in which they were designed, under the conditions most common in those areas. Ultimately, the choice of simulation model is left to the individual user, while giving strong consideration to the location and intended use of the model.

CHAPTER 5: INTEGRATION OF THE BIOREFINERY AND AGRICULTURAL SYSTEM WITH THE BIOREFINERY AND FARM INTEGRATION TOOL (BFIT)

5.1 Background

BFIT is a new research tool designed for expert users to simulate the biorefinery integrated with a realistic agricultural landscape, which provides biomass feedstock and receives AFEX treated grass as an animal feed. For the first time in research, this program simulates all the elements highlighted in Figure 1.1 directly for combined analysis.

The leading model for direct simulation of US ethanol production from cellulosic biomass is the biorefinery model developed at NREL, and subsequently updated at Dartmouth College and Michigan State University, which is described in detail, including the state of the version, in Chapter 3.

The analysis in Chapter 4 evaluated simulation programs to determine which cropping and/or animal production model should be integrated with the biorefinery simulation program described in Chapter 3. As a result of the outcomes in Chapter 4, the work presented in this chapter uses IFSM for all agricultural simulation.

The model framework and conceptual design diagram can be seen in Figure 5.1. This diagram displays the flow of data within the system and all major underlying components. The elements that are described in Chapter 3 and 4 are outlined in dark gray, while elements that are new and part of the BFIT development are outlined in light grey.

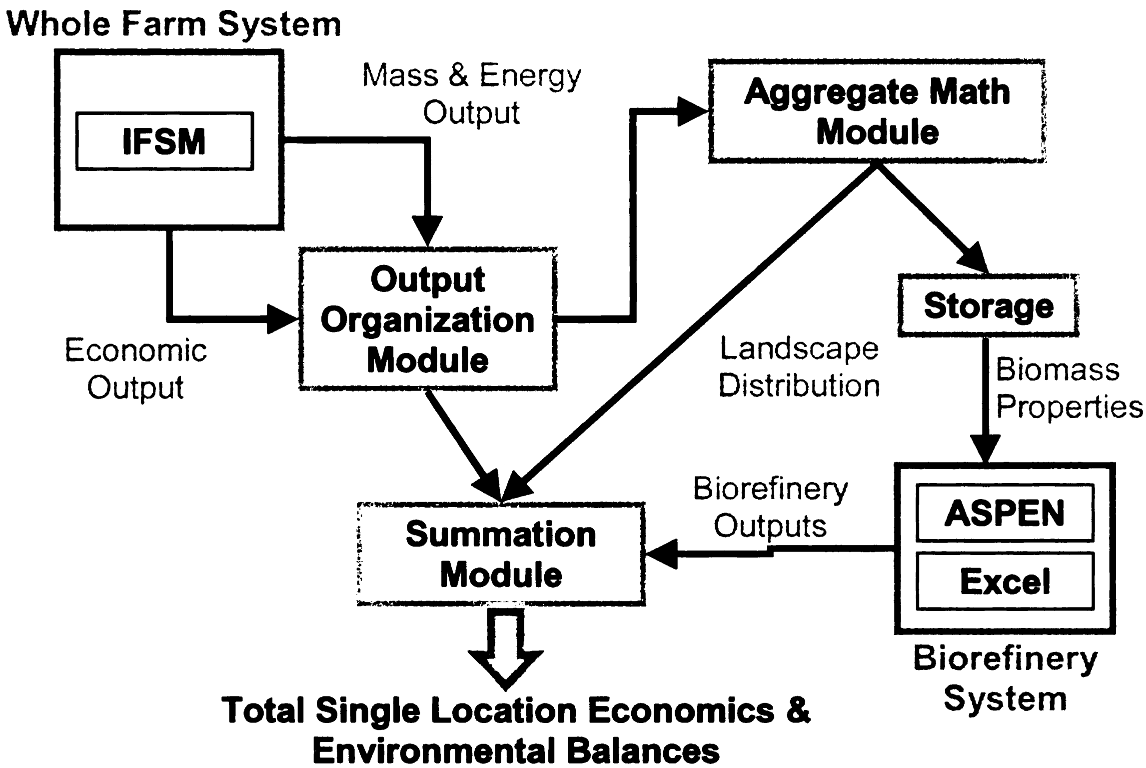

Figure 5.1: Conceptual framework and data flow for the biorefinery system outlined in Figure 1.1.

5.2 Materials and Methods

For landscape calculation development, the Aggregate Math Module in Figure 5.1, six farm management strategies were chosen for analysis. These management strategies are outlined in Table 5.1. These management strategies are chosen because they are the primary farm types that produce the two largest anticipated sources of biomass, corn stover and switchgrass [3,4,54]. Strategies X, A, and C are more conventional methods of farming, while Y, Z, and B are designed to project future farm management better suited to a market that includes the biorefinery. All farms were simulated with no-till management because this more environmentally friendly farming method is growing in popularity, particularly with rapidly rising fuel prices making it a more economical choice [54,55,56,57].

Table 5.1: Outline of management strategies used in model development, indicating whether animals are included and which crops are farmed.

Management Strategy (alpha-identifier)	Corn	Switchgrass	Alfalfa	Rye Cover	Cattle
Cattle-Corn-Alfalfa (X)	•		•		•
Cattle-Corn (Y)	•				•
Cattle-Corn-Switchgrass (Z)	•	•			•
Corn Only (A)	•				
Switchgrass (B)		•			
Corn-Rye Cover (C)	•			•	

For the BFIT development study, the six management strategies outlined in Table 5.1 are simulated in nine locations within the contiguous US. These locations were chosen because of their significance to national agriculture and the readily available and validated soil and weather data for each site [58,59,60]. These locations are outlined in Table 5.2, along with the farm size, cattle type, and herd size simulated in each location. The farm acreage reported in Table 5.2 was chosen for each state using the USDA reported averages for the year 2006 [61]. There are no consistent data available for the average number of cattle (head) per farm by individual states, so a “rule of thumb” of two acres per head was used for all farms.

Table 5.2: Outline of locations used in model development, indicating corresponding average farm size, dominant cattle type, and average herd size based on acreage. States are standard two letter postal abbreviations.

Weather Station City	**County**	**State**	**Farm (ac)**	**Cattle Type (when applicable)**	**Herd size (head)**
Waterloo	Black Hawk	IA	355	Dairy	178
East Lansing	Ingham	MI	191	Dairy	96
St. Cloud	Stearns	MN	345	Dairy	173
Cooperstown	Otsego	NY	214	Dairy	107
Akron	Summit	OH	187	Dairy	94
State College	Centre	PA	131	Dairy	66
Huron	Beadle	SD	1392	Beef Finishing	696
San Angelo	Tom Green	TX	564	Beef Finishing	282
Madison	Dane	WI	201	Dairy	101

The distribution of the farm management strategies in the landscape surrounding the biorefinery, the Aggregate Math Module calculation, is determined using the following equation:

$$\text{Total Biomass} = x\,(X) + y\,(Y) + z\,(Z) + a\,(A) + b\,(B) + c\,(C)$$

Simulated average annual biomass production (tons/yr/farm)...
X = from cattle + corn grain, stover, & alfalfa farm type
Y = from cattle + corn grain & stover farm type
Z = from cattle + corn grain, stover, & switchgrass farm type
A = from corn grain & stover farm type
B = from switchgrass farm type
C = from corn grain & stover + mulched cover crop farm type

In area surrounding biorefinery, number of farms of...
x = cattle + corn grain, stover, & alfalfa farm type
y = cattle + corn grain & stover farm type
z = cattle + corn grain, stover, & switchgrass farm type
a = corn grain & stover farm type
b = switchgrass farm type
c = corn grain & stover + mulched cover crop farm type

This equation is constrained by biorefinery size and statistical data specific to the state being simulated [62]. To facilitate analysis, the biorefinery feedstock input, after storage, was fixed at 2000 TPD for 350 operating days each year (700,000 US ton DM/yr). This size was used rather than metrics such as annual ethanol production or fixed equipment size because it is a common unit for both the biorefinery and agricultural components. The statistical data constrains the landscape distribution of alfalfa acreage grown for animal feed, the fraction of farms with animal operations, the fraction of farms using cover cropping methods, and the portion of farms converting land to switchgrass. For development, each statistical constraint was set to the 2006 USDA reported average except "acreage converted to switchgrass", which is assumed to be 30% based on a study by Jensen et al. [63]. A sample of this calculation can be found in Appendix C.1.

The farm type specific items produced to be sold for income are presented in Table 5.3. Not all farm types are represented in each landscape, but each strategy must be simulated to allow the landscape calculation in the Aggregate Math Module.

Table 5.3: Products sold by each farm management type for farm income by location.

	Management Strategy					
Locations	**X**	**Y**	**Z**	**A**	**B**	**C**
IA, MI, MN, NY, OH, PA, WI	Milk, Corn Grain & Stover	Milk, Corn Grain & Stover	Milk, Corn Grain & Stover, Switchgrass Hay	Corn Grain & Stover	Switchgrass Hay	Corn Grain & Stover
SD, TX	Finished Beef, Corn Grain & Stover	Finished Beef, Corn Grain & Stover	Finished Beef, Corn Grain & Stover, Switchgrass Hay	Corn Grain & Stover	Switchgrass Hay	Corn Grain & Stover

The corn grain yields used for development of all farm simulations are outlined in Table 5.4. For all locations the annual switchgrass combined pre-harvest yield of approximately 6 ton/ac/yr was used due to a lack of reliable data for individual location yields. This value is a conservative yield that is consistent with those studies that are available and is achieved using low levels of fertilizer and no irrigation [28,29,64,65,66].

Table 5.4: Annual corn grain yields by location obtained from USDA 11 year averages upto and including 2006 [62].

Location (State)	Corn Grain Yield (ton DM/acre)
IA	3.79
MI	3.06
MN	3.09
NY	2.45
OH	2.85
PA	2.56
SD	2.29
TX*	2.82
WI	3.49

*This location required 3.2 inches of annual irrigation to achieve proper yield

The corn stover biomass removal rate was is 40% (leaving 60% on the field) because it is a conservative value for this base-case study, which ensures proper soil protection and prevents over drawing from soils [67,68,69]. The corn stover yield, per acre, is thus a result of mathematical computation performed by the model based on its internal biomass production calculations. The stover yields are consistent with other publications [70]. When using a cover crop as natural fertilizer (farm management strategy C) an additional 20% of corn stover is collected raising collection to 60%, leaving 40% on the field. The winter rye cover crop is used as a "green manure" and is not harvested. Rye is the cover crop used for all locations due to its relatively low cost and suitability for soil protection [71].

Although work is currently being done on the pretreatment and processing of wet, or un-dried, biomass, in these simulations all biomass is assumed to be dried to 20-25% [70]. To achieve and maintain this moisture content, biomass simulation includes wide-swath windrows, baling in round bales, and transportation to the biorefinery by truck, with storage inside on a concrete slab. This operation is a reasonably low priced and historically used practice in farming [28]. Storage losses are calculated using the same time-rate storage equation in IFSM, also known as the Rotz and Buckmaster Equation [27]. This loss rate is calculated for the maximum moisture content (25% dry basis) and maximum storage length (12 months) for all biomass to account for the worst case scenario.

The economic assumptions used for development simulation of all agricultural activities are outlined in Table 5.5. All values are conservative 2006 values based on published studies or expert opinion referenced in the last column of Table 5.5. These historical values maintain internal model consistency but can and should be updated in any future work given the rapid change of these economic variables, particularly in the time since this model development and preparation.

Table 5.5: Economics assumptions used for farm development simulations using sources for the year 2006.

Economic Variable	Unit	Value	Source
Diesel Purchase Price	$/gallon	2.00	72
Electricity Purchase Price	$/kWh	0.08	4
Labor Wage	$/hr	10.00	72
Forage Planting-Seed and Chemical Cost	$/acre	50.00	29,73,74
Corn Planting-Seed and Chemical Cost	$/acre	63.31	62
Rye Planting-Seed and Chemical Cost	$/acre	17.00	71
Nitrogen Fertilizer Cost	$/lb N	0.43	72
Phosphorous Fertilizer Cost	$/lb P2O5	0.34	72
Potassium Fertilizer Cost	$/lb K2O	0.16	72
Soybean Meal, 44% Purchase Price	$/ton DM	230.00	72
Meat and Bone Meal Purchase Price	$/ton DM	272.00	72
Hay Feed Purchase Price	$/ton DM	125.19	72
Corn Purchase and Sales Price	$/ton DM	260.00	37
Corn Grain Silage Sales Price	$/ton DM	75.00	72
AFEX Treated Grass Feed Purchase Price	$/ton DM	104.28	11
Biomass (Corn Stover or Switchgrass) Sales Price	$/ton DM	80.00	28,29,75
Milk Sales Price	$/cwt	15.00	72
Bred Heifers Sales Price	$/animal	1200.00	72
Finished Cattle Sales Price	$/cwt	89.99	72

A biomass transportation radius is calculated for each landscape by assuming the land area of the landscape is approximately circular and the biorefinery is located in the center. Each development simulation includes a transportation radius calculation, increasing linearly, for three distances, which assume 100%, 75%, and 50% use of land area surrounding the biorefinery. Because of land use for schools, homes, roads and other non-participating farms, the 100% land utilization transportation radius is very optimistic and represents the extreme minimum transportation for biomass in the system. The location of biorefineries, however, can be assumed to be in rural, agricultural landscapes, thus reducing the use of land for other purposes. In addition, conservation reserve program (CRP) lands are viable for cropping switchgrass and can thus be attributed to grass production, making the 50% land use radius also less likely [64]. All of these considerations suggest that the transport radius for 75% land use is a reasonable scenario, while 100% and 50% participation radii are the best and worst case scenarios, respectively. With these considerations in mind, all three radius calculations are provided for the development simulation outputs showing the influence of transportation distance on economics and the environment. Simulations for the sensitivity analysis and scenario tests, however, were calculated for the 75% land use radius only.

All farm preparations in IFSM were reviewed by agricultural expert and author of IFSM, Dr. C. Alan Rotz of the USDA-ARS-Pasture Systems and Watershed Management Research Unit in Pennsylvania [72]. These inputs include many of the conditions outlined in Tables 5.1-5.5. Detailed tables of all inputs for each farm preparation in both Section 5.3.1 and 5.3.3 can be seen in Appendix C.2 and C.3, respectively.

The parameters chosen for development of biorefinery simulation include the biological conversion process, pretreatment conditions, and animal feed separation. The SSCF was selected for the biological conversion process with a purchased enzyme loading of 15 FPU per gram of glucan, at a cost of $0.2374/lb of enzyme cocktail ($0.5235/kg), which is representative of near-term technology expectations [4,7,18,54,76]. Pretreatment conditions were simulated at 0.3 kg of ammonia per kg of dry biomass, 60% biomass moisture, treated by the AFEX process at 100 C for 5 minutes residence time. These conditions have been demonstrated to give a conversion of 95% for cellulose and 85% for hemi-cellulose (patent applied for). The separation of animal feed directly after pretreatment required the addition of solid separating equipment, which was designed, sized, and priced following precedence for the existing biorefinery model [77].

The ash produced in the cogeneration facility of the biorefinery can be sold and used as a product similar to fly ash [78]. The current market for fly ash products includes building materials, such as concrete, cement, and asphalt, and soil stabilization or back filling materials [79,80,81,82]. This vast market gives the co-generation ash in the biorefinery a fair market value of $20/ton, and it is assumed to be sold at this price [83]. The residue composition is based on calculations already built into the biorefinery model [20].

The post-treatment wastewater bled from the biorefinery contains only trace amounts of any one component, none of which are harmful. Because of the small amount of any item present, the bleed water is assumed to be pH neutral and to have no effect on plant growth, other than that provided by regular irrigation water [21]. The waste water was therefore assumed to be sold back to nearby specialty consumers, such as small farms or greenhouses, for irrigation at half the purchase price, or $0.127/kL.

The economic assumptions for development simulations of the biorefinery are summarized in Table 5.6. All values are based on 2006 sources or near-term biorefinery technology expectations from other studies [4,7,19]. The raw economic "summary" outputs for key biorefinery simulations in Section 5.3.1 and 5.3.3 can be seen in Appendix C.2 and C.3, respectively.

Table 5.6: Economics assumptions used for biorefinery simulations.

Parameter	Assumed Value
Debt/Equity Ratio	40/60
Loan Rate (APR)	7.5%
IRR	12%
Federal and State Tax Rate	39%
Economic Life	25 years
Depreciation Period	• 7 years general plant • 20 years steam and power generation
Depreciation Method	MACRS
Capital Charge Rate	~17%
Indirect Costs	48% of installed cost

All economic variables are independent inputs defined by the user and are simulated as an equilibrium value at a static period. These parameters do not change or compensate automatically when other changes are made within the model and are assumed to be an annual average. This design was selected to reduce the potential for compound effects in the model, therefore increasing transparency and maintaining flexibility for this tool.

Gaseous emissions for the agricultural system and the biorefinery are directly simulated while biomass transportation GHG emissions are calculated using the GREET model [84]. All of the emissions are combined in BFIT, yielding the total CO_2 equivalent GHG emissions for each whole biorefinery system, what could be called the "GHG footprint". Biorefinery GHG emissions include both biological ethanol production and electricity co-generation. Negative GHG values reported for crop agriculture are carbon sequestration credits from plant growth.

5.3 Results and Discussion

5.3.1 Development Simulations

Using the conditions and locations described in the Materials and Methods section, nine biorefineries were simulated with a surrounding landscape including six management strategies distributed according to historical data. The outputs of the BFIT development simulations include the following: design of the landscape, including size and farm distribution (Figure 5.2); farm economics, including farm income by product source, net return per acre, and total landscape net return to farmers (Figures 5.3, 5.4, and Table 5.7); environmental emissions, including nitrogen loss by ecological process and GHG emissions (Figures 5.5 and 5.6); and biorefinery economics, as characterized by MESP and TPI (Figure 5.7 and 5.8). To test the agricultural landscape portion of the model, a control was calculated for the "no biorefinery" condition, meaning the landscape is calculated using only conventional farming strategies (X, A, and C) and biomass is not sold as a product. The outputs of these control tests are given in Figures 5.9-5.12 and Table 5.8.

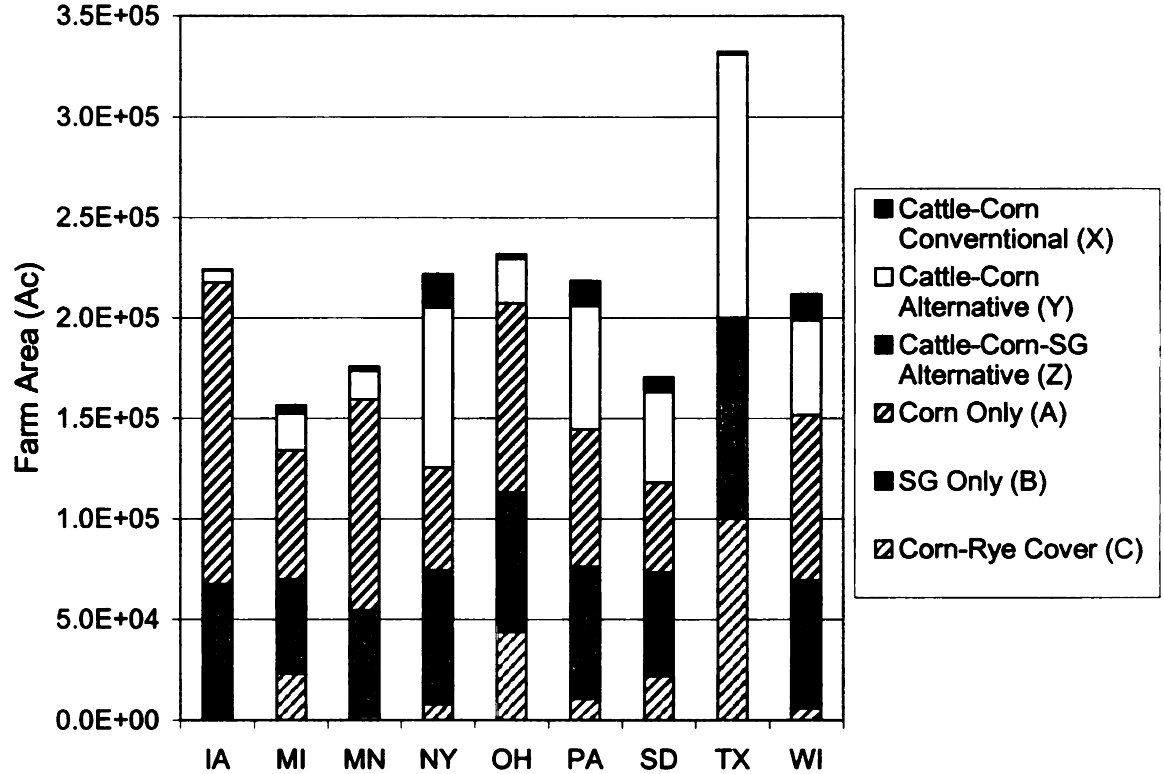

Figure 5.2: Landscape area required to produce the biomass required for a 2,000 TPD biorefinery for development simulations. Participation of each farm type contributing to the total area, also called "landscape distribution", is indicated by colors and patterns.

The results in Figure 5.2 highlight those locations that use the least land area to produce the 2000 TPD required biorefinery biomass and visually distinguish the farm management distribution in the landscape. In Figure 5.2, stripes indicate farm management strategies that are crop only, and solid bars indicate strategies that include animal operations, while the overall total draws attention to locations with the largest participation area. Using patterns and colors to show the landscape distribution results underscores for the user the farming strategies that are most important in each landscape, which can also be called the "agricultural emphasis".

The locations with the highest overall land requirements in Figure 5.2 have more farms that include animal operations, such as Texas, or have less farm type variety, also know as monoculture type farming, as in Iowa. Landscapes with the greatest animal agriculture have larger participation area because the use of land for feed growth and animal production overlaps the acreage used for biomass production. Monoculture type farming often raises land area because the management strategies that dominate the landscape are more conventional strategies that do not reach the full productivity potential of the land. Locations simulated in BFIT that have large land requirements, but have moderate animal agriculture and well mixed distributions, are experiencing the effect of low productivity. In Figure 5.2 this effect is seen for the location selected in Ohio. Having greater land area has the benefit of more soil surface area for sequestration, but has the draw back of greater transportation distance, which ultimately leads to higher emissions and cost associated with transportation.

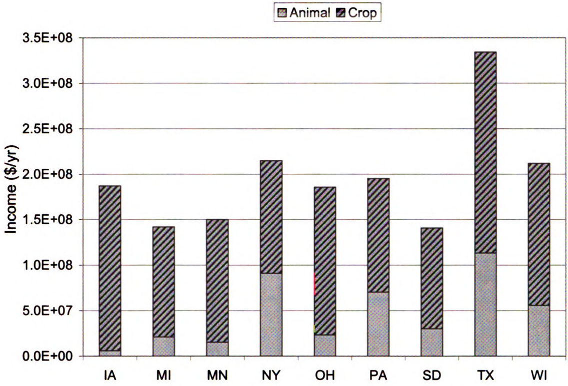

Figure 5.3: Annual income combined for all participating farms for development simulations by product source, animal agriculture or crop agriculture. Products for each location are outlined in Table 5.3.

Table 5.7: Net return on a per acre basis for each farm type, as well as an overall landscape average, for each location for development simulations. Values in grey are farm types that were calculated as not occurring in the landscape distribution.

	Management Strategy						
Location	X	Y	Z	A	B	C	Average
IA	$386.09	$567.51	$526.03	$602.77	$339.47	$534.11	$522.23
MI	$159.25	$378.19	$392.91	$366.90	$645.01	$375.69	$447.62
MN	$328.37	$540.56	$550.99	$413.02	$561.30	$359.30	$466.05
NY	$159.52	$371.94	$384.17	$271.47	$395.13	$218.43	$334.43
OH	$204.31	$404.40	$434.88	$454.60	$296.51	$393.28	$388.35
PA	$34.58	$233.84	$240.23	$268.20	$333.73	$211.09	$262.17
SD	$155.59	$202.04	$143.66	$292.27	$502.83	$282.72	$324.53
TX	$155.60	$236.30	$163.56	$447.49	$356.61	$249.68	$238.41
WI	$361.48	$566.53	$568.20	$493.76	$383.06	$412.43	$466.38

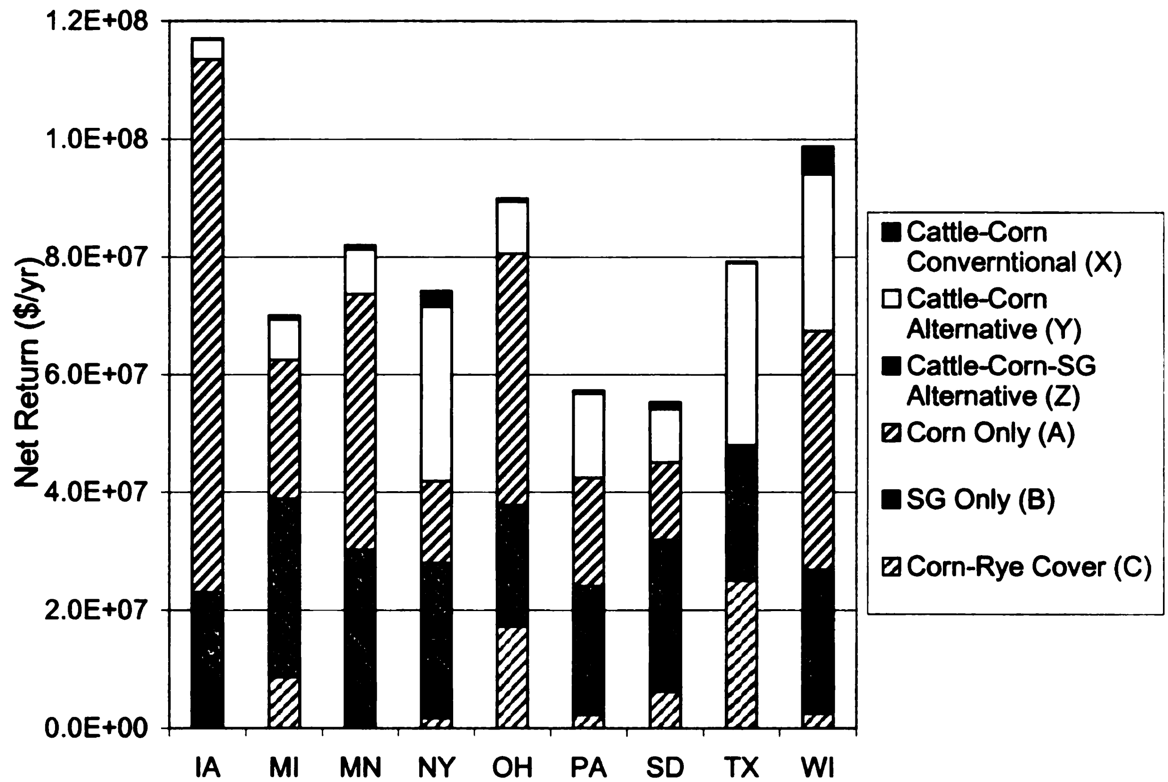

Figure 5.4: Total annual net return combined for all participating farms for development simulations. Contribution of each farm type to the total profit is indicated by colors and patterns.

For the results in Figure 5.3, stripes again illuminate each location's agricultural emphasis, with overall values showing productivity. States with greater animal production have greater income in Figure 5.3, but, after accounting for production costs, the net return results in Table 5.7 and Figure 5.4 show true profitability. Net return includes costs for the following: planting, production, harvesting, temporary storage for biomass, purchased feed, feed storage, and animal housing; and income from the following: animals and/or animal products, feed, bedding, and biomass sales. The details of the farm parameters are outlined in the Materials and Methods section.

The net return per acre in Table 5.7 is highest for the switchgrass only management strategy (B) for all locations, except for the corn only management strategy (A) for Iowa and Ohio, and the dairy growing corn based feeds supplemented with AFEX feeds (Y) for Wisconsin. These results reiterate the reduced productivity for Ohio, showing clearly that the problem is particularly important for switchgrass, and reinforces the commonly accepted identity of Iowa as a "corn state" and Wisconsin as a "dairy state".

It can be easily seen in Table 5.7 that the corn-switchgrass animal farm using AFEX feed (Z) type farm is not included in any landscape calculation except for Texas. This result suggests that switchgrass conversion to larger continuous acreage (whole farms) fits with current farming distributions better, except in locations like Texas that have a strong agricultural emphasis on animal production.

Average landscape values in Table 5.7 suggest that some traditional farm strategy distributions do not achieve the highest potential return per acre. These averages, which are weighted for the distribution of farm types in the landscape, indicate that with historic farm distribution, the Iowa landscape has the highest overall average net return per acre. The landscapes with the next highest average returns on a per acre basis are grouped closely, being Michigan, Minnesota, and Wisconsin. These four locations with the highest landscape average return per acre are known for their agricultural significance and have some of the highest returns per acre for each individual farm type as well.

Total landscape net return and the contribution of each farm type to this return can be seen in Figure 5.4. These results show the influence of land requirement and distribution, from Figure 5.2, combined with the individual farm type returns, given in Table 5.7. Iowa and Wisconsin have high returns and high land requirements, while Michigan and Minnesota have high returns but fewer farms (lower land area) giving a lower total landscape return. An opposite combination yields a moderate total net return for the Texas landscape, where the high income seen in Figure 5.3 is offset by costs giving lower net return in Table 5.7. Also, Table 5.7 indicates that little acreage is dedicated to the farm type with the highest calculated returns.

The economic results described above demonstrate BFIT's ability to highlight potential increased landscape return by conversion to underutilized management strategies having greater return per acre. This change from conventional farming is not easy, but may be more readily accepted when farming communities are shown their potential for increased revenue. The current results already reinforce the generally accepted idea that the Midwest region is a prime location for agricultural industries.

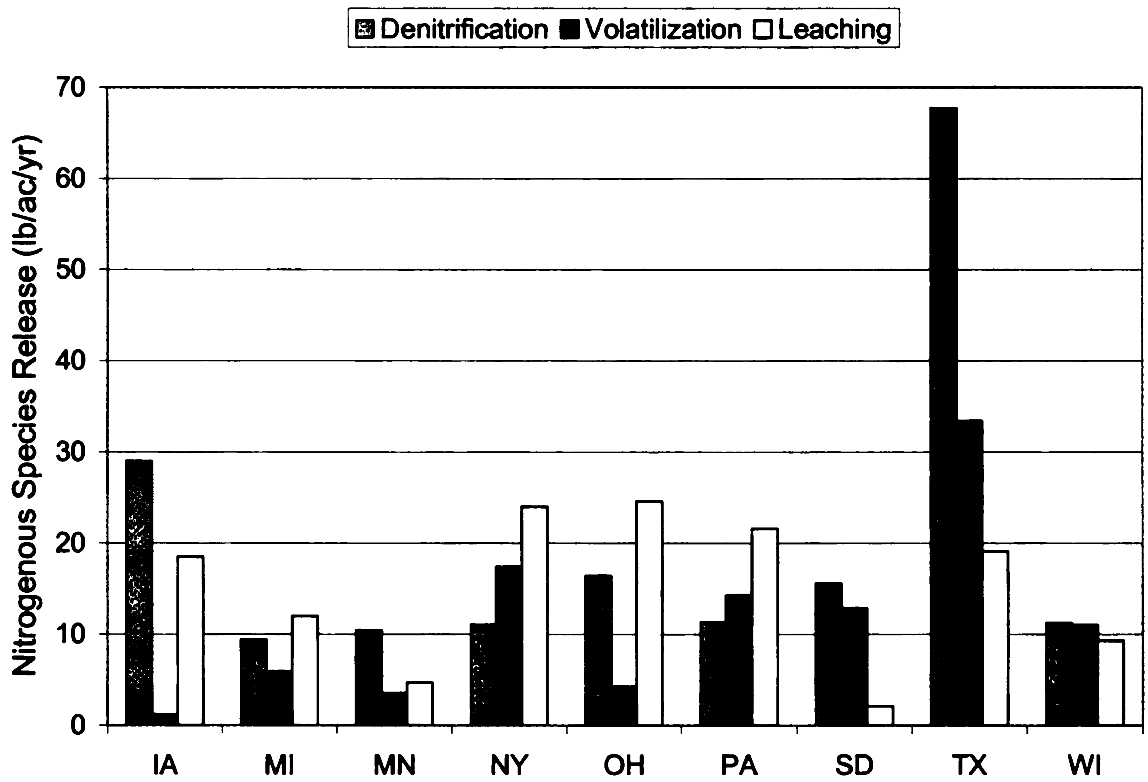

Figure 5.5: Landscape average annual nitrogen loss per acre by ecological process from which they are lost for development simulations. Species produced are NO2, NO, N2O, and N2 by denitrification, NH3 by volatilization, and NO3 by leaching.

