THE POTENTIAL OF PRODUCING BIOENERGY CROPS ON CONSERVATION RESERVE PROGRAM LAND IN MISSOURI, IOWA, NEBRASKA, AND KANSAS (MINK REGION) TO MITIGATE CARBON DIOXIDE EMISSIONS: AN INTEGRATED ECONOMICS AND BIOLOGICAL MODELING APPROACH

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by

LOISE N. WAMBUGUH

Dr. Bruce Cutter, Dissertation Supervisor

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The undersigned, appointed by the dean of Graduate School, have examined the dissertation entitled

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Presented by Loise N. Wambuguh

A candidate for the degree of Doctoral of Philosophy,

And hereby certify that, in their opinion, it is worthy of acceptance.

Dr. Bruce E. Cutter

Dr. Harold E. Garrett

Dr. Francisco X. Aguilar

Dr. Verel W. Benson

Dr. Abner W. Womack

Dr. Patrick Westhoff

DEDICATION

This dissertation is dedicated to the following people:

- The memory of my late father, Bernard Kariuki, who emphasized the importance of education and who instilled in me the confidence to achieve my goals.

- To my mother, Beatrice Wangari, my role model for hard work, persistence, and the rewards of personal sacrifice.

- To my husband, Dennis Wambuguh, who has been endlessly encouraging and proud of my work and has shared many of the challenges in the course of finishing this dissertation.

- To my daughters Patricia, Pamela, and Jacqueline who, incredibly, managed to graduate through college despite the long absences from their mother while she worked on this dissertation.

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If today, I see a little further and deeper, it is only because I stood on the shoulders of these giants, to paraphrase Isaac Newton.

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ABSTRACT

Concerns about global warming and subsequent climate change have generated increasing interest in development of bioenergy crops as a potential source of low-carbon energy. Because power generation emits significant amounts of greenhouse gases (mainly CO2), sequestering carbon in biomass energy crops such as poplar and switchgrass coupled with cofiring has the potential to reduce emissions and fossil fuel consumption. Biomass energy brings along numerous economic and environmental benefits. This analysis evaluates the environmental and economic impacts of putting the U.S. CRP land under bioenergy crops.

The APEX model was used to evaluate the potential of switchgrass and hybrid poplar as biomass feedstock, potential to sequester soil carbon and provide other environmental co-benefits including improvement of soil and water quality in the Midwest (MINK region). Biomass yields and change in soil organic carbon varied with the bioenergy crop, soil type, climatic conditions, and cultural management. Converting CRP land into bioenergy crop production and adopting conservation management practices significantly reduced sediment loss, N and P loading into water bodies relative to traditional food crop production under conventional and conservation tillage practices.

The economic impacts of reverting CRP land into traditional food crop production show modest declines in the prices of major U.S. commodities and savings of nearly $ 1.7 billion annually on CRP rental payments by federal government. Planting buffers on some of the cropland currently under tradition crop production has insignificant impact on commodity prices. Policymakers benefit greatly from quantified information on environmental and economic effects of producing large-scale bioenergy crops in their quest to develop sustainable and balanced energy, agricultural, and environmental policies.

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CHAPTER 1

INTRODUCTION

Global warming and the resulting climate change is one of the greatest environmental concerns facing the world today. The concern arises out of the apprehension that human activities, particularly burning of fossil fuel and land use, have increased the level of carbon dioxide (CO_2) in the atmosphere and the consequent global warming. In the 1980s, the annual anthropogenic carbon emitted into the atmosphere was estimated at 7.1 billion tons, of which three-quarters were from fossil fuel combustion. These emissions were estimated to contribute roughly 3.3 billion tons of carbon accumulation in the atmosphere annually (Houghton 2004).

Policymakers in the United States are working in partnership with the scientific community to develop cost-effective ways of reducing CO_2 and other greenhouse gas (GHG) emissions associated with anthropogenic activities. This partnership has prompted an interest to develop integrated agricultural, energy, and environmental policy objectives. For example, the U.S. Congress enacted the Energy Independence & Security Act of 2007 (EISA, H.R. 6). The EIAS intends to increase production of renewable fuel, under 2005 Renewable Fuel Standard (RFS), from 9.0 billion gallons in 2008 to 36 billion gallons by 2022 (P.L. 110-140). In addition, Congress is currently debating on the American Clean Energy Security Act of 2009 (ACES, H.R. 2454). The ACES is a proposed comprehensive system of energy and climate change legislation that intends to establish a nationwide cap-and-trade program to limit GHG emissions by 17% below 2005 levels by 2020 and by 83% below 2005 levels by 2050 (U.S. House of Representatives 2010).

Under the cap-and-trade program of H.R. 2454, agricultural and forestry sectors are not regulated. Instead, landowners are encouraged to sell GHG offsets to regulated entities, including producers and users of fossil fuel energy. Initial assessments of GHG reduction policies indicate there is an opportunity for landowners to increase their income not only from sales of biomass feedstock and GHG offsets but also through high crop prices from land use competition (USDA 2009, Baker et al. 2009, and De La Torre Ugarte et al. 2009). Due to the complexity and uncertainties associated with greenhouse gas emissions, continued research on their economic, social, and environmental effects is required in order to provide informed debate to GHG policy development and implementation.

Several studies have singly discussed the economic (De La Torre Ugarte et al. 2000, McCarl et al. 2003, De La Torre Ugarte et al. 2003, De La Torre Ugarte et al. 2004, Burton et al. 2006) and environmental effects (McLaughlin et al. 1998, McLaughlin et al. 2005, McDonald et al. 2006) of using agricultural cropland to mitigate CO_2 and other GHG emissions. Only a limited number of studies have considered the combined effects that result from situations in which croplands are managed and used simultaneously to reduce carbon dioxide emissions, sequester soil carbon, and to offer other environmental benefits including improvement of soil and water quality.

This dissertation evaluates the environmental and economic effects that arise from CO_2 mitigation policies designed to promote production of biomass energy in U.S. Conservation Reserve Program (CRP) acreage. Converting CRP land into bioenergy crop production and application of appropriate land management practices can enhance soil carbon sequestration and improve soil and water quality and, in addition, diversify landowner's sources of income and help develop of rural economies.

It is worthy to note that evaluation of economic impact of returning CRP acreage to food crop production and allocating some cropland to conservation buffer production was carried out prior to the implementation of the 2008 Farm Bill. Under the 2008 Farm Bill, the USDA decided to re-enroll and extend contracts but imposed a maximum limit of 12.95 Mha starting October 2009.

Carbon Dioxide Management

In order to slow global warming and avoid climate change disruptions, the Intergovernmental Panel on Climate Change (IPCC) recommended a reduction of 60 to 80% of 2001 carbon dioxide (CO_2) emission into the atmosphere (IPCC 2001). Fossil fuel combustion is the largest contributor to anthropogenic CO_2 emissions in the United States and the world, accounting for 56.6% of the global CO_2 emissions in 2004 (IPCC 2007) and about 98% (or 5,868 million metric tons) of the total 2004 carbon dioxide emissions in the United States (UNFCCC 2002). On the other hand, agricultural activities contributed about 17.3% of global atmospheric CO_2 emission through soil degradation and deforestation (IPCC 2007).

Global energy consumption has increased during the twentieth century and is predicted to increase by 50% from 2005 to 2030 (EIA, 2008). In the United States, total primary energy consumption is projected to increase from 98.2 quadrillion British Thermal Units (Btu) in 2003 to 133 quadrillion Btu in 2025 (EIA, 2008). Given that there are no indications of constraints in fossil fuel supplies in the near-term, an increase in atmospheric CO_2 concentration is likely to continue unless measures are taken to reduce anthropogenic CO_2 emissions (IPCC 2001; Hall et al. 2000).

Carbon sequestration technologies, such as capturing CO_2 emissions at the point of fossil fuel combustion before reaching the atmosphere and storing the emissions in geologic formations or deep in the oceans, have been suggested as one of the ways that might enable the use of fossil fuel while reducing the buildup of CO_2 in the atmosphere (U.S.DOE 1999). However, these technologies are currently in a developmental stage and their impact on environmental, economic and social entities continue to be evaluated. In the meantime, agriculture has proposed a means of reducing CO_2 emissions in the atmosphere through production of biomass feedstock for energy use and enhancing carbon storage in vegetation and soils.

The Role of Agriculture in CO_2 Mitigation

Almost all CO_2 emissions from agricultural are through conversion of grassland and forestland to cropland and through inappropriate land management such as overuse of agrochemicals and reduced ground cover. Despite this, the agricultural sector can be used to reduce global warming effects.

Previous policies in the United States and elsewhere that link the agriculture and energy sectors have focused primarily on the energy security problem (De La Torre Ugarte et al. 2000). Recently, however, there are considerations of expanding the energy-agriculture relationship to include global warming problems. The competition between energy and agriculture for limited resources (including land) has initiated discussions on possible use of marginal and degraded lands to mitigate CO_2 without negatively impacting food and fiber production (Hall et al. 1993; Williams 1994; Berndes and Hoogwijk 2003).

In the United States, policies for the USDA's Conservation Reserve Program (CRP) are mainly designed to conserve environmental benefits, including reduction in soil loss, improvement of water quality, and creation of wildlife habitat. However, with appropriate policy support, CRP acreage can be utilized to simultaneously enhance mitigation of carbon dioxide emissions, maintain the environmental objectives, and offer economics benefits including farm income and reduction in government expenditure. The U.S. government currently spends about $2 billion dollars per year as rental payments for landowners under CRP contracts to conserve environmental benefits (USDA 2008). The purpose of this dissertation is to quantify the environmental and economic effects of using CRP lands as a CO_2 mitigation strategy. This information will assist policymakers in agriculture and energy sectors to develop policies that will support the use of CRP and other idled agricultural lands to mitigate CO_2 emissions and to offer other environmental and economic benefits.

There are two ways that the CRP acreage can be used to mitigate atmospheric CO_2: 1) provision of biomass feedstock to substitute for fossil fuel energy, and 2) implementation of land management practices to enhance soil and biomass carbon sequestration.

Biomass Energy

Woody biomass has been used for heating and cooking by human throughout most history. It was the main source of global energy consumption until the mid-1800s when its share progressively declined (Davis 1990). Biomass resources provided about

13% of the world energy supply in 2006 (REN21 2008). Its largest contribution is in the developing world where biomass is a primary source of energy.

Despite the declining trend of biomass energy use in developed countries, biomass has regained considerable interest since the early 1990s. A growing number of countries are beginning to view biomass-based energy systems as an important policy tool to address problems such as increasing greenhouse gas emissions, alternative domestic energy sources, improvement of national environmental quality, and diversification of agricultural market opportunities.

Biomass-based energy systems, planted purposely for electricity production, are carbon neutral because combustion of biomass into energy does not contribute additional CO_2 in the atmosphere as occurs during fossil fuels combustion. This is primarily because plants extract carbon from the atmosphere through photosynthesis during growth and release carbon stored in biomass back into the atmosphere upon combustion, creating a "closed carbon-neutral cycle" with no net additional CO_2 into the atmosphere as long as the plant biomass combusted equals to the biomass planted in a given period (IPCC 2001).

Various studies on climate change show that use of biomass energy to substitute for fossil fuel in energy production could be an effective and sustainable strategy of addressing the global warming challenge because it can be carried out indefinitely (Cole et al. 1997; Paustian et al. 1998) and can also be used to reduce dependency on imported oil.

In the United States, electricity generation is one of the most significant sources of CO_2 emissions, representing roughly 40.6% of total U.S. energy-related CO_2 emissions in 2008 (USDOE/EIA 2008). Most CO_2 emissions related to electricity production come from coal-fired power plants, which are currently responsible for about 80% of the total CO_2 emissions from electricity production (USDOE/EIA 2008). While coal contributes about 50% of total electricity generated in the United States, it has the highest carbon intensity relative to all other fossil fuel sources.

At present, biomass energy provides about 4% of the total primary energy consumed in the United States. It is used to generate steam for electricity or heat production for industrial processes. Most of the biomass power boilers use direct-combustion technology to convert biomass into energy. At present these boilers are small with a capacity ranging between 20 to 50 Megawatts (MW) compared to coal-fired plants capacity in the range of 100 to 1500 MW. The small capacity of biomass combustion limits their energy conversion efficiency, estimated to be as low as 20% (USDOE 1999).

Development of more efficient conversion technologies is needed for biomass to be economically competitive with fossil fuel energy sources and for it to increase its share in the energy market (Larson 1993; Williams 1994; Johansson et al. 1996; Hall et al. 2000).

These technologies can be used to convert biomass into various energy carriers including liquid fuels, electricity, and biomass-gasification. In the U.S., biomass-gasification is in a development and demonstration stage. The Vermont Biomass Gasifier Project initiated in 1998 has the capacity to generate 50 MW of electric power and to convert 200 tons of biomass per day into gaseous fuel (USDOE 2000).

In the near-term, however, cofiring biomass and coal has been suggested as possibly the most promising and cost-effective option to reduce CO_2 emissions from electricity generation. Cofiring involves the use of existing coal-fired power plants to combust together a combination of biomass and coal (Boylan et al. 2000). According to the National Renewable Energy Laboratory (2000), cofiring 5 and 15% of biomass with coal would reduce CO_2 by 7 and 22%, respectively (USDOE 2000). In addition to reducing CO_2 emissions, cofiring biomass with coal can simultaneously reduce sulfur dioxide (SO_2) and nitrogen (NOx) emissions that are tied to acid rain and urban ozone pollution respectively (Easterly and Burnham 1996).

Bioenergy Crops

Growing bioenergy crops specifically for energy production is receiving increased attention as a potential renewable energy resource that could play an important role in reducing atmospheric CO_2 emissions. Hohenstein and Wright (1994) and Hall (1997) predict that bioenergy crop production has the potential to contribute 17-30% of global energy requirement by 2050. A study by Sampson et al. (1993) concluded that bioenergy crops could reduce CO_2 emissions in the atmosphere by 0.2 to 1.0 GtC[1] (Gigatonnes of carbon) per year. In order to reduce a significant amount of CO_2 emissions, large-scale bioenergy crop production would require to be implemented.

However, establishment of widespread biomass energy systems is not currently economically competitive with traditional food crop production and fossil fuel for energy uses. Several barriers including high costs of production, lack of an established market,

[1] 1 GtC = 1 billion metric tons of Carbon

and low development efficient technologies to convert biomass into useful energy contribute to the limited competition.

Selection of crops grown specifically for energy production is based on the crop's capacity to produce high biomass feedstock and ability to offer other ecological benefits, including conservation of soil and water and capacity to grow on marginal lands (Lemus and Lal 2005; McLaughlin et al. 1994). Since the late 1970s, the U.S. Department of Energy's Biofuel Feedstock Development Program (BFDP) at Oak Ridge National Laboratory has explored both short rotation woody crops and non-woody plants species for energy production. The BFDP has focused on switchgrass, hybrid poplar, and willow as model bioenergy crops that require further development for large-scale production and utilization (Ferrell et al. 1995).

Soil Carbon Sequestration

Soil carbon sequestration is defined as a process in which CO_2 is removed from the atmosphere through photosynthetic processes by plants and incorporated into the soil carbon pool with other nutrients, including nitrogen and phosphorus (Lemus and Lal 2005).

Globally, agricultural croplands occupy about 1.7 billion hectares with a soil carbon stock of about 170 GtC (Paustian et al. 2000). Agricultural activities contribute about 20% of atmospheric CO_2 emission through soil degradation and deforestation (IPCC 2001). Implementation of improved land management practices can be used to reverse agricultural lands from being net sources of CO_2 emissions to net carbon sinks.

Studies on agricultural soil carbon sequestration have concluded that agricultural land has the potential to sequester about 24 – 43 GtC over a 50 to 100 year period through improved management of cropland, marginal land, and restoration of degraded land (Houghton and Skole 1990; Cole et al. 1997; Paustian et al. 1998). While soil carbon sequestration options might be cost-effective in CO_2 mitigation, they are limited to near-term duration (estimated at 50-100 years) due to the finite capacity of soils to sequester carbon (Cole et al. 1997). However, these options can be used to 'buy time' as new carbon sequestration technologies are developed.

Land management practices including greater returns of organic carbon to the soil, reduced tillage, erosion control, and agroforestry systems have the potential to sequester atmospheric CO_2, thereby partially mitigating the current increases in atmospheric CO_2 (Kern and Johnson 1993; Lal and Kimble 1997).

Implementation of conservation tillage in marginal areas has the potential to increase soil carbon and long-term soil productivity through reduced soil erosion. Lal, et al (1998) estimated that conservation tillage can sequester a total carbon of 0.08 to 0.208 GtC in the soil. Kern and Johnson (1993) estimated that increases in no-till tillage from 27% to 76% would result in about an additional 0.2-0.3 GtC sequestered.

Purpose

The purpose of this dissertation is to quantify the combined economic and environmental effects of alternative policy scenarios aimed at targeting CRP land for CO_2 mitigation. The policy scenarios discussed include: 1) conversion of all current land under CRP into bioenergy crop production, 2) conversion of all current CRP land into traditional crop production, and 3) conversion of some traditional cropland into bioenergy crops as buffer conservation crops. The assumption made under policy scenarios 1) and 2) is that conservation tillage practices would be utilized to allow continuation of current environmental conservation objectives of the CRP. A biophysical and economic modeling system was developed to predict the likely variability of biomass feedstock supply and environmental effects associated with bioenergy crop production in Missouri, Iowa, Nebraska and Kansas, the MINK region. The system was also used to evaluate the economic effects on farm income and U.S. commodity prices. Information from the study is intended to assist federal and state, policymakers and agencies with quantitative information as they debate on long term investment in biomass-based energy development and sustainable use of CRP land.

Objectives of the Study

1) To evaluate and compare farm-level environmental effects of producing bioenergy and traditional crops under various tillage management practices on CRP land.
2) To determine economic effects of converting CRP acreage into bioenergy crop production.
3) To determine the economic effects of converting CRP acreage into traditional food crop production.

Hypotheses

1) Conversion of CRP land into bioenergy crop production can mitigate CO_2 emissions, reduce soil erosion, and runoff compared to conventional crop production.
2) Bioenergy crop production on CRP acreage can provide sustainable farm economic returns and reduce government expenditures on CRP.

Organization of the Study

Chapter 2 presents and defines the carbon cycle, CO_2 emissions, greenhouse effect, and global warming as well as policies and strategies aimed at using agriculture to offset CO_2 emissions. A literature review on CRP land, bioenergy crop production and their environmental co-benefits are presented in Chapter 3. Biophysical and economic models are discussed in Chapter 4, followed by Chapter 5 on data source and methodology. Chapter 6 contains the results and discussions followed by conclusions in Chapter 7.

CHAPTER 2

AN OVERVIEW OF CO_2 EMISSIONS

Carbon dioxide (CO_2) is one of the major greenhouse gases released to the atmosphere as a result of human activities, particularly combustion of fossil fuel for energy use and large-scale land use change which contribute roughly 56.6% and 17.3% of the total greenhouse gases (IPCC 2007). While natural processes such as photosynthesis absorb about 55% of these emissions, the remaining 45% or 3.3 GtC is added to the atmosphere annually resulting in continued increase in atmospheric concentration of CO_2 and a subsequent rise in global surface temperature (Houghton 2004).

Carbon Cycle

Concentrations of CO_2 in the atmosphere are naturally regulated by numerous processes collectively identified in the “carbon cycle”. The global carbon cycle is currently the topic of great interest because of its importance in global warming debate and because the human activities are, to a certain degree, altering the balance between carbon sources and carbon sinks.

The term carbon cycle is used to describe the exchange of carbon (in various forms) among its reservoirs including the atmosphere, ocean, terrestrial biosphere, and geological deposits (IPCC 1997). The carbon exchanges between its reservoirs involve various chemical, physical, geological and biological processes making the global carbon cycle one of the most complex and significant biogeochemical cycles (NASA 2009). The cycle is composed of both geological and biological carbon cycle components. While the geological carbon cycle involves weathering processes in the formation of carbonate sedimentary rocks such as limestone or in fossil fuel deposits and operates on a time scale of millions of years, the biological cycle involves carbon that is in land, ocean and in the atmosphere.

Unlike the geological cycle, the biological carbon cycle operates on a time scale of days to thousands of years and is the most important cycle in the discussions of the human activities and CO_2 emissions. The cycle involves the movement of carbon between the atmosphere and land (vegetation and soils) and between the atmosphere and surface water of the oceans. The land-atmospheric carbon cycle entails absorbing CO_2 from the atmosphere through photosynthesis and incorporating it as carbon in plant biomass. Plant biomass ultimately decays releasing CO_2 back into the atmosphere or storing organic carbon in soil or rock (Follett 2001).

Carbon dioxide and other greenhouse gas emissions have both natural and human-made emission sources. Whereas natural processes, both land-based and ocean-based "sinks", play a significant role of removing these emissions from the atmosphere, human-made emissions increase the total level of greenhouse gas emissions above their natural absorption rate.

For several thousands of years, prior to the beginning of the industrial revolution, atmospheric-land and atmospheric-ocean carbon fluxes were generally at equilibrium and the level of CO_2 in the atmosphere were relatively stable (Leggett 1990). However the increase in anthropogenic CO_2 emissions that has been observed since the industrial revolution has gradually increased the earth's average surface temperature, creating the human-induced global warming conditions that may be currently affecting global climate (Houghton 2004).

Greenhouse Effects

The greenhouse effect results from the fact that certain atmospheric gases are more transparent to the short-wave radiation from the sun than they are to the long-wave re-radiation from the earth's surface.

When shortwave solar radiation heats the earth's surface and the oceans, they in turn emit radiation back to space mostly in longer wavelengths, known as infrared radiation (IR). Some atmospheric gases, known as greenhouse gases (GHGs), allow incoming solar radiation to pass through the atmosphere, but absorb the outgoing IR radiation and re-radiate the absorbed energy in all directions including downward to the earth's surface, thus, resulting in a greenhouse effect. The natural process of absorption and re-radiation by greenhouse gases creates a natural greenhouse gas effect. Without the natural greenhouse effect, the earth's annual average surface temperature would be -18^0Celsius, rather than $+15^0$ Celsius which makes the earth habitable (Houghton 2004).

The most significant infrared-trapping gases in the earth's atmosphere are: water vapor which contributes about 60% of the greenhouse effect, CO_2 about 25%, ozone about 8% and the rest including methane and nitrous oxide contribute about 7% (Kiehl and Treberth 1997).

The theory behind the greenhouse effect was first discussed by a French mathematician Baron Jean-Baptiste-Joseph Fourier in 1827 (Paterson 1996). Fourier found that certain atmospheric gases trap some outgoing radiation from the earth and reradiates a portion of it back, a process he termed as “hothouse effects” and which later came to be known as the “greenhouse effects”.

Although Fourier laid the theoretical foundation of the greenhouse effect, it took close to 100 years to make clear connections between human activities and increasing levels of atmospheric greenhouse gas and the rise in the earth’s surface temperature (Long 2004). At present, scientific evidence suggests that human activities have contributed to the increased atmospheric concentrations of greenhouse gases including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs). These gases have, as a result, enhanced the absorption and emission of infrared radiation and have intensified the natural greenhouse effect creating “enhanced greenhouse effect”.

Carbon dioxide remains the most dominant among the greenhouse gases that are influenced by human activities. Anthropogenic CO_2 emissions currently contribute about 70 per cent of the greenhouse effect relative to methane with a contribution of about 24%, nitrous oxide 6% and CFCs 24% (Houghton 2004).

CO_2 Emissions and Global Warming

Anthropogenic carbon dioxide emissions and their implications for global warming were first studied and reported by a Nobel Prize-winning chemist from Sweden, Svante August Arrhenius. Arrhenius (1896) estimated the effect of atmospheric carbon dioxide concentrations to earth’s temperature and concluded that doubling levels of CO_2 in the atmosphere would lead to a temperature rise of 5 to 6^0C, a figure that is not far from current IPCC’s findings. From that study, Arrhenius concluded that massive consumption of fossil fuel (coal, gas, oil) would lead to an increase in the earth’s surface temperature of about 4.5^0C. Concerned about the rapidly increasing rate of fossil fuel consumption in Europe, Arrhenius in his 1908 book "Worlds in the Making" claimed that massive consumption of fossil fuels may eventually result in enhanced global warming.

Prior to the1950s, the prevailing view to most scientists was that oceans could quickly absorb excess CO_2 emissions produced by human activities. However, in the mid-1950s, Roger Revelle and Hans Suess observed that oceans could not absorb anthropogenic CO_2 emissions as fast as they were being produced. In their 1957 seminal paper, Roger Revelle and Hans Suess stated "humans are conducting large-scale geophysical experiments through worldwide industrial activity that could lead to a buildup of CO_2 larger than the rate of CO_2 production from volcanoes" (Revelle and Suess 1957). Their findings were instrumental in the establishment of the first CO_2 monitoring station at Mauna Loa Observatory Station in Hawaii.

In 1958, Revelle and Charles David Keeling began regular monitoring of atmospheric CO_2 concentration at the Mauna Loa station (Revelle and Suess 1957). Results from these measurements indicate an upward trend widely recognized as the "Keeling curve". These findings in combination with the long-term temperature records have demonstrated a positive relationship between global surface mean temperature and CO_2 build up in the atmosphere. For example, the ambient carbon concentration in 1998 was 367 ppm compared to the 1996 level of 363 ppm (Figure 2.1). In1988, high temperatures were also recorded as shown in Figure 2.2.

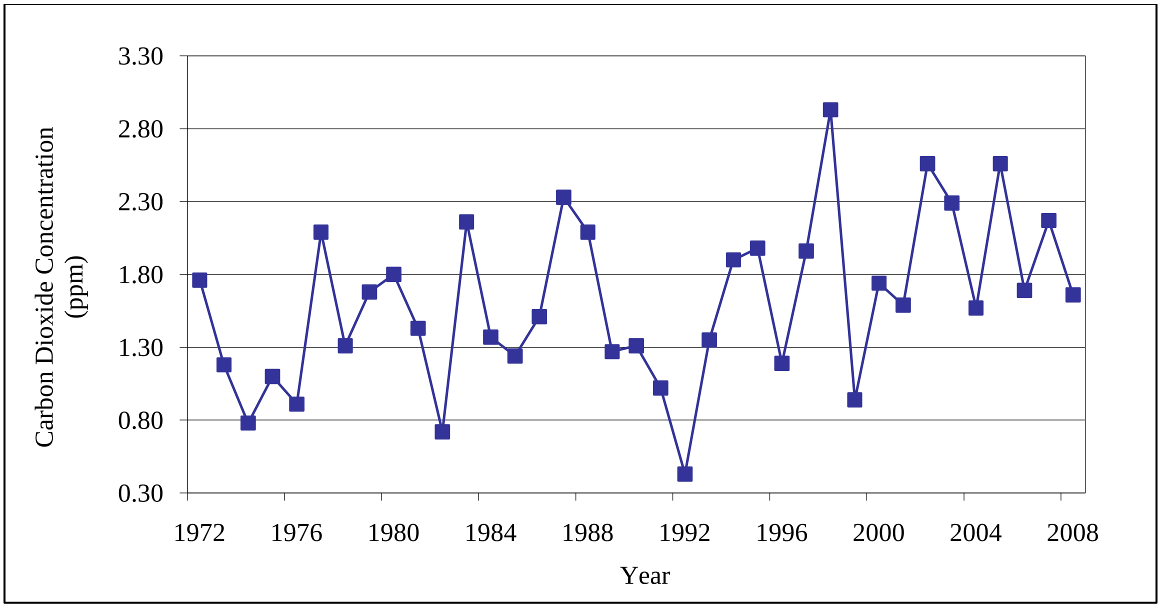

Figure 2.1. Annual Mean CO2 Growth Rate for Mauna Loa, Hawaii, 1970-2008

Source: Dr. Pieter Tans, 2009, NOAA/ESRL www.esrl.noaa.gov/gmd/ccgg/trends)

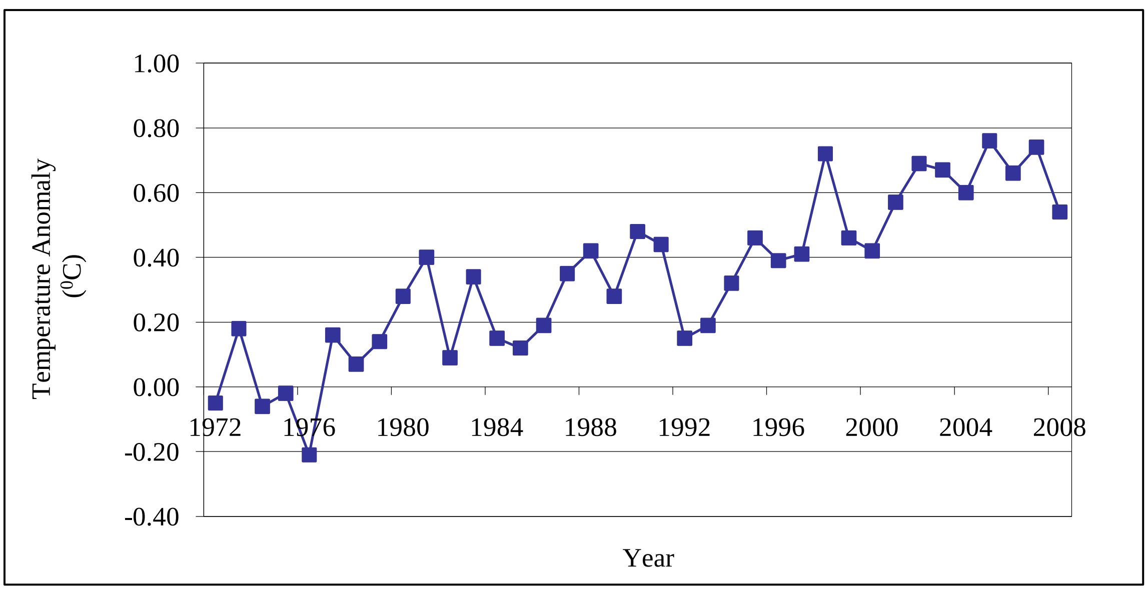

Figure 2.2. Annual Mean Global Temperatures (^{0}C), 1970–2008

Source: Hansen, Ruedy, Sato, & Lo, 2009, NASA Goddard Institute for Space Studies (http://cdiac.ornl.gov)

In order to address the scientific issues underlying the link between human-induced carbon dioxide enrichment in the atmosphere and global warming, an international, interdisciplinary consortium of the scientific community, the International Panel for Climate Change (IPCC), was established in 1988 by the World Meteorology Organization (WMO) and the United Nations Environmental Program (UNEP). The IPCC panel, which consists of about 2,500 of the world's leading scientists, was established to assess climate data and locate trends driven by human activity.

Various scientific publications summarized in the IPCC's assessment reports since 1996 show an increase in atmospheric CO_2 emissions from its pre-industrial revolution level of 280 parts per million (ppm[1]) to 376 ppm in 2003, about a 34% increase (IPCC 2007). Increases in atmospheric CO_2 concentration have caused the earth's surface temperature to rise by 0.6^0Celsius since the 19th century (IPCC 2001). If the current rates in CO_2 emissions continue, the IPCC panel predicts a rise in atmospheric CO_2 concentration to about by 540 and 970 ppm by 2100 and this may result in an increase in the earth's surface temperature of about 1.4 to 5.8^0C between 1990 and 2100 (IPCC 2001).

Furthermore, in its Second Assessment Report (1995), the IPCC stated that: "the balance of evidence suggests a discernible human influence on global climate" (IPCC 1995). The panel also concluded that global warming resulting from continued build up

[1] ppm (parts per million) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air, e.g., 280 ppm means 280 molecules of GHG per million molecule of dry air.

of CO_2 in the atmosphere might lead to climate disruptions, including increased average sea levels, change in distribution of vegetation, and other changes of the complex climate system.

Carbon Dioxide Mitigation Strategies

The landmark findings from the IPCC scientific documents prompted world governments to sign an unbinding international treaty, the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC took effect in 1994 and states its long-term objective as "to achieve…. stabilization of greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate" (UNFCCC 2002).

By ratifying the UNFCCC, developed countries committed to adopt and implement national policies that would protect and enhance their greenhouse gas sinks and reservoirs (UNFCCC 2002). Further, in 1997, the UNFCCC adopted a binding agreement, the Kyoto Protocol which was ratified in February 2005. The agreement requires Annex 1 countries that have ratified the Kyoto protocol to cut their collective GHG emissions to at least 5% below 1990 levels during 2008 to 2012 (UNFCCC 2002). The United States signed and ratified the UNFCCC in 1992 and agreed to a 7% cutback of greenhouse gas emissions from the 1990 levels but opted out of the Kyoto protocol.

In compliance with the U.N. Framework's objective of stabilizing atmospheric concentration of CO_2 and other greenhouse gases, and with the acknowledgment that global warming is a problem that requires short- and long-term solutions, the U.S. government has committed to pursue a broad range of policies to address the global warming challenge without negatively impacting economic development.

The United States CO_2 Stabilization Policies

Of the total global energy-related CO_2 emissions in 2005, estimated at about 28,051 million metric tons (MMT), about 21%, or 5,895 MMT were produced in the United States (USEIA 2008). Combustion of fossil fuel accounted for about 94% of the total CO_2 emissions in 2007 with electricity generation accounting roughly for 42% of the total CO_2 emissions from fossil fuels during that year. U.S. policymakers have discussed the opportunities of using agriculture to provide low carbon energy feedstock, enhance soil carbon sequestration, and to preserve other environmental benefits.

