# ECONOMICS AND GREEN HOUSE GAS ABATEMENT OF TILLAGE SYSTEMS IN THE BLACK SOIL ZONE OF SASKATCHEWAN

A Thesis Submitted to the College of Graduate Studies and Research

in Partial Fulfilment of the requirements for the Degree of Master of Science

in the Department of Agricultural Economics

University of Saskatchewan

Saskatoon

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## Acknowledgements

I would first like to thank my supervisor Dr Ken Belcher who first of all kept guiding me in this research and secondly kept me motivated throughout the process. Secondly, I would like to express gratitude to my committee members Professor Suren Kulshreshtha and Dr Marie Boehm for their continued insight and support with the research. Next, I am grateful to all the producers of the Black soil without whom it would have been impossible to gather the data that would make this model applicable to the region. Finally, I would like to express a big thankyou to my mother for her words of encouragement.

**Abstract**

Climate Change has been related to GHG emissions, of both natural and anthropogenic origin. Agricultural management practices like reduced tillage and intensive cropping systems have a significant impact on the flow of C among it's sources and sinks. These management practices involve complex biophysical interactions resulting in a range of impacts on farm income and GHG abatement. The focus of this study was on the impact of alternative annual crop tillage systems on GHG emissions and income to better inform climate change mitigation policy in agriculture. Besides tillage intensity, cropping intensity and crop mix and the interaction of these characteristics with the biological and physical attributes, the emission and income effects are a function of factor inputs, factor costs and commodity prices. Therefpre, the analysis was multi-disciplinary in nature and the tool of choice that depicts impacts on individual indicators is Trade-off Analysis (TOA). A component of risk analysis was also included. The analysis focused on short and long-term performance, the uncertainty of soil $N_2O$ emission coefficients as well as changes in weather patterns. As the adoption of reduced till has been a relatively recent development and as such, there is not a lot of long-term biophysical and economic data, which limits the effectiveness of econometric analysis. The different scenarios of uncertainty and long-term impacts were analysed by use of a simulation model. The model was parameterised with Intergovernmental Panel on Climate Change (IPCC) 1996 coefficients, a farmer survey, and cost data from Saskatchewan Agriculture Agri-Food and Rural Revitalization (SAFRR) for 2004. Results indicated that net GHG emissions were relatively lower for reduced tillage management while conventional tillage may be relatively more attractive from an economic perspective. However, results indicated that such economic factors as risk and economies of size may have a significant influence on this latter result. The study also highlighted the need to evaluate the GHG abatement potential of reduced tillage while simultaneously considering the abatement capability of the farm.

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# CHAPTER 1
# INTRODUCTION

## 1.1 Background

When one looks at historic evidence, the past has shown warmer mean global temperatures than the present (Table 1). However, what is more interesting is how the present shows greater change in mean temperature variance: While it has been estimated that temperature variance changed by only two degrees Celsius in the last 10,000 years, the variance has changed by 0.5 to 0.7 Celsius within the last 150 years (Splash, 1994). Coincidentally, these 150 years have been within the industrialisation period, the period when fossil fuels have been used extensively as an energy source.

**Table 1.1 Mean Global Temperatures**

| Years ago | Mean global temperature relative to present (°C) |
|---|---|
| 5,000-6,000 | +1 |
| 125,000 | +2 |
| 3-4 million | +3-4 |

(Source: Splash, 1994)

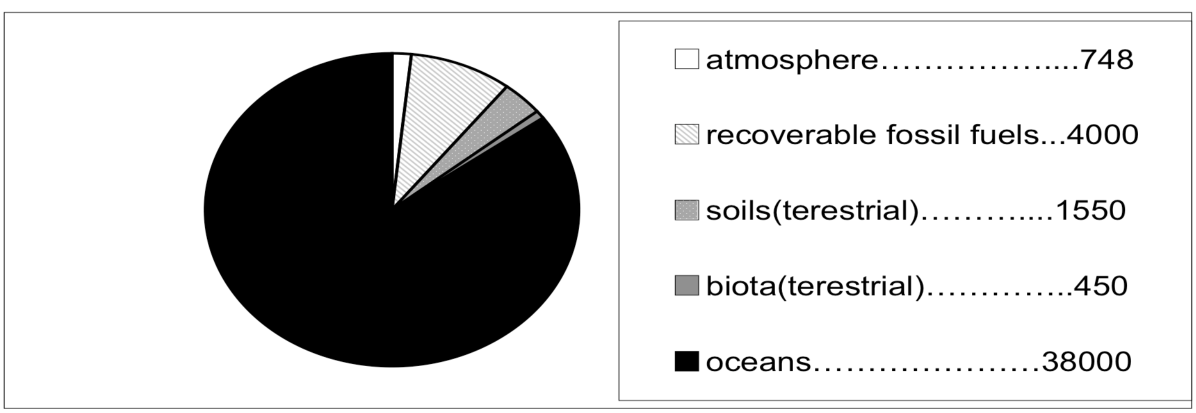
There are increasing concerns that human activity, through the increased emissions of greenhouse gases (GHG), is having an impact on global climate. Among the early efforts to link climate change with GHG emissions associated with the burning of fossil fuels, was the Frenchman, Jean Baptiste Fourier, who in 1827 first postulated an analogy between atmospheric warming and warming properties of a greenhouse. In addition, Swedish Nobel laureate in Chemistry, Svante Arrhenius, postulated an anthropogenic greenhouse effect occurring as carbon dioxide ($CO_2$) concentrations accumulated in the atmosphere from increased burning of fossil fuels. In 1938 G.D. Callendar's failed attempt to convince the Royal Society that global warming was underway (Tucker, 1997).

The response to anthropogenic changes in climate forcing occurs against a backdrop of natural climate variability. The Intergovernmental Panel on Climate Change (2001) state that the presence of this natural climate variability means that the detection and attribution of anthropogenic climate change is a statistical “signal-in-noise” problem. However, detection and attribution studies have advanced beyond addressing the simple question “have we detected a human influence on climate?” to such questions as “how large is the anthropogenic change?” and “is the magnitude of the response to greenhouse gas forcing as estimated in the observed record consistent with the response simulated by climate models?” (IPCC,2001). The concluding remarks of the IPCC third assessment report are as follows (IPCC, 2001):

1. The 20th century climate was unusual
2. The observed warming is inconsistent with model estimates of natural internal climate variability.
3. The observed warming in the latter half of the 20th century appears to be inconsistent with natural external (solar and volcanic) forcing of the climate system.
4. The observed change in patterns of atmospheric temperature in the vertical[1] is inconsistent with natural forcing. Changes in the vertical refer to patterns of air temperature changes seen in the stratosphere and troposphere. What was observed are stratospheric cooling and tropospheric warming.
5. Anthropogenic factors do provide an explanation of 20th century temperature change
6. The effect of anthropogenic greenhouse gases is detected, despite uncertainties in sulphate aerosol forcing and response
7. It is unlikely that detection studies have mistaken a natural signal for an anthropogenic signal
8. The detection methods used should not be sensitive to errors in the amplitude of the global mean forcing or response

9. Studies of the changes in the vertical patterns (as discussed in 4 above) of temperature also indicate that there has been an anthropogenic influence on climate over the last 35 years
10. Observed and simulated vertical lapse rate changes are inconsistent over the last two decades, but there is an anthropogenic influence on tropospheric temperatures over a longer period
11. Natural factors may have contributed to the early century warming

The scientific community has been careful to maintain a focus on the management of sources and sinks of the carbon pool in the environment (Lal *et. al.,* 2000 a). A source is any process, activity or mechanism that releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol into the atmosphere (IPCC, 2001 a). A sink is any process activity or mechanism that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas or aerosol from the atmosphere (IPCC, 2001a). How sources and sinks are distributed among various reservoirs of the carbon pool is shown in Figure 1.1: The ocean is the largest carbon sink. Next in importance are both world soils and the biota that also influence atmospheric concentration of $CO_2$ and other radiatively active gasses (Lal *at. al.,* 2000b and Azar and Sterner, 1996). In the long run, an equilibrium prevails between the atmosphere and the ocean.




(Sources: Lal *et. al*., 2000b; Johnson ,2000; Bouzaher et. al., 2000)
**Figure. 1.1 Estimates of GlobalCarbon Pool among Various Reservoirs (Gigatonnes)**

While, in equilibrium approximately 15% of emitted $CO_2$ remains in the atmosphere, this could rise to as high as 30% (or in other words, double the concentration of $CO_2$ of the pre-industrial era (Azar and Sterner, 1996; Johnson , 2000).

The movement of carbon among the various reservoirs within the global carbon cycle involves a number of processes (Table 1.2). Although, the largest effluxes are plant respiration and residue decay and the largest influx is through photosynthesis, these processes are influenced by human activity while such processes as the burning of fossil fuels and land use are are based on the level of human activity. Hence, the impact of land use and soil management practices are considered for GHG accounting by the IPCC (1996).

**Table 1.2 Carbon Change among the Reservoirs**

| Flux | Reservoir | | Rate (Gigatonnes carbon per year) |
|---|---|---|---|
| Efflux to the atmosphere | (i) | fossil fuel burning | 5.3 |
| | (ii) | land use | 0.6-2.6 |
| | (iii) | plant respiration | 40-60 |
| | (iv) | residue decay | 50-60 |
| | | sub total | 95.9-127.9 |
| Influx from the atmosphere | (i) | photosynthesis | 100-120 |
| | (ii) | ocean uptake | 1.6-2.4 |
| | | sub total | 101.6-122.4 |
| Imbalance (efflux-influx) | | | 1.8 + or – 1.4 |

(Sources: Lal *et. al.,* 2000 b; Johnson,2000)

Production practices on soil systems found in the prairies of western Canada and the U.S. Great Plains have been driven by the limitation of soil moisture; and in order to counter this problem summer-fallow (leaving a parcel of land uncultivated for an entire cropping season) has been used. Summer-fallow conserves soil moisture at critical growing periods to reduce the risk of crop failure (Cihacek and Ulmer, 2000). However, the more frequent the land is left fallow the greater the reduction of Soil Organic matter Carbon (SOC) (Nyborg *et. al.,* 2000, Cihacek and Ulmer, 2000 and Campbell *et. al.,* 2004). This is due to the fact that during the fallow period carbon is released to the atmosphere[2] but not replaced by the adoption of crop production and only in the crop growing period is carbon added to the soil (Cihacek and Ulmer, 2000). Hence, by reducing the frequency of fallow and by reducing tillage intensity[3] SOMC losses could be decreased and soil could function as a net C sink (Cihacek and Ulmer, 2000 and Cambell et. al., 2004).

