THE COST OF AGRICULTURALLY BASED GREENHOUSE GAS OFFSETS IN THE TEXAS HIGH PLAINS

A Thesis

by

RAJAPAKSHAGE INOKA ILMI CHANDRASENA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2003

Major Subject: Agricultural Economics

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ABSTRACT

The Cost of Agriculturally Based Greenhouse Gas Offsets in the Texas High Plains.

(December 2003)

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The broad objective of this thesis involves investigation of the role agriculture might play in a society wide greenhouse gas emissions reduction effort. Specifically, the breakeven price for carbon emission offsets is calculated for agriculturally based emission reducing practices. The practices investigated in the Texas High Plains involve reduced tillage use, reduced fallow use, reduced crop fertilization, cropland conversion to grassland, feedlot enteric fermentation management and digester based dairy manure handling. Costs of emission reductions were calculated at the producer level.

The calculated offset prices are classified into four cost categories. They are: negative cost, low cost (less than $20 per ton of carbon saved), moderate cost ($20 through $100 per ton of carbon saved), and high cost (over $100 for tons of carbon saved).

Negative cost implies that farmers could make money and reduce emissions by moving to alternative practices even without any carbon payments. Alternatives in the positive cost categories need compensation to induce farmers to switch to practices that sequester more carbon.

All fallow dryland crop practices, dryland and irrigated cotton zero tillage, dryland and irrigated wheat zero tillage, irrigated corn zero tillage, cotton irrigated nitrogen use reduction under minimum tillage and dryland pasture for all systems, and anaerobic lagoon complete mix and plug flow systems fall in the negative cost category.

Dryland and irrigated wheat under minimum tillage are found to be in the low cost category. Cotton dryland under minimum tillage and cotton irrigated with nitrogen use reduction under zero tillage fell into the moderate cost class. Both corn and cotton irrigated minimum tillage are found to be in the high cost category.

This study only considers the producer foregone net income less fixed costs as the only cost incurred in switching to an alternative sequestering practice. More costs such as learning and risk should probably be included. This limitation along with other constraints such as use of short run budget data, lack of availability and reliability of local budgets, overlooking any market effects, and lack of treatment of costs incurred in selling carbon offsets to buyers are limitations and portend future work.

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CHAPTER I

INTRODUCTION

1.1 Background

The Intergovernmental Panel on Climate Change (IPCC) estimates that the Earth's temperature has increased by 0.6^{o}C (1^{o}F) over the last century and projects it will increase by 1.4-5.8°C (2.2-10°F) by the year 2100. Scientists expect that future human activity generated emissions will raise average global surface temperature by $0.6\text{-}2.5^{o}$C (1-4.5°F) in the next 50 years and by $1.4\text{-}5.8^{o}$C (2.2-10°F) in the next 100 years. This average increase in temperature and projected future temperature increase is called global warming. The United States Environmental Protection Agency (U.S. EPA) and the IPCC argue that evidence shows global warming may have been accelerated during the past two decades (U.S. EPA, 2002b and IPCC, 1997).

IPCC asserts that global warming is caused by a buildup of greenhouse gases in the atmosphere. An accumulation of such gasses makes the planet warm by trapping the heat from long wavelength radiation. This heat retaining process by atmospheric gases is referred to as the "greenhouse effect". Over the last 50 years the major changes in greenhouse gas emissions have arisen from human activities (U.S. EPA, 2003b).

Rising temperatures are expected to raise the sea level by melting the ice cap, altering precipitation patterns, and causing other climatic changes. Changing local climates could affect crop yields, water supplies, forest cover, human health, animal

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This thesis follows the style of the *American Journal of Agricultural Economics*.

health, and ecosystem characteristics. Melting glaciers, decreased snow cover in the northern hemisphere and warming below ground has also been observed (U.S. EPA, 2003b).

The above discussion portends an uncertain future climate and production environment. Society has felt the danger of this and is beginning to take steps to cut down on greenhouse gas emissions (GHGE). The United Nations Framework Convention on Climate Change (UNFCCC, 2003) was signed in 1992 with the explicit goal of reducing GHGE and had 165 signatory countries. In 1997, UNFCCC signatory parties met for a conference in Kyoto, Japan. During the third session of this conference a protocol was formulated that specified GHGE reduction targets by country. This document is known as the Kyoto Protocol. According to the protocol, signatories were required to reduce the GHGE by 5.2% on average relative to the 1990 emission levels.

Even though the U.S. has chosen not to sign the Kyoto Protocol, the U.S. has established or proposed policies that lead to GHGE limitations. Specifically, in President Bush’s February 2002, Global Climate Change Policy Book (see White House 2002b) there is a stated goal to “reduce the greenhouse gas intensity of the U.S. economy by 18% in the next ten years” (U.S EPA, 2002b). This would result in a 4.5% reduction from forecast emissions for 2012. In addition, several states have also responded to take necessary action to mitigate the GHGE. For instance, in Texas, the Texas Natural Resource Conservation Commission (TNRCC) working with the state legislature introduced House Bill 3777, which called for a review of the extent to which activities in Texas contribute to global warming (U.S. EPA, 2001a).

In the U.S. over 80% of the emissions come from energy use such as burning of fossil fuel and electricity generation. Cutting down on the emissions by only altering energy use may be costly as well as economically expensive. According to McCarl and Schneider (1999), reduction in GHGE by agriculture and forestry may be a low cost alternative. Thus, a relevant social question is how can GHGE be reduced? Related ones are: What alternatives could be used? Can agriculture produce cost effective GHGE reductions?

This study will examine Agriculture's potential role in reducing GHGE by employing management strategies in a specific region. Specifically, agriculturally based GHGE reductions involved with alternative crop management, cropping fertilization, grassland reversion, feedlot operations and dairy manure handling practices in the Texas High Plains area will be studied. Costs will be calculated at the producer level.

1.2 Thesis Objectives

The broad objective of the study involves determination of the appropriate role for agriculture in a society wide GHGE reduction effort. More specifically, the study will identify the cost of a regional set of agricultural GHGE offsets that can be used in comparison with other alternatives. Specifically, the breakeven price for carbon will be calculated for the major available agricultural practices that could be employed in the High Plains of Texas.

1.3 Organization of the Thesis

The remaining chapters are organized as follows. Chapter II presents a literature review discussing the issues related to global warming and GHGE emission mitigation. Chapter III introduces the methodology and data that will be used to develop estimates of the breakeven cost of offsetting GHGE in the High Plains Texas region. Chapter IV presents the breakeven cost analysis results. Chapter V presents a summary of the study conclusions, limitations of the study and offers recommendations for future studies.

CHAPTER II

LITERATURE REVIEW

2.1 Global Warming and GHGE in a Global Context

Global warming refers to the rise in the world average temperature caused by the accumulation of greenhouse gasses in the atmosphere. Carbon dioxide is the most abundant greenhouse gas. Others are nitrous oxide, methane and chlorofluorocarbons (CFCs) (U.S. EPA, 2003a).

2.1.1 Impacts of Global Warming

IPCC projects that global warming will cause major changes in every part of the earth. They suggest that there will be more frequent weather changes. For instance, more frequent and severe floods, heat waves, windstorms, droughts and disruption in water supplies are anticipated. In addition, there could be a wider spread of serious diseases like malaria and yellow fever. Also, due to melting ice caps in Polar Regions sea levels are likely to rise and island nations could be inundated. Natural resource industries like agriculture, forestry, and fishing will be impacted. Frequent floods may leave hundreds of thousands homeless in poor developing countries (U.S. ENN, 2003). Much more on the potential consequences of global warming can be found in IPCC (2001).

2.1.2 Actions to Mitigate GHGE

The UNFCCC has the stated objective of stabilizing atmospheric GHGE concentrations. The UNFCCC was established in 1992. As of 1998, 176 countries had signed the convention including the U.S. However, the convention itself does not specify GHGE concentration targets or emission reduction levels.

The Kyoto Protocol (KP) signed in Kyoto, Japan, in 1997, is an UNFCCC generated agreement that mandates actions reducing GHGE. The KP creates specific GHGE target levels. If fully implemented, the KP requires the U.S. to achieve a 7% reduction in net GHGE relative to 1990 levels by the 2008 to 2012 first commitment period (Reilly et al., 1999). However the KP has not yet been ratified and put in place. Furthermore, several countries have announced they would not sign (notably the U.S. and Australia).

In the KP agriculture is considered as both an emitter and a sink of GHGE (in particular carbon dioxide). The KP also identifies manure management, rice cultivation, and soil management as sources of GHGE and afforestation and reforestation as GHG sinks (UNFCCC, 2003).

The year 2001 is considered a turning point in international climate negotiations. The sixth UNFCC conference, which was held in 2000 in Bonn, Germany ended without any firm consensus between nations regarding adherence to KP targets. Then in 2002 the United States announced it would not ratify the Protocol. This is important as 36% of global emissions arise in the U.S. As of 2003 a sufficient number of countries have agreed to ratify the KP so that it will be put into force (providing Russia follows through). However, it may not be terribly effective due to the absence of the U.S. in implementation.

2.2 U.S. Emissions and Mitigation Program

In this section we discuss the major sources of GHGE and mitigation efforts done in the U.S.

2.2.1 Major Sources of GHGE in the U.S.

The largest global contributor of GHGE is the U.S. Per capita annual emissions are about 6.6 metric tonnes of carbon equivalent (CE) or 15,000 pounds. Emissions have been increasing at a rate of 3.4% per year from 1990 to 1997 (U.S. EPA, 2000).
U.S.

The U.S. EPA (2000) estimated that in 1999 82% of these emissions came from burning fossil fuels to generate electricity and power automobiles. The rest is from several other sources including natural gas pipelines, livestock, landfills and chemical manufacturers.

As indicated in Figure 2.1, U.S. GHGEs increased by 12% between 1990 and 1999. This increase in GHGEs is largely due to substantial growth in the U.S. economy over the last decade (U.S. EPA, 2002b).

Carbon dioxide (CO_2) emissions, mainly from fossil fuel combustion, accounted for 82% of total GHGE in 1999. Methane (CH_4) emissions, largely arising from landfills, livestock operations, and natural gas systems, contribute 9% of the total

GHGE. Nitrous oxide (N_2O), largely from livestock, and fertilization accounts for 6%. The rest is composed of other gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6) (U.S. EPA, 2000). Only CO_2, CH_4 and N_2O directly relate to agricultural cropping and livestock operations.

The U.S. EPA (1999b) estimates that methane emissions from livestock manure management amount to 17 million metric tonnes of carbon equivalent (MMTCE) or 10% of total 1997 U.S. methane emissions. These methane emissions mainly come from dairy and swine farms that manage manure in liquid form. The U.S. EPA expects a 25% increase in such methane emissions by 2020 rising from 18.4 to 26.4 MMTCE. This increase is basically due to an expected increase in liquid and slurry manure management systems (U.S. EPA, 1999). In the U.S. cattle emits about 96% of methane from livestock enteric fermentation (U.S. EPA, 1999). The U.S. EPA estimates that methane emissions from livestock enteric fermentation is 34.1 MMTCE, or 19% of total 1997 US methane emissions (U.S. EPA, 1999).

In the U.S., nitrous oxide emissions from agricultural soil management increased by 11% between 1990 and2000 as fertilizer consumption and cultivation of nitrogen fixing crops rose (U.S. EPA, 2001b). Possible ways to reduce the nitrous oxide emission involve reducing the application of excessive nitrogen fertilizer and reducing livestock herd numbers.

2.2.2 Mitigation Efforts in the United States

To prevent dangerous impacts on the climate system, the UNFCCC argues that all countries should work together to attain the long-term goal of reducing atmospheric GHG concentrations through reductions in net GHGE (U.S. EPA, 2002b). At the UNFCCC meeting in Kyoto, Japan in 1997, the U.S. delegation agreed to reduce emissions to 7% below 1990 levels by 2008-2012 (U.S. DOE-EIA, 2003).

In 2001, President Bush announced a Climate Change Research Initiative. This focuses on anthropogenic climate changes and their potential impacts. The President also announced the National Climate Change Technology Initiative (NCCTI) designed to develop improved energy technologies to abate emissions and develop sequestering technologies.

In February 2002, the U.S. administration declared an emissions control approach designed to achieve significant reductions in emissions of various pollutants (mercury, nitrogen oxides, sulfur dioxides). This program is known as the "Clear Skies Initiative" and utilizes the system called "cap and trade". This will allow companies to trade emission credits (U.S. DOE-EIA, 2003). Originally carbon dioxide was included in that approach but it was removed.

President Bush has allocated $3 billion in fiscal year 2003 budgets to address current climate issues. This is the first part a of ten-year (2002-2011) program for enhancing natural storage of carbon. This is a $1 billion increase above the base. He also has recommended future targeted incentives for forest and agricultural sequestration of GHG (White House, 2002a).

2.3 Agriculture as a Source and Sink of GHGE

Agriculture acts as a source and a sink of GHGE. Globally, agriculture emits about 50% of total methane, 70% of nitrous oxide and 7% of carbon dioxide (U.S. EPA, 2003a). Ruminants, manure and rice cultivation are the major sources of methane emissions. Carbon dioxide emissions arise from fossil fuel burning, soil tillage, deforestation, biomass burning, and land degradation (McCarl et al., 2002a). Nitrous oxide emissions come from manure, legumes and fertilizer use (McCarl et al, 2002b). There is a varying degree of GHG emission contributions across developing and developed countries.

When considering alternative gases, one should recognize that the global warming effect differs across gases. This has been estimated using the global warming potential (GWP) concept. N_2O has been estimated to have a 100 year heat trapping ability 310 times greater than that of the CO_2, while CH_4 has a 100-year heat-trapping ability 21 times that of CO_2 (CO_2 is assigned a GWP of 1). Thus, even though concentration and flux rates of N_2O and CH_4 are much lower than for CO_2, their effects are greater due to the characteristics of those gases with respect to global warming (U.S. EPA, 2001b). Use of the GWP concept in this study is explained in the methodology section.

Agriculture also acts as a sink for the important GHG, carbon dioxide. Carbon dioxide is retained in the soil. One way net GHGE can be offset is through increases in soil carbon retention. Lal et al., (1998) argue this can be enhanced through several practices, such as use of less intensive tillage practices, conversion of land usage into alternative practices (conversion from crop to pasture and forests), adapting different crop rotation practices, and reducing fuel use.

2.3.1 Role of Agriculture in Mitigation of GHGE

Several studies have examined the economic potential of agriculture as a participant in GHGE emission mitigation efforts. Schneider (2000) found production of biomass feedstock for power plants to be a dominant mitigation strategy for GHGE offsets at high prices: eighty dollars or more per tonne of carbon equivalent. He also found that other mitigation strategies such as reduced fertilization, tillage and irrigation, increased afforestation and improved liquid manure management are viable for carbon prices in the range of \$5 to \$80 per tonne of carbon equivalent. Andrasko et al., (2002) found that in the U.S. Mid-West many competitive opportunities exist for carbon sequestration in cropland, while afforestation in Southern and Lake States are attractive at low and moderate carbon prices.

2.3.1.1 Crop Sector

Two major types of actions can be employed to achieve GHGE reductions in the crop sector. These involve changes in the way land is managed and changes in the way land is used. The most widely discussed management changes involve tillage intensity reduction, addition of organic manure and alteration of fertilization. Changes in land use involve conversion of croplands to grasslands, pasture or forestry, and conversion of pasture to forestry (McCarl et al., 2002b).

2.3.1.2 Livestock Sector

Livestock generate methane emissions through enteric fermentation and manure, and nitrous oxide emissions through manure. Several mechanisms are available to reduce the methane emissions. These largely involve recovering methane and using it as an energy source. The basic approach involves use of anaerobic digesters, which help in decomposing manure in a controlled environment and recovering methane emissions. This recovered methane is in turn used to produce electricity or heat by fueling engines and generators.