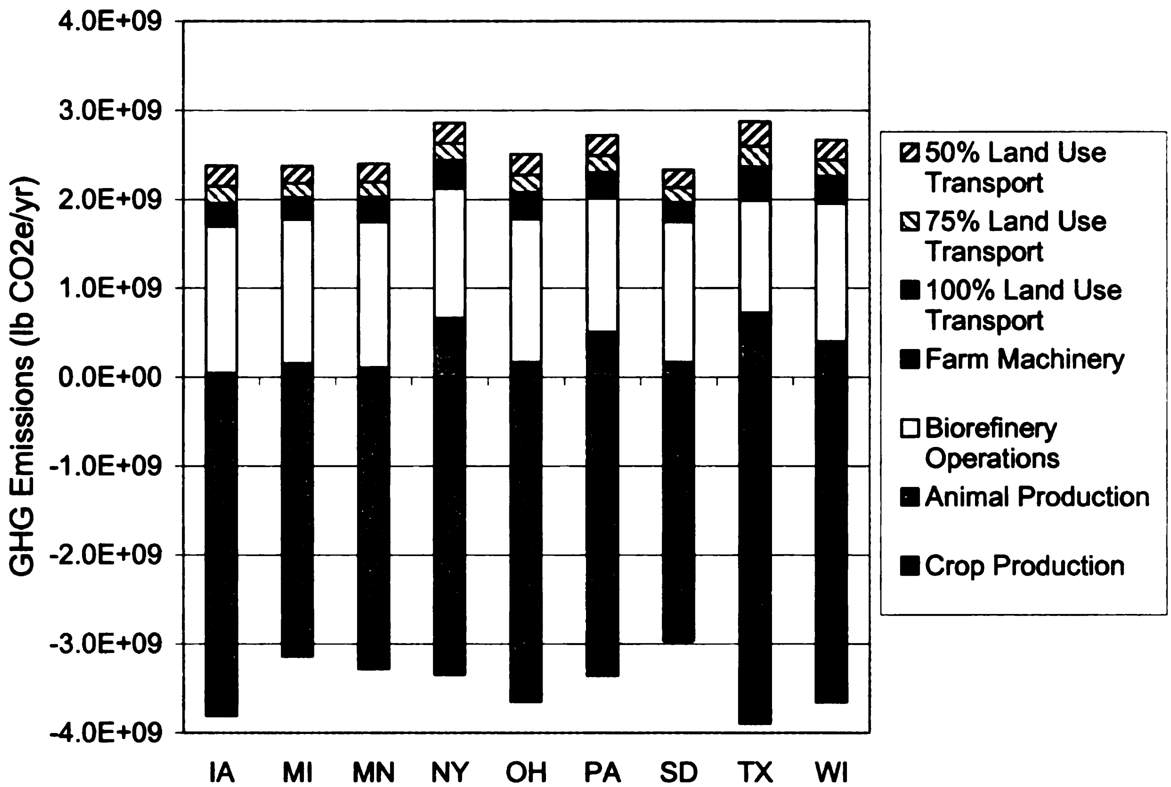

Figure 5.6: Greenhouse gas (GHG) emissions for all participating farms in the landscape, all corresponding biorefinery operations, and biomass transportation for development simulations. Emissions are broken out by source and given as the sum of all GHG emissions in CO2 equivalents.

Two of the three processes represented in Figure 5.5 are directly affected by water in the agricultural system. Denitrification losses increase with increasing soil moisture and drainage controls leaching. Drainage depends on water flow through the soils, rainfall and/or irrigation, and the amount and timing of manure and fertilizer application. The patterns for denitrification follow reported soil moistures with the exception of Texas, which is the only location with irrigation [85]. Leaching trends are similar but are influenced by how much and when water reaches the soil, as well as fertilization parameters. Volatilization depends on the expulsion of waste products by animals and therefore follows trends for animal production in each landscape distribution. Soil type and farming intensity requirements can also affect the trends observed in Figure 5.5.

The calculations and assumptions for the GHG emissions presented in Figure 5.6 are further described in the Materials and Methods section of this chapter. The three "land use" values in Figure 5.6 correspond to biomass transportation radii, which are also described in Section 5.2, Materials and Methods.

The GHG results in Figure 5.6 are heavily influenced by the land requirement results in Figure 5.2 because of the relationship of surface area and carbon sequestration by crops. It can also be seen in Figure 5.6 that landscapes with greater animal production have increased GHGs, mostly from methane. Biorefinery emissions are directly proportional to overall biorefinery operation (total size), which is discussed in the paragraphs following Figure 5.7 and 5.8. It is also clear that farm machinery and biomass transportation emissions are similar for all the locations included in this study. These results also indicate that changes for different land use or transportation distances are small, and may not be significant for many studies. This limited influence may decrease concern for previously emphasized environmental impacts from biomass transportation [1,7,28].

Figure 5.7: Total project investment (TPI) for each biorefinery development simulation, which includes account for total installed equipment cost, facility costs, and a 3% project contingency.

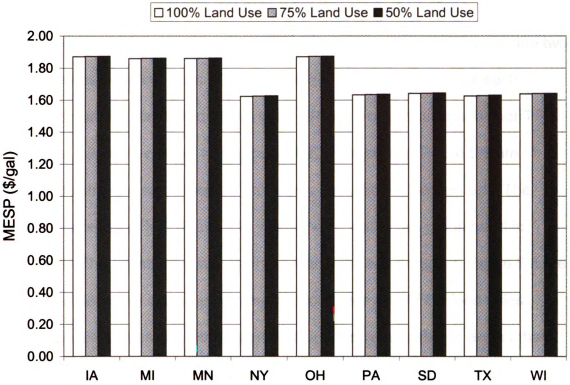

Figure 5.8: Minimum ethanol selling price (MESP) calculated for each biorefinery development simulation, which includes account for capital and operating costs as well as a fixed 12% return to management.

The total project investment (TPI) results in Figure 5.7 depend directly on the biorefinery equipment cost, which directly corresponds to equipment size. In this system, equipment is sized based on the amount of biomass passing through each unit operation, which fluctuates for steps before and after pretreatment. Before pretreatment, equipment used for handling corn stover biomass is more costly than for switchgrass because corn stover harvest has a greater potential for undesirable inclusions, such as dirt, rocks or metal, which require additional washing and removal equipment. Pretreated grass feed removal after pretreatment varies by location and defines the amount of biomass continuing through the biorefinery for ethanol production. Locations with greater animal production have greater feed return that leads to a smaller biorefinery for that location, which in turn has a lower TPI. Based on these correlations, the two distinct groups seen in Figure 5.7 reflect the agricultural emphasis of each location for either animal production (lower TPI) or crop production (higher TPI).

The minimum ethanol selling price (MESP) results in Figure 5.8 are calculated using the same method previously described in Section 3.1. The relationship between MESP and TPI yields the repeated two group trend in Figure 5.8. The variations amongst those within the two groups in Figure 5.8 are muted by differences in biomass transportation costs and AFEX feed sales, which essentially subsidize ethanol production. It is reasonable to expect that the differences between these two groups would decrease long-term, where biorefinery size is 5,000-10,000 TPD, due to economies of scale [4,19,20].

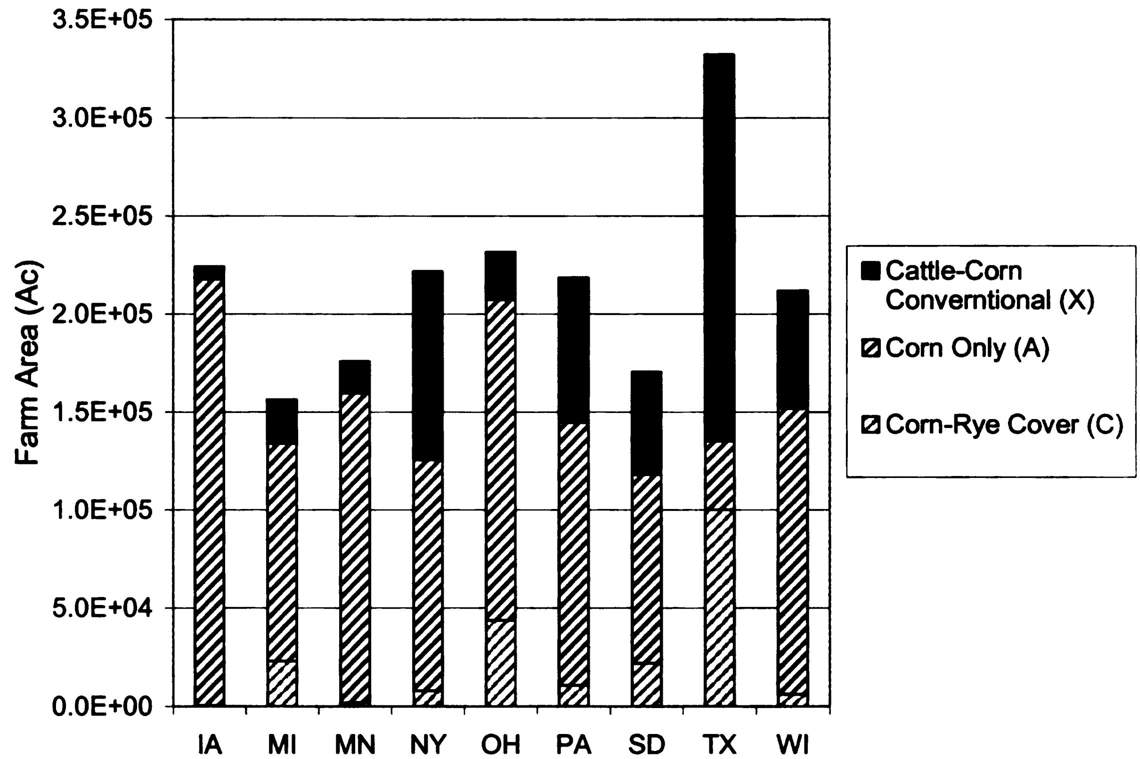

Figure 5.9: Redistribution of the landscape, which was fixed to development simulation size, for control test of Figure 5.2.

The results in Figure 5.9 are the landscape distribution calculation for the same area corresponding to each location in Figure 5.2. These distribution calculations use only management strategies that are "conventional", as previously described. This figure shows BFIT simulations for each landscape before the introduction of the biorefinery and its corresponding biomass supply chain. When limited to conventional management strategies, one can see even more clearly locations where animal production is emphasized. It is also clear that distributions continue to follow what is expected for the locations included in these development simulations. These results suggest that alternative management strategies are beneficial to the farmer, because they are included by the landscape optimization algorithm to replace some conventional management acreage.

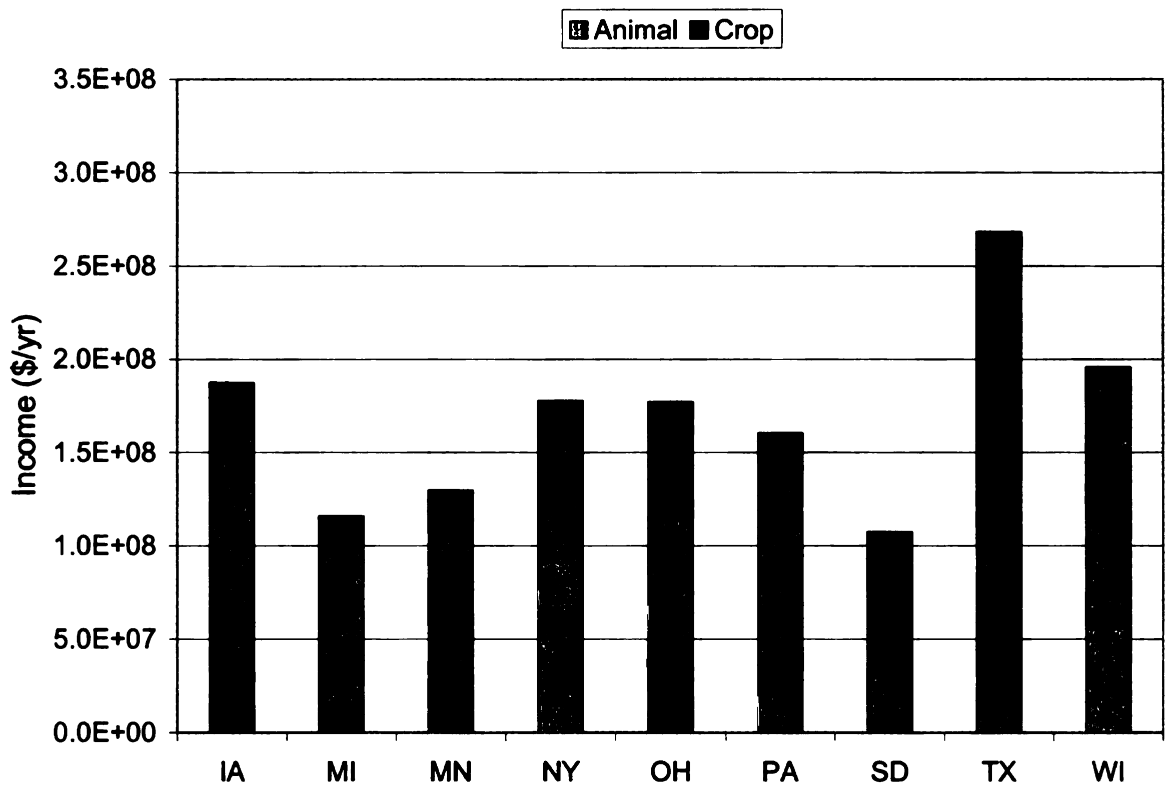

Figure 5.10: Annual income for control test of Figure 5.4. Crop products do not include biomass sales (switchgrass hay or corn stover).

Table 5.8: Net return on a per acre basis for control test of Table 5.7.

	Management Strategy			
Location	**X**	**A**	**C**	**Average**
IA	$310.83	$493.93	$371.41	$488.44
MI	$85.95	$261.76	$220.72	$230.59
MN	$254.40	$310.99	$207.42	$304.69
NY	$89.99	$173.52	$76.37	$133.81
OH	$129.44	$349.36	$243.98	$306.44
PA	-$48.47	$158.89	$54.76	$83.71
SD	$58.81	$188.82	$138.35	$142.41
TX	$52.76	$338.41	$136.91	$108.01
WI	$274.32	$385.90	$258.00	$350.69

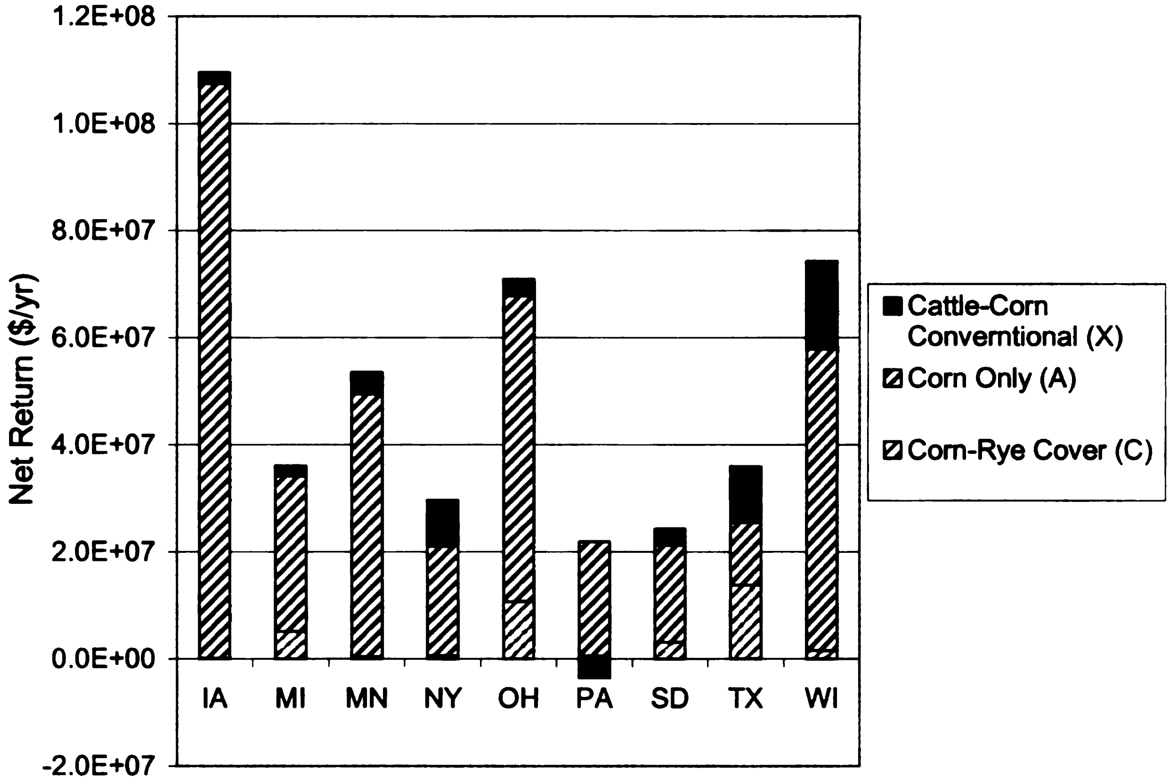

Figure 5.11: Total annual net return for control test of Figure 5.3.

For the income results in Figure 5.10, the trends and patterns are similar to those reported in Figure 5.4, but absolute values are lower for all locations except Iowa and Ohio. These results show the influence of increased crop income for switchgrass and reduced animal feed costs for AFEX feed in the BFIT income calculations. This influence suggests that the existence of the biorefinery, and thus an additional market for crop sales, is of value to farmers.

For the net return calculations in Table 5.8, the corn only management strategy (A) is always the most profitable farm type, as would be expected given the high corn price in recent years. The highest landscape averages are the same as those in Table 5.7 except the landscape calculated for Ohio increases net returns and Michigan drops below that of the top four. The exchange of these most profitable landscapes again emphasizes the influence of switchgrass in the landscape, because Iowa and Ohio maintain higher returns in this non-switchgrass (conventional) landscape. This occurs because Iowa was already highly profitable, with limited switchgrass effects for the development landscape, and the Ohio development net return was reduced by the influence of switchgrass, which has been removed in Table 5.8. The reduced returns in Table 5.8 combined with fixed land requirements in Figure 5.9 reduce all total net returns.

The animal income in Figure 5.10 appears to be a larger fraction of farm economics than for net return results in Figure 5.11, which underscores the high costs that are offsetting the income from animal products. In one case, Pennsylvania, the costs are actually greater than the income, once again pointing to a landscape that could greatly benefits from the inclusion of new alternative farm management strategies.

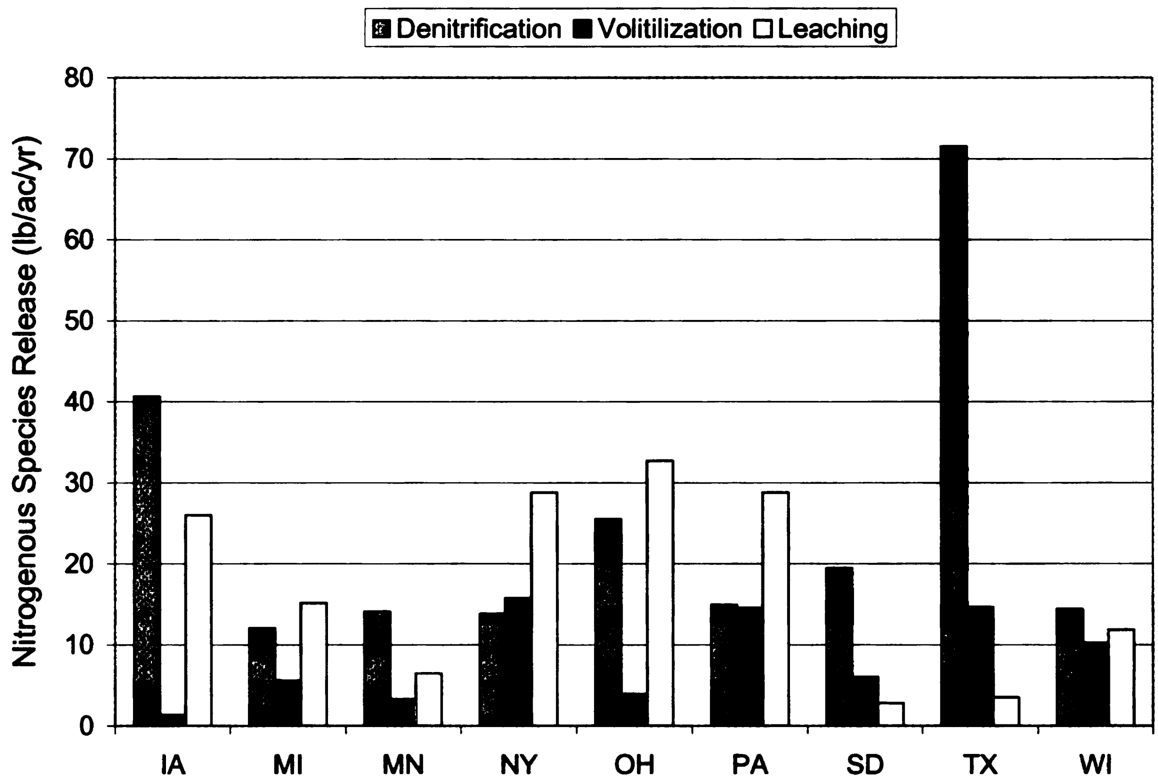

Figure 5.12: Average annual nitrogen loss per acre for control test of Figure 5.5.

In Figure 5.12 nitrogen loss is greater for denitrification and leaching for all landscapes because the same area is simulated with more "conventional farming", which require more intensive crop management. Nitrogen loss through volatilization is nearly unchanged in dairy states (IA, MI, MN, NY, OH, PA, WI) because conventional strategies do not differ as much from alternative strategies for animal rationing. Nitrogen losses for beef cattle, on the other hand, are actually reduced using conventional farming methods because the finishing ration uses a number of feed stuffs (high moisture and dry grain, grain silage, soybean meal, and meat and bone meal). This ration more carefully meets animal protein needs, keeping nitrogen excretions low. For the alternative feeding simulations (Y and Z) the finishing ration is calculated to be entirely comprised of the high energy protein feed, which is AFEX treated grass from the biorefinery. This ration is simulated using NRC recommendations, but allows over feeding of nitrogenous protein, which then leads to excretion of unused nitrogen.

This control test of the BFIT development simulations reveals valuable insights that can be obtained through running simulations on a fixed landscape area in future studies. The outputs of these types of simulations reveal the underlying structure of BFIT and its landscape calculations. This type of pre-biorefinery simulation, used as a control, can reveal agricultural changes that can enhance farmer and community profits, reduce emissions over conventional farming practices, and direct land use for both biorefinery feedstocks and animal feed production.

It is important to note that all simulations presented here, both the control and basic simulations, do not include any "new land" for agriculture. All area simulated in this model is assumed to be existing farms or previously farmed acreage converted to the selected management.

5.3.2 Sensitivity Analysis

To assess which input variables have the strongest effect on model outcomes, a sensitivity analysis was performed. The variable changes made are outlined in Table 5.9.

Table 5.9: Sensitivity variables tested and the values used for each test.

Sensitivity Variable	Increase Test Value	Original (Development) Value	Decrease Test Value
Diesel Purchase Price ($/gal)	4	2	1
Corn Purchase & Selling Price ($/ton DM, $/ac seeded)	311, 75.97	260, 63.31	207, 50.64
Electricity Purchase & Selling Price ($/kWh)	0.16	0.08	0.04
Grass Seed Purchase Price ($/ac seeded)	60	50	40
Biomass Selling Price ($/ton DM)	160	80	40
AFEX Feed Purchase Price ($/ton DM)	208	104	52
AFEX Feed Crude Protein Content (CP % DM)	26.04	21.7	17.36
Switchgrass Yield (ton DM/ac)	12	6	3
Biorefinery Feed Size (ton DM fed/day)	5000	2000	1000
Biorefinery Internal Rate of Return (%)	15	12	9
Biomass Storage Dry Matter Loss (%)	0.14	0.069	0.035

Sensitivity analysis results using three system indicators are in Table 5.10. Values in this table are the ratio of the percentage change in outcomes to the percentage change in the sensitivity input value. The outcome indicators reported are total landscape net return as a farm economic indicator, MESP as a biorefinery economic indicator, and total landscape GHG emissions as an environmental indicator. Negative values represent changes opposing sensitivity variable adjustment (e.g. an indicator increases when the sensitivity variable is decreased).

Table 5.10: Change in simulated outcome indicators as a ratio of percentage outcome change to percentage sensitivity input change. Sensitivity tests are outlined in Table 5.9.

Variable Change	Farm Economics (Net Landscape Farm Return)	Biorefinery Economics (MESP)	Environment (Landscape GHG Emissions)
Hi Diesel Price	-0.1	0	0
Lo Diesel Price	-0.1	0	0
Hi Corn Price	0.9	0	0
Lo Corn Price	1.3	0	0
Hi Electricity Price	0	0	0
Lo Electricity Price	0	0	0
Hi Grass Seed Price	0	0	0
Lo Grass Seed Price	0	0	0
Hi Biomass Price	0.3	0.4	0
Lo Biomass Price	0.4	0.4	0
Hi AFEX Feed Price	0	0	0
Lo AFEX Feed Price	0	0	0
Hi AFEX Feed Protein	0	0	0
Lo AFEX Feed Protein	0	0	0
Hi SG Yield	-0.4	0	0.3
Lo SG Yield	-1.3	0	1.1
Hi Bioref. Size	1.0	-0.1	-0.9
Lo Bioref. Size	1.0	-0.2	-1.0
Hi IRR	0	0.3	0
Lo IRR	0	0.3	0
Hi DML	0.1	0	0.2
Lo DML	0.1	0	0.1

Values in Tables 5.10 increase and decrease equally with sensitivity variable change follow linear trends. All results in Table 5.10 that are less than one have a smaller system influence, and those greater than one have a stronger influence on BFIT results. Those values reported as zero have either no or very small influence on outcomes (<5%), meaning that input variable change is insignificant to outcomes.

The unequal change in the farm economic indicator seen for corn price changes occurs because farms in the landscape have differing or no corn acreage and are thus not affected equally by corn price changes. The non-linear farm economic results for biomass price change occur because grain price overwhelms stover price changes for farms having primarily grain profit (farm types Y, A, & C), while biomass prices have a distinct effect on farms having income from hay (farm types X, Z, & B). The uneven change in both farm economics and environmental indicators for switchgrass yield findings is the result of an adjustment in the distribution. This distribution change occurs because switchgrass acreage contributes differing amounts of biomass to the landscape total, while switchgrass acreage is a fixed fraction of the landscape area (30%). The non-linear nature of economies of scale in the range studied here causes the non-linear biorefinery economic and environmental indicator changes when biorefinery size is adjusted. These same results have also been shown in previous publications for these same biorefinery sizes, using NREL model versions similar to that used as the BFIT sub-model [4,7,20,42,44]. The uneven environmental indicator change with DML adjustments occurs because biomass requirement differences cause a land requirement change, thus a transportation distance change, and produce small distribution changes as well.

The results of this sensitivity analysis highlight the compound effect of some variables on multiple parts of the system, particularly switchgrass yields, biorefinery design (sizing), biomass pricing, and biomass storage and losses. Unfortunately, these areas are still under study and developing, and they are sources of disagreement amongst scientists [1,3, 7,70,74,75,86].

These sensitivity results also underline the non-linear effect of some input parameters as a result of the landscape algorithm. These non-linear effects highlight the need for great care in selecting all model input assumptions and the need for transparency reporting them. The non-linear effects explained here are also important for future studies using this research tool because they can guide user input adjustments made for system design and/or decision making.

5.3.3 Scenario Tests

Because this research tool estimates a system that is not currently in existence at an equivalent (commercial) scale, it is unable to be validated, but it can be verified [87,88]. The reliability of the two model pieces that are combined by this tool has already been proven [4,19,20,27]. To verify the combination of these pieces in BFIT, I devised a series of scenario tests that were carried out by Pragnya Eranki. This researcher was trained on the model, and is educated in the related issues making her an "expert user" [87,88,89]. The contribution from this verifier was limited to execution of the model and a description of challenges facing new users, no intellectual content was contributed. The scenarios are outlined in Table 5.11.

Table 5.11: Outline of scenarios used to test BFIT for verification.

Scenario Name	Location	Change
Decreased Precipitation	IA	Precipitation decreased 42 cm/yr
Increased Switchgrass (SG) Productivity	IA	Switchgrass yield increased to 12 ton/ac and fraction of farms growing switchgrass increases to 70%
Decreased Meat Production	TX	Fraction of farms with animals decreased to 1%
Decreased Winter Temperature and Precipitation	MI	Winter (Nov.-Apr.) temperature decreased by 11°F and precipitation decreased 19 cm/yr
Increased Meat Production	TX	Fraction of farms with animals increased to 90%, cover cropping requirement was reduced to 10%
Increased Temperature and Precipitation	SD	Temperature increased by 13°F and precipitation increased by 50 cm/yr
Increased Corn Stover Productivity	IA	Corn stover collection increased by 20% on all farms
Decreased Biorefinery Productivity	PA	Biorefinery operation reduced to 283 days/yr, biomass storage loss increased 1% making annual required biomass production 614,248

The results of the changes made for the eight scenarios in Table 5.11 can be seen in Figures 5.13-5.33 and Table 5.12. The outputs, labeled by scenario name, are the same metrics as those presented in Section 5.3.1 for development simulations. Each scenario figure also contains the corresponding development value for that location, labeled as "original" with the two letter state abbreviation. Results for these scenario tests are grouped by similar variable changes for weather, crop productivity (including reduced usage from the biorefinery), and meat production.

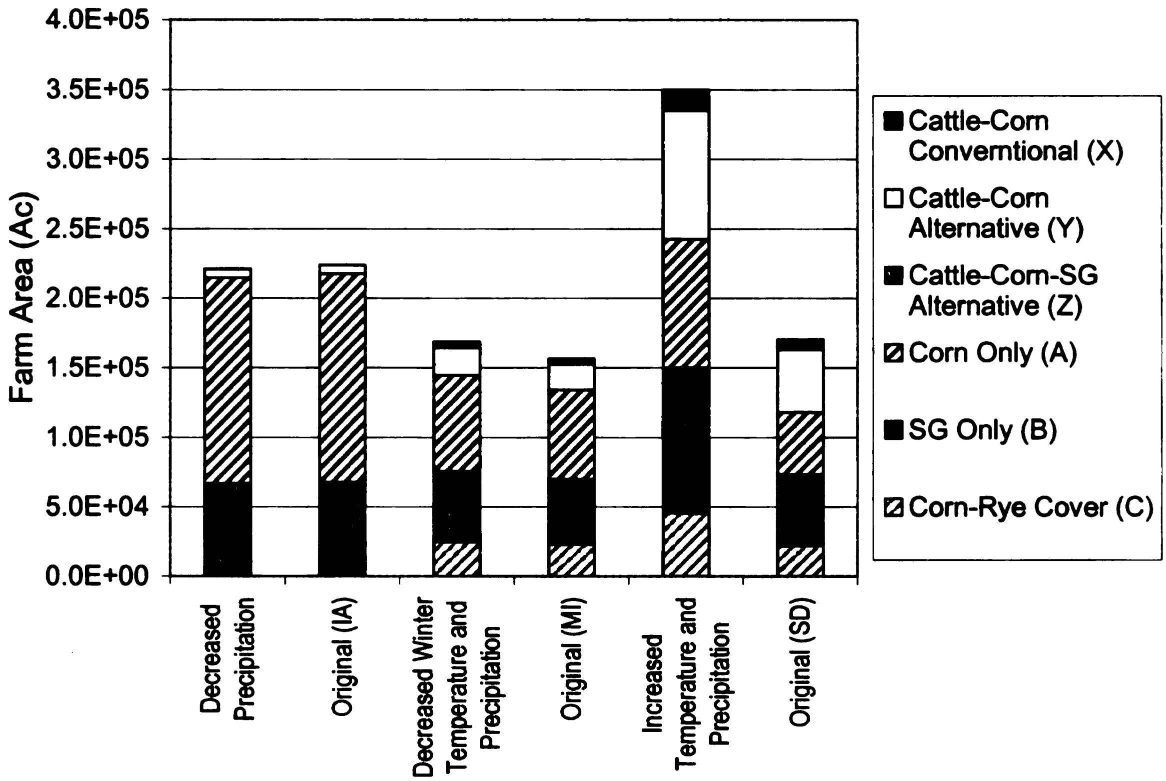

Figure 5.13: Landscape size and distribution for scenario tests having weather adjustments.