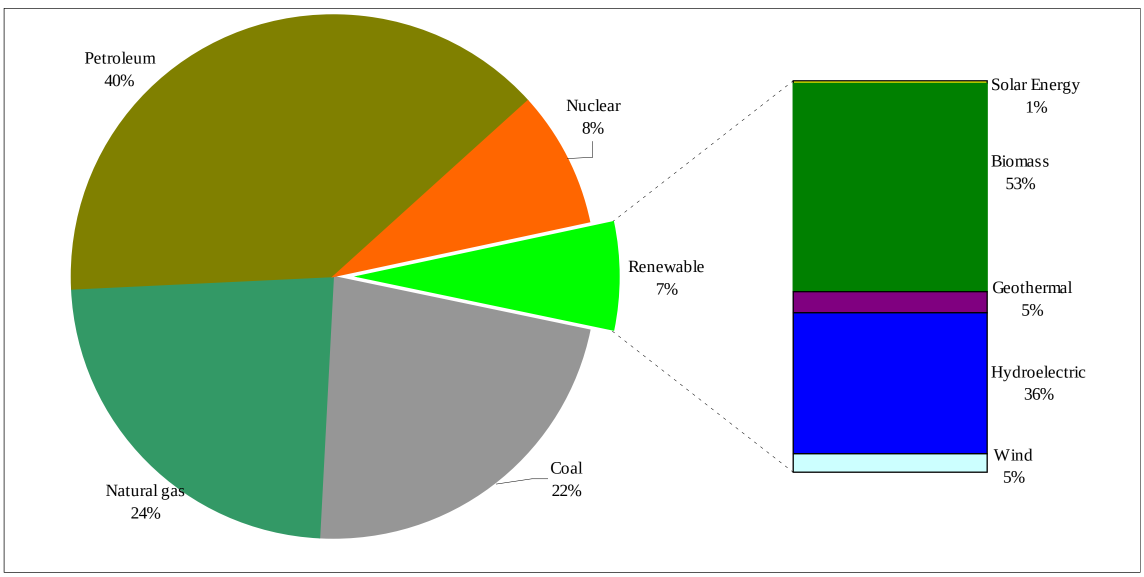

Figure 2.3. Total Energy Consumption in the United States, 2007.
Source: Energy Information Administration, Renewable Energy Trends, 2009, (http://www.eai.doe.gov)

Since 2003, use of renewable energy has increased rapidly in the United States contributing about 6.83 quadrillion British Thermal Units (Btu) or 7% of the total energy use. At present, biomass-based energy use represents nearly 53% of the total renewable energy use in the U.S., making it the largest domestic source of renewable energy (Figure

2.3). Forest residue contributes about 70% of the total U.S. biomass energy, waste products contribute about 20%, and about 10% comes from alcohol fuels (USDA 2006).

Federal Legislations in Support for Biomass Energy

The interest in biomass energy development in the United States dates back into the early 1970s. During this period, the driving force behind legislation and regulation policy incentives to promote biomass energy systems was to enhance energy security and to conserve the environment (USDA 2006). In recent periods, however, there are discussions to expand these incentives to include atmospheric carbon dioxide mitigation.

In 2000, President Clinton released Executive Order 13134, “Developing and Promoting Biobased Products and Bioenergy.” The Executive Order emphasized research and development of biomass energy systems technologies that would be cost-competitive with fossil fuel sources. The Biomass Research and Development Act (BRDA) of 2000 (Title III of Agricultural Risk Protection Act of 2000, P.L. 106-224) was established to facilitate President Clinton’s national goal of tripling the use of biomass by 2010.

Most recently, various agricultural legislation and regulations have included energy conservation and biomass energy production (USDA 2006). The Farm Security and Rural Investment Act of 2002 is the first legislation in the Farm Bill to contain an energy title, Title IX (P.L. 107-127). Title IX establishes a range of programs to promote the development of agricultural bioenergy production and consumption and conversion of biomass into energy carriers such as fuel and electricity. In addition, amendment of Section 2101 of Title II (Conservation) of the Farm Bill allows managed harvesting of biomass on CRP acreage. Management practices should be consistent with CRP’s objectives of soil conservation, water quality, and wildlife habitat.

The renewable fuels standard (RFS) of the Energy Policy Act of 2005 requires the U.S. fuel production to include 4 billion gallons of biofuels in 2006, reaching to 7.5 billion gallons in 2012 (P.L. 109-190). The Energy Independence & Security Act of 2007 supports further increase of 2005 RFS from 9.0 billion gallons in 2008 to 36 billion gallons by 2022 (P.L. 110-140). In addition, the 2008 Farm Bill, Title IX of the Food, Conservation, and Energy Act of 2008 proposes a continuation of funding in renewable energy programs, including research and development of renewable energy systems (P.L. 110-234). More recently, the U.S. Congress debate on climate change through the American Clean Energy Security Act of 2009 (ACES, H.R. 2454) has proposed a nationwide cap-and-trade program to limit GHG emissions by 17% below 2005 levels by 2020 and by 83% below 2005 levels by 2050 (U.S. House of Representatives 2010). When fully implemented, the cap-and-trade program would provide incentives for farmers to use agricultural land to sequester carbon.

Agricultural Soil Carbon Sequestration Policies

Conservation programs have been adopted in the U.S. to reduce environmental pollutants associated with agricultural activities and to improve soil productivity. Conservation practices such as implementation of conservation buffers, nutrient management, pest management, and conservation tillage are designed to reduce soil erosion, improve water quality, and to enhance wildlife habitat.

In early 2002, President George W. Bush announced the ‘Clear Sky Initiative” setting a national goal of reducing greenhouse gas “intensity” by 18% over the 2002 to 2012 time period (Winters 2002). Greenhouse gas intensity is defined as the ratio of greenhouse gas emissions to economic output (USEPA 2009). Among the wide array of policy instruments which were established to meet this goal was utilization of agriculture and forestry for biomass production and carbon sequestration (USDOE, 2003)

In addition, the Farm Security and Rural Investment Act of 2002, Title II (Conservation Security Program) has a provision to pay producers to adopt conservation measures on working land.

CHAPTER 3

LITERATURE REVIEW

This chapter presents an overview of Conservation Reserve Program (hereafter CRP) land and reviews the literature on the potential of bioenergy crops to provide biomass feedstock, sequester carbon in the soil, and provide other environmental benefits. The review also includes biophysical and economic simulation models as decision making tools of the environmental and economic effects of producing large-scale bioenergy crops on CRP land.

Land Availability for CO_2 Mitigation

Biomass energy has not widely penetrated the energy market largely because of the limited availability and high costs of production relative to other fossil fuel sources. Large-scale production biomass feedstock and use of efficient conversion technologies has the potential to reduce considerable amounts CO_2 emissions and provide an opportunity for biomass-based energy systems to become a major primary global energy source in the future (Hall et al. 2000).

Studies on producing global biomass feedstock availability recommend the use of degraded land in tropical countries and surplus set-aside land in North America and Europe. Using these lands would minimize the possible conflict of bioenergy crops with traditional food crops, fiber, and forestry production. In addition, cofiring biomass with coal in existing coal-fired power plants has been suggested as a cost-effective means of controlling CO_2 emissions, at least for the near-term (Hall 1997; Hall et al. 2000; Johansson et al.1996; Williams 1994).

In the United States, agriculture is the third largest single use of land. Of the total land area in the United States (estimated at 0.93 billion hectares) about 178.87 million hectares (Mha) or 20% was classified as cropland in 2002. About 137.6 Mha of cropland were planted with traditional food crops, 16.2 Mha were left idle either for crop production reduction or for soil conservation, while 25.1 Mha were used for pasture (Ruben et al. 2002). Under the 2008 Farm Bill, CRP enrollment was limited to about 12.95 Mha with the current enrollment at 12.63 Mha (USDA 2008).

The extent to which landowners allocate land for bioenergy production depends on the profitability of these crops and the economic returns per unit of land relative to conventional food crop production. There are two recommendations of using U.S. CRP acreage to offset CO_2 build-up: 1) growing bioenergy crops to provide biomass feedstock for energy production, and 2) implementing management strategies for enhancement of soil carbon sequestration.

The objective of this dissertation is to evaluate the effects of growing and managing bioenergy crops on CRP land for potential biomass yields and soil carbon sequestration and to assess other co-environmental benefits as well as to determine its impact on farm income and government expenditures in maintenance of CRP land.

Background of the CRP Policy

In the United States, managing agricultural land for conservation has been addressed in farm legislation since the dust bowl days of the 1930s. During this period, land diversion policies, which had been established to control commodity supply and to support farm income and prices, were expanded to include resource and environmental conservation. Cost share programs and other incentives were introduced to encourage landowners to control soil erosion.

The CRP is a voluntary long-term cropland diversion program and it is currently the largest conservation program on private lands in the United States. The program was established under the Conservation Title XII of the 1985 Food Security Act (Lewrene 1986) to protect soil productivity and to provide income support for farmers through control of traditional food crop supply and prices. In order to achieve the environmental benefits in cost-effective ways, the government provides economic incentives to landowners and farm operators to voluntarily convert environmentally sensitive cropland into conservation use for a period of about 10 – 15 years. The economic incentives include: annual rental payment, cost-share assistance of up to 50% of establishing perennial vegetation (usually grasses and trees), and technical assistance.

According to the USDA-Economic Research Service (ERS) report (1994), the original environmental goals of the CRP were to reduce soil erosion. The Food, Agriculture, Conservation and Trade Act (FACTA) of 1990, however, broadened the goals to incorporate the reduction of nutrient and sediment pollutants from agricultural activities to water bodies and to provide wildlife habitat (Margot, 1994). Furthermore, the level of enrollment has varied over the years (as shown in Figure 3.1) depending on subsequent farm legislation and the economy. The 1985 Act authorized 16 to 18 million hectares (40-45 million acres) to be enrolled in the CRP but the Federal Agriculture Improvement and Reform (FAIR) Act of 1996 capped the enrollment at 14.7 million hectares (36.4 million acres) while the Conservation Title II of the Farm Security and Rural Investment of 2002 increased the acreage cap to 15.86 million hectares (Mha) through the 2007 calendar year (Cain and Lovejoy 2004; Allen and Vandever 2005). The 2008 Farm Bill limits CRP acreage to 12.95 Mha (32 million acres) starting in 2010 (USDA 2008).

Various studies have been conducted to evaluate the effectiveness of the CRP in achieving its proposed environmental objectives. Estimates from the USDA (2008) show that the CRP has reduced soil erosion by 470 million tons per year compared with pre-CRP erosion rates and has sequestered about 50 million metric tons of carbon in soil and vegetation. In addition, the 0.73 million hectares (1.8 million acres) of streamside riparian grass and forested buffers protect surface water from sedimentation and nutrient pollutants and provide forage and cover for wildlife habitat and nesting areas for migratory and non-migratory birds, small mammals, and large game animals.

From the economics perspective, the CRP participants benefit from guaranteed annual rental payments which in some cases are equal to or exceed the land's cash rental value. The total government expenditure on rental payments and cost-sharing for establishing conservation cover crops approximates a total of $38 billion (in 2006 constant dollars) since the CRP was established in 1985 (Heimlich 2007). Rental payments account approximately 84.5% of annual CRP spending, with average annual rental payments of about $1.8 billion dollars (USDA/ERS, 2006). The high federal spending on CRP limits the amount of land enrolled in CRP contract each period and raises uncertainties on the future extensions of CRP contracts, the enrollment caps, and the contract periods after the expiration of the current CRP contracts. Of the total idled land, about 86%, or 14 Mha, was enrolled in the conservation reserve program (CRP) contracts in 2002 (Ruben et al. 2006).

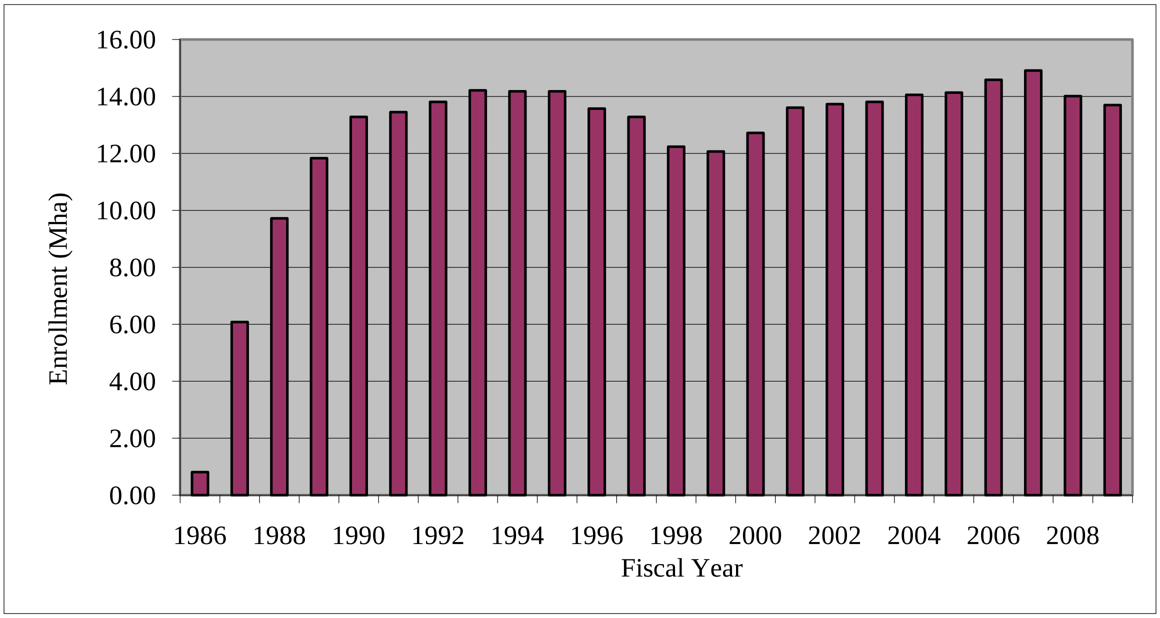

Figure 3.1. Enrollments over Time, 1986-2009

Source: USDA - Farm Service Agency, 2008

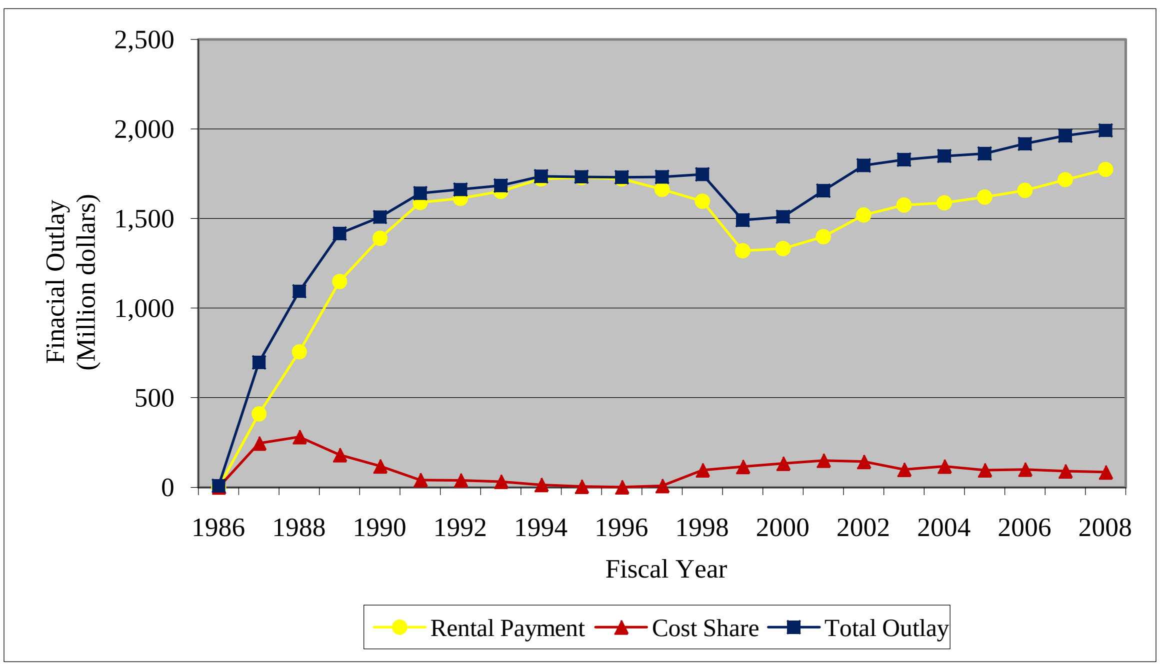

Figure 3.2. Government Expenditure on the CRP, 1986–2008

Source: USDA-FSA 2008

At the end of the CRP contract expiration period, annual rental payments made by the USDA to CRP-contract holders will cease and landowners will have no obligation to continue maintaining the CRP environmental benefits. Previous studies show that most landowners tend to return to traditional food crop production, (Osborn et al. 1994) especially if prices and/or commodity programs are favorable when CRP contracts expire.

CO_2 Mitigation Using CRP Land

Concerns of returning the CRP land into traditional crop production and the probable accompanying loss of the existing environmental benefits have initiated discussions of converting CRP acreage into bioenergy crop production. Conversion of CRP land into bioenergy crop production can provide a cost-effective means of using agricultural land to reduce the concentration of CO_2 in the atmosphere. Growing bioenergy crops on CRP land has the potential to provide biomass feedstock for electricity generation and an extra source of income to farmers, while reducing government outlay in CRP.

Similarly, carbon sequestration in agricultural and forestry sectors has attracted considerable interest both in scientific community and policymakers as a cost-effective way to control atmospheric carbon dioxide (McCarl and Schneider 2001). The Kyoto Protocol allows carbon emissions to be offset by verifiable removal of carbon from the atmosphere, including improvement of agricultural soil management (article 3.4 of Kyoto Protocol). Implementing conservation management practices for production of bioenergy crops on CRP lands has the potential to sequester carbon into the soils while continuing to provide the intended CRP environmental objectives of reducing soil loss and improving water quality.

Bioenergy Crop Production

Bioenergy crops can be categorized into two main types: 1) herbaceous energy crops such as switchgrass and 2) short-rotational woody crops such as fast-growing poplar and willows. After screening different plant species for bioenergy crop production across various regions in the United States, the Biofuel Feedstock Development Program (BFDP) of the U.S. Department of Energy identified switchgrass and hybrid poplar as model herbaceous and woody energy crops, respectively (McLaughlin and Walsh 1998).

Selection of switchgrass and hybrid poplar bioenergy crops was based on their potential to adapt in a wide range of geographic regions across the United States, the capacity to produce high biomass feedstock, and the ability to fix significant amounts of soil carbon (McLaughlin et al. 1992). Furthermore, the perennial characteristics of these crops allow their production on marginal and erosive lands and they can be used to reduce soil degradation and reduce nonpoint water pollution from agricultural lands.

In addition, switchgrass and hybrid poplar has also to be able to economically compete with other sources of energy (McLaughlin et al. 1992). In order to increase their competition and promote large-scale commercialization, costs of production and utilization have to be minimized. This can be achieved through adoption of optimal cultural management practices to increase biomass yields and biomass quality for energy use and to harness other environmental benefits. The objective of the following sections is to review the results from previous studies on the effects of various management practices when switchgrass and hybrid poplar are grown and managed to provide biomass feedstock and sequester soil carbon.

Aboveground Biomass Production

Switchgrass

Switchgrass (*Panicum virgatum* L.) is a warm season (C4) grass that is native to North America. It is a component of tall-grass prairies which grew naturally in much of the central and eastern United States, including Missouri, Iowa, Nebraska, and Kansas. It is one of the warm season perennial grasses currently used in the Midwest to supply forage for livestock during summer periods when yields from cool season C3 grasses are insufficient (Moser and Vogel 1995). It is also one of permanent vegetations grown on CRP land to reduce soil erosion and protect water quality as well as provide for wildlife habitat.

Switchgrass has the potential to produce aboveground biomass in the range of 3.2 to 35 Mg ha^{-1} per year in various parts of the United States (McLaughlin et al. 1992; Casler et al. 2004; Cassida et al. 2005; Lemus et al. 2002; Boe and Casler 2005). The differences in biomass production vary with switchgrass cultivar combined with cultural management and the intended end-use of biomass. Switchgrass occurs in two main ecotypes that are characterized by their genetic and morphological differences: 1) the lowland ecotypes, which are tall, thick-stemmed, and vigorous and tend to be adapted to the warmer and more moist conditions of the southern latitude of the U.S. and 2) the upland types, which are thin-stemmed, short and are adapted to the drier conditions of the northern latitudes of the U.S. (Casler 2005). The traits of the ecotypes play a significant role in determining the survival of switchgrass cultivars (Casler et al. 2004).

According to Casler and Boe (2005), differences in biomass yields within and among cultivars differ when switchgrass is managed for energy as opposed to fodder or conservation purposes. Their study recommends that switchgrass cultivars be matched with site specific environmental conditions and the intended end-use. Lemus et al (2002) reported yields of 17.5 Mg ha^{-1} for the Alamo variety in southern Iowa when managed for bioenergy compared to 9.3 Mg ha^{-1} for Cave-In- Rock, an upland cultivar highly recommended for forage in Iowa. Cassida et al. (2005) reported biomass yields that were three fold greater for lowland varieties (Alamo and Kanlow) than for upland varieties in experimental trials carried out in the U.S. Southern and Central regions. Lack of the ability to withstand thinning and poor persistence was reported as some of the reasons for low yields in upland switchgrass cultivars.

Other cultural management practices that affect switchgrass biomass yields as a bioenergy crop include: planting density; nutrient application; and harvest regimes (Vogel et al. 2002; Mulkey et al. 2006; Lee and Boe 2005). Nutrient rates and seasonal time of harvest affects not only switchgrass biomass yields but also its persistence and the economics of the harvested biomass. A study by Lee and Boe (2005) realized maximum biomass yields when switchgrass was harvested at anthesis development stage, (August to September) for Central South Dakota. In the Midwest, (Vogel et al. 2002) recommend first harvest to be done at R3 to R5 stage of maturity (when panicle fully emerges from boot to anthesis) to achieve maximum yields.

While harvesting during the anthesis stage tends to increase yields, biomass harvested at this stage might contain high levels of mineral elements including N, potassium, silica, and chlorine that can cause corrosion, slagging and fouling during combustion, decreasing its biomass-energy conversion efficiency and increasing electric power equipments maintenance costs. Delaying harvesting to the late-maturity stage and harvesting after a killing frost increases switchgrass's persistence over the years and increases concentration of lignocellulose, an important component in biomass-energy conversion processes. In addition, late-harvested switchgrass biomass contains low levels of ash and mineral elements because mineral elements have remobilized into the roots and other storage areas, which also reduces the need for fertilizer inputs in subsequent switchgrass regrowth (Vogel et al. 2002; Mulkey et al. 2006).

Hybrid Poplar

Recent concerns about global warming, energy prices and other environmental issues have promoted interest in the development of SRWC (Short Rotational Woody Crops) as part of carbon mitigation strategy on agricultural lands. Among the SRWC plant species, poplar was selected as the best suited bioenergy crop because of its rapid growth and high biomass production (Heilman and Stettler 1985) together with the ability of hybrid poplar to grow in wide a geographical range in the United States and on marginal lands (Wright 1994).

Poplar species are members of the genus Populus *L*. in the family of Salicaceae (willow family). Of the 6.7 million hectares (Mha) of poplars planted globally, 3.8 Mha (56%) were planted primarily for wood production and 2.9 Mha for environmental purposes (Ball et al. 2005). In the United States, poplar plantations commonly consist of hybrid crosses, predominatly between *Populus deltoides* and *Populus trichocarpa* (Heilman 1999). As in many tree species, hybrid poplars differ from parental species in the following attributes: faster growth rates; easier to propagate; better rooting system;

higher survival rates from cutting; higher biomass yields; and tolerance to close spacing (Heilman and Stettler, 1985).

Following the 1970s oil embargo, intensive research was emphasized on developing fast growing, short rotation woody trees including poplar species to provide woody biomass as an alternative energy to fossil fuel. However, since the mid-1980s, management of hybrid poplar has focused more on production of fiber for paper and pulp industries, for which there are about 20,234 hectares of land under hybrid poplar in the Pacific Northwest, 12,000 in the Southeast, and 4,000 in Northeast regions of the United States (Tuskan 1998).

Poplar biomass yields in the order of 20 to 43 Mg ha^{-1} per year have been achieved in various parts of the U.S. when poplar clones are produced under optimal conditions in research trials (Wright 1994). Poplar can grow in a wide range of soils from fine sandy soils to clay soils but it performs best when grown on well aerated and drained soils with a high pH (5.5 to 7.0), adequate nutrient, and water availability (Stanturf et al. 2001). Water logged and poorly aerated soils limit the oxygen exchange and nutrient uptake and limits growth of poplar species (Mitchell et al. 1999). Besides selecting suitable clones for specific soil and climatic conditions, timely and intensive cultural practices are required for poplar species development particularly when they are planted under sub optimal conditions.

Several studies have individually been conducted on the effects of management practices on biomass production (Proe et al. 2002; Benetka et al. 2002; Pellis et al. 2004), and soil carbon storage (Grigal and Berguson 1998; Charles and Garten 2002; Crow and Houston 2004). However, limited information exists on the impact of poplar species when grown and managed for both biomass feedstock production and soil carbon sequestration on marginal lands.

Cultural practices that have been reported to influence poplar biomass production include: plant spacing, fertilizer application and, rotation cycle. Earlier research studies promoted high planting density (about 3700 plants/ha) and short rotation cycles of 3 to 5 years to increase biomass yields (Ranney et al. 1987). Close spacing facilitates rapid canopy cover, suppresses weed competition and increases yields at least in short rotations (Ledin and Willebrand, 1995). However, it is associated with high cost of planting materials, which is estimated to account for up to 65% of establishment costs (Mitchell et al. 1999). In addition to spacing density and rotation cycles, studies have been conducted to compare the effects of replanting or coppicing on biomass productivity and soil carbon sequestration following single stem planting.

Coppicing refers to the cutting of a tree at the base of its trunk. This cultural management has been practiced since the dawn of agricultural settlement to use the ability of poplar and some other deciduous trees to regenerate new shoots and roots from the cut stump (Dickmann 2006). The rapid shoot growth facilitates leaf area development, canopy closure and efficient utilization of land. In addition, the regrowth of SRWC that follows the initial harvest has higher shoot densities than in the single stem of the original cutting or seedling, increasing biomass production and reducing the cost of replanting (Mitchell et al. 1999).

Coppice culture in poplar is not commonly used in North America (Strauss and Wright 1990) possibly because the current poplar clones are not suitable for coppicing and limited information exists on the influence of coppicing on biomass production when poplar trees are managed as bioenergy crops. Stool survival of coppiced poplars differs among species and selections due to morphological and physiological differences (Laureysens et al. 2005; Sims et al. 2001).

Soil Carbon Sequestration

In the past decade, soil carbon sequestration in agricultural and forestry sectors has attracted interest from the scientific community and policymakers in most countries as an efficient way to curb atmospheric carbon dioxide. The Kyoto Protocol allows carbon emissions to be offset by verifiable removal of carbon from the atmosphere. The Protocol has recommended land use and land management, including afforestation, reforestation, and deforestation (article 3.3 of Kyoto Protocol) in forestry and conservation tillage management in agricultural soils (article 3.4 of Kyoto Protocol). Additionally, most literature on cost-effectiveness of soil carbon sequestration in the agriculture and forestry sectors has reported that these sectors have the potential to abate a significant amount of carbon emissions at moderate prices (McCarl and Schneider, 2001).

Coupled with high aboveground biomass production, both switchgrass and hybrid poplar are considered to be effective crops for sequestering soil organic carbon and for nutrient and soil conservation (McLaughlin et al. 1994). The massive deep-rooted and prolific root system influences carbon sequestration by allowing movement of carbon into deep soil layers and by adding significant quantities of organic matter into the soil. However, despite their similarity in root biomass, switchgrass and hybrid poplar differ in their capacity to accumulate soil carbon primarily because of their differences in the amount of residue, nutrient content, and rate of decomposition and decay processes (Za et al. 2001).

Several studies on the evaluation of switchgrass potential to sequester carbon into the soil indicate that the main sources of soil carbon sequestration are deposition and mineralization of plant material on the soil surface as well as root growth and turnover below the soil surface (Bransby et al. 1998). Switchgrass has extensive and deep-rooted systems which have the potential to enhance CO_2 sequestration from the atmosphere into soils. Additionally, the level and rate of carbon sequestration increases with increase in soil depth primarily because of the reduction in carbon oxidation and microbial activities in deep soil profiles. Thus, the deep roots in switchgrass allows it to store carbon at lower depths of soil profiles, minimize its loss through mineralization and decomposition and making it less available for removal during crop harvest (Sanderson et al. 1999; Liberg et al. 2005). Switchgrass roots have been reported to extend over 300 cm into the soil (Ma et al. 2000a) and can account for over 80% of total plant biomass (Liberg et al. 2005). However, root biomass and distribution depends on soil type and varies with switchgrass cultivar. A study by Ma et al. (2000b) on three cultivars (Cave-in Rock, Alamo, and Kanlow) showed that differences in growth habits and root characteristics of cultivars affect root biomass distribution in the soil.

Hybrid poplar has the potential to accumulate carbon in agricultural soil through effective plant and soil management. Based on the limited information in the literature, (Grigal and Berguson 1998) hypothesized that SRWC stands can accumulate soil carbon at the rate of 10 to 25 Mg ha^{-1} per year over a 10 to 15 year rotation mainly from leaf litter and root biomass.

Economics of Bioenergy Crops

There is an increasing interest among policymakers and policy analysts on the economic effects of large-scale biomass-energy systems on food and energy prices and the impact on the environment. Such information is necessary in development of suitable policies to curb global warming, provide domestic energy sources, and to meet the public demand on environmental conservation.

Bioenergy crops have the potential to produce high biomass yields on U.S. croplands chiefly due to the suitability of the soils and because their cultivation uses existing implements for agricultural food production. For example, switchgrass can be planted, managed and harvested in the same way as hay crops using existing agricultural equipment while hybrid poplar can be planted and harvested using fairly conventional forestry equipment (De La Torre Ugarte et al. 2003).

Graham (1994) identified 158.6 million hectares (Mha) of U.S. cropland as land capable of producing bioenergy crops. Using a production potential of at least the criterion 11.2 dry Mg $ha^{-1}year^{-1}$ (1 Mg = 1.1 short tons), the study estimated that up to 131 Mha, of that total, would qualify for herbaceous energy crops while 91 Mha of the total would qualify for short rotational woody crops (Graham 1994).

According to a report prepared for the U.S. Environmental Protection Agency (USEPA), Hohenstein and Wright (1994) report that the Soil Conservation Service (SCS) projects that about 88 Mha of land in agricultural production will be required to meet domestic and export demand in 2030. Accordingly, there would be about 16 Mha available for bioenergy crop production without affecting conventional crop production.

At the moment, bioenergy crops are not economically competitive with conventional food crop production. The impact of allocating agricultural land into large-scale bioenergy crop production depends on their profitability to landowners and on the federal policies in the food sector. Due to the limited data specifically on the economic viability of bioenergy crop production and its potential impact on the food crop production and other land uses, varied results exist on major economic determinant factors, including costs of production, market prices, and biomass-energy conversion costs (Turhollow et al. 1994; Walsh et al. 2003; De La Torre Ugarte et al. 2003). For example, Walsh et al. (1998) found that the estimation of production costs from various models ranged from less than \$20 per dry ton to more than \$100 per dry ton, depending on the crop, the region studied, the approach used, and the assumptions made on yields and management practices. Likewise, there is limited information on the effects of large-scale bioenergy production on agricultural land allocation and the subsequent food crop prices. Walsh et al (2003) show that, at a switchgrass farmgate price of U.S. \$44 dry Mg^{-1}, about 17 Mha of cropland could be converted to bioenergy crop production with 9.5 Mha coming from land under traditional crop production. This would increase market prices for the major food crops by 9 to 14% depending on the crop and the region. In the Midwest, Turhollow (1994) found that the cost of land for growing bioenergy crops accounted for 15 to 25% of the total economic costs and for bioenergy crops to compete for land in this region, their long-term market price would be from \$30 to \$43 per dry Mg.

Besides low competition with food crops for land use, bioenergy crops are currently not cost-competitive with fossil fuel sources including coal, natural gas and oil.

The cost of biomass energy has been reported to fluctuate from \$1.35 - \$2.56Mbtu^{-1} (million BTU) as opposed to coal cost of \$0.90 -\$1.35 Mbtu^{-1} and \$1.25 - \$2.25Mbtu^{-1} for natural gas (Moore 1996). According to the National Renewable Energy Laboratories (NREL), the cost of forestry biomass ranges from \$2.40-\$3.50Mbtu^{-1} depending on the distance from the fuel source to the power plant. Nevertheless, sustainable production of bioenergy crops has the potential to provide a carbon-neutral renewable energy source because during their production, these crops extract CO_2 from the atmosphere through photosynthesis and incorporate it into biomass and belowground plant tissues. Turhollow and Perlack (1991) estimated that CO_2 emissions from switchgrass is about 1.9 Kg C GJ^{-1} compared with 13.8, 22.3, and 24.6 Kg C GJ^{-1} for gas, petroleum, and coal, respectively.

Coal produces about 50% of the total electricity consumed in the United States. Additionally, coal-fired plants are responsible for approximately 80% of CO_2 emissions from electricity generation (USDOE 2000). Cofiring biomass with coal using the existing power plants could offer cost-effective and near-term measures to control CO_2 and other greenhouse gas emissions (GHGs) from power plants. Biomass and coal fuels can be cofired at 10 to 25% without significant impact on heat values in the boilers. Mann and Spath (2001) demonstrate that, at the rate of 5%, a biomass-coal fired system can reduce global warming potential (measure of the total effects of GHGs on global climate change) by 5.2% and by 18.2% when the rate is increased to 15%.

Biomass-coal cofiring also provides higher efficiency in converting biomass energy into electricity compared to traditional direct biomass combustion methods, which have conversion efficiencies of 18 to 25%. Furthermore, it can offset CO_2 and other greenhouse gas emissions (GHGs) at low capital investments compared to higher efficient technologies such as gasification which require modification of power plants. Moore (1996) estimates the cost of CO_2 reduction at \$4.50Mg^{-1} using biomass-coal cofiring compared to \$45-90Mg^{-1} when direct emission controls are used.

Environmental Co-Benefits

Policy programs designed to mitigate CO_2 emissions through production and management of large-scale bioenergy crops on CRP land will not only provide a renewable source energy and alternative income to landowners, but may also have other environmental benefits, including improved soil and water quality, increased soil organic matter, and increased water-holding capacity. These benefits are referred to as "co-benefits" to the CO_2 mitigation strategy policy programs, since they are externalities to the intended benefits of such programs.