In addition to reducing $CO_2$ emissions by sequestering more SOMC, reduced tillage is known to reduce the emission of $CO_2$ by reducing fuel use and by reducing machinery use- and the $CO_2$ emissions that they give rise to (Desjardins and Riznek, 2000, and Coxworth, 1998). However, the C cycle is linked to the nitrogen (N) cycle such that increases in the soil carbon stock will also increase the soil N stock which could result in reduced tillage systems facilitating an increase in emission of nitrous oxide ($N_2O$). Further, under production systems that involve more intensive crop production there is an associated increase in the quantity of fertiliser used, particularly with more N based fertiliser, which may give rise to more $N_2O$ emissions (Desjardins and Riznek, 2000 and Coxworth, 1998). Reduced tillage farmers are also known to use more legumes in their rotations. This could have contrasting effects with respect to soil $N_2O$ emissions. On the one hand legume crops are known to add more N to the soil, which is released as $N_2O$ than cereal crops and on the other hand if wheat or barley follows a legume these crops, in turn, need less N based fertiliser (Desjardins and Riznek, 2000 and Coxworth, 1998). There is still uncertainty about the effect of zero tillage on soil $N_2O$ emissions; it has been postulated that reduced tillage systems may cause a reduction in soil $N_20$ emissions in western Canadian but an increase in the east (Boehm, M. 2004c). However, it is poorly understood what the capacity is of reduced tillage systems in terms of *net* GHG abatement (in terms of net $CO_2$ equivalent) compared to more traditiona conventional tillage systems.

[2] After the crop is harvested, tillage incorporates the residue back into the soil where carbon is released by decomposition of microbial activity: This released carbon has two possible paths it could take; it could enter the SOMC pool or it could enter the atmospheric pool as $CO_2$.

[3] Reduced tillage intensity during the fallow period maintains more carbon in the undecomposed form. i.e., for longer periods before being decomposed to SOMC or released out of the soil carbon pool to atmospheric $CO_2$.

The same factors that make the calculation of net GHG abatement complex makes the calculation of economic returns complex. For example while fuel use and labour use are expected to decline, due to the reduction of tillage, weed pressures may rise and herbicide costs increase. As well investment in different machinery could change the net machinery stock and changes to the yields would impact farm gross revenues.

## 1.2 Problem

To design policy aimed at abating GHG emissions in agricultural systems there needs to be an understanding of the effect of agricultural and land management systems on GHG emissions and abatement. This study aims to find the net effects of GHG abatement and farm income of reduced tillage systems relative to conventional tillage systems.

## 1.3 Objectives

The overall objective is to understand the characteristics of different tillage systems including the expected long-term net farm income and the capacity for net GHG abatement. To meet this objective one must first determine how the benefit of soil conservation under reduced tillage manifests itself as long-term net farm income. To meet this objective the following specific objectives will be addressed:

1. Identify a simulation-modelling framework that integrates biophysical and economic components of an agricultural ecosystem and can be adapted for the impact analysis.
2. Perform simulations with the model under different crop rotations, time frames, weather conditions and other bio-physical factors.
3. Evaluate the economic/environmental impacts for different tillage systems.

## 1.4 Scope of the Study

The study will focus on the black soil zone of Saskatchewan. The black soil zone covers nearly 10.7 million hectares in the north and east of the agricultural landscape. The biophysical characteristics of this region allow for a wider variety of cropping practices than are viable in other parts of the province as provided by Saskatchewan Agriculture Agri-Food and Rural Revitalisation (SAFRR) (2002).

## 1.5 Organisation of the Thesis

Chapter 2 reviews the literature over climate change, agriculture's role and policy initiatives taken to reduce the GHG emissions and compares the methods of evaluation with specific reference to benefit cost analysis, abatement costs analysis and trade-off analysis. Chapter 3 constructs a conceptual framework for the research, how trade-off analysis would be used with the simulation model. Chapter 4 provides a description of the survey used to parameterise the simulation model. Chapter 5 provides an empirical framework of the model with respect to how it is parameterised and provides some descriptive statistics. Chapter 6 provides the simulation results of the model to come up with trade-off curves for the practices surveyed. Chapter 7 concludes with a discussion of implications for policy.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Introduction

This chapter principally examines the literature concerning the economic and environmental impacts of agricultural management practices with respect to GHG emissions and climate change. Secondly, an evaluation of the economic tools available to assess these economic and environmental impacts is presented. The chapter begins by shedding light on the role of GHGs in climate change. Then, a discussion of policy that is directed at mitigating climate change and Canada's role in it is provided. Next, the economic and environmental impact of alternative agricultural management practices is discussed. Following which, is a comparison of assessment tools, including benefit cost analysis (BCA), abatement cost analysis and trade-off analysis (TOA).

## 2.2 GHGs and Climate Change

The previous chapter began by presenting the possible relation between GHG emissions and its impact on climate change. This uncertain link between GHGs and global warming is theorised to work as follows: The earth absorbs solar radiation and then reflects radiation back into the atmosphere, where certain gasses act like greenhouse windows and trap this radiant heat. These GHGs include water vapour, nitrous oxide ($N_2O$), methane ($CH_4$), carbon dioxide ($CO_2$), and ozone. Because each gas's capacity to trap radiation differs they have been standardised to a common denominator - the $CO_2$ equivalent. For example $CH_4$ has 21 times the global warming capacity of $CO_2$ and $N_2O$ has 310 times the global warming capacity. Therefore they are each assigned a $CO_2$ equivalency of 21 and 310 respectively (Agriculture and Agri-Food Canada, 2000 and Johnson, 2000).

The trapped radiation has warmed the earth for billions of years by bringing the average surface temperature to 15 degrees Celsius - instead of the minus 18 it would have been without the GHGs.  As a result, the presence of this “greenhouse effect” is essential to support life as we know it. Both the concentrations of these gasses and average global temperature are thought to have varied little from century to century over the last 10,000 years: However, during the last 50-100 years they have both risen dramatically, warming the atmosphere and the earth’s surface by trapping more outgoing terrestrial radiation (Agriculture and Agri-Food Canada, 2000 and Johnson, 2000). The capacity of these gasses to raise the global temperature has been calculated. In 1896 Arrhenius calculated the effect of doubling of $CO_2$ concentration in the atmosphere and found that it could lead to an increase in mean global temperature of approximately six degrees Celsius. It is currently predicted that doubling atmospheric concentrations of $CO_2$ will increase mean global temperatures by 1.5 to 4.5 degrees Celsius. North America has warmed by about 0.7°C during the past century and precipitation has increased, but both trends display large regional variation (e.g., seasonal reductions in precipitation in some areas) (IPCC, 2001b). Changes in precipitation are highly uncertain. The IPCC (2001b) Third Assessment Report (TAR) model results suggest that North America could warm by 1-3°C over the next century for a low-emissions case but it has been estimated that warming could be as much as 3.5-7.5°C for the higher emission case.

The impact that a doubled atmospheric concentration of $CO_2$ will have on sectors such as agriculture is an important area of research.  Agriculture is one of the sectors most likely to be affected. Sudden changes in climate could have drastic effects such as changes in production patterns, increases in crop damage, water shortages, new unpredictable changes in the interactions among crops, weeds, insects and disease (Agriculture and Agri-Food Canada, 2000). Some expressions of benefits from global warming have also been postulated (Splash, 1994)). However, there is a large uncertainty with respect to these benefits and should they materialise they would be seen only under a certain range of a temperature increase. Such postulated benefits to agriculture includes a possible increase in crop yields through a process known as $CO_2$ crop fertilisation. Crop fertilisation will only provide benefits as long as $CO_2$ remains a dominant gas, but as other gasses become relatively more important, yields will fall while negative impacts of global warming increase (Splash, 1994). How climate change may impact agriculture in North America has been summarised by the Third Assessment Report of the IPCC (2001b) as follows:

> *"Food production is projected to benefit from a warmer climate, but there probably will be strong regional effects, with some areas in North America suffering significant loss of comparative advantage to other regions (high confidence). There is potential for increased drought in the U.S. Great Plains/Canadian Prairies and opportunities for a limited northward shift in production areas in Canada (high confidence). Crop yield studies for the United States and Canada have indicated a wide range of impacts. Modeled yield results that include direct physiological effects of CO2 ($CO_2$), with sufficient water and nutrients, are substantially different from those that do not account for such effects. Economic studies that include farm- and agricultural market-level adjustments (e.g., behavioural, economic, and institutional) indicate that the negative effects of climate change on agriculture probably have been overestimated by studies that do not account for these adjustments (medium confidence). However, the ability of farmers to adapt their input and output choices will depend on market and institutional signals, which may be partially influenced by climate change."* (IPCC, 2001b)

Some of the Third Assessment Report highlights for North America are;

- Precipitation changes for the Prairies and Peace River regions ranging from decreases of 30% to increases of 80%
- Although warmer spring and summer temperatures might be beneficial to crop production in northern latitudes, they may adversely affect crop maturity in regions where summer temperature and water stress limit production
- Predicted shifts in thermal regimes indicate a significant increase in potential evapotranspiration, implying increased seasonal moisture deficits. Modeling studies addressing the southeast United States have shown that changes in

thermal regimes under conditions of doubled $CO_2$ would induce greater demand for irrigation water and lower energy efficiency of production (Pearl *et al*., 1995).

- Summarised studies for Canada that show varying results such as changes in cropping area ranging from decreases by 75 % to increases by 124%; increases in soil C and soil quality (not quantified);
- Increases in pesticide expenditure for corn ranging from 10% to 20% and for wheat ranging from a decrease of 15% to an increase of 15% as well as an increase in irrigated acreage (not quantified)

Changes in diurnal and inter-annual variability of temperature and moisture can result in substantial changes in the mean and variability of wheat yields. The main risk of climate change to some regions may be primarily from the potential for increased variability.