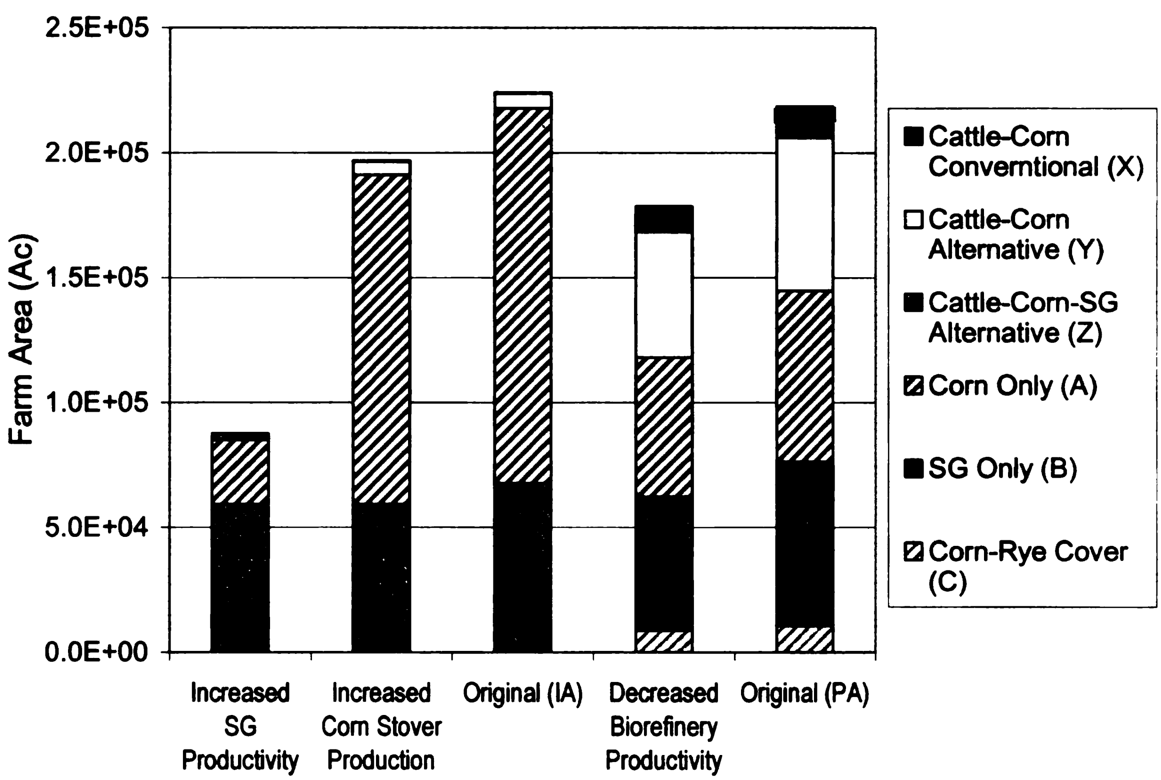

Figure 5.14: Landscape size and distribution for scenario tests having productivity adjustments.

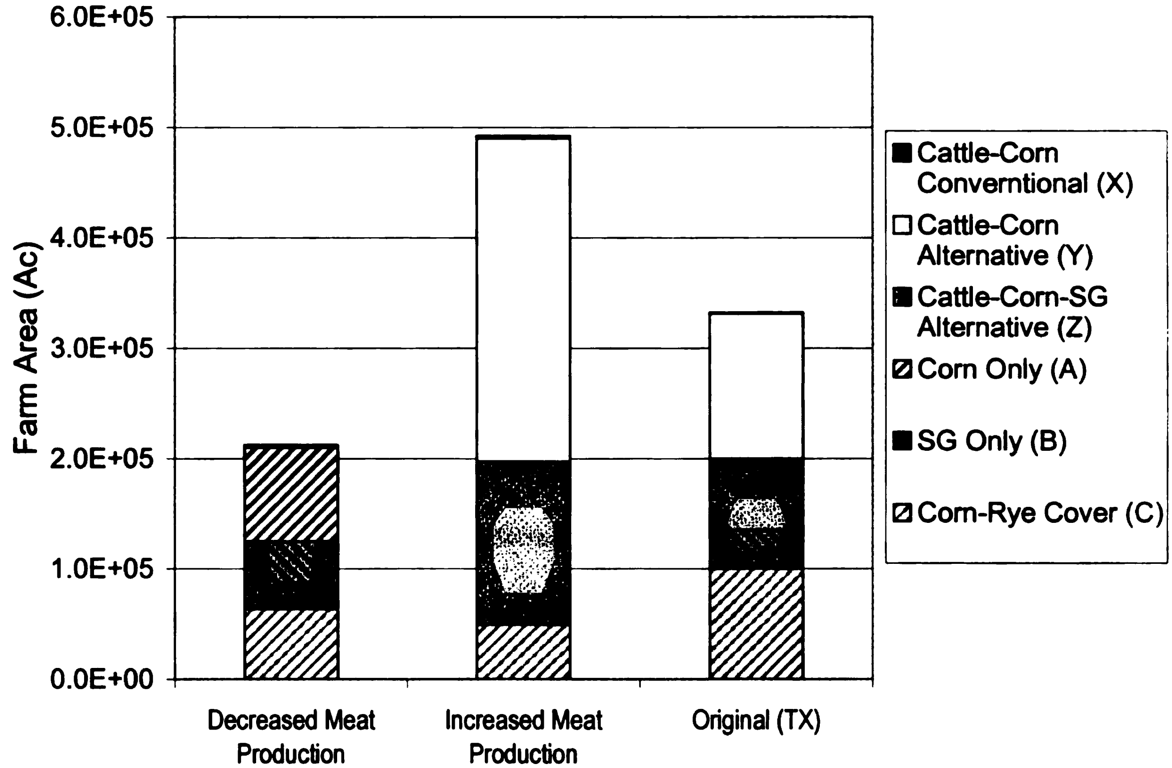

Figure 5.15: Landscape size and distribution for scenario tests having meat production adjustments.

The greatest factor for the changes seen in Figure 5.13 is variation in crop productivity as a result of climatological adjustments. Because corn yields decreased slightly and switchgrass yields increase with drier conditions in the Decreased Precipitation scenario, tested in Iowa, the distribution and overall land requirement did not change much. Changes to the winter weather in Michigan showed very minor decreases in all farm type yields increasing land requirement slightly, while the distribution remains unchanged. The increase in precipitation for the third weather scenario had potential corn yield benefits, but the year round temperature increase caused corn yields to decrease instead. The increase in precipitation also drastically reduced switchgrass yields, as might be expected in opposition to the results for the Decreased Precipitation scenario. This reduction of all yields, particularly switchgrass yields, in this final weather scenario caused the calculation of a significantly higher land requirement to reach the same level of biomass production.

For Figure 5.14, as expected from the previous scenario results, when biomass productivities increase, as it does for the first two scenarios in this figure, the overall land requirement decreases. The Increased Switchgrass Productivity scenario distribution changes are prescribed by the scenario test design, switchgrass acreage increases to 70% of the landscape. This distribution thus requires some switchgrass acreage on what little animal farming that does occur (farm type Z). The third scenario in Figure 5.14, Decreased Biorefinery Production, shows the effect of a reduction in biomass needs for this scenario, reducing overall land requirement.

In Figure 5.15 the near elimination of animal production for the Decreased Meat Production scenario is clearly shown in the distribution, having the stripe pattern for almost every acre. The opposite is seen for the Increased Meat Production scenario, having solid bars for much of the landscape acreage. The lack of land required for animal feed production in the Decreased Meat Production scenario decreases overall land requirement, and again the opposite is seen for the Increased Meat Production scenario.

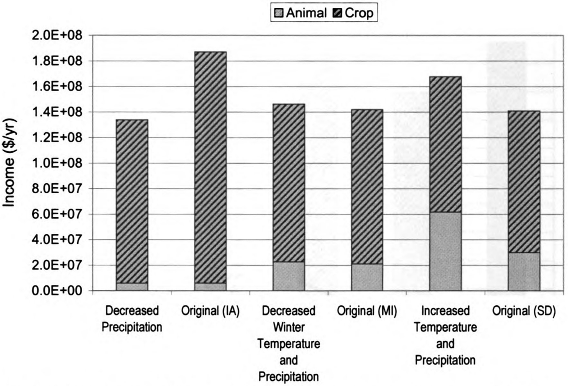

Figure 5.16: Annual income by product source for scenario tests having weather adjustments. Products are the same as those in Figure 5.4.

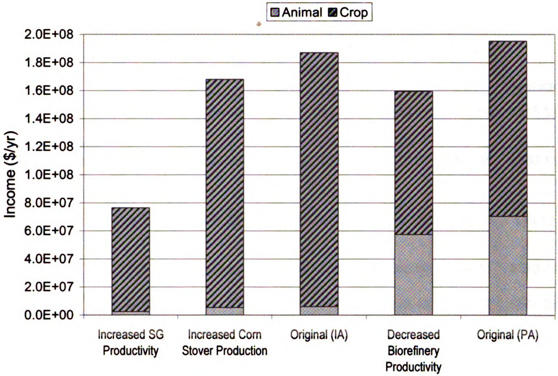

Figure 5.17: Annual income by product source for scenario tests having productivity adjustments. Products are the same as those in Figure 5.4.

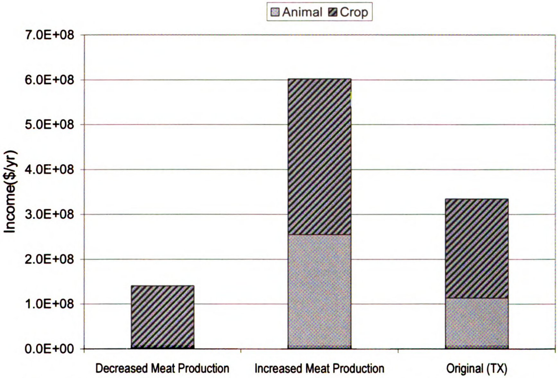

Figure 5.18: Annual income by product source for scenario tests having meat production adjustments. Products are the same as those in Figure 5.4.

Table 5.12: Net return on a per acre basis for all scenario tests. Values in grey are farm types that were calculated as not occurring in the landscape distribution.

	Management Strategy						
Scenario	**X**	**Y**	**Z**	**A**	**B**	**C**	**Average**
Decreased Precipitation	**$193.82**	**$323.69**	$396.56	**$301.99**	**$346.11**	**$280.56**	**$315.52**
Decreased Winter Temperature and Precipitation	**$100.93**	**$335.90**	$367.80	**$324.43**	**$516.61**	**$340.95**	**$380.13**
Increased Temperature and Precipitation	**-$153.58**	**-$51.32**	-$97.57	**$179.43**	**$72.13**	**$164.33**	**$70.12**
Increased SG Productivity	$386.09	$567.51	**$680.86**	**$602.77**	**$565.60**	**$534.11**	**$579.74**
Increased Corn Stover Production	**$405.47**	**$587.95**	$544.35	**$630.22**	**$339.48**	**$561.37**	**$541.25**
Decreased Biorefinery Productivity	**$34.58**	**$233.84**	$240.23	**$268.20**	**$333.73**	**$211.09**	**$262.17**
Decreased Meat Production	$155.60	$236.30	**$163.56**	**$447.49**	**$356.61**	**$249.68**	**$358.92**
Increased Meat Production	**$155.60**	**$236.30**	**$163.56**	$447.49	$356.61	**$249.68**	**$215.40**

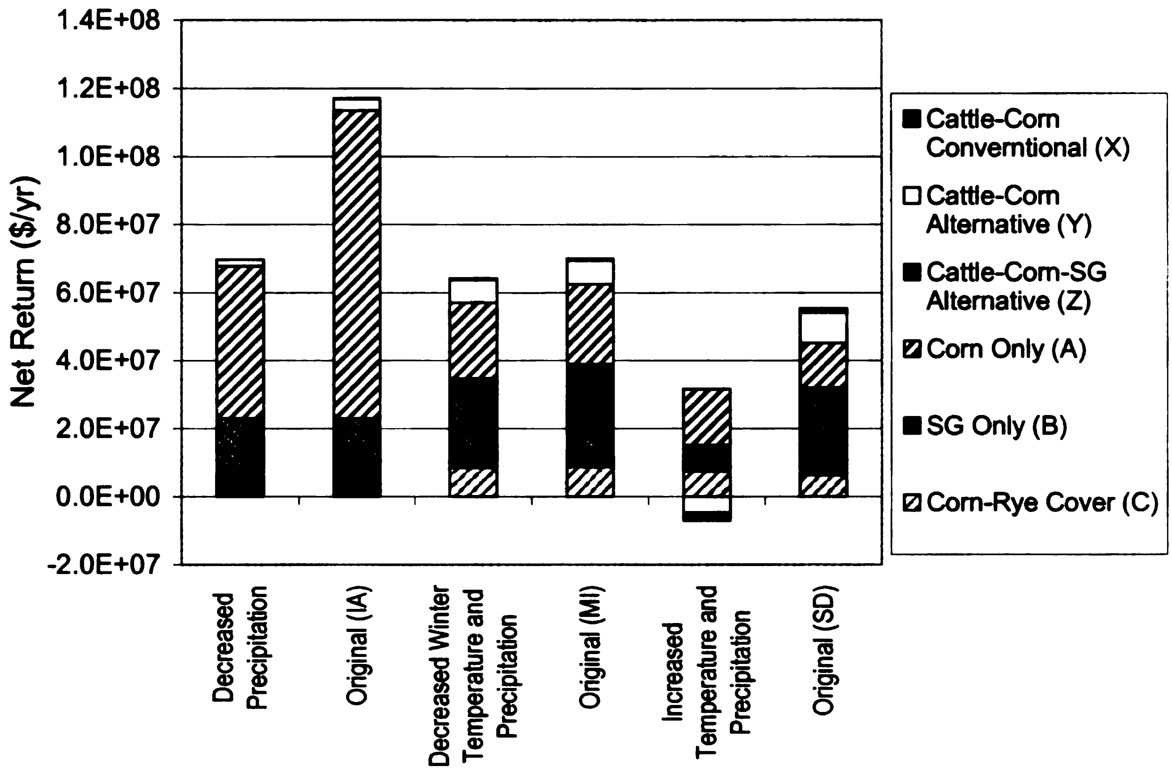

Figure 5.19: Total annual net return for scenario tests having weather adjustments.

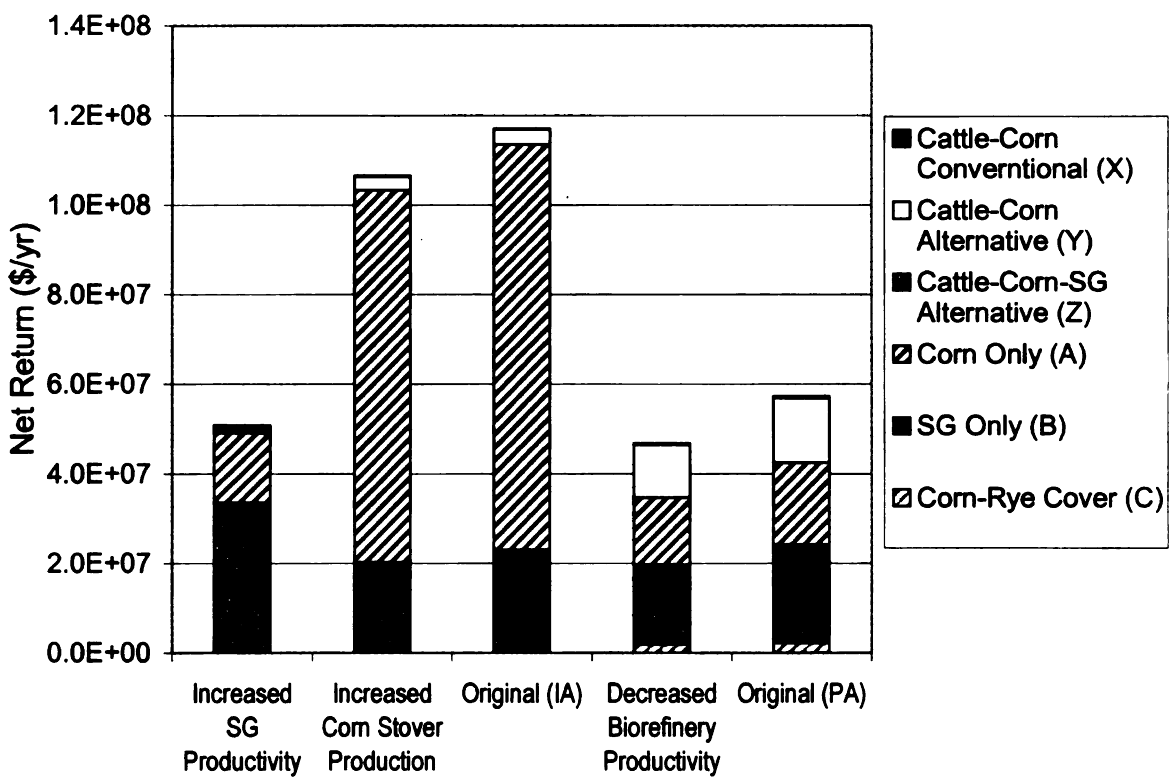

Figure 5.20: Total annual net return for scenario tests having productivity adjustments.

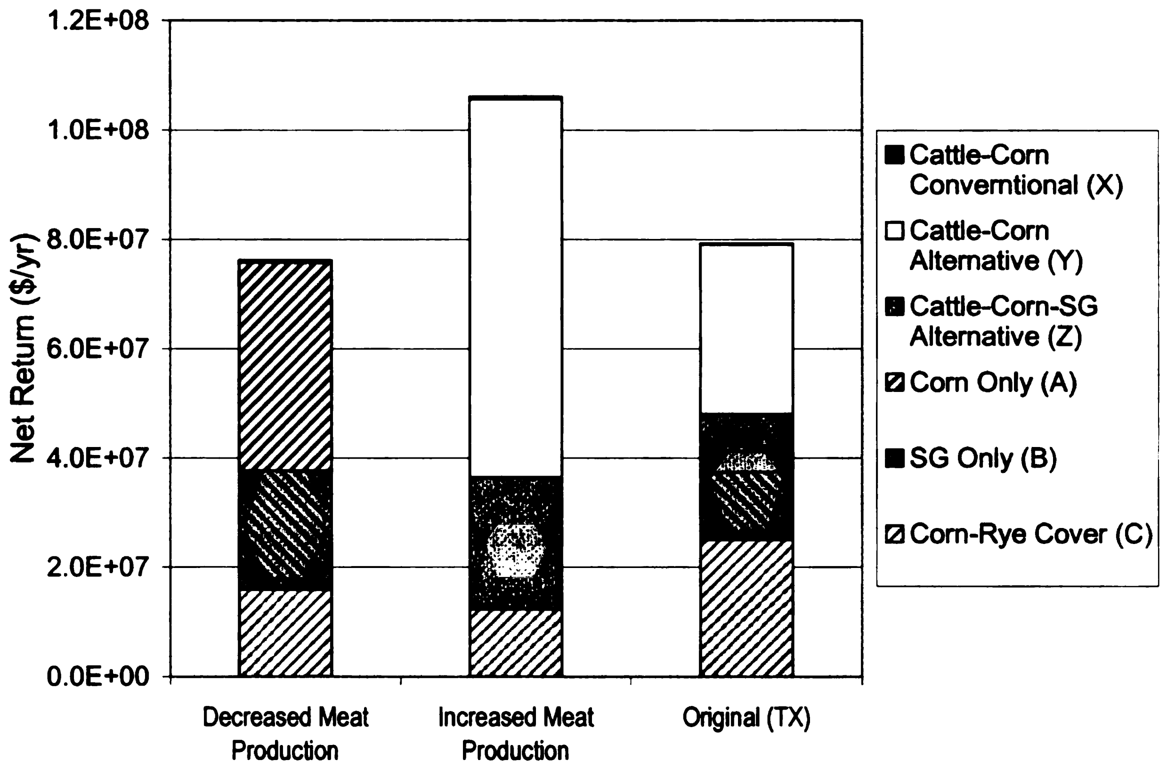

Figure 5.21: Total annual net return for scenario tests having meat production adjustments.

Income for the Decreased Precipitation scenario is reduced in Figure 5.16. This reduction is a result of compounding distribution and land requirement changes, shown in Figure 5.13, that lower overall corn acreage, thus reducing income from both corn stover and corn grain. In Figure 5.16 it is evident, again, that only minor changes occur for the winter weather scenario. Because landscape distribution is calculated by fractions of the total landscape, not biomass contributions, and all biomass yields per acre decrease in the Increased Temperature and Precipitation scenario, the acreage of all farm types increases. This increase in acreage includes those farms with animal production, thereby increasing animal income and showing very little change in crop product income in Figure 5.16.

The Switchgrass Productivity scenario income reduction seen in Figure 5.17 is due to the almost exclusive sale of switchgrass hay, nearly eliminating both corn stover and corn grain as sources of additional crop income. This same landscape size constraint yields less total income for the Increased Corn Stover Productivity scenario as well. In other words, if a biorefinery can get all the biomass they need from 200 farms, and the year before they needed 300, the 100 farms no longer needed are "left out". This does not mean that these farms cannot participate in other landscapes/markets, but the BFIT scale is a fixed biorefinery intake size, a limitation of the model. This explains the third productivity scenario in Figure 5.17, where diminished biorefinery requirements means reduced biomass demand, which ultimately leads to less income from biomass over the whole landscape.

The income by product for the Meat Production scenarios can be seen in Figure 5.18. The greater switchgrass hay contribution to the landscape biomass total and a corn acreage reduction lowers crop income for the Decreased Meat Production scenario, which lacks any significant animal income by design. This income result is in contrast to the Increased Meat Production scenario, where animal income increases by design, but, as a side effect, the greater acreage overall lends itself to greater crop sales as well.

As with the development simulations, individual farm type and landscape average net return per acre is calculated and displayed in Table 5.12. The reduction in farm return for the Decreased Precipitation scenario emphasizes the cost to maintain corn yields under dry conditions. The limited effect of winter weather changes are reflected in only minor reductions in net return for the second scenario. The greatest change from this scenario test occurs for farm type B, which highlights the effects of these weather changes on switchgrass. The effect of weather, as noted for Figures 5.13 and 5.16, is most obvious in the third weather scenario, where the year round increase in temperature and precipitation raises costs and, in some cases, reduces income per acre. Although there is an increase in overall income in Figure 5.16, the drastic increase in acreage and costs far outweighs these gains.

For the productivity scenarios in Table 5.12, greater biomass production raises returns for both the switchgrass and corn stover productivity scenarios for farms producing these biomass sources respectively. As expected given the scenario design, the returns for the Decreased Biorefinery Production scenario landscape are unchanged individually and for the landscape average, because the farms and their distribution drop proportionally with reduced need at the biorefinery. For the Meat Production scenario results in Table 5.12, the individual farm returns are maintained, while the landscape average return per acre changes with the appropriate distribution adjustments. Because crop only farms are more profitable per acre in this design, the average net return per acre is higher for the Decreased Meat Production scenario, and the opposite occurs for the Increased Meat Production Scenario.

The net return results in Table 5.12 when combined with land requirement results in Figures 5.13-15, as before, yield the total landscape net returns seen in

Figures 5.19-21. Reduced income and increased costs over a similar sized landscape reduces farm returns for the Decreased Precipitation scenario.

The minor changes seen in all variables for the Winter Weather scenario carry through to display very little change in Figure 5.19. In contrast, the severity of previous changes for the Increased Temperature and Precipitation scenario are reflected in this scenario's overall returns. This last weather scenario suggests that the landscape distribution and/or farm management should change in response to weather initiated productivity declines. It is not realistic for a farm to continue operating with negative net return. This type of scenario result gives the beginning indicators of where changes might be made when using BFIT as a decision making tool in the future.

For the two Increased Productivity scenarios in Figure 5.20, again it can be seen that the reduction in the number of participating farms reduces overall landscape size and thus overall landscape return. It is also apparent for the Increased Switchgrass Productivity scenario that a limitation in the number of products that can be sold also deceases total landscape income, but switchgrass has a higher per acre return than corn. These results show great switchgrass expansion potential for non-ideal land, such as CRP lands. This is better than replacing high yielding arable lands currently producing corn, which is a valuable livestock feedstuff. For the final scenario in Figure 5.20, reduced biorefinery productivity decreases biomass purchases, lowering the overall landscape return.

The overall landscape returns seen in Figure 5.21 reflect the income results seen in Figure 5.18 for both meat production scenarios. Costs for both these scenarios were balanced by income changes yielding the landscape net return results. These results show that a shift away from beef agriculture in Texas, a beef dominated state, does not reduce farm income much. However, the Increased Meat Production scenario shows that further expansion of the beef industry in Texas offers even greater potential revenue.

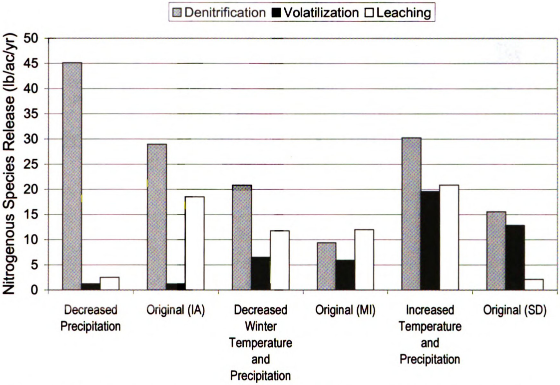

Figure 5.22: Nitrogen loss, as described for Figure 5.5, for scenario tests having weather adjustments.

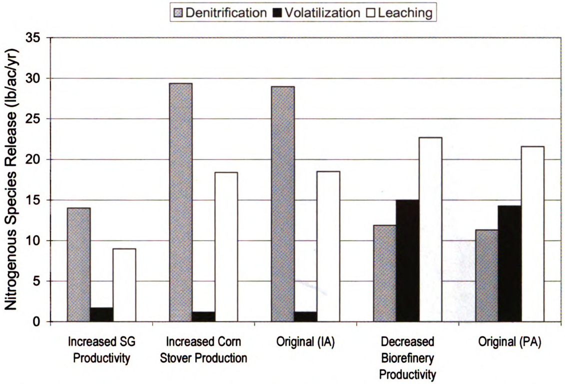

Figure 5.23: Nitrogen loss, as described for Figure 5.5, for scenario tests having productivity adjustments.

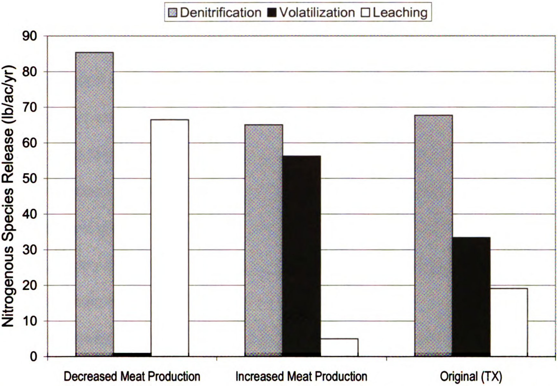

Figure 5.24: Nitrogen loss, as described for Figure 5.5, for scenario tests having meat production adjustments.

For the Decreased Precipitation scenario in Figure 5.22, leaching decreases while denitrification increases because fewer rain events are simulated with each being less intense. These conditions allow water to wet the soil but not pass through it, thereby removing less nitrate, which is the first electron acceptor for the denitrification process, and creating anoxic zones ideal for this process. The same can be said for the winter weather scenario, but the effects are not as great due to the limited time of decreased precipitation. The yield reduction for the final weather scenario in Figure 5.22 increases farming intensity, which is, in part, responsible for nitrogen loss increases seen in this figure. The remaining loss is from the combination of increased rainfall intensity, which increases leaching, and afterward prolonged soil wetting with warmer ambient temperatures, which, when combined, also increase denitrification [90]. The only volatilization change in Figure 5.22 is for the Increased Temperature and Precipitation scenario, because elevated temperatures evaporate additional ammonia from animal excretions.

For the first scenario in Figure 5.23, the switchgrass farm management severity reduction drives down nitrogen loss because of reduced fertilizer application and greater root structure uptake. For the remaining two scenarios in Figure 5.23 very little change is seen on a per acre basis because farming practices remain mostly unchanged.

The results in Figure 5.24 show an increase in intensively managed farm strategies in the Decreased Meat Production scenario that drives up both denitrification and leaching, while the opposite shift is seen for the Increased Meat Production scenario. The opposing changes seen for volatilization correspond directly to the increase or decrease in the number of animals in the scenario landscape.

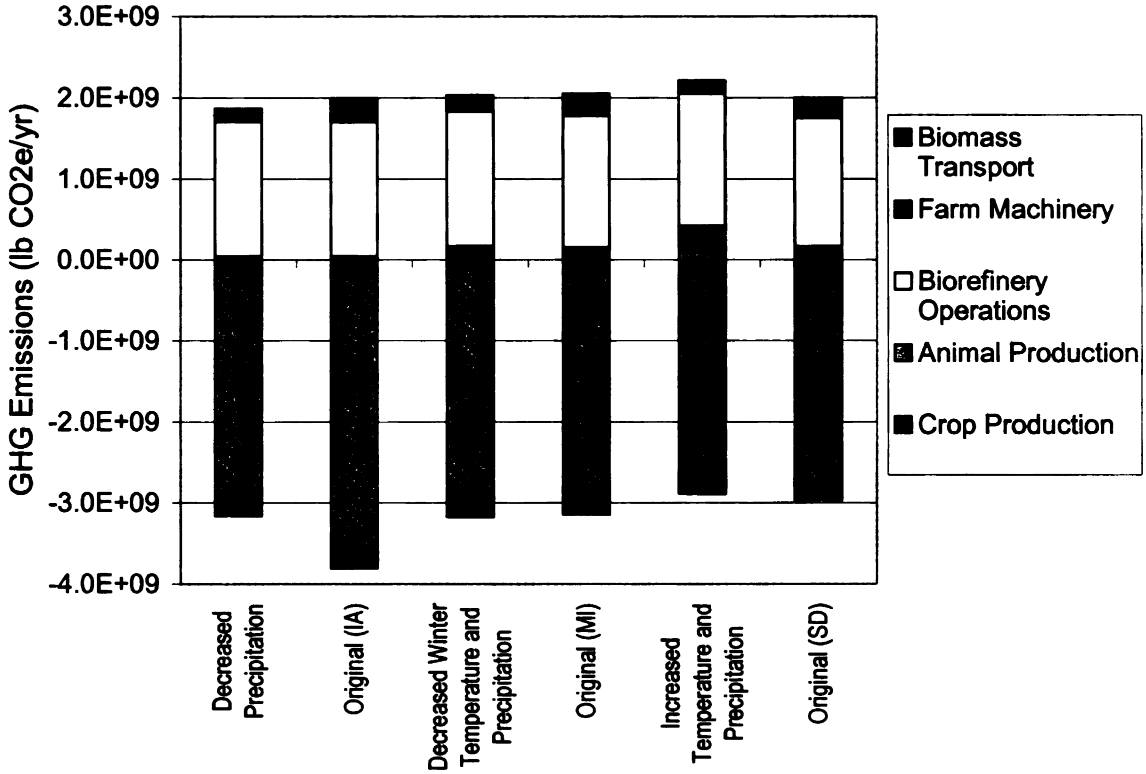

Figure 5.25: Greenhouse gas (GHG) emissions for scenario tests having weather adjustments.

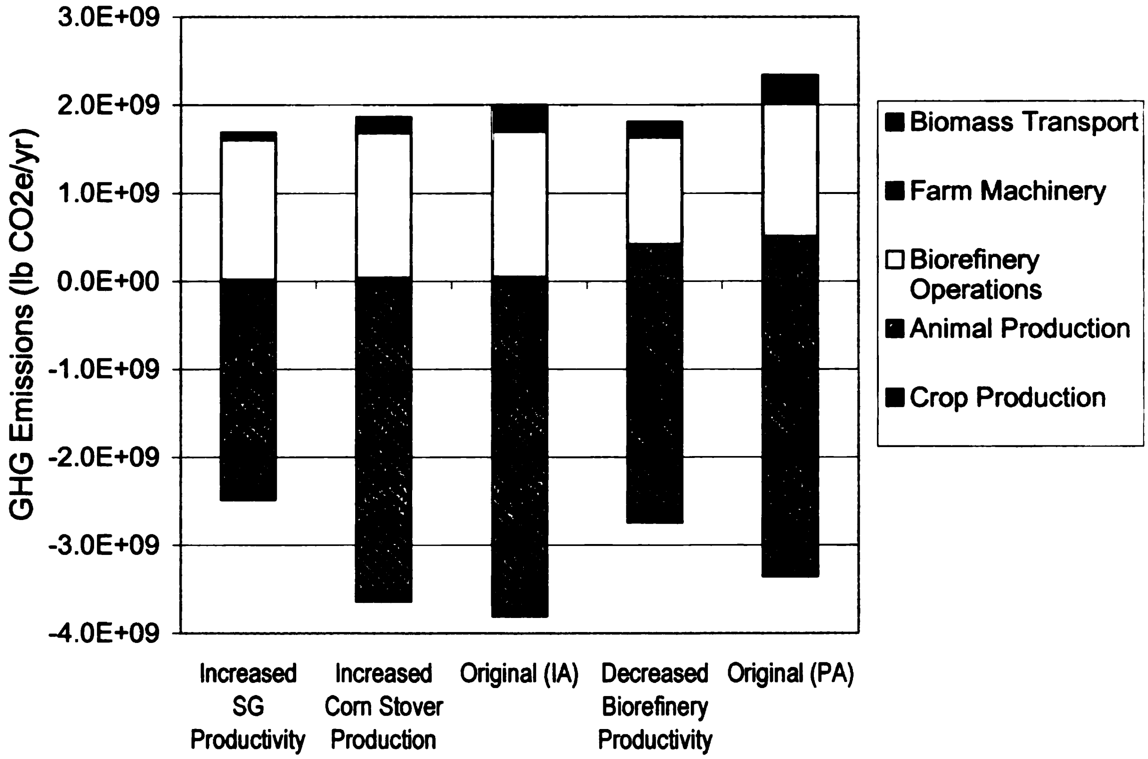

Figure 5.26: Greenhouse gas (GHG) emissions for scenario tests having productivity adjustments.