Various studies have focused on evaluating the costs of using various strategies to mitigate atmospheric CO_2 emissions (Mathews et al. 2002). However, limited quantitative information exists that includes environmental co-benefits of agricultural mitigation strategies on soil and water quality. Quantifying these co-benefits and including them in the assessment of economic and environmental effects of bioenergy crop production can assist decision-makers in internalizing them in the development of suitable policies on a carbon credit market system. Such policies would provide landowners with incentives to produce and manage bioenergy crops to mitigate CO_2 on CRP land and also to reduce soil erosion and nonpoint source pollution generated from agricultural activities.

Currently, the United State's CRP policies are designed to compensate landowners to retire environmentally sensitive land out from crop production in exchange for rental payments. In the 1985 Farm Bill, there were suggestions to convert about 20 Mha of cropland, most of which was under CRP and Acreage Reduction Programs (ARP), into bioenergy crop production in order to provide economic uses and to reduce government expenditures (Raneses et al. 1998). Although this program was not implemented, evaluation of its implementation showed that, at farmgate prices of $16.5 and $24.2 dry $Mgha^{-1}yr^{-1}$ for switchgrass and short rotational woody crops, respectively, and biomass yields of $11.25Mgha^{-1}yr^{-1}$, these crops can compete with fossil fuels (Walsh et al. 1999). The study also showed that the government could be save up to $2.2 billion on the expenditure if switchgrass was planted in the CRP and up to $750 million if SRWC were planted.

Marland et al. (2001) have speculated that programs involving agricultural cap and trade carbon emissions could encourage continuation and/or expansion of the CRP program and may increase the commitment of adopting conservation tillage practices which, in turn, would reduce soil erosion and sedimentation and improve water quality as well as land ecology. McCarl and Schneider (2001) report that carbon emission trading programs in the U.S. agriculture and forestry fields could benefit farmers from the higher prices of their output. The high prices would encourage widespread adoption of conservation tillage. Unfortunately, information resulting from these studies and others that have assessed the co-benefits associated with bioenergy production are too broad to be applied in designing policies related to specific bioenergy crops within regions.

Soil and Water Quality

Soil quality is “the capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al. 1997). Soil erosion refers to the dislodgement of a soil particle by water or wind and it is the most widely used indicator of loss of soil quality (Larson 1993). Soil erosion by water remains a major concern influencing soil and water quality in agricultural land within the U.S. and around the world. It affects long-term onsite crop productivity and causes offsite nonpoint-source pollution in water bodies. In the United States, the total annual cropland soil losses attributed to water erosion were estimated at 1.75 billion tons year^{-1} (USNRCS 2007). In addition, in its National Water Quality Inventory Report to the Congress, the USEPA suggested that sedimentation and nutrients from agricultural and nonagricultural sources affected 44% and 64% of the impaired rivers and lakes in 1992, respectively (USEPA 2009).

Several research studies have found that, compared to traditional row crops, bioenergy crops have the potential to add significantly more organic carbon in the soil. Increased soil organic carbon helps in reduction of soil erosion and minimization of nonpoint source pollutants into water bodies due to their extensive and prolific rooting (Lemus and Lal 2005). McLaughlin and Walsh (1998) mention three significant environmental co-benefits when switchgrass is planted for energy use, including improved soil quality and stability, cover value for wildlife, and relatively low inputs of energy, water, and agrochemicals required per unit of energy produced. An experiment carried out at Auburn University, Alabama showed that there was an increase in soil organic carbon of about 8 Mg ha^{-1} in the top 75 cm after four years of producing and managing switchgrass as a bioenergy crop (McLaughlin et al. 1994).

Conservation Tillage and Buffer

Conservation management practices have increasingly been adopted in the United States as means to reduce erosion and water pollutants and to enhance soil carbon levels (USDOE/USDA 2005). Since 1983, the USDA has spent about $30 billion USD on conservation and water quality programs through technical and education programs, cost-sharing assistance and incentive for practice installation, public work projects, paid retirement for conservation, and research (USDA/ERS 1994)

While in the previous years the objective of reducing soil erosion has been the major driving force for using conservation tillage, in the recent past there has been considerable interest in adopting conservation tillage practices as a cost-effective means to enhance agricultural soil carbon sequestration (USDOE/USDA 2005). Of the total 111.94 Mha of the U. S. planted in 2004, about 40.7% (46 Mha) was under conservation tillage and 21.5% was under reduced tillage (CTIC 2005). In the Midwestern U.S., more than 22% of all cropland in 2002, almost double the amount in 1992, was established under a conservation tillage system such as no-tillage, strip tillage, and chisel plow for crop production (CTIC 2005).

Various research projects investigating the importance of tillage practices and their influence on CO_2 loss report that conservation tillage not only accumulates soil organic carbon but also decreases the processes of biomass decomposition and soil carbon mineralization maintaining soil organic matter (Paustian et al. 1997; Follett 2001; Swift 2001). Thus, adoption of conservation practices can be used to increase organic carbon content, mitigate CO_2 emissions, and improve soil water-holding capacity, thereby reducing soil erosion and nonpoint water pollution (Lal and Kimble, 1997).

Conservation buffers are designed to reduce biological and chemical materials from agricultural lands, conserve natural resources, enhance quality of agro-ecosystems, and establish wildlife habitat. Buffers can be established along streams, around lakes or wetlands, or installed at field edges and within fields to slow water runoff, trap sediment, fertilizer, heavy metals, and enhance water infiltration into the buffer itself. In order to maximize their effectiveness, buffers should be combined with other proven conservation practices, such as conservation tillage, nutrient management, and integrated pest management.

Farm-Level Simulation Model

The interactions of economic and biological conditions may provide better estimates of using agricultural marginal lands to mitigate atmospheric carbon dioxide emissions. Analyses by Antle et al. (2002) on responses of carbon sequestration costs to soil carbon rates, showed that the latter depends on economic and biological conditions and varies across the regions. The study also found that the economic efficiency of carbon sequestration depends on site-specific opportunity costs of changing practices, on site-specific rates of soil carbon sequestration, and on the design of payment policy.

Given the complexity of simultaneous evaluation of realistic crop biomass yields/production under different soil types and different climatic conditions and their impact on economic and environmental outcomes, integrative economic and biological modeling frameworks are increasingly being used to give reasonable representation of economic factors and their linkage with biophysical conditions.

The interactions of economic and biological conditions may provide better estimates of using agricultural marginal lands to mitigate atmospheric carbon dioxide emissions. Graham et al. (2000) employed a Geographical Information System model to estimate the cost of delivered energy. De La Torre Ugarte and Ray (2000) used the POLYSYS model to estimate land use allocated to bioenergy crops and to quantify the impact on farm income of producing these crops. This dissertation develops a modeling system that links the biophysical simulation model, APEX (Agricultural Policy/Environmental eXtender), and an econometric model to provide tools that allow policymakers and landowners to make informed decisions of the effects of alternative CO_2 mitigation strategies in the U.S. on marginal lands including land currently enrolled in the conservation reserve program.

The APEX Model Application

APEX was developed in 1990s to facilitate simulation of multiple fields and large-scale farms that could not be simulated by the EPIC model. The crop growth model in APEX is similar in function and structure to that in the Environmental Policy Integrated Climate (EPIC) model. EPIC simulations of crop yield have extensively been validated against actual yields. Kiniry et al. (2005) used ALMANAC (Agricultural Land Management Alternative in the Numerical Assessment Criteria) to compare simulated crop yields to agronomic yield data in Texas. ALMANAC is a cropping system model that has functions similar to EPIC. The study found similar results between simulated and actual yields of corn, wheat, rice, soybean, barley, and sorghum under a variety of management systems and climatic conditions.

Easterling et al. (1998) reported that EPIC simulations of representative farms with soils and climate data on 0.5^0 grid scale explained 65% of the annual variations in eastern Iowa corn, and 54% of western Kansas wheat yields. Brown et al. (2000)

compared EPIC yield simulations for dryland corn, soybean, winter wheat, and sorghum to the USDA-NASS county mean crop yield for the period of 1983-1993. Their results found that EPIC-simulated crop yields accounted for 78% of the variability in USDA-NASS yields for all crops considered.

Currently there are no long-term historic yields to validate APEX-simulated switchgrass and hybrid poplar results. Limited validation has been conducted on switchgrass yields using experimental trial yields. Rosenberg et al. (1992) argue that, EPIC-simulated results are best compared with experimental yields in the absence of historic data since both utilize optimal management. Their study compared EPIC-simulated yields using yield estimates from agronomic experiments and local agricultural experts, and concluded that EPIC is suitable for simulating crop production in MINK region. Kiniry et al. (2005), compared switchgrass yields simulated by ALMANAC to actual yields from agronomic sites in Texas, Arkansas, and Louisiana. The study concludes that the model realistically simulated switchgrass at each of five study sites, varying by less than 2% within any location.

Since the late 1900s, the U.S. Environmental Protection Agency (USEPA) funded "Livestock and Environment: National Pilot Project (NPP)," has applied APEX extensively to simulate the economic and environmental effects of management strategies for multiple subareas of livestock and crop production systems and to evaluate the effectiveness of buffer strips in controlling sediment loading and pollutants from these cropping systems at the edge of fields and at watershed outlets (Gassman et al. 2002; Osei et al. 2000; Osei et al. 2003). Assessments from the NPP studies have found that the

APEX model replicates the measured runoff, sediment, and nutrient losses with reasonable accuracy.

APEX model validation was also carried out by Pantone et al. (1996) on a Houston Black clay soil, at the USDA Grassland, Soil, and Water Conservation Laboratory, Texas. The study compared the APEX-simulated corn yield for 1988-1999 with yields reported by farmers and reported that the simulated results were within 5% of the actual corn yield. Wyatte et al. (2004) used the APEX model in the same area to estimate the effects of alternative management practices on atrazine runoff.

CHAPTER 4

THEORETICAL FRAMEWORK AND MODEL STRUCTURE

The Biophysical APEX Model

Biophysical simulation models have been developed and widely used to estimate the physical effects of changes in land use, land management practices, or climatic conditions on crop yields, water and soil erosion at field or watershed scales. These models use mathematical functions and have been parameterized using measured data from controlled research trials to represent the real world in estimation of the effects of complex environmental measures which would be too costly to monitor and to realistically quantify.

Field-scale models such as the Erosion-Productivity Impact Calculator (EPIC) provide estimates of pollutant loading at the edge of the field and bottom of root zones while watershed scale models like the APEX (Agricultural Policy/Environmental eXtender) and SWAT (Soil and Water Assessment Tool) are used to simulate large complex farming systems with complex landscape, multiple crops and soil types.

The APEX model is a crop and environmental assessment tool that simulates cropping systems and land management practices and their environmental impact. The model runs on daily time step and was developed in the 1990s to facilitate simulation for the whole farm and small watershed.

Farms can be subdivided into multiple subareas to allow for large-scale watershed simulation, however, limiting watershed size to about 2500 km^2 has been recommended to assure relative homogeneity in terms of soil characteristics, land use, management and weather (Williams et al. 2000). A subarea can be a field, soil type, buffer strip, landscape or any other configuration. A subarea simulation component of the APEX model is taken from the EPIC model which assumes homogeneity in soils and climatic conditions. In addition, the APEX model enables simultaneous simulation of combinations of multiple fields with a wide range of soils, landscape, climate, crop rotations and management practice combinations (Williams et al. 2000). The model predicts the effects of management strategies such as irrigation, drainage, water yield, buffer strip, terraces, crop rotation, and nutrient and pesticides. It is also designed to evaluate the effect of global climate/CO_2 changes and to design biomass production systems for energy. The current updated version of APEX includes detailed features of carbon cycling practices (Williams and Izaurralde 2005).

The APEX model contains all functions found in EPIC including the nine sub-models: weather, hydrology, erosion, nutrients, soil temperature, plant growth, plant environment control, tillage, and economic budgets. In addition, it has sub-models that simulate routing of water, sediments, nutrients, and pesticides in both solution and sediment phase across complex landscapes and channel systems to the watershed outlet (Williams and Izaurralde 2005). The routing mechanism in the APEX model allows the user to evaluate surface runoff, sediment deposition and degradation, nutrient transport, and nutrient concentrations in water bodies. While each sub-model in APEX performs a specific function, they are mathematically linked to predict the environmental outcomes of specific management practices.

The weather sub-model contains variables necessary for driving the APEX model. These include precipitation, air temperature, solar radiation, and daily average soil temperature for estimating nutrient cycle and hydrology. Wind speed and relative humidity may also be required if Penman-Monteith methods are used to estimate potential evapotranspiration.

The hydrology sub-model estimates surface runoff, percolation, lateral subsurface flow, evapotranspiration, snowmelt, and water table dynamics. APEX offers five options for estimating potential evapotranspiration (PET): the Hargreaves and Samani (1985), Priestley and Taylor (1972), Penman (1948), Penman-Monteith (Monteith, 1965), and Baier and Robertson (1965). Evaporation from the soil and plants are estimated separately as described by (Ritchie 1972). The potential soil water evaporation is estimated as a function of potential evaporation and leaf area index (the area of plant leaves relative to the soil surface) while the actual soil water evaporation is estimated as a exponential function of soil depth and water content of the top 0.2 meters. The actual plant water evaporation is simulated as a linear function of potential evaporation and leaf area index. The snowmelt is simulated as a function of the snow pack temperature and this only occurs when the second soil layer temperature exceeds 0^0 Celsius.

The erosion sub-model simulates both wind and water erosion. The physical processes of water-induced erosion include detachment of soil particles, their transportation and deposition of soil sediments by rain and its runoff. The impact of the raindrops and concentrated flow can detach soil particles and transport lighter particles such as fine sand, silt, clay, and organic matter, causing both on-site and off-site effects in agricultural lands. The on-site effects of water erosion include reduction in soil quality, structure, texture, water holding capacity, and soil organic carbon, which can reduce soil productivity, crop yields, and contribute to soil carbon loss. The off-site effects include transportation of soil sediments and the attached nutrient and pesticide pollutants, which can be deposited into surface and ground water bodies. The capacity and erosive power of the raindrops and surface runoff to detach and carry soil particle depends on soil erodibility, the volume and intensity of precipitation, as well as depth of flow and flow velocity.

The APEX model offers six equations to estimate rainfall and runoff erosion, including the USLE (Wischmeier and Smith 1978); modification of USLE by Onstand and Foster (1975); the MUSCLE (Williams 1975); two variations of MUSLE, the MUST and the MUSS; and MUSI, a MUSCLE structure that accepts input coefficients. The six equations are identical except for their energy components. The model calculates long-term water, sediment, nutrients, and other chemical yields from farms into water bodies and the interactions between fields involving surface run-on and runoff, sediment deposition and degradation. These estimates are used to assess long term impacts of soil and chemicals transportation associated with agricultural activities on water quality as well as deposition problems on downstream and groundwater infiltration.

Nutrient Cycling

Nutrient cycling involves all the processes by which nutrients are transferred from one organism to another in an ecosystem. Plants use atmospheric CO_2 through the photosynthesis process and obtain mineral elements, including nitrogen and phosphorous, from the soil solutions to produce plant organic materials. During plant growth and at maturity, part of the plant material is added in the soil where they are decomposed and recycled. In addition, some nutrients are lost through leaching, erosion and crop harvest. The following sections discuss soil carbon, nitrogen and phosphorus cycling processes as modeled in the APEX model.

Carbon Cycling Process

As discussed in Chapter 2, carbon cycling is the continuous transformation of organic and inorganic carbon compounds between the soil, plants and atmosphere. The soil organic carbon (SOC) component is an important factor in the global carbon cycle. It affects not only the rate of CO_2 emissions from the soil into the atmosphere but also the level of soil quality.

Carbon absorbed from the air through the photosynthetic process is stored as organic plant material (stem, leaves, and roots) and soil organic and inorganic carbon. Carbon leaves the field through crop harvest, soil microbial respiration, and/or attached to sediment leaching. Plant residue on the soil surface eventually decomposes releasing carbon use by soil microorganisms as an energy source. The less decomposable plant material is converted to structural or metabolic litter while the material that is highly resistant to decomposition is converted into stable soil humus. Thus, the processes of vegetation production and rate of decomposition by soil microbial organisms play a major role in determining the amount of carbon stored in the soil.

The APEX model links the carbon cycling process to hydrology, erosion, nitrogen and phosphorus cycling, crop growth, and even tillage components of the model. APEX version 1310, which was used for this study, splits organic materials into fresh organic crop residue and microbial biomass, active soil humus, and stable soil organic humus pools based on carbon-nitrogen contents (Figure 4.1). The model uses a modification of PAPRAN model of Seligman and Keulen (1981) to calculate mineralization and the immobilization of fresh organic nitrogen associated with fresh crop residue and the microbial biomass pool as well as the soil humus pool based on carbon-nitrogen contents (Williams et al. 2000).

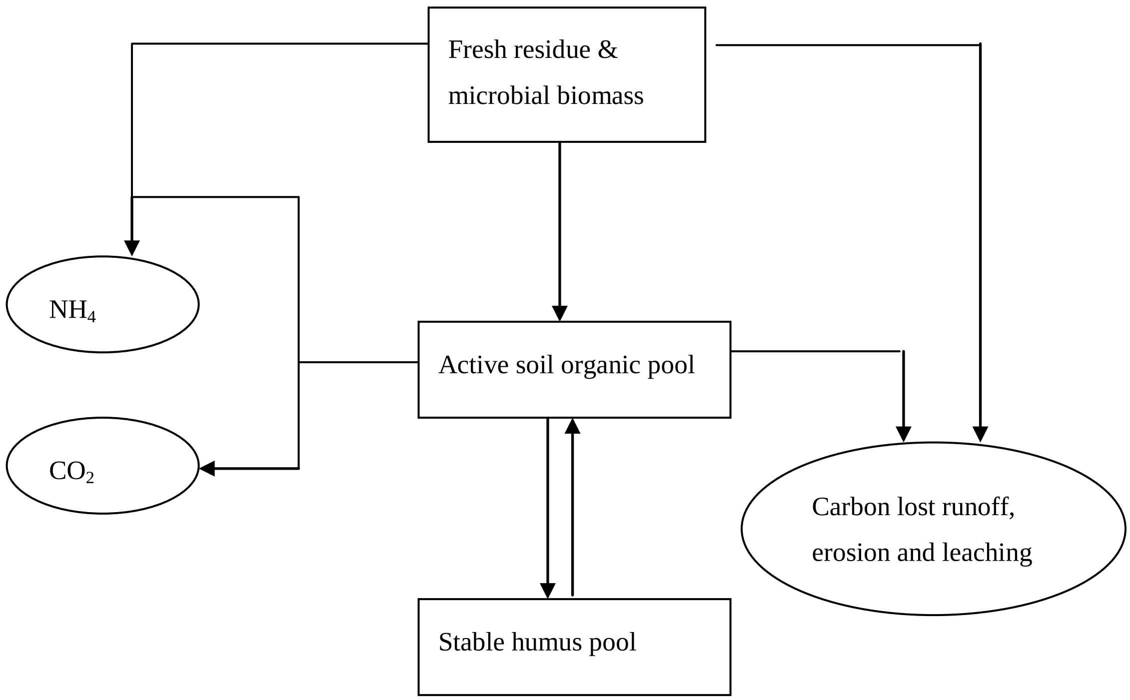

Figure 4.1. Schematic Structure of Organic C/N Pools as Modeled in APEX 1310

The nitrogen transformations are, in turn, used to estimate soil organic carbon in each soil profile and the stabilization of soil organic matter is calculated as a function of soil texture and the number of years of cultivation. The model also calculates carbon leached in sediment through soil profiles as well as that lost through runoff and soil erosion.

Nitrogen Cycling

Nitrogen is found in various forms in the environment. Inorganic nitrogen forms include: nitrogen gas (N_2), ammonia (NH_3), nitrite (NO_2) and nitrate (NO_3). Organic nitrogen includes nitrogen found in crop and animal residues, protein, amino acids and urea. However, organic nitrogen must first be converted into inorganic nitrogen through the mineralization process to be available for plant use.

Nitrogen continually cycles among plants, soil, water, and the atmosphere. It is added in the soil from commercial fertilizer, animal manure, atmospheric deposition and nitrogen fixation. The rhizobia microbes within nodules in most legume plants such as alfalfa, clover, soybeans and peanuts fix atmospheric nitrogen into plant-available nitrogen. Plant residue left on the soil surface after harvest eventually decomposes and returns organic nitrogen to the soil.

Nitrogen moves out of a field with harvested crops as organic nitrogen; volatilized as ammonia during the mineralization process and with application of commercial fertilizer; and lost as nitrogen molecules and nitrous oxide during denitrification and volatilization processes, respectively. In addition, organic and inorganic nitrogen adsorbed to soil sediments can be leached into ground water or transported in the runoff.

The APEX nitrogen cycling model contains equations that compute various forms of nitrogen inputs in the field, their transformations and pathways and nitrogen losses, including leaching, surface runoff, and lateral subsurface flow. The inputs required for APEX to simulate the nitrogen cycle includes: the amount and form of fertilizer applied, nitrogen fixation associated with legume crops, and nitrogen deposited by rainfall. The model partitions organic nitrogen into fresh, stable, and active pools and inorganic nitrogen into ammonia and nitrate pools. It evaluates various nitrogen pathways between and within these pools on a daily time-step.

The nitrogen mineralization model is a modification of the PAPRAN mineralization model (Seligman and Keulen 1981). Two sources of mineralization are considered: the fresh organic nitrogen pool (associated with crop residue and microbial biomass), and the stable organic nitrogen pool (associated with soil humus). Mineralization from fresh organic nitrogen is estimated as a product of the amount of fresh organic nitrogen and a constant representing the rate of decay. This constant is a function of the C: N ratio, C: P ratio, composition of crop residue, temperature, and soil water.

Nitrogen immobilization is computed by subtracting the amount of nitrogen in the crop residue from the amount assimilated by the microorganisms. Denitrification is estimated as a function of temperature and water content while the nitrification process is estimated by using a combination of the methods of Reddy et al. (1979) and Godwin et al. (1984). Volatilization is simulated simultaneously with nitrification as a function of surface applied ammonia and temperature.

The organic nitrogen loss with sediment is estimated by a loading function which was originally developed by McElroy et al. (1976) and modified by Williams and Hann (1978) for application of individual runoff events. The loading function calculates organic nitrogen runoff loss as a function of nitrogen level in the top soil layer, sediment yield, and nutrient enrichment ratio (level of organic nitrogen in sediment divided by level of organic nitrogen in the soil).

Phosphorus Cycling

Phosphorus exists in both organic and inorganic forms ($H_2PO_4^-$) and (HPO_4^{2-}) in the soil. It is added in the soil mainly through fertilizer application (phosphates and manure) and residue decomposition. Generally, phosphorus transformation processes consists of: mineralization, immobilization and adsorption. Phosphorus in organic materials is decomposed through the mineralization process associated with soil microbial activity and made available for plant use while the organic form is stored in the humus pool. Only soluble phosphorus compounds are available to the plant. Phosphorus leaves the field in harvested plants, in runoff and percolation.

Like in the nitrogen cycle, the APEX model simulates organic and inorganic phosphorus. Organic phosphorus consists of fresh residual (phosphorus in microbial biomass and crop residue), active and stable humus pools. Mineral phosphorus is partitioned in labile, active and stable mineral; however, only phosphorus in the labile (soluble) pool is available for plant use. Phosphorus in fertilizer is labile and available for plant use.

The soluble phosphorus in runoff is mostly associated with the sediment phase which is why the approach in APEX is based on the concept of partitioning pesticide into solution and sediment phase as described by Leonard and Wauchope (Knisel 1980). The phosphorus transport by sediment is simulated with a loading function as described by Jones (1984), in which mineral phosphorus is transferred among three pools: labile, active mineral, and stable mineral.

Crop Growth Model

Over the last 25 years, biophysical models have been developed to simulate crop growth, along with the associated phenomena that influence crop growth such as water and solute movement in soils. A single model is used in APEX for simulating more than 100 different crops using parameter values for specific crops (Williams et al. 2000). APEX is capable of simulating growth for both annual and perennial crops. The model allows annual crops to grow from the date of planting to harvest date or until the accumulated heat units equal the potential heat units of the crop. The perennial crops are allowed to maintain their roots throughout the year, become dormant after frost, and start growing again when the average daily air temperatures exceed their base temperature. The crop growth component of APEX calculates crop phenological development based on daily heat units[1] accumulation and crop-specific parameters. These parameters include biomass and energy conversion, harvest index, canopy height, root depth and leaf development, which are provided in the APEX crop database.

The model uses Beer's law to calculate the amount of solar radiation intercepted by the leaf area of the plant for biomass production as shown in Equation 4.1.

$$IPAR = 0.5(RA)\,(1 - e^{-kLAI}) \qquad (4.1)$$

where IPAR is the intercepted photosynthetic active radiation in MJm^{-2}, k is light extinction coefficient for the plant canopy (APEX assumes k = 0.65 for all plants), LAI is

[1] Heat units accumulated on a given day are calculated from the difference between the daily mean temperature and the crop's base temperature.

the leaf area index[1], and RA is daily solar radiation. The constant 0.5 is used to convert 50% of total solar radiation intercepted on the leaf surface into photosynthetically active radiation. Leaf area is one of the key determinants of the amount of biomass produced by plant species, primarily because it intercepts solar energy and converts the absorbed energy into biomass. The APEX model uses LAI to measure plant leaf development using functions for leaf appearance, expansion, and senescence of leaves.

The APEX model uses the concept of radiation-use efficiency (RUE) to calculate plant biomass production. The RUE describes the fraction of daily PAR intercepted by the plant canopy and converted into plant biomass. In other words, RUE is the amount of biomass produced when PAR is increased with one unit (the slope of biomass and PAR relationship).

The APEX model estimates the daily potential increase as the product of crop-specific RUE and the IPAR, Equation 4.2.

$$\Delta\text{biomass} = (\text{RUE})\,(\text{IPAR}) \tag{4.2}$$

where Δbiomass is daily maximum potential biomass increment from the previous day in $kgha^{-1}$, RUE is crop-specific radiation use efficiency in $kgha^{-1}MJ^{-1}m^{2}$ and IPAR is the intercepted photosynthetic active radiation.

Equation 4.2 is based on research conclusions that a positive linear relationship occurs between biomass production and photosynthetically active solar radiation intercepted by foliage crops (Monteith 1981) and forest stands (Linder 1984). The APEX

[1] Leaf Area Index is defined as the ratio of the total area of all leaves on the plant to the ground covered by the plant.

crop database contains default RUE parameters for specific crops based on ambient atmospheric CO_2 concentration (300 ppm). The RUE values used for corn, soybeans, switchgrass, and poplar were 45, 25, 45, and 30, respectively.

Daily increases in plant biomass are affected by the atmospheric CO_2 concentration and water vapor pressure processes. The atmospheric CO_2 concentration affects the plant's stomatal conductance which affects the plant's radiation and water use efficiency and, consequently, photosynthesis and evapotranspiration. In addition, APEX uses the value of the most severe of temperature, water, nutrients, soil aeration, solar radiation stresses to adjust for daily biomass accumulation. The amount of total biomass is partitioned to the root system by decreasing the fraction linearly from 0.4 at emergence to 0.2 at maturity (Williams et al. 2000). The potential root growth is adjusted for soil strength, temperature, and aluminum toxicity stresses.

The APEX model assumes crop maturity when the accumulated heat units during the growing season equals potential heat units required by the crop to reach physiological maturity. The APEX crop database contains a crop-specific harvest index (HI) parameter but the parameter is adjusted if water stress occurs during the period when the economic yield is being developed. The potential crop yield is calculated as a product of harvest index (HI) and the aboveground biomass at maturity. The harvest indexes used in this study were 0.05 for hybrid poplar, 0.02 for switchgrass, 0.50 for corn, and 0.30 for soybeans. While the HI is used to specify the fraction of aboveground biomass removed from the crop, the harvest efficiency parameter (specified in APEX tillage database) is used to estimate the portion of the harvest material that actually leaves the field.

Externalities and Environmental Policy

For decades, environmental quality has been viewed as a public good. A public good is defined as a common property which provides free goods such as air, water, the amenity and recreation of landscape (Siebert 1981). However, in the recent past there are concerns that human activities are altering both global and local natural environmental quality in unprecedented ways. For example, high atmospheric concentrations of CO_2, mainly from energy production, are speculated to have led to increased global temperatures (IPCC 2001). Additionally, intensive agricultural production and wide-scale conversion of native prairie and forest to cultivated farmland has led to increased soil erosion and nonpoint source pollutants of surface water bodies.

One of the key assumptions of neoclassical microeconomic theory is that resources are efficiently allocated in perfect competitive market equilibrium. In such conditions, market systems send signals on how individual economic agents allocate resources to maximize utility for consumers and profit for firms. However, price and market systems sometimes may fail to efficiently allocate resources at social optimal levels which lead to market failure.

One of the major reasons for market failure is the presence of externalities, also called side-effects or spillover effects. According to Tietenberg (2000), "An externality exists whenever the welfare of some agent (firms or households) depends not only on his or her activities, but also on the activities under the control of some other agent." In other words, externalities are external effects of production or consumption processes that are not included in the decision making process. When these effects impose costs to society, they are referred to as negative externalities while positive externalities entail benefit effects to the society. In the absence of pollution control policy, negative externalities impose a divergence between private and social costs where the marginal private cost of producing an output is lower than the marginal social cost as shown in Figure 4.2 and also leads to overproduction of an output being considered. P* and P_p represents the prices of quantity demanded at Q and Q_p, respectively.

At Qp, the firm's equilibrium quantity is higher than the social net benefit output level, Q*. D represents the demand curve. For example, in case of energy production using coal-fired power plants, a firm bears only the cost of production energy while the society bears both the costs of energy and the effects of CO_2 atmospheric concentration in the atmosphere, including global warming and the probable consequent effects of climate change.

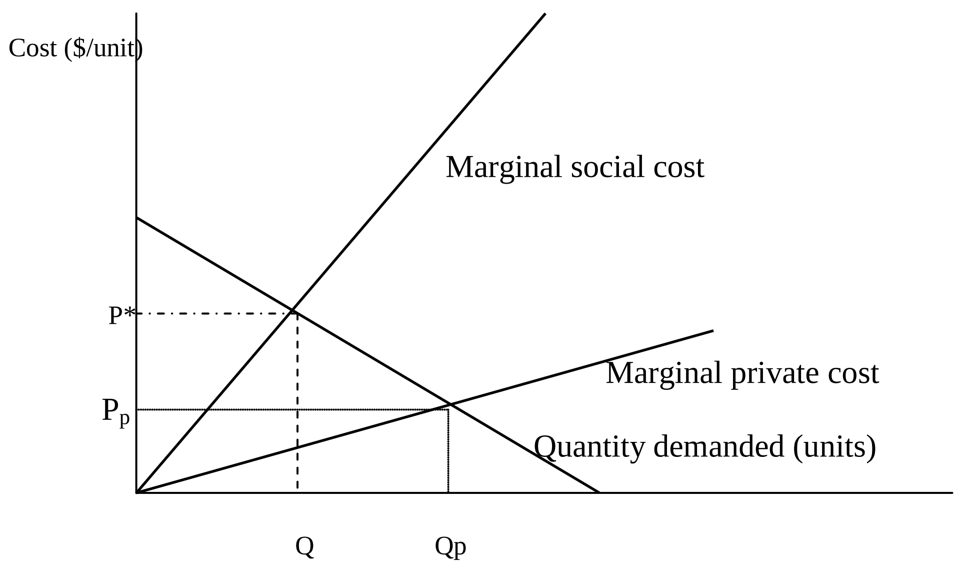

Figure 4.2. Social and Private Cost Curves and Output in Absence of Pollution Control Policy.

Source: Adapted from Tietenberg (2000)

Environmental Policy

Presence of environmental externalities leads to violation of competitive market conditions. Under such circumstances, the government may impose regulations to correct the market failure, a process known as internalization.

Internalizing negative externalities into production and consumption decisions ensures that the effluent costs are integrated into total costs and inefficiency use of environmental and natural resources degradation is reduced. The objective is to create necessary conditions required for a competitive market to provide a Pareto-optimal resource allocation (Baumol and Oates, 1975).

Most economists in the past have emphasized the use of efficiency criteria for evaluation of environmental policies. This criterion seeks to maximize social net benefit, benefits minus cost of pollution control or avoidance. Social net benefit (efficiency) is achieved when the marginal cost of abatement at each source of emission equals marginal benefit of abatement (Tietenberg 2000). The marginal cost of abatement is the cost associated with reducing an additional increment of pollution, while the marginal benefit is the additional benefit of reducing that increment. In practice, implementation of efficient policies is limited by the exorbitant and sometimes unreliable information needed to calculate all costs and benefits of control measures particularly when considering a large number of emission facilities.

An alternative approach is the use of cost-effective criteria. Under this criterion, policy instruments are used to attain predetermined environmental quality standards (Baumol and Oates 1975). Primarily, the policymaker first decides the target level of pollution control, based on specified environmental goals, and then selects policy instruments to achieve those levels (Hahn and Stavins 1991). Policy instruments for achieving target level of environmental protection are divided into two broad categories: 1) ‘Command-and-control’ instruments, which depend on government regulatory authorities to determine the methods of achieving environmental goals, and 2) ‘incentive-based’ instruments, which allow pollution emitters the flexibility to select effective ways of achieving the set environmental goals.

Research studies show that, relative to command-and-control methods, the incentive-based approach provides lower compliance costs for individual firms and also minimizes the cost of achieving a predetermined level of pollution (Baumol and Oates 1971; Hahn and Stavins 2000; Stavin 2000; Tietenberg 2000). According to Stavin (2000), the following are the major categories of incentive-based instruments: pollution charges, emission trading, deposit refund systems, and government subsidies.

Emission trading approach sets limits of specific pollutant emissions from major sources and allows the sources to trade emission reductions. There are two forms of the emission trading approach, credit trading, in which firms that reduce their emissions below the legal requirement earn certification of the excess (credits), and allowance trading also commonly known as “cap-and-trade”, in which aggregate cap of emission control is distributed among polluters of specific pollutant. Excess emission reductions can be sold or purchased in credits under credit trading and in allowances under the allowance trading system.