Increased variability of temperature and precipitation results in substantially lower mean simulated yields, whereas decreased variability produces only small increases in yield that were insignificant

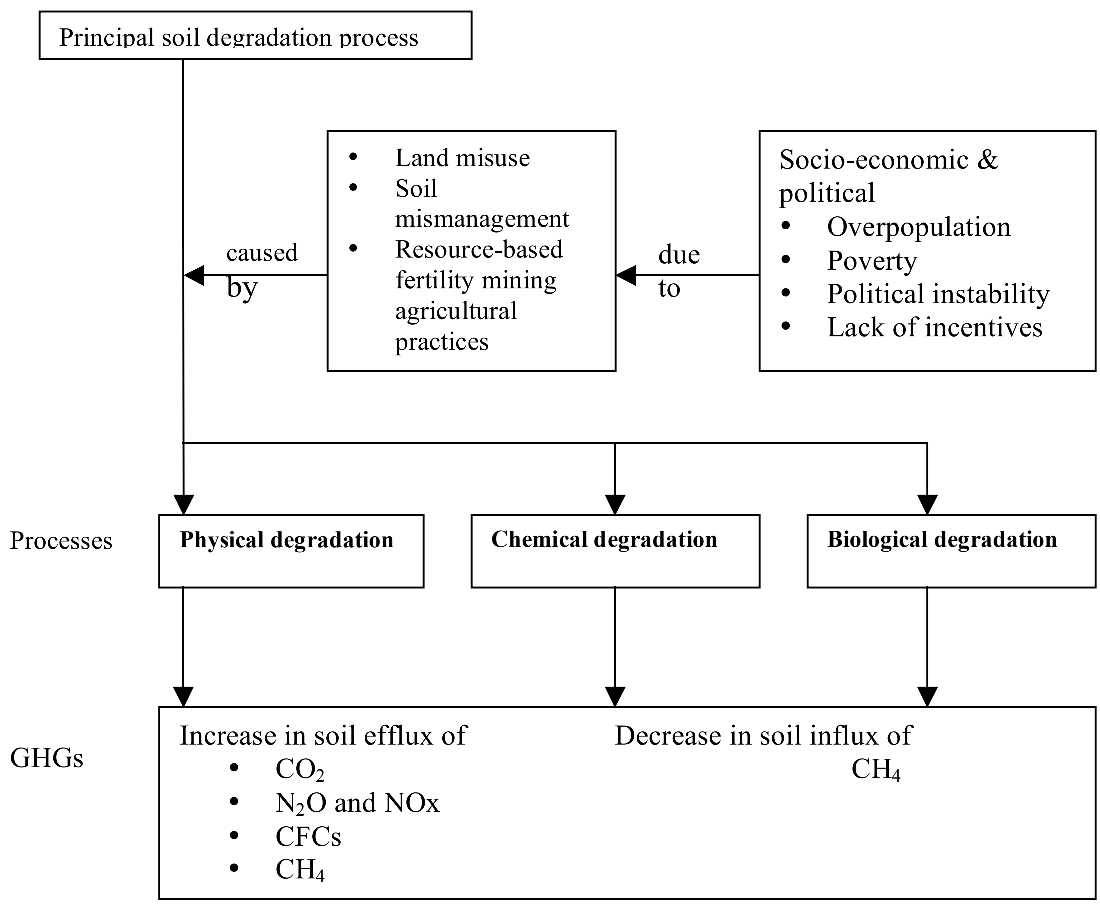
It has also been predicted that higher temperatures could shift away the carbon already sequestered in soils. Globally 100 pica grams (1 pica gram = $10^{15}$ grams) of carbon is estimated to evolve out of soil from temperature increases as small in magnitude as 0.5 degree Celsius per decade over the next 50-60 years (Johnson, 2000). This is through a process of faster decomposition of dead organic matter promulgated by higher temperatures (Boehm, 2005). Adding to the causes, land use and expansion of agricultural activities drives soil degradation. Firstly, soil biological degradation has an effect on soil GHG emissions[4] through a reduction in soil organic carbon content, in biomass carbon and a reduction in $CH_4$ influx. Second, soil physical degradation causes an increase in efflux of GHGs. A summary of how land use and soil degradation contributes is presented in Figure 2.1.

[4]Further, one finds concomitant effects on activity and species diversity of soil fauna and flora.

### 2.3 Policy

Concerns over climate change have driven the need for policy response. Policy actions to influence climate change will motivate either mitigation or adaptation activities (Larsen and Tobey, 1994). A chronology of international policy efforts have been compiled from those such as Tucker (1997), Larsen and Tobey (1994) Azar and Sterner (1996) and Agriculture and Agri-Food Canada (2000):

- In 1935, the first international conference on record that set the tone for intransigence towards accepting the possibility of climate change, was the " Conference of the International Organisation for Meteorology" Tucker (1997)




(Source: derived from Lal *et. al.,* 2000 b)

**Figure 2.1 Process of Soil Degredation and GHG Emission**

- In 1987, was the "Montreal Protocol" aimed at mobilising the global community to phase down Chloro-Fluoro-Hydrocarbon (CFC) production (Tucker, 1997).
- In 1998, the Toronto Conference acknowledged the major environmental concerns of increasing GHG emissions (Azar and Sterner, 1996).
- In 1990, under the auspices of the United Nations, the Intergovernmental Panel on Climate Change (IPCC) in it's 1990 report predicted that a business as usual scenario with respect to the use of fossil fuels would still raise global temperatures by three degrees Celsius by 2100 (Tucker, 1997).
- In 1992, under the auspices of the United Nations Conference on Environment and Development (UNCED), 154 nations signed the "United Nations Framework Convention on Climate Change", agreeing to roll back emissions to 1990 levels by the year 2000. This was signed in Rio de Janeiro, Brazil, calling for the governments of developed nations to adopt policies to limit anthropogenic emissions to protect sinks, but it failed to specify abatement targets (Tucker, 1997, and Larsen and Tobey, 1994 and Azar and Sterner, 1996)
- Since 1994 each annual meeting of the countries (that signed United Nations Framework Convention on Climate Change) to discuss climate change and reduction of GHG emissions has been referred to as the Conference of the Parties (COP). The acceleration of the preparation of the COP-3 was begun in Kyoto, Japan and was adopted by more than 160 countries in December of 1997. Unlike the convention held in Rio de Janeiro, COP-3 was clear to specify abatement targets. Hitherto, it has been referred to as the 'Kyoto Protocol'. The Protocol is aimed at lowering overall emissions of six GHGs by the period 2008-20012. The three most important gasses, $N_2O$, $CH_4$, and $CO_2$, will be measured against a base year of 1990 under the requirements of the protocol. The three long lived industrial gasses-hydroflorocarbon, perflurocarbon, and sulfur hexafloride – will be measured against either the 1990 or 1995 base year (Desjardins and Agriculture and Agri- Food Canada, 2000).
- Under the Kyoto Protocol, individual countries have negotiated different levels of GHG emission reduction. For example, Switzerland will lower its emissions by eight percent below 1990 levels, as will the European Union and many central and

east European states. The U.S. may lower its emissions by seven percent (although it has stated it would not ratify the accord) and Canada, Hungary, Japan and Poland will lower theirs by six percent. Russia, New Zealand and the Ukraine will stabilise their emissions, while Norway may increase its emissions by one percent; Australia may increase emissions by as much as eight percent; and Iceland, by ten percent (Desjardins and Agriculture and Agri-Food Canada, 2000).

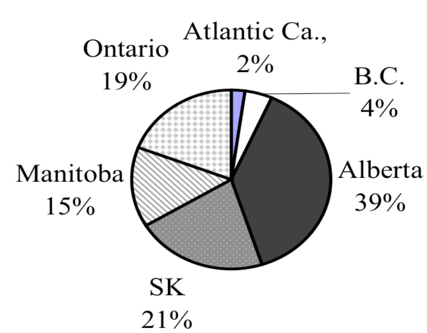
- The role of agricultural soils as C sinks was recognized in agreements at COP 6 in Bonn (July, 2001) and at COP 7 in Marrakech (November, 2001) in which the removal of $CO_2$ from the atmosphere into agricultural soils and forests was accepted (UNFCCC, 2001). The rules under which agricultural soils may be used by signatory countries, to meet their GHG emission reduction commitments under the Kyoto Protocol, have been established. These rules now pave the way for Parties to develop emission reduction strategies that include agricultural soils as sinks.

## 2.4 Canada and Kyoto

Canada has both signed and ratified the KyotoProtocol. Within the Kyoto Protocol, the government committed to reduce GHG emissions by six percent below 1990 levels between the years 2008 and 2012 - representing an estimated 25 percent reduction from ‘business as usual’ forecasts for 2008 (UNFCC, 2001; CBC, 2004). When the Kyoto protocol was ratified the government committed to slash 240,000 tonnes of $CO_2$ equivalent emissions annually by 2010 (Natural Resource Canada Website, 2004). In August of 2003, Prime Minister Jean Chrétien announced the government's plan to spend more than $1 billion to reduce greenhouse gas emissions by 20 megatonnes over five years (CBC, 2004). Such a reduction will require a joint effort from all sectors of the economy. Canada has had higher per capita energy consumption than other Organisation for Economic Co-Operation and Development (OECD) countries attributable to its size, settlement patterns and cold climate, export oriented economy, relatively low energy costs. The government has many stakeholder groups who analyze the economic, sociological and environmental impacts of the GHG abatement measures (UNFCC).

## 2.5 The Agriculture Sector

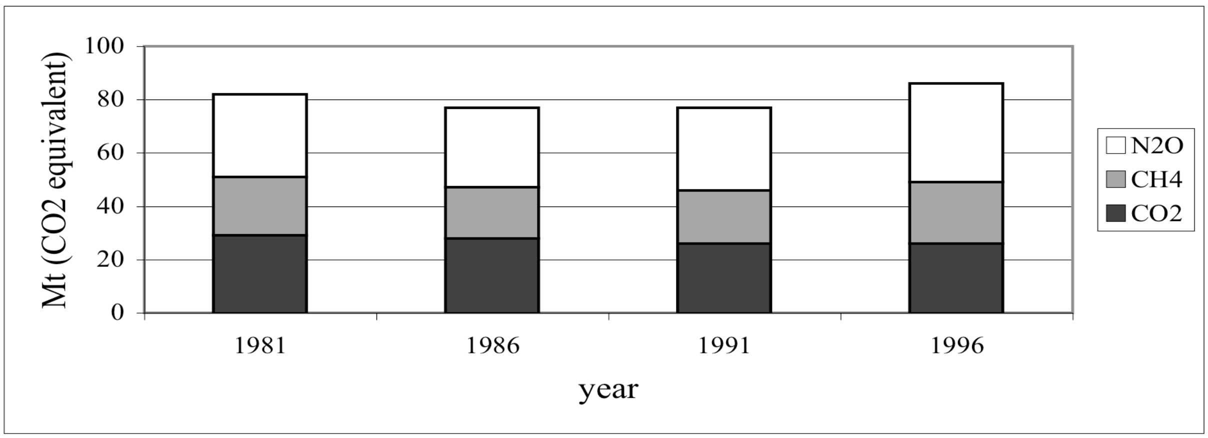
Atmospheric concentrations of GHGs have been rising in the past 20 years. If these concentrations continue to rise at the current rate, computer models that simulate the workings of the atmosphere predict that the average global surface air temperature will rise by two degrees Celsius by the year 2100 (Agriculture and Agri-Food Canada, 2000). Such a temperature change is expected to cause greater fluctuations in weather conditions with severe effects on the agricultural industry and other human resource activities. (Agriculture and Agri-Food Canada, 2000, and Desjardins and Reznek, 2000).According to most recent estimates, total agricultural GHG emissions (in $CO_2$ equivalents) have been between 10 and 14 percent of total Canadian GHG emissions (Lemke *et al*., 2004, and Desjardins and Reznek,2000). Saskatchewan is responsible for 21% of total national GHG emissions (Figure 2.2). From 1981 to 1996 national GHG emissions from the agriculture industry changed as follows, $N_2O$ increased by 21 percent, $CH_4$ was relatively constant, and emissions of $CO_2$ declined by 13 percent (Figure 2.3). The reduction in $CO_2$ emission was estimated to be mainly a result of adopting conservation farming practices (Desjardins and Reznek, 2000). More N fertiliser use has partly contributed to an increase in $N_2O$ while the remainder of $N_2O$ and $CH_4$ emissions were estimated to be due to more intense livestock operations (Boehm, 2004 c).