According to the U.S. EPA (1999b), unlike other methane emission sources for which there are technologies aimed specifically to reduce emissions, currently no such control method to reduce methane emission from enteric fermentation exists. However, some aspects of dairy management can help reduce emissions. Some of them are as follows: improvement of animal nutrition and health to absorb more nutrients as they consume feed; implementation of intensive grazing management systems to keep animals in grazing units rather than allowing them to do continuous grazing reduces the methane emitted; and artificial insemination using highly productive bulls to increase animal productivity and therefore lessen methane emissions. Nitrous oxide can be reduced through some of the same mechanisms.

2.3.2 Carbon Sequestration in General

Agriculture functions as a potential sink for CO_2 by absorbing CO_2 from the atmosphere and storing it in the form of carbon, either in the soil or in the plants (perennial plants like trees). This process is called “biological carbon sequestration” (Davis et al., 2002) and typically focuses on soils and forests.

2.3.2.1 Soil Carbon Sequestration

According to Watson et al (2000) about 80% of terrestrial carbon is stored in soil. Furthermore, a lot of carbon cycles through the soils and plant ecosystem each year. Enhancement of agricultural soil carbon sequestration has been argued to be a cheap and a good alternative for GHGE reduction (Davis et al., 2002). Due to this and the prospect of a market or subsidy program that would pay producers to increase the carbon content in soils, sequestration of atmospheric carbon in agricultural soils has become of interest to the agricultural community.

2.3.2.2 Forest Carbon Sequestration

Conversion of croplands to forests is another alternative suggested to reduce net GHGE (IPCC, 2001). Currently U.S. forests are a net carbon sink. According to Murray (2000), the U.S. private forest base is projected to sequester 100 to 120 MMT per year annually from now until to year 2040. The average cost of carbon is estimated as $20 through $40 per ton.

2.4 Policy Actions to Enhance Participation in Mitigation Programs

There are many ways that policy can be designed to enhance participation directly and indirectly in mitigation programs. Broad classes of approaches involve the institution of: transfer payments (taxes and subsidies), emission standards and use of emission caps with tradable emission permits. Below each is discussed in detail.

2.4.1 Transfer Payments

Transfer payments include emission taxes and sequestration subsidies. Taxes and reduction incentives can be aimed at quantity of effluent discharged or inputs, which emit GHG. These taxes and incentives allow the firm to reduce the emissions where marginal abatement cost equals tax rate. On the other hand, incentives/taxes allow firms to adapt practices that emit less GHG.

2.4.2 Emission Standards

Policy can set upper limits on GHG emissions for firms. In the economics literature, emission standards are addressed as command and control methods. Such methods are generally asserted to not be cost effective as the policies reduce the total quantity of emissions, but do not employ a least cost approach (Tietenberg, 2003).

2.4.3 Tradable Emission Permits

Tradable emission permits arises when the regulator issues emission permits for the target level of aggregate emissions by all parties. These permits can be auctioned between polluting parties (McCarl et al., 2002b). Emission permit trading allows countries or companies to purchase reduction permits from others and use them to offset their own commitments. This allows lower cost producers to trade with higher cost producers and reduces total cost while the collective total emissions remain below agreed standard levels (IEA, 2003).

2.5 Case Study Examinations

Below we discuss studies done on GHGE offset possibilities in crop and livestock sectors.

2.5.1 Crop Sector

McCarl and Schneider (1999) surveyed the literature on the ways that agricultural operations could offset GHG emissions. They found that converting crop tillage practices to practices that store more carbon in soils is one potentially promising practice. This can be achieved by adopting reduced tillage practices. Net emission impacts differ across a wide range of situations such as climatic regions, soils and cropping systems (McCarl and Schneider, 2001). For instance, an incentive level of $25 per tonne of carbon emitted leads to less fertilization and tillage, improved liquid manure management and reduces overall emissions by about 50 million metric tonnes of carbon equivalents (McCarl and Schneider, 2001).

A similar study was done by Antle et al (2001) in Montana to estimate the payments to farmers to convert their cropping practices into alternative crop management practices. Producers' actions were simulated under payments for additional sequestered carbon generated via changing cropping systems from either a crop-fallow system to grass or continuous cropping. They found conversion from crop/fallow to continuous cropping systems is an economically viable way to increase soil C in the Northern Plains. The average cost per tonne of carbon ranges from $12 to $50 per tonne and the marginal costs range from $12 to $130 per MT. They also found grass conversions yielded more carbon with an average cost range from $34-$250 per tonne of carbon and marginal costs range from $34-$500 per tonne of carbon.

Richard et al., (2001) reviewed studies that examine conversion of crop lands into grasslands and resultant contributions to carbon sequestration. They state that the introduction of improved management practices such as fertilization and grazing management in grasslands have contributed to increasing rates of carbon sequestration. Although grasslands act as a carbon sink with the implementation of improved management, conversion of significant amounts of cropland into grassland lowers the production of certain crops. This in turn increases the price of that crop in the market. In the absence of supply from the region, farmers from other regions may enter into the market seeing the high price creating leakage (Murray et al., accepted).

Ugarte et al., (2002) studied the cost of enhancing agriculture's CO_2 potential through increased use of reduced tillage practices on croplands. As a secondary objective they estimated the level of incentive necessary to adopt reduced tillage practices. Preliminary results indicate that in the Corn Belt, the incentive required for corn and soybeans grown on poorly drained soils is $25 per hectare and $20 per hectare on well-drained soils. In the Central Great Plains, continuous sorghum required an incentive level of $36 per hectare. In the Western Great Plains, wheat/fallow and wheat/sorghum/fallow yields when no tillage is done are higher than when the intensive tillage is done. In this case the incentive level was found to be $15 per hectare.

House et al., (2001) estimated how much carbon would be sequestered in agriculture soils and biomass at different carbon prices. They also considered different incentive payment designs. All their scenarios assume a 15-year contract period and are simulated based on a range of carbon payments, $10 through $125 per metric ton.

According to Schneider (2000), alternative fertilizer management impacts both CO_2 emissions and N_2O emissions. He concludes that, nitrogen fertilization intensity for traditional crops decreases, followed by a rise in average nitrogen fertilizer application, if the price for carbon savings is more than $80 per TCE. He further concludes that, nitrous oxide emission reductions occur due to the fact that the total amount of nitrogen fertilizer applied for traditional crops decreases.

2.5.2 Livestock Sector

Livestock production GHGE offset possibilities fall into two basic classes. There are (1) manure handling practices, (2) enteric fermentation management. Enteric fermentation contributed 19% of methane emissions in 1997 while manure-handling practices contributed 10% of total emissions (U.S. EPA, 1999).

2.5.2.1 Enteric Fermentation

Gerbens (1999) suggests genetic improvements and dietary changes are two ways of cutting down the GHG emission through enteric fermentation (EF). Johnson et al., (2001) investigated site-specific costs of GHG modifications in dairy and cow -calf herds along with changes in pasture management. They found negative costs for intensive grazing management in Wisconsin as the practices constituted an increase in profitability. Different scenarios were studied to find out the quantity and costs of GHGE reductions. Out of which, a 20% higher milk yield category reduced the GHGE per kg milk by 12% with $28,000 more profit. Category with more bovine somatotropin resulted in from 6 to lower GHGE per kg of milk while increasing the profits by $6,000.

2.5.2.2 Manure Management Practices

Manure handling practices involving use of anaerobic lagoons for manure disposal contribute 10% of total methane emissions (U.S. EPA, 1999). According to the EPA-AgSTAR program, different cost effective technologies can cut down on GHGE by recovering methane and using it as an energy source. The technologies involved, commonly referred to as anaerobic digesters, decompose manure in a controlled environment and recover methane produced from manure (U.S. EPA, 1999).

The U.S. EPA (1999) developed cost curves for reducing manure-based methane emissions that are based on recovering and using the methane produced. The U.S. EPA bases these curves on anaerobic digestion technologies to capture methane and in turn assumes use for on-site energy generation. They estimate that at a price of $30/TCE one can achieve emission reductions of 31% in 2010 and 32% in 2020. At $100/TCE, emissions would be reduced by about 65% in 2010 and 67% in 2020 (U.S.EPA, 2002a).

CHAPTER III

METHODOLOGY AND DATA

As society moves to reduce GHGE, it becomes important to find low cost options Agriculture may provide such options. Costing of potential options is needed to see if this is the case. In the Texas High Plains the agricultural options include actions such as manipulation of agricultural tillage practices, fertilization management, alteration of manure handling practices, conversion of agricultural land into grasslands and control of feedlot enteric fermentation. The cost of these options depends on their relative costs and returns in comparison with existing practices (McCarl, 2003) and the net GHGE emission effect relative to the existing practice. In this study attention will be limited to the farm level foregone net income that is caused by adoption of a GHGE offsetting practice. McCarl (2003) argues that sale of that offset to others also involves other costs such as market transaction and risk overcoming incentives and may be subject to discounts on carbon, but such items are neglected herein.

3.1 Breakeven Carbon Price Calculation

The cost to transfer from one agricultural practice to another influences the cost of carbon and requires data on the cost, revenue and GHG emission changes for each practice (this term is hereafter called the producer development cost- PDC). In turn, given estimates of the net change in GHGE (hereafter called the QGHG) on a carbon equivalent basis, a break-even carbon price can be calculated for the comparison of an alternative practice with the existing practice. The producer development breakeven carbon price is the change in cost incurred by the producer in adopting the new ACS method divided by the net GHGE offset.

3.1.1 Producer Development Cost (PDC)

When changing an existing practice to a more carbon sequestering or emission reducing practice, input usage, fixed costs and yields may change. As a result, they need to be included in calculations. PDC is the difference in net revenue and variable cost plus the difference in fixed cost requirements. The PDC estimate gives a lower bound of the cost required to induce a practice change. Higher inducement may be required to stimulate the adoption of new practices, which lower carbon emissions (McCarl, 2003). This study focuses on the calculation of this PDC part of the carbon cost. PDC is calculated as shown in equation (1).

$$(1) \qquad (NR_{alternative} - NR_{base}) = PDC$$

where

$NR_{alternative}$ is the net revenue of the alternative practice considered

NR_{base} is the net revenue of the base practice.

Net returns are calculated for each alternative practice as shown in equation (2),

$$(2) \qquad NR = (TR - TVC - TFC)$$

NR is the net revenue ($ per acre), *TR* is the total revenue ($ per acre), *TVC* is the *t*otal variable cost ($ per acre), and *TFC* is the total fixed cost ($ per acre).

3.1.2 Calculation of Breakeven Carbon Price (BCP)

The Breakeven Carbon price (BCP) is calculated according to equation (3).

(3) $$\frac{-\ (PDC\quad)}{\Delta\ QGHG} = BCP$$ or

(4) $$\frac{-(NR_{alternative} - NR_{base})}{QGHG_{alternative} - QGHG_{base}} = BCP$$

The GHG quantity in the denominator of equation (3) is the amount of net GHGE stored or emitted by each alternative practice.

(5) $\Delta QGHG = QGHG_{alternative} - QGHG_{Base}$

$\Delta QGHG$ is the change in the net quantity of GHGE from practices. $QGHG_{alternative}$ is the net GHGE emissions from the alternative practice (emissions minus sequestration) on a carbon equivalent basis. $QGHG_{Base}$ is the net GHGE emissions from the current (base) practice (emissions minus sequestration) on a carbon equivalent basis.

3.2 Greenhouse Gas Carbon Equivalent GWP Based Conversion

Emission reductions can involve multiple greenhouse gasses. To compare across alternatives involving different bundles of gasses a standard unit is needed and in the literature has been established as carbon equivalence. In deriving that result a conversion based on GWP and chemical weight of carbon is employed. In particular methane emissions were converted into CO_2 equivalent measures by multiplying by GWP.

According to the GWP concept[a], one tonne of methane has the same warming effect as 21 tonnes of CO_2. That is to say, to convert a tonne of methane into the number of tonnes of equivalent CO_2, we multiply the methane amount by 21. In turn, to convert to tonnes of carbon we multiply by the molecular share of carbon in CO_2. Thus since the mass of carbon is 12 and the mass of CO_2 is 44, we multiply the CO_2 amount by 12/44. Nitrous oxide conversions are done the same way using a GWP of 310.

3.3 Region for Case Study

Texas is divided into 15 agricultural statistical districts. Out of them, this study concentrates on the Texas High Plains. The Texas High plain is composed of the Northern and Southern High Plains (see the map below). The Northern High Plains district is located in the northern part of the Texas panhandle near Amarillo. There are 21 counties in this area. The Southern high plain district is located in the lower west side of the panhandle and also accounts for 20 counties (NASS, 2001).

The High Plains is the largest agricultural area in Texas involving 7 million acres. The High Plains has a semiarid, continental climate. It has dry, mild winters. Mean annual precipitation ranges from 22 inches in the northeast to less than 14 inches in the southwest. Most of the rainfall occurs during the spring and summer months.

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[a] Global warming potential (GWP) is defined as the total impact over time of adding a unit of a greenhouse gas to the atmosphere. It is calculated by multiplying effect if the instantaneous radiative forcing by the concentration of gas added and integrating over time from 0 to some arbitrary time period T. CO_2 has a very low radiative forcing but a very high volume is released to the atmosphere, so it has a very high GWP.

Temperature and precipitation varies considerably from season to season and from year to year (TPW, 2003).

About 60% of the area is cropland. Half of the cropland is irrigated. Major crops grown in this area are cotton, corn, sorghum, wheat, vegetables, and sugar beets. According to the USDA's national agricultural statistical service (NASS), about 99% of the corn grown in Texas High Plains in 2002 was irrigated. On the other hand, 50% of cotton was irrigated and nearly 60% of wheat was dryland (TASS, 2003).

There are different tillage methods used with each crop grown. 49.03% of the corn, 88.41% of the cotton and 31.38% of the wheat is grown with conventional tillage (CTIC, 2003). Reduced tillage is the second highest with respect to cotton, which is 9.26% out of total cotton grown while 2.33% is grown under conservation/zero tillage. For wheat in the High Plains 41% is raised under conservation/zero tillage, while 27.38% is raised under reduced tillage. With respect to corn, 28.38% of the land is treated with conservation/zero tillage and 22.58% with reduced tillage.

The High Plains is an important livestock region. Cattle and calves in feedlots totaled 2.88 million head on June 2003 (TASS, 2003). Winter cereals are used for stocker operations. Rangeland grazing is also important in this area. It is done on about 40% of the total area. A small amount of cow-calf production is present.

Common agricultural problems are high winds, dry winters, low annual rainfall and a falling aquifer water table. As ground-water availability falls, regional use of pasture and range for livestock production increases and is expected to continue to do so (HPCC, 2002).

3.4 Development of Soil Carbon Change Data

The Erosion Productivity Impact Calculator (EPIC) was used in generating soil carbon numbers for each cropping practice as discussed below.

3.4.1 Erosion Productivity Impact Calculator (EPIC)

The Erosion-Productivity Impact Calculator (EPIC) model (Williams et al., 1989) was initially developed to assess the effect of soil erosion on soil productivity. Since then the model has been expanded and refined to simulate many additional processes important to agricultural management (Sharpley and Williams, 1990) with a recent focus on carbon sequestration and GHGE emissions.

EPIC is commonly used to simulate the effect of management strategies on agricultural production and soil and water resources. EPIC results describe the carbon, crop yield, and irrigation water use, consequences of alternative management strategies along with environmental co-benefits (CASMGS, not dated).