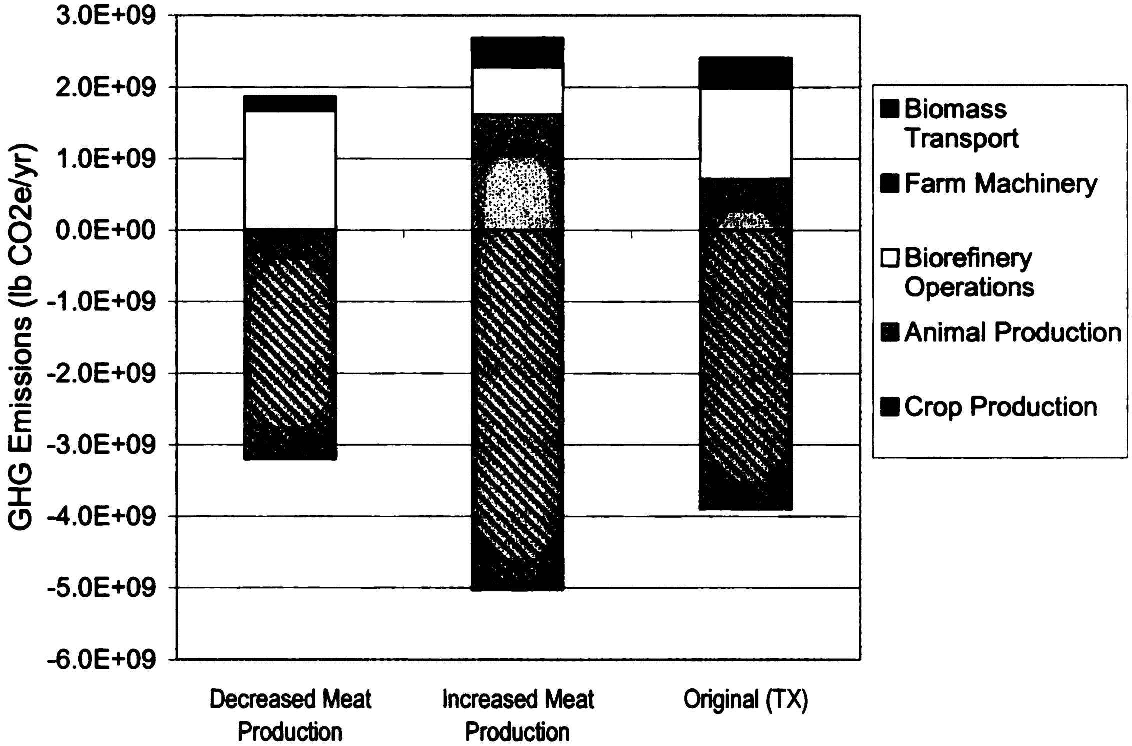

Figure 5.27: Greenhouse gas (GHG) emissions for scenario tests having meat production adjustments.

The GHG emissions results for the Decreased Precipitation scenario in Figure 5.25 show a small transportation emission decrease, which is a direct result of decreased area. This area decrease combined with lowered corn productivity reduces total carbon sequestration such that emissions reductions are insignificant relative to the additional carbon that remains unfixed. As with the other results for the winter weather scenario, very little change is seen in Figure 5.25 for this scenario as well. For the Increased Temperature and Precipitation scenario, just as with volatilization, animal emissions of GHG's increase from warming. This negative impact is coupled with a decrease in carbon sequestration that occurs from the decrease in switchgrass yield, which includes reduced root biomass that helps maintain soil carbon and nitrogen.

The reduction in area requirement for the Switchgrass Productivity scenario causes the reduced transportation emissions seen in Figure 5.26, but also leads to less carbon sequestration as well. Once again, it is important to note that the monoculture farming limits the system boundary to the small area required for biomass growth, which is the functional unit of the model. This same landscape area influence affects the other two production scenarios at varying degrees of severity, reducing sequestration with shrinking area.

In Figure 5.27 land requirement again affects transport emissions and sequestration, and landscape distribution changes cause shifts in emissions sources. The increase or decrease in animal agriculture is reflected in the "animal production" emissions results, indicating once again that the production of animals involves certain trade-offs for economic benefits and environmental impacts.

It is important to note, in many of these scenario tests, GHG emissions reductions are often offset by diminished carbon sequestration, and vice versa. This suggests that one very important use for this tool is quantification, pound for pound, of the trade-offs associated with potential environmentally or economically beneficial landscapes/farm management arrangement.

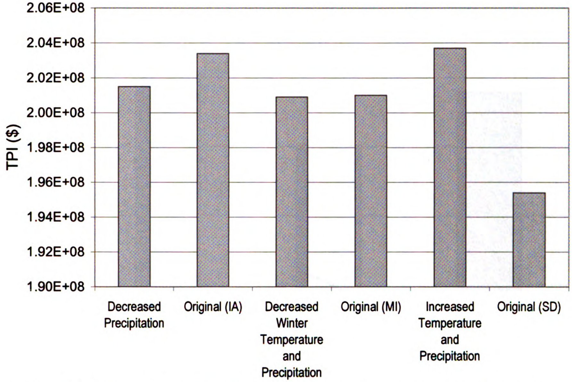

Figure 5.28: Total project investment (TPI) for scenario tests having weather adjustments.

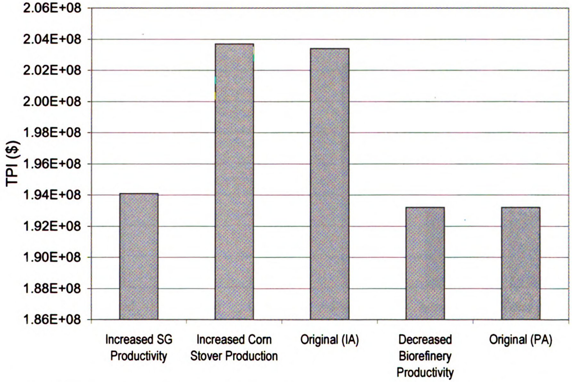

Figure 5.29: Total project investment (TPI) for scenario tests having productivity adjustments.

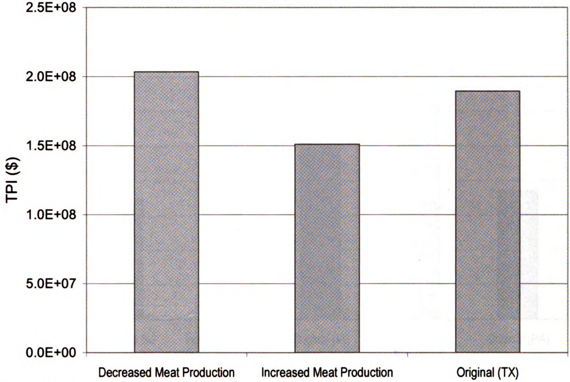

Figure 5.30: Total project investment (TPI) for scenario tests having meat production adjustments.

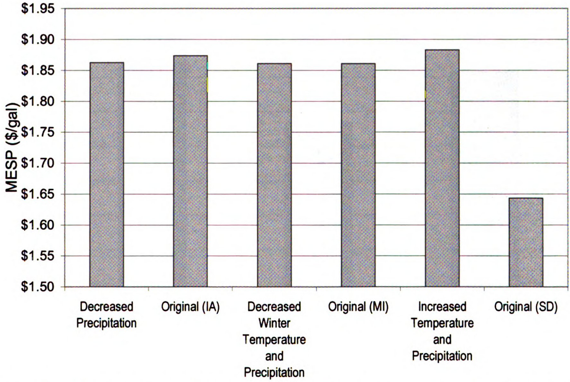

Figure 5.31: Minimum ethanol selling price (MESP) for scenario tests having weather adjustments.

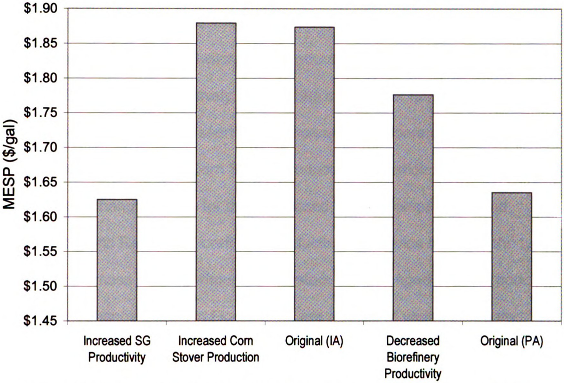

Figure 5.32: Minimum ethanol selling price (MESP) for scenario tests having productivity adjustments.

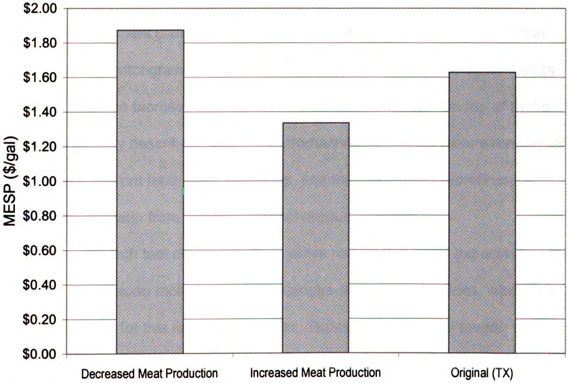

Figure 5.33: Minimum ethanol selling price (MESP) for scenario tests having meat production adjustments.

The increased biomass switchgrass composition for the Decreased Precipitation and Increased Switchgrass Productivity scenarios reduces TPI in Figure 5.28 and 5.29, respectively, by lowering corn stover handling equipment costs. The opposite effect is seen for the Increased Temperature and Precipitation and Increased Corn Stover Production scenarios in these same figures. Little change is seen for the Decreased Winter Temperature and Precipitation, and Reduced Biorefinery Productivity scenarios because the type and rate of biomass passing through the system is unchanged. Meat Production scenario TPI changes, seen in Figure 5.30, are a result of varied pretreated grass feed sales, as expected from previous results.

The limited MESP change for the Decreased Precipitation scenario in Figure 5.31 occurs because TPI is the only biorefinery parameter that changed from the development scenario. The Increased Temperature and Precipitation, and Increased Switchgrass Productivity scenarios experience additional effects on MESP because biomass transportation costs also change. On top of these influences already described, both meat productivity scenarios have even further MESP changes from feed sales variations, and the Decreased Biorefinery Productivity scenario from reduced ethanol product revenue.

The research tool developed here yields results that meet expectations for scenarios that include multiple variable changes and extreme values, which is a positive outcome for this model verification. Some scenario tests reveal limitations of the model and the necessity of the user to carefully select inputs and review outputs for irregularities. An example of such irregularities would be farm management strategies that have negative returns, as was the case for the Increased Temperature and Precipitation scenario.

These scenario tests not only verify the function of BFIT, but also verify its value as a tool for inexperienced, expert users in the future. These tests also verify that the trained users' guide offered to aid in the simulation of the scenario tests was helpful and has value for future use. This BFIT trained users' guide is presented in Appendix D.

Although the outcomes here indicate some important trends and patterns for the biorefinery, the scenarios tested here should not be used for projection of realistic scenarios and/or decision making. Elaboration on the work presented here will require careful economic consideration. Future input selection should include updated or projected future values to provide meaningful projections for decision making.

5.4 Conclusion

The simulations here are the first biorefinery simulations to directly include a realistic landscape and cover a variety of US locations. Research tool development aimed to allow side-by-side comparison of similar biorefineries, over different regional landscapes following real-world statistical distributions. The assumptions, inputs, and biorefinery technologies used in this model development are all subject to the same temporal limitations and follow recent to near-term expectations for the included elements.

When designing future biorefinery projects, choice of location will be important. The results of the development simulations presented here suggest the Midwest, also referred to as the Corn Belt, is ideal for the cellulosic ethanol industry. Higher simulated investment results in the Midwest indicate that biorefinery construction may be more difficult to fund, but economies of scale may put these same locations in a strategic position in a more developed market. Ultimately, for a combination of agricultural and industrial interests, while also reducing environmental impact, the preliminary results presented here point to the Midwest, which is already a center for bioethanol production [6]. These results also point to locations where farm management adjustments would provide greater farm return and potential emissions reduction, particularly when compared to "conventional" farming distributions.

The model sensitivity analyses presented here showed that BFIT outputs change in various ways for the input variables tested. This test revealed four parameters which, when adjusted, show greater impact on the whole system, including both the biorefinery and associated landscape, and in some cases non-linear effects on outcomes. These important inputs are biorefinery size, switchgrass yield, biomass selling price, and biomass storage losses. This result highlights the need for careful assumption selection, as well as a need for further research on specific biorefinery system elements. Many of these areas already receive attention because the lack of realistic expectations and data for actual systems has been identified.

The scenario-based verification test presented here confirms the flexibility of BFIT and also underscores the potential for future scenario work with this tool. Using properly developed conditions, this modeling tool could allow comparison of a variety of circumstances with changes to the biorefinery and its surrounding landscape. The verification process also draws attention to some shortcomings of this new research tool, which are addressed in Section 6.2.

Using tools like the one developed here, biorefinery project designs can be tested for trade-offs and define scenarios for industrial projects where there are winners on all sides. The interests of investors, farmers, government, and our greater society can all be balanced if proper care is taken to address concerns for each, which can be evaluated using systems such as BFIT.

CHAPTER 6: CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

6.1 Conclusions

The biorefinery system, which includes the landscape that provides biomass feedstock and uses pretreated grass feeds, has the potential to provide cellulosic ethanol as a liquid transportation fuel to our national energy portfolio. The research presented here realizes the desire to use modeling tools to help project the potential economic and environmental impacts of producing this alternative fuel.

The first research stages, presented in Chapters 3 and 4, prepared existing biorefinery and agricultural models for integration. The NREL chemical engineering and economic model of the biorefinery, updated at Dartmouth College and Michigan State University, simulates the industrial portion of this work. This model, written in ASPEN PLUS and Microsoft Excel, was adjusted to simulate a 2000 TPD biorefinery with AFEX pretreatment and SSCF biological processing for the BFIT sub-model. Results presented in Chapter 3 verify that this modified NREL model version still produced the same outcomes as previous studies.

The whole farm agricultural model IFSM, developed at the USDA, is shown in Chapter 4 to be the best choice for farm simulations, which are aggregated for the biorefinery landscape. This FORTRAN model, which has its own user-interface, is used here to simulate six farm management strategies that would customarily produce the two most common biomass feedstocks, corn stover and switchgrass. This model also includes animal operations, which were limited to cattle, deemed acceptable because they are the dominant US livestock.

The combination of the two sub-models described above into a new research tool, called BFIT, is presented in Chapter 5. This tool allows expert users to project baseline expectations for the fully integrated biorefinery with a realistic landscape across various US regions for the first time. The BFIT development simulations, sensitivity analysis, and scenario-based verification are all presented in Section 5.3. These projection results show the model to be functional and working properly, which meets the primary goal of basic model development.

The development simulation results in Section 5.3.1 illustrate the strong potential for the cellulosic ethanol industry in the Midwest region of the US. Sensitivity results in Section 5.3.2 indicate that great care should be used for selection of biorefinery size, switchgrass yield, and economic assumptions in future BFIT simulations.

Verification of this tool in Section 5.3.3 demonstrates the future value of BFIT as a research tool for others. Verification also highlighted the ability of a trained user to operate the model and confirms the usefulness of the current trained users' guide. These scenario-based tests emphasize areas where improvements can be made and open the door for future scenario simulations using this model. The current inability to validate this model urges further research to update and upgrade this tool and its components.

Analysis of simulation trends and suggestions for future research are presented throughout Chapter 5. The research and outcomes in Chapter 5 directly address the application portion of the primary goal stated in Chapter 1, to "identify trends and build a foundation for future decision-making research".

The only objective of this work not accomplished was automation of the model. After deeper investigation of the two pre-existing sub-models, it was found that this goal was more difficult than expected and would require an expert programmer for this task. The development of user-friendly interfaces that reduce user input will be more fully developed and useful if designed by a specialist in this area.

The objectives and outcomes achieved here are not just important to engineers or scientists, but also investors, farmers, politicians, and indeed all of society, because the search for environmental, economic, and socially beneficial transportation fuels affects all inhabitants of the world.

6.2 Suggestions for Future Research

Advances in modeling techniques, process technology, and farm management practices are constantly occurring, and this model will continue to improve as it is updated to reflect these changes. Future steps for the enhancement of this tool are described in this section.

First, validation of the model for commercial scale biorefineries and full biomass supply chains is needed. There are currently several commercial biorefinery scale-up projects taking place, which will allow full validation of this system as real-world data for a full-scale biorefinery will be available for the first time [91]. As this data becomes available, some model parts will need updating for improved understanding of underlying processes, at which time validation can commence. In addition to industrial process advances, a biomass market supply chain will develop for the first time. The observations for this supply chain can also be incorporated into the model and validated, yielding an even fuller view of the near-term biorefinery, its agricultural landscape, and the biomass delivery system.

As an elaboration on the validation of the model and the sensitivity analysis, a deeper study of biorefinery size and its influence on the overall system should be performed. Future BFIT studies on biorefinery size and annual operation should included comparisons with previous work on economies of scale.

Second, further system automation and development of a user interface, as suggested by the objectives, are important. One current limitation of BFIT is the number of user mediated steps, or lack of automation. It will also be valuable to upgrade the BFIT user interface, reduce user steps, and improve model speed with sub-model program-version updates (Excel, ASPEN, etc.).

Along with the aforementioned improvements, it will be necessary to broaden the scope and overcome many of the limitations described in Section 1.2. This will require new biorefinery simulations with a variety of biorefinery sizes and locations. Other simulation changes should incorporate new landscape designs with different farm management strategies, which could allow additional biomass sources.

Future work should also feature commonly accepted LCA methodologies, specifically emissions allocations to the various product outputs. Also, animal excretion collection for biogas production might be added to the model, because it is a growing “environmental farm practice”. This process would integrate well with the environmental goals of many who are interested in “green engineering” [92,93,94,95].

Finally, the adjustment of the temporal setting for the model will require regular updates to current prices. Simulations showing the effect of updating model development assumptions to more recent values will be particularly relevant given recent drastic changes in many costs, particularly petroleum products. It is important, however, that any economic assumption change should be followed by either update of all other economic assumptions, maintaining internal consistency, or fully transparent reporting of which changes were made independently.

In combination, all the changes described above will enhance BFIT biorefinery simulations and yield results that can bring to light prospective winners and losers in the alternative fuels outlook.

APPENDICES

APPENDIX A

Table A.1: Biorefinery economic summary output for SSCF-COMP-OLD.

Minimum Ethanol Selling Price	$1.4176
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	69.7
Ethanol Yield (Gal / Dry US Ton Feedstock)	90.3
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$4,500,000	4.3%	Feedstock	44.3
Pretreatment	$21,600,000	20.7%	Other Raw Materials	15.3
Biological conversion	$4,700,000	4.5%	Waste Disposal	1.1
Distillation and Solids Recovery	$15,400,000	14.7%	Electricity	-8.6
Wastewater Treatment	$13,600,000	13.0%	Fixed Costs	15.0
Storage	$1,400,000	1.3%	Capital Depreciation	12.9
Residue Processing	$38,400,000	36.7%	Average Income Tax	1.9
Utilities	$4,900,000	4.7%	Average Return on Investment	59.9
Total Installed Equipment Cost	$104,500,000			
			Operating Costs ($/yr)	
Added Costs	$74,800,000		Feedstock	$30,900,000
(% of TPI)	42%		Other Raw Matl. Costs	$10,600,000
			Waste Disposal	$800,000
Total Project Investment	$179,300,000		Electricity	-$6,000,000
			Fixed Costs	$10,400,000
Loan Rate	7.5%		Capital Depreciation	$9,000,000
Term (years)	25		Average Income Tax	$1,300,000
Capital Charge Factor	0.2906		Average Return on Investment	$41,800,000

Table A.2: Biorefinery economic summary output for SSCF-COMP-UPD.

Minimum Ethanol Selling Price	$1.3676
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	69.7
Ethanol Yield (Gal / Dry US Ton Feedstock)	90.3
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		% of total
Feed Handling	$4,500,000	4.5%
Pretreatment	$18,600,000	18.7%
Biological conversion	$3,700,000	3.7%
Distillation and Solids Recovery	$15,100,000	15.2%
Wastewater Treatment	$13,500,000	13.6%
Storage	$1,300,000	1.3%
Residue Processing	$38,400,000	38.7%
Utilities	$4,200,000	4.2%
Total Installed Equipment Cost	$99,300,000	
Added Costs	$70,900,000	
(% of TPI)	42%	
Total Project Investment	$170,200,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.2979	

Operating Costs (cents/gal ethanol)	
Feedstock	44.3
Other Raw Materials	15.1
Waste Disposal	1.1
Electricity	-11.4
Fixed Costs	15.0
Capital Depreciation	12.2
Average Income Tax	1.8
Average Return on Investment	58.7

Operating Costs ($/yr)	
Feedstock	$30,900,000
Other Raw Matl. Costs	$10,500,000
Waste Disposal	$800,000
Electricity	-$8,000,000
Fixed Costs	$10,400,000
Capital Depreciation	$8,500,000
Average Income Tax	$1,300,000
Average Return on Investment	$40,900,000

Table A.3: Biorefinery economic summary output for SSCF-NEW-OLD.

Minimum Ethanol Selling Price	$1.0682
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	69.6
Ethanol Yield (Gal / Dry US Ton Feedstock)	90.3
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		%of total
Feed Handling	$7,100,000	6.7%
Pretreatment	$12,800,000	12.2%
Biological conversion	$5,100,000	4.8%
Distillation and Solids Recovery	$15,500,000	14.7%
Wastewater Treatment	$19,300,000	18.3%
Storage	$1,300,000	1.2%
Residue Processing	$39,200,000	37.2%
Utilities	$5,000,000	4.7%
Total Installed Equipment Cost	$105,300,000	
Added Costs	$74,600,000	
(% of TPI)	41%	
Total Project Investment	$179,900,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.1656	

Operating Costs (cents/gal ethanol)	
Feedstock	44.3
Other Raw Materials	20.7
Waste Disposal	1.1
Electricity	-13.5
Fixed Costs	11.4
Capital Depreciation	12.9
Average Income Tax	1.9
Average Return on Investment	28.0

Operating Costs ($/yr)	
Feedstock	$30,800,000
Other Raw Matl. Costs	$14,400,000
Waste Disposal	$800,000
Electricity	-$9,400,000
Fixed Costs	$7,900,000
Capital Depreciation	$9,000,000
Average Income Tax	$1,300,000
Average Return on Investment	$19,500,000

Table A.4: Biorefinery economic summary output for SSCF-NEW-UPD.

Minimum Ethanol Selling Price	$1.0314
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	69.6
Ethanol Yield (Gal / Dry US Ton Feedstock)	90.3
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		%of total
Feed Handling	$7,100,000	7.2%
Pretreatment	$10,300,000	10.4%
Biological conversion	$2,600,000	2.6%
Distillation and Solids Recovery	$15,100,000	15.2%
Wastewater Treatment	$19,300,000	19.5%
Storage	$1,300,000	1.3%
Residue Processing	$39,200,000	39.6%
Utilities	$4,200,000	4.2%
Total Installed Equipment Cost	$99,100,000	
Added Costs	$70,000,000	
(% of TPI)	41%	
Total Project Investment	$169,100,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.1662	

Operating Costs (cents/gal ethanol)	
Feedstock	44.3
Other Raw Materials	20.7
Waste Disposal	1.1
Electricity	-14.4
Fixed Costs	11.0
Capital Depreciation	12.2
Average Income Tax	1.8
Average Return on Investment	26.4

Operating Costs ($/yr)	
Feedstock	$30,800,000
Other Raw Matl. Costs	$14,400,000
Waste Disposal	$800,000
Electricity	-$10,000,000
Fixed Costs	$7,700,000
Capital Depreciation	$8,500,000
Average Income Tax	$1,300,000
Average Return on Investment	$18,300,000

Table A.5: Biorefinery economic summary output for CBP-COMP-OLD.

Minimum Ethanol Selling Price	$0.9307
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	78.1
Ethanol Yield (Gal / Dry US Ton Feedstock)	101.2
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		%of total
Feed Handling	$4,500,000	4.3%
Pretreatment	$21,600,000	20.7%
Biological conversion	$4,300,000	4.1%
Distillation and Solids Recovery	$15,500,000	14.8%
Wastewater Treatment	$13,800,000	13.2%
Storage	$1,400,000	1.3%
Residue Processing	$38,400,000	36.8%
Utilities	$4,900,000	4.7%
Total Installed Equipment Cost	$104,400,000	
Added Costs	$74,900,000	
(% of TPI)	42%	
Total Project Investment	$179,300,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.1651	

Operating Costs (cents/gal ethanol)	
Feedstock	39.5
Other Raw Materials	9.0
Waste Disposal	1.0
Electricity	-7.8
Fixed Costs	13.4
Capital Depreciation	11.5
Average Income Tax	1.7
Average Return on Investment	24.8

Operating Costs ($/yr)	
Feedstock	$30,900,000
Other Raw Matl. Costs	$7,100,000
Waste Disposal	$800,000
Electricity	-$6,100,000
Fixed Costs	$10,400,000
Capital Depreciation	$9,000,000
Average Income Tax	$1,300,000
Average Return on Investment	$19,300,000

Table A.6: Biorefinery economic summary output for CBP-COMP-UPD.

Minimum Ethanol Selling Price	$0.8773
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	78.1
Ethanol Yield (Gal / Dry US Ton Feedstock)	101.2
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		%of total
Feed Handling	$4,500,000	4.5%
Pretreatment	$18,600,000	18.5%
Biological conversion	$4,300,000	4.3%
Distillation and Solids Recovery	$15,200,000	15.1%
Wastewater Treatment	$13,700,000	13.6%
Storage	$1,400,000	1.4%
Residue Processing	$38,400,000	38.2%
Utilities	$4,300,000	4.3%
Total Installed Equipment Cost	$100,400,000	
Added Costs	$71,700,000	
(% of TPI)	42%	
Total Project Investment	$172,100,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.1656	

Operating Costs (cents/gal ethanol)	
Feedstock	39.5
Other Raw Materials	7.4
Waste Disposal	1.0
Electricity	-10.0
Fixed Costs	13.4
Capital Depreciation	11.0
Average Income Tax	1.6
Average Return on Investment	23.9

Operating Costs ($/yr)	
Feedstock	$30,900,000
Other Raw Matl. Costs	$5,800,000
Waste Disposal	$800,000
Electricity	-$7,800,000
Fixed Costs	$10,400,000
Capital Depreciation	$8,600,000
Average Income Tax	$1,300,000
Average Return on Investment	$18,600,000

Table A.7: Biorefinery economic summary output for CBP-NEW-OLD.

Minimum Ethanol Selling Price	$0.8314
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	78.0
Ethanol Yield (Gal / Dry US Ton Feedstock)	101.2
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$4,500,000	4.6%	Feedstock	39.5
Pretreatment	$12,800,000	13.2%	Other Raw Materials	5.8
Biological conversion	$800,000	0.8%	Waste Disposal	1.0
Distillation and Solids Recovery	$15,300,000	15.7%	Electricity	-11.8
Wastewater Treatment	$18,100,000	18.6%	Fixed Costs	13.4
Storage	$1,400,000	1.4%	Capital Depreciation	10.6
Residue Processing	$39,300,000	40.4%	Average Income Tax	1.6
Utilities	$5,100,000	5.2%	Average Return on Investment	23.0
Total Installed Equipment Cost	$97,300,000			
			Operating Costs ($/yr)	
Added Costs	$68,300,000		Feedstock	$30,800,000
(% of TPI)	41%		Other Raw Matl. Costs	$4,500,000
			Waste Disposal	$800,000
Total Project Investment	$165,600,000		Electricity	-$9,200,000
			Fixed Costs	$10,400,000
Loan Rate	7.5%		Capital Depreciation	$8,300,000
Term (years)	25		Average Income Tax	$1,200,000
Capital Charge Factor	0.1661		Average Return on Investment	$18,000,000

Table A.8: Biorefinery economic summary output for CBP-NEW-UPD.

Minimum Ethanol Selling Price	$0.8055
Feedstock Rate (dry ton/day)	2,205
Ethanol Production (MM Gal. / Year)	77.9
Ethanol Yield (Gal / Dry US Ton Feedstock)	101.2
Feedstock Cost $/Dry US Ton	$40
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$4,500,000	4.9%	Feedstock	39.5
Pretreatment	$9,400,000	10.1%	Other Raw Materials	5.8
Biological conversion	$800,000	0.9%	Waste Disposal	1.0
Distillation and Solids Recovery	$15,300,000	16.5%	Electricity	-12.8
Wastewater Treatment	$18,100,000	19.5%	Fixed Costs	13.4
Storage	$1,400,000	1.5%	Capital Depreciation	10.1
Residue Processing	$39,300,000	42.4%	Average Income Tax	1.5
Utilities	$3,900,000	4.2%	Average Return on Investment	22.0
Total Installed Equipment Cost	$92,700,000			
			Operating Costs ($/yr)	
Added Costs	$64,800,000		Feedstock	$30,800,000
(% of TPI)	41%		Other Raw Matl. Costs	$4,500,000
			Waste Disposal	$800,000
Total Project Investment	$157,500,000		Electricity	-$10,000,000
			Fixed Costs	$10,400,000
Loan Rate	7.5%		Capital Depreciation	$7,900,000
Term (years)	25		Average Income Tax	$1,200,000
Capital Charge Factor	0.1663		Average Return on Investment	$17,100,000

APPENDIX B

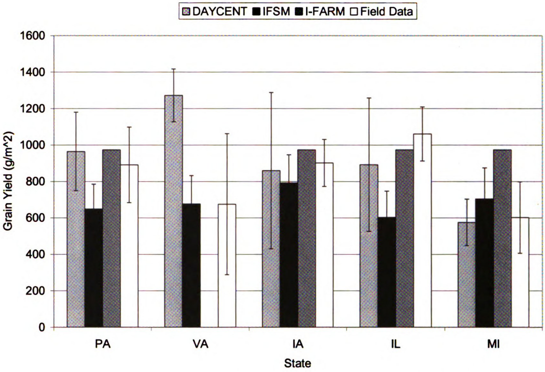

Figure B.1: Corn grain yield data and available published data for each state included in this comparison.

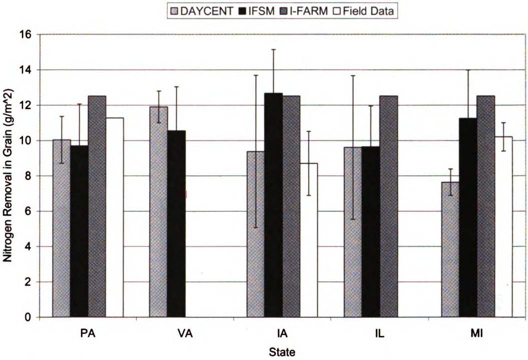

Figure B.2: Corn grain nitrogen removal data and available published data for each of the five states included in this comparison.

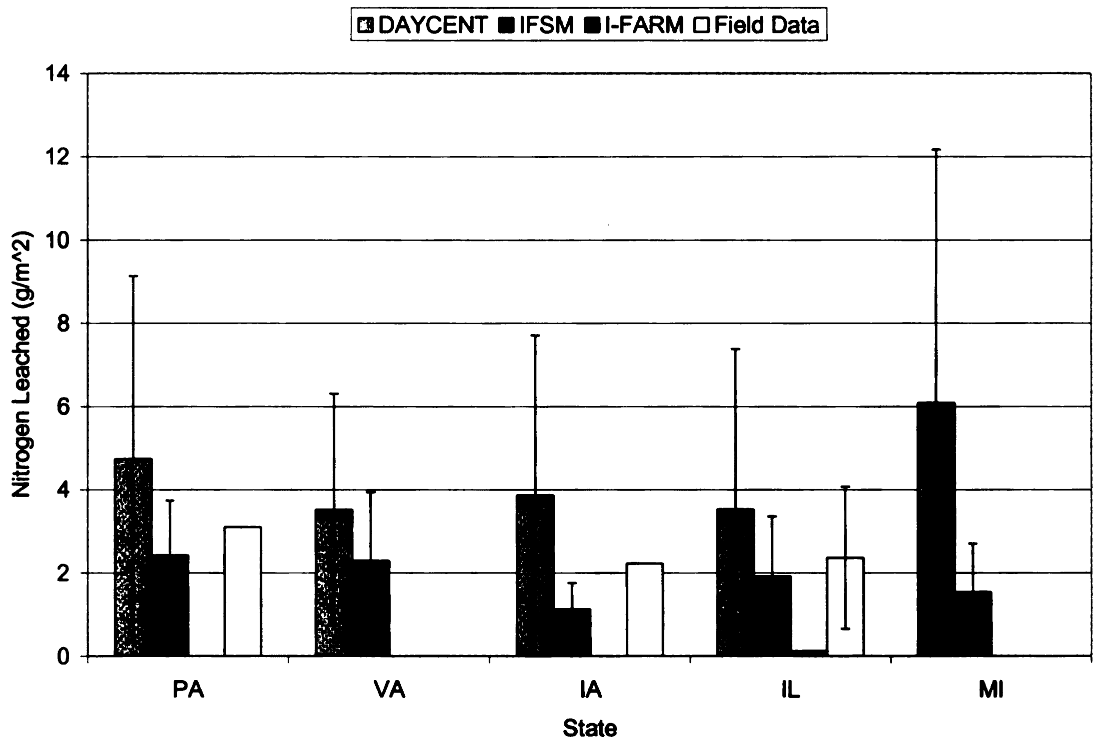

Figure B.3: Corn grain nitrogen leaching data and available published data for each of the five states included in this comparison.