(Source: Desjardins and Reznek, 1996)

**Figure 2.2 Provincial Agricultural Contributions to GHG Emissions**

The largest increase in $N_2O$ emissions was observed from 1991 to 1996. This is the result of a nine percent rise in crop production, including 22% in legume production, and changes in livestock production including an 18% increase in beef cattle production, 15% increase in the number of hogs and 33% increase in the amount of fertiliser used (Desjardin and Riznek, 2000).




(Source: Desjardins and Reznek, 2000)
**Figure 2.3 National GHG Emissions from Agroecosystems -Indirect Emissions Inclusive**

According to estimates by Desjardins and Riznek (2000) the changes in GHG emissions from 1981 to 1996 at the provincial level have been as follows: Alberta and Manitoba increased; British Colombia, Saskatchewan and Atlantic Canada were relatively steady; Ontario and Quebec declined (Desjardins and Reznek, 2000). Environment Canada (2004) explains how the components of agricultural emissions within each province have changed between 1990 and 2000. In Ontario, Quebec, and the Atlantic provinces declines were evident in CH4 emissions from enteric fermentation as cattle populations declined. Whereas, emissions from manure management increased as swine and poultry populations increased. Increases in direct $N_2O$ emissions from cropland soils were also evident, and indirect off-site $N_2O$ emissions as a result of a decline in crop production, crop residue and nitrogen fixing crops and reduced use of synthetic nitrogen fertiliser. In Ontario, Nova Scotia and Quebec and the prairie provinces, soil $CO_2$ emissions declined as a result of increased adoption of no till and reduced acreage under summer fallow. In the prairie provinces direct $N_2O$ from cropland soils and off-site indirect $N_2O$ emissions increased - from manure management, enteric fermentation both attributable to greater cattle and swine populations, and from increased use of synthetic fertiliser and nitrogen fixing crops. In British Columbia, direct $N_2O$ from cropland soils, off-site indirect $N_2O$ emissions from enteric fermentation and manure management increased due to higher cattle and poultry populations. This has been partly offset by declining use of synthetic fertiliser.

### 2.6 Agriculture Management Impact

Of the total agricultural soil $N_2O$ emissions, direct[5] $N_2O$ emissions account for about one half, indirect emissions[6] account for about a third and the balance is attributable to animal production (Table 2.1). Of the direct emissions, a third is attributed to crop residues. The indirect emissions are the most difficult to measure; however, as more measurements of N deposition became available, the emission factors will be modified to better reflect indirect emissions under Canadian conditions. It should be noted that all direct, indirect and livestock related emissions in Canada are on the rise.

Canadian agriculture soils are considered to be a net sink of $CH_4$, absorbing about 12 kilo-tonnes of $CH_4$ each year (Table 2.2) (Desjardins and Reznek, 2000). On the other hand emissions of agricultural $CH_4$ are attributable to livestock. On a positive note, much progress has been made in reducing livestock related emissions by increasing the efficiency of milk and animal production (Desjardins and Riznek, 2000).

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5 Direct emissions from soil include those from mineral fertilisers applied to agricultural soils; animal manure used as fertiliser; nitrogen fixing crops; crop residues; the cultivation of organic soils (IPCC guidelines 1996 and Desjardins and Riznek , 2000)

6 Indirect emissions derived from N that come from agricultural systems include those from applying nitrogen fertilisers and animal manure can result in indirect release of $N_2O$ by: volatilisation and atmospheric deposition of ammonia and various oxides of nitrogen; nitrogen leaching and runoff (IPCC guidelines 1996 and Desjardins and Riznek , 2000)

**Table 2.1: Agricultural Emissions of $N_2O$ (Mt $CO_2$ equivalent)**

| | 1981 | 1986 | 1991 | 1996 |
|---|---|---|---|---|
| Fertiliser | 3.5 | 3.5 | 3.4 | 4.8 |
| Manure | 3.3 | 3.0 | 3.2 | 3.5 |
| N-fixing crop | 2.3 | 2.8 | 3.0 | 3.9 |
| Crop residue | 4.7 | 4.7 | 4.7 | 5.5 |
| Organic soils | 0.1 | 0.1 | 0.1 | 0.1 |
| Total Soils (Direct) | 13.9 | 14.1 | 14.4 | 17.8 |
| Animal production systems | 6.9 | 6.2 | 6.7 | 7.6 |
| Total (Indirect) | 9.9 | 9.5 | 9.6 | 11.8 |
| Total | 31 | 30 | 31 | 37 |

(Source: Desjardins and Riznek, 2000)

**Table 2.2. Agricultural Emissions of CH4 (Mt $CO_2$ equivalent)**

| | 1981 | 1986 | 1991 | 1996 |
|---|---|---|---|---|
| Livestock | 17.8 | 15.7 | 16.2 | 18.4 |
| Manure | 4.4 | 4.0 | 4.0 | 4.4 |
| Soils | -0.3 | -0.3 | -0.3 | -0.3 |
| Total | 22 | 19 | 20 | 23 |

(Source: Desjardins and Reznek, 2000)

Soils have lost around a quarter of their C content since cultivation began (Desjardins and Riznek, 2000). Agricultural soils accounted for around seven percent of agricultural emissions of $CO_2$ in 1996 (Table 2.3). Predictions are that at the present rate of conversion of agricultural soils from conventional to zero tillage, these soils will shift from being a net source of $CO_2$ to a net sink (Desjardins and Reznek, 2000). These predictions mention that Canadian agricultural soils will store between 0.5 and 0.7 Mt of carbon each year by 2010 and the trend will continue until soils reach a new equilibrium. However, reduced tillage may increase SOC stocks only to a limit. This limit is the carrying capacity of the soil where no more additional C sequestration is possible. This limit is the level the SOC stocks were before their depletion by intensive tillage (point A in Figure 2.4). These SOC stocks are labile or ephemeral because they would be again depleted if the farmer returns to practice conventional tillage (Boehm, 2005). However, with reduced tillage some western Canadian soils are close to replacing this lost SOC to a point C close to the original level at D (Figure 2.4). However, a much greater share of $CO_2$ emissions from agriculture comes from burning fossil fuels (Table 2.3). Indirect sources contribute a further 14 to 16 Mt from fuel combustion.  Looking at how agricultural soil carbon is being balanced by each province the Century model estimates that most provincial agricultural soils are still losing soil organic matter carbon, albeit at a decreasing rate. And Saskatchewan has already started sequestering soil organic carbon (Smith et. al., 2000).

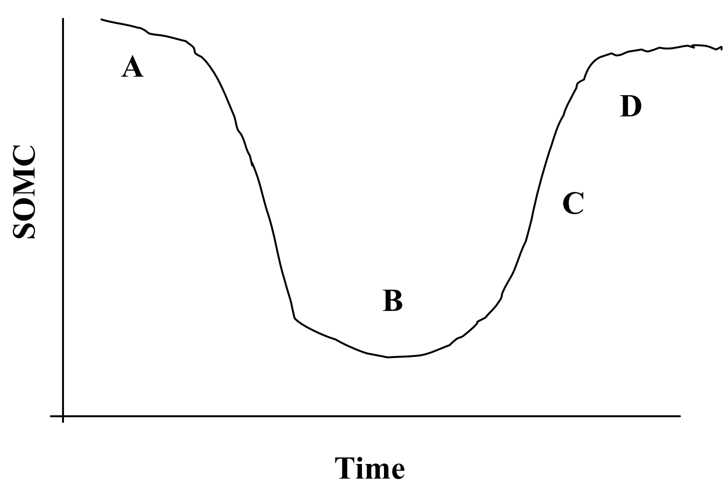



**Figure 2.4 SOC Change With Breaking of Native Soil**

**Table 2.3. Direct and Indirect Agricultural Emissions of $CO_2$ (Mt/yr)**

| | 1981 | 1986 | 1991 | 1996 |
|---|---|---|---|---|
| Fossil fuels | 9.5 | 7.7 | 8.1 | 9.5 |
| Soils | 7.7 | 7.3 | 5.1 | 1.8 |
| Total Direct emissions | 17.2 | 15.0 | 13.2 | 11.3 |
| Fertiliser manufacture, transport & application | 4.4 | 5.5 | 5.1 | 6.6 |
| Machinery manufacture & repair | 4.7 | 4.3 | 3.9 | 3.7 |
| Building construction | 1.5 | 1.4 | 1.7 | 1.4 |
| Pesticide manufacture | 0.2 | 0.3 | 0.3 | 0.3 |
| Electricity generation | 1.8 | 1.9 | 2.1 | 2.4 |
| Total Indirect emissions | 12.6 | 13.4 | 13.1 | 14.4 |
| Total agricultural emissions | 30 | 28 | 26 | 26 |

(Source: Desjardins and Reznek, 2000)

**Table 2.4 Percent of Cropland in Actual and Predicted use of No-till**

| Province | 1991 | 1996 | 2000 | 2005 | 2010 |
|---|---|---|---|---|---|
| B.C. | 5 | 10 | 13 | 16 | 20 |
| Alberta | 3 | 10 | 17 | 23 | 28 |
| Saskatchewan | 10 | 22 | 30 | 35 | 38 |
| Manitoba | 5 | 9 | 12 | 15 | 20 |
| Ontario | 4 | 18 | 20 | 20 | 20 |
| Quebec | 3 | 4 | 7 | 9 | 11 |
| Atlantic | 2 | 2 | 2 | 2 | 2 |
| Canada | 7 | 16 | 22 | 26 | 30 |

(Source: Smith *et. al.,* 2000)

## 2.7 Environmental and Economic Benefits of Tillage

Agricultural management practices that sequester C include reduced tillage, management of crop residue, cover crops and improved water management[7]. Any given single practice may not be as effective at sequestering soil C in all regions. The underlying effectiveness is influenced by spatial heterogeneity. Estimates from the U.S. show that 49 percent of agricultural C sequestration can be achieved by adopting reduced tillage and residue management, 25 percent by changing cropping practices, 13 percent by land restoration efforts, seven percent through land use change and six percent by better water management (Antle *et. al.,*1999). Also in the U.S., it has been found that reduced tillage is capable of reducing between 10 to 50 percent of the 3000 to 5000 kg $CO_2$ equivalent of emissions from agriculture per year. This net benefit of reduced tillage is reported to be higher among C rich soils (Li *et. al.,* 1995). In the Canadian prairies of Alberta, Saskatchewan and Manitoba, additional net GHG abatement could be achieved by improving fuel efficiency of machinery, reduction of fertiliser use and improvements in livestock management (Kulshreshtha, *et. al.,* 1998). This again underscores the impact spatial variation in North America with respect to the efficacy of reduced tillage *vis-à-vis* other management strategies in impacting net GHG abatement.