Considering that firms face different costs of meeting their emission limits, emission trading approach provides firms with the flexibility to sell or purchase emissions. A firm that faces lower costs of emission control can reduce more emissions than its legal requirement and sell the surplus credits or allowance. Likewise, a firm that faces higher costs can purchase unused credits or allowances to allow it to emit more than its initial allocation. Trade would continue up to the point where the marginal cost of abatement is equal across all firms (Stavin 2000).

Carbon Emission Trading

There is considerable interest in using carbon emission trading policies to offset carbon dioxide emissions into the atmosphere. One policy option is to establish limits on CO_2 emission from electricity generation and to allow carbon markets that would enhance bioenergy crop development.

At present, CO_2 emission is not capped in the United States. However, Emission Trading Programs (ETP) has been used since the mid-1980s to control various air pollutants. An example is the sulfur-allowance program which has widely been recognized as successful in meeting environmental goals at low cost. The sulfur allowance program was enacted in Title IV of the Clean Air Act Amendment of 1990 to reduce sulfur dioxide emission in power plant facilities which were thought to be contributing to acid rain. This program has resulted in cost savings of up to 1 billion dollars annually compared to the command-and-control method (Stavins 2005).

The experience with emission trade markets in the U.S. and the success in the sulfur-allowance program in particular, most likely led to the UNFCCC- Kyoto Protocol recommendation of emission trade in CO_2 associated with combustion of fossil fuels (Article 17, 1997). Land use and improved management in agricultural soils are included in Kyoto emission targets as verifiable activities that can be used to reduce atmospheric CO_2 levels (article 3.4 of Kyoto Protocol). While the U.S. has currently not ratified the

Kyoto Protocol (as of November 2009), there are proposals to cap CO_2 emitted in electric plants and to allow carbon sequestered in agricultural soils to be traded. For example, the McCain-Lieberman "Climate-Stewardship and Innovation Act of 2005" and Waxman "Safe Climate Act of 2006" proposed the establishment of caps in greenhouse gas, including CO_2, emitted by the electricity generation.

In addition, many state governments have established regulations and programs to mitigate CO_2 emissions within their economic, energy, environmental goals. For instance, the Western Climate Initiative (which currently include the states of Arizona, California, Oregon, New Mexico, Utah, and Washington) have agreed on aggregate reduction of major greenhouse gases of 15% below 2005 levels by the year 2020. Some of the measures to achieve this goal will be through increased use of renewable energy in power utilities and conservation measures for soil carbon sequestration, among others.

Currently there are no binding emission reductions in the U.S. agricultural sector. However, if carbon markets are developed and the agricultural sector starts playing a key role in CO_2 mitigation, farmers can mitigate CO_2 emissions through bioenergy crop production and soil carbon sequestration. Carbon emission reductions can then be purchased to offset carbon emissions by regulated companies. In addition to reducing CO_2 emissions, such trade may lower CO_2 mitigation costs, provide farmers' with extra income, and simultaneously provide other environmental benefits such as improved soil and water quality.

Economic Models

Microeconomic theory provides the foundation of economics that studies how economic agents such as individuals, households, and firms, make decisions on how to allocate limited resources among competing uses. The theory also examines how decisions and behaviors of economic agents affect the supply and demand of goods and services, which determine market prices. The neoclassical economic theory assumes that the amount of goods and services produced or consumed is based on the primary objectives of consumers and producers which are to maximize utility and profit (cost minimization), respectively.

The Supply Model

Microeconomic theory of supply is based on the assumption that the primary objective of the firm, which is described as the basic decision unit, is to maximize profit or to minimize costs in production processes. This means that the revenues from sales of output must exceed the cost of producing such outputs. Given these assumptions and the assumption that the firm operates in a perfect competitive market (firms take prices of output and inputs as given), the objective of this section is to describe the supply theoretical model underlying an individual firm's decision making process on what and how much agricultural commodities to produce in order to maximize its profit.

Assuming that an individual farm represents a firm, consider a profit maximizing multiple-input, multiple-output farmer involved in a production process of producing n agricultural commodities using m inputs. The farmer's implicit transformation production function may be expressed as follows:

$$F(y,x) = 0 \tag{4.3}$$

where y is an n-dimension vector of output and x is an m-dimension vector of inputs. F is assumed to be an increasing function of *y* and *x*. F is also assumed to possess first and second-order partial derivatives. As mentioned earlier, the firm's objective is to maximize profit which can be defined algebraically as follows:

$$\Pi = \sum p_i y_i - \sum w_j x_j \qquad \text{For } i = 1,\ldots, n \text{ and } j = 1,\ldots,m \tag{4.4}$$

where p and w are prices for y (outputs) and x (inputs), respectively. Further, assuming a constraint maximization problem, equation (4.4) is maximized subject to technological production function (y). The basic supply function is derived following Henderson and Quandt (1980). The Lagrangean multiplier approach is used to solve the constraint optimization problem as illustrated in equation (4.5).

$$L = \sum p_i y_i - \sum w_j x_j - \lambda F(y,x) \tag{4.5}$$

Lambda (λ) is the Lagrangean multiplier. The first order necessary conditions (FOCs) for the maximum point are obtained by taking the partial derivatives of equation (4.5) and setting the derivatives to zero as given in equations (4.6) –(4.8).

$$\frac{\delta L}{\delta y_i} = p_i + \lambda \frac{\delta F}{\delta y_i} = 0 \qquad \text{for } i = 1,\ldots\ldots, n \tag{4.6}$$

$$\frac{\delta L}{\delta x_j} = -w_j + \lambda \frac{\delta F}{\delta w_j} = 0 \qquad \text{for } j = 1,\ldots\ldots, m \tag{4.7}$$

$$\frac{\delta L}{\delta \lambda} = F(y,x) = 0 \tag{4.8}$$

Solving the equations simultaneously provides input demand and output supply functions as given in equations (4.9) and (4.10). The total industry supply can be obtained by the summation of quantities produced by individual farmer (Varian R. 1984).

$$x_j^* = f_j(p, w) \qquad \text{for } j = 1, \ldots, m \qquad (4.9)$$

$$y_i^* = f_i(p, w) \qquad \text{for } j = 1, \ldots, n \qquad (4.10)$$

Equations (4.9) and (4.10) describe the derivation of a static supply functions. Static supply functions assume that an instantaneous adjustment to optimal level of production would occur in each period. This means that, holding all other supply stimuli constant, an increase in price of a commodity would lead to an increase in its production while a low price would lead to decrease in commodity production. Given the biological nature and time lags inherent in agricultural production processes, farmers gradually adjust to optimal levels of production over a period of time and, as a result, dynamic supply relationships are considered in modeling supply response to changing economic and technical conditions.

While there are various models that have been developed to incorporate the dynamic nature of the supply response in agricultural commodities, one of the commonly adopted is the Nerlovian partial adjustment model (Nerlove, 1956). The model describes a change in supply, from one period to the next, as some proportion, β, of the difference between the current level, Y_t, and desired or planned level, Y_t^* as given in equation (4.11).

$$Y_t - Y_{t-1} = \beta(Y_t^* - Y_{t-1}) + u_t \qquad 0 \leq \beta \leq 1$$

or

$$Y_t = (1-\beta)Y_{t-1} + \beta Y_t^* + u_t \tag{4.11}$$

β is the partial adjustment coefficient which illustrates how fast the supply adjusts in response to supply stimuli in one period. It takes on values between zero and one, if β = 1, it implies that the producer fully adjusts to supply shocks in one period and the current level of supply would equal the desired output (Y_t, $= Y_t^*$), if β = 0, it implies that there is no adjustment and the current level of supply would be equal to the previous level ($Y_t = Y_{t-1}$). Since desired level of supply, Y_t^* cannot be observed, an assumption is made that the desired level is a function of last the period's price, according to equation (4.12)

$$Y_t^* = \alpha + \delta P_{t-1} \tag{4.12}$$

Substituting equation (4.12) into equation (4.11) gives

$$Y_t = \alpha\beta + (1-\beta)Y_{t-1} + \delta\beta P_{t-1} + u_t \tag{4.13}$$

Equation (4.13) is the Nerlove's dynamic supply response model. The equation is also useful in the estimation of short-run and long-run elasticities of supply. Short-run elasticities are obtained by calculating the adjustment coefficient δβ of the price variable while long elasticities are calculated by dividing the short-run elasticities by the adjustment coefficient β, to obtain δ.

Again, due to the inherent delays in agricultural production processes, farmers' decisions on acreage, production and marketing are based upon expectations about future prices. The cobweb expectation model implies a naive expectation where producers are assumed to expect the price in the next period to be the same as that in the last period. A widely used model is the adaptive expectation model which assumes that supply, Y_t, depends on expected prices, P_t^e as represented in equation (4.14)

$$Y_t = \alpha + \beta P_t^e + u_t \tag{4.14}$$

According to Nerlove (1956), producers revise their expected price for the coming period in proportion to the error they made in predicting this period price, equation 4.15.

$$P_t^e - P_{t-1}^e = \phi(P_{t-1} - P_{t-1}^e) \qquad 0< \phi <1$$

or

$$P_t^e = \phi P_{t-1} + (1-\phi)P_{t-1}^e) \tag{4.15}$$

where ϕ is coefficient of expectation which lies between zero and one, the closer ϕ is to one, the more the producer would depend to the most recent prices or outputs.

Nerlove's acreage supply model combines both the partial adjustment and adaptive expectation models. In its simplest form, the model assumes that a desired level supply, A_t^*, depends upon expected prices, P_t^e, equation 4.16.

$$A_t^* = \alpha_0 + \alpha_1 P_t^e \tag{4.16}$$

According to the partial adjustment model, supply adjusts towards a desired level, equation 4.17.

$$A_t - A_{t-1} = \delta(A_t^* - A_{t-1}) \qquad 0< \delta <1$$

or

$$A_t = \delta A_t^* + (1-\delta)A_{t-1} \tag{4.17}$$

Substituting (4.16) into (4.17) gives equation 4.18.

$$A_t = \delta(\alpha_0 + \alpha_1 P_t^e) + (1-\delta)A_{t-1}$$

or

$$A_t = \alpha_0\delta + \alpha_1\delta P_t^e + (1-\delta)A_{t-1} \tag{4.18}$$

According to the adaptive expectations model, equation 4.19.

$$P_t^e - P_{t-1}^e = \phi(P_{t-1} - P_{t-1}^e)$$

or

$$P_t^e = \phi P_{t-1} + (1-\phi)P_{t-1}^e \tag{4.19}$$

combining partial adjustment and adaptive expectation hypothesis results in equation 4.20.

$$A_t = \alpha_0\delta\phi + [(1-\delta)+(1-\phi)]A_{t-1} - (1-\delta)(1-\phi)S_{t-2} + \beta\delta\phi P_{t-1} \tag{4.20}$$

Supply Response in the Presence of Government Programs

Acreage-supply response models play a major role in the allocation of land to specific crop commodities. Most studies on the estimation of acreage responses have used the basic Nerlove's partial adjustment/adaptive expectation models which hypothesize that farmers' decisions on acreage devoted to various crops is based on average expected future prices (Nerlove 1956). However, government commodity programs in the U.S. come with incentives for participation such as price support and land diversion payments which may also influence producers' acreage decisions.

More recent studies have, as a result, explored alternative acreage supply response models by incorporating the effects of government programs on farmers' planting decisions (Houck and Ryan 1972; Lidman and Bawden 1974; Morzuch et al. 1980; Lee and Helmberger 1985; Bailey and Womack 1985; Chembezi and Womack 1991;

Chembezi and Womack, 1992). The most adopted model to quantify the effects of government programs in supply responses, which was introduced by Houck and Subotnik (1969) and later by Houck and Ryan (1972), collapsed the price support and program acreage restrictions into one measure called “effective” or “weighted” support price. While this model forms the basic methodology for estimating acreage response in the presence of government programs, it has lately been criticized for underestimating the expected prices and for lack of separating factors that affect producers’ program participation decisions from those that affect their planting decisions.

Demand Theory

Total demand consists of three components: retail (primary) demand, derived demand, and inventory demand. Retail demand occurs when a commodity is demanded in its final form at the retail level. The functions of this demand component are derived from the consumer theory.

Commodity Inventory Demand

Commodity Inventory demand refers to commodity stockholding from one period to the next. According to Labys (1973), commodity stockholding plays an important role in markets for storable commodities. Most agricultural grain commodity stocks are held by producers including the farmers, wholesalers, processors, and exporters, mainly for speculative, precautionary and transaction purposes. Transaction demand for stocks is expressed as a proportion of quantity produced:

$$St_t = \beta_1 Q_t \qquad 0<\beta<1 \tag{4.29}$$

where St_t is transaction demand for stocks, Q_t is quantity produced in period t, and β_1 is the amount of production held in stock. Precautionary demand occurs when stocks are held as a buffer for unexpected shocks in supply or demand. It is usually treated as a constant

$$Sp_t = \beta_0 \tag{4.30}$$

where Sp_t is precautionary demand and β_0 is a constant. Speculative demand for stocks occurs when expectations of the future prices are high and, therefore, it is expressed as a function of expected prices (4.31)

$$Ss_t = \beta_2 P_{t+1} \tag{4.31}$$

where Ss_t is speculative demand and P_{t+1} is the expected price. Combining all the demand components, equations (4.30) through (4.31), gives total demand for stocks as given by equation (4.32)

$$ST = \beta_0 + \beta_1 Q_t + \beta_2 P_{t+1} + U_t \tag{4.32}$$

where ST is the total demand for stocks, U_t is the error term, and all other variables are as previously defined.

The above specification assumes full adjustment in stocks from one period to the next. However, in the real world certain constraints such as long-term contracts between stock owners with suppliers or the cost of storing stocks may only allow for partial adjustment in period t. If the adjustment follows Nerlove's partial adjustment framework, whereby firms adjust stocks by a proportion of the distance required to reach desired stock level then

$$S_t - S_{t-1} = \alpha(S_t^* - S_{t-1}) \qquad 0 \leq \alpha \leq 1 \tag{4.33}$$

where S_t^* is the desired level of stocks. The coefficient of adjustment α lies between zero and one which means that, as long as the error term is zero, full adjustment takes place in the first period and $S_t^* = S_t$

Theory of Derived Demand

This section discusses the theoretical development of derived demand. Tomek and Robinson (1972) define derived demand to denote demand schedules for inputs which are used to produce final products (p. 24). For example, demand for corn is derived from demand for end products of the livestock industry such as livestock feed and number of livestock units while demand for soybeans is derived from demand for soybean meal and soybean oil. Thus, demand for corn and soybean is derived from the demand of their end-products.

Theoretical development of derived demand for a commodity is derived from the profit maximization problem where the commodity is used to produce an intermediate or final product. For example, consider a production process where livestock is produced using corn, soybean meal, and other inputs required for production. The livestock production function is defined as

$$Q_Y = f(Q_c, Q_s, Q_o) \tag{4.34}$$

where Q_Y represents the quantity of output such as number of livestock, Q_C is demand for corn, Q_S is demand for soybeans, and Q_O is demand for other inputs. The profit function for the producer can be expressed as

$$\pi = P_Y Q_Y - P_C Q_C - P_S Q_S - P_O Q_O \tag{4.35}$$

where P_Y is the price for livestock output and P_C, P_S, and P_O represent input prices for corn, soybeans and other inputs, respectively. The first order conditions are given by the following equations:

$$Q_C = f_C(P_Y, P_C P_S P_O) \tag{4.36}$$

$$Q_S = f_S(P_Y, P_C P_S P_O) \tag{4.37}$$

$$Q_O = f_O(P_Y, P_C P_S P_O) \tag{4.38}$$

Equations (4.36) through (4.38) suggest that derived demand functions are functions of input prices such as corn and soybeans, other substitute or complement inputs, and price for livestock products.

Simulation Concept

Pindyck and Rubinfeld (1976) define simulation as the mathematical solution of a simultaneous set of different equations that can be solved simultaneously and simulation model as the set of the equations. Simulation models can be used for testing the validity of estimated structural models, historical policy analysis, and forecasting. Simulation models are often used to study and compare the short-run and long-run responses of one variable to another variable.

There are two main types of simulation: static and dynamic. Static simulation uses actual values of lagged endogenous variables to generate the endogenous variables over the estimation period, while dynamic simulation uses solved values of the lagged endogenous variables to reproduce endogenous variables of the system of equations. The two types of simulation generate the same values of the endogenous variables in the first period, but the values differ thereafter.

The following single equation model for commodity area planted is used to illustrate the difference between static and dynamic simulations.

$$A_t = \alpha_0 + \alpha_1 P_{t-1} + \alpha_2 A_{t-1} \tag{4.39}$$

where A_t is the commodity area planted in period t while P_{t-1} and A_{t-1} are the commodity price and area planted in period t-1. The estimated form of the equation is represented as

$$\hat{A}_t = \hat{\alpha}_0 + \hat{\alpha}_1 P_{t-1} + \hat{\alpha}_2 A_{t-1} \tag{4.40}$$

the static simulation of this model is represented by the following

$$\hat{A}_{t_1} = \hat{\alpha}_0 + \hat{\alpha}_1 P_{t_0} + \hat{\alpha}_2 A_{t_0}$$

$$\hat{A}_{t_2} = \hat{\alpha}_0 + \hat{\alpha}_1 P_{t_1} + \hat{\alpha}_2 A_{t_1}$$

.

. (4.41

$$\hat{A}_{t_k} = \hat{\alpha}_0 + \hat{\alpha}_1 P_{t_{k-1}} + \hat{\alpha}_2 A_{t_{k-1}}$$

The dynamic simulation of the same model is represented as

$$\hat{A}_{t_1} = \hat{\alpha}_0 + \hat{\alpha}_1 P_{t_0} + \hat{\alpha}_2 A_{t_0}$$

$$\hat{A}_{t_2} = \hat{\alpha}_0 + \hat{\alpha}_1 P_{t_1} + \hat{\alpha}_2 \hat{A}_{t_1}$$

.

.

$$\hat{A}_{t_k} = \hat{\alpha}_0 + \hat{\alpha}_1 P_{t_{k-1}} + \hat{\alpha}_2 \hat{A}_{t_{k-1}} \tag{4.42}$$

Note that the first period of the two simulation values are the same because there are no solved lagged variables for dynamic simulation during that period.

Multiplier Analysis

The two main reasons for developing commodity models are for policy analysis and forecasting. Multiplier analysis allows researchers to evaluate the response of endogenous variables to shocks in exogenous variables. This is of particular interest to policymakers when considering different policy options and their impacts on the objectives of interest. There are short-run and long-run dynamic multipliers. A short-run (static) or impact multiplier explains the initial changes in endogenous variables, while the long-run or dynamic multiplier explains the cumulative changes of endogenous variable over a number of time periods. The long-run multiplier indicates the total change in the endogenous variable that results from a unit change in the exogenous variable.

CHAPTER 5

METHODOLOGY

This chapter discusses the modeling system used to evaluate the environmental and economic effects of using agricultural land to offset carbon dioxide (CO_2) emissions. The objective is to provide quantifiable information that would assist landowners and policy makers at the federal and state level in the ongoing policy debate related to carbon management and energy production in the U.S. The modeling system developed for the study links the biophysical simulation model APEX (Agricultural Policy/Environmental eXtender model) to an econometric model (Figure 5.1). The APEX simulation model evaluates environmental effects while the econometric model was used to determine the economic effects of converting the CRP land into food crop production.

The modeling system examines three policy scenarios that might be adopted after CRP contracts expire, including: (1) policy scenario, in which government supports bioenergy crop production on CRP acreage (2) policy scenario that allows landowners to grow traditional crops on CRP while encouraging adoption of land conservation practices and (3) policy scenario that encourages adoption of buffer crop production on traditional food cropland to soil reduce and water pollutant. The environmental field-level simulations are estimated for the Missouri-Iowa-Kansas-Nebraska (MINK) region, whereas the economic impact is evaluated for the whole nation.

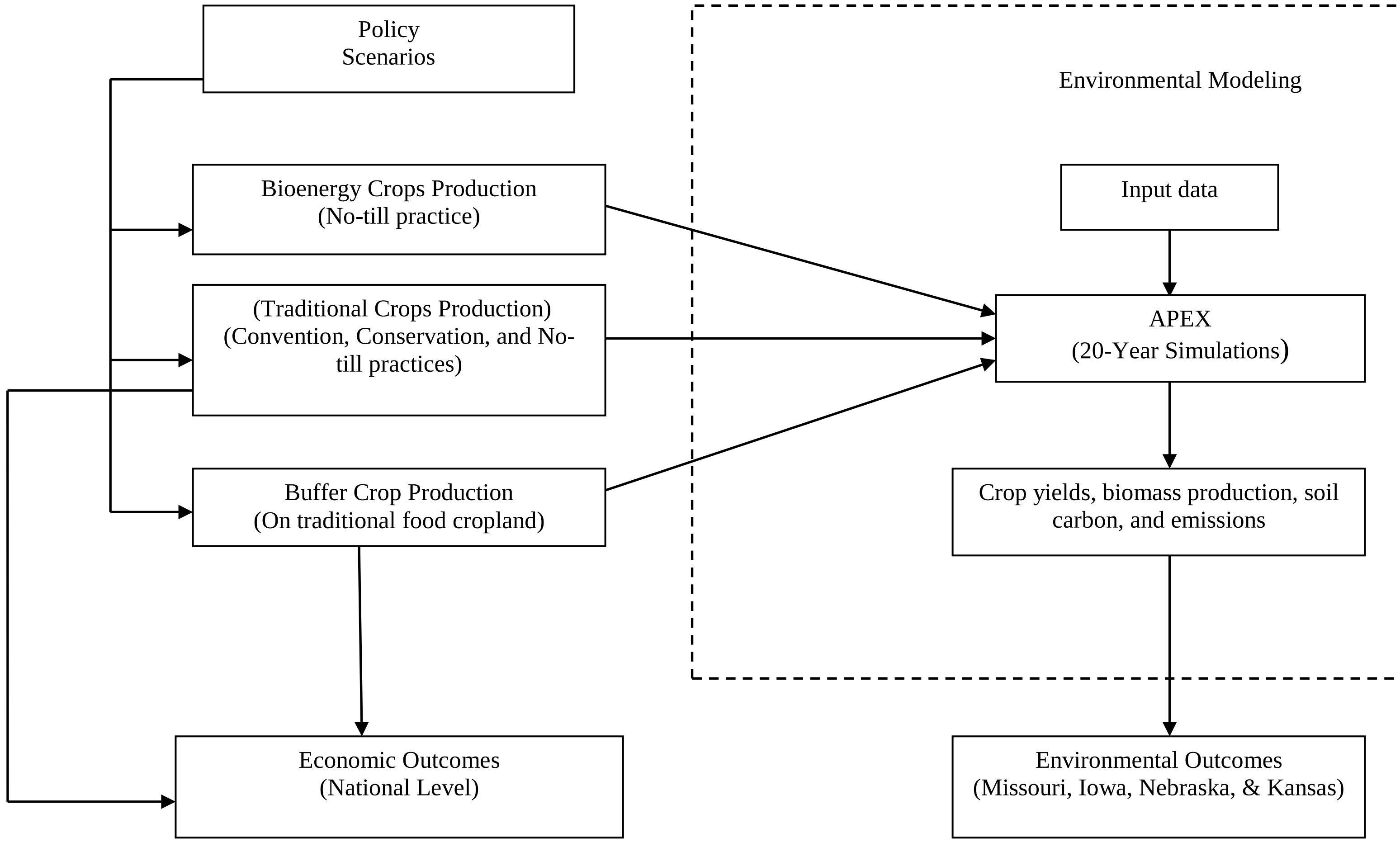

Figure 5.1. Schematic of Comprehensive Economic and Environmental Modeling System

General Description of the MINK Region

The U.S. Environmental Protection Agency (USEPA) has adopted ten regional boundaries to develop and coordinate effective environmental protection programs focused on specific resources and problems in specific areas. Missouri, Iowa, Nebraska, and Kansas are included in the MINK region, also referred to as Region 7.

The MINK region is located in the central region of the United States and covers about 734,111.41 square kilometers (283,442 square miles). It has a total population of about 13 million people (U.S. Census Bureau, 2003) (Table 5.1).

Table 5.1. The Distribution of Surface Area and Population Size in the Missouri-Iowa Nebraska-Kansas

State	Surface Area (Sq. km)	Population
Missouri	178,413.74	5,595,211
Iowa	144,700.98	2,926,324
Nebraska	199,098.63	1,711,263
Kansas	211,899.57	2,688,418

Source: U.S. Census Bureau 2003

Although at the moment there is limited data to predict the effects of CO_2 emissions on climate change, it is certain that the four states have combustion sources that contribute to greenhouse gas formation. According to the USEPA (2005) state greenhouse gas inventory report, combustion of fossil fuels contributed a total of approximately 84 million metric tons of carbon emission which accounted for about 85% of the total GHG emissions in the region. Coal-fired power plants contribute over 80% of electricity marketed in the region. There are about 68 coal-fired power plants within the MINK region, of which 24 are located in Missouri, 28 in Iowa, 8 in Kansas, and 8 in Nebraska (USDOE/EIA 2008).

The four states are focusing on building partnerships with all levels of government (state, local, and federal), universities, and non-profit organizations to develop renewable energy and energy-efficient programs. For example, Iowa and Kansas are among the six states which signed the Midwestern Regional Greenhouse Reduction Accord in 2007. The accord establishes a long-term greenhouse gas reduction target of 60-80% below the current levels and aims at developing a multi-sector cap-and-trade system to help meet the target (PEW 2009).

In addition to developing programs to manage the atmospheric CO_2 emissions, the MINK states are also faced with challenges of minimizing soil and water quality problems. Nonpoint source (NPS) pollution is the major cause of surface and ground water impairment in the United States as well as globally. The USEPA defines NPS pollution as pollution primarily from rainfall runoff, whereas the runoff picks up and transports pollutants as it moves over the land surface and percolates through the soil. Agricultural nonpoint pollutants, including sediments, nutrients, and pesticides, are the main source of NPS pollution to water bodies. NPS pollution from agricultural lands in the U.S. contributed about 48% of impaired rivers and streams (USEPA 2000).

Agriculture is the main land use and one of the most important industries in the four states of the MINK region. There were a total of 311,221 farms under agricultural land use within the four states covering about 62.7 Mha, of which about 39.7 Mha were under crops (USDA/NASS 2002). In 2002, approximately 9.8 Mha were planted in corn worth 8 billion dollars, while 9.1 Mha were in soybean valued at 5 billion dollars (Table 5.2). In 2007, these two crops were valued at 14.2 billion dollars for corn and 6.8 billion for soybeans in the four states.

Table 5.2. Distribution of Agricultural Land in MINK Region

State	Number of farms	Land in Farms (1,000 Ha)	Cropland (1,000 Ha)	Corn Acreage (1,000 Ha)	Soybeans Acreage (1,000 Ha)
Missouri	106,797	12,119	7,643	1,084	2,024
Iowa	90,655	12,841	10,989	4,760	4,216
Nebraska	49,355	18,577	9,114	2,972	1,850
Kansas	64,414	19,113	11,956	1,009	1,026

Source: Calculated from USDA/NASS 2002

Although agriculture contributes significantly to the economic development of the MINK region, the use of nutrients and chemicals to increase crop yields poses environmental challenges in the region. The main use of nitrogen and phosphorus in the region is corn production, with an annual use of about 1.655 billion tons of nitrogen and 460 million tons of phosphorous. In order to maintain increased agricultural production and to address nonpoint source water quality and soil erosion problems, the four states have established various nutrient and chemical management initiatives including tillage conservation practices and land use changes. An example is the Heartland Region Water Coordination Initiatives, created to build capacity on nutrient and pollutant management at the state and regional level. The initiative is a partnership between Iowa State University, Kansas State University, University of Missouri, and the University of Nebraska-Lincoln, the USDA Cooperative State Research, Extension and Education Service and the USEPA Region 7.

Furthermore, there is an increasing interest to produce energy crops on CRP land and to employ management practices that would increase soil carbon sequestration and meet the environmental objectives of minimizing soil and water degradation. In 2006, about 3.2 million ha of cropland were enrolled under CRP in the four states of the MINK region (about 22% of the 14.5 million hectares of the U.S.). A total of about 0.5 billion dollars was used as rental payment to maintain the CRP land. The total area of land enrolled in each state and per hectare rental payments are shown in Table 5.3.

Table 5.3. CRP Land Enrollment in the MINK Region in 2006

	Enrolled CRP Land (1,000 Ha)	Annual Rental ($1,000)	Payment ($/Ha)
U.S.	14,570	1,762,491	48.95
Missouri	637	104,741	66.49
Iowa	793	206,318	105.32
Nebraska	523	73,706	57.07
Kansas	1,249	120,509	39.06
Total	3,201	505,274	

Source: Calculated from the USDA 2006 CRP Report

The APEX Model and Data

APEX model version 1310 was used to evaluate the potential environmental effects of policy scenario that would support production of bioenergy crops on CRP land and to compare the results with the policy option of allowing production of traditional crops. The model was run for a 20-year period for the following seven locations: central Iowa, northeastern Iowa, south Iowa, west Iowa, Missouri, Kansas, and Nebraska. The criteria used to select these locations include homogeneity in land use, soils and climatic conditions. The locations provided representative weather, soils, cropping systems, and land management data requirements to drive the APEX model simulations. The APEX outputs included projected crop and biomass yields, amount of soil carbon sequestered, runoff, soil erosion, sedimentation, and nitrogen and phosphorus pollutants in water bodies.

The Weather Data Inputs

Weather data sets are required to drive processes such as hydrologic (evaporation, infiltration, and runoff), nutrient cycling and crop models. Historic daily weather variables for maximum and minimum air temperature (^oC), precipitation (mm), solar radiation (MJ/m^2), relative humidity (%), and wind speed (m/s) are required to drive the APEX model. Since the daily weather records were unavailable for long-term predictions, APEX weather generator (WXGEN) was used to generate weather data sets from the actual long-term average monthly databases (Richardson and Nicks, 1990).

The nearest climate stations for each sub-region that were selected are shown in Table 5.4. The average monthly values for maximum and minimum air temperature, precipitation, solar radiation, relative humidity, and wind speed are shown in Table 1 (Appendix A).

Table 5.4. Climate stations and study sites specifications

Location	Climate Station	Latitude (deg)	Longitude (deg)	Elevation (m)
Central Iowa	Dubuque WB Airport	42.50	90.70	326.1
Northeastern Iowa	Oelwein	42.86	91.92	313.9
South Iowa	Kirksville	40.74	92.57	292.6
West Iowa	Castana 4E	42.03	95.82	438.9
Kansas	Wichita WB Airport	37.75	97.42	402.3
Missouri	Kirksville	40.74	92.57	292.6
Nebraska	Valentine LKS Games	42.75	100.68	893.1

Source: APEX Version 1310 database

Soil Data

The 1997 Natural Resources Inventory (NRI) survey data was used to specify representative soils for the APEX model simulation. The NRI is a scientifically-designed survey conducted on soils, water and other related natural resources to assess the trends of land management, soil characteristics, and topography of all non-federal lands in the United States (USDA/NRCS 2008). The survey is conducted by the U.S. Department of Agriculture's National Resources Conservation Service in cooperation with the Center for Survey Statistics and Methodology at Iowa State University Statistical Laboratory.

The NRI survey uses a statistically designed primary sampling unit (PSU) and sample sites nationwide (USDA/NRCS 2001). For example, the 1997 NRI database samples consisted of about 300,000 Primary Sampling Units (PSUs) and 800,000 sample sites nationwide. The sample points provide data to assess the impact of alternative agricultural policy programs on natural and environmental degradation at the national, regional, state, and county level. They have also been used by various studies as "representative fields" to provide a modeling simulation framework. Kellogg et al. (1997) used these points to carry out a nationwide study on the watersheds with the greatest potential to exceed pesticide threshold in groundwater quality and to evaluate runoff from agricultural fields. Kellogg (2000) used these sample points to evaluate and identify the priority watersheds for protection of water quality from contamination by nutrients from manure at the national level. Goebel (1998) used the sample points to provide information on the distribution of highly eroded cropland throughout the nation, which contributed to the development of the CRP provision of the Food Security Act of 1985.

This study used the 1979 NRI database to select soil representatives for the APEX simulation. The NRI 1979 national survey involves analysis of 16 soil categories by land use (Dr. Verel Benson *pers. comm.*). The database includes soil type, crops, acreage, hydrologic group and erodibility. This study selected soil types with the highest acreage of specific crops to represent the dominant soils in APEX simulations. Soils under hay production were selected to represent CRP land use, based on the assumption that these are the main grasses currently growing on CRP land and represented the most erodible lands in the MINK region. According to the NRI database, the following soil types are listed as dominant in hay production within specific MINK states: Fayette for central Iowa, Downs for northeastern Iowa, Shelby for south Iowa, Marshall for west Iowa, Viraton for Missouri, Harney for Kansas, and Nora for Nebraska.

Further, the selected soils were classified according to their potential for erodibility. The NRI survey uses the Universal Soil Loss Equation (USLE) erodibility factor (K-factor) to classify a soil type according to its potential for water erosion considering its physical and chemical properties, climatic conditions of the site, and land use. The study classified soils with the K-factors of <0.17, 0.17 - 0.32, and >0.32 as low, medium, and severely erodible, respectively. The selected soils were also categorized into the four hydrologic groups (A, B, C, and D) based on their potential of water infiltration[1] rate (potential runoff) and transmission rate. According to the USDA-NRCS (2007), the hydrologic group A soils have high infiltration rate (low runoff potential) when

[1] The infiltration rate is defined as the rate at which the surface water enters the soil. The rate is controlled by surface conditions and transmission rate at which water moves down and horizontally in the soil.

thoroughly wetted and a high rate of water transmission. Group B has moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. Group C soils have a slow infiltration rate when thoroughly wetted and have a slow rate of transmission, while group D has very slow infiltration rate (high runoff potential) when thoroughly wetted and a very slow rate of water transmission. Table 5.5 describes the erodibility, hydrologic group, and the depth of the selected soils in each study area for APEX simulation.