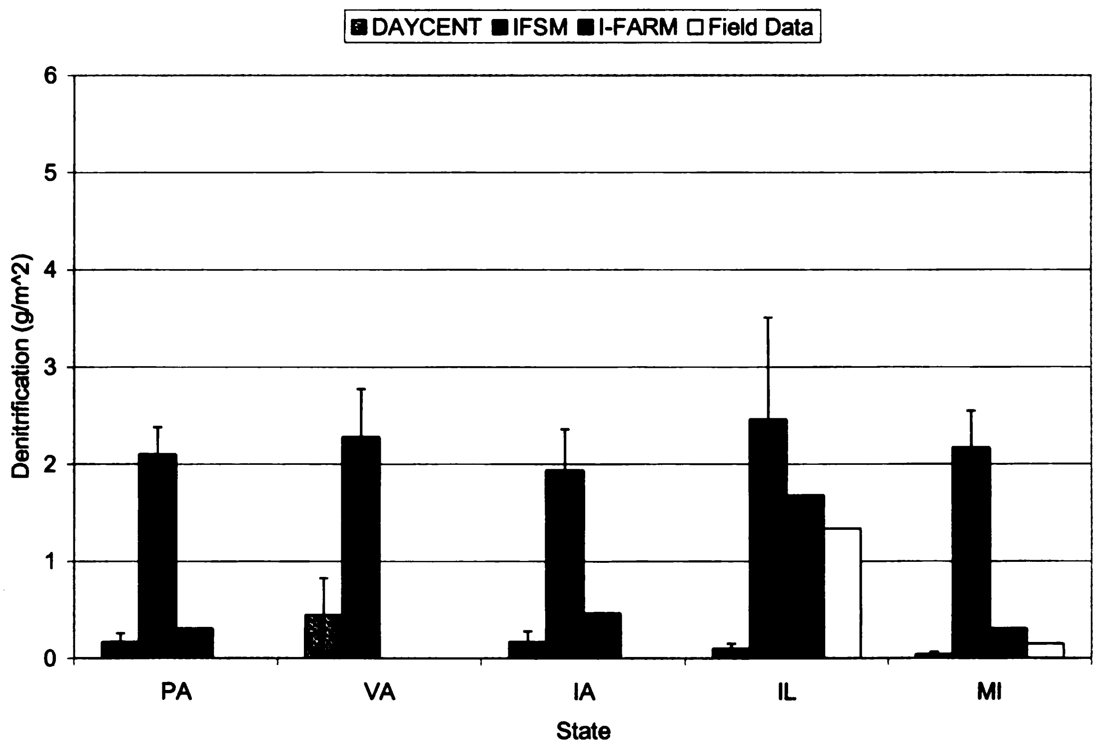

Figure B.4: Corn grain denitrification data and available published data for each if the five states included in this comparison.

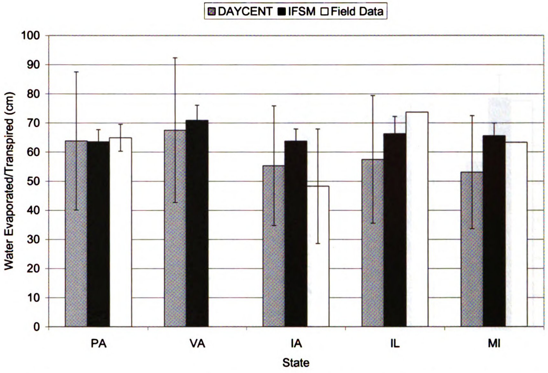

Figure B.5: Corn grain evapotranspiration data and available published data for each of the five states included in this comparison.

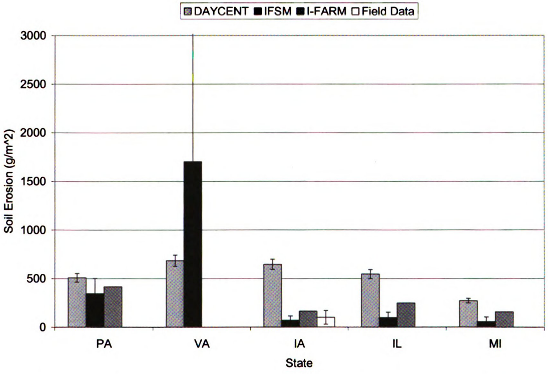

Figure B.6: Corn grain soil erosion data and available published data for each of the five states included in this comparison.

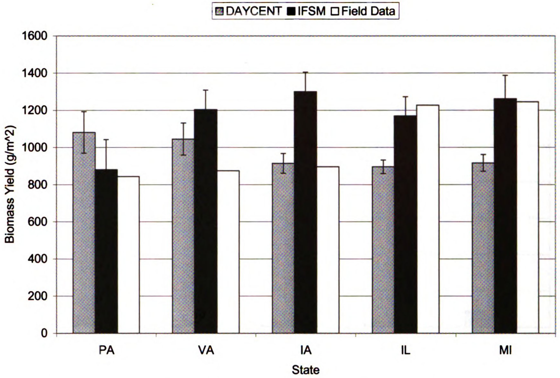

Figure B.7: Switchgrass yield data and available published data for each of the five states included in this comparison.

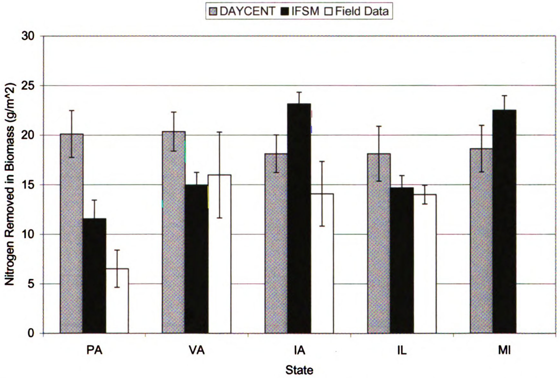

Figure B.8: Switchgrass nitrogen removal data and available published data for each of the five states included in this comparison.

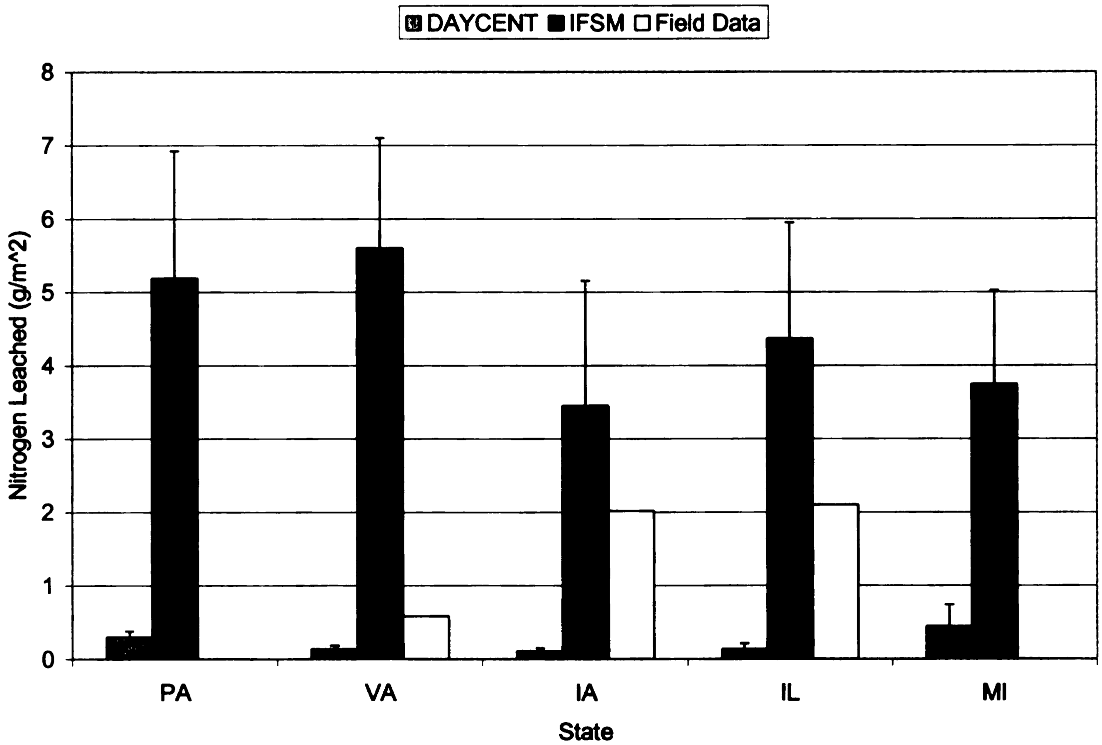

Figure B.9: Switchgrass nitrogen leaching data and available published data for each of the five states included in this comparison.

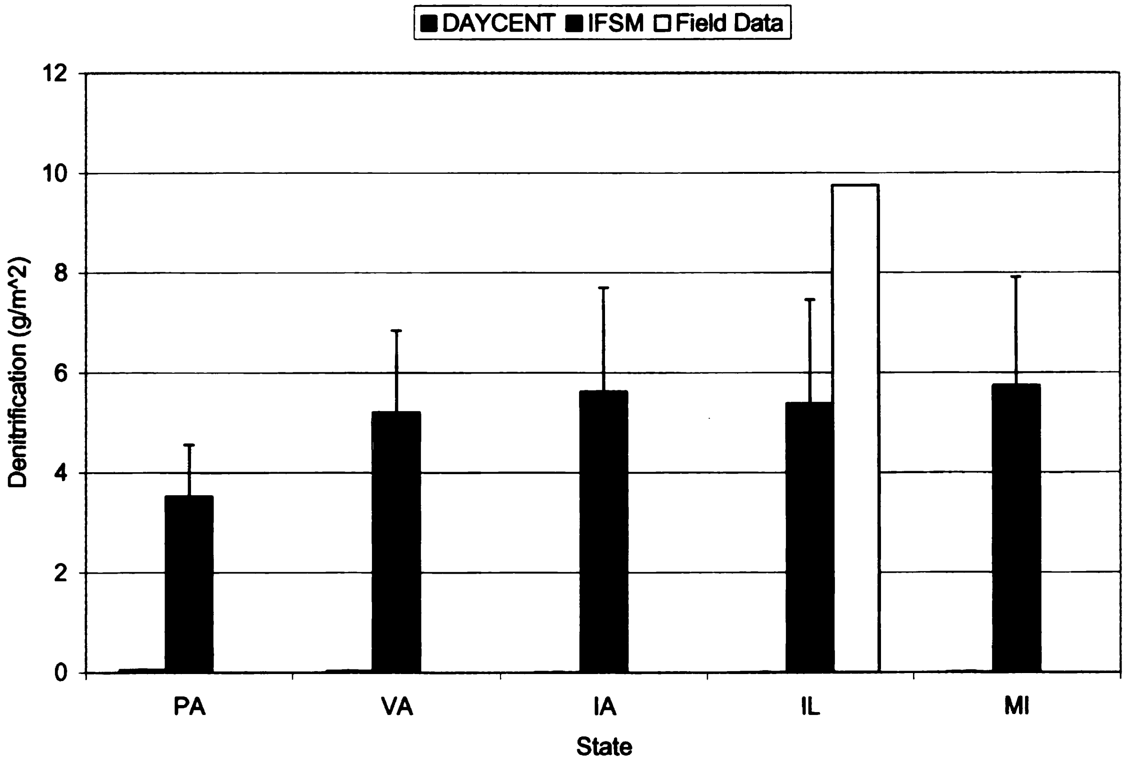

Figure B.10: Switchgrass denitrification data and available published data for each of the five states included in this comparison.

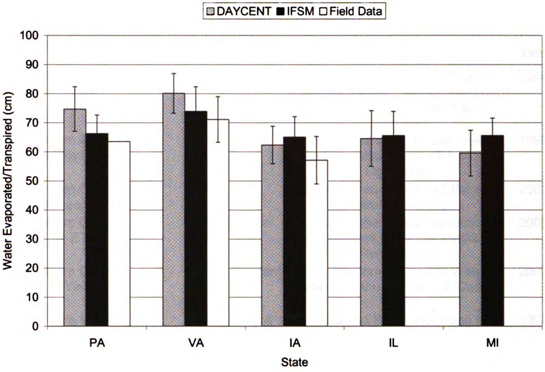

Figure B.11: Switchgrass evapotranspiration data and available published data for each of the five states included in this comparison.

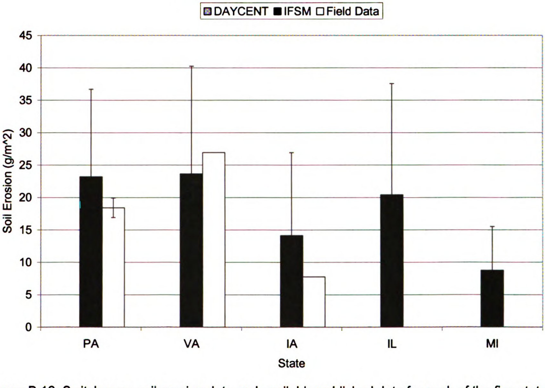

Figure B.12: Switchgrass soil erosion data and available published data for each of the five states included in this comparison.

Table B.1: Field data sources with location and variable for which they were used.

Location	Variable	Reference	Primary Author	Title	Year
PA	Corn Grain Yield	96	B.L. Dillehay	Performance of Bt Corn Hybrids, their Near Isolines, and Leading Corn Hybrids in Pennsylvania and Maryland	2004
PA	Corn Grain N Removal	97	Z. Dou	Managing Nitrogen on Dairy Farms: An Integrated Approach I. Model Description	1996
PA	Corn Grain N Leaching	98	Y. Zhu	Corn–Soybean Rotation Effects on Nitrate Leaching	2003
PA	Corn Grain ET	99	Y. Zhongbo	Evaluating the spatial distribution of water balance in a small watershed, Pennsylvania	2000
VA	Corn Grain Yield	100	J.K.F. Roygard	No-Till Corn Yields and Water Balance in the Mid-Atlantic Coastal Plain	2002
IA	Corn Grain Yield	101	J.M. Bordoli	Deep and Shallow Banding of Phosphorus and Potassium as Alternatives to Broadcast Fertilization for No-Till Corn	1998
IA	Corn Grain N Removal	102	D.L. Karlen	Field-Scale Nitrogen Balances Associated with Long-Term Continuous Corn Production	1998
IA	Corn Grain N Leaching	103	D.L. Dinnes	Nitrogen Management Strategies to Reduce Nitrate Leaching in Tile-Drained Midwestern Soils	2002
IA	Corn Grain ET	104	R.F. Dale	The climatology of soil moisture, atmospheric evaporative demand, and resulting moisture stress days for corn at Ames, Iowa	1965
IA	Corn Grain Soil Erosion	105	J.E. Gilley	Runoff, erosion, and soil quality characteristics of a former conservation reserve program site	1997
IL	Corn Grain Yield	106	J.A. Lory	Yield Goal versus Delta Yield for Predicting Fertilizer Nitrogen Need in Corn	2003
IL	Corn Grain N Removal	107	D.B. Jaynes	Nitrate Loss in Subsurface Drainage as Affected by Nitrogen Fertilizer Rate	2001
IL	Corn Grain N Leaching	107	D.B. Jaynes	Nitrate Loss in Subsurface Drainage as Affected by Nitrogen Fertilizer Rate	2001
IL	Corn Grain Denitrified N	108	M.B. David	Estimated Historical and Current Nitrogen Balances for Illinois	2001
IL	Corn Grain ET	109	J.A. Bowman	Impacts of Irrigation and Drought on Illinois ground-water resources	1987
IL	Corn Grain Soil Erosion	110	I. Hussain	Long-term effects on physical properties of eroded soil	1998

Table B.1 (cont'd)

MI	Corn Grain Yield	111	A.S. Grandy	Long-Term Trends in Nitrous Oxide Emissions, Soil Nitrogen, and Crop Yields of Till and No-Till Cropping Systems	2006
MI	Corn Grain N Removal	112	S. Jose	Defining competition vectors in a temperate alley cropping system in the Midwestern USA: 3. Competition for nitrogen and litter decomposition dynamics	2000
MI	Corn Grain Denitrified N	111	A.S. Grandy	Long-Term Trends in Nitrous Oxide Emissions, Soil Nitrogen, and Crop Yields of Till and No-Till Cropping Systems	2006
MI	Corn Grain ET	113	G.A. Unterreiner	Spatial and Temporal Distribution of Herbicides and Herbicide Degradates in a Shallow Glacial Drift Aquifer/Surface Water System, South-Central Michigan	2005
PA	Switchgrass Yield	114	G.A. Jung	Warm-Season grass diversity in yield, plant morphology, and nitrogen concentration and removal in northeastern USA	1990
PA	Switchgrass N Removal	114	G.A. Jung	Warm-Season grass diversity in yield, plant morphology, and nitrogen concentration and removal in northeastern USA	1990
PA	Switchgrass ET	115	M.H. Ehlke	Comparison of methods for computing streamflow statistics for Pennsylvania streams	1999
PA	Switchgrass Soil Erosion	116	P.J.A. Kleinman	Evaluation of Phosphorus Transport in Surface Runoff from Packed Soil Boxes	2004
VA	Switchgrass Yield	117	D.P. Belesky	Warm-season grass production and growth rate as influenced by canopy management	1995
VA	Switchgrass N Removal	118	E.R. Beaty	Root-herbage production and nutrient uptake retention by Bermudagrass and Bahiagrass	1975
VA	Switchgrass N Leaching	119	W.L. Stout	Water quality implications of dairy slurry applied to cut pastures in the northeast USA	2000
VA	Switchgrass ET	120	E.A. Johnson	Effect on streamflow of cutting a forest understory	1956
VA	Switchgrass Soil Erosion	121	E.A. Christopher, Jr.	Post Harvest Evaluation of Best Management Practices for the Prevention of Soil Erosion in Virginia	2002
IA	Switchgrass Yield	65	R. Lemus	Biomass yield and quality of 20 switchgrass populations in southern Iowa, USA	2002

Table B.1 (cont'd)

IA	Switchgrass N Removal	122	K.P. Vogel	Switchgrass Biomass Production in the Midwest USA: Harvest and Nitrogen Management	2002
IA	Switchgrass N Leaching	123	J.H. Ehrenreich	An Ecological Study of the Effect of Certain Management Practices on Native Prairie in Iowa	1963
IA	Switchgrass ET	124	D.A. Frank	Temporal variation in actual evapotranspiration of terrestrial ecosystems: patterns and ecological implications	1994
IA	Switchgrass Soil Erosion	125	K.H. Lee	Multispecies Riparian Buffers Trap Sediment and Nutrients during Rainfall Simulations	2000
IL	Switchgrass Yield	126	J.J. Faix	Quality, Yield, and Survival of Asiatic Bluestems and an Eastern Gamagrass in Southern Illinois	1980
IL	Switchgrass N Removal	127	S.M. Old	Microclimate, Fire, and Plant Production in an Illinois Prairie	1969
IL	Switchgrass N Leaching	128	W.J. Mitsch	Reducing Nutrient Loads, Especially Nitrate–Nitrogen, to Surface Water, Ground Water, and the Gulf of Mexico	1999
IL	Switchgrass Denitrified N	128	W.J. Mitsch	Reducing Nutrient Loads, Especially Nitrate–Nitrogen, to Surface Water, Ground Water, and the Gulf of Mexico	1999
MI	Switchgrass Yield	129	W.I. Graham	A National Assessment of Promising Areas for Switchgrass, Hybrid Poplar, or Willow Energy Crop Production	1999

APPENDIX C

C.1 Sample Landscape Calculation

Example values for Iowa

ST1 = 0.0287, ST2 = 0.0862, ST3 = 0.0018, ST4 = 0.30

X = 334, Y = 315, Z = 714, A = 483, B = 2859, C = 722

x = 1, y = 17, z = 0, a = 423, b = 189, c = 1 (numbers are rounded to whole farms, no fractions)

$T = x+y+z+a+b+c = 631$

$ST1 = (x+y+z)/T = (1+17+0)/631 \cong 0.0287$

$ST2 = x/y = 1/17 \cong 0.0862$

$ST3 = c/T = 1/631 \cong 0.0018$

$ST4 = (z+b)/T = (0+189)/631 \cong 0.30$

$$BM_0 = X \cdot x+Y \cdot y+Z \cdot z+A \cdot a+B \cdot b+C \cdot c$$
$$= (334)(1)+(315)(17)+(714)(0)+(483)(423)+(2859)(189)+(722)(1) = 752332$$

$$BM_R = BM_0 \cdot (1\text{-DML}) = 752332 \cdot (1\text{-}0.0695) = 700000$$

C.2 Development Simulations

Table C.2.1: Parameter inputs for farm management A (Table 5.1).

Variable	Unit	IA	MI	MN	NY	OH	PA	SD	TX	WI
Crop and Soil Parameters										
Owned Land	acres	355	191	345	214	187	131	1392	564	201
Rented Land	acres	0	0	0	0	0	0	0	0	0
Corn Relative Maturity Index	days	120	120	120	120	120	120	120	130	120
Corn Grain Yield Adjustment Factor	%	104	100	100	100	102	83	91	120	100
Corn Silage Yield Adjustment Factor	%	100	100	100	100	100	100	100	100	100
Maximum Annual Irrigation	inches	0	0	0	0	0	0	0	3.2	0
Preplanting Nitrogen	lb N/ac	150	113	93	0.88	120	71	75	80	86
Postplanting Ammonia	lb N/ac	0	0	0	0	0	0	0	0	0
Phosphate	lb P2O5/ac	47	41.5	41.5	38	44	34.5	32	25	45
Potash	lb K2O/ac	120	108	106	98	109	100	99	70	113
Manure	% of collected	0	0	0	0	0	0	0	0	0
Predominant Soil Type	N/A	Deep Clay Loam	Deep Sandy Loam	Deep Loam	Deep Clay Loam	Deep Clay Loam	Deep Clay Loam	Deep Loam	Deep Clay Loam	Deep Loam
Available Water Holding Capacity	inches	8.268	10.236	10.63	8.268	8.268	8.268	10.63	8.268	10.63
Fraction of Available Water When Stress Begins	N/A	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Bare Soil Albedo	N/A	0.11	0.13	0.12	0.11	0.11	0.11	0.12	0.11	0.12
Soil Evaporation Coefficient	inches	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236
Moist Bulk Density	lb/ft3	87.72	88.282	85.035	81.726	84.91	84.598	78.23	84.723	78.105
Organic Carbon Concentration	%	1.8	0.5	0.9	1.8	1.8	1.8	0.9	1.8	0.9
Silt Content	%	42	43	62	53	40	16	66	45	67
Clay Content	%	25	17	18	10	20	19	24	38	23
Sand Content	%	32	40	20	37	1	14	10	10	10
Runoff Curve Number	N/A	83	73	77	83	83	83	77	83	77
Whole Profile Drainage Rate Coefficient	N/A	0.35	0.48	0.42	0.035	0.35	0.35	0.42	0.35	0.42
Soil pH	N/A	6	6	6	6	6	6	6	6	6

Table C.2.1 (cont'd)

Spring Tillage and Planting, Upper Soil Tractability Coefficient	N/A	0.95	0.99	0.96	0.95	0.95	0.95	0.96	0.95	0.96
Fall Tillage and Planting, Upper Soil Tractability Coefficient	N/A	0.98	1	0.99	0.98	0.98	0.98	0.99	0.98	0.99
Fall Harvest and Planting, Upper Soil Tractability Coefficient	N/A	1.02	1.06	1.04	1.02	1.02	1.02	1.04	1.02	1.04
Spring Tillage and Planting, Lower Soil Tractability Coefficient	N/A	0.97	1	0.98	0.97	0.97	0.97	0.98	0.97	0.98
Fall Tillage and Planting, Lower Soil Tractability Coefficient	N/A	0.99	1.01	1	0.99	0.99	0.99	1	0.99	1
Fall Harvest and Planting, Lower Soil Tractability Coefficient	N/A	1	1.04	1.02	1	1	1	1.02	1	1.02
Tillage and Planting Parameters										
Corn Row Planting	day month	1 May	19 Apr	20 Apr	1 May	6 May	5 May	8 May	1 Apr	28 Apr
Maximum Operations Performed Simultaneously	N/A	2	2	2	2	2	2	2	2	2
Time available for tillage and planting operations	hrs/day	15	15	15	15	15	15	15	15	15
Harvest, Feeding, Tillage and Planting Machine Parameters										
Baling Machine Type	N/A	Med round	Med round	Lrg round	Med round	Med round	Sm round	Lrg round	Lrg round	Med round
Number of Baling Machines	N/A	1	1	1	1	1	1	2	1	1
Initial Cost of Baling Machines	$	19400	19400	24000	19400	19400	13800	24000	24000	19400
Baling Tractor Size	hp	108	108	108	108	108	108	108	108	108
Baling Tractor Initial Cost	$	65700	65700	65700	65700	65700	65700	65700	65700	65700
Grain Harvesting Machine Type	N/A	Lrg corn combine 12 row	Lrg corn combine 12 row	Lrg corn combine 12 row	Lrg corn combine 12 row	Lrg corn combine 12 row	Med corn combine 8 row	Lrg corn combine 12 row	Lrg corn combine 12 row	Lrg corn combine 12 row

Table C.2.1 (cont'd)

Number of Grain Harvesting Machines	N/A	2	2	2	2	2	1	4	3	2
Initial Cost of Grain Harvesting Machines	$	89000	89000	89000	89000	89000	80000	89000	89000	89000
Grain Harvesting Tractor Size	hp	108	108	108	108	108	108	108	108	108
Grain Harvesting Tractor Initial Cost	$	65700	65700	65700	65700	65700	65700	65700	65700	65700
Row Crop Planting Machine Type	N/A	Zone till corn planter, 8 row	Zone till corn planter, 8 row	Zone till corn planter, 8 row	Zone till corn planter, 8 row	Zone till corn planter, 8 row	Zone till corn planter, 4 row	Zone till corn planter, 12 row	Zone till corn planter, 12 row	Zone till corn planter, 8 row
Number of Row Crop Planting Machines	N/A	1	1	1	1	1	1	1	1	1
Initial Cost of Row Crop Planting Machines	$	27600	27600	27600	27600	27600	12000	52400	52400	27600
Row Crop Planting Tractor Size	hp	108	108	108	108	108	108	108	108	108
Row Crop Planting Tractor Initial Cost	$	65700	65700	65700	65700	65700	65700	65700	65700	65700
Miscellaneous Machine Parameters										
Number of Transport Tractors	N/A	1	1	1	1	1	1	1	1	1
Size of Transport Tractors	hp	108	108	108	108	108	108	108	108	108
Size of Bale Loader	hp	108	108	108	108	108	108	108	108	108
Initial Machine Shed Cost	$	10000	10000	10000	10000	10000	10000	10000	10000	10000
Custom Grain Harvest	$/ac	26	26	26	26	26	26	26	26	26
Harvested Crop Haul Distance	miles	0.42	0.31	0.41	0.33	0.3	0.25	0.83	0.53	0.32
Number of Hay Bale Wagons	N/A	1	1	2	1	1	1	2	3	1
Number of Grain Trucks	N/A	2	2	3	2	2	1	4	4	2
Dried Grain Harvest Start Date	day month	13 Oct	18 Oct	17 Oct	12 Oct	19 Oct	25 Oct	21 Oct	7 Aug	20 Oct

Table C.2.1 (cont'd)

Storage and Preservation Parameters										
Dry Hay Storage Type	N/A	Outside elevated no cover	Outside elevated no cover	Outside elevated no cover	Outside elevated no cover	Outside elevated no cover	Outside elevated no cover	Outside elevated no cover	Outside elevated no cover	Outside elevated no cover
Dry Hay Storage Capacity	ton DM	1000	1000	1000	1000	1000	1000	1000	1000	1000
Dry Hay Storage Cost	$	0	0	0	0	0	0	0	0	0
Economic Parameters										
Diesel Fuel Price	$/gal	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Electricity Price	$/kWh	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Grain Drying Price	$/pt/ton DM	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Labor Wage	$/hr	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Land Rental Rate	$/ac	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Property Tax	%	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Machinery Economic Life	years	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Structure Economic Life	years	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Machinery Salvage Value	%	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Structure Salvage Value	%	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interest Rate	%	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Cost of Seeds and Chemicals for Corn Land	$/ac	63.31	63.31	63.31	63.31	63.31	63.31	63.31	63.31	63.31
Nitrogen Fertilizer Price	$/lb	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Phosphate Fertilizer Price	$/lb	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Potash Fertilizer Price	$/lb	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Corn Grain Selling Price	$/ton DM	260.00	260.00	260.00	260.00	260.00	260.00	260.00	260.00	260.00

Table C.2.2: Parameters in addition to those listed in C.2.1 for farm management B (Table 5.1).

Variable	Unit	IA	MI	MN	NY	OH	PA	SD	TX	WI
Additional Parameters										
Life of Grass Stand	years	10	10	10	10	10	10	10	10	10
Grass Yield Adjestment Factor	%	220	255	230	220	220	220	225	220	220
Legume Portion in Sward	%	0	0	0	0	0	0	0	0	0
Maximum Annual Irrigation	inches	0	0	0	0	0	0	0	0	0
Nitrogen	lb N/ac	49	74	67.5	63.5	48	50	65	26.5	69
Phosphate	lb P2O5/ac	60	63	58	60	60	60	70	64	63
Potash	lb K2O/ac	270	260	240	275	275	275	290	300	280
Manure	% of collected	0	0	0	0	0	0	0	0	0
Grass Seeding	day month	3 June	3 June	3 June	3 June	3 June	3 June	3 June	3 June	3 June
Mowing Machine Type	N/A	Disk mow-cond., 10 ft	Disk mow-cond., 13 ft	Disk mow-cond., 10 ft	Disk mow-cond., 10 ft	Disk mow-cond., 10 ft	Disk mow-cond., 10 ft	SP mow-cond., 16 ft	SP mow-cond., 16 ft	Disk mow-cond., 10 ft
Number of Mowing Machines	N/A	1	1	1	1	1	1	4	2	1
Initial Cost of Mowing Machines	$	19200	25000	19200	19200	19200	19200	61000	61000	19200
Mowing Tractor Size	hp	87	87	87	87	87	87	none	none	87
Mowing Tractor Initial Cost	$	36400	36400	36400	36400	36400	36400	none	none	36400
Raking Machine Type	N/A	Tandem rake, 18 ft	Tandem rake, 18 ft	Tandem rake, 18 ft	Single rake, 9 ft	Single rake, 9 ft	Single rake, 9 ft	Tandem rake, 18 ft	Windrow merger, 32 ft	Single rake, 9 ft
Number of Raking Machines	N/A	1	1	1	1	1	1	4	2	1
Initial Cost of Raking Machines	$	14000	14000	14000	5100	5100	5100	14000	57200	5100
Raking Tractor Size	hp	87	87	87	87	87	87	134	134	87
Raking Tractor Initial Cost	$	36400	36400	36400	36400	36400	36400	81600	81600	36400
Baling Machine Type	N/A	Lrg round	Lrg round	Lrg round	Lrg round	Lrg round	Med round	Lrg round	Lrg round	Lrg round
Number of Baling Machines	N/A	2	1	2	1	1	1	8	3	1

Table C.2.2 (cont'd)

Initial Cost of Baling Machines	$	24000	24000	24000	24000	24000	19400	24000	24000	24000
Baling Tractor Size	hp	87	87	87	87	87	87	134	134	87
Baling Tractor Initial Cost	$	36400	36400	36400	36400	36400	36400	81600	81600	36400
Drill Seeding Machine Type	hp	108	108	108	108	108	108	134	134	108
Number of Drill Seeding Machines	N/A	1	1	1	1	1	1	2	1	1
Number of Transport Tractors	N/A	1	1	1	1	1	1	2	1	1
Size of Transport Tractors	hp	87	87	87	87	87	87	134	134	87
Size of Bale Loader	hp	87	87	87	87	87	87	134	134	87
Number of Hay Bale Wagons	N/A	3	3	3	3	3	3	10	4	3
Grass Harvest Parameters										
First Harvest Type	N/A	Baling	Baling	Baling	Baling	Baling	Baling	Baling	Baling	Baling
First Harvest Start Date	day month	5 July	5 July	5 July	5 July	5 July	5 July	5 July	5 July	5 July
NDF at First Harvest	%	80	80	80	80	80	80	80	80	80
Moisture at First Harvest	%	20	20	20	20	20	20	20	20	20
Drying Treatment for First Harvest	N/A	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath
Second Harvest Type	N/A	Baling	Baling	Baling	Baling	Baling	Baling	Baling	Baling	Baling
Second Harvest Start Date	day month	23 Sept	23 Sept	23 Sept	23 Sept	23 Sept	23 Sept	23 Sept	23 Sept	23 Sept
NDF at First Harvest	%	80	80	80	80	80	80	80	80	80
Moisture at First Harvest	%	20	20	20	20	20	20	20	20	20
Drying Treatment for First Harvest	N/A	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath

Table C.2.3: Parameters in addition to those listed in C.2.1 for farm management C (Table 5.1).