Similar to net GHG abatement, economic profitability is also spatially dependant (on weather and soil type). Economic profitability of tillage systems are also dependent on relative yields, crop rotations, frequency of cropping, product prices, factor costs, and risk levels. These impacts have been studied for different soils of Saskatchewan by Zentner *et. al.,* (1996), Grey *et. al.,* (1996), Young *et. al.,* (1994) and also for some soils within southern Ontario by Yiridoe *et. al.,* (2000) and Weersink *et. al.,* (1992). Within Saskatchewan a change to zero till brought a 5.25 percent yield advantage in the Black soil zone near the community of Melfort, between zero to 18.5 percent yield advantages in Indian Head (Black soil zone), and a 11.4 percent yield advantage for wheat and a 5.7 percent yield disadvantage for oil seeds at Scott (Dark

Brown soil zone) (Gray et. al., 1996). Yield advantages have also been cited for the Black soil zone of Saskatchewan with zero tillage and credited to greater water conservation, particularly when precipitation is limited during the growing season (Brandt 1992 and Lafond et al., 1992). Other advantages contributing to economic profits as studied for Saskatchewan are greater yields accruing from reduced incidence of diseases and other crop rotational benefits (Zentner *et. al.,* 1996 and Bailey, 1996). Greater yields and hence greater gross revenue could also be expected on a rotation basis with reduced tillage. This is because reduced tillage is associated with continuous cropping which translates into more hectares under cultivation than under conventional tillage where a portion of the field is under summer-fallow. Also impacting economic profits are changes in costs. Product costs were higher for continuous wheat associated with reduced till compared with fallow wheat on three soil textures in southwestern Saskatchewan (Zentner et. al., 1996). With respect to production costs, there are studies indicating a reduction in machinery costs after the change to reduced tillage for Saskatchewan (Zentner et. al., 1996) as there are studies indicating otherwise (Grey et. al., 1996) as this depends on existing practices and how intensive the change to zero till was from conventional tillage (Gray *et. al.,* 1996). Tillage related labour and fuel costs were expected to decline with the change, whereas, herbicide costs (glyphosate) were expected to rise for Saskatchewan (Gray *et. al.,* 1996 and Zentner *et al.,* 1996) . Whether the greater gross revenue (should there actually be a greater yield) would suffice to balance the greater production costs associated with reduced till will determine the net economic profitability while the variability of these results help determine economic risk.

The economic impact of risk in the studies of this nature considers three factors; producer's preference for risk, the variance of net returns and the expected value of net returns (Weersink *et. al.,* 1992, Yiridoe *et. al.,* 2000, Grey et. al., 1996 and Zentner *et. al.,* 1996). Gray et al., (1996) assumed that the standard deviation of yields will be the same or 10 percent lower for the reduced tillage system compared with conventional tillage. This study considered anecdotal evidence suggesting that zero tillage systems

[7] The stored C is lost if a producer subsequently reverts to conventional management practices.

(in the Black soil zone of Saskatchewan) tended to produce relatively better in drought and relatively lower in cool wet conditions. However Zentner *et. al.,* (1996) in a separate study in Saskatchewan reported that the trade off between expected net returns and its variance depended on soil and market price for the product (Zentner *et. al.,* 1996). Generally conventional tillage had lower income variability in silt loam and sandy loam soils and minimum tillage and zero tillage had lower variability in heavy clay soil of Saskatchewan (Zentner *et. al.,* 1996).

**2.8 Co-Benefits of Alternative Management Systems**

In many situations economic development has typically led to a number of negative environmental impacts including increased pollutants and resource degradation. Any management changes or other actions taken to reduce a particular environmental impact will provide the intended benefits but may also provide a range of ancillary benefits. Any evaluation of the net benefits associated with a particular change that ignores these additional, or co-benefits, may undervalue the justification for encouraging these types of management changes (IPCC, 2001b).

There are a number of on-farm benefits associated with landowners adopting soil conservation management, including improved soil texture, structure and water holding capacity as well as reduced wind and water based soil erosion. In addition, a number of benefits extend beyond the farm. For example, the reduction of soil erosion reduces the clogging of waterways and rivers with sediment beyond the boundaries of the farm (Dormar and Carefoot, 1996). Improvement of water retention improves off-farm ground water tables (Dormar and Carefoot, 1996). Moreover, with improvement of water retention less nutrient, soil particle and pesticide rich runoff water is available to discharge into surface and ground water. Reduced tillage can also positively impact air quality (Table 2.5). From an immediate human health perspective there is widespread agreement that fine particulate matter is of serious concern. Smoke is the greatest particulate matter of concern from agriculture in the prairies (Lemke *et. al.,* 2004). The public has pressured government to enact regulation of particulate matter sources and more regulations can be expected (Lemke *et. al.,* 2004). Having spoken to farmer groups and listened to local media it became apparent that with the practice of direct seeding burning of stubble and crop residue has been reduced. Moreover, as discussed above, reduced tillage not only reduces wind erosion but also can decrease the demand for fossil fuels. All of these co-benefits helps reduce concerns related to air quality (Table 2.5). However, many people and scientists rate the most serious agricultural air quality concern as its contribution to the build-up of GHGs that can cause climate change (Lemke *et. al.,* 2004).

While there may be off-site related benefits associated with reduced tillage, there may also be off-site related costs. The stubble and residue left on the field, that would otherwise have been buried or burnt under conventional management, could provide a breeding ground for more rodents and insects that could be pests and disease carrying agents to the farmer and his neighbours (Dormar and Carefoot, 1996). Some diseases that were of lower economic importance would now be higher in economic importance (Bailey, 1996). As well, the potential for additional weed problems may require more herbicide be used under reduced tillage than conventional there could be greater damage to sensitive plants and aquatic organisms and humans with pesticide sensitivities (Table 2.5).

The numerous ancillary benefits of reduced tillage in improvement of air, water and soil quality extend from the local to the global society. As mentioned in the beginning of this sub-section, these numerous ancillary benefits, if they go un-acounted for, may weaken the justification for its implementation. On the other hand, should it be possible to quantify these benefits to society, it may enable society to compensate the producers for any economic trade-offs should there be any. This study, however, attempts to quantify only the net GHG abatement benefit along with any economic trade-offs producers may have to face.

**2.9 Evaluation of Tillage Systems**

This study looks at the impact assessment of tillage systems by finding the net economic and net GHG abatement effects. As specified in the introduction, this information will help inform policy makers when developing climate change policies or simply relevant agricultural policies concerning the potential economic benefit to farmers and also the potential benefit due to changes in GHG abatement. This section examines tools that could be used to evaluate the tillage systems before deciding to adopt. The tools of analysis discussed in this section are cost benefit analysis (CBA), abatement cost analysis and trade-off analysis (TOA).

**Table 2.5 Air Quality Concerns Related to Primary Agriculture**

| Air Quality Concern | Agricultural Sources | Impact | Range of Impact |
|---|---|---|---|
| Particulate Matter | Soil erosion by wind, dust raised during soil tillage; Burning farm wastes, bush piles, and crop residues; Diesel engines; Grain and feed processing and handling; Driving on dirt and gravel roads; Pollen. | Crop damage for particles > 10 microns, especially greater than 1000 microns ("sand blasting"); Animal and human health for particles < 10 microns (PM10), especially < 2.5 microns (PM2.5), organic particulates more harmful to health than inorganic particulates; Some particulates are allergens; Impaired visibility for driving. | Local (0-10 km) for large particulate matter to regional (0-1000km) to global (0-1000s km) for fine particulate matter |
| Odour | Livestock generally especially Intensive Livestock Operations (ILO); Manure storage, handling, and land application; Dead animal storage and handling. | Nuisance. | Local |
| Ammonia | Manure storage, handling, and land application; Losses during N fertiliser handling and application. | Precursor to formation of various toxic compounds and aerosols that are also PM2.5; Irritant; Nutrient pollutant. | Local to regional |
| Pesticides | Pesticide application and handling, drift during application and volatilisation after application or from spills. | Damage to sensitive plants and aquatic organisms; Humans with pesticide sensitivities; Aerosols that are PM2.5. | Local to global |
| N2O | N inputs on agricultural land from animal manures, N-rich crop residues, and fertilizer-released | Destroys stratospheric ozone; Climate change from additions of this | Global |

| Air Quality Concern | Agricultural Sources | Impact | Range of Impact |
|---|---|---|---|
| | from nitrification of ammonia to nitrate and denitrification of nitrate. | potent GHG. | |
| CO2 | Sources are fossil fuel burning and net decay of soil organic matter. | Climate change from additions of this GHG. | Global |
| CH4 | Animal digestion, especially ruminants; Manure storage and handling. | Climate change from additions of this GHG. | Global |

(Source: Lemke et. al., 2004)

### 2.9.1 Cost Benefit Analysis

In CBA, as the name implies, the benefits of some proposed action are estimated and compared with the total costs that society would bear if that action were undertaken. It is the main analytical tool used by economists to evaluate environmental decisions (Field and Olewiler, 2002). It was first used by the U.S. Army Corps of Engineers to evaluate water-development projects. In Canada, it was widely used in the public sector up until the 1970's, in projects involving natural resource use (Field and Olewiler, 2002). In 1996 a group of economists of different political persuasions reached consensus on its role in environmental decision making. The following is a summary of their conclusions:

> *CBA can play an important role in legislative and regulatory policy debates on protecting and improving health, safety and the natural environment. Although formal CBA should not be viewed as either necessary or sufficient for designing sensible policy, it can provide an exceptionally useful framework for consistently organising disparate information, and in this way, it can greatly improve the process and hence, the outcome of policy analysis. If properly done, CBA can be of great help to agencies participating in the development of environmental, health, and safety regulations, and it can likewise be useful in evaluating agency decision- making and in shaping statutes* (Tietenberg, 2002)

Some researchers have identified problems with CBA. A key criticism of CBA is related to discounting, intergenerational externalities and compensation. An arbitrary selection of discount rate to determine intergenerational resource allocation implies moral judgement. The underlying logic behind discounting is that the present is more important than the future. Any revenues or costs that are to be incurred in the present should be given greater weight than those of the future. There is also the concept of the opportunity cost of money. A particular project has an opportunity cost of the return from investing in the next best alternative. Under the principle of discounting if conventional agricultural practices were hypothetically to cost a future generation of people 1 million dollars to rectify and occurs in 100 years time would be discounted to be equivalent to a mere 5,000 dollars of current damage under an annual discount rate of three percent. And, if by continuing such agricultural practices an additional benefit greater than 5,000 dollars could be reaped today then the CBA assumes that the gainers of the present could compensate the losers of the future and still be better off.