3.4.2 EPIC Simulations Done in This Study

EPIC simulations are employed in this study to develop information on the quantity of carbon sequestered over a time period (40 years) in soil by cropping practices. This is done under dry and irrigated land management as well as conventional, conservation and no till tillage practices. Dryland pasture is also simulated. The total amount of carbon sequestered is taken for the 40 year simulation period and is annualized to yield the per year average soil carbon sequestration for each alternative crop practice.

3.5 Alterations in Farm Practices

We consider alterations in five farming practices in this study. They are crop tillage alteration, cropping fertilization, grassland reversion, dairy manure management and feedlot enteric fermentation management. This section explains the different practices examined.

3.5.1 Crop Tillage Alteration

Part of the study considers the costs of GHGE offsets developed through tillage alterations yielding enhanced sequestration practices. These are examined for several cropping systems. With respect to tillage practices, reduction in the tillage intensity is considered, starting from the conventional tillage through no tillage. Tillage alternatives are considered with respect to dryland and irrigated systems.

When considering the crop budget data, with the absence of budget data in some crop practices, several assumptions are utilized based on Pennsylvania State Cooperative Extension, 1996 results. Assumptions under this study consists of:

1. Total variable cost (TVC) for conservation tillage is 6% greater than that of conventional tillage.
2. TVC for no (zero) tillage is 3 % greater than that of conventional tillage.

3. Total fixed costs (TFC) for conservation tillage is 8% less than that of the conventional tillage.
4. TFC for zero tillage is 46% less than that of conventional tillage

In one part of the analysis we consider the conventional tillage as the base tillage method and on the other part we consider the minimum tillage as the base tillage practice. Table 3.1 and Table 3.2 show the base and alternative crop and pasture practices considered in this study.

3.5.1.1 Dryland Crop Practices

Under dryland practices, we consider crop rotations, reduced fallow use, dryland cotton and dryland wheat. Alternatives under these practices are considered taking conventional tillage and minimum tillage as the base (see Table 3.1, Table 3.2, and Table 3.3). We consider crop rotations with wheat and sorghum. Base practices considered are conventional tillage and minimum tillage for each rotation practice. Alternatives considered in each practice are different in tillage method, such that when one considers the conventional tillage as the base, minimum and zero tillage practices are considered as alternatives. When minimum tillage is the base, zero tillage is the alternative considered. Other than tillage alternatives, conversion into dryland pasture is also considered.

3.5.1.2 Irrigated Crop Practices

Under irrigated practices, we consider irrigated corn, irrigated cotton and irrigated wheat. Alternatives under these practices are compared against conventional and minimum tillage practices (see Table 3.1). When conventional tillage is taken as the base, minimum and zero tillage practices are considered as alternatives and when minimum tillage is taken as the base, zero tillage is the alternative practice. Pastureland conversion is also considered as an alternative.

3.5.1.3 Fertilizer Management Alternatives

Different nitrogen fertilizer stress levels are considered for irrigated cotton. They are, 10% and 20% nitrogen stress levels. The base is the irrigated cotton under conventional tillage no nitrogen stress. Alternatives are 10%and 20% stress levels with respect to reduced and zero tillage.

3.5.2 Dairy Manure Management

Part of the study considers the costs of GHG offsets when developed through improved manure management for an emerging and growing regional dairy industry. Carbon prices are calculated for potential conversion of base manure handling to alternative two manure handling practices. The base manure handling practice considered is anaerobic lagoon (AL) open. Alternative practices considered are,

1. AL covered.
2. AL Complex mix.
3. Plug Flow digester system.

In this case, the GHG emission quantity will be computed by converting the methane emission to CO_2 then to Carbon equivalent using the Global Warming Potential concept (details of the conversion of methane to CO_2 Eq and then to CE is explained in the methodology section).

At this point, it is worth discussing some details of each of the above different type of manure handling practices. An anaerobic digester in general is an enclosed tank that excludes oxygen in the digestion process. A specific population of naturally existing anaerobic bacteria helps breakdown dairy manure into a variety of gases. Methane is one of them. Once methane is produced, it can either be captured and burned or passed through an electric generator to generate electricity. By producing electricity, the farms can realize cost savings (without having to buy electricity from other sources) or sell the electricity to a grid supply to generate revenue.

3.5.2.1 Anaerobic Lagoon Covered

A plastic cover is used on top of the lagoon to minimize odor problems and to trap the gas emitted. This system works well in climates that are temperate to warm year round. This is good when manure is collected through a flush system (less solid manure).

3.5.2.2 Anaerobic Lagoon Complete Mix Digester

Manure is collected in above or below ground tanks and heated to increase the digestion process. A mechanical or gas mixing system keeps the solids in suspension. This too accelerates the digestion process. This system too is good when manure is collected through a flush system (less solid matter in it).

3.5.2.3 Plug-Flow Digester

This system is good for manure with more solid matter in it. In other words, it is good for systems where manure is collected through scraping. An underground tank collects manure and it gradually settles to the bottom of the tank. This plug takes several days to settle onto the bottom of the tank. This needs heating to keep the constant temperature year round. The plug flow digester is good for cooler climates.

3.5.3 Feedlot Enteric Fermentation

Another part of the study considers the costs of GHG offsets when developed through alternative feedlot management practices designed to modify enteric fermentation. Carbon prices are calculated for potential conversion of base feedlot management practices to alternative feedlot management practices. There are 7 different alternative practices considered in the study as developed in the study by Johnson et al., (2001). They are as follows:

1. TXBase is the best portrayal of the average system in the Texas High Plains feedlots (base steer has 28% fat at the time of marketing). The weaned calves or stocker calves arrive in the feedlot from the TX Base Cow-calf or TX Base Stocker systems, respectively. The base system is made up of 100 heads of mature cows, with about 17% of heifer calves being kept for replacements and correction for calf and stocker mortality.
2. TXSmall involves feeding steers and heifers 20% less feed than under the base. This assumes a genetically induced 20% decrease mature body weight.
3. TXLarge involves feeding the steers and heifers 20% more feed than under base. This assumes a genetically induced 20% increase mature body weight.
4. TXDirect involves stocker phase elimination. None of heifers and steers going through a stocker phase following weaning before coming into the feedlot.
5. TXNo-Direct involves complete set of heifers and steers, which are gone through a stocker phase following weaning before coming into the feedlot. Stocker is the stage of growth for calves after weaning, but before entering the feedlot. These calves will become yearlings (one year of age) during this phase.
6. TXFat-27% is to say that animals are fed so they are 1% less fat than the base steer at the time of marketing. Animals are kept a shorter time in the feedlot.

7. TXFat-29% is to say that that animals are fed so they are 1% more fat than the base steer at the time of marketing. Animals are kept a longer time in the feedlot.

CHAPTER IV

DATA ANALYSIS AND EMPIRICAL RESULTS

In this chapter the Breakeven Carbon Price (BCP) is calculated for cropping, dairy manure handling and feedlot enteric fermentation management alternatives and the data underlying the calculations are explained.

4.1 Crop Sector

BCP is calculated according to equations (3) and (4) in Chapter 3. In equation (4), the denominator is the amount of soil carbon under different tillage and rotation practices. NR is computed for each crop rotation and tillage methods as $/ac/year via equation (2). The carbon stock is measured in tonnes/ac. Quantity of carbon-sequestered (tonnes/ha) in each crop rotation is extracted from EPIC and converted into tonnes/ac. The change in carbon stock is calculated using equation (5).

4.1.1 Dryland Practices

This section discusses development of the budget components, GHGE components and breakeven carbon price calculation for dryland crops.

4.1.1.1 Development of Budget Components

The first step in BCP calculation is to identify the crop budget components. Revenue and cost data for all of the basic crops and crop rotation practices, and pastureland, are drawn from "Texas Crop Enterprise Budgets" projected for 2001 for Texas High Plains area by the Texas Agricultural Extension Service (TAES). Total revenue (TR), variable costs (VC) and fixed costs (FC) are directly taken from the crop budget reports and total cost (TC) is calculated as $TC = VC+FC$. Then the net revenue (NR) is calculated as $NR = TR-TC$. All measures are in U.S. dollars per acre per year. Whenever the relevant budget data were not available they were approximated by the assumptions stated in section 3.5.1.

Table 4.1 shows revenue and cost information for crop rotation practices and pastureland and calculated net revenue. In Table 4.1, TR for each alternative practice is more or less similar (except dryland pasture). It ranges from \$151 per acre to \$163 per acre. TC figures exhibit considerable difference among the practices. This is basically due to the difference in FC related to each practice. VCs are almost the same between alternatives. It ranges from \$143 per acre to \$153 per acre. FC change is high from base to alternative rotations compared to all other costs. Base Wheat-Fallow-Wheat conventional tillage practice has the highest FC at \$176.42 per acre. This is basically due to the machinery used in conventional tillage. FC for no (zero) tillage is \$80 per acre, which is the least among all the alternatives. This is due to the absence of machinery cost for zero tillage practice. Given all these cost figures, the least cost crop practice is WFW zero (no) tillage crop rotation (\$228 per acre per year) due to the least FC.

All the NR computations show a negative value, except pasture, which means all crop practices are incurring losses. Farmers do not like to move away from this crop cultivation even though they face losses due to several reasons. They are as follows:

Farmers get many government subsidies and credits for this crop cultivation. Also they do not like to move away from these practices, as crop have become their way of life. Also they need a long learning period if they are to move into new crop practices, which they do not prefer. They are also uncertain about the new crop practices that they have not previously used.

When considering rotation practices, the least NR is for no tillage and the highest is for conventional (intensive) tillage. Although the total revenue does not have a big difference, this difference is basically due to FC differences between these practices. Therefore, the most preferable in terms of the least loss is the zero tillage WFW crop rotation practice that has a NR of $76.61 per acre. The least preferred practice in terms of negative NR is the WFW conventional tillage, which loses $168.45 per acre. On the other hand, dryland pasture has a positive NR at $7.00 per acre. Change of NR is calculated from the base NR to alternative crop practices NR that is expressed as PDC in equation (1).

In equation (1), if PDC is greater than zero, then NR of the base is greater. Hence, if a farmer moves from base (existing practice) to alternative practices, he loses money. Therefore, if one wants to move the farmer away from the base to alternative, an incentive has to be paid. This incentive is called the PDC. On the other hand, if PDC is less than zero, NR of the alternative is greater than the base practice. Therefore, if a farmer moves away from base to alternative, he gains money.

WFW no (zero) tillage crop rotation has the highest NR difference. This implies that switching from WFW conventional tillage to WFW no tillage farmers gain $92 per acre. When moving from conventional tillage to minimum tillage crop rotations a farmer gains $71 to $49 per acre. Therefore, the farmer benefits from moving away from conventional tillage either to minimum tillage or to zero tillage crop rotation practices. Further, it is more advantageous as he gains more from this move.

When one moves from WFW conventional tillage to pasture, the farmer gains $161 per acre. Hence it is still advantageous to move into pasture growing from conventional tillage, since farmer gains in terms of NR.

As shown in Table 4.4, PDC for minimum tillage is positive $10 per acre per year. This means if a farmer is forced to switch from an existing conventional practice to minimum tillage he has to be compensated by at least $10 per acre per year. The rest of the PDC figures are negative. This means if a farmer moves from existing conventional tillage practice to these alternatives or dry land pasture he gain money. Given these alternatives, the highest gain is $131 per acre per year. The farmer gains this amount if he moves away from conventional tillage practice to dry land pasture. Therefore, the farmer is better off from moving from base to alternative crop practices.

Table 4.7 displays the budget components and PDC for cotton grown in dryland. All NRs are negative. Zero tillage has the least loss among the alternative tillage methods. This is a result of a low FC component due to the use of less machinery. Dryland pasture has the least losses as cost is considered only for land rent. PDCs are calculated considering base as the conventional tillage practice. Moving from conventional to minimum tillage has a positive PDC, which is equal to $5 per acre per year. Hence, if a farmer were to switch from conventional to minimum tillage he would need to be paid at least $5 per acre. On the other hand if a farmer moves from conventional to zero tillage and dryland pasture he gains $10 and $192 per acre, respectively. Therefore, a farmer is better off in moving to zero tillage and dryland pasture. The change in NR from base to minimum tillage is negative and the change from base to zero tillage and pasture is positive. Hence, farmer has to be paid if he were to move from base to minimum tillage. On the other hand, he gains if he switches his base practice into the other alternatives.

Results in Table 4.9 show that when cotton is grown dryland under minimum tillage, the NR losses are less than under the base conventional tillage. Therefore, the farmer gains by moving from base to alternative practices by $15 per acre and $198 per acre for zero tillage and dryland pasture respectively. The losses are less in alternative practices.

Table 4.13 displays the results for the dryland wheat practice with conventional tillage as the base. NRs are negative for all crop practices except dry land pasture, which is $7 per acre. This is the dry land pasture rent. PDC for minimum tillage is positive $0.73 per acre. Hence if the farmer were to move from conventional to minimum tillage he would need to be paid at least $.73 per acre. PDC for zero tillage and dryland pasture is negative. This means if farmer decides to switch his base to these alternatives he gains $13 and $33 per acre respectively.

Table 4.26 displays the revenue and cost results for reduced fallow for wheat. NRs for wheat fallow practice and reduced fallow are negative. However, reduced fallow has least losses. PDC values are calculated for reduced fallow use for both minimum and zero tillage as alternatives. Both PDCs are negative and they are $141 per acre and $155 per acre, respectively. This means moving form fallow wheat rotation to continuous (reduced fallow) wheat practice is profitable. Farmer gains from switching into reduced fallow practices.

4.1.1.2 Development of GHGE Quantity Components

GHGE increments for the cropping alternatives, dryland cotton, dryland wheat and pastureland are calculated using EPIC simulations. EPIC simulations are done to get carbon sequestered for alternative crops. It was originally done in tonnes of carbon per hectare. This is converted into tonnes of carbon per acre to keep the consistency with other data. EPIC simulations are run for crop rotation practices, dryland cotton, dryland wheat and pasture land (forty simulations). Over the years the rate at which carbon is sequestered (storage) in the soil decreases as the soil gets saturated with carbon (See Appendix C).

To get the carbon quantity for each practice, the following method is used. Carbon stored in the soil for each practice is taken by calculating the difference between the first and the final year carbon number and it is annualized to get the carbon quantity sequestered per year for each crop practice.

In the crop rotation analysis, both WFW conventional tillage (see Table 4.2) and WFW minimum tillage (see Table 4.3) are used as the base practices to compare the alternative crop rotations and pastureland practices. To calculate the BCP, the change in net revenue and the change in carbon number from the base to alternative practice are calculated. BCP is calculated for both scenarios such as base WFW conventional tillage and base WFW minimum tillage.

Carbon change is positive for all tillage deintensification alternatives. When one moves from WFW conventional tillage to WFW minimum tillage, there is an increase of carbon in the soil. This is 0.14 tonnes per acre per year. The highest increase of carbon is found when one moves from WFW conventional tillage to dryland pasture.

Table 4.8 shows the NR and carbon change for dryland cotton with conventional tillage as the base. Carbon sequestration increases when one moves from this base to alternative practices. Among all alternatives, dryland pasture results in the highest quantity of sequestered carbon. Therefore the carbon quantity gain is high when one moves from the base to dryland pasture. When dryland cotton minimum tillage is considered as the base, carbon sequestration ability increases with alternatives (See Table 4.9). It is 0.07 tonnes more in zero tillage and 1.38 tonnes more in dryland pasture.

As shown in Table 4.14, when one moves away from dryland wheat conventional tillage to alternatives carbon quantity saved has increased. This means that carbon savings are more in alternative tillage methods and dryland pasture.

As shown in Table 4.27 carbon quantity has increased when moving from wheat fallow rotation to continuous wheat. That is, move from fallow wheat to continuous wheat is profitable in terms of saving carbon. The carbon gain when moving from rotation to reduced fallow wheat minimum tillage 0.33 tons per acre per year and reduced fallow zero tillage is 0.47 tons carbon per acre per year.