Variable	Unit	IA	MI	MN	NY	OH	PA	SD	TX	WI
Additional Parameters										
Rye Yield Adjestment Factor	%	100	100	100	100	100	100	100	100	100
Maximum Annual Irrigation	inches	0	0	0	0	0	0	0	0	0
Nitrogen	lb N/ac	0	0	0	0	0	0	0	0	0
Phosphate	lb P2O5/ac	0	0	0	0	0	0	0	0	0
Potash	lb K2O/ac	38	41	39	35	35	44	34	1	36
Manure	% of collected	0	0	0	0	0	0	0	0	0
Rye Planting Start Date	day month	23 Oct	25 Oct	14 Oct	19 Oct	26 Oct	31 Oct	28 Oct	17 Sept	27 Oct
Drill Seeding Machine Type	hp	108	108	108	108	108	108	134	134	108
Number of Drill Seeding Machines	N/A	1	1	1	1	1	1	1	1	1
Cost of Seeds and Chemicals for Rye Land	$/ac	17	17	17	17	17	17	17	17	17

Table C.2.4: Parameters in addition to those listed in C.2.1 for farm management Y (Table 5.1).

Variable	Unit	IA	MI	MN	NY	OH	PA	SD	TX	WI
Grazing area	acre	0	0	0	0	0	0	0	0	0
Feed Mixing Machine Type	N/A	Sm mixer 5 ton	Sm mixer 5 ton	Sm mixer 5 ton	Sm mixer 5 ton	Sm mixer 5 ton	Sm mixer 5 ton	Med mixer 9 ton	Med mixer 9 ton	Sm mixer 5 ton
Number of Feed Mixing Machines	N/A	1	1	1	1	1	1	1	1	1
Initial Cost of Feed Mixing Machines	$	16800	16800	16800	16800	16800	16800	22000	22000	16800
Feed Mixing Tractor Size	hp	87	87	87	87	87	87	108	108	87
Feed Mixing Tractor Initial Cost	$	36400	36400	36400	36400	36400	36400	65700	65700	36400
Silo Filling Machine Type	N/A	Forage blower/ bunker packer	Forage blower/ bunker packer	Forage blower/ bunker packer	Forage blower/ bunker packer	Forage blower/ bunker packer	Forage blower/ bunker packer	Forage blower/ bunker packer	Forage blower/ bunker packer	Forage blower/ bunker packer
Number of Silo Filling Machines	N/A	1	1	1	1	1	1	1	1	1
Initial Cost of Silo Filling Machines	$	20700	20700	20700	20700	20700	20700	20700	20700	20700
Silo Filling Tractor Size	hp	108	87	108	87	87	87	108	108	87
Silo Filling Tractor Initial Cost	$	65700	36400	65700	36400	36400	36400	65700	65700	36400
Manure Handling Machine Type		Med V-tank spreader	Med V-tank spreader	Med V-tank spreader	Med V-tank spreader	Med V-tank spreader	Med V-tank spreader	Lrg V-tank spreader	Lrg V-tank spreader	Med V-tank spreader
Number of Manure Handling Machines	N/A	1	1	1	1	1	1	2	1	1
Initial Cost of Manure Handling Machines	$	21600	21600	21600	21600	21600	21600	27200	27200	21600
Manure Handling Tractor Size	hp	108	108	108	108	108	108	108	108	108
Manure Handling Tractor Initial Cost	$	65700	65700	65700	65700	65700	65700	65700	65700	65700
Feed/Manure Loader Type	N/A	Med skid-steer loader	Med skid-steer loader	Med skid-steer loader	Med skid-steer loader	Med skid-steer loader	Med skid-steer loader	Lrg skid-steer loader	Lrg skid-steer loader	Med skid-steer loader
Number of Feed/Manure Loaders	N/A	2	2	2	2	2	2	2	1	2
Number of Silage Dump Wagons	N/A	3	3	3	3	3	3	N/A	N/A	3
Corn Silage Harvest Start Date	day month	7 Sept	7 Sept	7 Sept	7 Sept	7 Sept	7 Sept	N/A	N/A	7 Sept

Table C.2.4 (cont'd)

Silage Moisture at Harvest	%	68	68	68	68	68	68	N/A	N/A	68
Silage Storage Type	N/A	Bunker Silo	Bunker Silo	Bunker Silo	Bunker Silo	Bunker Silo	Bunker Silo	N/A	N/A	Bunker Silo
Silage Storage Capacity	ton DM	974	448	816	466	448	318	N/A	N/A	448
Silage Storage Initial Cost	$	81463	50984	72395	52103	50984	45026	N/A	N/A	50984
Silage Storage Annual Cost	$/ton DM	1.6	1.6	1.6	1.6	1.6	1.6	N/A	N/A	1.6
Cattle Type	N/A	Holstein	Holstein	Holstein	Holstein	Holstein	Holstein	Angus	Angus	Holstein
Target Milk Production	lb/cow/yr	20000	20000	20000	20000	20000	20000	N/A	N/A	20000
First Lactation Animals	%	35	35	35	35	35	35	N/A	N/A	35
Number of Lactating Animals	N/A	101	55	99	62	55	38	N/A	N/A	57
Number of Young Stock Over 1 Yr	N/A	37	20	36	22	19	13	N/A	N/A	21
Number of Young Stock Under 1 Yr	N/A	39	21	38	23	20	15	N/A	N/A	22
Milking Center Type	N/A	Double Six Parlor	Double Six Parlor	Double Six Parlor	Double Six Parlor	Double Six Parlor	Double Six Parlor	N/A	N/A	Double Six Parlor
Milking Center Value	$/cow	93000	93000	93000	93000	93000	93000	N/A	N/A	93000
Cow Housing Type	N/A	Free Stall Barn	Free Stall Barn	Free Stall Barn	Free Stall Barn	Free Stall Barn	Free Stall Barn	N/A	N/A	Free Stall Barn
Cow Housing Value	$/cow	101000	55000	10100	55000	55000	38000	N/A	N/A	55000
Heifer (Steer) Housing Type	N/A	Free Stall Barn	Free Stall Barn	Free Stall Barn	Free Stall Barn	Free Stall Barn	Free Stall Barn	Free stall, low emission floor	Free stall, low emission floor	Free Stall Barn
Heifer (Steer) Housing Value	$/head	51150	27600	51150	27600	27600	18750	696000	696000	27600
Feed Facility Type	N/A	Short Term Storage	Short Term Storage	Short Term Storage	Short Term Storage	Short Term Storage	Short Term Storage	Commodity Shed	Commodity Shed	Short Term Storage
Feed Facility Value	$/cow	51150	27600	51150	27600	27600	18750	696000	696000	27600
Milking and Animal handling/Labor	minutes/cow/day	4	4	4	4	4	4	0.5	0.5	4
Grain Feeding Method	N/A	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon
Sillage Feeding Method	N/A	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	Loader & mixer wagon	No Silage fed	No Silage fed	Loader & mixer wagon
Hay Feeding Method	N/A	Self fed bales	Self fed bales	Self fed bales	Self fed bales	Self fed bales	Self fed bales	No hay fed	No hay fed	Self fed bales

Table C.2.4 (cont'd)

Minimum Dry Hay in Rations	% of forage	0	0	0	0	0	0	0	0	0
Relative Forage to Grain Ratio	N/A	High	High	High	High	High	High	Low	Low	High
Crude Protein Supplement	N/A	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed
Undegradable Protein Supplement	N/A	Custom Mix	Custom Mix	Custom Mix	Custom Mix	Custom Mix	Custom Mix	Meat & Bone Meal	Meat & Bone Meal	Custom Mix
Energy Supplement	N/A	Grain only	Grain only	Grain only	Grain only	Grain only	Grain only	Grain only	Grain only	Grain only
Phosphorous Feeding Level	% NRC reccomendation	100	100	100	100	100	100	100	100	100
Veterinarian and Medication Expenses	$/cow	100	100	100	100	100	100	45	45	100
Semen and Breeding Costs	$/cow	45	45	45	45	45	45	33	33	45
Milking and Supplies Costs	$/cow	100	100	100	100	100	100	35	35	100
Animal Insurance	$/cow	10	10	10	10	10	10	10	10	10
Milking and Animal Handling Utilities	$/cow	85	85	85	85	85	85	55	55	85
Hauling	$/cow	7	7	7	7	7	7	5	5	7
DHIA, Registration, etc.	$/cow	22	22	22	22	22	22	23	23	22
Manure Collection Method	N/A	Scraper, bucket loading	Scraper, bucket loading	Scraper, bucket loading	Scraper, bucket loading	Scraper, bucket loading	Scraper, bucket loading	Scraper, bucket loading	Scraper, bucket loading	Scraper, bucket loading
Manure Type	N/A	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)
Average Manure Hauling Distance	mile	0.42	0.31	0.41	0.33	0.3	0.25	0.83	0.53	0.32
Manure Storage Method	N/A	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)
Animal Bedding Type	N/A	Straw	Straw	Straw	Straw	Straw	Straw	Straw	Straw	Straw
Amount of Bedding	lb/day	3	3	3	3	3	3	3	3	3
Crude Protein Supplement Purchase Price	$/ton DM	104.28	104.28	104.28	104.28	104.28	104.28	104.28	104.28	104.28
Undegradable Protein Supplement Purchase Price	$/ton DM	358.34	358.34	358.34	358.34	358.34	358.34	272	272	358.34

Table C.2.4 (cont'd)

Feed Corn Grain Purchase Price	$/ton DM	260	260	260	260	260	260	260	260	260
Feed Hay Purchase Price	$/ton DM	125.19	125.19	125.19	125.19	125.19	125.19	125.19	125.19	125.19
Fat Supplement Purchase Price	$/ton	399.17	399.17	399.17	399.17	399.17	399.17	399.17	399.17	399.17
Minerals/Vitamins Purchase Price	$/ton	395	395	395	395	395	395	395	395	395
Bedding Material Purchase Price	$/ton	40	40	40	40	40	40	40	40	40
Grain Crop Silage Selling Price	$/ton DM	75	75	75	75	75	75	75	75	75
Milk Selling Price	$/cwt	15	15	15	15	15	15	N/A	N/A	15
Cull Cow Selling Price	$/cwt	49.99	49	49	49	49	49	N/A	N/A	49
Heifer Selling Price	$/animal	1200	1200	1200	1200	1200	1200	N/A	N/A	1200
Calf Selling Price	$/animal	20	20	20	20	20	20	N/A	N/A	20
Milk Hauling, Marketing, & Advertising Fees	$/cwt	1	1	1	1	1	1	N/A	N/A	1

Table C.2.5: Parameters in addition to those listed in C.2.4 (management type Y) for locations with beef rather than dairy.

Variable	Unit	SD	TX
Final shruken body weight	lb	1234.58	1234.58
Genetic influence on maintenance energy requirement	N/A	1	1
Genetic influence on fiber intake capacity	N/A	1	1
Genetic factor for carcass leanness	N/A	6	6
Finished Cattle Selling Price	$/cwt	89.99	89.99

Table C.2.6: Parameters in addition to those listed in C.2.4 for farm management X (Table 5.1).

Variable	Unit	IA	MI	MN	NY	OH	PA	WI
Additional Parameters								
Corn Land	acres	255	161	300	188	169	113	176
Alfalfa Land	acres	100	30	45	26	18	18	25
Life of Alfalfa Stand	years	4	4	4	4	4	4	4
Alfalfa Yield Adjustment Factor	%	100	100	100	100	100	100	100
Maximum Annual Irrigation	inches	0	0	0	0	0	0	0
Nitrogen	lb N/ac	0	0	0	0	0	0	0
Phosphate	lb P2O5/ac	20	10	1	1	0	20	1
Potash	lb K2O/ac	50	40	1	1	0	60	1
Manure	% of collected	0	0	0	0	0	0	0
Alfalfa Seeding Start Date	day month	17 Sept	17 Sept	17 Sept	17 Sept	17 Sept	17 Sept	17 Sept
Mowing Machine Type	N/A	Disk mow-cond., 10 ft	mow-cond., 9 ft	Disk mow-cond., 10 ft	Disk mow-cond., 10 ft	mow-cond., 9 ft	mow-cond., 9 ft	mow-cond., 9 ft
Number of Mowing Machines	N/A	1	1	1	1	1	1	1
Initial Cost of Mowing Machines	$	19200	15500	19200	19200	15500	15500	15500
Mowing Tractor Size	hp	108	87	108	108	87	67	87
Mowing Tractor Initial Cost	$	65700	36400	65700	65700	36400	28100	36400
Raking Machine Type	N/A	Tandem rake, 18 ft	Single rake, 9 ft	Tandem rake, 18 ft	Tandem rake, 18 ft	Single rake, 9 ft	Single rake, 9 ft	Tandem rake, 18 ft
Number of Raking Machines	N/A	1	1	1	1	1	1	1
Initial Cost of Raking Machines	$	14000	5100	14000	14000	5100	5100	14000
Raking Tractor Size	hp	67	67	108	87	87	67	87
Raking Tractor Initial Cost	$	28100	28100	65700	36400	36400	28100	36400
Number of Hay Silage Dump Wagons	N/A	3	2	1	1	1	3	1
High Quality Forage Storage Type	N/A	Bunker silo	Bunker silo	Bunker silo	Bunker silo	Bunker silo	Bunker silo	Bunker silo
High Quality Forage Storage Capacity	ton DM	324	132	119	100	67	80	92
High Quality Forage Storage Initial Cost	$	41724	24085	21162	22918	17451	18614	24768
High Quality Forage Storage Annual Cost	$/ton DM	1.6	1.6	1.6	1.6	1.6	1.6	1.6

Table C.2.6 (cont'd)

Dry Alfalfa Hay Storage Type	N/A	Inside a shed	Inside a shed	Inside a shed	Inside a shed	Inside a shed	Inside a shed	Inside a shed
Dry Alfalfa Hay Storage Capacity	ton DM	1000	1000	1000	1000	1000	1000	1000
Dry Alfalfa Hay Storage Initial Cost	$	10000	10000	10000	10000	10000	10000	10000
Dry Alfalfa Hay Storage Annual Cost	$/ton DM	0	0	0	0	0	0	0
Crude Protein Supplement	N/A	Soybean meal, 44%	Soybean meal, 44%	Soybean meal, 44%	Soybean meal, 44%	Soybean meal, 44%	Soybean meal, 44%	Soybean meal, 44%
Crude Protein Supplement Purchase Price	$/ton DM	230	230	230	230	230	230	230
Cost of Seeds and Chemicals for Alfalfa Land	$/ac	50	50	50	50	50	50	50
Alfalfa Harvest Parameters								
First Harvest Type	N/A	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping
First Harvest Start Date	day month	25 May	25 May	25 May	25 May	25 May	25 May	25 May
NDF at First Harvest	%	36	36	36	36	36	36	36
Moisture at First Harvest	%	65	68	68	68	68	68	68
Drying Treatment for First Harvest	N/A	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath
Raking Treatment for First Harvest	N/A	No raking	No raking	No raking	No raking	No raking	No raking	No raking
Second Harvest Type	N/A	Hay harvest by baling	Hay harvest by baling	Hay harvest by baling	Hay harvest by baling	Hay harvest by baling	Hay harvest by baling	Hay harvest by baling
Second Harvest Start Date	day month	1 July	1 July	1 July	1 July	1 July	1 July	1 July
NDF at Second Harvest	%	36	36	36	36	36	36	36
Moisture at Second Harvest	%	20	20	20	20	20	20	20
Drying Treatment for Second Harvest	N/A	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath

Table C.2.6 (cont'd)

Raking Treatment for Second Harvest	N/A	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest
Third Harvest Type	N/A	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping
Third Harvest Start Date	day month	15 Aug	15 Aug	15 Aug	15 Aug	15 Aug	15 Aug	15 Aug
NDF at Third Harvest	%	39	39	39	39	39	39	39
Moisture at Third Harvest	%	68	68	68	68	68	68	68
Drying Treatment for Third Harvest	N/A	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath
Raking Treatment for Third Harvest	N/A	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest
Fourth Harvest Type	N/A	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping
Fourth Harvest Start Date	day month	15 Oct	15 Oct	15 Oct	15 Oct	15 Oct	15 Oct	15 Oct
NDF at Fourth Harvest	%	0	0	0	0	0	0	0
Moisture at Fourth Harvest	%	68	68	68	68	68	68	68
Drying Treatment for Fourth Harvest	N/A	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath
Raking Treatment for Fourth Harvest	N/A	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest	Raking before harvest

Table C.2.7: Parameters in addition to those listed in C.2.6 (management type X) for locations with beef rather than dairy.

Variable	Unit	SD	TX
High Moisture Corn Harvest Start Date	day month	1 Oct	31 July
High Moisture Corn Type	N/A	w/ little or no cob & husk	w/ little or no cob & husk
High Moisture Corn Storage Type	N/A	Stave silo	Stave silo
High Moisture Corn Storage Capacity	ton DM	901	331
High Moisture Corn Storage Initial Cost	$	40002	18644
High Moisture Corn Storage Annual Cost	$/ton DM	0	0
Number of Silage Dump Wagons	N/A	3	3
Corn Silage Harvest Start Date	day month	7 Sept	23 July
Silage Moisture at Harvest	%	68	68
Silage Storage Type	N/A	Bunker Silo	Bunker Silo
Silage Storage Capacity	ton DM	280	101
Silage Storage Initial Cost	$	45252	23014
Silage Storage Annual Cost	$/ton DM	1.6	1.6

Table C.2.8: Parameter in addition to those listed in C.2.2 and C.2.6 for farm management Z (Table 5.1).

Variable	Unit	IA	MI	MN	NY	OH	PA	SD	TX	WI
Corn Land	acres	255	161	300	188	169	113	1066	457	176
Switchgrass Land	acres	100	30	45	26	18	18	326	107	25
Silage Storage Capacity	ton DM	311	175	299	185	177	125	N/A	N/A	189
Silage Storage Initial Cost	$	37958	30769	39695	29411	29089	21477	N/A	N/A	28112
Crude Protein Supplement	N/A	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed
Crude Protein Supplement Purchase Price	$/ton DM	104.28	104.28	104.28	104.28	104.28	104.28	104.28	104.28	104.28

Table C.2.9: Parameter in addition to those listed in C.2.8 (management type Z) for locations with beef rather than dairy

Variable	Unit	SD	TX
Mowing Machine Type	N/A	SP mow-cond., 16 ft	Disk mow-cond., 10 ft
Number of Mowing Machines	N/A	2	1
Initial Cost of Mowing Machines	$	61000	19200
Mowing Tractor Size	hp	none	180
Mowing Tractor Initial Cost	$	none	65700
Raking Machine Type	N/A	Tandem rake, 18 ft	Tandem rake, 18 ft
Number of Raking Machines	N/A	2	2
Initial Cost of Raking Machines	$	14000	14000
Raking Tractor Size	hp	108	108
Raking Tractor Initial Cost	$	65700	65700

Table C.2.10: Biorefinery economic summary output for development simulation in IA at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8738	
Feedstock Rate (dry ton/day)	2,000	
Ethanol Production (MM Gal. / Year)	72.4	
Ethanol Yield (Gal / Dry US Ton Feedstock)	103.4	Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81	*0.717*
Internal Rate of Return (After-Tax)	12%	
Equity Percent of Total Investment	60%	

Capital Costs		%of total
Feed Handling	$6,800,000	5.7%
Pretreatment	$15,200,000	12.8%
Biological conversion	$3,300,000	2.8%
Distillation and Solids Recovery	$18,300,000	15.4%
Wastewater Treatment	$21,500,000	18.0%
Storage	$1,700,000	1.4%
Residue Processing	$44,400,000	37.2%
Utilities	$8,000,000	6.7%
Total Installed Equipment Cost	$119,200,000	
Added Costs	$84,200,000	
(% of TPI)	41%	
Total Project Investment	$203,400,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.3510	

Operating Costs (cents/gal ethanol)	
Feedstock	78.1
Other Raw Materials	6.2
Waste Disposal	0.0
Co-Product Sales	-7.8
Fixed Costs	12.1
Capital Depreciation	14.1
Average Income Tax	2.1
Average Return on Investment	82.5

Operating Costs ($/yr)	
Feedstock	$56,600,000
Other Raw Matl. Costs	$4,500,000
Waste Disposal	$600,000
Co-Product Sales	-$5,600,000
Fixed Costs	$8,800,000
Capital Depreciation	$10,200,000
Average Income Tax	$1,500,000
Average Return on Investment	$59,700,000

Table C.2.11: Biorefinery economic summary output for development simulation in MI at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8610		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	71.2		
Ethanol Yield (Gal / Dry US Ton Feedstock)	101.7	Switchgrass Fraction	
Feedstock Cost $/Dry US Ton	$81	*0.796*	
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$6,500,000	5.5%	Feedstock	79.4
Pretreatment	$15,100,000	12.8%	Other Raw Materials	7.0
Biological conversion	$3,300,000	2.8%	Waste Disposal	0.0
Distillation and Solids Recovery	$18,100,000	15.4%	Co-Product Sales	-11.3
Wastewater Treatment	$20,600,000	17.5%	Fixed Costs	12.3
Storage	$1,700,000	1.4%	Capital Depreciation	14.2
Residue Processing	$44,400,000	37.8%	Average Income Tax	2.1
Utilities	$7,900,000	6.7%	Average Return on Investment	82.4
Total Installed Equipment Cost	$117,600,000			

		Operating Costs ($/yr)	
Added Costs	$83,400,000	Feedstock	$56,500,000
(% of TPI)	41%	Other Raw Matl. Costs	$5,000,000
		Waste Disposal	$600,000
Total Project Investment	$201,000,000	Co-Product Sales	-$8,100,000
		Fixed Costs	$8,700,000
Loan Rate	7.5%	Capital Depreciation	$10,100,000
Term (years)	25	Average Income Tax	$1,500,000
Capital Charge Factor	0.3498	Average Return on Investment	$58,700,000

Table C.2.12: Biorefinery economic summary output for development simulation in MN at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8620	
Feedstock Rate (dry ton/day)	2,000	
Ethanol Production (MM Gal. / Year)	71.6	
Ethanol Yield (Gal / Dry US Ton Feedstock)	102.3	Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81	*0.793*
Internal Rate of Return (After-Tax)	12%	
Equity Percent of Total Investment	60%	

Capital Costs		%of total
Feed Handling	$6,600,000	5.6%
Pretreatment	$15,100,000	12.8%
Biological conversion	$3,300,000	2.8%
Distillation and Solids Recovery	$18,200,000	15.4%
Wastewater Treatment	$20,600,000	17.5%
Storage	$1,700,000	1.4%
Residue Processing	$44,400,000	37.7%
Utilities	$8,000,000	6.8%
Total Installed Equipment Cost	$117,900,000	
Added Costs	$83,300,000	
(% of TPI)	41%	
Total Project Investment	$201,200,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.3509	

Operating Costs (cents/gal ethanol)	
Feedstock	78.9
Other Raw Materials	6.7
Waste Disposal	0.0
Co-Product Sales	-10.1
Fixed Costs	12.2
Capital Depreciation	14.1
Average Income Tax	2.1
Average Return on Investment	82.3

Operating Costs ($/yr)	
Feedstock	$56,500,000
Other Raw Matl. Costs	$4,800,000
Waste Disposal	$600,000
Co-Product Sales	-$7,200,000
Fixed Costs	$8,700,000
Capital Depreciation	$10,100,000
Average Income Tax	$1,500,000
Average Return on Investment	$59,000,000

Table C.2.13: Biorefinery economic summary output for development simulation in NY at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.6262		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	64.4		
Ethanol Yield (Gal / Dry US Ton Feedstock)	92.0		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.757*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total
Feed Handling	$6,700,000	6.0%
Pretreatment	$14,900,000	13.2%
Biological conversion	$3,200,000	2.8%
Distillation and Solids Recovery	$17,100,000	15.2%
Wastewater Treatment	$20,200,000	17.9%
Storage	$1,600,000	1.4%
Residue Processing	$44,400,000	39.4%
Utilities	$4,500,000	4.0%
Total Installed Equipment Cost	$112,600,000	
Added Costs	$79,500,000	
(% of TPI)	41%	
Total Project Investment	$192,100,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.3389	

Operating Costs (cents/gal ethanol)	
Feedstock	87.9
Other Raw Materials	11.2
Waste Disposal	0.0
Co-Product Sales	-50.7
Fixed Costs	13.2
Capital Depreciation	14.9
Average Income Tax	2.3
Average Return on Investment	83.9

Operating Costs ($/yr)	
Feedstock	$56,600,000
Other Raw Matl. Costs	$7,200,000
Waste Disposal	$500,000
Co-Product Sales	-$32,700,000
Fixed Costs	$8,500,000
Capital Depreciation	$9,600,000
Average Income Tax	$1,500,000
Average Return on Investment	$54,000,000

Table C.2.14: Biorefinery economic summary output for development simulation in OH at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8735		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	70.7		
Ethanol Yield (Gal / Dry US Ton Feedstock)	101.0		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.688*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total
Feed Handling	$6,900,000	5.8%
Pretreatment	$15,100,000	12.7%
Biological conversion	$3,300,000	2.8%
Distillation and Solids Recovery	$18,100,000	15.2%
Wastewater Treatment	$21,500,000	18.1%
Storage	$1,700,000	1.4%
Residue Processing	$44,400,000	37.3%
Utilities	$7,900,000	6.6%
Total Installed Equipment Cost	$118,900,000	
Added Costs	$84,000,000	
(% of TPI)	41%	
Total Project Investment	$202,900,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.3470	

Operating Costs (cents/gal ethanol)	
Feedstock	80.1
Other Raw Materials	7.3
Waste Disposal	0.0
Co-Product Sales	-12.1
Fixed Costs	12.4
Capital Depreciation	14.3
Average Income Tax	2.2
Average Return on Investment	83.2

Operating Costs ($/yr)	
Feedstock	$56,600,000
Other Raw Matl. Costs	$5,200,000
Waste Disposal	$600,000
Co-Product Sales	-$8,600,000
Fixed Costs	$8,800,000
Capital Depreciation	$10,100,000
Average Income Tax	$1,500,000
Average Return on Investment	$58,800,000

Table C.2.15: Biorefinery economic summary output for development simulation in PA at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.6353		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	66.3		
Ethanol Yield (Gal / Dry US Ton Feedstock)	94.7		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.724*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$6,800,000	6.0%	Feedstock	85.3
Pretreatment	$14,900,000	13.2%	Other Raw Materials	9.7
Biological conversion	$3,200,000	2.8%	Waste Disposal	0.0
Distillation and Solids Recovery	$17,400,000	15.4%	Co-Product Sales	-44.6
Wastewater Treatment	$20,300,000	17.9%	Fixed Costs	12.9
Storage	$1,700,000	1.5%	Capital Depreciation	14.6
Residue Processing	$44,400,000	39.2%	Average Income Tax	2.2
Utilities	$4,500,000	4.0%	Average Return on Investment	83.3
Total Installed Equipment Cost	$113,200,000			

		Operating Costs ($/yr)	
Added Costs	$80,000,000	Feedstock	$56,600,000
(% of TPI)	41%	Other Raw Matl. Costs	$6,500,000
		Waste Disposal	$500,000
Total Project Investment	$193,200,000	Co-Product Sales	-$29,500,000
		Fixed Costs	$8,500,000
Loan Rate	7.5%	Capital Depreciation	$9,700,000
Term (years)	25	Average Income Tax	$1,500,000
Capital Charge Factor	0.3437	Average Return on Investment	$55,200,000

Table C.2.16: Biorefinery economic summary output for development simulation in SD at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.6432		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	69.4		
Ethanol Yield (Gal / Dry US Ton Feedstock)	99.2		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.763*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$6,600,000	5.8%	Feedstock	81.4
Pretreatment	$15,000,000	13.1%	Other Raw Materials	7.5
Biological conversion	$3,300,000	2.9%	Waste Disposal	0.0
Distillation and Solids Recovery	$17,800,000	15.6%	Co-Product Sales	-35.6
Wastewater Treatment	$20,400,000	17.8%	Fixed Costs	12.4
Storage	$1,700,000	1.5%	Capital Depreciation	14.1
Residue Processing	$44,400,000	38.8%	Average Income Tax	2.1
Utilities	$5,100,000	4.5%	Average Return on Investment	82.4
Total Installed Equipment Cost	$114,300,000			
			Operating Costs ($/yr)	
Added Costs	$81,100,000		Feedstock	$56,500,000
(% of TPI)	42%		Other Raw Matl. Costs	$5,200,000
			Waste Disposal	$600,000
Total Project Investment	$195,400,000		Co-Product Sales	-$24,700,000
			Fixed Costs	$8,600,000
Loan Rate	7.5%		Capital Depreciation	$9,800,000
Term (years)	25		Average Income Tax	$1,500,000
Capital Charge Factor	0.3506		Average Return on Investment	$57,200,000

Table C.2.17: Biorefinery economic summary output for development simulation in TX at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.6288		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	56.1		
Ethanol Yield (Gal / Dry US Ton Feedstock)	80.1		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.434*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$7,500,000	6.8%	Feedstock	101.1
Pretreatment	$14,600,000	13.1%	Other Raw Materials	18.6
Biological conversion	$3,000,000	2.7%	Waste Disposal	0.0
Distillation and Solids Recovery	$15,800,000	14.2%	Co-Product Sales	-79.5
Wastewater Treatment	$19,900,000	17.9%	Fixed Costs	15.0
Storage	$1,600,000	1.4%	Capital Depreciation	16.9
Residue Processing	$44,400,000	40.0%	Average Income Tax	2.6
Utilities	$4,300,000	3.9%	Average Return on Investment	88.1
Total Installed Equipment Cost	$111,100,000			
			Operating Costs ($/yr)	
Added Costs	$78,400,000		Feedstock	$56,700,000
(% of TPI)	41%		Other Raw Matl. Costs	$10,500,000
			Waste Disposal	$500,000
Total Project Investment	$189,500,000		Co-Product Sales	-$44,600,000
			Fixed Costs	$8,400,000
Loan Rate	7.5%		Capital Depreciation	$9,500,000
Term (years)	25		Average Income Tax	$1,500,000
Capital Charge Factor	0.3187		Average Return on Investment	$49,400,000

Table C.2.18: Biorefinery economic summary output for development simulation in WI at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.6410		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	68.3		
Ethanol Yield (Gal / Dry US Ton Feedstock)	97.6		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.732*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total
Feed Handling	$6,700,000	5.9%
Pretreatment	$15,000,000	13.2%
Biological conversion	$3,300,000	2.9%
Distillation and Solids Recovery	$17,700,000	15.6%
Wastewater Treatment	$20,400,000	17.9%
Storage	$1,700,000	1.5%
Residue Processing	$44,400,000	39.0%
Utilities	$4,600,000	4.0%
Total Installed Equipment Cost	$113,800,000	
Added Costs	$80,400,000	
(% of TPI)	41%	
Total Project Investment	$194,200,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.3486	

Operating Costs (cents/gal ethanol)	
Feedstock	82.8
Other Raw Materials	8.2
Waste Disposal	0.0
Co-Product Sales	-38.5
Fixed Costs	12.5
Capital Depreciation	14.2
Average Income Tax	2.2
Average Return on Investment	82.7

Operating Costs ($/yr)	
Feedstock	$56,600,000
Other Raw Matl. Costs	$5,600,000
Waste Disposal	$600,000
Co-Product Sales	-$26,300,000
Fixed Costs	$8,500,000
Capital Depreciation	$9,700,000
Average Income Tax	$1,500,000
Average Return on Investment	$56,500,000

C.3 Scenario Tests

Table C.3.1: Parameter inputs for farm management A (Table 5.1).