The arbitrary selection of the discount rate is decided by the current generation who prefer gratification of their current consumption as more important than the gratification of their own consumption of a future date or the consumption of future generations'. This has led to the criticism of the use of a discount rate.

> *The present generation deciding that the benefit to them is higher to than to another in a future generation is akin to a dictatorship.* (Larsen and Tobey, 19994)

Proponents of discounting hold the view that the current generation should be unconcerned over the loss or injury caused to future generations because these future generations will benefit from advances in technology, investments in both man made and natural capital and direct bequests (Larsen and Tobey, 1994). However, such proponents do not appreciate that there are two distinct types of intergenerational transfer of resources which are relevant in the context of global warming (Larsen and Tobey, 1994). The first is a set of basic distributional transfers as compensation for reducing stocks of non-renewable resources. The second consists of compensatory transfers made because damage is inflicted. Proponents of discounting ignore that the transfer of improved technology and increased capital investments is mere compensation of the first set of transfer of resources and not the second (Larsen and Tobey, 1994). Compensation for damages has been neglected partly because they are assumed to be identical to basic distributional transfers and partly due to the principle of 'potential compensation'. The notion of 'Potential compensation', is described as follows. If the current generation could adequately compensate future generations for their loss in welfare due to climate change, and the current generation could still be better off relative to their condition when mitigating GHG emissions. In this case continued emission would be considered welfare improving regardless of whether compensation actually occurs (Larsen and Tobey, 1994). This is akin to the compensation criterion of efficiency of saying that if benefits out weigh costs, it would be possible for gainers to compensate fully the losers and still be better off. A further critique of discounting within CBA with respect to intergenerational inequity is that society has a much larger life expectancy than individuals and thus the value society attaches to natural resources and the environment is likely to deviate from the aggregate of individual values (Larsen and Tobey, 1994).

Besides intergenerational distribution impacts, CBA causes intragenerational as well as ecological distribution impacts (the latter is also known as territorial asymmetries or spatial ecological distribution, an example of which is depicted in section 3.3) (Munda, 1996). Intragenerational distribution impacts may arise when aggregating individual values the project runs the risk of placing greater weight on the preferences of higher income groups (Munda, 1996). A value judgement comes in to play regarding the appropriateness of the present generation valuing various services for future generations (IPCC, 2001).

### 2.9.2 Abatement Cost Analysis

The costs of reducing pollutants being released into the environment (or more specifically the mitigation of GHG emissions) or of lowering their ambient concentrations are called abatement costs (Field and Olewiler, 2002). To understand abatement cost one needs to look at a firm's behaviour with respect to profit maximisation. Assume that a firm participates in a competitive market where price is fixed at P. Also, assume that the firm has not internalised its damage to society through its polluting practice. Hence, it produces an output ($Q_0$) until the marginal cost of production (MC) equals it's market price (P) (panel A Figure 2.5. Now assume that the firm is required by regulatory policy to internalise it's cost of marginal damage (MD) which is also the first derivative of the cost of damage inflicted upon society by undertaking to produce. When forced to internalise MD, the firm decreases its output to Q* - the socially efficient level of output, where MC+MD = P.

Before the regulation the firm's marginal profits were P-MC which was greatest at the first unit of good produced and declined to zero up until P=MC, which is the competitive equilibrium. These marginal profits are what the firm has to sacrifice when it reduces it's output for every unit below $Q_0$. Hence, it could be called the opportunity cost of abatement or marginal abatement cost (MAC). Panel B of Figure 2.3 plots the MAC curve on the MD curve and assumes that every unit of production gives one unit of emission. It shows that at the socially efficient level of production Q*, the emission level would be E*. Using both panels of Figure 2.5, three possible scenarios of improvement in production technology are estimated as follows:

a) Under the first technological improvement, only the marginal cost (MC) of production is reduced, but no change is made in MD. This shifts both the MC and MC+MD curves back in panel A, decreasing the level of production Q* and hence the level of emissions. The reduction in MC also helps widen the P-MC gap or the marginal opportunity cost of abatement (P-MC) or MAC. Hence the MAC curve shifts upward and the MD stays unchanged in panel B. This again shows that the level of emissions increases.
b) Under the second technological improvement only the cost of damage from each unit of production or the MD is reduced with no change in MC. This shifts only the MC+MD curve downward in panel A, raising the socially efficient level of production Q* which should also raise the level of emissions. In panel B the MAC stays the same but the MD shifts downward. Which again shows that the level of emissions increases. Whether this increase is higher than the previous scenario

depends on how much of a shift in the MC and MD curves were brought by the technological improvement and the elasticities of the MC and MD curves.

c) Under the third technological improvement, both MC and MD are reduced. This shifts both the MC and MC+MD curves downward in panel A, raising the socially efficient level of production Q* and the emissions along with it. Both the upward shift in the MAC curve and downward shift in the MD curve in panel B , add to the increase of emissions.

The above analysis requires the estimation of a cost function and a damage function. In this example we can assume that price is given. Under the assumption of a firm behaving under the objective of cost minimisation, cost is a function of level of output, input prices and technology (Varian, 1992). Further, one may add that it is also a function of the level of regulatory intensity (Gallop and Roberts, 1985) as depicted in equation 2.1. The MAC function would be price less the first derivative of the cost function.

$$C = C(\underline{w}, y, T, R,) \qquad (2.1)$$

where;

C –production cost

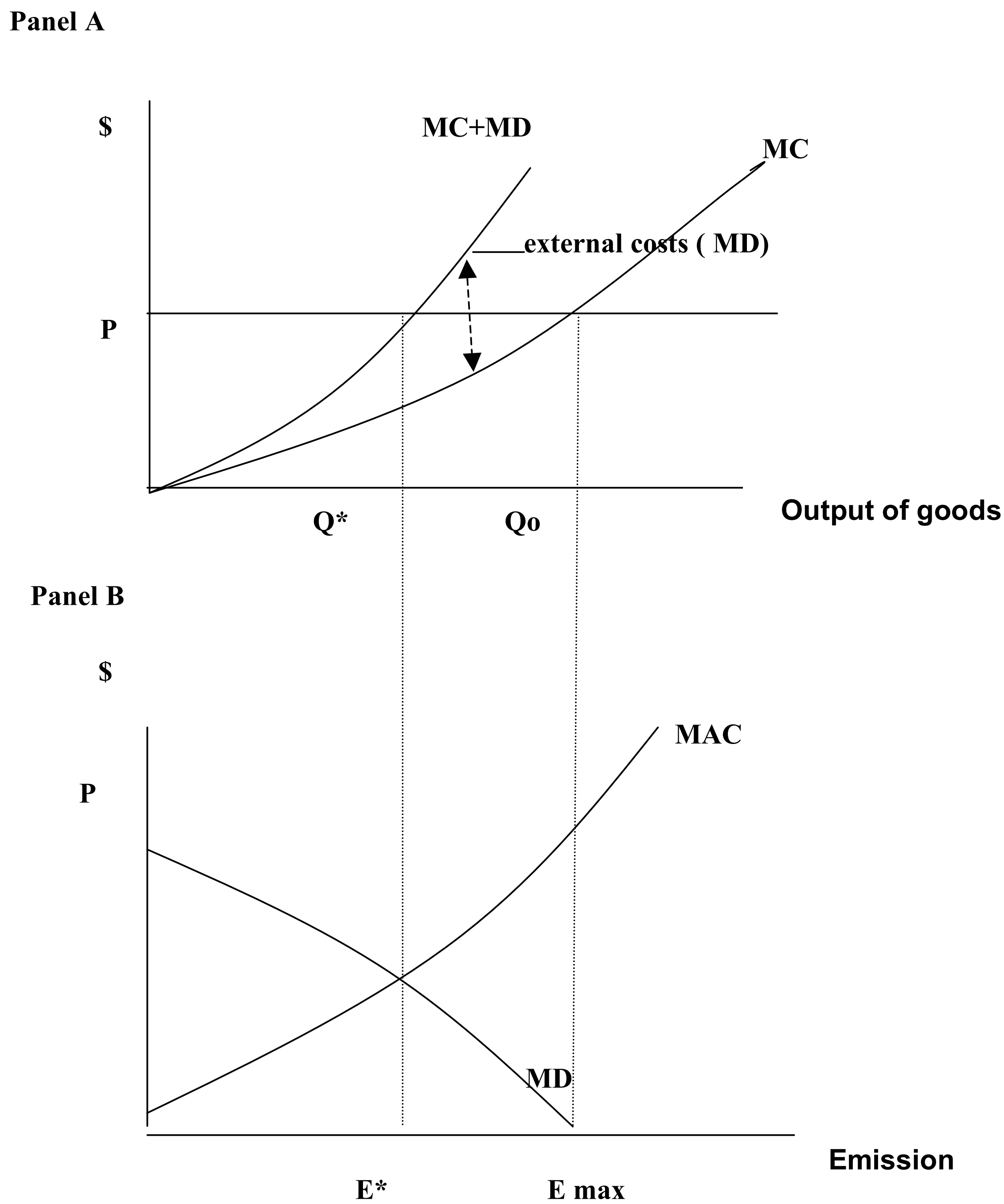
$\underline{w}$ – a vector of input prices

y – level of output

T – index of technology

R - level of regulatory intensity

The MAC is appropriate for evaluating the present consequences of current regulatory policy as well as for quantifying the presently available cost savings that could result from policy changes (Gallop and Roberts, 1985). Its potential application to the present area of research is that one could analyse the cost savings that could result from both regulatory policy changes and changes in the cropping system (or tillage technology).