4.1.1.3 Breakeven Carbon Equivalent Prices

The price of carbon is calculated by dividing the change in NR by the change in GHGE. For the change of WFW conventional tillage rotation to minimum tillage NR change is \$49.71 per acre while the carbon quantity change is 0.14 tonnes per acre. Then the BCP is;

$$\frac{-(49.71)}{(0.14)} = -350.1 = BCP\ .$$

This is the amount of money (dollars per tonne) that farmer gains if farmer moves from WFW conventional tillage to WFW minimum tillage practice. Likewise all BCP are calculated for each alternative practice (crop rotation and pasture). Table 4.2 shows the carbon prices (BCP) in the last column for potential conversion of alternative crop practices from the base crop rotation practice which is the wheat fallow wheat conventional tillage practice.

The calculated BCPs show that the farmer need not be compensated for most of the switches. For example a farmer gains \$350 per tonne of carbon, when he moves away from the WFW conventional tillage to WFW min tillage. If he moves from WFW conventional tillage to WFW zero (no) tillage he gains \$280 per tonne of carbon. The BCP for WFS minimum tillage and SFW minimum tillage are \$207 per tonne and \$474 per tonne respectively. Hence, the farmer gains if he moves away from conventional tillage to any of the other alternative rotations and tillage practices.

Forcing the farmer to move away from WFW conventional tillage to pastureland gives a BCP of \$310 per tonne of carbon. That is to say, the farmer gains \$310 per tonne of carbon saved by changing the practice from WFW conventional tillage to pastureland. BCP for pasture is low as the carbon increment from base to dryland is big, and BCP is calculated by taking this carbon increment as the denominator.

In the Table 4.3 results, WFW minimum tillage is set as the base and WFW zero tillage and dryland pasture are alternative practices. Here the farmer gains from moving into other alternatives as the NR changes are positive. Carbon sequestering ability is greater in zero tillage and dryland pasture compared to the base. BCPs are calculated following similar procedures as discussed above. When moving from base to WFW zero tillage and dryland pasture the farmer gains $226 per tonne of carbon and $297 per tonne of carbon respectively.

Table 4.8 shows the BCP calculation for dryland cotton, when conventional tillage is taken as the base. BCP from conventional to minimum tillage is positive $73 per tonne of carbon. This means that if the farmer moves from base conventional to minimum tillage he should be compensated by at least $73 per tonne of carbon saved. On the other hand, if he moves from conventional to zero and dryland pasture he gains $72 and $134 per tonne of carbon respectively.

Table 4.9 shows the BCP calculation for dryland cotton with minimum tillage used as the base. BCPs are calculated for zero tillage and dryland pasture alternatives. They are negative $218 and $143 per tonne of carbon for zero tillage and dryland pasture, respectively. Hence, if a farmer switchs from base minimum tillage to these alternatives he gains $218 and $143 per tonne of carbon, respectively.

Dryland wheat conventional tillage base and respective alternatives for BCP calculation appear in Table 4.14. The BCP for minimum tillage is \$3.42 per tonne of carbon. That is, if the farmer switches current conventional tillage practice into minimum tillage he would need to be compensated by at least \$3.42 per tonne of carbon saved. If the farmer moves from conventional base to zero tillage and dryland pasture he gains \$36 and \$74 per tonne of carbon saved respectively. Therefore he is better off moving into these alternatives.

Table 4.15 shows the dryland wheat practice with minimum tillage as the base. Here the farmer gains from switching to alternative practices. This is because the NR changes are positive, ranging from \$13 to \$20 per acre. Carbon gains are also positive. They are 0.14 and 0.23 tonne per acre from zero tillage and dryland pasture, respectively. BCP figures are negative \$97 and \$145 per tonne of carbon. Hence, the farmer does not need a carbon price incentive to switch as he benefits by moving from minimum to zero tillage or dryland pasture.

Table 4.27 shows BCPs computed for reduced fallow what when the base is considered as conventional tillage. BCPs for switches to wheat continuous minimum tillage and zero tillage are negative \$428 per mt and \$328 per mt, respectively. Hence, abandoning fallow is more profitable.

Table 4.28 shows the BCP when minimum tillage as the base for fallow rotation. Where the subsequent BCP for continuous wheat zero tillage is negative \$319 per mt. Therefore farmer again gains switching abandoning fallow practices.

4.1.2 Irrigated Practices

In this section we discuss the development of budget components, GHGE components and breakeven carbon price calculation for irrigated crops. Here we deal with corn, cotton and wheat.

4.1.2.1 Development of Budget Components

Revenue and cost data for irrigated corn, pastureland, irrigated cotton and irrigated wheat are collected from "Texas Crop Enterprise Budgets" projected for 2001 for Texas High Plains area by TCE. TR, VC and FC are directly taken from the crop budget reports and total cost (TC) is calculated. NR is calculated as $NR = TR\text{-}TC$. All measures are in U.S. dollars per acre per year. Whenever the relevant budget data were not available, they were approximated by the assumptions stated in section 3.5.1.

In Table 4.4 irrigated corn alternatives appear. There corn for grain conventional tillage is taken as the base. TR for corn conventional tillage is $504 per acre per year. TVC and TFC for this practice are $434 and $193 per acre per year respectively. TR, TVC, and TFC data are calculated using the assumptions explained in section 3.5.1. Land rent is taken as the FC cost for dryland pasture. As zero tillage incorporates minimum machinery, the fixed costs are lowest. The NR losses are least in zero tillage corn crop practice, which is $48 per acre per year. Hence, if farmer adopts the zero tillage crop practice he incurs fewer losses. Dryland pasture has the positive NR of $7 per acre per year compared to all alternatives. Hence the farmer benefits by moving to dryland pasture as he gains.

The corn PDCs are calculated considering conventional tillage as the base. When irrigated corn moves away from conventional to minimum tillage, the PDC is positive $10 per acre per year. Therefore, the farmer has to be compensated by at least $10 if he switches from conventional to minimum tillage. On the other hand, by moving from conventional to zero tillage and dryland pasture he gains $76 and $131 per acre per year, respectively.

Table 4.16 provides PDC results for irrigated wheat when conventional tillage is used as the base. In this case the NRs are negative. NR loses are least for zero tillage, which is $170 per acre among given tillage practices. Dryland pasture has a positive NR of $7 per acre among all alternatives. PDC is positive $8 per acre for minimum tillage. This means for the farmer to move from conventional to minimum tillage he would need to be paid $8 per acre. On the other hand if he moves from conventional to zero tillage and dryland pasture he gains $18 and $195 per acre, respectively. Therefore moving to these alternatives benefits the farmer.

Irrigated wheat PDC results with conventional tillage as the base appear in Table 4.16. There NRs are negative, which shows the farmer loses from each of these crop practices. The highest NR is with respect to dryland pasture. This is the dryland pasture rent. PDCs are calculated for alternatives. PDC for minimum tillage is $1.44 per acre. That is if the farmer were to switch from conventional to minimum tillage, he would need to be paid at least $1.44 per acre. On the other hand if farmer decided to shift his base conventional to zero tillage and dryland pasture, he gains $52 and $125 per acre, respectively. The farmer loses moving from conventional to minimum tillage. He gains by moving to other practices.

4.1.2.2 Development of GHGE Quantity Components

Carbon increments for the tillage practices and pastureland are calculated using EPIC simulations. As shown in Table 4.5, carbon-storage increases when one moves from irrigated corn conventional tillage to alternative tillage practices. When one makes these moves the carbon stored increases by 0.04 and 0.35 tonnes per acre, respectively. When moving from corn conventional tillage to dryland pasture, the carbon storage the carbon storage increases by 0.51 tonnes per acre per year. Hence, to sequester carbon, the best alternative is converting into pastureland.

Table 4.11 shows the carbon saved when the irrigated cotton tillage method is switched from conventional tillage. Moving into dryland pasture gives the highest gain of 1.4 tonnes per acre per year. This is also found in Table 4.12, for irrigated cotton with minimum tillage as the base practice. The results show that switching from cotton minimum tillage to dryland pasture gives the highest carbon saving of 1.3 tonnes per acre per year.

Table 4.18 shows the results for irrigated wheat with conventional tillage as the base. There carbon sequestration increases under all the alternatives. The highest increase is for dryland pasture and is 0.23 tonnes per acre per year. Moving into dryland pasture again yields the highest carbon saving. This is also true when the base is minimum tillage (see Table 4.19).

4.1.2.3 Breakeven Carbon Equivalent Prices

To calculate the BCP, the change in net revenue and the change in carbon from the base to alternative practices are calculated. Table 4.5 shows the NR, change in the NR, quantity of carbon sequestered, and changes in the carbon quantity and the BCPs when one moves from corn for grain conventional tillage to other alternative practices.

If farmers move from conventional tillage to minimum tillage then they need to be compensated by at least $263 per tonne of carbon saved. When moving from conventional tillage corn to zero tillage corn they gain $216 per ton of carbon. Conversion to pastureland gives $256 per tonne of carbon. This means that potential conversions to these alternatives are preferable since the farmer gains more money.

According to Table 4.6, when using corn irrigated minimum tillage as the base, BCP for corn zero tillage and dryland pasture are $277 and $300 per tonne of carbon respectively. This means the farmer gains by moving from base minimum tillage to the other alternatives.

In Table 4.11, BCPs are reported for irrigated cotton with conventional tillage as the base. The BCP for minimum tillage is positive: $125 per tonne of carbon. That means if farmer moves from conventional to minimum tillage he should be compensated by at least $125 per tonne of carbon. On the other hand if the farmer moves from base to zero tillage practice and dryland pasture he gains $159 and $139 per tonne of carbon, respectively.

Table 4.12 shows the BCP calculation for irrigated cotton using minimum tillage as the base. BCP are calculated for zero tillage and dryland pasture alternatives. Both

BCPs are negative. This means that if farmer were to switch from minimum tillage to alternatives zero tillage and dryland pasture he gains \$524 and \$152 per tonne of carbon respectively. Therefore, he benefits by switching from base to alternatives.

Table 4.17 shows the BCP calculation results for irrigated wheat when conventional tillage is used as the base. BCP for minimum tillage is \$6.6 per tonne of carbon. That is if the farmer switches from conventional to minimum tillage he should be compensated by at least \$6.6 per tonne of carbon saved. If he moves from conventional to zero tillage and dryland pasture he gains \$144 and \$283 per tonne of carbon saved.

When irrigated wheat is examined with minimum tillage as the base the BCP calculation results are in Table 4.18. Here the NR changes are positive for both zero tillage and dryland pasture. Therefore, BCPs are negative showing the farmer gains if he moves from minimum tillage to the alternatives.

4.1.3 Nitrogen Fertilizer Management Practices

In this section, we discuss the effect of reduced fertilization by examining different nitrogen stress levels for irrigated cotton. Stress levels considered are 10% and 20% under alternative tillage practices.

4.1.3.1 Development of Budget Components

As shown in Table 4.24, TR, VC and FC are from the TCE crop budgets. For the 10% and 20% nitrogen stress levels, TR is calculated as follows. The change in yield when 10% and 20% nitrogen stress levels are imposed is taken from EPIC simulations. The revenue change is calculated related to that yield change. TR is found by taking this revenue change into account at each stress level. Cost change is taken with respect to each nitrogen stress level. At each nitrogen stress level, the change in fertilizer level is taken from EPIC simulations for each stress level. Cost reductions due to less fertilizer application for each of these stress levels are calculated. Then the TC is calculated accounting for these cost reductions for each stress level. NR for each of these alternatives is calculated according to equation (2).

According to the results in Table 4.24, at 10% and 20% stress level minimum tillage NRs are negative \$187 and \$177 per acre per year. Therefore these alternatives yield fewer losses compared to base no stress conventional tillage. This is basically due to two reasons: 1) small decreases in yield are found as the base quantity of fertilizer is excessive and 2) cost is reduced due to less fertilizer application. The PDCs for 10% and 20% nitrogen stress level minimum tillage are negative \$1.4 and \$11.2 per acre per year respectively. Therefore, if farmer moves from base to these alternatives, he gains by this amount per acre per year

On the other hand, 10% and 20% stress levels for zero tillage exhibit reduced NRs of negative \$203 and \$201 per acre per year respectively. Losses in these alternatives are more than the loss from the base practice. This is due to lesser yields as a result of nitrogen stress levels, hence less revenue. PDC is calculated for these alternatives. If the farmer moves from base (zero nitrogen stress) under conventional tillage to 10% and 20% stress level zero tillage, the farmer has to be compensated by $15 and $13 per acre per year.

4.1.3.2 Development of GHGE Quantity Components

As shown in Table 4.25, the carbon equivalent change for each stress level is calculated in the following way. Carbon quantities for each stress level are directly taken from EPIC simulations. Levels of nitrogen fertilizer change for each stress level are found using the EPIC simulations. These are in pounds per hectare. They are converted into pounds per acre. It is calculated that the carbon equivalent cost of nitrous oxide emissions when one pound of nitrogen fertilizer is applied is 2 pounds of carbon.. Carbon change is taken from base no stress conventional tillage to alternative practices for whole simulation periods and converted into per year basis. Carbon Eq quantity increases on net. The highest carbon quantity increases are from base 10% and 20% zero tillage alternatives. Therefore, by using these alternatives greater level of carbon can be saved.

4.1.3.3 Breakeven Carbon Equivalent Prices

As shown in Table 4.25, BCP from base to 10% and 20% minimum tillage are negative $4 and $37 per tonne of carbon respectively. That means if farmer moves from conventional no stress base to 10% stress minimum tillage he gains $4 per tonne of carbon. Additionally, if he moves from conventional no stress base to 20% minimum tillage alternative he gains $37 per tonne of carbon.

On the other hand, BCPs for 10% and 20% stress level under zero tillage are positive. Therefore, in order to switch from base to 10% and 20% zero tillage alternatives, he should be compensated by $28 and $24 per tonne of carbon, respectively.

4.2 Manure Handling Practices

BCPs are calculated for four alternative dairy manure management practices. They are Anaerobic Lagoon (AL) open, AL covered, AL complete mix digester and Plug flow digester.

4.2.1 Development of Budget Components

Budget data (cost and revenue) for the AL open alternative is from Bennett et al. (1994) for a 500-cow herd. Budget data for the Plug flow digester are gathered from U.S. EPA (1997) for a 400 herd dairy operation in Durham, California (from Langerwerf Dairy farm, CA). Operational and maintenance cost is estimated through the electricity produced from the digester system. It is assumed that the cost to produce one-kilo watt-hour is $0.015 (According to personal communication with the contact person in the Minnesota Project, the cost of producing one kilowatt hour of electricity from plug flow digester system is $0.015). Revenue data for the plug flow system is calculated assuming that the amount of electricity produced per cow per day is 4-kilowatt hours, out of which 2-kilowatt hours are used on the farm at $0.07 per kilowatt and the other 2-kilowatt hours are sold to outside utility grid at $0.025 per kilowatt. Budget data for the AL covered digester was obtained from Williams and Frederick (2001) for a 400 cow dairy operation. Budget data for AL complete mix is taken from the U.S. EPA (1997) for a 250 cow dairy cow operation.

The first step in computing BCP involves the calculation of net cost and net returns components for different manure handling practices. Table 4.19 shows revenue and cost information for manure handling practices and calculated net revenue per cow basis. All NRs are negative, which shows that currently these systems are running under losses. The highest NR losses are for the covered lagoon system. This is basically due to high FC component as well as lower revenue. The lowest NR loss is $16 per cow per year for the plug flow digester system.

Even though TC in the Plug Flow digester system is high, revenue gains are also high. Revenue gains come from electricity generation. Costs basically are from machinery and other maintenance and operational costs. Negative NR for the open lagoon system is basically due to low revenues. The lowest total cost among all alternatives is for the open lagoon system.