Variable	Unit	Decreased Precipitation	Decreased Winter Temperature and Precipitation	Increased Temperature and Precipitation	Increased Corn Stover Production
Crop and Soil Parameters					
Owned Land	acres	355	191	1392	355
Rented Land	acres	0	0	0	0
Corn Relative Maturity Index	days	120	120	120	120
Corn Grain Yield Adjustment Factor	%	104	100	91	104
Corn Silage Yield Adjustment Factor	%	100	100	100	100
Maximum Annual Irrigation	inches	0	0	0	0
Preplanting Nitrogen	lb N/ac	87	113	75	150
Postplanting Ammonia	lb N/ac	0	0	0	0
Phosphate	lb P2O5/ac	28	41.5	32	47
Potash	lb K2O/ac	52	108	99	120
Manure	% of collected	0	0	0	0
Predominant Soil Type	N/A	Deep Clay Loam	Deep Sandy Loam	Deep Loam	Deep Clay Loam
Available Water Holding Capacity	inches	8.268	10.236	10.63	8.268
Fraction of Available Water When Stress Begins	N/A	0.5	0.5	0.5	0.5
Bare Soil Albedo	N/A	0.11	0.13	0.12	0.11
Soil Evaporation Coefficient	inches	0.236	0.236	0.236	0.236
Moist Bulk Density	lb/ft3	87.72	88.282	78.23	87.72
Organic Carbon Concentration	%	1.8	0.5	0.9	1.8
Silt Content	%	42	43	66	42
Clay Content	%	25	17	24	25
Sand Content	%	32	40	10	32
Runoff Curve Number	N/A	83	73	77	83
Whole Profile Drainage Rate Coefficient	N/A	0.35	0.48	0.42	0.35
Soil pH	N/A	6	6	6	6
Spring Tillage and Planting, Upper Soil Tractability Coefficient	N/A	0.95	0.99	0.96	0.95

Table C.3.1 (cont'd)

Fall Tillage and Planting, Upper Soil Tractability Coefficient	N/A	0.98	1	0.99	0.98
Fall Harvest and Planting, Upper Soil Tractability Coefficient	N/A	1.02	1.06	1.04	1.02
Spring Tillage and Planting, Lower Soil Tractability Coefficient	N/A	0.97	1	0.98	0.97
Fall Tillage and Planting, Lower Soil Tractability Coefficient	N/A	0.99	1.01	1	0.99
Fall Harvest and Planting, Lower Soil Tractability Coefficient	N/A	1	1.04	1.02	1
Tillage and Planting Parameters					
Corn Row Planting	day month	1 May	19 Apr	8 May	1 May
Maximum Operations Performed Simultaneously	N/A	2	2	2	2
Time available for tillage and planting operations	hrs/day	15	15	15	15
Harvest, Feeding, Tillage and Planting Machine Parameters					
Baling Machine Type	N/A	Med round	Med round	Lrg round	Med round
Number of Baling Machines	N/A	1	1	2	1
Initial Cost of Baling Machines	$	19400	19400	24000	19400
Baling Tractor Size	hp	87	108	108	108
Baling Tractor Initial Cost	$	36400	65700	65700	65700
Grain Harvesting Machine Type	N/A	Lrg corn combine, 12 row	Lrg corn combine, 12 row	Lrg corn combine, 12 row	Lrg corn combine, 12 row
Number of Grain Harvesting Machines	N/A	1	2	4	2
Initial Cost of Grain Harvesting Machines	$	89000	89000	89000	89000
Grain Harvesting Tractor Size	hp	108	108	108	108
Grain Harvesting Tractor Initial Cost	$	65700	65700	65700	65700
Row Crop Planting Machine Type	N/A	Zone till corn planter, 8 row	Zone till corn planter, 8 row	Zone till corn planter, 12 row	Zone till corn planter, 8 row
Number of Row Crop Planting Machines	N/A	1	1	1	1
Initial Cost of Row Crop Planting Machines	$	27600	27600	52400	27600
Row Crop Planting Tractor Size	hp	108	108	108	108

Table C.3.1 (cont'd)

Row Crop Planting Tractor Initial Cost	$	65700	65700	65700	65700
Miscellaneous Machine Parameters					
Number of Transport Tractors	N/A	1	1	1	1
Size of Transport Tractors	hp	108	108	108	108
Size of Bale Loader	hp	108	108	108	108
Initial Machine Shed Cost	$	10000	10000	10000	10000
Custom Grain Harvest	$/ac	26	26	26	26
Harvested Crop Haul Distance	miles	0.42	0.31	0.83	0.42
Number of Hay Bale Wagons	N/A	1	1	2	1
Number of Grain Trucks	N/A	2	2	4	2
Dried Grain Harvest Start Date	day month	13 Oct	18 Oct	21 Oct	13 Oct
Storage and Preservation Parameters					
Dry Hay Storage Type	N/A	Outside elevated, no cover	Outside elevated, no cover	Outside elevated, no cover	Outside elevated, no cover
Dry Hay Storage Capacity	ton DM	1000	1000	1000	1000
Dry Hay Storage Cost	$	0	0	0	0
Economic Parameters					
Diesel Fuel Price	$/gal	2.00	2.00	2.00	2.00
Electricity Price	$/kWh	0.08	0.08	0.08	0.08
Grain Drying Price	$/pt/ton DM	2.00	2.00	2.00	2.00
Labor Wage	$/hr	10.00	10.00	10.00	10.00
Land Rental Rate	$/ac	50.00	50.00	50.00	50.00
Property Tax	%	2.50	2.50	2.50	2.50
Machinery Economic Life	years	15.00	15.00	15.00	15.00
Structure Economic Life	years	20.00	20.00	20.00	20.00
Machinery Salvage Value	%	30.00	30.00	30.00	30.00
Structure Salvage Value	%	0.00	0.00	0.00	0.00
Interest Rate	%	6.00	6.00	6.00	6.00
Cost of Seeds and Chemicals for Corn Land	$/ac	63.31	63.31	63.31	63.31
Nitrogen Fertilizer Price	$/lb	0.43	0.43	0.43	0.43
Phosphate Fertilizer Price	$/lb	0.34	0.34	0.34	0.34
Potash Fertilizer Price	$/lb	0.16	0.16	0.16	0.16
Corn Grain Selling Price	$/ton DM	260.00	260.00	260.00	260.00

Table C.3.2: Parameters in addition to those listed in C.3.1 for farm management B (Table 5.1).

Variable	Unit	Decreased Precipitation	Increased SG Productivity	Decreased Winter Temperature and Precipitation	Increased Temperature and Precipitation	Increased Corn Stover Production
Additional Parameters						
Life of Grass Stand	years	10	10	10	10	10
Grass Yield Adjestment Factor	%	220	220	255	225	220
Legume Portion in Sward	%	0	0	0	0	0
Maximum Annual Irrigation	inches	0	0	0	0	0
Nitrogen	lb N/ac	47	49	74	65	49
Phosphate	lb P2O5/ac	140	60	63	70	60
Potash	lb K2O/ac	600	275	260	290	275
Manure	% of collected	0	0	0	0	0
Grass Seeding	day month	3 June	3 June	1 June	3 June	3 June
Mowing Machine Type	N/A	Disk mow-cond., 10 ft	Disk mow-cond., 10 ft	Disk mow-cond., 10 ft	SP mow-cond., 16 ft	Disk mow-cond., 10 ft
Number of Mowing Machines	N/A	1	1	1	4	1
Initial Cost of Mowing Machines	$	19200	19200	25000	61000	19200
Mowing Tractor Size	hp	87	87	87	none	87
Mowing Tractor Initial Cost	$	36400	36400	36400	none	36400
Raking Machine Type	N/A	Tandem rake, 18 ft	Tandem rake, 18 ft	Tandem rake, 18 ft	Tandem rake, 18 ft	Tandem rake, 18 ft
Number of Raking Machines	N/A	1	1	1	4	1
Initial Cost of Raking Machines	$	14000	14000	14000	14000	14000
Raking Tractor Size	hp	87	87	87	134	87
Raking Tractor Initial Cost	$	36400	36400	36400	81600	36400
Baling Machine Type	N/A	Lrg round	Lrg round	Lrg round	Lrg round	Lrg round
Number of Baling Machines	N/A	2	2	1	8	2
Initial Cost of Baling Machines	$	24000	24000	24000	24000	24000
Baling Tractor Size	hp	87	87	87	134	87
Baling Tractor Initial Cost	$	36400	36400	36400	81600	36400
Drill Seeding Machine Type	hp	108	108	108	134	108
Number of Drill Seeding Machines	N/A	1	1	1	2	1
Number of Transport Tractors	N/A	1	1	1	2	1

Table C.3.2 (cont'd)

Size of Transport Tractors	hp	87	87	87	134	87
Size of Bale Loader	hp	87	87	87	134	87
Number of Hay Bale Wagons	N/A	3	3	3	10	3
Grass Harvest Parameters						
First Harvest Type	N/A	Baling	Baling	Baling	Baling	Baling
First Harvest Start Date	day month	5 July	5 July	5 July	5 July	5 July
NDF at First Harvest	%	80	80	80	80	80
Moisture at First Harvest	%	20	20	20	20	20
Drying Treatment for First Harvest	N/A	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath
Second Harvest Type	N/A	Baling	Baling	Baling	Baling	Baling
Second Harvest Start Date	day month	23 Sept	23 Sept	23 Sept	23 Sept	23 Sept
NDF at First Harvest	%	80	80	80	80	80
Moisture at First Harvest	%	20	20	20	20	20
Drying Treatment for First Harvest	N/A	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath	mech'l cond'ng, wide swath

Table C.3.3: Parameters in addition to those listed in C.3.1 for farm management C (Table 5.1).

Variable	Unit	Decreased Precipitation	Decreased Winter Temperature and Precipitation	Increased Temperature and Precipitation	Increased Corn Stover Production
Rye Yield Adjestment Factor	%	100	100	100	100
Maximum Annual Irrigation	inches	0	0	0	0
Nitrogen	lb N/ac	0	0	0	0
Phosphate	lb P2O5/ac	0	2	0	0
Potash	lb K2O/ac	38	41	34	38
Manure	% of collected	0	0	0	0
Rye Planting Start Date	day month	23 Oct	25 Oct	28 Oct	23 Oct
Drill Seeding Machine Type	hp	108	108	134	108
Number of Drill Seeding Machines	N/A	1	1	1	1
Cost of Seeds and Chemicals for Rye Land	$/ac	17	17	17	17

Table C.3.4: Parameters in addition to those listed in C.3.1 for farm management Y (Table 5.1).

Variable	Unit	Decreased Precipitation	Decreased Winter Temperature and Precipitation	Increased Temperature and Precipitation	Increased Corn Stover Production
Grazing area	acre	0	0	0	0
Feed Mixing Machine Type	N/A	Sm mixer 5 ton	Sm mixer 5 ton	Med mixer 9 ton	Sm mixer 5 ton
Number of Feed Mixing Machines	N/A	1	1	1	1
Initial Cost of Feed Mixing Machines	$	16800	16800	22000	16800
Feed Mixing Tractor Size	hp	87	87	108	87
Feed Mixing Tractor Initial Cost	$	36400	36400	65700	36400
Silo Filling Machine Type	N/A	Forage blower/bunker packer	Forage blower/bunker packer	Forage blower/bunker packer	Forage blower/bunker packer
Number of Silo Filling Machines	N/A	1	1	1	1
Initial Cost of Silo Filling Machines	$	20700	20700	20700	20700
Silo Filling Tractor Size	hp	108	87	108	108
Silo Filling Tractor Initial Cost	$	65700	36400	65700	65700
Manure Handling Machine Type		Med V-tank spreader	Med V-tank spreader	Lrg V-tank spreader	Med V-tank spreader
Number of Manure Handling Machines	N/A	1	1	2	1
Initial Cost of Manure Handling Machines	$	21600	21600	27200	21600
Manure Handling Tractor Size	hp	108	108	108	108
Manure Handling Tractor Initial Cost	$	65700	65700	65700	65700
Feed/Manure Loader Type	N/A	Med skid-steer loader	Med skid-steer loader	Lrg skid-steer loader	Med skid-steer loader
Number of Feed/Manure Loaders	N/A	2	2	2	2
Number of Silage Dump Wagons	N/A	2	3	N/A	3
Corn Silage Harvest Start Date	day month	7 Sept	7 Sept	N/A	7 Sept
Silage Moisture at Harvest	%	68	68	N/A	68
Silage Storage Type	N/A	Bunker Silo	Bunker Silo	N/A	Bunker Silo
Silage Storage Capacity	ton DM	974	448	N/A	974
Silage Storage Initial Cost	$	81463	50984	N/A	81463

Table C.3.4 (cont'd)

Silage Storage Annual Cost	$/ton DM	1.6	1.6	N/A	1.6
Cattle Type	N/A	Holstein	Holstein	Angus	Holstein
Target Milk Production	lb/cow/yr	20000	20000	N/A	20000
First Lactation Animals	%	35	35	N/A	35
Number of Lactating Animals		101	55	N/A	101
Number of Young Stock Over 1 Yr		37	20	N/A	37
Number of Young Stock Under 1 Yr		39	21	N/A	39
Milking Center Type	N/A	Double Six Parlor	Double Six Parlor	N/A	Double Six Parlor
Milking Center Value	$/cow	93000	93000	N/A	93000
Cow Housing Type	N/A	Free Stall Barn	Free Stall Barn	N/A	Free Stall Barn
Cow Housing Value	$/cow	101000	55000	N/A	101000
Heifer (Steer) Housing Type	N/A	Free Stall Barn	Free Stall Barn	Free stall low emission floor	Free Stall Barn
Heifer (Steer) Housing Value	$/head	51150	27600	696000	51150
Feed Facility Type	N/A	Short Term Storage	Short Term Storage	Commodity Shed	Short Term Storage
Feed Facility Value	$/cow	51150	27600	696000	51150
Milking and Animal handling/Labor	minutes/cow/day	4	4	0.5	4
Grain Feeding Method	N/A	Loader and mixer wagon	Loader and mixer wagon	Loader and mixer wagon	Loader and mixer wagon
Sillage Feeding Method	N/A	Loader and mixer wagon	Loader and mixer wagon	No Silage fed	Loader and mixer wagon
Hay Feeding Method	N/A	Self fed round bales	Self fed round bales	No hay fed	Self fed round bales
Minimum Dry Hay in Rations	% of forage	0	0	0	0
Relative Forage to Grain Ratio	N/A	High	High	Low	High
Crude Protein Supplement	N/A	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed
Undegradable Protein Supplement	N/A	Custom Mix	Custom Mix	Meat & Bone Meal	Custom Mix
Energy Supplement	N/A	Grain only	Grain only	Grain only	Grain only
Phosphorous Feeding Level	% NRC reccomendation	100	100	100	100
Veterinarian and Medication Expenses	$/cow	100	100	45	100
Semen and Breeding Costs	$/cow	45	45	33	45
Milking and Supplies Costs	$/cow	100	100	35	100

Table C.3.4 (cont'd)

Animal Insurance	$/cow	10	10	10	10
Milking and Animal Handling Utilities	$/cow	85	85	55	85
Hauling	$/cow	7	7	5	7
DHIA, Registration, etc.	$/cow	22	22	23	22
Manure Collection Method	N/A	Scraper with bucket loading	Scraper with bucket loading	Scraper with bucket loading	Scraper with bucket loading
Manure Type	N/A	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)	Slurry (8 - 10% DM)
Average Manure Hauling Distance	mile	0.42	0.31	0.83	0.42
Manure Storage Method	N/A	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)	No Storage (Daily haul)
Animal Bedding Type	N/A	Straw	Straw	Straw	Straw
Amount of Bedding	lb/day	3	3	3	3
Crude Protein Supplement Purchase Price	$/ton DM	104.28	104.28	104.28	104.28
Undegradable Protein Supplement Purchase Price	$/ton DM	358.34	358.34	272	358.34
Feed Corn Grain Purchase Price	$/ton DM	260	260	260	260
Feed Hay Purchase Price	$/ton DM	125.19	125.19	125.19	125.19
Fat Supplement Purchase Price	$/ton	399.17	399.17	399.17	399.17
Minerals/Vitamins Purchase Price	$/ton	395	395	395	395
Bedding Material Purchase Price	$/ton	40	40	40	40
Grain Crop Silage Selling Price	$/ton DM	75	75	75	75
Milk Selling Price	$/cwt	15	15	N/A	15
Cull Cow Selling Price	$/cwt	49.99	49	N/A	49.99
Heifer Selling Price	$/animal	1200	1200	N/A	1200
Calf Selling Price	$/animal	20	20	N/A	20
Milk Hauling, Marketing, & Advertising Fees	$/cwt	1	1	N/A	1

Table C.3.5: Parameters in addition to those listed in C.3.4 (management type Y) for locations with beef rather than dairy.

Variable	Unit	Increased Temperature and Precipitation
Final shruken body weight	lb	1234.58
Genetic influence on maintenance energy requirement	N/A	1
Genetic influence on fiber intake capacity	N/A	1
Genetic factor for carcass leanness	N/A	6
Finished Cattle Selling Price	$/cwt	89.99

Table C.3.6: Parameters in addition to those listed in C.3.4 for farm management X (Table 5.1).

Variable	Unit	Decreased Precipitation	Decreased Winter Temperature and Precipitation	Increased Corn Stover Production
Additional Parameters				
Corn Land	acres	255	161	255
Alfalfa Land	acres	100	30	100
Life of Alfalfa Stand	years	4	4	4
Alfalfa Yield Adjustment Factor	%	100	100	100
Maximum Annual Irrigation	inches	0	0	0
Nitrogen	lb N/ac	0	0	0
Phosphate	lb P2O5/ac	0	10	20
Potash	lb K2O/ac	0	40	50
Manure	% of collected	10	0	0
Alfalfa Seeding Start Date	day month	11 Sept	17 Sept	17 Sept
Mowing Machine Type	N/A	Disk mow-cond., 10 ft	mow-cond., 13 ft	Disk mow-cond., 10 ft
Number of Mowing Machines	N/A	1	1	1
Initial Cost of Mowing Machines	$	19200	25000	19200
Mowing Tractor Size	hp	87	87	108
Mowing Tractor Initial Cost	$	36400	36400	65700
Raking Machine Type	N/A	Tandem rake, 18 ft	Single rake, 9 ft	Tandem rake, 18 ft
Number of Raking Machines	N/A	1	1	1
Initial Cost of Raking Machines	$	14000	5100	14000
Raking Tractor Size	hp	67	67	67
Raking Tractor Initial Cost	$	28100	28100	28100
Number of Hay Silage Dump Wagons	N/A	2	2	3
High Quality Forage Storage Type	N/A	Bunker silo	Bunker silo	Bunker silo
High Quality Forage Storage Capacity	ton DM	324	132	324
High Quality Forage Storage Initial Cost	$	41724	24085	41724
High Quality Forage Storage Annual Cost	$/ton DM	1.6	1.6	1.6
Dry Alfalfa Hay Storage Type	N/A	Inside a shed	Inside a shed	Inside a shed
Dry Alfalfa Hay Storage Capacity	ton DM	1000	1000	1000
Dry Alfalfa Hay Storage Initial Cost	$	10000	10000	10000

Table C.3.6 (cont'd)

Dry Alfalfa Hay Storage Annual Cost	$/ton DM	0	0	0
Crude Protein Supplement	N/A	Soybean meal, 44%	Soybean meal, 44%	Soybean meal, 44%
Crude Protein Supplement Purchase Price	$/ton DM	230	230	230
Cost of Seeds and Chemicals for Alfalfa Land	$/ac	50	50	50
Alfalfa Harvest Parameters				
First Harvest Type	N/A	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping
First Harvest Start Date	day month	25 May	25 May	25 May
NDF at First Harvest	%	36	36	36
Moisture at First Harvest	%	65	68	65
Drying Treatment for First Harvest	N/A	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, narrow swath
Raking Treatment for First Harvest	N/A	No raking	No raking	No raking
Second Harvest Type	N/A	Hay harvest by baling	Hay harvest by baling	Hay harvest by baling
Second Harvest Start Date	day month	1 July	1 July	1 July
NDF at Second Harvest	%	36	36	36
Moisture at Second Harvest	%	20	20	20
Drying Treatment for Second Harvest	N/A	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath
Raking Treatment for Second Harvest	N/A	Raking before harvest	Raking before harvest	Raking before harvest
Third Harvest Type	N/A	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping
Third Harvest Start Date	day month	15 Aug	15 Aug	15 Aug
NDF at Third Harvest	%	39	39	39
Moisture at Third Harvest	%	68	68	68
Drying Treatment for Third Harvest	N/A	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath	Mech'l cond'ng, wide swath
Raking Treatment for Third Harvest	N/A	Raking before harvest	Raking before harvest	Raking before harvest
Fourth Harvest Type	N/A	Wilted silage, chopping	Wilted silage, chopping	Wilted silage, chopping
Fourth Harvest Start Date	day month	15 Oct	15 Oct	15 Oct

Table C.3.6 (cont'd)

NDF at Fourth Harvest	%	0	0	0
Moisture at Fourth Harvest	%	68	68	68
Drying Treatment for Fourth Harvest	N/A	Mech'l cond'ng, wide swath	Mech'l cond'ng, narrow swath	Mech'l cond'ng, wide swath
Raking Treatment for Fourth Harvest	N/A	Raking before harvest	Raking before harvest	Raking before harvest

Table C.3.7: Parameters in addition to those listed in C.3.6 (management type X) for locations with beef rather than dairy.

Variable	Unit	Increased Temperature and Precipitation
High Moisture Corn Harvest Start Date	day month	1 Oct
High Moisture Corn Type	N/A	w/ little or no cob & husk
High Moisture Corn Storage Type	N/A	Stave silo
High Moisture Corn Storage Capacity	ton DM	901
High Moisture Corn Storage Initial Cost	$	40002
High Moisture Corn Storage Annual Cost	$/ton DM	0
Number of Silage Dump Wagons	N/A	3
Corn Silage Harvest Start Date	day month	7 Sept
Silage Moisture at Harvest	%	68
Silage Storage Type	N/A	Bunker Silo
Silage Storage Capacity	ton DM	280
Silage Storage Initial Cost	$	45252
Silage Storage Annual Cost	$/ton DM	1.6

Table C.3.8: Parameter in addition to those listed in C.3.2 and C.3.6 for farm management Z (Table 5.1).

Variable	Unit	Decreased Precipitation	Increased SG Productivity	Decreased Winter Temperature and Precipitation	Increased Temperature and Precipitation	Increased Corn Stover Production
Corn Land	acres	255	255	161	1066	255
Switchgrass Land	acres	100	100	30	326	100
Silage Storage Capacity	ton DM	311	311	175	N/A	311
Silage Storage Initial Cost	$	37958	37958	30769	N/A	37958
Crude Protein Supplement	N/A	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed	AFEX Feed
Crude Protein Supplement Purchase Price	$/ton DM	104.28	104.28	104.28	104.28	104.28

Table C.3.9: Parameter in addition to those listed in C.3.8 (management type Z) for locations with beef rather than dairy.

Variable	Unit	Increased Temperature and Precipitation
Mowing Machine Type	N/A	SP mow-cond, 16 ft
Number of Mowing Machines	N/A	2
Initial Cost of Mowing Machines	$	61000
Mowing Tractor Size	hp	none
Mowing Tractor Initial Cost	$	none
Raking Machine Type	N/A	Tandem rake, 18 ft
Number of Raking Machines	N/A	2
Initial Cost of Raking Machines	$	14000
Raking Tractor Size	hp	108
Raking Tractor Initial Cost	$	65700

Table C.3.10: Biorefinery economic summary output for the Decreased Precipitation Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8625		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	72.6		
Ethanol Yield (Gal / Dry US Ton Feedstock)	103.8		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.8194*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$6,500,000	5.5%	Feedstock	77.9
Pretreatment	$15,200,000	12.9%	Other Raw Materials	6.1
Biological conversion	$3,300,000	2.8%	Waste Disposal	0.0
Distillation and Solids Recovery	$18,300,000	15.5%	Co-Product Sales	-7.7
Wastewater Treatment	$20,600,000	17.5%	Fixed Costs	12.0
Storage	$1,700,000	1.4%	Capital Depreciation	13.9
Residue Processing	$44,400,000	37.6%	Average Income Tax	2.1
Utilities	$8,000,000	6.8%	Average Return on Investment	82.0
Total Installed Equipment Cost	$118,000,000			

		Operating Costs ($/yr)	
Added Costs	$83,500,000	Feedstock	$56,600,000
(% of TPI)	41%	Other Raw Matl. Costs	$4,400,000
		Waste Disposal	$600,000
Total Project Investment	$201,500,000	Co-Product Sales	-$5,600,000
		Fixed Costs	$8,700,000
Loan Rate	7.5%	Capital Depreciation	$10,100,000
Term (years)	25	Average Income Tax	$1,500,000
Capital Charge Factor	0.3529	Average Return on Investment	$59,500,000

Table C.3.11: Biorefinery economic summary output for the Increased Switchgrass Productivity Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.6251	
Feedstock Rate (dry ton/day)	2,000	
Ethanol Production (MM Gal. / Year)	69.4	
Ethanol Yield (Gal / Dry US Ton Feedstock)	99.2	Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81	*0.9526*
Internal Rate of Return (After-Tax)	12%	
Equity Percent of Total Investment	60%	

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$5,900,000	5.2%	Feedstock	81.2
Pretreatment	$15,000,000	13.2%	Other Raw Materials	7.6
Biological conversion	$3,300,000	2.9%	Waste Disposal	0.0
Distillation and Solids Recovery	$17,900,000	15.7%	Co-Product Sales	-36.6
Wastewater Treatment	$20,400,000	17.9%	Fixed Costs	12.3
Storage	$1,700,000	1.5%	Capital Depreciation	14.0
Residue Processing	$44,400,000	39.1%	Average Income Tax	2.1
Utilities	$5,100,000	4.5%	Average Return on Investment	81.9
Total Installed Equipment Cost	$113,700,000			
			Operating Costs ($/yr)	
Added Costs	$80,400,000		Feedstock	$56,400,000
(% of TPI)	41%		Other Raw Matl. Costs	$5,300,000
			Waste Disposal	$500,000
Total Project Investment	$194,100,000		Co-Product Sales	-$25,400,000
			Fixed Costs	$8,500,000
Loan Rate	7.5%		Capital Depreciation	$9,700,000
Term (years)	25		Average Income Tax	$1,500,000
Capital Charge Factor	0.3503		Average Return on Investment	$56,800,000

Table C.3.12: Biorefinery economic summary output for the Decreased Meat Production Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8766		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	72.8		
Ethanol Yield (Gal / Dry US Ton Feedstock)	104.0		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.717*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$6,800,000	5.7%	Feedstock	77.9
Pretreatment	$15,200,000	12.7%	Other Raw Materials	5.9
Biological conversion	$3,300,000	2.8%	Waste Disposal	0.0
Distillation and Solids Recovery	$18,300,000	15.3%	Co-Product Sales	-6.7
Wastewater Treatment	$21,600,000	18.1%	Fixed Costs	12.1
Storage	$1,700,000	1.4%	Capital Depreciation	14.0
Residue Processing	$44,400,000	37.2%	Average Income Tax	2.1
Utilities	$8,000,000	6.7%	Average Return on Investment	82.4
Total Installed Equipment Cost	$119,300,000			

		Operating Costs ($/yr)	
Added Costs	$84,300,000	Feedstock	$56,700,000
(% of TPI)	41%	Other Raw Matl. Costs	$4,300,000
		Waste Disposal	$600,000
Total Project Investment	$203,600,000	Co-Product Sales	-$4,900,000
		Fixed Costs	$8,800,000
Loan Rate	7.5%	Capital Depreciation	$10,200,000
Term (years)	25	Average Income Tax	$1,500,000
Capital Charge Factor	0.3522	Average Return on Investment	$60,000,000

Table C.3.13: Biorefinery economic summary output for the Decreased Winter Temperature and Precipitation Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8671		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	72.7		
Ethanol Yield (Gal / Dry US Ton Feedstock)	103.8		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.7985*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$6,500,000	5.5%	Feedstock	77.8
Pretreatment	$15,200,000	12.8%	Other Raw Materials	6.1
Biological conversion	$3,300,000	2.8%	Waste Disposal	0.0
Distillation and Solids Recovery	$18,300,000	15.4%	Co-Product Sales	-7.5
Wastewater Treatment	$21,500,000	18.1%	Fixed Costs	12.1
Storage	$1,700,000	1.4%	Capital Depreciation	14.0
Residue Processing	$44,400,000	37.3%	Average Income Tax	2.1
Utilities	$8,000,000	6.7%	Average Return on Investment	82.2
Total Installed Equipment Cost	$118,900,000			
			Operating Costs ($/yr)	
Added Costs	$84,200,000		Feedstock	$56,500,000
(% of TPI)	41%		Other Raw Matl. Costs	$4,400,000
			Waste Disposal	$600,000
Total Project Investment	$203,100,000		Co-Product Sales	-$5,500,000
			Fixed Costs	$8,800,000
Loan Rate	7.5%		Capital Depreciation	$10,200,000
Term (years)	25		Average Income Tax	$1,500,000
Capital Charge Factor	0.3516		Average Return on Investment	$59,700,000

Table C.3.14: Biorefinery economic summary output for the Increased Meat Production Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8738		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	29.8		
Ethanol Yield (Gal / Dry US Ton Feedstock)	42.5		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.049*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$8,200,000	9.2%	Feedstock	191.5
Pretreatment	$1,200,000	1.3%	Other Raw Materials	70.4
Biological conversion	$2,300,000	2.6%	Waste Disposal	0.0
Distillation and Solids Recovery	$11,600,000	13.0%	Co-Product Sales	-232.7
Wastewater Treatment	$16,700,000	18.7%	Fixed Costs	25.2
Storage	$1,300,000	1.5%	Capital Depreciation	25.5
Residue Processing	$44,400,000	49.7%	Average Income Tax	4.1
Utilities	$3,600,000	4.0%	Average Return on Investment	103.5
Total Installed Equipment Cost	$89,300,000			

		Operating Costs ($/yr)	
Added Costs	$61,700,000	Feedstock	$57,000,000
(% of TPI)	41%	Other Raw Matl. Costs	$20,900,000
		Waste Disposal	$300,000
Total Project Investment	$151,000,000	Co-Product Sales	-$69,300,000
		Fixed Costs	$7,500,000
Loan Rate	7.5%	Capital Depreciation	$7,600,000
Term (years)	25	Average Income Tax	$1,200,000
Capital Charge Factor	0.2623	Average Return on Investment	$30,800,000

Table C.3.15: Biorefinery economic summary output for the Increased Temperature and Precipitation Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8830		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	71.9		
Ethanol Yield (Gal / Dry US Ton Feedstock)	102.7		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$81		*0.611*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total	Operating Costs (cents/gal ethanol)	
Feed Handling	$7,100,000	6.0%	Feedstock	78.9
Pretreatment	$15,100,000	12.7%	Other Raw Materials	6.4
Biological conversion	$3,300,000	2.8%	Waste Disposal	0.0
Distillation and Solids Recovery	$18,200,000	15.3%	Co-Product Sales	-8.5
Wastewater Treatment	$21,500,000	18.0%	Fixed Costs	12.2
Storage	$1,700,000	1.4%	Capital Depreciation	14.2
Residue Processing	$44,400,000	37.2%	Average Income Tax	2.1
Utilities	$8,000,000	6.7%	Average Return on Investment	82.9
Total Installed Equipment Cost	$119,300,000			

		Operating Costs ($/yr)	
Added Costs	$84,400,000	Feedstock	$56,700,000
(% of TPI)	41%	Other Raw Matl. Costs	$4,600,000
		Waste Disposal	$600,000
Total Project Investment	$203,700,000	Co-Product Sales	-$6,100,000
		Fixed Costs	$8,800,000
Loan Rate	7.5%	Capital Depreciation	$10,200,000
Term (years)	25	Average Income Tax	$1,500,000
Capital Charge Factor	0.3500	Average Return on Investment	$59,600,000

Table C.3.16: Biorefinery economic summary output for the Increased Corn Stover Production Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$1.8795
Feedstock Rate (dry ton/day)	2,000
Ethanol Production (MM Gal. / Year)	72.2
Ethanol Yield (Gal / Dry US Ton Feedstock)	103.2
Feedstock Cost $/Dry US Ton	$81
Internal Rate of Return (After-Tax)	12%
Equity Percent of Total Investment	60%

Switchgrass Fraction

0.6289

Capital Costs		%of total
Feed Handling	$7,000,000	5.9%
Pretreatment	$15,200,000	12.7%
Biological conversion	$3,300,000	2.8%
Distillation and Solids Recovery	$18,200,000	15.3%
Wastewater Treatment	$21,500,000	18.0%
Storage	$1,700,000	1.4%
Residue Processing	$44,400,000	37.2%
Utilities	$8,000,000	6.7%
Total Installed Equipment Cost	$119,300,000	
Added Costs	$84,400,000	
(% of TPI)	41%	
Total Project Investment	$203,700,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.3510	

Operating Costs (cents/gal ethanol)	
Feedstock	78.3
Other Raw Materials	6.3
Waste Disposal	0.0
Co-Product Sales	-7.8
Fixed Costs	12.2
Capital Depreciation	14.1
Average Income Tax	2.1
Average Return on Investment	82.8

Operating Costs ($/yr)	
Feedstock	$56,500,000
Other Raw Matl. Costs	$4,500,000
Waste Disposal	$600,000
Co-Product Sales	-$5,600,000
Fixed Costs	$8,800,000
Capital Depreciation	$10,200,000
Average Income Tax	$1,500,000
Average Return on Investment	$59,800,000

Table C.3.17: Biorefinery economic summary output for the Decreased Biorefinery Productivity Scenario at the 75% land use transportation radius.

Minimum Ethanol Selling Price	$2.0060		
Feedstock Rate (dry ton/day)	2,000		
Ethanol Production (MM Gal. / Year)	58.5		
Ethanol Yield (Gal / Dry US Ton Feedstock)	103.4		Switchgrass Fraction
Feedstock Cost $/Dry US Ton	$80		*0.717*
Internal Rate of Return (After-Tax)	12%		
Equity Percent of Total Investment	60%		

Capital Costs		%of total
Feed Handling	$6,800,000	5.7%
Pretreatment	$15,200,000	12.8%
Biological conversion	$3,300,000	2.8%
Distillation and Solids Recovery	$18,300,000	15.4%
Wastewater Treatment	$21,500,000	18.0%
Storage	$1,700,000	1.4%
Residue Processing	$44,400,000	37.2%
Utilities	$8,000,000	6.7%
Total Installed Equipment Cost	$119,200,000	
Added Costs	$84,200,000	
(% of TPI)	41%	
Total Project Investment	$203,400,000	
Loan Rate	7.5%	
Term (years)	25	
Capital Charge Factor	0.3147	

Operating Costs (cents/gal ethanol)	
Feedstock	77.8
Other Raw Materials	6.2
Waste Disposal	0.0
Co-Product Sales	-7.8
Fixed Costs	15.0
Capital Depreciation	17.4
Average Income Tax	2.6
Average Return on Investment	89.4

Operating Costs ($/yr)	
Feedstock	$45,500,000
Other Raw Matl. Costs	$3,600,000
Waste Disposal	$500,000
Co-Product Sales	-$4,600,000
Fixed Costs	$8,800,000
Capital Depreciation	$10,200,000
Average Income Tax	$1,500,000
Average Return on Investment	$52,300,000

APPENDIX D

BFIT Instructions (Trained Users Guide)

System requirements:

This system is designed to run in a Microsoft Windows XP environment using MS Excel 2003, ASPEN PLUS 2006 w/ Intel Visual FORTRAN 9.0 and custom database (included), and Python 2.5 or higher (available for download at www.python.org).