The Fayette and Downs soil series under hay production in central and northeastern Iowa, respectively, are categorized under hydrologic group B category and identified to have a K-factor >0.32 (NRI, 1997).

Table 5.5. Soil Types under Hay Production in the Seven Study Sites

Location	Slope (m/m)	Slope length (m)	Soil Type	Soil Erodibility	Hydrologic Group
Central Iowa	0.12	58.98	Fayette	Severe	B
NE Iowa	0.07	85.07	Downs	Severe	B
South Iowa	0.12	332.12	Shelby	Medium	B
West Iowa	0.19	82.15	Marshall	Medium	B
Missouri	0.12	332.12	Viraton	Severe	C
Kansas	0.06	56.32	Harney	Medium	B
Nebraska	0.17	100.29	Nora	Medium	B

Source: Selected from NRI 1997 survey database

The Shelby soil series, selected for hay production in south Iowa consists of very deep well-drained clay loam soils formed in till while the Marshall series in Western Iowa consists of very deep, well-drained silt clay loam soils formed in loess. Both soil series have medium potential to water erosion (K-factor lies between 0.17 -0.32) and a moderate water infiltration rate (hydrologic group B).

The Viraton soil series identified as the dominant soil series for hay production in Missouri are commonly found in Southern Missouri, in the Ozarks Highlands Plains, and Springfield Plains (Cooperative Soil Survey 2006). This series consists of moderately fine texture and silt loamy soils formed in loess. The soil series has high potential to water erosion with a k-factor greater than 0.32 and falls under the hydrologic group C category. Hydrologic category C soils have a sub-surface (fragipan) layer that impedes the downward water flow and root penetration.

The Kirksville climate station was selected to provide data representative of weather conditions in CRP land in the northern part of Missouri where most of CRP land is located (USDA/FSA 2008). Like Viraton series, soil series within Adair County, including Adoca and Vesser have a restrictive high-clay subsoil layer with a fragipan. Soils with a fragipan are usually classified as somewhat poorly to poorly drained and have slow to very slow permeability which may lead to high runoff (Blanco-Canqui et al. 2002). Due to these similarities and for the purposes of this study, Viraton soil series were assumed to be representative soils for CRP land in APEX simulations.

The Harney series, for hay production in Kansas, consists of moderately slow permeable silt loam formed in loess while the Nora series in Nebraska consists of very deep well-drained silt clay loam formed in loess and falls under hydrologic soil group B. Both soil types have moderate potential to water erosion and are categorized under hydrologic group B.

The physical and chemical properties of the selected soils are required to initialize APEX runs. This information was obtained from the EPIC model soil database which consists of a wide-range of soil series with their physical and chemical data linked to the

U.S. Soil Conservation database. The model partitions a given soil series into 10 layers of varying thickness, each with its own bulk density, pH, field water capacity, percentage of sand, silt, clay and organic carbon as well as nitrogen and phosphorus components and other soil characteristics (Williams et al. 1990). Some of soil the parameters and data that were used as inputs for APEX simulation are specified in Table 2 (Appendix 1). The APEX model splits the first layer into two, keeping 1 cm for most of its computation, including crop growth, tillage, and nutrient and sediment runoff. As the top layer is eroded and lost, APEX decreases the thickness of the surface layer and adjusts the number of soil layers to the initial maximum number.

Hydrology Data Input

The Hargreaves method was used to estimate daily potential evapotranspiration (PET) calculations (Hargreaves and Samani 1985). This method generally gives a realistic estimation when limited data exists on wind speed, relative humidity, and solar radiation (Williams and Izaurralde 2005). The APEX model calculates soil and plant evapotranspiration separately. The hydrology sub-model was also used to calculate the volume of surface runoff and peak runoff values for daily precipitation.

The curve number (CN) method of the Soil Conservation Service (currently Natural Resources Conservation Service) was used to calculate surface runoff volume (USDA-SCS 1972). This number partitions precipitation between surface runoff and runoff which infiltrates into the soil. The standard runoff curve number for antecedent moisture condition 2 (CN2) was used to provide baseline CN values based on the rainfall amount, soil type, land use, land management and soil water content. These values were automatically adjusted on a daily basis using the APEX internal algorithms to estimate CN values for dry (CN1) or wet (CN3) antecedent moisture conditions

The peak runoff values were estimated using the modified rational formula (USDA-SCR 1986). The formula calculates peak runoff by considering watershed infiltration characteristics, including rainfall intensity, watershed's time of concentration, and the field size. The runoff coefficient is calculated as the ratio of runoff volume to rainfall while rainfall intensity during the watershed time of concentration is estimated for each storm using a stochastic technique. Williams (1990) defines watershed time of concentration as the time required for surface runoff to travel from the most distant point to the watershed outlet and depends on both overland and channel flow.

Management Practices

Land management practices (including tillage and soil conservation methods) can be used to increase biomass productivity and soil carbon sequestration and concurrently reduce soil and water degradation. The APEX model was used to evaluate long-term effects of alternative management practices on bioenergy crop productivity, soil carbon sequestration and soil and nutrient loss.

Three tillage methods were considered for the analysis: the conventional (CT), conservation (CN) and no till (NT). The CT is defined as any tillage system that leaves 15% or less of soil covered with crop residue after planting while the CN and NT are defined as tillage systems that leave 15-30% and 30% or more, respectively, of soil covered with crop residue after planting (CTIC 2005). The CT method was used to provide the baseline information for comparing the effects on soil carbon sequestration and soil and water quality when CN and NT tillage practices are adopted.

The study also assessed the effects of producing switchgrass and hybrid poplar as conservation buffer crops. Conservation buffers in agricultural land are strips of land in vegetation designed to slow water runoff, intercept sediment, nutrient and pesticides from farm fields. In April 1997, the USDA Natural Resource Conservation Services (NRCS) initiated a National Conservation Buffer Initiative to install 2 million miles of conservation buffer by 2002. As part of this initiative, the current study evaluates the added environmental and economic benefits when riparian buffers of switchgrass and hybrid poplar are designed to provide biomass, sequester soil carbon, and reduce water pollution.

The APEX tillage component is designed to mix nutrient and crop residue within the plow depth. Detailed description of tillage operations, including planting, fertilizer application, cultivation, and harvesting, and their timing are required to run APEX. The model simulates tillage operations on the specified date if the soil is dry enough, otherwise it carries the operation to the next suitable day. Combination of date of operation and heat unit accumulations[1] routine were used to specify the timing of tillage operations for specific crops in each location. In addition, APEX requires input parameters associated with tillage implement, including mixing efficiency of operation, tillage depth, ridge height and interval, and random roughness coefficient, to calculate the change in bulk density and to convert standing residue into flat residue (Williams et al. 2000).

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[1] The heat units are calculated as the difference between the average daily maximum and minimum temperature and crop-specific base temperature.

Production of switchgrass and hybrid poplar was limited to rainfed conditions in all MINK states. The crops were planted between the months of March and April, at planting densities of 65 plants m^{-2} for switchgrass and 10,000 trees ha^{-1} (1 m by 1m) for hybrid poplar. In south and central regions of the United States, water availability has been reported to be critical in the months of April to July (Sanderson et al. 1999). Uniform nitrogen (N) fertilizer application was assumed for switchgrass in all study sites, at a rate of 150 kg ha^{-1} at emergence and after every harvest. Similarly, N and phosphorous (P) application rates of 88 and 11 kg ha^{-1}, respectively, was assumed for corn production across all the study sites. There was no fertilizer application in hybrid poplar production.

Fertilizer application, principally nitrogen, determines switchgrass yield potential but the optimal rates depend on site, cultivar, and other cultural management considerations (Vogel et al. 2002). In general, switchgrass biomass increases with increase in fertilizer application but the optimal application rates depend on the soil type, prices, and environmental considerations relative to air and water pollution. Wolf and Fiske (1995) recommend nitrogen (N) application rates of 150 kg ha^{-1} or less during the first year after switchgrass emergence, followed by 80-100 kg ha^{-1} thereafter. Vogel et al. (2002) reported N application rates of 120 to 180 kg ha^{-1} to optimize switchgrass biomass production in Nebraska and Iowa. Their study also concluded that at 120 kg ha^{-1}, the N applied would be balanced by N removed in the harvested biomass. Brejda (2000) recommends N application rates for switchgrass ranging from 50 to 150 kg ha^{-1} in the Central Plains and Midwest.

Different implements are used depending on tillage system. Tractors for plowing, chiseling, and disking operations are assumed for conventional tillage while tools such as chisels, field cultivators, which minimize disturbance of soils, are assumed for conservation tillage. Direct planting and injection of fertilizers are assumed for the no-till system. Table 3 (Appendix 1) lists planting, fertilizer application, and harvesting dates considered for tillage and cropping systems.

Harvesting of both switchgrass and hybrid poplar was performed in early fall (late September to early October) when soil and air temperatures are sufficiently low. Harvesting bioenergy crops during this period would lower water and ash contents in harvested biomass and also reduce labor competition with traditional food production (Vogel et al. 2002; Sanderson and Wolf 1995). The simulation was based on single-cut annual harvesting for a 10-year rotation in switchgrass and single harvest for a 4-year rotation of uncoppiced hybrid poplar. Coppiced poplar was harvested after every 2 years and the stool was replaced after 15 years. About 90% total switchgrass biomass yield and 85% of hybrid poplar was removed from the field.

Soil Losses

Adoption of appropriate cropping systems and land management practices to reduce soil erosion in agricultural land has the potential to increase the rate and level of carbon sequestered in agricultural soils and to improve soil and water quality. The following section discusses the methods used to estimate the impact of various policy scenarios considered in the study on soil and nutrient losses.

The mineral and organic levels of N (ammonia, nitrate and organic), P (soluble and adsorbed/mineral and organic) and their transport are calculated to determine their impact on water quality (Williams and Izaurralde 2005).

The APEX model uses the following equation to calculate water erosion:

$$Y = X * EK * CE * PE * LS * ROKF \qquad 5.2$$

Y = sediment yield in tons per hectare

X = energy factor

EK = soil erodibility factor

CE = crop management factor

PE = erosion control practice (terraces, contour farming, and strip-cropping)

LS = slope length and steepness factor, and

ROKF = coarse fragment factor.

The Modified Universal Soil Loss Equation (MUSCLE) was used in this study to predict long-term soil sediment and nutrient losses. The MUSCLE uses runoff energy to calculate erosion and sediment yield (Williams et al. 2000). Use of runoff energy for estimating soil erosion does not require specification of a delivery ratio to calculate the amount of soil delivered at the edge of the field and it also allows simulations of single storms. The USLE, on the other hand, depends on rainfall to simulate annual sediment yields and requires delivery ratio estimates. The energy factor in the MUSCLE is represented as:

$$X = 1.586 * (Q * q_p)^{0.56} * WSA^{0.12} \quad (5.3)$$

where:

X = energy factor

Q = daily runoff volume in millimeters

q_p = the peak runoff rate in millimeters per hour

WSA = watershed area in hectares

Daily rainfall and curve number for moisture condition 2 were used as the inputs to calculate daily runoff volume using the SCS curve number (USDA-SCS 1972). Peak runoff rate was estimated using the modified rational method as a function of peak runoff rate, runoff coefficient, rainfall intensity, and watershed area. The peak runoff rate-rainfall energy adjustment factor was set at 1.0 to fine tune the energy factor in estimating water erosion.

Nutrient Losses

The equations used to partition nitrogen and phosphorus are linked to other model components such as hydrology and crop growth sub-models to estimate nutrient transport and plant uptake. Inorganic nitrogen losses include nitrate contained in runoff, lateral sub-surface flow and percolation whereas organic nitrogen is lost in the runoff attached to sediment. The amounts of nitrogen in the surface runoff, lateral sub-surface flow, and percolation are estimated as the products of volume of water and the change in nitrogen concentration in the soil layer. The amount of nitrate moved from the lower to the top layers by mass flow, when water evaporates from the soil, is calculated as a product of water evaporation and the average nitrogen concentration in soil layers.

The APEX model calculates the amount of soluble phosphorus lost in the runoff and with percolation, as a function of runoff volume, concentration of phosphorus in the top 10 millimeters of soil and its partitioning coefficient.

Sediment transport of organic nitrogen and phosphorus are each estimated as a product of sediment yield, concentration of organic nitrogen in the top soil layer, and enrichment ratio. The results of the amount of nitrogen and phosphorus dissolved in surface runoff and attached to water sediments for various crops within and across study regions are presented in Chapter 6.

Soil Carbon Sequestration

The initial soil physical and chemical properties of various soil representatives served as inputs for the APEX model. These properties include organic carbon content, bulk density, and soil layer thickness among others. A 20-year simulation under alfalfa and fescue was first conducted based on the assumption that alfalfa and fescue are some of the main types of hay grown on most CRP land in the MINK region. The resulting soil properties were then used as the input to simulate soil organic carbon sequestration when bioenergy and traditional crops are planted in the CRP land.

The APEX model uses the following equation to calculate the total soil organic carbon in soil profile:

$$S = \sum_{i=1}^{n} T_i * BD_i * (ORGC / 100\%) + (CRS/1.72) \qquad (5.1)$$

Where:

S =soil organic carbon in tons per hectare

i = ith layer

n = number of soil layers in the soil profile

T_i = thickness of the layer in meters

BD_i =dry oven bulk density in tons per hectare

$ORGC_i$ =concentration of organic carbon in percentage

CRS =fresh crop residue in tons per hectare

In the APEX model, the amount of fresh crop residue and litter is divided by a conversion factor of 1.72 to estimate carbon content in crop residue. Traditionally, a conversion factor of 1.72 is used to convert organic carbon to organic matter based on the assumption that organic matter contains 58% organic carbon (Nelson and Sommers 1996). The difference between the values of the first and the 20th-year carbon contents were used to estimate the change in soil carbon sequestered when the CRP land is converted to energy or food crop production.

Economic Model Data Input

There has been a growing interest both in the U.S. and worldwide to utilize set-aside and marginal lands to produce biomass for energy use and to sequester carbon in the soil. Various studies on the economics of bioenergy crops have concluded that production of these crops on U.S. agricultural cropland is not currently economically competitive with food crop production. However, with appropriate agricultural, environmental and energy policies, bioenergy crop production on CRP land has the potential not only to substantially offset CO_2 emissions but also to help minimize federal agricultural expenditure on such lands and to provide alternative sources of farm income. In discussions of cost-effective carbon trade policies, quantifying these economic effects remains an important issue for the government, landowners, and energy companies. The following discusses the methodology used to analyze the possible economic effects of reverting CRP acreage into food production and the economic impact of converting some of this land under food crop into conservation buffers.

Econometric Model

One of the basic assumptions underlying agricultural policy is that acreage supply responds to changes in commodity prices. When prices of a certain crops increase, it is expected that acreage planted to that crop would increase and, conversely, if the prices decrease the planted acreage declines. Government commodity programs, including the conservation reserve program, also play a critical role in decisions on the amount of land allocated to crop production. For example, if government rental and cost-sharing payments cease after the contract expires, landowners may revert land under CRP to traditional food crop production.

This study used annual commodity baseline forecast projections developed by the Food and Agricultural Policy Research Institute (FAPRI) as the reference point of analyzing two policy scenarios: 1) no extension of CRP contracts after 2007; and 2) converting some land under crop production into buffer crop production. Since 1984, FAPRI has developed a series of interrelated structural econometric models of the U.S. and world. The FAPRI models of U.S. commodities have been extensively used to provide information on the impact of alternative policy scenarios to agricultural producers, policymakers and other stakeholders.

The flow chart shown in Figure 5.2 and a price-quantity (P/Q) tool shown in Figure 5.3 demonstrate the econometric modeling structure and major components of demand and supply of a typical U.S. crop commodity, respectively. The arrows in the flow chart show the direction of flow, the solid lines specify direct influences and the dotted lines suggest lagging influences. That is, the landowners' decision on the amount of land to plant to a specific crop is influenced by the price of the previous period while the amount of area harvested and yield are directly influenced by the area planted. The product of the harvested area and yield determine the total domestic production. Adding the total imports and the total beginning Stock during a given period to total production gives the total supply. The total demand is a summation of domestic use, exports, and ending stock.

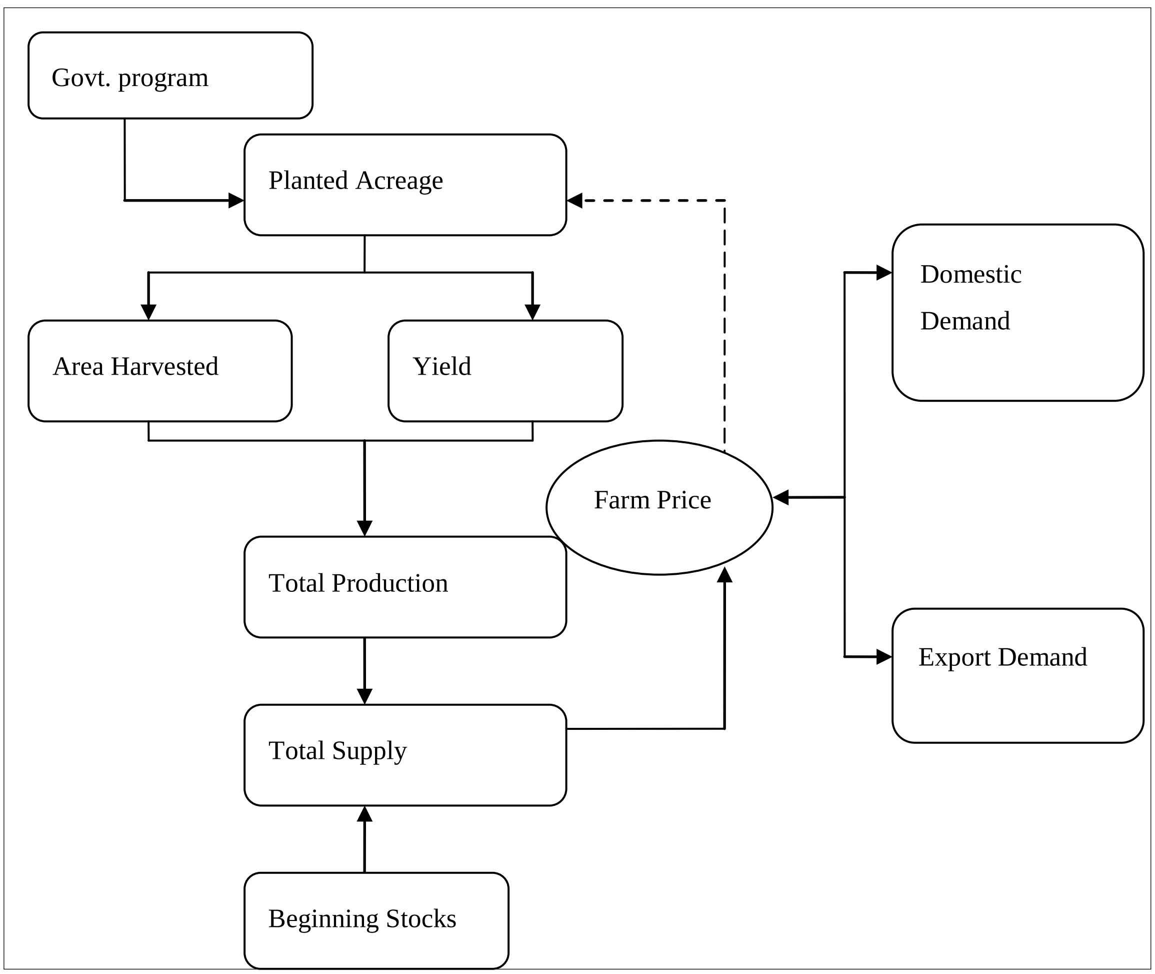


Figure 5.2. Commodity Modeling Structure of the U.S. Crop Market

The P/Q space representation of the model in Figure 5.3 helps to visualize the changes in endogenous variables associated with changes in exogenous variables at each specific point in time. It also shows the appropriate demand and supply shifters for some non-price variable effects when the price of a commodity is held constant.

The downward sloping of demand curves shows the direct influence of the current price to current demand whereas the vertical supply curves show the fixed behavior of supply in current prices. In other words, domestic supply does not depend on current market prices but depends on lagged prices (expected prices) of a commodity.

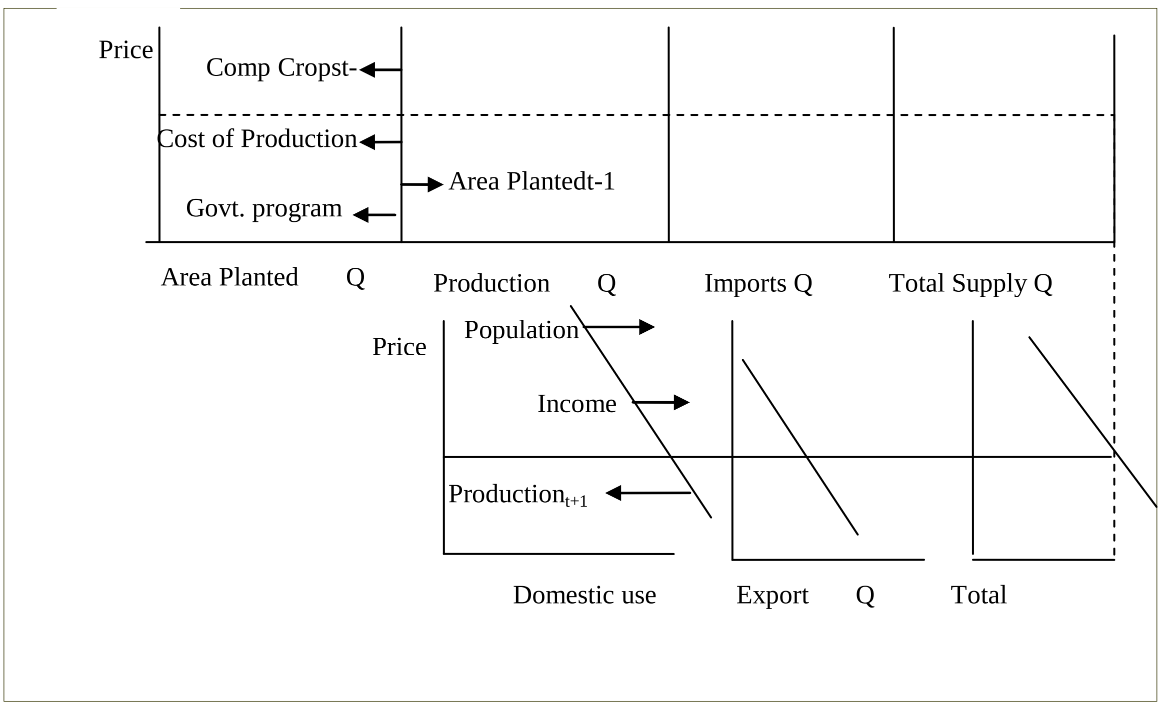


Figure 5.3. P/Q Space on U.S Crop Model

The interaction between the total supply and total demand determines the equilibrium market price. Once the structural econometric models are developed and extensively discussed with experts for different commodities, FAPRI uses the information to prepare 10-year baseline projections each year for major agricultural commodity markets. The FAPRI baseline projections assume constant current agricultural policies for a given period and can therefore be used as a “benchmark” for comparing the impact of alternative policy scenarios.

The current study used the FAPRI baseline projections developed in 2005 for the 2005/06 – 2014/15 period to analyze the implications of not extending CRP contracts after 2007 in nine production regions including the Corn Belt (Illinois, Indiana, Iowa, Missouri); Central Plains (Colorado, Kansas, Nebraska); Far West; Lake States (Michigan, Minnesota, Wisconsin); Northern Plains (Montana, North Dakota, South Dakota, Wyoming); Southeast (Alabama, Florida, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, Virginia); and Southern Plains (New Mexico, Oklahoma, Texas).

The area under specific crop and hay production over the projected period is presented in Table 5.6. The baseline projection of the CRP acreage for the nine regions is presented in Table 5.7. The total CRP acreage was projected to reach approximately 16 Mha nationwide by 2011/12. Of this total, about 24, 18, 16, and 14% are, respectively, in the Northern Plains, Central Plains, Southern Plains, and Corn Belt regions, respectively.

Studies show that about 68% of CRP lands tend to revert to previous row food crop production after ten-year contract (Osborn et al. 1994; Downing et al. 1995), particularly under speculation of future increases in commodity prices and/or costs of production.

Table 5.6. FAPRI Baseline Projected Area for the Eight Major Crops and Hay 2005/06 –2014/15

	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15
U.S. Total	126.91	126.95	127.00	126.93	126.85	126.81	126.70	126.58
Corn	33.33	33.42	33.51	33.64	33.74	33.76	33.78	33.75
Wheat	23.54	23.53	23.59	23.46	23.37	23.31	23.24	23.16
Soybeans	29.48	29.49	29.56	29.54	29.53	29.59	29.61	29.68
Sorghum	3.26	3.23	3.19	3.16	3.13	3.10	3.08	3.07
Barley	1.79	1.76	1.71	1.68	1.65	1.62	1.61	1.60
Oat	1.67	1.66	1.65	1.64	1.62	1.61	1.60	1.59
Upland Cotton	5.43	5.36	5.24	5.25	5.25	5.24	5.21	5.18
Rice	1.27	1.28	1.27	1.26	1.25	1.24	1.23	1.22
Hay	25.30	25.36	25.40	25.44	25.46	25.47	25.48	25.47

Area in Million Hectares

Table 5.7. Projected Area under CRP land by Region 2005/06 – 2014/15

	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15
U.S. Total	15.09	15.09	15.19	15.39	15.59	15.59	15.59	15.59
Corn Belt	2.17	2.17	2.19	2.22	2.24	2.24	2.24	2.24
Central Plains	2.76	2.76	2.78	2.81	2.85	2.85	2.85	2.85
Delta States	0.59	0.59	0.60	0.60	0.61	0.61	0.61	0.61
Far West	1.33	1.33	1.34	1.36	1.37	1.37	1.37	1.37
Lake States	1.15	1.15	1.15	1.17	1.19	1.19	1.19	1.19
Northeast	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Northern Plains	3.69	3.69	3.72	3.77	3.82	3.82	3.82	3.82
Southeast	0.82	0.82	0.82	0.84	0.85	0.85	0.85	0.85
Southern Plains	2.43	2.43	2.45	2.48	2.51	2.51	2.51	2.51

Area in million hectares

The following section discusses the major components of corn, soybean, wheat and hay markets. These commodities account for significant planted land area in United States. Corn, soybeans, and wheat account for about 88% of the total acreage under the eight major crops (corn, soybeans, wheat, sorghum, barley, oat, rice, and upland cotton), 34% would be under corn production, 30% under soybeans, and 24% under wheat.

Further, corn currently ranks first in planted area with an average of about 33 Mha planted annually and soybean ranks second in area planted with an average of about 29 Mha planted annually. Soybean accounts for about 90% of the U.S. oilseed production. Both corn and soybean are mainly grown in the Midwest usually in rotation. Hay production accounts for about 20% of the total U.S. area under production. The detailed econometric model structure and specification of these commodities are discussed in Adams (1994).

Table 5.8. U.S. Supply and Utilization for Selected Crops 2005/06-2014/15

	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15
Corn								
Planted Area	33.33	33.42	33.51	33.62	33.74	33.76	33.79	33.75
Harvested Area	30.25	30.36	30.47	30.61	30.72	30.76	30.81	30.80
Yield	9.35	9.46	9.57	9.68	9.79	9.90	10.01	10.12
Production	282.44	286.83	291.22	295.84	300.28	304.08	307.90	311.17
Beginning Stock	31.738	31.722	30.738	29.700	28.99	29.32	30.06	31.12
Total Supply	314.56	318.93	322.34	325.92	329.65	333.78	338.33	342.67
Domestic Use	226.25	228.98	231.64	234.61	237.55	240.30	243.12	245.43
Net Export	56.59	59.22	61.00	62.33	62.78	63.43	64.`10	65.49
Total Use	282.84	288.19	292.64	296.94	300.32	303.73	307.22	310.92
Ending Stock	31.72	30.74	29.70	28.99	29.32	30.06	31.12	31.76
Soybeans								
Area Planted	29.48	29.49	29.56	29.54	29.53	29.59	29.61	29.68
Area Harvested	28.99	29.00	29.06	29.04	29.04	29.10	29.11	29.19
Yield	2.72	2.74	2.77	2.79	2.81	2.83	2.86	2.88
Production	78.71	79.43	80.27	80.89	81.53	82.35	83.05	83.90
Beginning Stock	8.70	8.05	7.80	7.81	7.83	7.89	8.04	8.13
Total Supply	87.58	87.64	88.24	88.86	89.52	90.40	91.26	92.19
Domestic Use	52.86	53.44	54.24	54.87	55.51	56.15	56.81	57.50
Net Export	26.66	26.40	26.19	26.16	26.13	26.21	26.32	26.43
Total Use	79.52	79.84	80.43	81.03	81.64	82.35	83.13	83.93
Ending Stock	8.05	7.80	7.81	7.83	7.88	8.04	8.13	8.27
Wheat								
Area Planted	23.54	23.53	23.59	23.46	23.37	23.31	23.24	23.16
Area Harvested	19.77	19.76	19.81	19.70	19.62	19.57	19.51	19.44
Yield	2.86	2.88	2.90	2.93	2.95	2.97	2.99	3.01

Table 5.8 Cont.

Production	56.50	56.88	57.46	57.56	57.76	58.02	58.25	58.45
Beginning Stock	16.38	16.09	15.27	14.94	14.69	14.59	14.64	14.71
Total Supply	74.91	75.00	74.77	74.54	74.49	74.66	74.94	75.20
Domestic Use	33.94	33.38	33.37	33.39	33.38	33.39	33.37	33.36
Net Export	24.88	26.35	26.47	26.46	26.52	26.62	26.86	27.10
Total Use	58.83	59.73	59.83	59.85	59.90	60.02	60.23	60.45
Ending Stock	16.09	15.27	14.94	14.69	14.59	14.64	14.71	14.75
Hay								
Area Planted	25.30	25.36	25.40	25.44	25.46	25.48	25.48	25.47
Yield	2.54	2.55	2.56	2.57	2.58	2.59	2.60	2.61
Production	159.41	160.46	161.38	162.22	163.00	163.74	164.38	164.97
Beginning Stock	28.62	28.10	27.78	27.47	27.19	26.91	26.85	26.91
Total Supply	188.03	188.56	189.15	189.69	190.18	190.65	191.23	191.88
Disappearance	159.37	159.93	160.78	161.68	162.51	163.27	163.80	164.32
Ending Stock	28.62	28.10	27.78	27.47	27.19	26.91	26.85	26.91

Area in million hectares; Yield in metric tons per hectare; Supply in million metric tons

CHAPTER 6

RESULTS AND DISCUSSION

This chapter presents the results of the integrated biophysical and economic modeling system to analyze the impact of a scenario under which land under CRP is converted to production of bioenergy crops and to sequester carbon.

Bioenergy Crop Production on CRP Land

A long-term (20 years) APEX simulation was used to predict aboveground biomass energy feedstock, soil carbon sequestration, and co-environmental benefits of producing bioenergy crops including switchgrass, coppiced and uncoppiced hybrid poplar, and traditional food crops on CRP land in the MINK region.

Aboveground Biomass Energy Feedstock

As discussed in Chapter 4, biomass productivity among plant species is influenced by the amount of photosynthetically active radiation (PAR) intercepted by the canopy and the efficiency with which the intercepted light is converted into biomass (Monteith 1977). The amount of light intercepted is largely determined by leaf area index (LAI), which varies depending on climate, water, and availability of nutrients (Vose et al. 1994). In this simulation, the optimal LAI varies across bioenergy crops and study sites. South Iowa has the highest switchgrass optimal LAI value (7.02) and Nebraska has the lowest value (6.09). The optimal LAI values range between 3.28 to 3.48 m^2 m^{-2} for uncoppiced poplar and 1.32 to 1.48 m^2 m^{-2} for coppiced poplar with the highest values for Northeast Iowa and lowest for Kansas (Table 6.1).

Table 6.1. Predicted Annual Biomass Yields

Location	Cropping System	Mean ($Mg\ ha^{-1}\ yr^{-1}$)	Std	Minimum	Maximum	Max. LAI (m^2m^{-2})
Missouri						
	Switchgrass	11.87	3.7	3.39	16.41	7.03
	Uncoppiced poplar	18.34	4.6	12.67	22.15	3.25
	Coppiced poplar	12.92	4.4	5.98	17.38	1.35
Central Iowa						
	Switchgrass	12.92	2.3	6.85	15.24	6.36
	Uncoppiced poplar	19.43	2.2	16.52	22.36	3.45
	Coppiced poplar	11.06	4.3	4.95	16.33	1.45
Northeast Iowa						
	Switchgrass	11.99	3.1	5.84	16.19	6.43
	Uncoppiced poplar	19.94	2.5	17.43	23.91	3.48
	Coppiced poplar	11.41	4.5	5.05	17.12	1.48
South Iowa						
	Switchgrass	13.68	4.2	3.97	20.84	7.20
	Uncoppiced poplar	21.60	4.5	16.53	26.10	3.25
	Coppiced poplar	13.48	4.8	5.98	19.10	1.35
West Iowa						
	Switchgrass	11.49	3.5	3.82	15.37	6.81
	Uncoppiced poplar	20.93	3.1	17.40	25.37	3.42
	Coppiced poplar	12.77	4.9	5.66	18.63	1.44
Nebraska						
	Switchgrass	7.34	2.8	2.45	12.02	6.09
	Uncoppiced poplar	10.86	2.9	6.32	13.23	3.35
	Coppiced poplar	8.43	2.6	4.80	13.27	1.46
Kansas						
	Switchgrass	14.16	4.0	7.68	25.13	6.79
	Uncoppiced poplar	13.86	3.9	9.10	19.67	3.24
	Coppiced poplar	14.98	4.7	6.93	20.06	1.32

The average monthly optimal LAI values for both switchgrass (Figure 6.1) and hybrid poplar (Figure 6.2) occur between July and August, months with highest average annual amounts of rainfall.