(Source: Field and Olewiler., 2002)

**Figure 2.5 MAC and Profit maximisation Link**

Going beyond the effect of both technology and policy changes on cost one could find the socially efficient level of production using a damage function (and its first derivative) along with the cost function or the MAC function. For example, as relevant to the present research a functional relationship between the damage cost and atmospheric $CO_2$ content (equation 2.2) was proposed by Aazar and Sterner (1996):

$$C(k, m_{h(t)}, m_p, y_{(t)}) = \frac{k \times m_{h(t)} \times y_{(t)}}{m_p}$$

where;

C –damage cost

k – fraction of world income that will be lost for a $CO_2$ equivalent doubling

$m_{h(t)}$ – anthropogenic level of $CO_2$ in the atmosphere

$m_p$ – pre-industrial level of $CO_2$

$y_{(t)}$ – world income or gross domestic product

While this model has the appeal of transparency , additional complexity does not increase the accuracy since uncertainties about k are so large, and also that it captures the fact that damage cost is a convex function of global average temperature change[8]. However, Aazar and Sterner (1996) provide the following caveats to this model. The authors highlight that the parameter k should be larger for poorer countries. The fraction of the income of poorer countries that would be lost for a $CO_2$ equivalent doubling will be greater than for the OECD. This is akin to the criticism of spatial inequity in the CBA. Further, the model does not consider that damage depends on rate of climate change, absolute magnitude of climate change, and how well and quickly human

[8] Economic cost of climate change is likely to be a convex function of global average surface temperature change. This property is captured since the temperature increase is a logarithmic function of atmospheric $CO_2$ concentration. Hence, the assumption of a linear relationship between anthropogenic $CO_2$ concentration and damage is equivalent to assuming this damage is exponentially dependant on the change in global average temperature. The value of k ranges from between one and two percent.

societies will adapt to climate change. Moreover, large scale migration (adjustments) are likely to give rise to social and political conflict and some poor will not be able to change. As well, the model ignores ethical dilemmas such as by the valuation bestowed upon human lives, biological diversity to a cost value. Similarly, when the above discussed MAC function is used alone to evaluate the impacts of policy or technology change on cost efficiency it only considers economic efficiency. Most GHG policy studies concentrate on the efficiency issues alone (Shukla ,1995). What should be addressed is the consideration of multiple issues including those issues that effect ecological, social and political concerns besides economic factors, issues that address distribution and equity.

### 2.9.3 Trade-off Analysis (TOA)

During a debate over the complexity of outcomes encompassing multiple disciplines[9] including the environment, economy and social welfare one researcher who advocated against the use of the single numeraire (in NPV or CBA) stated that;

> *Our first task must be to define the context within which to conduct the analyses…requir[ring] specifying the larger infrastructure scheme within which this [project] is concerned. The role of the analyst is to help define the terms of the debates that should be opened for clarifying the role of nation-states, communities, and private capital in evaluating the structural transformations.*
> (Barkin, D., 1996)

Defining the terms of the debate is what TOA addresses. And the terms could cover multiple issues that CBA and abatement cost and damage cost analysis could not. The concept of TOA encompasses an illustration of outputs of goods and services using a production possibility frontier (PPF) and as such represents a way of diagrammatically depicting the choice faced by a group of people between two desirable outcomes. For example, the choice between the output of goods or services and health or between

[9] During the early to mid 1990s there was heated debate across the south Americas on the environmental and ecological trade-offs of a proposal to link the great rivers and water bodies beginning in the south from Uruguay across Brazil to the northern tip of South America.

output of goods and environmental (Field and Olewiler, 2002). Within the basic structure (Figure 2.6) one of the axes represent some economic indicator and the other represents some environmental indicator. Farther from the origin shows increase in benefit in both axes.

The PPF is determined by technical capacities in the economy together with ecological effects such as hydrology, meteorology such as precipitation and temperature patterns (Field and Olewiler., 2002). Where society chooses to locate itself is a matter of social choice illustrated by a community indifference curve (CIC). This social choice today may have a bearing on where the PPF curve would lie in the future. Thus TOA could be analysed for different points in time.

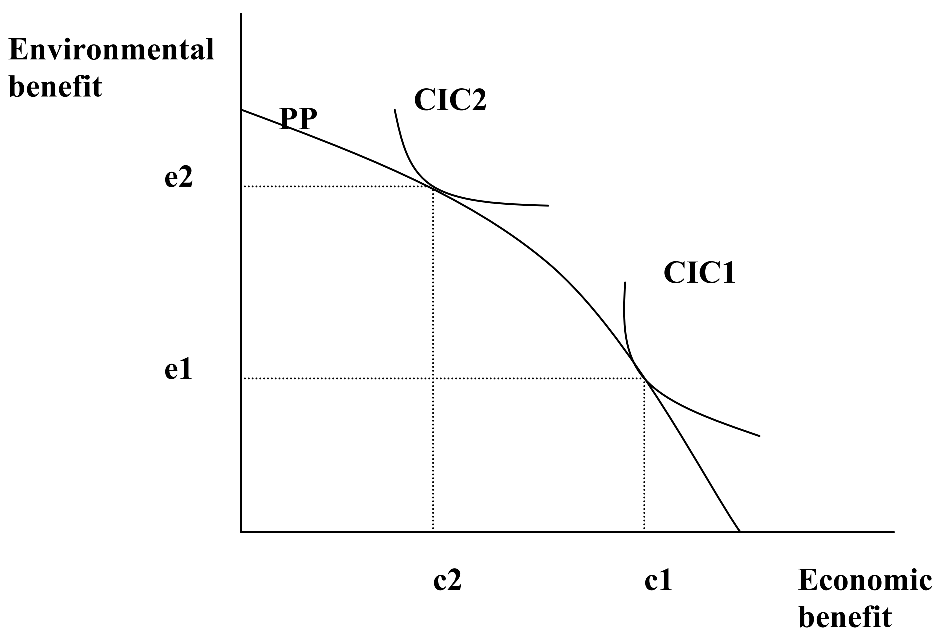



**Figure 2.6 A PPF of Goods Produced and Environmental Quality**
(Source: Field and Olewiler., 2002)

The PPF or TOA could also be analysed for different points in space and hence may be described as spatially representative. TOA could also be used to simulate the exogenous effect of a change in technology or of policy across a given space or over a given period of time. Under such a change one could expect to see shifts or pivots in the trade off curve as well as possible changes in the standard deviation of the trade-off points, which is used to draw the trade-off curve.

The most important advantage to TOA is that it avoids the criticisms of using a single numeraire or measure of efficiency. TOA allows the ecological or sociological (or other) criteria to be measured each in its own unit (Yanggen *et. al.,* 2002). In addition the approach avoids other ethical dilemmas surrounding the monetary quantification of losses to human lives and biological diversity as damage cost analysis (Azar and Sterner, 1996). Further, it does not purport to induce intergenerational, intragenerational or spatial externalities as does CBA (Splash, 1994).

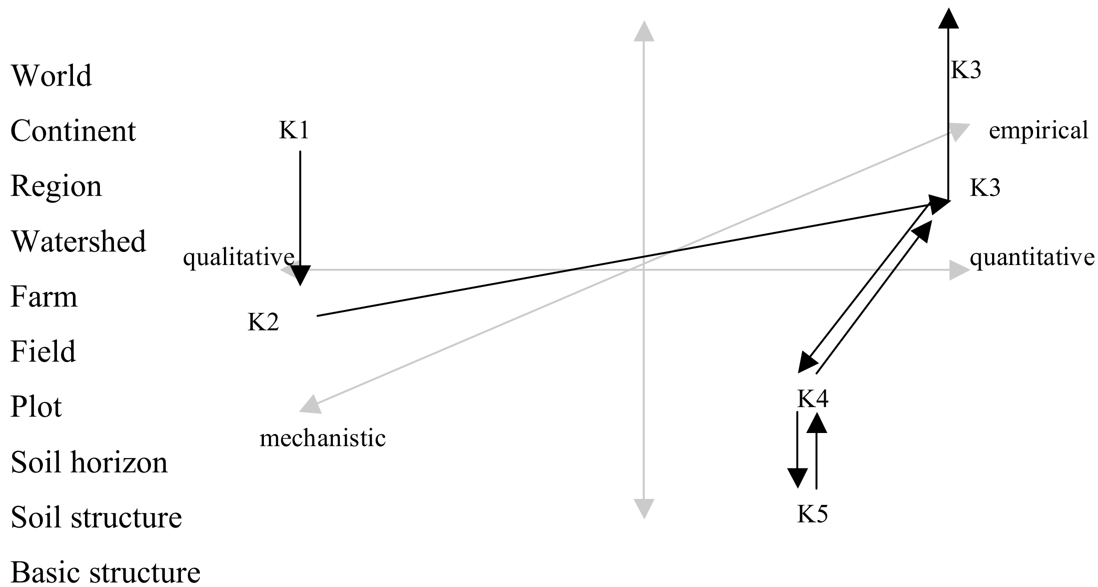
While a TOA offers a number of advantages when evaluating a development it has been described as an oversimplification of reality as it is limited to a two-dimensional space and thus compares only two outcomes, at least at any one given comparison or trade-off analysis (Yanggen et. al., 2002). However, one is not prevented from running many comparisons subsequent to each other (i.e., first run a comparison between economic output and health then run a comparison between economic output and environmental quality). TOA may not be appropriate when multiple issues are relevant and they all have to be given importance. How one decides which of all those issues have more or lesser importance than the other, and at the same time compare the trade-off of the indictors with each other and with the economic impact indicator (Yanggen et. al., 2002).

**2.10 Simulation Model Approaches in TOA**

A TOA curve constructed is derived by regressing a curve through data points between the two indicators of interest in this study, profit and abatement. The curve would be regressed through data points that obviously have a certain variation among them. The variation between them would be attributable to such parameters as precipitation or temperature. Time and monetary constraints limit the collection of abatement and profit data that could be obtained using field studies, especially if one is interested in finding the abatement and profit impact over 30 years or under a hypothetical situation where the environment shows climate change. Thus, a simulation model was used to help generate appropriate data by simulating temperature and precipitation changes over a long-term as well as under changes to the environmental variables.