Change in NR from the base to the covered lagoon is negative. This means that if farmer moves from open lagoon to covered lagoon he losses $55per cow per year. On the other hand, if he moves to plug flow and complete mix digester systems he gains $24 and $3 per cow per year respectively.

4.2.2 Development of GHGE Quantity Components

Methane emissions for the AL open system are calculated following the procedures and data in Johnson et al., (2001). The amount of milk assumed to be produced per cow per year is 9691 kilograms. The amount of methane emitted from manure in CO_2 equivalent is 398 grams per kilogram of milk produced. The total amount of methane emitted on a CO_2 Eq basis is 3.86 tonnes/cow/year. In turn the molecular weight of carbon in carbon dioxide is 12/44. Then multiplying 3.86 by 12/44 gives the tonnes of CO_2 produced per cow per year in CE. This is 1.05 tonnes of carbon/cow/year.

GHGE numbers for AL covered, AL complete mix and Plug flow digesters are calculated using the U.S EPA (2002a) estimates. First, we calculate the methane emission from dairy in the absence of any of manure handling practices. Then we extract the methane reduction when each of above mentioned manure-handling methods are practiced. The difference between these two values is the amount of methane emitted from each manure handling practice. The methane emission when there is no manure handling practice is calculated according to equation (6).

$$MethaneEmission = VS * B_0 * MCF \tag{6}$$

VS is the kilograms of volatile solids produced per day per 1000kg cow weight. B_0 is the maximum methane generation potential in cubic meters of methane per kilogram of VS produced. MCF is the state specific methane conversion factor for dairy. The mass of a typical cow is assumed to be 640 kg. Once the right hand side of the equation is calculated we get the methane emission in cubic meters of methane emitted per day. This is annualized by multiplying by 365. Next we get the methane emission in cubic meters per cow per year. Then we convert the methane emission in cubic meters per cow per year into metric tonnes per cow per year using a volume-mass conversion factor for methane (one cubic foot of methane is 0.04130 lbs). Then we convert the methane emission into CO_2 Eq using the Global Warming Potential (GWP) factor. Finally we come up with the amount of methane emitted in tonnes of Carbon equivalent which equals 0.977 metric tonnes of carbon per cow per year.

To calculate the methane emission saved when moving to an AL covered manure-handling system, data from a 250 cow California dairy farm are used. There the MCF is 0.44 (U.S. EPA, 2002a) and the estimated methane reduction is 800 metric tonnes of CO_2 Eq per year. On a CE and per cow annual basis the methane emission is 0.87 metric tonnes. The methane emission reduction from adopting this system as opposed to the base is the difference between 0.977 and 0.87, which is 0.10 metric tonnes of CE per cow per year.

Data from another California dairy is used to calculate the methane emission from the AL complete mix digester system again following U.S. EPA (2002a). This farm has 5000 dairy cows and again the MCF is 0.44. The methane emission under this manure handling system is estimated at 119 metric tonnes of CO_2 Eq per year. On a CE and per cow basis this amounts to 0.0238 metric tonnes of CE per cow per year. The methane emission reduction for adopting this systems is the difference between 0.977 and 0.0238, which is 0.953 metric tonnes of CE per cow per year.

For the plug flow manure handling system, the U.S. EPA (2002a) describe a 400 cow California farm that has methane emissions of is 0.81 metric tonnes of CE per cow per year. The reduction from system adoption as opposed to the open lagoon is 0.17 metric tonnes of CE per cow per year.

Table 4.20 summarizes the results. Namely, when moving from open lagoon to covered lagoon one can reduce emissions by 0.95 tonnes of CE per cow per year while the plug flow system and complete mix digesters yield 0.88 and 0.16 tonnes of CE per cow per year respectively. The highest carbon saving is from covered digesters. The lowest emission is from the covered lagoon system.

4.2.3 Breakeven Carbon Equivalent Prices

Then BCP is calculated according to equation (2) for a move away from an open lagoon. BCPs are calculated for alternative practices. BCP for covered lagoon is positive $58 per tonne of carbon. If the farmer were to move from open to covered lagoon he would need to be compensated at least by $58 for tonne of carbon saved. On the other hand if he moves to plug flow and complete mix digesters he gains $27 and $19 per tonne of carbon saved, respectively.

4.3 Enteric Fermentation Management on Cow Feedlot

Methane emissions from enteric fermentation (EF) are produced by the digestive process of ruminant animals (Gibbs et al., 2000). Emissions can be reduced by increasing the amount of absorbed energy from feedstuff, hence reduce the rumination. In this case potential conversion of the base feedlot practice to different alternative feedlot practices were considered. CE of CH_4 emissions related to each system were compared.

The practices evaluated are adapted from Johnson et al., (2001). A base and 7 alternative practices are considered. They are as follows:

1. TX-Base base practice (base steer has 28% fat at the time of marketing).
2. TX-Small: feeding the steers and heifers 20% less feed than in the base case.
3. TX-Large: feeding the steers and heifers 20% more feed than in the base. case.
4. TX-Direct: none of heifers and steers pass through a stocker phase but rather following weaning all go straight to a feedlot.
5. TX-No-Direct: all of heifers and steers pass through a stocker phase before coming into the feedlot.
6. TX-Fat-27%: feedlot cattle are fed to a lesser fat content (27% as opposed to 28% in base).
7. TX-Fat-29%: feedlot cattle are fed to a grater fat content (29% as opposed to 28% in base).

Total income comes from selling fat heifers and fat steers. Total expenses are for cattle, feed and miscellaneous inputs.

4.3.1 Development of Budget Components

Table 4.21 shows Johnson et al., (2001) estimates of the total income, expenses, and net revenue for a 100-cow herd for the 7 alternative practices. The base feedlot management practice has positive profits. Most other alternatives exhibit negative profits or losses. Management alternative Fat29% has a positive NR. This is basically due to high TR and relatively less TC incurred in this practice.

4.3.2 Development of GHGE Quantity Components

Johnson et al., (2001) calculate annual GHGE production from these feedlot cattle on a CO_2 Eq basis. Methane production comes from enteric fermentation and manure handling. Grazing, manure management and other direct and indirect practices also contribute to nitrous oxide emissions and CO_2 emission from fossil fuel and fertilizer use. Using all these attributes they calculate the total emissions in CO_2 Eq for a 100-cow herd operation.

The highest carbon emissions are related to the Large and Direct feedlot scenarios. The lowest carbon emission is related to the Small feedlot scenario and the next lowest is the Fat27%. Therefore, in order to save carbon the largest reductions come from the Small and Fat27% feedlot scenarios.

Therefore, in terms of carbon saving it is not preferred to switch from base to following alternatives: TX-Large, TX-No-Direct, TX-Direct and Fat29% feedlot scenarios. Carbon emissions are higher when using these practices.

4.3.3 Breakeven Carbon Equivalent Prices

Table 4.23 shows BCP calculations for alternative feedlot management scenarios. They are TX Small and TX Fat 27%. BCPs for other alternatives are not calculated due to the fact that carbon emissions are more in those practices relative to the existing base practice. Therefore, theses alternatives are not preferred to the base feedlot management scenario in terms of carbon gains.

If practitioner were to move from the TX-Base to TX-Small, $23.60 per tonne of carbon he would need to be paid. To move from base to Fat 27% feedlot scenario he would need to be paid $997 per tonne of carbon saved.

CHAPTER V

SUMMARY AND CONCLUSIONS

This thesis broadly focused on the costs of agricultural participation alternatives to mitigate greenhouse gas emissions. The analysis specifically focused on the costing of the agricultural possibilities found in the High Plains of Texas. The method employed the calculation of breakeven prices in terms of net income foregone divided by the increment in greenhouse gasses that would be a minimum bound on what producers would need to receive in order that they would switch from an existing chosen practice to a greenhouse gas emission mitigating alternative.

The Texas High Plains was selected as the study area as it is the major agricultural production region in Texas having large acreages of crops and many cattle in feedlots as well as an emerging dairy industry.

5.1 Systems Evaluated

Breakeven prices were calculated for

1. Reduced tillage adoption in dryland and irrigated cropping.
2. Land use change from cropland to permanent grass pasture.
3. Discontinuation of dryland wheat fallow practices.
4. Fertilization reduction in irrigated cropping.
5. Digester based dairy manure management.
6. Feedlot alterations to reduce enteric fermentation.

5.1.1 Reduced Tillage

Carbon sequestered in soil increases when less intensive tillage practices are used. The study examined three crop tillage practices: conventional deep plowing, minimum and no tillage arrayed in the order of tillage intensity. Two tillage methods were considered as base practices: conventional tillage and minimum tillage as these are the two predominant tillage practices currently employed. Generally, tillage intensity reductions were found to be profitable and emissions reducing. This lead to negative computed breakeven carbon equivalent prices indicating compensation would not be needed considering only the producer income situation.

5.1.2 Crop Land Use Change

Traditionally grasslands have higher amounts of carbon sequestered than do croplands. Conversion of croplands to permanently grassed dryland pasture was considered for both dryland and irrigated cropping. Conversion into dryland pasture was always found to be profitable and greenhouse gas emissions reducing showing a negative breakeven adoption price. This indicates that farmers would not need to be compensated when considering only the producer income situation.

5.1.3 Wheat Fallow Discontinuation

Recently it has been found that switching into continuous cropping from fallow cropping is profitable to the farmer. This is also investigated in this study. Base practice considered was the fallow wheat and reduction in fallow practices are considered as alternatives. Switching from base practices into reduced fallow practices are found to be profitable, indicating that farmers need not be compensated when considering only the producer income situation.

5.1.4 Crop Fertilization Reduction

Fertilizer use causes nitrous oxide releases. Reductions in fertilization were considered by examining three nitrogen fertilizer stress levels for minimum tilled irrigated corn. They are no stress plus 10% and 20% nitrogen stress levels. The base practice was no nitrogen fertilizer stress. Crops other than corn are not considered here, since they performed poorly in EPIC simulations (cotton showed no yield or nitrogen use levels) or were not examined. Reducing fertilizer use by accepting higher nitrogen stress levels was again found to be profitable and emissions decreasing causing a negative breakeven carbon price indicating that farmers would need not be compensated when considering only the producer returns and costs.

5.1.5 Dairy Manure Management

Dairy cow manure when handled in a wet handing system generates methane emissions. Three alternative emission reducing manure-handling systems were considered as alternatives with the base being an open anaerobic lagoon (AL). Alternatives considered are AL covered, AL complete mix digester and Plug flow digester. In the absence of information on dairy manure handling systems in Texas, data from case studies in California under somewhat similar climatic conditions were employed to describe the net returns and emission reductions that could be introduced into Texas High Plains dairies. Adoption of the AL complete mix digester and Plug flow are profitable relative to the AL open base system also emitting less methane yielding negative breakeven carbon equivalent prices. This shows that farmers would not need to be compensated for converting to AL complete mix and plug flow digesters only considering producer returns and costs.

5.1.6 Feedlot Enteric Fermentation Management

Ruminant animals release methane as a byproduct of feed digestion and this is called enteric fermentation. A lot of animals are in Texas feedlots. Six enteric fermentation alternatives were considered for those animals. These involve variations in feeding rates, stocker phase use and finished animal fat content. Some of alternative management scenarios yield negative effects on net greenhouse gas emissions. Therefore, these alternatives are not further examined. The reduced feeding rate alternative saves emissions to the base scenario but returns less net income. Thus the Breakeven price is positive equaling $23 per mt of carbon saved, and the farmer has to be compensated to switch into this alternative.

5.2 Cost Classification of Opportunities

The breakeven carbon equivalent prices can be characterized into a number of cost groups. Arbitrarily, we use 4 classifications: negative cost opportunities, low cost items (less than $20 per tonne of carbon saved), moderate cost items (between $20 through $100 per tonne of carbon saved), and high cost items (more than $100 for tonnes of carbon saved). Table 4.26 summarizes the cost classification of opportunities and respective agricultural practices for each category.

5.2.1 Negative Cost Items (Cost Less Than Zero)

A lot of negative cost items were found where in fact farmers could make money and reduce emissions by moving to alternative practices even without any carbon payments. All the fallow wheat dryland, and reduced fallow crop practices fell into this class. When we consider dryland and irrigated cotton, zero tillage has a negative carbon cost. This is also true for, dryland and irrigated wheat zero tillage, irrigated corn zero tillage, cotton irrigated nitrogen use reduction under minimum tillage and dryland pasture for all systems. In dairy manure handling systems, AL complete mix and plug flow are in negative cost category.

5.2.2 Low Cost Items (Cost Between $0 and $20)

Dryland and irrigated wheat under minimum tillage are found to be in the low cost category. Use of practices in this category cause adopters to make less net income than under current practices. Hence, compensation is needed to induce farmers to switch to these practices.

5.2.3 Moderate Cost Items (Cost Between $20 and $100)

Under this category, farmers make at least $20 less per tonne of emissions offset compared to what they can make under their existing practices. Cotton dryland under minimum tillage and cotton irrigated 10% and 20% nitrogen stress level under zero tillage fell into the moderate cost class. The AL covered dairy manure management practice fell here as did the reduced animal size feedlot enteric fermentation management alternative (this is the TXSmall alternative).

5.2.4 High Cost Items (Cost More Than $100)

Corn irrigated minimum tillage and cotton irrigated minimum tillage fall in the high cost category. There a farmer would have to be compensated by more than $100 per tonne of carbon saved.

5.3 Limitations

The breakeven carbon price calculated was often found to be negative in this study. This raises a question of whether the farmers are overlooking an economic activity or we are not considering all of the costs. This study limits attention only to the change in farmer level net income less fixed costs as the full costs incurred when switching into an alternative sequestering practice. This may not be complete and is a limitation of this study. For example the costs of training farmers and extra risk inherent in the new practice are not considered in this study. In addition other costs would be incurred when selling greenhouse gas offsets to a buyer like a power plant needing greenhouse gas offsets. McCarl (2003) enumerates a number of Costs of assembling farmers to get a substantial amount of greenhouse gas offsets needed by a power plant which emits a large amount of greenhouse gases is one of other costs not considered in this study. Other costs that are not considered in this study are, the costs of measurement of greenhouse gas emissions and monitoring systems, costs of obtaining certification on government rating established on number of offset credits when switching from one practice to the other, costs encountered in education and training of producers on how to alter their practices so that they most efficiently produce greenhouse gas offsets, and costs that will be encountered for the enforcement of permit contractual obligations. Government may have an active role in some of the assembly, measurement, producer education or other market transactions. Costs due to Government inefficiencies in doing so are also not considered in this study.

Another limitation of this study is the lack of available budget data in some crop and dairy manure management practices for Texas High Plains area. In the absence of some crop practices budget data, several assumptions are utilized based on Pennsylvania State Cooperative Extension, 1996 as described in section 3.5.1. In the absence of the dairy manure management data, case studies done in California are taken as best approximations. However, this may not be a good assumption due to differences in soil, climatic conditions and technology used.

Yet another limitation involves the use of budget data from the year 2000 for each practice. Recently agriculture has not generally been very profitable. Almost all of our base budgets exhibited income losses. To get a better picture of the situation, we may need to consider longer run multi year budgets.

A problem with respect to the calculation of costs and returns in dairy manure management practices are that energy costs may differ across states. When costs and returns from Californian dairy manure management systems are used to get an approximation in the situation in Texas, this may not give a clear picture of the dairy manure management systems in Texas due to the disparity in energy costs.

This study also does not take the market effects into account, such that say if farmer switches from corn cultivation to pasture, corn supply may reduce, which in tern create a short supply of corn and drive the market price of corn high. This has an adverse effect on the corn consumer.