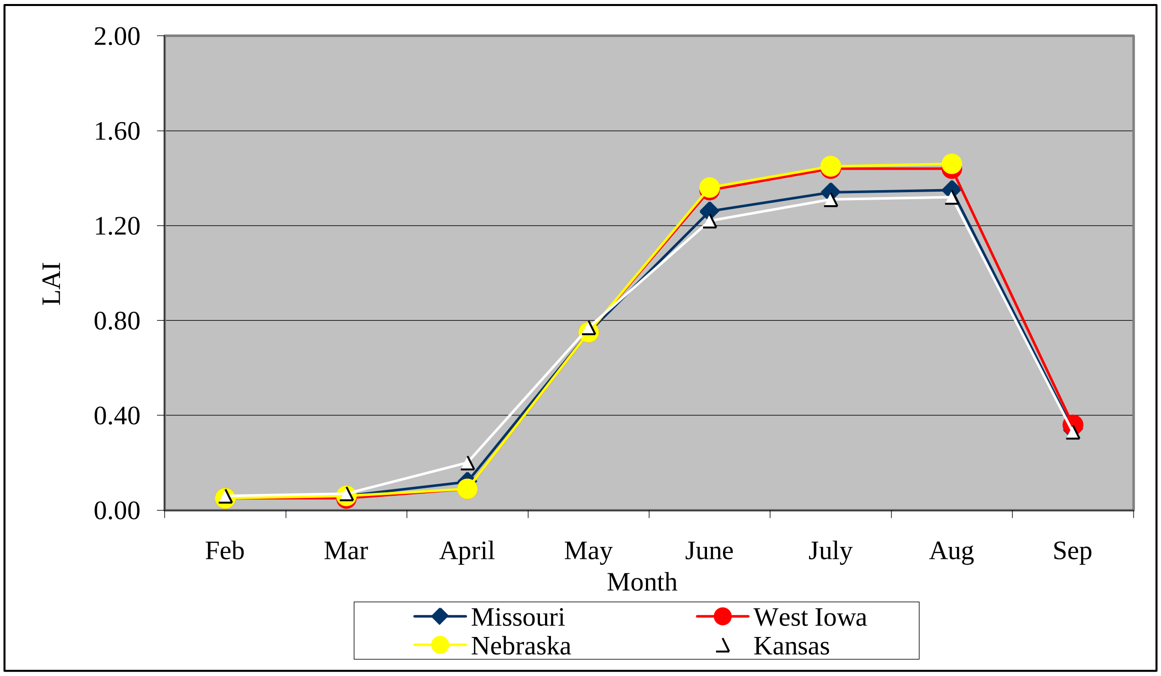


Figure 6.1. Optimum Monthly Leaf Area Index for Switchgrass

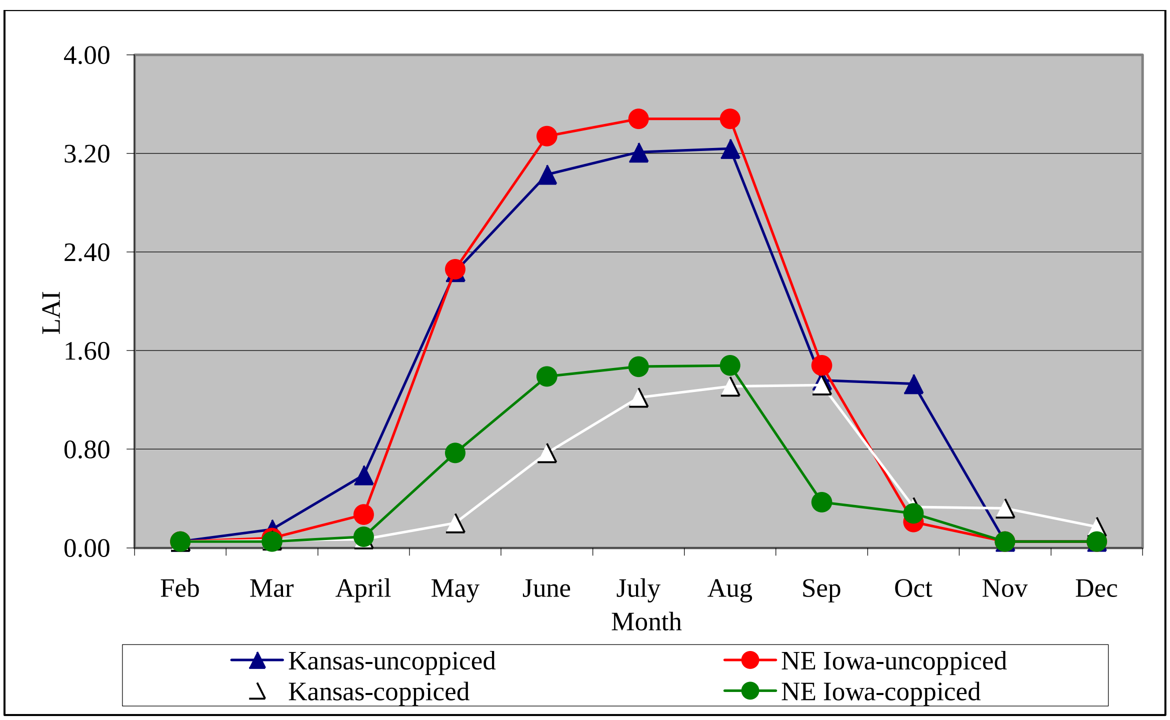


Figure 6.2. Optimum Monthly Leaf Area Index for Uncoppiced and Coppiced Hybrid Poplar

The APEX-predicted dry matter biomass yields for switchgrass, uncoppiced, and coppiced hybrid poplar also vary within and across the MINK states (Figure 6.3). Uncoppiced hybrid poplar seems to produce higher biomass yield than switchgrass and coppiced poplar with the highest yields in Iowa (20.48 Mg ha^{-1}) and the lowest in Nebraska (10.86 Mg ha $^{-1}$)

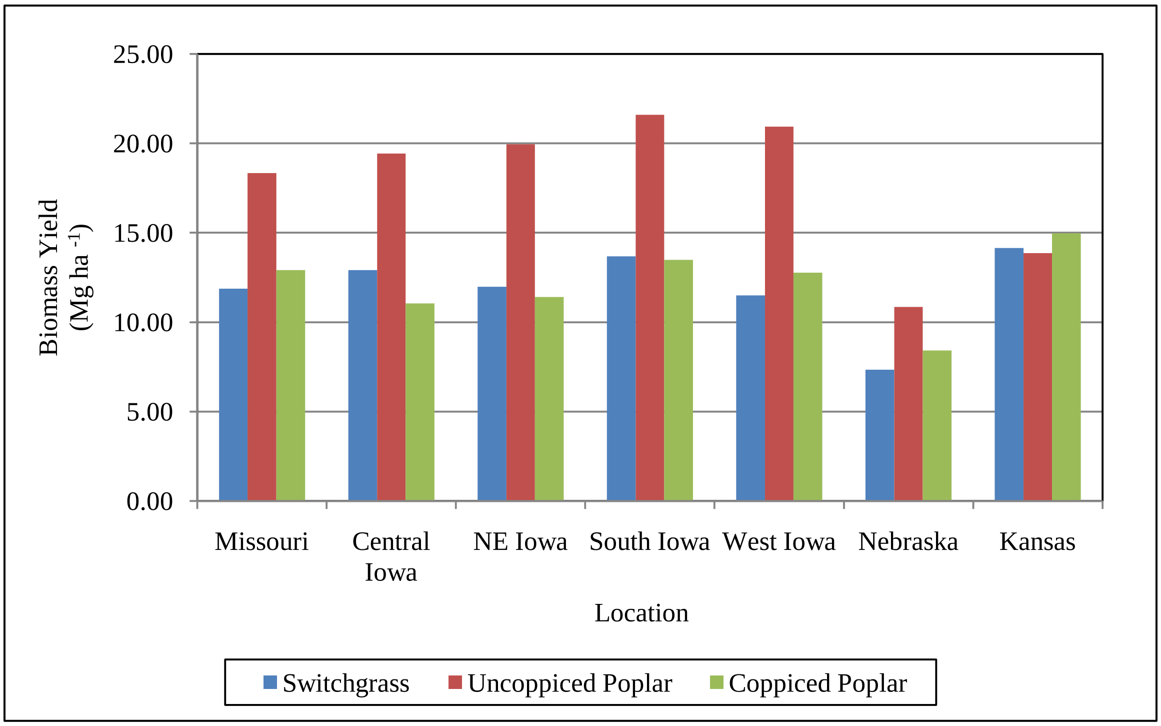


Figure 6.3. Mean Annual Biomass Yield for Switchgrass, Uncoppiced and Coppiced Hybrid Poplar

The annual mean yields for 10-year rotation of switchgrass fertilized with 150 kg N ha^{-1} is predicted to be 11.87, 12.52, 7.34, and 14.16 Mg ha^{-1} for Missouri, Iowa, Nebraska, and Kansas, respectively. These simulated yields are in close agreement with the reported range of switchgrass biomass yields of 11.7-13.7 Mg ha^{-1} with fertilizer application rates of 120 to 180 kg N ha^{-1} in the western cornbelt region (Vogel, et al.

2002). Walsh (1994) reported mean annual yields ranging at 10.5 to 12.6 Mg ha^{-1} in Northern Plains region with a fertilizer application rate of 112 kg N ha^{-1}. Results from the Oak-Ridge County Level Energy Crop (ORECCL) database and the Oak-Ridge Integrated Bioenergy Analysis System (ORIBAS) model, report annual yields of 13.64, 13.44, 10.12, and 10.12mt ha^{-1} for Missouri, Iowa, Nebraska, and Kansas, respectively (Graham and Walsh 1999).

Although standardized rates of N application, planting, and harvesting management were used for switchgrass production, variations in biomass yields were realized across the states because of the differences in pattern of seasonal climate (light, temperature, and humidity), soil nutrient, and the soil water holding capacity. According to Sanderson et al. (1990), these factors are critical in determining switchgrass yields. For example, low yields in Nebraska may have occurred because of the low average rainfall during the growing months (April to August), estimated at about 78.94 mm compared to 107.3 mm in Missouri, 102.45 in Iowa, and 85.02 mm for Kansas (Figure 6.4). In addition, there was an average of 64.4 days of water stress in Nebraska compared to 32.7 days in Missouri, 4.9 days in Central Iowa, 17.8 days in Northeast Iowa, 27.4 days in South Iowa, 35.3 days in West Iowa, and 48.1 days in Kansas. These factors may explain the low mean annual biomass yield in Nebraska (7.13 Mg ha^{-1}).

In addition to variation in biomass yield across the study sites, there were also differences in yields across the years within each site. For example, biomass yields were 68% and 46% lower in the second year compared to the tenth year for Missouri and Central Iowa, respectively.

According to McLaughlin and Kszos (2005), switchgrass achieves only 33-66% of its optimum yield capacity during the first and second years before attaining its full yield potential in the third year after planting, primarily because it allocates a large amount of energy towards the establishment of its root system during the initial growing seasons.

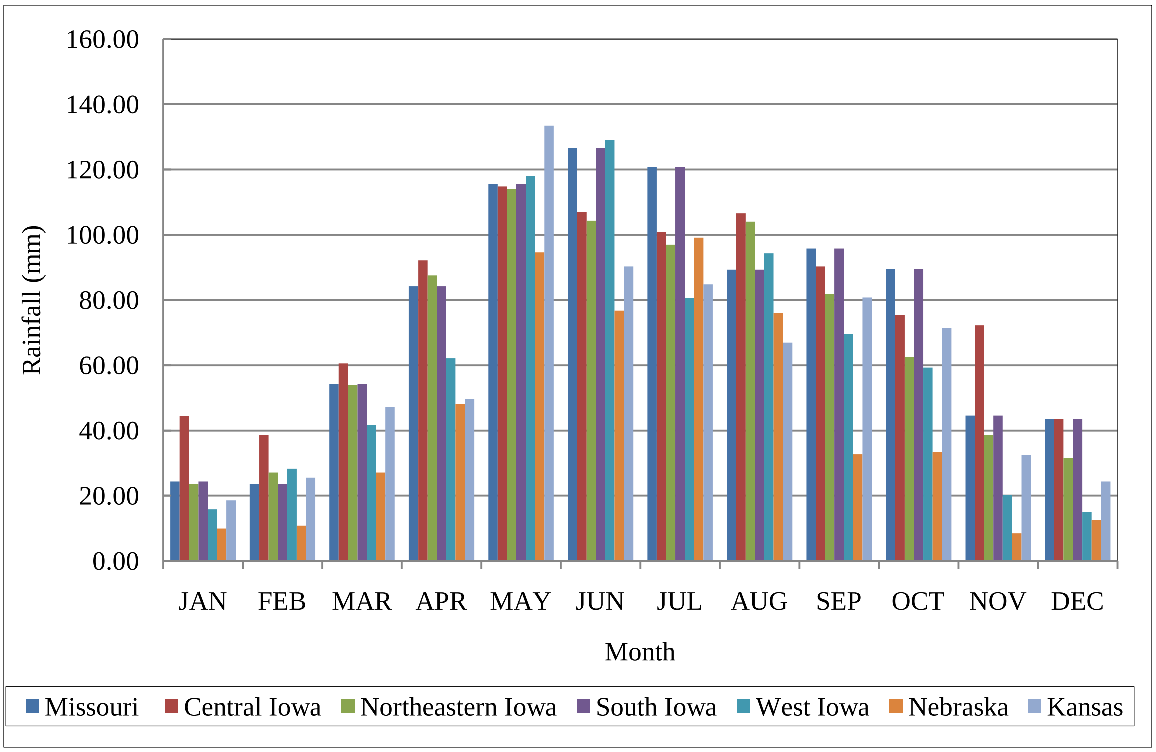


Figure 6.4. Average Monthly Rainfall for the MINK Region

Source: APEX Database

The mean annual aboveground woody biomass yield for a 4-year-rotation of uncoppiced hybrid poplar varies between 21.60 Mg ha^{-1} in South Iowa and 10.86 Mg ha^{-1} in Nebraska (Table 6.1). These results are within the range of aboveground biomass yield reported in literature for various poplar clones. Annual average yields of 16.3-35.2 Mg ha^{-1} for 4-year rotation of various poplar clones have been reported in the United States under optimal environmental conditions of favorable climate, fertilizer application, and irrigation (Heilman and Xie 1993; Heilman et al. 1994; Heilman and Stettler 1985; Scarascia-Mugnozza et al. 1997). However, annual yields of 10.0 to 15.0 Mg ha^{-1} for various poplar species have been reported to be more realistic depending on the clone, soil, climate and management regime (Cannell and Smith 1980; Hansen 1991). Dowell et al. (2009) reported an average annual biomass yield of 14 Mg ha-1 for a densely populated short-rotation *Populus spp.* in the lower Midwest USA.

Some studies have reported that coppicing poplar promotes a higher number of shoots per unit area as well as more rapid leaf area development than single stem cuttings (Cannell et al. 1988; Ceulemans et al. 1990; Heilman and Xie 1994). This occurs because new shoot growth benefits from the already established root system leading to rapid leaf area development, fast crown canopy closure, and efficient utilization of space and light resources and therefore higher biomass yield compared to uncoppiced poplar (Rae et al. 2004).

This study realized biomass yields ranging from 14.98 Mg ha^{-1} in Kansas to 8.43 Mg ha^{-1} in Nebraska (Table 6.1). The lower yields relative to uncoppiced poplar could probably have occurred as a result various factors, including length of rotation cycle, planting density and spacing, water, and nutrient availability. Simulation of coppiced poplar was based on a planting density of 10,000 plants, coppice and harvest after every 2 years, and replacement of stool (root system) after 15 years. Using the SECRET model to simulate biomass yield in coppiced poplar Deckmyn, et al. (2004a) reported higher yields for a 3 to 4-years rotation cycle compared to a 5- or 6-year rotation cycle. Similar results have been found in field studies (Fang et al. 2007).

Pontailler et al. (1999) reported biomass yields of poplar clones harvested on a 2-year rotation cycle, a rotation cycle similar to this study. In their experiment, biomass production of ranged from 18-28 Mg ha^{-1} yr-^{1} after coppicing. Fertilizer application (N, P, K) at the rate of 100 kg ha^{-1} and irrigation was applied twice every year from establishment until the end of the second coppice. This study found lower yields than those reported by Pontailler et al. (1999) mainly because the simulation was based on marginal area conditions (no fertilizer application and rainfed). Lack of sufficient water and nutrients could explain the low LAI in both coppiced and uncoppiced poplar (Deckmyn, et al. 2004a).

As mentioned earlier, LAI plays a key role in determining plant biomass productivity. Most studies have reported LAI of ranging from 5.8 to 7.1 after coppicing (Deckmyn, et al. 2004a, Pontailler et al. 1999). In this study, the maximum LAI values range between 1.48 in Northeastern Iowa and 1.32 in Kansas. The average monthly LAI development for both switchgrass and poplar are detailed in Table 1 (Appendix B). The low LAI might have occurred as a result of APEX not capturing all the processes in leaf area development of short rotation woody trees. APEX was designed to capture leaf area development in annual and perennial crops, characterized by rapid LAI development after seedling stage and after harvesting within a single growing season. Tree growth was designed to simulate LAI over a multiyear growth period with a single harvest for lumber or biomass. The model therefore does not currently capture the dynamics of coppiced tree systems. Additional crop parameters for trees are needed to capture multi-year leaf area development in coppiced systems. APEX would therefore need modification to be applicable in predicting biomass from coppiced tree biomass production systems as well as the effects of management regimes.

Soil Carbon Sequestration

A 20-year simulation was conducted to evaluate the change in soil organic carbon in the MINK region under the following two CRP policy scenarios:

Table 6.2. Annual Average Predictions of 20-year Soil Organic Carbon Simulation

		Missouri	Central Iowa	NE Iowa	South Iowa	West Iowa	Nebraska	Kansas
	Initial C content[1]	46.02	43.39	102.81	213.96	106.39	87.17	109.29
Switchgrass	20-year net Change	4.36	4.38	3.49	-0.77	2.05	2.60	1.65
	20-year %change	9.48	10.09	3.40	-0.36	1.92	2.98	1.51
Uncoppiced poplar	20-year net Change	8.34	8.28	7.64	1.72	6.06	5.22	6.57
	20-year %change	18.13	19.09	7.43	0.81	5.69	5.99	6.01
Coppiced poplar	20-year net Change	4.29	4.74	3.95	-1.30	2.44	2.72	3.13
	20-year %change	9.33	10.92	3.84	-0.61	2.29	3.12	2.86
Traditional crops-CT	20-year net Change	5.37	6.17	3.79	-5.61	2.58	4.15	2.14
	20-year %change	11.68	14.23	3.69	-2.62	2.42	4.76	1.96
Traditional crops-CS	20-year net Change	5.20	6.23	3.87	-4.68	2.60	4.04	2.47
	20-year %change	11.31	14.37	3.76	-2.19	2.44	4.63	2.26
Traditional crops-NT	20-year net Change	8.68	9.43	7.47	1.42	5.86	5.50	5.07
	20-year %change	18.86	21.74	7.27	0.66	5.51	6.31	4.64

[1]C content = Carbon content (Mg C ha^{-1} yr^{-1}) CT = Conventional tillage

CS = Conservation tillage NT = No-till tillage

1) Conversion of the CRP land to bioenergy crops (switchgrass and coppiced and uncoppiced poplar), and;

2) Conversion of CRP to traditional food crop production under various tillage management practices. The difference in soil organic matter between the initial values and values at the end of the 20-year simulation was used to calculate the average annual change in soil organic carbon (Table 6.2).

The model was used to estimate the potential of soil carbon sequestration by comparing: 1) the change in soil organic carbon under different soil types and weather conditions across the study sites using the same cropping system and management practices and, 2) the change in soil organic carbon under various cropping systems within each study site using the same climatic and soil conditions.

In this study, the APEX model predictions on change in soil carbon differ depending on cropping systems, soil type, and management practices. Assessment of various bioenergy crops within each study location (that is, assuming similar climatic, soil type, and initial carbon content) show higher change in soil carbon under SWRCs than under switchgrass. For example, change in soil carbon was 19% under uncoppiced poplar compared to 10% under switchgrass in Central Iowa (Table 6.2).

Similar results were reported in a study by Zan et al. (2001) which compared soil carbon sequestration under willow, switchgrass, and corn production systems in southern Quebec. Their results show higher carbon storage under the willow compared to switchgrass. The high soil carbon levels under willow plantation was attributed to higher N-fixing capacity, litter fall after harvest, and root turnover compared to switchgrass stands. In general, root turnover for SWRCs occur at least once per year in willow as opposed to once every 4 years in switchgrass (Zan et al. 2001).

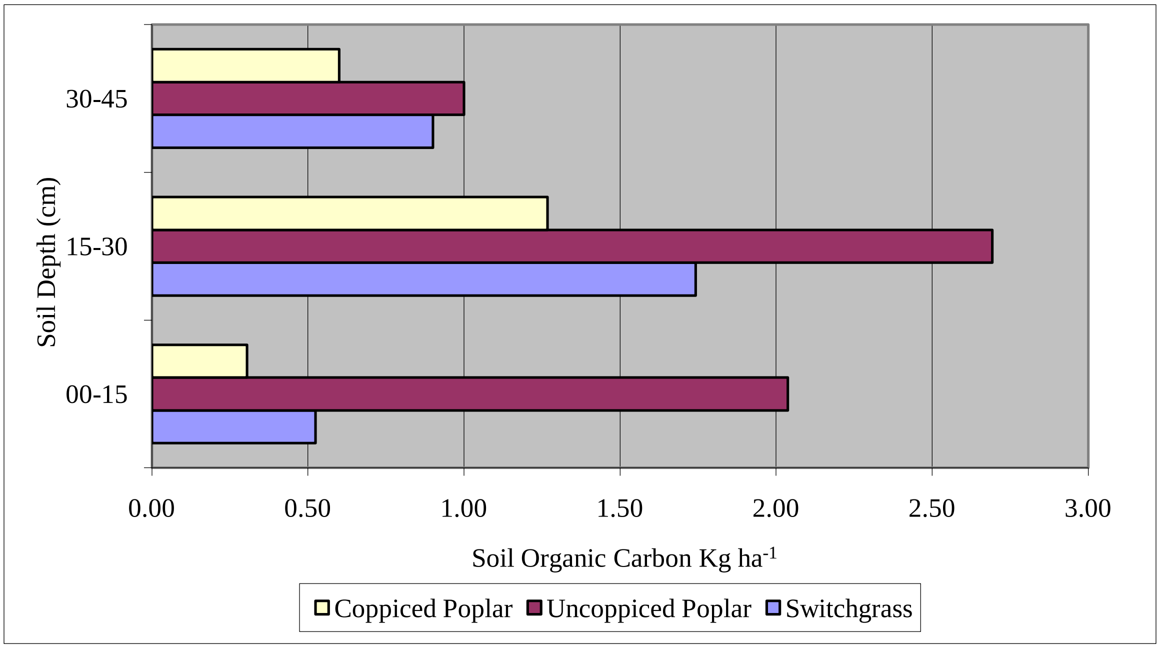


Figure 6.5. Soil Organic Carbon Levels for Different Soil Depth in Central Iowa

This study also noted prominent higher carbon storage in deeper soil depths under both bioenergy crops, 15- 30 cm. Previous studies suggest that high carbon gains below 30 cm in switchgrass are likely due to high carbon input from the deep root turnover (McLaughlin et al. 1998, Liebig et al. 2005). Liebig et al. (2005) found differences of 7.74 and 4.35 Mg ha^{-1} for the 30-60 and 60-90 cm depths, between switchgrass and cultivated crops, respectively.

This study also found that soil carbon change under each bioenergy crop varies across soil types and climatic conditions. The highest gain occurred in Central Iowa under uncoppiced poplar, estimated at 19% over the 20-year period, while the greatest loss was in South Iowa under coppiced poplar, estimated at 0.6% loss of carbon (Table 6.2). High initial carbon and sand content may possibly have caused the high loss of carbon in South Iowa through decomposition and soil erosion (Six et al. 2002). McConkey et al. (2003) report that soil texture, including the initial carbon content, bulk density, and the percentages of clay, sand, and silt affect the amount of organic matter retained in crop residue.

The Fayette soil series used in Central Iowa has lower initial carbon content (43%), lower sand content (7%), and higher silt contents (63%) compared to the Shelby series used in South Iowa with initial carbon, sand, and silt content of 224%, 17%, and 52%, respectively (Appendix A). Soils with high sand content have been reported to have higher rates of fresh residue decomposition than those with high clay and silt, primarily because of the clay formation of micro- and macro aggregates by clay soils which protect labile organic matter from further decomposition (Hassink 1997). In a study on 27 study sites across the North Central region of USA, Coleman et al. (2004) showed variation on soil carbon ranging from 20 Mg ha^{-1} to 160 Mg ha^{-1} across the various soil types, with the lowest soil carbon levels on sandy soils sites and the highest on lowland riparian sites.

In comparing bioenergy and traditional row crop production on CRP land, this study found higher soil carbon changes under no-tillage, traditional food crop production than under bioenergy crops. Moreover, soil carbon losses occurred mainly in initial years of crop establishment. For example, high losses of carbon through soil mineralization and erosion occur in South Iowa (Figure 6.6). Consistent with previous studies, lower soil carbon gains under perennial crops than cultivated and fallow soils has been associated with soil type and initial soil carbon inventory (Gebhart et al. 1994, Bransby et al. 1998). Gebhart et al. (1994) estimated that the maximum soil carbon sequestration was 1.1 Mg ha^{-1} yr^{-1} in 0 to 100 cm in soil of the Midwestern United States during the first 5 years of converting CRP land to perennial grasses.

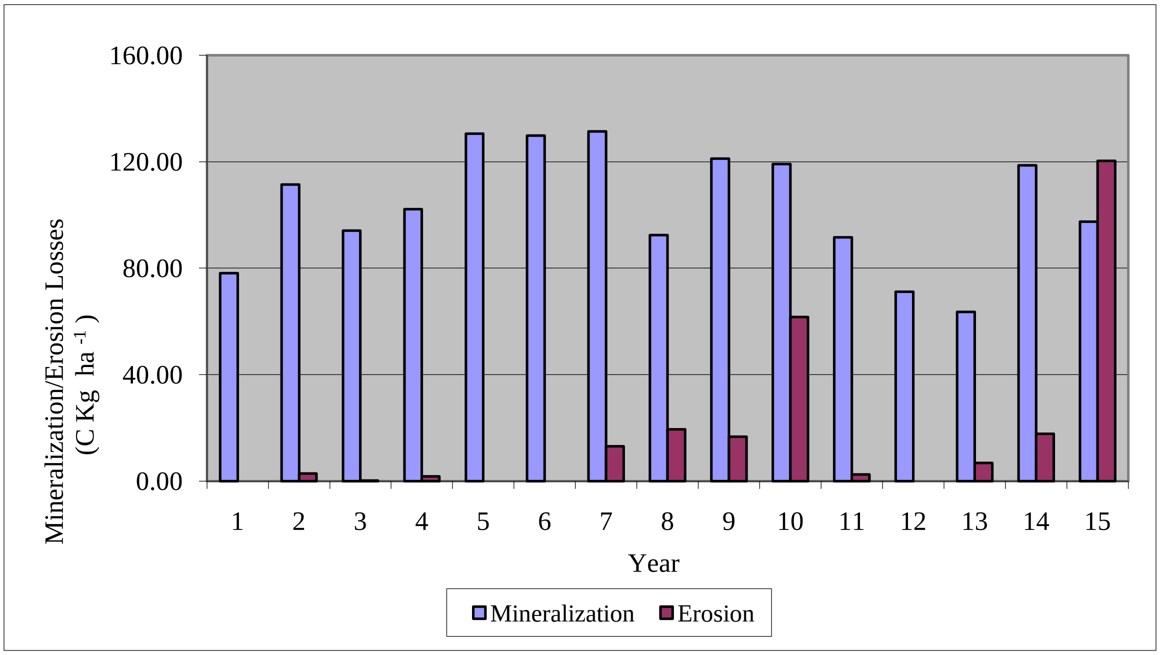


Figure 6.6. Soil Carbon Mineralization and Erosion in South Iowa

Other studies have reported that the length of period after perennial crop establishment affects the total amount of soil carbon gains. Ma et al. (2000a) reported no difference in total soil carbon at 0-15 and 15-30 cm under a switchgrass stand after 2-3 years of establishment. However, soil carbon was 45% and 28% higher at those depth intervals after 10 years of establishment than under adjacent fallow soils. Bransby et al. (1998) suggest that net soil carbon gains can only be realized if switchgrass was planted on lands degraded by long-term row crop cultivation. They also suggest that switchgrass would be more economical if grown and managed as a biofuel crop rather than for soil carbon sequestration.

In case of SRWC, limited and variable data is documented on soil carbon changes after their establishment. Makeschin (1994) for example, found that soil carbon storage nearly doubled after three years under hybrid poplar compared to adjacent arable fields in Germany. In a study to compare soil carbon changes on various hybrid poplar clones in the upper mid-West, Hansen (1993) reported a decrease in soil carbon during the first 6-12 years. However, Hansen (1993) also reported that hybrid poplar plantations in North Central United States, on average, sequestered 24.4 Mg C ha^{-1} more soil carbon than adjacent soil under agricultural row crops over 15 years. Likewise, in a study on soil carbon change under young poplar plantations in Minnesota, Grigal and Berguson (1998) found no significant difference in soil carbon content between 7-8 year old poplar stands and adjacent traditional row food crops, hay, and pasture.

In addition to initial soil carbon inventory, management practices including rotation length, harvesting frequencies, water and nutrient availability, and crop residue after harvests have been suggested to affect the amount of soil carbon under various cropping systems (Tolbert et al. 2000, Paul et al. 2003, Teklay and Chang 2008). Paul et al. (2002) point out that increasing rotation length and leaving high fraction of biomass after harvest can add substantial amounts of carbon to the soil. Leaving more than 30% of crop residue after harvest and minimal soil disturbance or no-till tillage minimizes fresh residue mineralization and decomposition, promotes soil aggregation, and reduces erosion and, thus, increases soil organic carbon (Lal 2005). In this study, coppicing poplar significantly reduced net soil carbon change under poplar, possibly because of high cutting frequency, short rotation length, and high planting density reported elsewhere (Grogan and Mathews 2002, Deckmyn et al. 2004b, Sartori et al. 2006, and Fang et al. 2007).

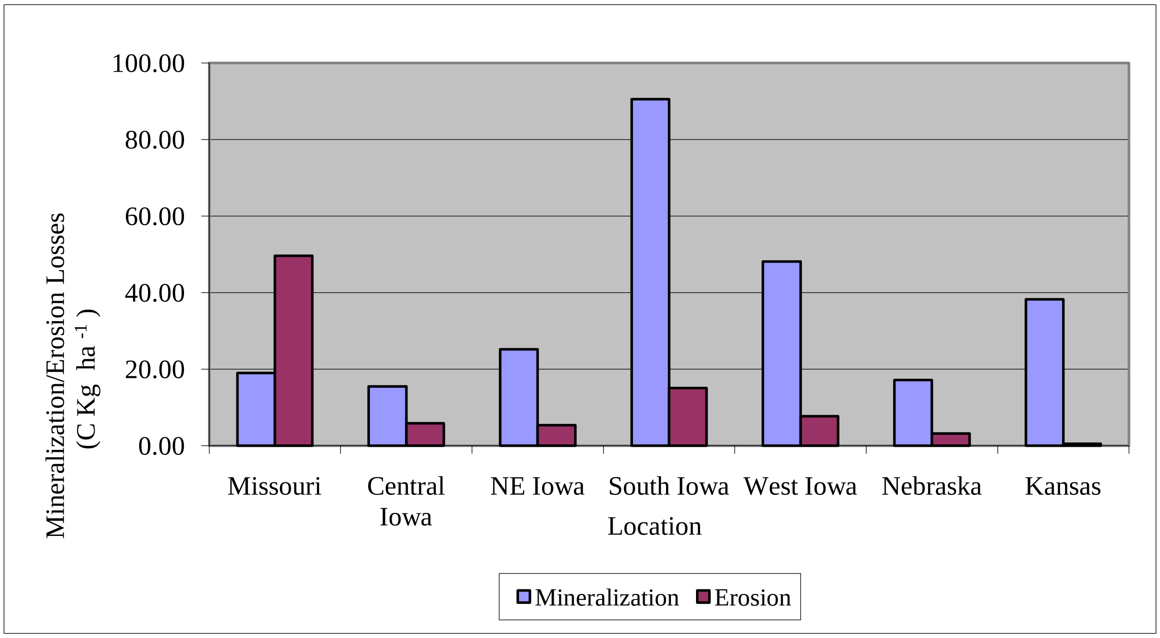


Figure 6.7. Carbon Losses under Coppiced Poplar in Missouri, Iowa, Nebraska, and Kansas

High harvesting frequency (assumed at 2-years in this study), shifts the allocation of carbon from active root biomass to regrowth of leaves (Ma et al. 2001) and also reduces the amount of litter input (Deckmyn et al. 2004b), thus reducing carbon-input from the re-sprouted trees.

A study by Fang et al. (2007) to evaluate the effects of various management patterns on soil carbon change under SRWC plantations, observed that the highest change occurred when coppiced poplars were planted at a spacing of 833 stems ha^{-1} and harvested at 6-year cutting cycles (rotation cycle).

Likewise, disturbance of soil during harvests may reduce carbon-input and increase carbon-output through decomposition and soil erosion (Paul et al. 2002). The rate of soil carbon loss through decomposition and erosion depends on soil type, soil moisture, and temperature. The high carbon losses through erosion in Missouri for example, might be due to the high sand content and fragipan associated with the Viraton soil series while carbon losses in South Iowa occurred through decomposition attributable to high initial carbon content and soil moisture content of the Shelby soil series (Figure 6.7).