Installation:

Included in the install package is the Integrated Farm System Model (IFSM), the model itself as well as the needed input files, which includes the biorefinery sub-model file for ASPEN (.bkp) and Excel (.xls), the farm set-up examples (.frm), the text files for the model to read (.txt), and the Python sub-model file (.py).

To begin installation, the user will need the NREL Model Files INHSPCD.DAT, which is the file that allows the GUI to directly access the in-house database pure components, and BIODFMS3.INP, which is the new file to create the NREL in-house pure component database. User should place INHSPCD.DAT in C:\Program Files\AspenTech\APRSYSTEM 2006\GUI\custom and place BIODFMS3.INP in C:\Program Files\AspenTech\Working Folders\Aspen Plus 2006 (on some systems may be C:\Documents and Settings\All Users\AspenTech\Aspen Plus 2006).

Next the user should open C:\Program Files\AspenTech\APRSYSTEM 2006\GUI\custom\tbprop.dat using Notepad (or another text editor) and add the following line at the end of the list of 'INCLUDE' statements in the file: INCLUDE inhspcd.dat (this adds the custom database to the list of useable databases).

Next the user should open the Aspen Plus Simulation Engine DOS window (go to: Start\All Programs\AspenTech\Aspen Engineering Suite\Aspen Plus\) and type the following command: dfms biodfms3.

The user should now open the Aspen Plus User Interface Customization DOS window (go to: Start\All Programs\AspenTech\Aspen Engineering Suite\Aspen Plus\) and type the following command: mmcustom mmtbs (this rebuilds the record definition files); then hit Return. Note: this takes a few minutes to execute.

Finally, type the following command: custinst (this copies the customized user interface definition files).

Next, the language installation for Python must be completed using the Python Software Foundation website, www.python.org. Follow the instructions on the website for download and install. Do this in the same directory as the model.

Introduction:

The biorefinery using Ammonia Fiber Expansion (AFEX) pretreatment has been modeled for the production of fuel ethanol from cellulosic biomass in ASPEN Plus, but this model does not integrate cropping and animal production systems. Combining these three subsystems in a single integrated model allows environmental and economic modeling of biomass production, possible secondary products, fertilizer production, and bioenergy production. Using the Integrated Farm System Model (IFSM) and the NREL/Dartmouth Biorefinery model in APSEN and Excel, the biorefinery is concurrently simulated with the animal and crop production units in US locations using this new research tool, BFIT: Biorefinery and Farm Integration Tool. Use of this system is intended for users with prior knowledge of the system in question, and should not be used as a hardened calculator for exacting design of biorefinery systems.

Model Components:

Figure 5.1 appears in this space for users. The colors are as described below.

All green boxes are encompassed in the BFIT model programming (BFIT.xls), the two blue boxes are labeled with the model in which they are contained.

Model use:

For each location to be analyzed, weather and soil data must be collect and formatted for use in IFSM. Existing weather files may be viewed in a text editor and used as templates. Data fields on line 1 are: location abbreviation, latitude, longitude, atmospheric CO_2 concentration, the remaining two characteristics should not be changed. Data fields on Lines 2 and more are: yrjda (year and Julian day 5 digits continuously), solar radiation in MJ/m^2, temperature max and min (in that order) in Celsius, precipitation in mm.

Soil data input is found in the "crop" input window during model operation. If soil information is limited or lacking all together, predefined soil characteristics may be used.

Next farm management strategies should be selected to be aggregated around the biorefinery. These strategies should be represented/set-up using the IFSM user-interface. For any questions or concerns in IFSM refer to its built-in 'help manual'.

*From the report (.RPT) and summary (.SMR) output files in IFSM complete the data identification text files to correspond to the farm types. The data identification text files should be developed using the template files CRN.txt, SG.txt, CC.txt, A.txt, B.txt, C.txt, DYCRN.txt, DYALF.txt, and DYSG.txt. In these files the farm file numbers (SIM#) are listed first and can include only one file of that type up to approximately 20 files of that type (20 is not a fixed limitation, it is an approximate number of files at which the program will slow down). The other changes required in these data identification files are the line and column numbers for each data point, which are in that order at the end of each data line.

Once the data identification files are complete, they should be listed in "inputs.txt" along with their number per the in-file description. Once this file is updated and saved, the file "parse.py" should be run by either double clicking this file or running from a Python prompt. This process may require some troubleshooting due to inconsistent outputs. If the output files (SIM#A, SIM#B, SIM#C) stop at a number before the last the script has stalled on a file with incorrect line or column output. The problem can be identified by opening the last A, B, and C files and seeing which data item stopped the run. By opening the SMR file for this data item the line can be adjusted by moving it down (hitting enter) or moving it up (hitting backspace), or the column can be adjusted using the space bar (all columns must be at least 2 spaces apart). Once this change is saved, parse.py can be run again to complete outputs.

The SIM#A, B, and C file should now be imported into "BFIT.xls" on the corresponding "importX" tab/worksheet. To update already imported fields, the data should be highlighted, right-clicking on this field will include an option for "refresh data". From the pop-up window, choose the location/file to be used for the new A, B, and C outputs. For blank worksheet space, new data can be imported by going to the "data" menu and choosing "Import External Data – Import Data". From the pop-up window, choose the location/file to be used for the new A, B, and C outputs.*

As an alternative to the parsing function of the model described *above*, the user may simply look up the values in the IFSM outputs and type them by hand into the corresponding cells in "BFIT.xls", which are labeled with the output field required.

On the "Farms" tab/worksheet in "BFIT.xls" the farm distribution algorithm must be solved for each case using the "Solver" function in Excel. Solver can be accessed in the "Tools" menu. If it not available, it can be installed quickly in the "Add-ins" function in the same "Tools" menu. The previous run of the distribution algorithm will be available when Solver is opened, so all that needs to be updated are the line numbers. If a solution is not reached, it is because the values in "x, y, z, a, b, c" are too far from the solution and should be adjusted closer to other distributions.

On the "ASPEN" tab/worksheet inputs for the biorefinery model in ASPEN are already calculated. Using these numbers the user should open "base.bkp" in APSEN and open the "data browser" by clicking the eyeglasses icon/button. In the "Blocks" folders, sub-folder "A200", sub-folder "Blocks", sub-folder "A200-1", sub-folder "Blocks", is the feedback solid splitter called "FBSPLIT". On the "Specifications" tab for this equipment "202FB" should be selected for the "stream name" pull down. "MIXED-Split fraction" and "CISOLID-Split fraction" correspond to values given in "BFIT.xls". Next, in the "data browser" in the "Flowsheeting Options" folder, in the sub-folder "Calculator" is the "FEEDPROP" folder. On the "Calculate" tab the FSWG should be changed to the corresponding value given in "BFIT.xls". The simulation should be run by clicking the N-> button. To verify that the model has run without errors check the lower right corner and save file with a unique name for the landscape being simulated if it is error free.

To import the results of the APSEN model to the corresponding economics workbook begin on the "Stream Data" tab/worksheet in "Base.xls". On this sheet the user should click the "clear stream table" button, then click the "open simulation" button and choose the corresponding ASPEN file (.bkp). To import the results the use should click the "run simulation" button and wait for "ready" in Excel status bar (lower left corner). After data is imported and "ready" the used should click the "close simulation" button and terminate macro if it can't self terminate (this can be done by selecting the "open simulation" button and then choosing "cancel"). This sheet is now complete, and should be saved as with a unique name corresponding to the ASPEN file (.xls). To import the remaining data the user should move to tab/worksheet "Heat Streams" and repeat the series of buttons as above, then save. These steps will be repeated again for the tab/worksheet "Work Streams" and the tab/worksheet "MASSFLOW Data".

The "Base.xls" workbook also requires updates for biorefinery parameters. In the "EQUIP" tab/worksheet the Biorefinery Scale should be updated in cell B3 (this is simply the six of the biorefinery in ton/day over 5000). In this same sheet the fraction of switchgrass should be updated (FEEDPROP). In the "OPCOST" tab/worksheet the Total Participation Radius, which should be selected for the chosen farmer participation in the corresponding "BFIT.xls" file, should be updated in cell B3. In the "DCFROR" tab/worksheet a variety of economic can be updated if so desired (electricity price should be changed in "OPCOST"). After updating, in the "DCFROR" tab/worksheet, the "solve ethanol price" macro should be run and the final results of the model economics can be found on the tab/worksheet "SUMMARY". At this time the file should be saved. If an alternate participation radius is being considered it may be changed in "OPCOST" and the "solve ethanol price" macro run again. This should then be "saved as" a different file name.

From the "SUMMARY" tab/worksheet several values should be copied and pasted into "BFIT.xls". Only the values should pasted, this can be done using "paste special" and selecting the "values" radio button, so as to not transfer the equations. The values to be transferred are listed in the left most column of the "Location" tab/worksheet in "BFIT.xls" and can be found, in order, in the following cells in "SUMMARY": F34, F35, D5, B27, D7, and D9. The "Location" tab/worksheet in "BFIT.xls" now contains all the agricultural and industrial emissions and economics, individually, as well as the combined "footprint" of emissions.

REFERENCES

REFERENCES

[1] Lavigne A, Powers SE (2007). Evaluating fuel ethanol feedstocks from energy policy perspectives: A comparative energy assessment of corn and corn stover. Energy Policy 35: 5918-5930.

[2] Service RF (2007). Cellulosic Ethanol: Biofuel Researchers Prepare To Reap a New Harvest. Science 315:1488-1491.

[3] USDA, USDOE (2005). Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. DOE Biomass Program, www.osti.gov/bridge.

[4] Greene N, et al. (2004). Growing Energy: How Biofuels Can Help End America's Oil Dependence. Natural Resources Defense Council.

[5] Ragauskas AJ, et al. (2006). The Path Forward for Biofuels and Biomaterials. Science 311:484-489.

[6] Baker A, Zahniser S (2007). Update: Ethanol reshapes the corn market. Amber Waves 5:66-71.

[7] Carolan JE, Joshi SV, Dale BE (2007). Technical and Financial Feasibility Analysis of Distributed Bioprocessing Using Regional Biomass Pre-Processing Centers. J Ag Food Ind Org 5(2):Article 10.

[8] Clark WC, Dickson NM (2003). Sustainability science: The emerging research program. PNAS 100(14):8059-8061.

[9] Kates RW, Clark WC (1999). Our Common Journey-Executive Summary. National Academy Press (Washington, DC).

[10] Blottnitz HV, Curran MA (2007). A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. J Cleaner Prod 15:607-619.

[11] Bals, BD (2008). Personal communication. Biomass Conversion Research Laboratory, Michigan State University.

[12] Ohara H (2003). Biorefinery. Appl Microbiol Biotechnol 62(5-6):474-477.

[13] Kamm B, Kamm M (2004). Principles of Biorefineries. Appl Microbiol Biotechnol 64(2):137-145.

[14] USDOE (2006). Breaking the Biological Barriers to Cellulosic Ethanol: A Joint Research Agenda, DOE/SC/EE-0095, U.S. Department of Energy Office of

Science and Office of Energy Efficiency and Renewable Energy, genomicsgtl.energy.gov/biofuels/.

[15] Seader JD, Henley EJ (1998). Separation Process Principles. John Wiley & Sons (New York, NY).

[16] Grady CPL, Daigger GT, Lim HC (1999). Biological Wastwater Treatment, 2nd ed. CRC Press (New York, NY).

[17] Dale BE, Moreira MJ (1982). A Freeze Explosion Technique for Increasing Cellulose Hydrolysis. Biotech Bioeng 24(12):31-43.

[18] Mosier N, Wyman C, Dale B, Elander R, Lee YY, Holtzapple M, Ladisch M (2005). Features of promising technologies for pretreatment of lignocellulosic biomass. Biores Tech 96(6):673-686.

[19] Sendich ED, Laser M, Kim S, Alizadeh H, Laureano-Perez L, Dale BE, Lynd L (2008). Recent Process Improvements for the Ammonia Fiber Expansion (AFEX) Process and Resulting Reductions in Minimum Ethanol Selling Price. Biores Tech 99(17):8429-8435.

[20] Laser M, Jin H, Jayawardhana K, Larson ED, Celik F, Lynd LR (2008). Co-production of Ethanol and Power from Switchgrass. Biomass Bioenergy In Press.

[21] Eggeman T, Elander R (2005). Process and economic analysis of pretreatment technologies. Biores Tech 96(18):2019-2025.

[22] Kudra T, Mujumdar AS (2002). Advanced Drying Technologies. Marcel Dekker, Inc. New York, NY.

[23] Pronyk C, Cenkowski S (2003). Superheated Steam Drying Technologies. ASAE Meeting Presentation Paper Number RRV03-0014.

[24] Lynd LR, van Zyl WH, McBride JE, Laser M (2005). Consolidated bioprocessing of cellulosic biomass: an update. Current Op Biotechnol 16 (5), 577-583.

[25] Lynd LR (2006). Activities of the Research Group Led by Professor Lee Lynd. Thayer School of Engineering at Dartmouth College, engineering.dartmouth.edu/thayer/research/llrs.html.

[26] USDOE, 2008. Biomass Feedstocks. DOE Biomass Program, www1.eere.energy.gov/biomass/biomass_feedstocks.html.

[27] Rotz CA, Coiner CU (2006). The Integrated Farm System Model: Reference Manual. USDA-ARS Pasture System and Watershed Management Research Unit.

[28] Kumar A, Sokhansanj S (2007). Switchgrass (Panicum virgatum, L.) delivery to a biorefinery using integrated biomass supply analysis and logistics (ISBAL) model. Biores Tech 98:1033-1044.

[29] Walsh ME (1998). US Bioenergy Crop Economic Analyses: Status and Needs. Biomass Bioenergy 14(4):341-350.

[30] Walsh ME, Becker D (1996). BIOCOST: a Software Program to Estimate the Cost of Producing Bioenergy Crops. Oak Ridge National Laboratory, bioenergy.ornl.gov/papers/bioen96/walsh2.html.

[31] Bittman S, Hunt DE, Shaffer MJ (2001). NLOS (NLEAP On STELLA) – A Nitrogen Cycling Model with a Graphical Interface: Implications for Model Developers and Users. In: Shaffer MJ, Ma L, Hansen S, editors. Modeling Carbon and Nitrogen Dynamics for Soil Management, CRC Press (Boca Raton FL):383-402.

[32] Wilkins RJ (2008). Eco-efficient approaches to land management: a case for increased integration of crop and animal production systems. Phil Trans Royal Soc B Bio Sci 363(1491):517-525.

[33] Del Grosso SJ, Parton WJ, Mosier AR, Hartman MD, Brenner J, Ojima DS, et al. (2001). Simulated Interaction of Carbon Dynamics and Nitrogen Trace Gas Fluxes Using the DAYCENT Model. In: Shaffer MJ, Ma L, Hansen S, editors. Modeling Carbon and Nitrogen Dynamics for Soil Management, CRC Press (Boca Raton FL):303-332.

[34] Schils RLM, Olesen JE, del Prado A, Soussana JF (2007). A review of farm level modeling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. Livestock Science 112(3):240-251.

[35] Groenendaal H, Galligan DT, Mulder HA (2004). An Economic Spreadsheet Model to Determine Optimal Breeding and Replacement Decisions for Dairy Cattle. J Dairy Sci 87:2146-2157.

[36] Wolfova M, Wolf J, Přibyl J, Zahrádková R, Kica J (2005). Breeding objectives for beef cattle used in different production systems: 1. Model development. Livestock Prod Sci 95:201-215.

[37] USDA (2006). Commodity Costs and Returns: U.S. and Regional Cost and Return Data (Most Recent 2 Years, 2005-06). Economic Research Service, www.ers.usda.gov/Data/CostsAndReturns/testpick.htm.

[38] van Ouwerkerk ENJ, Richard TL, Anex RP (2007). Web based and Database Driven Support Tool for Integrated Farming. Farming Systems Design 07:2.

[39] van Ouwerkerk ENJ (2003). I-FARM Short Description. Iowa State University, www.i-farmtools.org/i-farm/i-farm_short_description.asp.

[40] Rotz CA, Buckmaster DR, Mertens DR, Black JR (1989). DAFOSYM: A Dairy Forage System Model for Evaluating Alternatives in Forage Conservation. J Dairy Sci 72(11):3050-3063.

[41] Guinee JB (2002). Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Kluwer Acedemic Publishers (Dordrecht Netherlands).

[42] Lynd LR, Wyman C, Laser M, Johnson D, Landucci R (2005). Strategic Biorefinery Analysis: Review of Existing Biorefinery Examples. NREL Subcontract Report NREL/SR-510-34895.

[43] Teymouri F, Laureano-Perez L, Alizadeh H, Dale BE (2005). Optimization of the ammonia fiber explosion (AFEX) treatment parameters for enzymatic hydrolysis of corn stover. Biores Technol 96(18):2014-2018.

[44] Eggeman T (2001). Ammonia Fiber explosion Pretreatment for Bioethanol Production. Midwest Research Institute National Renewable Energy Laboratory Division.

[45] Eidman VR (2007). Economic Parameters for Corn Ethanol and Biodiesel Production. J Ag Appl Econ 39(2):345-356.

[46] Ma L, Shaffer MJ (2001). A Review of Carbon and Nitrogen Processes in Nine U.S. Soil Nitrogen Dynamics Models. In: Shaffer MJ, Ma L, Hansen S, editors. Modeling Carbon and Nitrogen Dynamics for Soil Management, CRC Press (Boca Raton FL):55-102.

[47] Marchetti R, Donatelli M, Spallacci P (1997). Testing Denitrification Functions of Dynamic Crop Models. J Envir Qual 26:394-401.

[48] Adler PR, Del Grosso SJ, Parton WJ (2007). Life-Cycle Assessment of Net Greenhouse-Gas Flux for Bioenergy Cropping Systems. Eco App 17(3):675-691.

[49] Parton WJ, Holland EA, Del Grosso SJ, Hartman MD, Martin RE, Mosier AR, et al. (2001). Generalized model for NOx and N2O emissions from soils. J Geophys Research 106(D15):403-417.

[50] Keough C (2006). Personal correspondence. Natural Resource Ecology Laboratory, Colorado State University.

[51] Rotz CA (2006). Personal correspondence. USDA-ARS-Pasture Systems and Watershed Management Research Unit, Penn State University.

[52] van Ouwerkerk, ENJ (2006). Personal correspondence. Department of Agricultural and Biosystems Engineering, Iowa State University.

[53] Corson MS, Rotz CA, Skinner H, Sanderson MA (2007). Adaptation and evaluation of the integrated farm system model to simulate temperate multiple-species pastures. Ag Sys 94:502-508.

[54] Anex RP, Lynd LL, Laser MS, Heggenstaller AH, Liebman M (2007). Potential for Enhanced Nutrient Cycling through Coupling of Agricultural and Bioenergy Systems. Crop Sci 47:1327-1335.

[55] No-till on the Plains (2008). "Articles and resources for no-till management practices". www.notill.org.

[56] Rodale Institute (2007). Researchers roll out the details of 2006 no-till organic corn numbers. www.newfarm.org/depts/notill/features/2007/0307/cornresearch.shtml.

[57] Lal R, Griffin M, Apt J, Lave L, Morgan MG (2004). ECOLOGY: Managing Soil Carbon. Science 304(5669):393.

[58] USDA (2002). Agriculture Atlas: Inventory and Acreage Charts. National Agricultural Statistics Service, www.nass.usda.gov/research/atlas02.

[59] USDA (2006). Soil Geochemistry Spatial Database. National Resource Conservation Service, soils.usda.gov/survey/geochemistry/index.html.

[60] NOAA (2006). Cooperative Summary of the Day US, Puerto Rico, Virgin Islands with Cognate. National Climatic Data Center, CD.

[61] USDA (2006). Average Farm Size by State 2006. National agricultural Statistics Service, www.nass.usda.gov/Charts_and_Maps/Farms_and_Land_in_Farms/fncht6.asp.

[62] USDA (2006). Agricultural Statistics Data Base – U.S. and State Data. National Agricultural Statistics Service, www.nass.usda.gov/Data_and_Statistics/Quick_Stats/.

[63] Jensen K, Clark CD, Ellis P, English B, Menard J, Walsh M, Ugarte DT (2007). Farmer willingness to grow switchgrass for energy production. Biomass Bioenergy 31:773-781.

[64] Mapemba LD, Epplin FM, Taliaferro CM, Huhnke RL (2007). Biorefinery Feedstock Production on Conservation Reserve Program Land. Review Ag Econ 29(2):227-246.

[65] Lemus R, Brummer EC, Moore KJ, Molstad NE, Burras CL, Barker MF (2002). Biomass yield and quality of 20 switchgrass populations in southern Iowa, USA. Biomass Bioenergy 23:433-442.

[66] Schmer MR, Vogel KP, Mitchell RB, Perrin RK (2008). Net energy of cellulosic ethanol from switchgrass. PNAS 105(2):464-469.

[67] Hoskinson RL, Karlen DL, Stuart JB, Radtke CW, Wilhelm WW (2007). Engineering, nutrient removal, and feedstock conversion evaluations of four corn stover harvest scenarios. Biomass Bioenergy 31:126-136.

[68] Blanco-Canqui H, Lal R (2007). Soil crop response to harvesting corn residues for biofuel production. Geoderma 141:355-362.

[69] Graham RL, Nelson R, Sheehan J, Perlack RD, Wright LL (2007). Current and Potential US Corn Stover Supplies. Agron J 99:1-11.

[70] Shinners KJ, Binversie BN, Muck RE, Weimer PJ (2007). Comparison of wet and dry corn stover harvest and storage. Biomass Bioenergy 31:211-221.

[71] Singer JW, Kaspar TC, Pedersen P (2005). Small grain cover crops for corn and soybean. Fact Sheet PM1999, www.extension.iastate.edu/pubs/Masterlist4.html#1800.

[72] Rotz CA (2007). Personal Communication. USDA-ARS-Pasture Systems and Watershed Management Research Unit, Penn State University.

[73] Wilkes HL (2007). Estimated production cost budgets for biomass: Switchgrass, 'Highlander' Eastern Gamagrass, Indiangrass, and Big Bluestem. USDA Natural Resource Conservation Service Plant Material Program, Plant Materials Technical Note No. 102:1-18.

[74] Pimentel D, Patzek TW (2005). Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower. Nat Res Research 14(1):65-76.

[75] Perrin R, Vogel K, Schmer M, Mitchell R (2008). Farm-Scale Production Cost of Switchgrass for Biomass. Bioenergy Res In Press.

[76] Novozymes USA (2005). Novozymes and NREL reduce enzyme cost. Focus on Catalysts 2005(7):4.

[77] Peters MS, Timmerhaus KD, West RE (2003). "Equipment pricing charts" in Plant design and economics for chemical engineers, 5th ed. (New York, NY).

[78] Bouzoubaâ N, Fournier B (2001). Concrete Incorporating Rice-Husk Ash: Compressive Strength and Chloride-Ion Penetrability. Materials Technology Laboratory MTL 2001-5 (TR):1-17.

[79] Mehta PK (1999). Advancements in Concrete Technology. Concrete International June 1999:69-76.

[80] Hemmings RT (2004). Evaluation of GVRD Municipal Incinerator Ash as a Supplementary Cementing Material in Concrete. AMEC Report No. VA06294:1-74.

[81] The Fly Ash Resource Center (2008). Fly Ash: Marketplace. www.rmajko.com/marindex.html.

[82] Fly Ash Direct (2008). Our Services. www.flyashdirect.com.

[83] Glass J (2008). Personal Communication: Fly-ash selling price year end 2005. Headwaters, Inc.

[84] Wang M, Wu Y, Elgowainy A (2007). Operating Manual for GREET: Version 1.7. Center for Transportation Research, Argonne National Laboratory Research report ANL/ESD/05-3, www.transportation.anl.gov/pdfs/TA/353.pdf.

[85] NOAA (2008). Calculated Soil Moisture (Map). Soil Wetness Climatology, http://www.cpc.ncep.noaa.gov/soilmst/wfull_mm_frame.html.

[86] Turhollow AF, Sokhansanj S (2007). Costs of Harvesting, Storing in a Large Pile, and Transporting Corn Stover in a Wet Form. Appl Eng Ag 23(4):439-448.

[87] Balci O (1997). Verification, Validation, and Accreditation of Simulation Models. Proceedsings of the 1997 Winter Simulation Conference, ed. S Andradottir, KJ Healy, DH Withers, BL Nelson.

[88] Macal CM (2005). Model Verification and Validation. Workshop on "Threat Anticipation: Social Science Methods and Models", Univeristy of Chicago and Argonne National Laboratory.

[89] Eranki P (2008). Personal Correspondance: scenario testing and verification of BFIT. Biomass Conversion Research Laboratory, Michigan State University.

[90] Vale M, Mary B, Justes E (2007). Irrigation practices may affect denitrification more than nitrogen mineralization in warm climatic conditions. Biol Fertil Soils 43(6):641-651.

[91] USDOE (2007). DOE Selects Six Cellulosic Ethanol Plants for Up to $385 Million in Federal Funding. COE Press Release, www.energy.gov/news/4827.htm.

[92] Kaparaju P, Ellegaard L, Angelidaki I (2008). Optimisation of biogas production from manure through serial digestion: Lab-scale and pilot-scale studies. Biores Tech In Press.

[93] Uemura S, Ohashi A, Harada H, Hoaki T, Tomozawa T, Ohara T, Ojima R, Ishida T (2008). Production of biologically safe digested manure for land application by a full-scale biogas plant with heat-inactivation. Waste Manag Res 26(3):256-260.

[94] Amon T, Amon B, Kryvoruchko V, Zollitsch W, Mayer K, Gruber L (2007). Biogas production from maize and dairy cattle manure – Influence of biomass composition on the methane yield. Ag Eco Enviro 118(1-4):173-182.

[95] Borjesson P, Berglund M (2007). Environmental systems analysis of biogas systems – Part II: The environmental impact of replacing various reference systems. Biomass Bioenergy 31(5):326-344.

[96] Dillehay BL, Roth GW, Calvin DD, Kratochvil RJ, Kuldau GE, Hyde JA (2004). Performance of Bt Corn Hybrids, their Near Isolines, and Leading Corn Hybrids in Pennsylvania and Maryland. Agron J 96:818-824.

[97] Dou Z, Kohn RA, Ferguson JD, Boston RC, Newbold JD (1996). Managing Nitrogen on Dairy Farms: An Integrated Approach I. Model Description. J Dairy Sci 79(11):2071-2080.

[98] Zhu Y, Fox RH (2003). Corn–Soybean Rotation Effects on Nitrate Leaching. Agron J 95:1028-1033.

[99] Zhongbo Y, Gburek WJ, Schwartz FW (2000). Evaluating the spatial distribution of water balance in a small watershed, Pennsylvania. Hydrological Processes 14(5):941-956.

[100] Roygard JKF, Alley MM, Khosla R (2002). No-Till Corn Yields and Water Balance in the Mid-Atlantic Coastal Plain. Agron J 94:612-623.

[101] Bordoli JM, Mallarino AP (1998). Deep and Shallow Banding of Phosphorus and Potassium as Alternatives to Broadcast Fertilization for No-Till Corn. Agron J 90:27-33.

[102] Karlen DL, Kramer LA, Logsdon SD (1998). Field-Scale Nitrogen Balances Associated with Long-Term Continuous Corn Production. Agron J 90:644-650.

[103] Dinnes DL, Karlen DL, Jaynes DB, Kaspar TC, Hatfield JL, Colvin TS, Cambardella CA (2002). Nitrogen Management Strategies to Reduce Nitrate Leaching in Tile-Drained Midwestern Soils. Agron J 94:153-171.

[104] Dale RF, Shaw RH (1965). The climatology of soil moisture, atmospheric evaporative demand, and resulting moisture stress days for corn at Ames, Iowa. J App Meterol 4(6):661-669.

[105] Gilley JE, Doran JW, Karlen DL, Kaspar TC (1997). Runoff, erosion, and soil quality characteristics of a former conservation reserve program site. J Soil Water Conserv 52(3):191-193.

[106] Lory JA, Scharf PC (2003). Yield Goal versus Delta Yield for Predicting Fertilizer Nitrogen Need in Corn. Agron J 95:994-999.

[107] Jaynes DB, Colvin TS, Karlen DL, Cambardella CA, Meek DW (2001). Nitrate Loss in Subsurface Drainage as Affected by Nitrogen Fertilizer Rate. J Environ Qual 30:1305-1314.

[108] David MB, McIssac GF, Royer TV, Darmody RG, Gentry LE (2001). Estimated Historical and Current Nitrogen Balances for Illinois. Scientific World 1:597-604.

[109] Bowman JA, Collins MA (1987). Impacts of Irrigation and Drought on Illinois ground-water resources. State of Illinois: Dept. of Energy and Natural Resources, Report of Investigation 109.

[110] Hussain I, Olson KR, Siemens JC (1998). Long-term effects on physical properties of eroded soil. Soil Sci 163(12):970-981.

[111] Grandy AS, Loecke TD, Parr S, Robertson GP (2006). Long-Term Trends in Nitrous Oxide Emissions, Soil Nitrogen, and Crop Yields of Till and No-Till Cropping Systems. J Environ Qual 35:1487-1495.

[112] Jose S, Gillespie AR, Seifert JR, Mengel DB, Pope PE (2000). Defining competition vectors in a temperate alley cropping system in the Midwestern USA: 3. Competition for nitrogen and litter decomposition dynamics. Agroforestry Systems 48(1):61-77.

[113] Unterreiner GA, Kehew AE (2005). Spatial and Temporal Distribution of Herbicides and Herbicide Degradates in a Shallow Glacial Drift Aquifer/Surface Water System, South-Central Michigan. Ground Water Monitoring & Remediation 25:87-95.

[114] Jung GA, Shaffer JA, Stout WL, Panciera MT (1990). Warm-Season grass diversity in yield, plant morphology, and nitrogen concentration and removal in northeastern USA. Agron J 82:21-26.

[115] Ehlke MH, Lloyd AR (1999). Comparison of methods for computing streamflow statistics for Pennsylvania streams. US Geological Survey/PA-DOT Water-Resources Investigations Report 99-4068.

[116] Kleinman PJA, Sharpley AN, Veith TL, Maguire RO, Vadas PA (2004). Evaluation of Phosphorus Transport in Surface Runoff from Packed Soil Boxes. J Environ Qual 33:1413-1423.

[117] Belesky DP, Fedders JM (1995). Warm-season grass production and growth rate as influenced by canopy management. Agron J 87:42-48.

[118] Beaty ER, Tan KH, McCreery RA, Jones JB (1975). Root-herbage production and nutrient uptake retention by Bermudagrass and Bahiagrass. J Range Manag 28:385-388.

[119] Stout WL, Weaver SR, Gburek WJ, Folmar GJ, Schnabel RR (2000). Water quality implications of dairy slurry applied to cut pastures in the northeast USA. Soil Use Manag 16(3):189-193.

[120] Johnson EA, Kovner JL (1956). Effect on streamflow of cutting a forest understory. Forest Sci 2:82-91.

[121] Christopher Jr. EA (2002). Post Harvest Evaluation of Best Management Practices for the Prevention of Soil Erosion in Virginia. Master's Thesis, Virginia Polytechnic Institute and State University.

[122] Vogel KP, Brejda JJ, Walters DT, Buxton DR (2002). Switchgrass Biomass Production in the Midwest USA: Harvest and Nitrogen Management. Agron J 94:413-420.

[123] Ehrenreich JH, Aikman JM (1963). An Ecological Study of the Effect of Certain Management Practices on Native Prairie in Iowa. Ecological Monographs 33:13-130.

[124] Frank DA, Inouya RS (1994). Temporal variation in actual evapotranspiration of terrestrial ecosystems: patterns and ecological implications. J Biogeography 21:401-411.

[125] Lee KH, Isenhart TM, Schultz RC, Mickelson SK (2000). Multispecies Riparian Buffers Trap Sediment and Nutrients during Rainfall Simulations. J Environ Qual 29:1200-1205.

[126] Faix JJ, Kaiser CJ, Hinds FC (1980). Quality, Yield, and Survival of Asiatic Bluestems and an Eastern Gamagrass in Southern Illinois. J Range Manag 33:388-390.

[127] Old SM (1969). Microclimate, Fire, and Plant Production in an Illinois Prairie. Ecological Monographs 39:355-384.

[128] Mitsch WJ, Day Jr. JW, Gilliam JW, Groffman PM, Hey DL, Randall GW, et al. (1999). Reducing Nutrient Loads, Especially Nitrate–Nitrogen, to Surface Water, Ground Water, and the Gulf of Mexico. NOAA Coastal Ocean Program: Decision Analysis Series 1999 No. 19.

[129] Graham RI, Walsh ME (1999). A National Assessment of Promising Areas for Switchgrass, Hybrid Poplar, or Willow Energy Crop Production. USDOE/ORNL Report 1999 ORNL-6944.