5.4 Suggestions for Further Work

To overcome the lack of information on other costs involving in switching into an alternative practice, future research should focus on the development of these costs. With the inclusion of a complete set of costs involving in switching into an alternative practice, future studies may be in a better position to ascertain the appropriate role for agriculture in a society wide GHGE reduction effort.

To get a clear picture of the costs and revenues of practices considered, one can incorporate long run budgets into the calculations. Also Consideration of the market demand and supply effects into this study would give us a clear indication of effect on consumer and producer as result of a switch in practice that sequester more carbon.

It would be useful in the future research to incorporate the finding in this study into the U.S. Agricultural Sector Model Greenhouse Gas version (ASMGHG) (McCarl and Schneider, 2000) or the Forest and Agriculture Sector Optimization Model (FASOMGHG) (Adams et al., 1996 and Lee, 2002). By incorporating these BCPs from this study into ASMGHG or FASOMGHG, consumer and producer surpluses in the Texas High Plains region and other regions in the U.S. as a result of conversion of base practices to alternative practices for sequestering carbon can be estimated.

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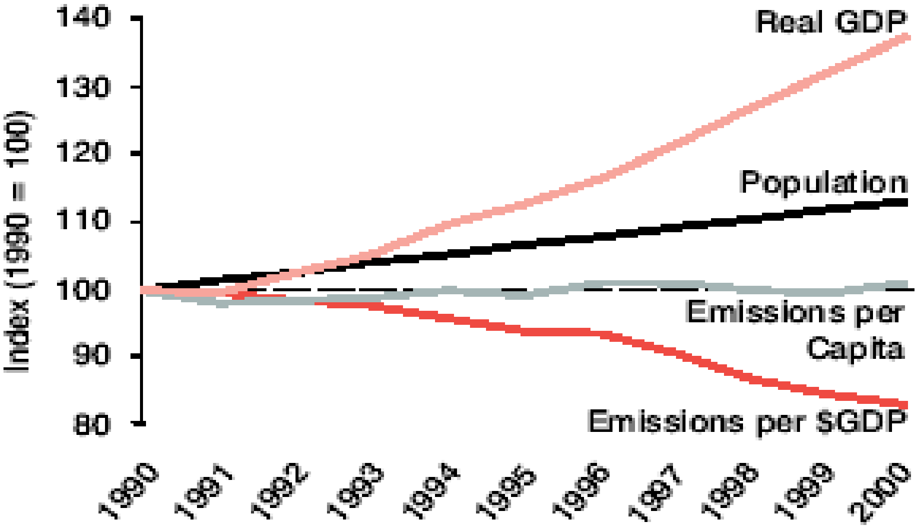
APPENDIX A

LIST OF FIGURES



Source: BEA (2001), U.S. Census Bureau (2000), and emission estimates in this report.

Figure 2.1. U.S. greenhouse gas emissions per capita and per dollar of gross domestic product

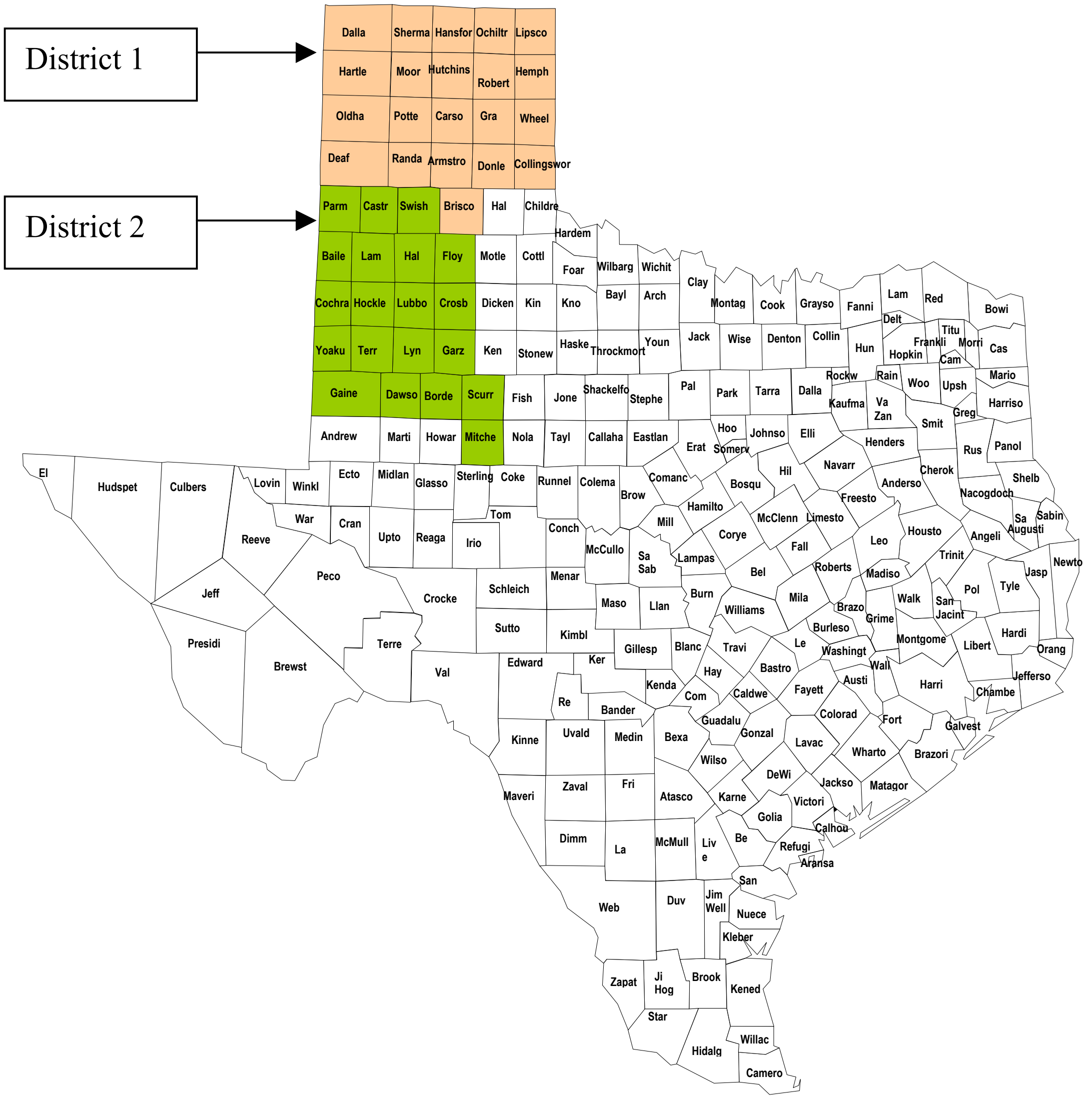


Figure 3.1. Selected study area in Texas (Districts 1 and 2)

APPENDIX B

LIST OF TABLES

Table 3.1. Bases and Alternatives Considered Under Crop Practices (Base Conventional Tillage)

	Corn for grain	Cotton		Wheat	
	Irrigated	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**
Base conventional tillage	Conventional Tillage	Conventional Tillage	Conventional Tillage	Conventional Tillage	Conventional Tillage
Alternatives	Minimum Tillage Zero Tillage Pasture Dryland	Minimum Tillage Zero Tillage Pasture Dryland	Minimum Tillage Zero Tillage Pasture Dryland	Minimum Tillage Zero Tillage Pasture Dryland	Minimum Tillage Zero Tillage Pasture Dryland

Table 3.2. Bases and Alternatives Considered Under Crop Rotations (Base Conventional Tillage and Minimum Tillage)

Base (fallow systems)	Alternatives
Wheat-Fallow-Wheat Conventional tillage	Wheat-Fallow-Wheat minimum tillage
	Wheat-Fallow-Wheat no tillage
	Wheat-Fallow-Sorghum minimum tillage
	Sorghum-Fallow-Wheat minimum tillage
	Pasture dryland
	Wheat dryland minimum tillage
	Wheat dryland zero tillage
Wheat-Fallow-Wheat minimum tillage	Wheat-Fallow-Wheat no tillage
	Pasture dryland
	Wheat dryland zero tillage

Table 3.3. Bases and Alternatives Considered Under Crop Practices (Base Minimum Tillage)

	Corn for grain	Cotton		Wheat	
	Irrigated	**Irrigated**	**Dryland**	**Irrigated**	**Dryland**
Base minimum tillage	Minimum Tillage	Minimum Tillage	Minimum Tillage	Minimum Tillage	Minimum Tillage
Alternatives	Zero Tillage Pasture dryland	Zero Tillage Pasture Dryland	Zero Tillage Pasture dryland	Zero Tillage Pasture dryland	Zero Tillage Pasture dryland

Table 4.1. PDC[a] Summary for Dryland Fallow Systems and Pastureland[b]

Crop Practice Rotations	TR $/ac/yr[c]	VC $/ac/yr	FC $/ac/yr	TC $/ac/yr	NR $/ac/yr	PDC from base $/ac/yr
WFW conventional tillage Base	151.90	143.93	176.42	320.35	-168.45	
WFW minimum tillage	151.90	144.23	126.41	270.64	-118.74	-49.71
WFW no tillage	151.90	148.25	80.26	228.51	-76.61	-91.84
WFS minimum tillage	163.07	153.24	110.72	263.96	-100.89	-67.56
SFW minimum tillage	163.07	152.71	107.69	260.40	-97.33	-71.12
Pasture dry (land rent)					7.00	-161.45

---

[a] PDC is the Producer Development Cost.

[b] TR is Total Revenue, VC is Variable Cost, FC is Fixed Cost, TC is Total Cost and NR is Net revenue.

[c] ac is the acreage and yr is the year.

Table 4.2. BCP for Dryland Fallow Systems Under Conventional Tillage

Crop Practice Rotations	NR[a] ($/ac/yr)	Change of NR ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP[b] ($/mt)
WFW conventional tillage base	-168.45		2.45		
WFW minimum tillage	-118.74	49.71	2.59	0.14	-350.1
WFW no tillage	-76.61	91.84	2.78	0.33	-280.0
WFS minimum tillage	-100.89	67.56	2.78	0.33	-207.2
SFW minimum tillage	-97.33	71.12	2.60	0.15	-474.1
Pasture dry (land rent)	7.00	161.45	3.02	0.56	-310.9

---

[a] NR is the Net Revenue.

[b] BCP is the Break Even Carbon Price.

Table 4.3. BCP[a] Summary for Minimum Tillage Dryland Fallow Systems

Crop Practice Rotations	NR[b] (\$/ac/yr)[c]	Change in NR (\$/ac/yr)	Reduction in Carbon (mt[d]/ac/yr)	Carbon change from base (mt/ac/yr)	BCP (\$/mt)
WFW minimum tillage base	-118.74		2.59		
WFW no tillage	-76.61	42.13	2.78	0.19	-226.49
Pasture dry (land rent)	7.00	111.74	3.02	042	-297.71

---

[a] BCP is breakeven carbon price.
[b] NR is net revenue.
[c] ac is acre and yr is year.
[d] mt is metric ton.

Table 4.4. PDC[a] Summary for Corn Sprinkler Irrigated

Crop practice irrigated corn	TR[b] $/ac/yr	VC $/ac/yr	FC $/ac/yr	TC $/ac/yr	NR $/ac/yr	PDC from base $/ac/yr
Corn for grain irrigated conventional tillage base	504.00	434.36	193.83	628.19	-124.19	
Corn for grain irrigated minimum tillage	504.00	460.42	178.32	638.75	-134.75	10.56
Corn for grain irrigated zero tillage	504.00	447.39	104.67	552.06	-48.06	-76.13
Pasture dry (land rent)					7.00	-131.19

---

[a] PDC is producer development cost.

[b] TR is total revenue, VC is variable cost, FC is fixed cost, TC is total cost and NR is net revenue.

Table 4.5. BCP[a] Summary for Irrigated Corn Tillage Practices from a Conventional Tillage Base

Crop practice Irrigated corn	NR[b] (\$/ac[c]/yr)	Change of NR (\$/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt[d]/ac/yr)	BCP (\$/mt)
Corn for grain irrigated conventional tillage base	-124.19		2.50		
Corn for grain-irrigated minimum tillage	-134.75	-10.56	2.54	0.04	263.9
Corn for grain irrigated zero tillage	-48.06	76.13	2.86	035	-216.3
Pasture dry (land rent)	7.00	117.19	3.02	0.51	-256.0

---

[a] BCP is breakeven carbon price.
[b] NR is net revenue.
[c] Ac is acre.
[d] mt is metric ton and yr is year.

Table 4.6. BCP[a] Summary for Irrigated Corn Tillage Practices from a Minimum Tillage Base

Crop practice Irrigated corn	NR[b] ($/ac/yr)	Change in NR ($/ac/yr)	Reduction in Carbon (mt/ac/yr)[c]	Carbon change from base (mt/ac/yr)	BCP ($/mt)
Corn for grain irrigated minimum tillage base	-134.75		2.54		
Corn for grain irrigated zero tillage	-48.06	86.69	2.86	0.31	-277.84
Pasture dry (land rent)	7.00	127.75	3.02	047	-300.08

---

[a] BCP is breakeven carbon price.
[b] NR is net revenue.
[c] Mt is metric ton, ac is acre and yr is year.

Table 4.7. PDC[a] Summary for Dryland Cotton[b]

Crop practice Dryland cotton	TR ($/ac/yr)	VC ($/ac/yr)	FC ($/ac/yr)	TC ($/ac/yr)	NR ($/ac/yr)	PDC from base ($/ac/yr)
Dry conventional tillage base	157.50	233.90	109.31	343.21	-185.71	
Dry conservation tillage	157.50	247.93	100.57	348.50	-191.00	5.29
Dry zero tillage	157.50	240.92	91.82	332.74	-175.24	-10.47
Pasture dry (land rent)					7.00	-192.71

---

[a] PDC is the producer development cost.

[b] TR is Total Revenue, VC is Variable Cost, FC is Fixed Cost, TC is Total Cost and NR is Net revenue.

Table 4.8. BCP[a] Summary for Dryland Cotton Conventional Tillage

Crop practice Dryland Cotton	NR[b] ($/ac/yr)	Change of NR ($/ac/yr)	Reduction in Carbon (mt/ac/yr)[c]	Carbon change from base (mt/ac/yr)	BCP ($/mt)
Dry conventional tillage base	-185.71		1.59		
Dry conservation tillage	-191.00	-5.29	1.66	0.07	73.46
Dry zero tillage	-175.24	10.47	1.73	0.14	-72.73
Pasture dry (land rent)	7.00	178.71	3.02	1.43	-134.92

---

[a] BCP is breakeven carbon price.
[b] NR is net revenue.
[c] Mt is metric ton, ac is acre and yr is year.

Table 4.9. BCP[a] Summary for Dryland Cotton Minimum Tillage

Crop practice Dryland Cotton	NR[b] ($/ac/yr)	Change in NR ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP ($/mt)
Dry conservation tillage base	-191.00		1.66		
Dry zero tillage	-175.24	15.76	1.73	0.07	-218.91
Pasture dry (land rent)	7.00	184.00	3.02	1.38	-143.86

---

[a] BCP is breakeven carbon price.
[b] NR is net revenue.

Table 4.10. PDC[a] Summary for Irrigated Cotton

Crop practice Irrigated cotton	TR[b] $/ac/yr	VC[c] $/ac/yr	FC[d] $/ac/yr	TC[e] $/ac/yr	NR[f] $/ac/yr	PDC from base $/ac/yr
Irrigate conventional tillage base	378.00	381.11	185.20	566.31	-188.31	
Irrigate conservation tillage	378.00	403.98	170.38	574.36	-196.36	8.05
Irrigate zero tillage	378.00	392.54	155.57	548.11	-170.11	-18.20
Pasture dry (land rent)					7.00	-195.31

---

[a] PDC is producer development cost.
[b] TR is total revenue
[c] VC is variable cost
[d] FC is fixed cost.
[e] TC is total cost.
[f] NR is net revenue.