This study used APEX 1310. The model may have underestimated the amount of soil carbon sequestered under bioenergy crops primarily because it lacked routines that provide direct interactions of carbon and nitrogen dynamics with lignin contents. These parameters were incorporated in APEX 0604, which was developed after the conclusion of this study. This latter version of the model has the capacity to partition soil organic material into five pools; metabolic litter, structural litter, microbial biomass, slow humus, and passive humus. It can also estimate the amount of carbon transferred from the litter pool to soil organic carbon pool as a function of lignin content, initial carbon content, soil properties, and climatic conditions (Izaurralde et al. 2006). These modifications may improve the understanding of carbon and nitrogen dynamics and help to draw more realistic conclusions of soil carbon sequestration under bioenergy crop plantations.

Environmental Co-Benefits

Growing bioenergy crops on CRP land has the potential not only to address atmospheric carbon problems but also to improve soil and water quality with the adoption of proper management practices. The following section presents the results of the amount of eroded soils, nitrogen and phosphorus lost under various land use and land management policy scenarios on CRP land including the conversion of CRP land into bioenergy crops (switchgrass and hybrid poplar), or traditional food crops (corn and soybeans) under various tillage practices coupled with implementation of riparian buffers.

Sediment loss under a 20-year simulation is highest under conventional and conservation traditional food crop across all study locations. The largest losses are found in Missouri, possibly due to high potential for water erosion associated with the Viraton soil series used as the representative soils for CRP land in Missouri (Figure 6.8). Like all soils with a fragipan horizon, Viraton soils are characterized by high clay content (50-60%), low water-holding capacity, poor hydraulic conductivity, and therefore poor root development.

The implication is that conversion of CRP land into row crop production would require landowners to adopt no-till management practice or put the land under cover crops to minimize soil and nutrient losses, particularly in soils with high clay content in combination with high rainfall.

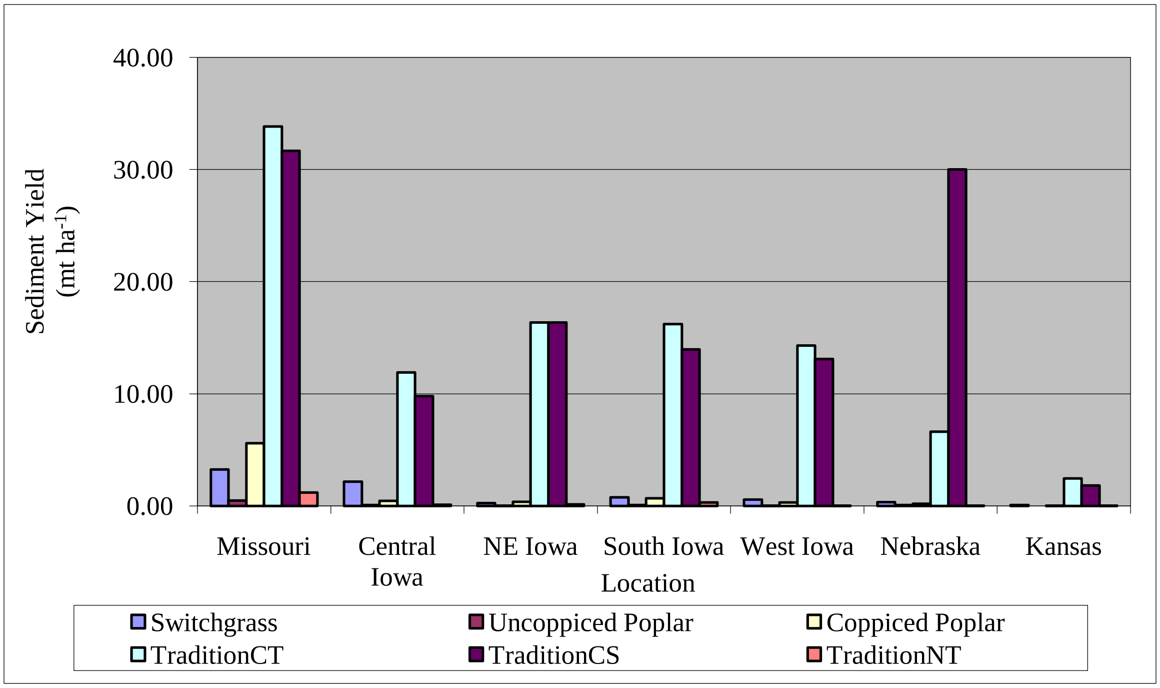


Figure 6.8. Total Sediment Losses in Runoff

Substantial loss in organic N occurs in traditional food crop production under conventional and conservation tillage practices (Figure 6.9). The high nitrogen loss under these systems could be attributed to soil disturbance, less residue on the soil surface. Higher rates of nitrogen application were applied under convection and conservation tillage practices compared to no-till. These conditions are conducive to nitrogen losses through leaching and runoff in sediment. For Nebraska, it is not clear why there was a higher N and P loss in runoff under conservation tillage than under conventional tillage (Figure 6.9 and Figure 6.10)

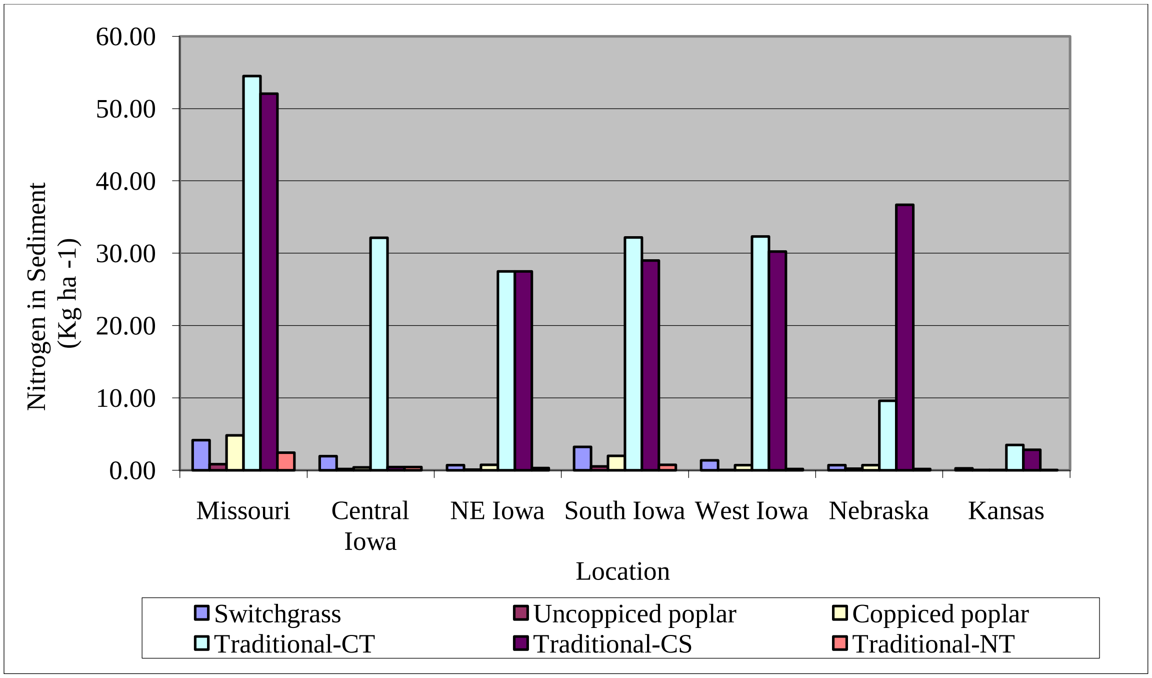


Figure 6.9. Nitrogen Transported in Sediment

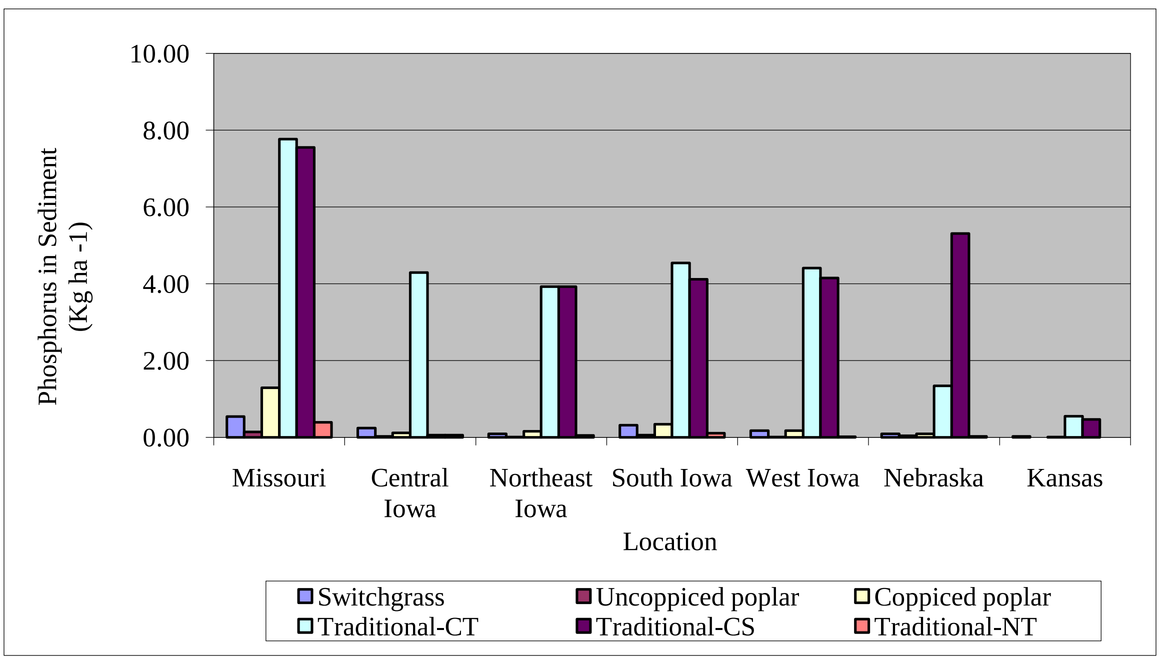


Figure 6.10. Phosphorus Transported in Sediment

Less phosphorus was lost in sediment across all regions and cropping systems relative to nitrogen. Phosphorus tends to be fixed in soil and is therefore less mobile. More phosphorus is lost under conventional and conservation tillage in food crop production, presumably because these systems are more prone to higher erosion losses (Figure 6.10).

In absolute terms, less nitrogen (in form of nitrate) was lost in solution than lost in the organic form in sediment (Figure 6.11). All cropping systems, including switchgrass and traditional food crop under all tillage systems, received nitrogen fertilizer application. No nitrogen was applied to poplar, which may explain the higher losses of soluble nitrogen in all other systems compared to poplar. As would be expected, insignificant phosphorus losses occurred in solution across all regions. However, the losses correlated with rainfall and tillage systems (Figure 6.12).

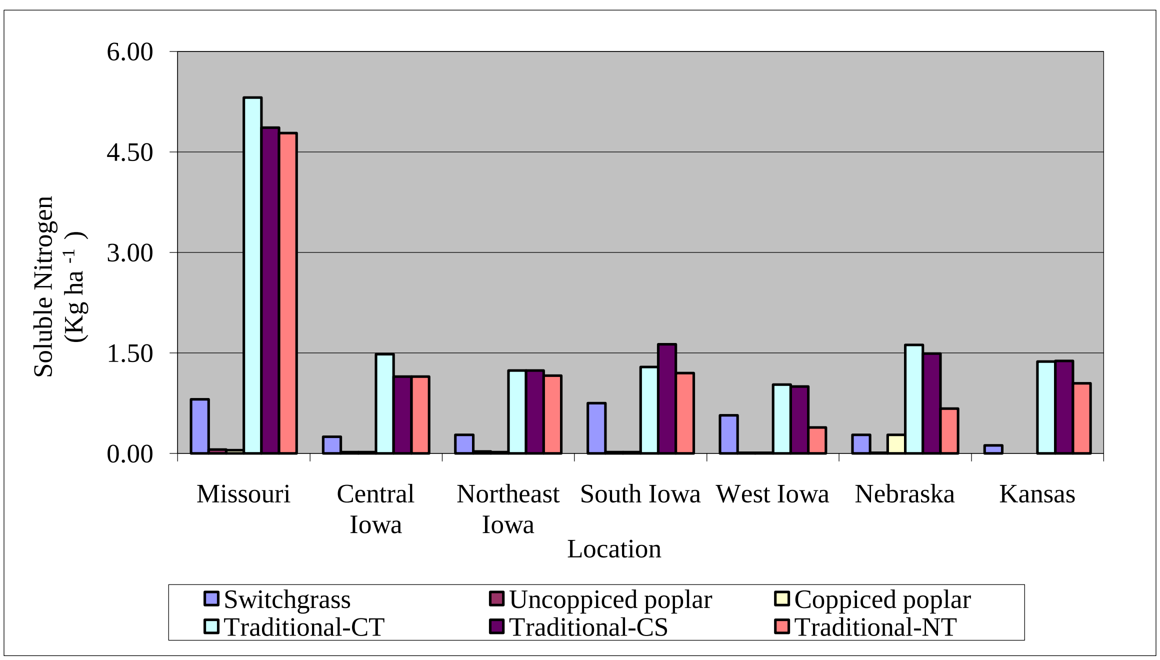


Figure 6.11. Soluble Nitrogen Losses

All the bioenergy crops reduced sediment and nutrient loading by about 90-98% relative to food crop production under conventional tillage.

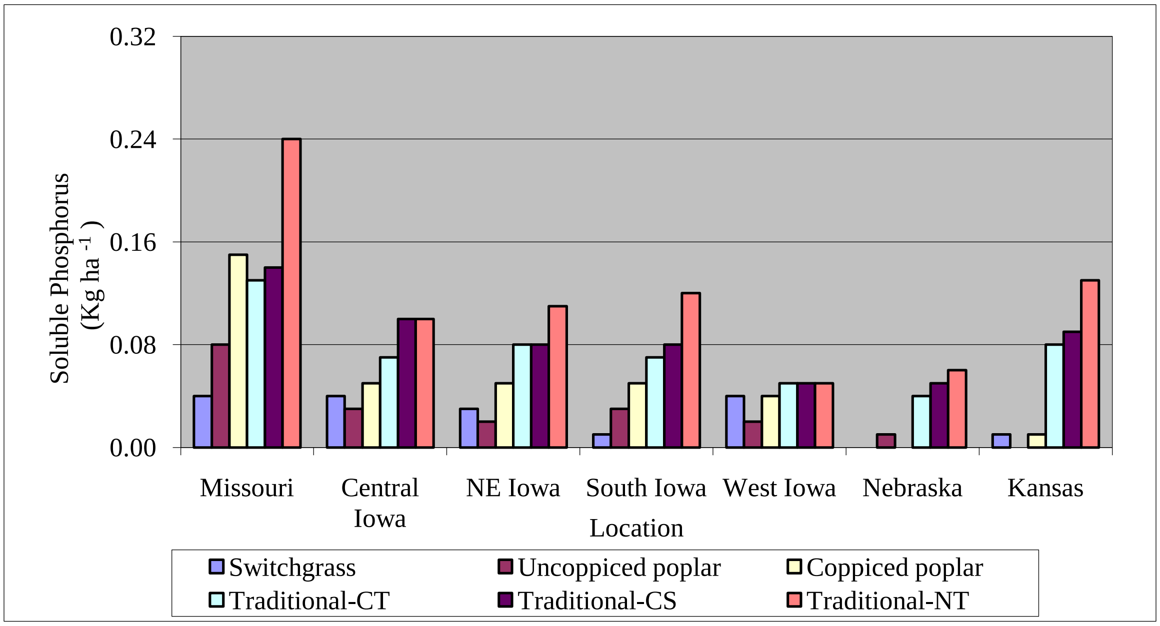


Figure 6.12. Soluble Phosphorus Losses

Scenario analysis was also conducted to evaluate the benefits of conservation tillage systems over conventional tillage on protecting soil and nutrient losses when CRP land is converted into food crop production. In all study locations, predicted results show an annual average sediment yield reduction of about 99% under no-till relative to conventional tillage and a reduction of about 96 to 99% in nitrogen and phosphorus loss in sediment (Appendix B, Table 2). Similar results have been reported in the literature in corn production (Wang et al. 2008; McDowell and McGregor 1984).

Using the APEX model to evaluate the impact of soil management practices on runoff and sediment yield, Wang et al. (2008) reported that implementation of a conservation tillage system reduced annual sediment loss by about 84% compared to conventional tillage. McDowell and McGregor (1984) showed that soil losses were reduced more than 92% by no-till practices over conventional tillage. The same study reported a reduction in losses of 70% and 80% for nitrogen and phosphorus, respectively.

While crop residue left on the soil surface under the no-till practice reduces soil erosion and increases water infiltration, the practice has been reported to be less effective in reducing nutrient losses associated with runoff and may even lead to an increase in loss of immobile nutrient like soluble phosphorus (USDA/NRCS 1997). This is primarily because, under the no-till practice, crop residue, nutrients and soils are not incorporated and, therefore, nutrients tend to be concentrated at the soil surface, leading to higher nutrient loss in the runoff relative to conventional and conservation tillage practices. McDowell and McGregor (1984) reported that about 40% of nitrogen and 42% of phosphorus were transported in solution in runoff from conservation tillage corn fields compared to 9% and 2% from conventional tillage.

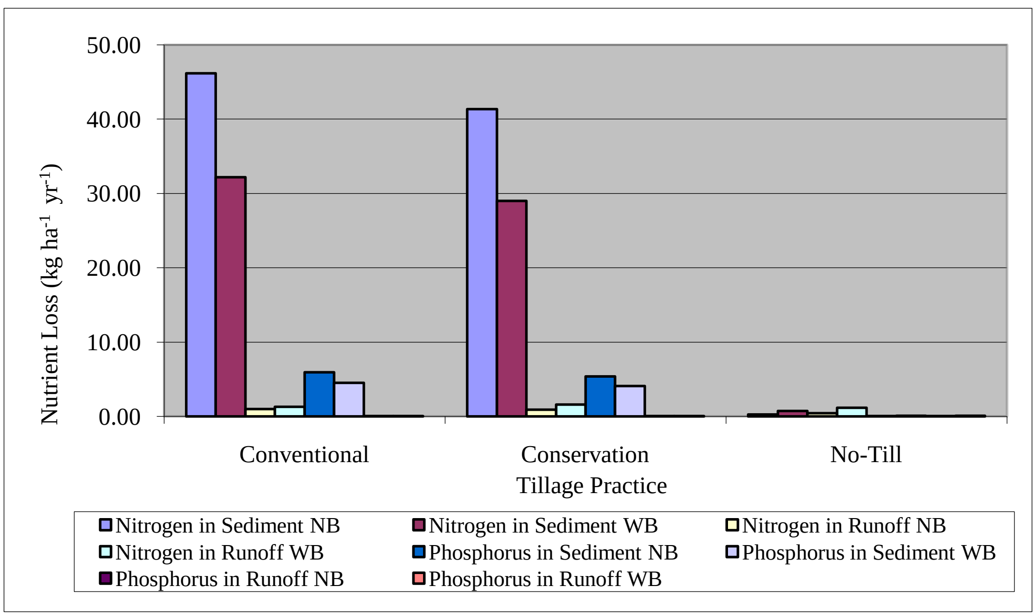
The current study found an annual average reduction of nitrogen loss in runoff ranging from 13.3 to 60.5% and an increase in phosphorus losses of about 50% under no-till compared to conventional tillage (Appendix B). An example is shown for South Iowa where nitrogen loss in runoff was reduced by about 52% while loss in soluble phosphorus increased by approximately 14% under no-till (Table 6.3).

As mentioned earlier, in 1997 the USDA/NRCS proposed to install 2 million miles of conservation buffers to reduce environmental degradation. This study assessed the effectiveness of switchgrass and hybrid poplar riparian buffers in trapping sediment and dissolved nitrogen and phosphorus pollutants from food crop production under various tillage systems. The results indicate that buffers performed better in some locations than in others (Appendix B).

Table 6.3. Effect of Tillage System on Soil and Nutrients in South Iowa

	Sediment Lost (mt ha^{-1})	N Lost in Sediment (kg ha^{-1})	N Lost in Runoff (kg ha$^{-1)}$	P Lost in Sediment (kg ha^{-1})	P Lost in Runoff (kg ha^{-1})
Conventional	18.07	46.17	0.99	5.96	0.06
Conservation (actual)	15.62	41.36	0.93	5.39	0.07
% Change	13.56	10.42	6.06	9.56	-16.67
No-Till (actual)	0.06	0.26	0.44	0.04	0.08
% Change	99.62	99.37	52.69	99.26	-14.29

Buffers, when coupled with no-till practice, significantly reduced nutrients attached to the sediment from loading into water bodies in South Iowa (Figure 6.13). However, implementing buffers in Missouri increased sediment and nutrient loading (Appendix B, Table 3).



NB=No Buffer and WB=With Buffer

Figure 6.13. Effects of Buffer and Tillage on Nutrient Loss in South Iowa

As discussed in Chapter 5, the Viraton soil representative of the Missouri site falls under hydrologic group C category. The Viraton soil texture is characterized by high sand and rock content and therefore prone to erosion and may therefore not allow enough time for buffers to trap the nutrient-loaded sediment. In addition, buffer crop development may be hampered by the low nutrient status of the sandy topsoil.

Economic Policy Scenario for CRP Land

The CRP policy is currently designed to meet specific environmental goals, including improving topsoil and water quality as well as enhancing wildlife habitat. While the program has achieved significant environmental benefits, concerns have been raised that reverting CRP land to food crop production may lead to loss of the environmental gains achieved over the years.

This section presents the potential economic impact of a policy scenario in which federal subsidies for CRP contracts are terminated. The scenario assumes that with cessation of CRP contracts, the land would revert to food crop production. Of the total predicted CRP contracts expiring during 2008/09 to 2014/15 nationwide, about 21% per year are in the MINK region, mostly in Kansas (Table 6.4).

Table 6.4. Land under CRP Contract Expected to Expire in MINK Region Cumulative, 2008/09-2014/15

	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15
U.S	6,530	9,106	11,053	12,145	12,227	12,520	13,357
Missouri	320	401	463	525	529	544	585
Iowa	213	365	480	570	576	600	668
Nebraska	228	305	375	416	419	429	457
Kansas	658	825	988	1,055	1,060	1,080	1,137
Total (MINK)	1,419	1,896	2,306	2,565	2,584	2,652	2,847

Source: The USDA Farm Service Agency, 2006; Area in 1000 Hectares

In the presence of voluntary government programs such as CRP, the landowner's decision on participating in the program is based on market returns of agricultural commodities relative to those of the program. If government rental and cost-share payments in CRP contracts cease, the landowner's decision on how much acreage to put under a specific crop would depend on the expected commodity prices. This study used the FAPRI baseline for the year 2005 to evaluate the impact of terminating the CRP program on the U.S. commodity markets.

The USDA/FSA predictions show that about 15.59 Mha would be enrolled under the CRP program by 2015. However, if the program is terminated as the CRP contracts expire, the current study estimates that about 13.36 Mha will move out of the program by 2015. Of this total, about 4.94 Mha will return to corn, soybeans, wheat, and hay production.

The impact of eliminating CRP contract on corn, soybean, wheat, and hay markets is evaluated as the percentage change from FAPRI's 2005/06 (Table 6.5) Corn acreage is estimated to increase by 2.19% by 2014/15. Increase in corn acreage would result in a corresponding increase in production estimated at 2.04%, domestic use by 0.71%, and exports by 6.24%. By 2015, corn average farm prices and gross revenues are estimated to decline by 4.03% and 4.19%, respectively. As in corn, the area planted to soybeans would increase by 3.24% and corresponding decline in farm price and gross revenue of about 4.11% and 4.32%, respectively. There would be an increase in area under wheat production of about 7.03% and a decline of 7.59 in hay farm price over the projected period.

Table 6.5. Percentage Change Relative to the Baseline in Area Planted, Production, Domestic Use, and Prices when CRP Contracts are Allowed to Expire 2008/09-2014/15

	08/09	09/10	10/11	11/12	12/13	13/14	14/15
Corn							
Planted Area	1.32	1.58	1.89	2.00	1.96	1.95	2.19
Production	1.22	1.47	1.76	1.87	1.82	1.81	2.04
Domestic Use	0.35	0.49	0.62	0.67	0.66	0.65	0.71
Exports	1.86	3.73	4.87	5.62	5.89	6.00	6.24
Price	-1.78	-2.58	-3.17	-3.49	-3.59	-3.72	-4.03
Gross Revenue	-1.90	-2.70	-3.32	-3.63	-3.73	-3.86	-4.19
Soybean							
Area Planted	1.20	1.75	2.20	2.54	2.58	2.92	3.24
Production	1.08	1.61	2.03	2.36	2.41	2.72	3.03
Domestic Use	0.72	1.06	1.32	1.52	1.60	1.77	1.97
Exports	1.21	2.40	3.22	3.90	4.37	4.75	5.40
Price	-1.21	-1.93	-2.51	-2.99	-3.27	-3.60	-4.11
Gross Revenue	-1.33	-2.07	-2.67	-3.16	-3.44	-3.79	-4.32
Wheat							
Area Planted	3.95	5.31	6.41	6.85	6.81	6.88	7.21
Production	3.77	5.12	6.16	6.63	6.59	6.67	7.03
Domestic Use	0.78	1.07	1.25	1.34	1.34	1.38	1.40
Exports	4.63	8.07	10.58	11.98	12.41	12.59	13.05
Price/Returns	-1.59	-2.55	-3.18	-3.54	-3.64	-3.72	-3.92
Gross Revenue	-1.89	-2.89	-3.61	-3.95	-4.05	-4.12	-4.31
Hay							
Area Planted	1.20	1.82	2.14	2.30	2.28	2.27	2.38
Production	1.09	1.67	1.96	2.12	2.10	2.10	2.21
Disappearance	0.57	1.13	1.55	1.83	1.95	2.01	2.09
Price	-1.92	-3.82	-5.25	-6.23	-6.76	-7.12	-7.59
Gross Revenue	-1.31	-3.43	-5.23	-6.52	-7.31	-7.78	-8.25

Shifting Some Cropland for Buffer Crop Production

The USDA Natural Resource Conservation Service (NRCS) has proposed to install 2 million miles of conservation buffers to prevent environmental degradation. This section presents the potential economic impact of a scenario under which conservation buffers, including switchgrass and poplar, are established on part of the land currently under food crop production.

Table 6.6. Effects of Buffer Conservation Crops on U.S. Crop Prices, Percentage Change from Baseline, 2008/09-2014/15

	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15
Corn	0.13	0.26	0.38	0.49	0.62	0.73	0.75
Wheat	0.10	0.22	0.34	0.45	0.57	0.68	0.71
Soybeans	0.09	0.20	0.31	0.42	0.53	0.69	0.70
Sorghum	0.14	0.27	0.40	0.52	0.66	0.78	0.80
Hay	0.12	0.30	0.52	0.74	0.98	1.23	1.37

With the implementation of conservation buffers the area planted under various commodities would decline (Appendix C). The decrease in area would lead to percentage price increase from FAPRI's 2005/06 baseline ranging from 0.70% in soybean to 1.37% in hay market by 2014/15 (Table 6.6).

CHAPTER 7

SUMMARY AND CONCLUSIONS

The IPCC 's fourth assessment report indicates that human generated CO_2 emissions has increased atmospheric CO_2 concentration from its pre-industrial value of 280 ppm to 379 ppm in 2005. Combustion of fossil fuels has increased CO_2 emissions from 6.2 GtC per year in the 1990s to 7.2 GtC per year in 2000-2005, contributing to most of the global warming and subsequent climate change in the past 50 years. The IPCC predicts that surface temperature is likely to increase further 1.1 to 6.4 ^{0}C during the twenty-first century. The UN Framework Convention on Climate Change has called on the world leaders to adopt policies that will reduce CO_2 emissions such as increased use of more energy-efficient technologies and higher investment in renewable energy, including biomass energy.

Production and management of bioenergy crops on CRP land has the potential to control CO_2 emissions, improve soil and water quality, and provide extra income to farmers. However, large-scale biomass feedstock is required for a biomass-energy system to achieve its potential. Currently, production of large-scale bioenergy crops is not economically competitive with conventional food crop production. Utilizing set-aside lands such as the CRP acreage to grow bioenergy crops has been suggested as one way to minimize such competition. Growing bioenergy crops on CRP land has the capacity not only to mitigate carbon by providing biomass energy feedstock and sequestering carbon in the soil but can simultaneously reduce soil and water degradation, offer an alternative source of farm income, and help reduce government expenditures on agricultural conservation programs.

This study developed an integrated modeling system to quantify long-term environmental and economic impacts of using USCRP land for large-scale bioenergy crop production. The study aims at providing landowners, state and federal government information to assist in developing policies that will offset global CO_2 emissions while at the same time supporting agricultural, energy, and environmental national objectives. The modeling system involved the use of the Agricultural Policy/Environmental EXtender (APEX) and commodity econometric models, to evaluate three policy scenarios that might be adopted upon the termination of the conservation reserve program in the United States.

The first policy scenario considered the potential of producing bioenergy crops, including switchgrass and hybrid poplar, on CRP acreage to provide biomass energy feedstock and to sequester carbon in the soil. The second scenario evaluated the environmental co-benefits (costs) of converting the CRP land into bioenergy crop production. The results were compared with a scenario in which traditional food crops are returned to CRP acreage accompanied with adoption of conservation tillage practices and buffer crop production. The third scenario considered the economic impact of returning traditional food crops to the CRP acreage and putting aside some cropland currently under food production for production of conservation buffers.

Under the first scenario, the APEX model was run over a 20-year period to estimate long-term predictions of biomass productivity under different climatic conditions, soil types, cultural management, and bioenergy crops within the MINK region. Across the study locations, switchgrass yields ranged from 14.16 to 7.34 Mg ha^{-1} for Kansas and Nebraska, respectively. The highest biomass yield for uncoppiced hybrid poplar was 21.60 Mg ha^{-1} in South Iowa while the lowest was 10.03 Mg ha^{-1} in Nebraska. The low levels of bioenergy yields in Nebraska were attributed to lower precipitation during the crop growing periods relative to other locations. Among the SRWC, uncoppiced hybrid poplar seems to produce higher biomass than coppiced yield ranging at 20.48 Mg ha^{-1} in Iowa and 10.86 Mg ha^{-1} in Nebraska. Biomass yields in coppiced poplar biomass range from 14.98 Mg ha^{-1} in Kansas to 8.43 Mg ha^{-1} in Nebraska.

In addition to biomass productivity, the study evaluated rates of change in soil carbon sequestration over a 20-year period among the bioenergy crops and traditional crop production under various tillage practices. The simulation results show that change in soil carbon stock differs with soil type, weather condition, cultural management, and bioenergy crop produced. The highest soil carbon increase occurs under uncoppiced poplar production in Central Iowa and Missouri, which was estimated at 19% and 18%, respectively. The greatest loss was found in South Iowa under coppiced poplar, estimated at a rate of 0.6% loss of carbon per year probably due to high average annual precipitation and clay content in Shelby soil in South Iowa. There was higher change in traditional crop production under no-till tillage practice compared to changes in soil carbon under any bioenergy crop. The unexpected results could probably be explained by high carbon losses occurring during the early years of bioenergy crop establishment, biomass removal at harvest, or measurement error. It should also be noted that most of the carbon in bioenergy crops is sequestered in biomass which eventually, if used in cofiring, has potential to offset CO_2 emissions from fossil fuel combustion.

Scientists continue to search for a better understanding of what constitutes soil carbon storage and how it can be accurately measured (Garten and Wullschleger 1999).

In the second policy scenario, effectiveness of bioenergy crops to maintain environmental objectives on CRP land was assessed. The results indicate that switchgrass and poplar significantly reduced sediment, nitrogen, and phosphorus loading into water bodies by about 90-98% over that of food crop production under conventional and conservation tillage practices. The study also found that, if CRP land is converted into food crop production, implementation of the no-till practice coupled with conservation buffers would reduce pollutant loading in water by over 90%. Growing bioenergy crops as the buffers can also be used to provide biomass feedstock for energy use.

The third scenario examined the impact of returning to food crop production on CRP acreage as the contracts expire and the impact of allocating some cropland to conservation buffer crop production on traditional commodity prices, farm income, and the level of government expenditure in the CRP program. This study estimated that if the CRP contracts were terminated as they expired in 2007/08, about 85.7% of land that was predicted to be under CRP in 2014/15 would have come out of the program over the 2007/08-2014/15 period. Using \$125 ha^{-1} as an average rental payment for the CRP land, it is estimated that the federal government could have saved nearly \$ 1.7 billion on CRP rental payments by 2014/15 period. Furthermore, about 80.6% of land coming out of CRP, was estimated to return to agricultural commodity production mainly under corn, soybean, wheat, and hay production. Consequently, an increase in corn, soybean, and wheat supply is estimated to result in an average farm price decline of about 4% by the year 2014/15. In addition, taking some cropland for conservation buffer crop production would raise farm prices by 0.75%, 0.71%, 0.70%, and 1.37% for corn, soybean, wheat, and hay, respectively, over the 2007/08-2014/15 period.

In conclusion, this study recommends further research on the interactions between bioenergy crops, soil types, climate, and management, which will eventually provide enough data and minimize uncertainty about estimates of long-term soil carbon changes associated with bioenergy crops in a region. Meanwhile, policy incentives, such as the proposed cap-and-trade policy, needs to be developed in support of biomass feedstock for energy production. The implementation of such a policy will aid in balancing agricultural, energy, and environmental objectives.