Table 4.11. BCP[a] Summary for Irrigated Cotton Conventional Tillage

Crop practice Irrigated cotton	Net Revenue ($/ac/yr)	Change of Net Revenue ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP ($\mt)
Irrigate conventional tillage base	-188.31		1.62		
Irrigate cons tillage	-196.36	-8.05	1.68	0.06	125.79
Irrigate zero tillage	-170.11	18.20	1.73	0.11	-159.64
Pasture dry (land rent)	7.00	181.31	3.02	1.43	-139.87

---

[a] BCP is breakeven carbon cost.

Table 4.12. BCP[a] Summary for Irrigated Cotton Minimum Tillage

Crop practice Irrigated cotton	Net Revenue ($/ac/yr)	Change in Net Revenue ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP ($\mt)
Irrigate conservation tillage base	-196.36		1.68		
Irrigate zero tillage	-170.11	26.25	1.73	0.05	-524.99
Pasture dry (land rent)	7.00	189.36	3.02	1.33	-152.63

---

[a] BCP is breakeven carbon price.

Table 4.13. PDC Summary for Dryland Wheat[a]

Crop practice Dryland wheat	TR $/ac/yr	VC $/ac/yr	FC $/ac/yr	TC $/ac/yr	NR $/ac/yr	PDC from base $/ac/yr
Dryland wheat conventional tillage base	60.90	55.07	32.15	87.22	-26.32	
Dryland wheat minimum tillage	60.90	58.37	29.58	87.95	-27.05	0.73
Dryland wheat zero tillage	60.90	56.72	17.36	74.08	-13.18	-13.14
Pasture dry (land rent)					7.00	-33.32

---

[a] PDC is producer development cost, TR is total revenue, VC is variable cost, FC is fixed cost, TC is total cost and NR is net revenue.

Table 4.14. BCP Summary for Dryland Wheat Conventional Tillage[a]

Crop practice Dryland wheat	Net Revenue ($/ac/yr)	Change of Net Revenue ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP ($\mt)
Dryland wheat conventional tillage base	-26.32		2.57		
Dryland wheat minimum tillage	-27.05	-0.73	2.78	0.21	3.42
Dryland wheat tillage	-13.18	13.14	2.92	0.36	-36.90
Pasture dry (land rent)	7.00	19.32	3.02	0.45	-74.31

---

[a] BCP is breakeven carbon price.

Table 4.15. BCP Summary for Dryland Wheat Minimum Tillage[a]

Crop practice Dryland wheat	Net Revenue ($/ac/yr)	Change in Net Revenue ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP ($\mt)
Dryland wheat minimum tillage base	-27.05		2.78		
Dryland wheat zero tillage	-13.18	13.87	2.92	0.14	-97.67
Pasture dry (land rent)	7.00	20.05	3.02	023	-145.30

---

[a] BCP is the breakeven carbon price.

Table 4.16. PDC Summary for Irrigated Wheat[a]

Crop practice irrigated wheat	TR $/ac/yr	VC $/ac/yr	FC $/ac/yr	TC $/ac/yr	NR $/ac/yr	PDC from base $/ac/yr
Wheat irrigated conventional tillage	198.50	191.63	125.70	317.33	-118.83	
Wheat irrigated minimum tillage	198.50	203.13	115.64	318.77	-120.27	1.44
Wheat irrigated zero tillage	198.50	197.38	67.88	265.26	-66.76	-52.07
Pasture dry (land rent)					7.00	-125.83

---

[a] PDC is producer development cost, TR is total revenue, VC is variable cost, FC is fixed cost, TC is total cost and NR is net revenue.

Table 4.17. BCP Summary for Irrigated Wheat Conventional Tillage[a]

Crop practice irrigated wheat	Net Revenue ($/ac/yr)	Change of Net Revenue ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP ($\mt)
Wheat irrigated conventional tillage base	-118.83		2.57		
Wheat irrigated minimum tillage	-120.27	-1.44	2.79	0.22	6.61
Wheat irrigated zero tillage	-66.76	52.07	2.93	0.36	-144.65
Pasture dry (land rent)	7.00	111.83	3.02	0.44	-283.17

---

[a] BCP is breakeven carbon price.

Table 4.18. BCP Summary for Irrigated Wheat Minimum Tillage[a]

Crop practice irrigated wheat	Net Revenue ($/ac/yr)	Change in Net Revenue ($/ac/yr)	Reduction in Carbon (mt/ac/yr)	Carbon change from base (mt/ac/yr)	BCP ($\mt)
Wheat irrigated minimum tillage base	-120.27		2.79		
Wheat irrigated zero tillage	-66.76	53.51	2.93	0.14	-376.87
Pasture dry (land rent)	7.00	113.27	3.02	0.23	-562.24

---

[a] BCP is the breakeven carbon price.

Table 4.19. PDC Summary for Dairy Manure Handling Practices[a]

Manure Handling System	FC ($/cow/yr)	VC ($/cow/yr)	TC ($/cow/yr)	TR ($/cow/yr)	NR ($/cow/yr)
Open Anaerobic Lagoon	33.62	20.11	53.73	12.53	-41.20
Covered Anaerobic Lagoon	84.38	52.50	136.88	40.00	-96.88
Plug Flow digester	75.00	11.25	86.25	69.35	-16.90
Complete mix digester	72.00	14.00	86.00	48.00	-38.00

---

[a] PDC is producer development cost, TR is total revenue, VC is variable cost, FC is fixed cost, TC is total cost and NR is net revenue.

Table 4.20. Net Revenue, Change of Net Revenue, Methane Emission in Carbon Equivalents, Change in Methane Emission for Base Open Lagoon Manure Handling Practice and Alternative Systems and BCPs

Manure Handling System	Net Revenue ($/cow/yr)	Change of Net Revenue ($/cow/yr)	CH_4[a] in CE[b] (mt/cow/yr)	Change of Carbon from base (mt/cow/yr)	BCP[c] ($/ton)
Open AL	-41.20		1.05		
Covered AL	-96.88	-55.68	0.10	0.95	58.75
Plug Flow	-16.90	24.30	0.17	0.88	-27.50
Complete mix	-38.00	3.20	0.89	0.16	-19.69

---

[a] CH_4 is the methane.

[b] CE is Carbon Equivalent.

[c] BCP is breakeven carbon price

Table 4.21. Total Income, Expenses and Net Revenue for a 100-Cow Herd Under Enteric Fermentation Alternatives

Feedlot Practice	Total Revenue ($/herd/yr)	Total Cost ($/herd/yr)	Net Revenue ($/herd/yr)
Base	41116	41095	21.53
Small	32934	33012	-77.52
Large	49279	49333	-53.91
No Direct	41987	42299	-312.34
Direct	39414	39622	-207.86
Fat27%	38247	40128	-1881.14
Fat29%	42541	42057	484.05

Table 4.22. Emissions Summary for a 100-Cow Herd Under Enteric Fermentation Alternatives

Feedlot practice	Total Carbon Dioxide (CO_2) Equivalent (mt/herd/yr)	Total Carbon (Carbon equivalents) (mt/herd/yr)
Base	61.9	16.9
Small	46.5	12.7
Large	78.6	21.4
No Direct	64.0	17.5
Direct	78.9	21.5
Fat27%	54.9	15.0
Fat29%	69.1	18.9

Table 4.23. BCP Summary for a 100-Cow Herd Under Enteric Fermentation Alternatives[a]

Feedlot practice	Net Revenue ($/herd/yr)	Change of Net Revenue	Quantity of Carbon (mt/herd/yr)	Change in Carbon from base	BCP ($/mt)
Base	21.53		16.9		
Small	-77.52	-99.05	12.7	4.2	23.60
Large	-53.91	-75.44	21.4	-4.5	---
No Direct	-312.34	-333.87	17.5	-0.6	---
Direct	-207.86	-229.39	21.5	-4.6	---
Fat27%	-1881.14	-1902.67	15.0	1.9	997.02
Fat29%	484.05	462.52	18.9	-2.0	---

---

[a] BCP is the breakeven carbon price. BCPs are not calculated for Large, No Direct, Direct, and Fat 29% alternatives since carbon emissions are more than the Base.

Table 4.24. PDC Summary for Irrigated Cotton: 0%, 10% and 20% Nitrogen Fertilizer Stress Levels[a]

Crop practice	TR ($/ac/yr)	VC ($/ac/yr)	FC ($/ac/yr)	NR ($/ac/yr)	PDC ($/ac/yr)
Cotton zero (no) nitrogen stress	378.00	381.11	185.20	-188.31	
10% nitrogen stress minimum tillage	379.19	380.90	185.20	-186.91	-1.40
10% nitrogen stress zero tillage	362.47	380.77	185.20	-203.51	15.20
20% nitrogen stress minimum tillage	388.20	380.09	185.20	-177.09	-11.22
20% stress zero tillage	363.46	379.82	185.20	-201.56	13.25

---

[a] PDC is producer development cost, TR is total revenue, VC is variable cost, FC is fixed cost, TC is total cost and NR is net revenue.

Table 4.25. BCP Summary for Irrigated Cotton: 0%, 10% and 20% Nitrogen Fertilizer Stress Levels[a]

Crop practice Irrigated cotton	Net Revenue ($/ac/yr)	Change of Net Revenue ($/ac/yr)	Quantity of Carbon (mt/ac/yr)	Change in Carbon from base (mt/ac/yr)	BCP ($\mt)
Cotton zero nitrogen stress	-188.31		30.37		
10% nitrogen stress minimum till	-186.91	1.40	32.85	0.31	-4.51
10% nitrogen stress zero tillage	-203.51	-15.20	34.69	0.54	28.15
20% nitrogen stress minimum tillage	-177.09	11.22	32.77	0.30	-37.46
20% nitrogen stress zero tillage	-201.56	-13.25	34.65	0.53	24.79

---

[a] BCP is the breakeven carbon price.

Table 4.26. PDC Summary for Reduced Fallow Systems[a]

Crop practice Rotations	TR $/ac/yr	VC $/ac/yr	FC $/ac/yr	TC $/ac/yr	NR $/ac/yr	PDC from base $/ac/yr
WFW conventional tillage Base	151.90	143.93	176.42	320.35	-168.45	
Wheat continuous dryland minimum tillage	60.9	58.37	29.57	87.95	-27.05	-141.40
Wheat continuous dryland zero tillage	60.9	56.72	17.36	74.08	-13.18	-155.27

---

[a] PDC is producer development cost, TR is total revenue, VC is variable cost, FC is fixed cost, TC is total cost and NR is net revenue.

Table 4.27. BCP[a] Summary for Reduced Fallow: Base Conventional Tillage

Crop Practice	Net Revenue ($/ac/yr)	Change of Net Revenue ($/ac/yr)	Quantity of Carbon (mt/ac/yr)	Change in Carbon from Base (mt/ac/yr)	BCP ($\mt)
WFW conventional tillage Base	-168.45		2.45		
Wheat continuous dryland minimum tillage	-27.05	141.39	2.78	0.33	-428.47
Wheat continuous dryland zero tillage	-13.18	155.26	2.92	0.47	-328.95

---

[a] BCP is breakeven carbon price.

Table 4.28. BCP[a] Summary for Reduced Fallow: Base Minimum Tillage

Crop Practice	Net Revenue ($/ac/yr)	Change of Net Revenue ($/ac/yr)	Quantity of Carbon (mt/ac/yr)	Carbon Change from base (mt/ac/yr)	BCP ($\mt)
WFW minimum tillage	-118.74		2.59		
Wheat continuous dryland zero tillage	-13.18	105.55	2.92	0.33	-319.86

---

[a] BCP is breakeven carbon price.

Table 4.29. Summary of Cost Classification of Opportunities and Respective Agricultural Practices

Cost Item	Agricultural Practices
1. Negative	All fallow dryland crop practices Dryland and irrigated cotton zero tillage Dryland and irrigated wheat zero tillage Irrigated corn -zero tillage Cotton irrigated 10% & 20% N stress, under min tillage Dairy-Al complete mix & plug flow
2. Low (less than$20)	Dryland and irrigated wheat minimum tillage
3. Moderate ($20-$100)	Cotton dryland minimum tillage Cotton irrigated 10% & 20% N stress levels under zero tillage In dairy manure Anaerobic Lagoon covered Enteric Fermentation practices TX Small
4. High (more than $100)	Corn irrigated minimum tillage Cotton irrigated minimum tillage

APPENDIX C

Erosion Productivity Impact Calculator (EPIC) Simulation Results

1. EPIC Simulation Results for Fallow System Tillage Practices

	Crop rotations				
	Wheat Fallow Wheat Conventional Tillage	Wheat Fallow Wheat Minimum Tillage	Wheat Fallow Wheat Zero Tillage	Wheat Fallow Sorghum Minimum Tillage	Sorghum Fallow Wheat Minimum Tillage
Year	Total organic Carbon	Total organic Carbon	Total organic Carbon	Total organic Carbon	Total organic Carbon
1	63.32	61.32	61.40	61.80	61.36
2	62.44	59.52	59.64	59.92	59.52
3	61.44	58.16	58.28	58.60	58.20
4	60.32	57.12	57.64	57.64	59.04
5	59.96	56.52	58.64	57.36	57.28
6	59.60	56.64	57.80	58.32	57.32
7	58.60	55.76	57.44	57.24	58.12
8	58.64	55.84	58.12	57.56	57.04
9	58.00	55.92	58.00	58.64	56.68
10	56.96	54.92	57.04	57.68	56.96
11	56.80	54.72	56.68	57.32	55.88
12	56.64	55.20	57.48	57.60	56.08
13	55.60	54.16	57.88	56.88	56.04
14	55.56	54.08	56.92	56.80	55.32
15	55.16	54.44	56.64	57.40	55.44
16	54.32	53.48	57.24	56.96	55.52
17	54.20	53.40	57.32	56.52	54.84
18	54.24	53.96	56.60	57.16	55.24
19	53.56	53.20	56.08	56.48	55.68
20	53.76	53.24	56.40	56.40	54.76
21	53.72	53.68	56.56	56.92	54.96
22	53.08	53.00	56.00	56.08	54.92
23	53.24	52.92	55.92	56.04	54.04
24	53.24	53.20	56.64	56.72	54.40
25	52.40	53.16	56.96	56.12	54.28
26	52.24	52.12	56.00	55.48	53.44
27	52.36	52.52	55.64	55.96	53.84
28	51.52	51.68	56.56	55.36	53.84
29	51.72	51.68	56.24	55.28	53.32
30	51.48	51.84	55.56	55.96	53.24

	Wheat Fallow Wheat Conventional Tillage	**Wheat Fallow Wheat Minimum Tillage**	**Wheat Fallow Wheat Zero Tillage**	**Wheat Fallow Sorghum Minimum Tillage**	**Sorghum Fallow Wheat Minimum Tillage**
Year	**Total organic Carbon**	**Total organic Carbon**	**Total organic Carbon**	**Total organic Carbon**	**Total organic Carbon**
31	50.68	50.92	55.68	55.28	53.00
32	50.76	50.88	55.84	55.04	52.60
33	50.68	51.16	56.24	55.40	52.76
34	50.00	50.32	55.32	54.88	52.52
35	50.00	50.16	55.40	54.60	51.88
36	50.08	50.60	55.68	55.52	52.16
37	49.44	49.76	55.76	54.60	52.36
38	49.76	49.96	55.32	54.68	51.92
39	49.80	50.28	55.00	55.68	52.00
40	49.04	50.68	55.60	54.68	52.04