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APPENDIX A

The APEX Model Inputs

Table 1: Monthly average weather values for weather stations that were used for the APEX simulations

Dubuque, Central Iowa	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	t.	Nov.	Dec.
Maximum air temperature		-4.4	-1.1	5.0	14.0	20.4	25.7	27.9	26.8	22.3	16.2	6.8	-1.1
Minimum air temperature		-13.4	-10.4	-4.7	2.8	8.7	14.1	16.6	15.6	10.6	4.9	-2.5	-9.5
Precipitation	Mm	33.1	33.7	69.0	103.7	6.0	102.9	103.0	13.4	91.9	71.4	64.2	49.8
Solar Radiation	MJ/m^2	170	248	324	402	78	537	461	59	364	269	180	138
Relative Humidity	%	-9.4	-.8	-3.9	1.7	7.2	15.0	17.8	16.7	11.1	5.6	-2.8	-7.2
Wind Speed	m/s	5.0	5.0	5.5	5.7	5.2	4.5	4.1	3.9	4.5	4.8	5.4	5.1
Oelwein, Northeastern Iowa	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	t.	Nov.	Dec.
Maximum air temperature		-4.1	-0.9	5.0	14.7	21.4	26.4	28.5	27.5	23.0	17.1	7.2	-0.9
Minimum air temperature		-14.6	-11.2	-5.2	2.2	8.7	13.8	16.2	15.0	9.9	4.3	-3.2	-10.3
Precipitation	Mm	22.8	28.5	47.5	83.3	100.7	110.9	104.3	100.0	79.6	57.9	41.8	35.4
Solar Radiation	MJ/m^2	164	240	321	400	475	530	499	457	360	261	170	132
Relative Humidity	%	-10.6	-8.6	-4.6	1.6	7.6	14.6	17.3	16.6	11.2	5.4	-2.5	-7.9
Wind Speed	m/s	5.6	5.6	6.0	6.3	5.7	5.0	4.4	4.3	4.6	5.1	5.6	5.6
Castana, West Iowa	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	t.	Nov.	Dec.
Maximum air temperature		-2.5	1.2	5.9	15.9	22.2	26.9	29.3	28.2	23.5	18.3	8.8	1.3
Minimum air temperature		-13.2	-9.7	-5.0	2.7	9.6	14.8	17.3	16.2	10.9	5.4	-2.8	-9.2
Precipitation	Mm	17.0	25.1	46.1	62.7	105.1	133.7	93.7	96.7	70.5	51.8	22.6	17.1
Solar Radiation	MJ/m^2	181	261	353	428	498	553	560	489	394	291	195	152
Relative Humidity	%	-11.1	-8.1	-4.0	2.2	8.6	15.0	17.5	16.9	11.3	5.2	-2.5	-7.6
Wind Speed	m/s	9.0	9.0	10.0	9.0	8.0	7.0	7.0	6.0	7.0	8.0	7.0	7.0

Table 1 Cont.

Kirkville, Missouri	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	t.	Nov.	Dec.
Maximum air temperature		1.2	4.4	10.6	17.7	23.4	28.2	31.2	30.1	26.0	20.0	10.9	3.6
Minimum air temperature		-9.3	-6.6	-1.6	4.9	10.8	15.9	18.4	17.2	12.7	7.0	-0.3	-6.2
Precipitation	Mm	33.3	29.9	65.8	87.0	99.5	120.8	88.8	96.3	106.1	75.6	52.6	44.5
Solar Radiation	MJ/m^2	174	253	335	423	511	562	560	499	420	304	211	153
Relative Humidity	%	-8.0	-6.0	-2.7	3.8	9.9	16.0	18.4	17.6	12.3	6.4	-0.9	-5.6
Wind Speed	m/s	6.0	6.0	5.0	5.0	5.0	4.0	4.0	4.0	4.0	6.0	5.0	4.0
Wichita, Kansas	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	t.	Nov.	Dec.
Maximum air temperature		4.0	7.5	13.3	20.2	24.8	30.4	34.0	33.1	27.7	21.6	12.9	6.6
Minimum air temperature		-7.2	-4.6	0.3	7.0	12.5	17.9	21.1	20.0	15.3	8.4	1.0	-4.6
Precipitation	Mm	18.5	20.9	52.2	60.0	102.2	6.5	88.6	68.5	86.9	64.9	39.2	25.8
Solar Radiation	MJ/m^2	250	312	412	520	565	42	633	587	486	373	280	228
Relative Humidity	%	-6.1	-3.9	-1.1	5.0	11.7	16.7	18.3	17.2	12.8	7.2	0.6	-3.9
Wind Speed	m/s	15.0	15.0	11.0	9.0	8.0	4.0	3.0	4.0	7.0	9.0	11.0	13.0
Valentine, Nebraska	Unit	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	t.	Nov.	Dec.
Maximum air temperature		1.1	4.6	7.9	15.4	21.8	27.5	31.4	30.4	25.1	18.6	9.4	3.5
Minimum air temperature		-9.4	-8.0	-5.1	1.4	7.5	12.8	16.2	15.1	9.3	3.3	-3.8	-8.1
Precipitation	Mm	8.4	11.9	26.2	56.7	88.9	90.5	87.2	64.2	43.7	30.1	15.1	11.4
Solar Radiation	MJ/m^2	185	269	378	453	515	567	580	516	417	306	201	158
Relative Humidity	%	-10.6	-9.1	-5.7	-0.6	4.4	10.8	13.5	12.9	6.6	1.2	-5.4	-8.7
Wind Speed	m/s	8.0	8.0	9.0	9.0	7.0	6.0	6.0	5.0	7.0	7.0	7.0	6.0

Table 2: Soil Layer Properties for the soils used for APEX simulations

		Soil Layer									
Central Iowa	Unit	1	2	3	4	5	6	7	8	9	10
Layer depth	m	0.01	0.12	0.20	0.28	0.36	0.44	0.60	0.75	1.39	1.75
Bulk density	t/m3	1.40	1.40	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
Field Capacity	m/m3	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.35
Wilting point	m/m3	0.16	0.16	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.14
Sand content	%	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	6.90	9.40
Silt content	%	63.30	63.30	63.30	63.30	63.10	63.10	63.10	63.10	63.10	66.70
Clay content	(%)	29.80	29.80	29.80	29.80	29.90	30.00	30.00	30.00	30.00	23.90
Organic carbon	%	0.37	0.35	0.32	0.32	0.22	0.15	0.15	0.15	0.15	0.15
PH		6.20	6.20	5.30	5.30	5.30	5.30	5.30	5.30	5.30	6.50
Northeastern Iowa	Unit										
Layer depth	m	0.01	0.10	0.21	0.36	0.51	0.65	0.80	1.10	1.40	1.50
Bulk density	t/m3	1.35	1.35	1.35	1.51	1.51	1.51	1.51	1.51	1.51	1.55
Field Capacity	m/m3	0.35	0.35	0.35	0.39	0.39	0.39	0.39	0.39	0.39	0.35
Wilting point	m/m3	0.13	0.13	0.13	0.18	0.18	0.18	0.18	0.18	0.18	0.14
Sand content	%	9.50	9.50	9.50	9.40	6.90	6.90	6.90	6.90	6.90	9.40
Silt content	%	65.20	65.20	65.20	62.50	62.60	62.60	62.60	62.60	62.60	66.70
Clay content	(%)	25.30	25.30	25.30	25.50	30.50	30.50	30.50	30.50	30.50	23.90
Organic carbon	%	1.02	0.99	0.99	0.87	0.44	0.44	0.44	0.44	0.44	0.15
PH		6.20	6.20	6.20	5.90	5.90	5.90	5.90	5.90	5.90	6.50

Table 2 Cont.

Southern Iowa	Unit

Layer depth	m	0.01	0.06	0.18	0.29	0.40	0.48	0.55	0.70	1.01	1.46
Bulk density	t/m^3	1.25	1.25	1.25	1.25	1.25	1.62	1.62	1.62	1.50	1.55
Field Capacity	m/m^3	0.39	0.39	0.39	0.39	0.39	0.46	0.46	0.46	0.39	0.35
Wilting point	m/m^3	0.17	0.17	0.17	0.17	0.17	0.25	0.25	0.25	0.20	0.16
Sand content	%	17.40	17.40	17.40	17.40	17.40	7.30	7.30	7.30	18.20	19.30
Silt content	%	52.10	52.10	52.10	52.10	52.10	53.70	53.70	53.70	47.80	52.20
Clay content	(%)	30.50	30.50	30.50	30.50	30.50	39.00	39.00	39.00	34.00	28.50
Organic carbon	%	0.51	0.46	0.45	0.44	0.53	0.44	0.44	0.44	0.87	0.29
PH		6.30	6.03	6.20	6.20	6.20	5.60	5.60	5.60	5.80	6.10
Western Iowa	Unit										
Layer depth	m	0.01	0.07	0.17	0.26	0.35	0.50	0.64	0.79	0.93	1.49
Bulk density	t/m^3	1.35	1.35	1.35	1.35	1.35	1.51	1.51	1.51	1.51	1.55
Field Capacity	m/m^3	0.36	0.36	0.36	0.36	0.36	0.38	0.38	0.38	0.38	0.34
Wilting point	m/m^3	0.14	0.14	0.14	0.14	0.14	0.16	0.16	0.16	0.16	0.13
Sand content	%	9.40	9.40	9.40	9.40	9.40	7.20	7.20	7.20	7.20	11.30
Silt content	%	67.10	67.10	67.10	67.10	67.10	65.30	65.30	65.30	65.30	67.70
Clay content	(%)	23.50	23.50	23.50	23.50	23.50	27.50	27.50	27.50	27.50	21.00
Organic carbon	%	1.28	1.24	1.23	1.23	1.24	0.58	0.58	0.58	0.58	0.15
PH		6.50	6.50	6.50	6.50	6.50	6.70	6.70	6.70	6.70	7.50
Missouri	Unit										
Layer depth	M	0.01	0.05	0.15	0.24	0.34	0.43	0.59	0.74	0.92	1.42
Bulk density	t/m^3	1.45	1.45	1.45	1.45	1.45	1.45	1.57	1.57	1.75	1.75
Field Capacity	m/m^3	0.24	0.24	0.20	0.20	0.20	0.20	0.04	0.05	0.19	0.06
Wilting point	m/m^3	0.09	0.09	0.09	0.09	0.09	0.09	0.02	0.02	0.13	0.04
Sand content	%	22.10	22.10	22.10	22.10	22.10	20.00	20.00	20.00	7.40	7.40

Table 2 Cont.

Silt content	%	52.80	52.80	52.80	52.80	52.70	52.50	52.50	52.50	47.60	47.60

Clay content	(%)	25.10	25.10	25.10	25.10	25.80	27.50	27.50	27.50	45.00	45.00
Organic carbon	%	0.51	0.51	0.51	0.51	0.48	0.15	0.15	0.15	0.15	0.15
PH		5.90	5.80	5.30	5.30	5.30	5.30	4.60	4.60	5.90	5.90
Kansas	Unit										
Layer depth	M	0.01	0.15	0.29	0.39	0.50	0.60	0.70	0.90	1.11	1.51
Bulk density	t/m^3	1.44	1.44	1.44	1.68	1.68	1.68	1.68	1.67	1.67	1.67
Field Capacity	m/m^3	0.38	0.38	0.38	0.43	0.43	0.43	0.43	0.39	0.39	0.39
Wilting point	m/m^3	0.17	0.17	0.17	0.25	0.25	0.25	0.25	0.19	0.19	0.19
Sand content	%	23.00	23.00	23.00	10.70	7.30	7.30	7.30	18.30	18.30	18.30
Silt content	%	51.50	51.50	51.50	53.60	54.20	54.20	54.20	52.20	52.20	52.20
Clay content	(%)	25.50	25.50	25.50	35.70	38.50	38.50	38.50	29.50	29.50	29.50
Organic carbon	%	0.91	0.77	0.70	0.79	0.58	0.58	0.58	0.19	0.19	0.19
PH		6.70	6.70	6.70	7.30	7.30	7.30	7.30	7.90	7.90	7.90
Nebraska	Unit										
Layer depth	m	0.01	0.09	0.18	0.26	0.34	0.43	0.51	0.76	1.01	1.52
Bulk density	t/m^3	1.40	1.40	1.40	1.53	1.53	1.53	1.53	1.63	1.63	1.63
Field Capacity	m/m^3	0.39	0.39	0.39	0.40	0.40	0.40	0.40	0.39	0.39	0.39
Wilting point	m/m^3	0.16	0.16	0.16	01.7	0.17	0.17	0.17	1.18	0.18	0.18
Sand content	%	8.40	8.40	8.40	8.40	8.30	7.20	7.20	7.20	7.20	7.20
Silt content	%	66.30	66.30	66.30	66.30	66.20	65.30	65.30	65.30	65.30	65.30
Clay content	(%)	25.40	25.40	25.40	25.40	25.50	27.50	27.50	27.50	27.50	27.50
Organic carbon	%	1.11	1.09	1.09	1.01	0.97	0.44	0.44	0.29	0.29	0.29
PH		6.70	6.70	6.70	6.90	6.90	6.90	6.90	7.50	7.50	7.50

Table 3. Tillage operation and date assumed for APEX simulations, bioenergy crops

Cropping system	Tillage	Year(s)	Operation	Date
Alfalfa	no-till	year 1	Harvest (90%)	October 30
Switchgrass	no-till	year 1	Planter No-till	April 15
			Mower	September 20
		year 2	Fert. application	June 15
		year 2	Harvest (90%)	September 30
		year 3 -10	Harvest (90%)	September 15
		year 10	Kill	October 30
Uncoppiced poplar	no-till	year 1	Cutting planter	March 20
		year 4	Clearcut (85%)	September 20
		year 4	Kill	September 21
Coppiced poplar	no-till	year 1	Cutting planter	March 25
		year 3	Clearcut (85%)	March 9
		Year 5	Clearcut (85%)	September 30
		Year 6	Thin (50%)	September 20
		Year 8,10,12&14	Thin (25%)	September 20
		Year 9,11,13&15	Clearcut (85%)	September 30
		Year 15	Kill	October 15

Table 4. Tillage system, operation and date assumed for APEX simulations, traditional crops

Cropping system	Tillage system	Fertilizer type	Year(s)	Fraction HU	Implement
Corn	Conventional	Element N (88kg/ha)	Year 1	0.06	Fert. application
		Element P (11kg/ha)		0.06	Fert. application
		Anhydrous-NH3		0.06	Fert. application
				0.08	Tandem disk
				0.11	Field cultivator
				0.06	Row cultivator
				0.12	Row planter
		Anhydrous-NH3		0.30	Fert. application
				1.15	Harvest (95%)
					Kill
Soybean	Conventional	Element P (11kg/ha)	Year 2	0.07	Fert. application
		Anhydrous-NH3		0.07	Fert. application
				0.08	Tanderm disk
				0.12	Field cultivator
				0.20	Row planter
		Element P (11kg/ha)		0.10	Fert application
				1.10	Harvest (95%)
					Kill
Corn	Conservation	Element N (88kg/ha)	Year 1	0.06	Fert. application
		Element P (11kg/ha)		0.06	Fert. application
		Anhydrous-NH3		0.06	Fert. application
				0.08	Field cultivator
				0.11	Row cultivator
				0.12	Row planter

Table 4 Cont.

		Anhydrous-NH3		0.30	Fert. application
				1.10	Harvest (95%)
					Kill
Soybean	Conservation	Element P (11kg/ha)	Year 2	0.07	Fert. application
		Anhydrous-NH3		0.07	Fert. application
				0.08	Tanderm disk
				0.12	Field cultivator
				0.20	Row planter
		Element P (11kg/ha)		0.21	Fert application
				1.10	Harvest (95%)
					Kill

Table 4 (continued)

Corn	No-till	Element N (88kg/ha)		0.05	Fert. application
		Element P (11kg/ha)		0.05	Fert. application
		Anhydrous-NH3		0.05	Fert application
				0.11	Drill planter
		Anhydrous-NH3		0.30	Fert application
				1.10	Harvest (95%)
					Kill
Soybeans	No-till	Element P (11kg/ha)		0.07	Fert. application
		Anhydrous-NH3		0.07	Fert application
				0.11	Drill planter
				1.11	Harvest (95%)
					Kill

APPENDIX B

The APEX Model Output

Table 1: Monthly Leaf Area Development for Bioenergy Crops in the MINK Region

	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Switchgrass											
Missouri	0.07	0.22	0.86	2.66	7.03	6.17	4.77	2.07	2.65	0.91	0.08
Central Iowa	0.05	0.05	0.30	1.65	6.08	6.36	5.65	1.24	1.33	0.17	0.05
NE Iowa	0.05	0.05	0.31	2.70	6.33	6.43	5.67	1.15	1.16	0.13	0.05
South Iowa	0.07	0.22	0.95	4.53	7.20	6.31	5.02	2.11	2.70	1.04	0.08
West Iowa	0.05	0.06	0.42	4.22	6.81	6.34	5.39	1.36	1.76	0.20	0.05
Nebraska	0.06	0.06	0.29	1.84	5.93	6.09	5.39	1.65	1.53	0.12	0.05
Kansas	0.16	0.58	1.89	4.57	6.79	5.62	3.06	0.98	2.24	1.71	0.26
Uncoppiced Poplar											
Missouri	0.05	0.11	0.47	2.28	3.12	3.24	3.25	1.35	1.01	0.05	0.05
Central Iowa	0.05	0.08	0.31	2.23	3.3	3.44	3.45	1.45	0.46	0.05	0.05
NE Iowa	0.05	0.08	0.27	2.26	3.34	3.48	3.48	1.48	0.21	0.05	0.05
South Iowa	0.05	0.11	0.47	2.28	3.12	3.24	3.25	1.35	1.01	0.05	0.05
West Iowa	0.05	0.09	0.34	2.29	3.28	3.42	3.42	1.44	0.63	0.05	0.05
Nebraska	0.05	0.1	0.3	2.22	3.2	3.34	3.35	1.53	0.29	0.05	0.05
Kansas	0.05	0.15	0.59	2.24	3.03	3.21	3.24	1.36	1.33	0.05	0.05
Coppiced Poplar											
Missouri	0.05	0.05	0.06	0.12	0.75	1.26	1.34	1.35	0.34	0.33	0.05
Central Iowa	0.05	0.05	0.05	0.09	0.74	1.36	1.44	1.45	0.36	0.34	0.05
NE Iowa	0.05	0.05	0.05	0.09	0.77	1.39	1.47	1.48	0.37	0.28	0.05
South Iowa	0.05	0.05	0.06	0.12	0.75	1.26	1.34	1.35	0.34	0.33	0.05
West Iowa	0.05	0.05	0.05	0.09	0.75	1.35	1.44	1.44	0.36	0.33	0.05
Nebraska	0.05	0.05	0.06	0.09	0.75	1.36	1.45	1.46	0.36	0.29	0.05
Kansas	0.05	0.06	0.07	0.2	0.77	1.22	1.31	1.32	0.33	0.32	0.17

Table 2: The Impact of Tillage Methods on Soil and Nutrient Loss

Subareas	Sediment Loss (mt/ha)	N Loss in Sediment (kg/ha)	N Loss in runoff (kg/ha)	P Loss in Sediment (kg/ha)	P Loss in runoff (kg/ha)
Missouri					
Conventional	21.85	15.13	1.43	2.27	0.06
Conservation (actual change)	19.06	14.07	1.42	2.12	0.06
% change	12.77	7.01	0.70	6.61	0.00
No-Till (actual change)	0.14	0.13	1.03	0.02	0.09
% change	99.36	99.14	27.97	99.12	-50.00
Central Iowa					
Conventional	19.52	10.62	3.09	1.58	0.09
Conservation (actual change)	17.07	9.86	3.15	1.48	0.09
% change	12.55	7.16	-1.94	6.33	0.00
No-Till (actual change)	0.37	0.18	2.68	0.03	0.16
% change	98.10	98.31	13.27	98.10	-77.78
Northeastern Iowa					
Conventional	15.33	16.43	1.86	2.42	0.07
Conservation (actual change)	15.04	16.40	1.92	2.44	0.07
% change	1.89	0.18	-3.23	-0.83	0.00
No-Till (actual change)	0.11	0.15	1.24	0.02	0.11
% change	99.28	99.09	33.33	99.17	-57.14

Table 2 Cont.

South Iowa					
Conventional	18.07	46.17	0.99	5.96	0.06
Conservation (actual change)	15.62	41.36	0.93	5.39	0.07
% change	13.56	10.42	6.06	9.56	-16.67
No-Till (actual change)	0.06	0.26	0.44	0.04	0.08
% change	99.62	99.37	52.69	99.26	-14.29
West Iowa					
Conventional	9.46	13.96	0.86	1.92	0.03
Conservation (actual change)	9.32	14.10	0.86	1.96	0.03
% change	1.48	-1.00	0.00	-2.08	0.00
No-Till (actual change)	0.07	0.16	0.34	0.03	0.03
% change	99.25	98.87	60.47	98.47	0.00
Nebraska					
Conventional	3.89	4.90	1.03	0.72	0.01
Conservation (actual change)	4.74	5.84	1.07	0.87	0.01
% change	-21.85	-19.18	-3.88	-20.83	0.00
No-Till (actual change)	0.04	0.16	0.70	0.02	0.02
% change	98.97	96.73	32.04	97.22	-100.00

Table 2 Cont.

Kansas					
Conventional	9.21	19.13	0.66	2.28	0.02
Conservation (actual change)	6.96	15.41	0.45	2.02	0.02
% change	24.43	19.45	31.82	11.40	0.00
No-Till (actual change)	0.05	0.50	0.26	0.07	0.03
% change	99.28	96.76	42.22	96.53	-50.00

Table 3: Effects of Buffers on Conserving Sediment and Nutrient Pollutants under Various Cropping Systems

	YS	YW	YNS	YNW	YPS	YPW	QNS	QNW	QPS	QPW
Missouri										
Traditional-CT	33.84	16.59	54.48	32.2	7.77	4.6	5.31	5.28	0.13	0.13
Traditional-CS	31.66	15.68	52.07	31.49	7.55	4.58	4.86	4.84	0.14	0.14
Traditional-NT	1.2	0.53	2.43	1.27	0.39	0.2	4.78	4.76	0.24	0.24
Central Iowa										
Traditional-CT	11.9	5.59	32.12	19.29	4.29	2.59	1.48	1.47	0.07	0.07
Traditional-CS	0.12	0.05	0.41	0.22	0.06	0.03	1.15	1.15	0.1	0.1
Traditional-NT	0.12	0.05	0.41	0.22	0.06	0.03	1.15	1.15	0.1	0.1
NE Iowa										
Traditional-CT	16.35	6.16	27.49	13.6	3.93	1.94	1.24	1.23	0.08	0.08
Traditional-CS	10.51	3.85	19.1	9.76	2.9	1.48	1.09	1.08	0.09	0.09
Traditional-NT	0.14	0.03	0.28	0.11	0.05	0.02	1.16	1.15	0.11	0.1

Table 3 Cont.

South Iowa										
Traditional-CT	16.21	7.94	32.19	19.15	4.54	2.71	1.29	1.28	0.07	0.07
Traditional-CS	13.96	6.87	29	17.7	4.12	2.52	1.63	1.62	0.08	0.08
Traditional-NT	0.3	0.07	0.75	0.28	0.11	0.04	1.2	1.19	0.12	0.12
West Iowa										
Traditional-CT	14.31	6.09	32.32	17.11	4.41	2.33	1.03	1.02	0.05	0.05
Traditional-CS	13.09	5.42	30.25	16.01	4.15	2.2	1	0.99	0.05	0.05
Traditional-NT	0.02	0.03	0.15	0.14	0.02	0.02	0.39	0.39	0.05	0.05
Nebraska										
Traditional-CT	6.61	2.14	9.62	4.47	1.34	0.63	1.62	1.62	0.04	0.04
Traditional-CS	30.01	10.24	36.69	13.74	5.31	2.01	1.49	1.48	0.05	0.04
Traditional-NT	0.07	0.02	0.15	0.09	0.03	0.02	0.67	0.67	0.06	0.06
Kansas										
Traditional-CT	2.45	0.95	3.47	2.42	0.55	0.39	1.37	1.36	0.08	0.08
Traditional-CS	1.82	0.69	2.84	2.08	0.47	0.35	1.38	1.36	0.09	0.09
Traditional-NT	0.01	0.01	0.03	0.02	0	0	1.05	1.04	0.13	0.13

Where:

YS = Sum of sediment transported from all subareas (mt/ha)

YW = Watershed sediment yield (mt/ha)

YNS = Sum of transported nitrogen from all subareas (kg/ha)

YNW = Watershed yield of sediment transported nitrogen (kg/ha)

YPS = Sum of transported phosphorus from all subareas (kg/ha)

YPW = Watershed yield of sediment transported phosphorus (kg/ha)

QNS = Sum of soluble nitrogen yield from all subareas (kg/ha)

QNW = Watershed soluble nitrogen yield (kg/ha)

QPS = Sum of soluble phosphorus yield from all subareas (kg/ha)

QPW = Watershed soluble phosphorus yield (kg/ha)

APPENDIX C

Table 1 Percentage Change on the Area Planted under U.S. Major Crops (Mha) if CRP Contracts are Allowed to Expire

2007/08 to 2014/15

	08/09	09/10	10/11	11/12	12/13	13/14	14/15
Corn	1.32	1.58	1.89	2.00	1.96	1.95	2.19
Soybeans	1.20	1.75	2.20	2.54	2.58	2.92	3.24
Wheat	3.95	5.31	6.41	6.85	6.81	6.88	7.21
Upland Cotton	3.06	4.19	4.46	4.64	4.48	4.57	5.13
Sorghum	4.55	6.04	7.10	7.62	7.77	7.85	8.21
Barley	6.67	8.71	11.27	13.03	13.90	13.84	14.36
Oats	2.51	3.48	4.16	4.46	4.44	4.52	4.94
Rice	0.19	0.59	0.85	1.16	1.37	1.38	1.40

Table 2 Percentage Change on Major U.S. Crop and Hay Prices by Regions if CRP Contracts are Allowed to Expire

2008/09 to 2014/15

	07/08	08/09	09/10	10/11	11/12	12/13	13/14	14/15
				Corn				
U.S.	-0.21	-1.78	-2.58	-3.17	-3.49	-3.59	-3.72	-4.03
Corn Belt	-0.21	-1.76	-2.56	-3.16	-3.48	-3.58	-3.71	-4.02
Central Plains	-0.20	-1.86	-2.64	-3.24	-3.55	-3.64	-3.76	-4.06
Delta States	-0.20	-1.74	-2.54	-3.14	-3.48	-3.61	-3.76	-4.10
Far West	-0.17	-1.55	-2.26	-2.77	-3.05	-3.13	-3.24	-3.50
Lake States	-0.21	-1.81	-2.62	-3.23	-3.56	-3.68	-3.82	-4.14
Northeast	-0.20	-1.65	-2.39	-2.94	-3.23	-3.33	-3.46	-3.77
Northern Plains	-0.23	-2.11	-2.91	-3.56	-3.87	-3.97	-4.12	-4.46
Southeast	-0.21	-1.76	-2.51	-3.09	-3.40	-3.50	-3.63	-3.94
Southern Plains	-0.18	-1.80	-2.54	-3.08	-3.35	-3.44	-3.55	-3.81
				Wheat				
U.S.	-0.07	-1.59	-2.55	-3.18	-3.54	-3.64	-3.72	-3.92
Corn Belt	-0.08	-1.65	-2.66	-3.33	-3.73	-3.86	-3.97	-4.20
Central Plains	-0.08	-1.81	-2.83	-3.52	-3.90	-4.02	-4.11	-4.31
Delta States	-0.07	-1.40	-2.25	-2.83	-3.18	-3.30	-3.40	-3.62
Far West	-0.07	-2.00	-3.38	-4.13	-4.69	-4.80	-4.93	-5.19
Lake States	-0.07	-1.21	-2.06	-2.60	-2.92	-3.02	-3.09	-3.27
Northeast	-0.08	-1.34	-2.21	-2.77	-3.09	-3.19	-3.29	-3.48
Northern Plains	-0.07	-1.52	-2.40	-2.99	-3.30	-3.37	-3.43	-3.60
Southeast	-0.07	-1.50	-2.42	-3.04	-3.40	-3.52	-3.62	-3.83
Southern Plains	-0.08	-1.87	-2.94	-3.65	-4.03	-4.16	-4.26	-4.46

Table 2 Cont.

Soybeans								
U.S.	-0.06	-1.21	-1.93	-2.51	-2.99	-3.27	-3.60	-4.11
Corn Belt	-0.06	-1.19	-1.89	-2.46	-2.93	-3.20	-3.52	-4.03
Central Plains	-0.06	-1.26	-1.99	-2.57	-3.05	-3.34	-3.67	-4.17
Delta States	-0.06	-1.23	-1.95	-2.54	-3.02	-3.30	-3.63	-4.16
Lake States	-0.06	-1.20	-1.92	-2.51	-2.98	-3.27	-3.59	-4.11
Northeast	-0.06	-1.15	-1.85	-2.41	-2.87	-3.14	-3.47	-3.97
Northern Plains	-0.07	-1.28	-2.05	-2.66	-3.16	-3.46	-3.81	-4.35
Southeast	-0.06	-1.20	-1.91	-2.48	-2.95	-3.23	-3.55	-4.06
Southern Plains	-0.06	-1.31	-2.07	-2.68	-3.16	-3.45	-3.77	-4.29
Sorghum								
U.S.	-0.14	-2.21	-3.02	-3.61	-3.91	-3.99	-4.09	-4.37
Corn Belt	-0.14	-2.15	-2.94	-3.52	-3.83	-3.92	-4.01	-4.31
Central Plains	-0.14	-2.15	-2.93	-3.53	-3.83	-3.91	-4.00	-4.28
Delta States	-0.11	-1.77	-2.43	-2.91	-3.15	-3.22	-3.30	-3.54
Northern Plains	-0.15	-2.36	-3.11	-3.71	-3.99	-4.05	-4.14	-4.44
Southeast	-0.12	-1.93	-2.62	-3.14	-3.41	-3.48	-3.58	-3.85
Southern Plains	-0.12	-2.54	-3.62	-4.18	-4.46	-4.55	-4.65	-4.91
Cotton								
U.S.	0.00	-2.39	-4.29	-5.44	-6.17	-6.41	-6.58	-7.06
Corn Belt	0.00	-1.90	-3.55	-4.54	-5.20	-5.40	-5.48	-5.82
Central Plains	0.00	-2.44	-4.36	-5.48	-6.18	-6.38	-6.51	-6.95
Delta States	0.00	-2.32	-4.16	-5.26	-5.98	-6.22	-6.39	-6.89
Far West	0.00	-1.85	-3.47	-4.44	-5.09	-5.33	-5.51	-5.96
Southeast	0.00	-2.42	-4.34	-5.48	-6.20	-6.43	-6.58	-7.05
Southern Plains	0.00	-2.55	-4.57	-5.75	-6.50	-6.73	-6.87	-7.35

Table 2 Cont.

				Hay				
U.S.	-0.02	-1.92	-3.82	-5.25	-6.23	-6.76	-7.12	-7.59
Corn Belt	-0.03	-1.82	-3.65	-5.02	-5.97	-6.49	-6.84	-7.31
Central Plains	-0.03	-2.75	-5.32	-7.27	-8.59	-9.31	-9.80	-10.45
Delta States	-0.01	-0.57	-1.15	-1.60	-1.92	-2.09	-2.21	-2.36
Far West	-0.02	-2.07	-4.11	-5.58	-6.60	-7.12	-7.45	-7.91
Lake States	-0.03	-2.10	-4.29	-5.93	-7.09	-7.74	-8.20	-8.84
Northeast	-0.01	-0.25	-0.64	-0.98	-1.23	-1.39	-1.50	-1.64
Northern Plains	-0.03	-2.86	-5.52	-7.51	-8.80	-9.48	-9.93	-10.54
Southeast	-0.00	-0.32	-0.68	-0.97	-1.19	-1.32	-1.39	-1.49
Southern Plains	-0.02	-1.81	-3.53	-4.79	-5.63	-6.08	-6.36	-6.74

Table 3 Percentage Change on Planted Area the U.S. Major Crops, if Convention Buffers are Established

2008/09 – 2014/15

	08/09	09/10	10/11	11/12	12/13	13/14	14/15
Corn	0.09	0.17	0.24	0.29	0.37	0.43	0.41
Soybeans	0.09	0.18	0.28	0.36	0.45	0.57	0.56
Wheat	0.22	0.44	0.65	0.86	1.08	1.29	1.29
Upland Cotton	0.18	0.36	0.51	0.66	0.80	1.08	1.05
Sorghum	0.24	0.46	0.68	0.93	1.17	1.42	1.42
Barley	0.40	0.69	1.02	1.37	1.73	2.07	1.98
Oats	0.16	0.32	0.46	0.61	0.75	0.89	0.88
Rice	0.01	0.05	0.09	0.16	0.21	0.25	0.29

VITA

Loise Njambi Wambuguh was born in the Laikipia District, Rift Valley Province in Kenya. She graduated from Mugoiri Secondary School in 1974 prior to joining Alliance Girls High School for two-year higher education. Loise received her Bachelors degree in agriculture from the University of Nairobi, Kenya. She worked as a Research Scientist and with the Kenya Agricultural Research Institute (KARI). She was awarded a scholarship by then U.K.'s Overseas Development Association (ODA), now the Department of International Development (DfID) in 1989 to pursue both a Higher Diploma in Development Economics at University of East Anglia and a Masters degree in Agricultural Economics at University of London.

Loise rejoined KARI after her studies in the position of Socioeconomic Research Coordinator, a position whose docket was to consolidate and coordinate all socioeconomic research activities at the institute. Among her major achievements was her role in the institutionalization of the Socioeconomics Division within the KARI system. She also oversaw initiatives that led to the formation of the East and Central Policy Research Program for Association for Strengthening Agricultural Research in East and Central Africa (ASARECA). Today, ASARECA is a vibrant organization that boasts a membership of over 10 countries from East and Central Africa. Within ASARECA, Loise oversaw the institutionalization of the Eastern and Central Africa Program for Agricultural Policy Analysis (ECAPAPA). In her role as KARI's Socio-economic Coordinator, Loise extensively worked with or was a consultant for several of the institute's major development partners including the World Bank, FAO, USAID, IFPRI, DFID, EC, among others. Within ASARECA, Loise oversaw the institutionalization of a major initiative, the Eastern and Central Africa Program for Agricultural Policy Analysis (ECAPAPA).

Loise was awarded a World Bank Fellowship to pursue a PhD at the University of Missouri-Columbia. Her studies spanned agricultural economics, econometrics, environmental/natural resource management, and policy analysis.