2. Erosion Productivity Impact Calculator Simulation Results for Dryland Corn Tillage Practices

	Dryland Corn		
	Conventional Tillage	**Minimum Tillage**	**Zero Tillage**
Year	**Total Oroganic Carbon**	**Total Organic Carbon**	**Total Organic Carbon**
1	61.12	57.64	57.84
2	60.28	56.24	56.64
3	58.92	56.04	57.36
4	58.52	56.16	57.60
5	57.84	56.04	57.64
6	57.56	56.08	57.52
7	57.04	56.20	57.44
8	56.12	55.32	57.04
9	55.68	54.96	57.32
10	55.36	55.00	57.36
11	54.60	54.12	57.20
12	54.20	53.84	57.12
13	54.40	54.56	57.44
14	54.08	54.32	57.36
15	53.84	53.96	57.40
16	53.80	53.88	57.24
17	53.32	53.24	57.24
18	52.72	52.80	57.16
19	53.52	53.52	57.32
20	53.64	53.40	57.40
21	53.04	53.24	57.60
22	52.68	52.56	57.44
23	52.72	53.08	57.40
24	52.08	52.04	57.04
25	51.80	51.64	56.92
26	52.16	52.32	57.16
27	52.20	52.52	57.20
28	52.04	51.76	57.16
29	51.92	51.64	56.84
30	52.12	51.80	57.00
31	51.36	51.56	57.20
32	51.72	51.36	57.24
33	51.16	50.92	56.88
34	50.92	51.08	56.76

	Conventional Tillage	**Minimum Tillage**	**Zero Tillage**
Year	**Total Oroganic Carbon**	**Total Organic Carbon**	**Total Organic Carbon**
35	50.52	50.28	56.52
36	50.96	51.20	56.88
37	50.52	50.24	56.84
38	50.40	50.16	56.76
39	50.72	50.68	56.68
40	50.44	50.04	56.84

3. Epic Productivity Impact Calculator Simulation Results for Dryland Cotton Tillage Practices

	Dryland Cotton		
	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
1	40.04	41.08	41.16
2	39.08	40.76	41.16
3	38.36	40.28	40.80
4	37.80	39.84	40.44
5	37.32	39.44	40.00
6	36.84	38.96	39.56
7	36.32	38.44	39.12
8	35.96	38.16	38.92
9	35.84	37.84	38.64
10	35.60	37.56	38.36
11	35.48	37.40	38.36
12	35.04	36.92	37.92
13	34.72	36.60	37.64
14	34.36	36.28	37.36
15	34.08	35.96	37.16
16	33.84	35.80	37.04
17	33.56	35.60	36.92
18	33.36	35.32	36.80
19	33.16	35.16	36.68
20	33.16	35.12	36.76
21	33.20	34.84	36.56
22	32.88	34.72	36.40
23	32.76	34.56	36.24
24	32.48	34.48	36.12
25	32.36	34.40	36.00
26	32.12	34.20	35.80
27	31.84	33.96	35.56
28	31.68	33.88	35.56
29	31.76	34.04	35.60
30	31.60	33.84	35.44
31	31.40	33.68	35.32
32	31.24	33.48	35.08
33	31.04	33.32	35.08

	Conventional tillage	**Minimum tillage**	**Zero tillage**
Year	**Total Organic Carbon**	**Total Organic Carbon**	**Total Organic Carbon**
34	30.96	33.28	34.92
35	30.76	33.24	34.92
36	30.76	33.20	34.88
37	30.60	33.16	35.00
38	30.56	33.00	34.80
39	30.40	32.84	34.68
40	30.32	32.80	34.64

4. Erosion Productivity Impact Calculator Simulation Results for Dryland Wheat Tillage Practices

	Dryland Wheat		
	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
1	60.80	61.68	63.52
2	58.80	59.84	64.00
3	57.72	60.20	63.56
4	57.36	59.88	63.08
5	57.04	59.72	62.96
6	57.00	59.60	62.72
7	57.04	59.64	62.64
8	56.84	59.28	62.32
9	56.48	58.96	61.88
10	56.08	58.60	61.40
11	56.00	58.56	61.44
12	55.72	58.32	61.16
13	55.24	58.08	60.96
14	54.92	57.84	60.76
15	54.56	57.84	60.80
16	54.76	57.96	60.84
17	54.60	58.04	60.80
18	54.68	58.40	61.08
19	54.52	58.04	60.80
20	53.96	57.72	60.52
21	53.80	57.44	60.20
22	53.52	57.20	60.00
23	53.36	57.24	60.04
24	53.28	57.48	60.28
25	53.12	57.28	60.12
26	52.96	57.04	60.00
27	52.72	56.76	59.72
28	52.48	56.56	59.52
29	52.52	56.48	59.40
30	52.44	56.36	59.28
31	52.44	56.36	59.20
32	52.24	56.08	58.84
33	52.16	56.16	59.04

	Conventional tillage	**Minimum tillage**	**Zero tillage**
Year	**Total Organic Carbon**	**Total Organic Carbon**	**Total Organic Carbon**
34	52.12	56.00	59.00
35	52.52	56.20	59.08
36	52.16	56.24	59.00
37	51.80	55.88	58.60
38	51.48	55.72	58.60
39	51.28	55.48	58.28
40	51.36	55.64	58.48

5. Erosion Productivity Impact Calculator Simulation Results for Irrigated Corn Tillage Practices

	Corn irrigated		
	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
1	61.12	57.64	57.84
2	60.32	56.24	56.64
3	58.92	56.04	57.36
4	58.52	56.16	57.60
5	57.84	56.04	57.64
6	57.56	56.08	57.60
7	57.04	56.12	57.48
8	56.12	55.32	57.04
9	55.68	54.92	57.40
10	55.36	55.00	57.44
11	54.64	54.12	57.32
12	54.20	53.84	57.24
13	54.32	54.52	57.60
14	54.04	54.36	57.52
15	53.80	54.00	57.56
16	53.76	53.92	57.40
17	53.28	53.28	57.48
18	52.72	52.80	57.40
19	53.36	53.56	57.56
20	53.80	53.48	57.64
21	53.08	53.32	57.84
22	52.72	52.64	57.72
23	52.76	53.12	57.64
24	52.12	52.08	57.28
25	51.80	52.16	57.16
26	52.16	52.36	57.44
27	52.24	52.56	57.48
28	52.08	51.80	57.44
29	51.96	51.68	57.08
30	52.12	51.84	57.24
31	51.40	51.60	57.52
32	51.76	51.40	57.52
33	51.20	50.92	57.12

	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
34	50.96	51.08	57.04
35	50.56	50.28	56.84
36	50.96	51.20	57.16
37	50.56	50.24	57.16
38	50.44	50.20	57.04
39	50.76	50.68	56.92
40	50.08	50.48	57.12

6. Erosion Productivity Impact Calculator Simulation Results for Irrigated Cotton Tillage Practices

	Irrigated cotton		
	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
1	40.04	41.08	41.16
2	39.08	40.76	41.16
3	38.36	40.28	40.80
4	37.80	39.84	40.44
5	37.32	39.44	40.00
6	36.84	38.96	39.56
7	36.32	38.44	39.12
8	35.96	38.16	38.92
9	35.84	37.84	38.64
10	35.60	37.56	38.36
11	35.48	37.40	38.36
12	35.04	36.92	37.92
13	34.72	36.60	37.64
14	34.36	36.28	37.36
15	34.08	35.96	37.16
16	33.84	35.80	37.04
17	33.56	35.60	36.92
18	33.36	35.32	36.80
19	33.16	35.20	36.68
20	33.16	35.12	36.76
21	33.20	34.84	36.60
22	32.88	34.72	36.40
23	32.76	34.60	36.28
24	32.48	34.48	36.16
25	32.36	34.40	36.00
26	32.12	34.20	35.84
27	31.84	33.96	35.60
28	31.68	33.92	35.60
29	31.76	34.04	35.64
30	31.64	33.88	35.48
31	31.40	33.68	35.36
32	31.24	33.48	35.12
33	31.04	33.32	35.12

	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
34	30.96	33.28	34.96
35	30.80	33.24	34.96
36	30.76	33.24	34.92
37	30.64	33.20	35.04
38	30.56	33.00	34.84
39	30.40	32.84	34.72
40	30.32	32.80	34.68

7. Erosion Productivity Impact Calculator Simulation Results for Irrigated Wheat Tillage Practices

	Irrigated wheat		
	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
1	60.80	61.68	63.52
2	58.80	59.88	64.00
3	57.72	60.24	63.56
4	57.36	59.92	63.08
5	57.08	59.76	62.96
6	57.04	59.64	62.76
7	57.08	59.72	62.68
8	56.88	59.36	62.40
9	56.48	59.04	61.96
10	56.12	58.68	61.48
11	56.00	58.68	61.52
12	55.80	58.40	61.24
13	55.28	58.16	61.04
14	54.96	57.96	60.84
15	54.64	57.92	60.88
16	54.84	58.08	60.96
17	54.68	58.16	60.92
18	54.72	58.48	61.20
19	54.60	58.16	60.92
20	54.04	57.84	60.64
21	53.88	57.56	60.32
22	53.56	57.32	60.12
23	53.44	57.36	60.16
24	53.36	57.64	60.40
25	53.20	57.44	60.36
26	53.04	57.16	60.20
27	52.80	56.92	59.88
28	52.56	56.68	59.68
29	52.56	56.60	59.56
30	52.52	56.52	59.44
31	52.52	56.52	59.36
32	52.36	56.24	59.00
33	52.24	56.32	59.20

	Conventional tillage	Minimum tillage	Zero tillage
Year	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
34	52.20	56.16	59.16
35	52.56	56.36	59.24
36	52.24	56.40	59.20
37	51.84	56.00	58.76
38	51.52	55.88	58.76
39	51.36	55.64	58.44
40	51.44	55.80	58.64

8. EPIC Simulation Results for Dryland Pasture

	Pasture
Year	Total Organic Carbon
1	65.48
2	65.60
3	66.88
4	67.00
5	68.56
6	68.72
7	70.16
8	70.20
9	71.00
10	71.44
11	71.92
12	72.20
13	72.52
14	72.40
15	72.76
16	72.88
17	72.56
18	71.76
19	71.92
20	71.52
21	71.36
22	71.68
23	71.72
24	72.08
25	72.80
26	73.20
27	72.80
28	72.48
29	72.16
30	71.64
31	72.24
32	71.64
33	71.72
34	70.80
35	70.92

Year	Total Organic Carbon
36	71.00
37	70.56
38	70.12
39	70.08
40	69.96

9. Total Organic Carbon Levels for Different Nitrogen Fertilizer Stress Levels

tonnes/ac

Year	0% stress Conventional tillage	10% Minimum tillage	10% Zero tillage	20% Minimum tillage	20% Zero tillage
	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon	Total Organic Carbon
1	40.04	41.08	41.16	41.08	41.16
2	39.08	40.76	41.16	40.76	41.16
3	38.36	40.28	40.8	40.28	40.8
4	37.8	39.84	40.44	39.84	40.44
5	37.32	39.44	40	39.44	40
6	36.84	38.96	39.56	38.96	39.56
7	36.32	38.44	39.12	38.44	39.08
8	35.96	38.16	38.92	38.16	38.92
9	35.84	37.84	38.64	37.84	38.64
10	35.6	37.56	38.36	37.56	38.36
11	35.48	37.4	38.36	37.4	38.36
12	35.04	36.92	37.92	36.92	37.92
13	34.72	36.6	37.64	36.6	37.64
14	34.36	36.28	37.36	36.28	37.36
15	34.08	35.96	37.16	35.96	37.16
16	33.84	35.8	37.04	35.8	37.04
17	33.56	35.6	36.92	35.6	36.88
18	33.36	35.32	36.8	35.32	36.8
19	33.16	35.16	36.68	35.16	36.64
20	33.16	35.12	36.76	35.12	36.76
21	33.2	34.84	36.56	34.8	36.56
22	32.88	34.72	36.4	34.72	36.36
23	32.76	34.56	36.24	34.52	36.24
24	32.48	34.48	36.12	34.44	36.12
25	32.36	34.4	36	34.36	35.96
26	32.12	34.2	35.8	34.16	35.8
27	31.84	33.96	35.56	33.92	35.56
28	31.68	33.88	35.56	33.84	35.52
29	31.76	34.04	35.6	34	35.6
30	31.64	33.84	35.44	33.8	35.4

Year	**0% stress Conventional tillage**	**10% Minimum tillage**	**10% Zero tillage**	**20% Minimum tillage**	**20% Zero tillage**
	Total Organic Carbon	**Total Organic Carbon**	**Total Organic Carbon**	**Total Organic Carbon**	**Total Organic Carbon**
31	31.4	33.68	35.32	33.64	35.32
32	31.24	33.48	35.08	33.44	35.04
33	31.04	33.32	35.08	33.28	35.04
34	30.96	33.28	34.92	33.24	34.92
35	30.8	33.24	34.92	33.2	34.88
36	30.76	33.2	34.88	33.16	34.84
37	30.64	33.16	35	33.12	34.96
38	30.56	33	34.8	32.96	34.76
39	30.4	32.84	34.68	32.8	34.64
40	30.32	32.8	34.64	32.72	34.6

10. Nitrogen Fertilizer Levels at Different Fertilizer Stress Levels for Irrigated Cotton lbs/ac

	Irrigated cotton				
Year	Zero stress	10% stress	10% stress	20% stress	20% stress
	Intensive tillage	Reduce tillage	Zero tillage	Reduce tillage	Zero tillage
1	30.24	30.24	30.24	30.24	30.24
2	30.24	50.24	50.24	30.24	50.24
3	30.24	30.24	40.00	30.24	30.24
4	30.24	30.24	30.24	30.24	30.24
5	30.24	30.24	50.24	30.24	30.24
6	30.24	30.24	30.24	30.24	30.24
7	30.24	30.24	30.24	30.24	30.24
8	30.24	30.24	30.24	30.24	30.24
9	30.24	50.24	50.24	50.24	50.24
10	33.80	50.24	60.00	30.24	50.24
11	42.64	50.24	50.24	50.24	50.24
12	70.77	50.24	50.24	30.24	30.24
13	30.24	50.24	55.00	50.24	50.24
14	35.88	50.24	50.24	50.24	50.24
15	70.82	30.24	30.24	30.24	30.24
16	52.50	50.24	50.24	50.24	50.24
17	32.44	50.24	60.00	50.24	50.24
18	71.03	50.24	49.00	30.24	50.24
19	40.30	50.24	50.24	70.24	50.24
20	52.61	50.24	60.00	50.24	50.24
21	80.00	70.24	55.00	50.24	70.24
22	30.24	50.24	50.24	50.24	30.24
23	72.14	60.00	50.24	70.24	50.24
24	70.70	50.24	50.24	50.24	50.24
25	38.24	50.24	50.24	50.24	50.24
26	56.95	70.24	60.00	50.24	50.24
27	50.38	50.24	50.24	50.24	50.24
28	50.60	50.24	50.24	50.24	50.24
29	53.48	50.24	50.24	50.24	50.24
30	73.29	70.24	50.00	50.24	50.24
31	50.24	50.24	50.24	50.24	50.24

Year	Zero stress	10% stress	10% stress	20% stress	20% stress
	Intensive tillage	**Reduce tillage**	**Zero tillage**	**Reduce tillage**	**Zero tillage**
32	80.00	50.24	55.00	70.24	30.24
33	57.58	60.00	50.24	50.24	50.24
34	70.25	50.24	50.00	50.24	50.24
35	32.56	50.24	50.24	50.24	50.24
36	78.78	50.24	50.24	50.24	50.24
37	51.35	80.00	60.00	50.24	50.24
38	59.22	50.24	50.24	50.24	50.24
39	58.69	50.24	50.24	50.24	50.24
40	80.00	60.00	60.00	70.24	50.24

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