The procedure to be followed to develop a TOA using simulation output was described by Antle et al. (2001) and Yanggen et al. (2002) using a three-dimesional flow diagram (Figure 2.7). Under the current study, the question to be addressed is how would cropping systems (tillage intensities and crop rotations) effect the trade-off between net economic profit and environmental benefit (net $CO_2$ equivalent abatement) in the Black soil zone of Saskatchewan. In Figure 2.7, the vertical axis represents the spatial scale one adopts when addressing the problem. The two horizontal axes represent the choice of research procedures: On the one horizontal axis, the range from qualitative to quantitative procedures is represented and on the other horizontal axis the range from mechanistic to the empirical procedure is represented. The lines that follow the different stages, K1 to K2 and K3 to K5 and so on, are defined as the "research chain" or simply their prescribed procedure to be followed.

The problem definition of the trade-off model is started at the regional level and is defined using expert knowledge (K1) - which is more descriptive and less quantitative. Even though the problem was defined at the regional level, the decisions of tillage practices are taken at the farm or field level by individual farmers. Based on this information the problem is yet redefined (still in mechanistic and qualitative terms, K2) at the field level. How will the trade off between net GHG abatement and economic profit be affected by different tillage systems and other farm inputs used for the type of crop rotation practised in that *farm*. In the next step, a quantitative, empirical economic simulation model (K3) is used to simulate decision making for *that* field; crop yield, soil organic C build up processes, GHG emissions from fertiliser for example are modelled. If weather variability occurs it would be necessary to carry out simulation runs for different precipitation levels.




notes:

K1: Application of user expertise (qualitative, empirical)
K2: Expert knowledge (qualitative, mechanistic)
K3: Use of simple comprehensive methods, including modelling (quantitative, Empirical)
K4: Complex, mechanistic methods, including modelling (quantitative, mechanistic)
K5: Detailed methods, including modelling, which focus on one aspect only, often with a disciplinary character (quantitative, mechanistic)

(Source: Antle *et. al.,* 2001)

**Figure 2.7 Classification Scheme for Research Procedures**

Then, during the simulation of these bio-physical processes it is necessary to consider such processes as nitrogen fixation by legumes, soil organic matter build up, and available nitrogen and phosphorus levels for the crop and it becomes necessary to come down to the *plot* level (K5). Then again, the quantitative processes are aggregated and taken up again to the field level and finally the results of the simulation for many fields are aggregated to the regional scale in the form of trade off curves.

## 2.11 Summary

Agricultural practices vary spatially and temporally because the effects of agricultural production depend on soil, weather and on economical factor. Agriculture as an industry is also in a unique position in that it is capable of both contributing to the emission and the abatement of climate changing GHGs. Practices such as reduced tillage and reduced tillage are able to sequester SOC and reduce the on farm energy consuming GHGs. Economic profitability and improved soil and moisture conservation have been shown to result with reduced tillage in the Black soils, under field trials. However, reduced tillage and reduced summer-fallow is also associated with the use of greater $N_2O$ emitting inorganic N fertiliser. There have not been any studies of the net effects on GHGs and profitability among tillage systems. TOA and a simulation model were selected for modelling the economic and environmental benefits of three cropping systems. The preceding section looks in to the detail at how trade-off analysis is used in simulating the trade off between economic profitability and net GHG abatement.

# CHAPTER 3
# THE CONCEPTUAL MODEL

## 3.1 Introduction

The preceding chapter provided a foundation for the study through the literature reviewed on agronomic, environmental and economical research that has been conducted on agricultural management strategies. This chapter provides a conceptual framework of the model aiding the study - looking at the agronomic, environmental, and economical components of the model. In so doing, the chapter walks through the individual components that comprise the model simulations, which would ultimately simulate the trade-off between the net GHG abatement and the economic profits within agricultural cropping systems. This chapter begins by explaining how the literature reviewed leads to the conceptual model and enters into the concept underlining trade-off analysis (section 3.2) followed by a description of the model itself with descriptions of the environmennt, economic and emissions components of the model (section 3.3). Next, the temporal and spatial considerations given by the model are discussed (section 3.4).

## 3.2 Concept of Multidisciplinarity and Concept of TOA

The literature review provided an idea of how the farm inputs could change the ecology and the economy of the farm. These inputs include pesticides, fertiliser, fuel and primarily the management decisions they are based on. Of concern also is how the economy and the physical environment of the farm react when one of the variables they depend on changes - like rainfall, growing season temperature or the coefficient of nitrogen volatilisation changes. To address questions such as these there is a requirement for an approach that integrates a number of disciplinary perspectives (Antle, *et. al.,* 1998b). When the individual pieces of disciplinary research are well coordinated and pieced together to assess trade-offs, it provides information for decision making. The trade-offs may be defined across several disciplines at a given point in time and also over many points in time as well as over spatial dimensions (Crissman *et al*.,1998).

To help understand the role of this interdisciplinary approach it is useful to develop scenarios. In the context of this study, assume a policy that would require farms in the Black soil zone to reduce tillage intensity (T) to minimum tillage. The policy was based on agricultural research, where data on yield and environmental effects were collected separately without sufficient location specific identifying factors. Suppose that this decision was based on a controlled trial[10] in the Indian Head research centre, Saskatchewan, where it was found that reducing T would induce net GHG abatement. However, the farm types within this soil zone can have internal variation, such as in size or scale of operations, yield, and input demand. Thus, the farms in this soil zone could have different farm types with respect to effect of tillage intensity on economic profit ($\pi$) and net GHG emissions (z). Four possible types are described below (Table 3.1). Between farm types 1 and 2 reducing tillage intensity has a greater reduction on profit, thus a higher coefficient on profit ($2\alpha$ ) than do types 3 and 4 (which have a coefficient of $\alpha$). Farm types 1 and 3 may have a higher coefficient on emissions ($2\beta$) than do farm types 2 and 4. A policy that considered only the effect on net GHG emissions (z) may not realise that reduction of T by the same intensity across all farms would have greater opportunity costs (in terms of profits forgone) on farms of types 1 and 2. Conversely, reduction in tillage intensity may not be worth the effort in farm type 2, as it has a high opportunity cost and does not provide as much emission reduction. The process of quantifying trade-offs for agriculture becomes more complex, the larger the spatial or temporal scale. The conceptual foundations provided by Antle *et al.,*(1998a and b ) will be used to depict why and how TOA must work in this study.

**10** The trial being based on an experimental plot in Indian Head and that the same crop rotation is used on all tillage systems.

Faced with a complex problem and stimulated by interdisciplinary interactions, a well-functioning research team naturally tends to attempt to address more questions than are feasible given the available time and resources. Keeping the project focussed on the key policy questions that need to be addressed helps the research team allocate scarce resources to the project's highest priorities.

**Table 3.1 Regional Distribution of Economical and Ecological Emission Potential of Tillage**

| | High GHG Emissions | Low GHG Emissions |
|---|---|---|
| High Economic Profits | Type 1 | Type 2 |
| | $\pi = 2\alpha T$ | $\pi = 2\alpha T$ |
| | $z = 2\beta T$ | $z = \beta T$ |
| Low Economic Profit | Type 3 | Type 4 |
| | $\pi = \alpha T$ | $\pi = \alpha T$ |
| | $z = 2\beta T$ | $z = \beta T$ |

Notes: $\pi$-economic profit, z-net GHG abatement, T- discrete variable adopted to reflect three different intensities of tillage operations
(Source: Adapted from Antle *et. al.,*1998)

It is important to keep in mind that it is not necessary to measure all possible health or environmental effects of a production system in order to assess the key trade-offs and provide useful guidance to policy makers and the public. There are trade-offs that must be considered between internal validity and generality in designing research projects. A key decision is the study site such that even with a limited number of impacts to be considered, the ideal site for a case study probably does not exist. (Antle et. al., 1998.a)

In economic terms, the trade-off curves provide essential information for making choices among policy alternatives because they show how much of one desired outcome, such as agricultural production, must be given up to obtain a unit of some other desirable outcome, such as improvements in net GHG abatement. The conversion from agriculture to another desirable outcome, for example manufacturing, usually cannot be made on a one-for-one trade-off, and at some point it becomes increasingly costly to transfer resources from one sector to another. This phenomenon is known as the law of increasing costs, and gives the trade-off curve a shape concave to the origin. However, the curvature properties of environmental or health functions are not necessarily the same as production functions. So these trade-off curves will not necessarily be concave to the origin.

The indicators of a generic trade-off function may include economic profit on the horizontal axis and net GHG abatement on the vertical. The former may be replaced by production and the latter by soil C sequestration, for example. But, for illustration net farm profit and net GHG abatement shall be used. Let economic profit ($\pi$) be a function of a vector of output prices (p), which are considered exogenous because the farm is assumed to be a price taker, a vector of input prices (w), also considered exogenous and a vector of crop production/yields (y), which are, of course, endogenous:

$$\pi = \pi(p, w, y) \tag{3.1}$$

Crop production is a vector of endogenous variable inputs like fertiliser, herbicides, pesticides, as well as available soil moisture which would be denoted as (x), as well a vector of inputs considered fixed in the short to medium term such as land, machinery and labour denoted as (a), and a vector of exogenous factors representing policy, technology and prices (p). The crop production, as a biophysical production function, is further dependent on a random weather variable denoted (u).

$$y = y(p, w, x, a, u) \tag{3.2}$$

Combining 3.1 and 3.2 , the profit function maybe extended as follows;

$$\pi = \pi(p, w, x, a, u) \tag{3.3}$$

Assuming that the farmer is motivated to maximise profit ($\pi$) and not by maximising net GHG abatement (z), the latter may be considered the indeterminate variable and the former the determinate, in the trade-off quadrant. It would be fair that net GHG abatement be a function of the above values that determine ($\pi$). A net GHG abatement (z) function may be defined as follows

$$z = z\ (x, a, p, u) \qquad (3.4)$$

If both indicators ($\pi$) and (z) used in the trade-off curve can be defined as functions of the same resources, then a downward sloping trade-off curve exists (Antle *et al.,* 1998 ). An upward sloping trade-off curve may also exist. For example, in Figure 3.1 the portion AB of the trade-off curve is similar to the PPF. However, beyond some point B the continued exploitation of environmental resources can lead to a reduction in productivity potential. Hence from B to C a reduction in the environmental resource (soil erosion, erosion of SOMC and reduction in net GHG abatement) can accompany a reduction in productivity as well as net farm income. Moving backwards from C to B, a situation of revival of soil organic matter carbon (and hence possibly an improvement in net GHG abatement) may accompany an improvement in farm income.

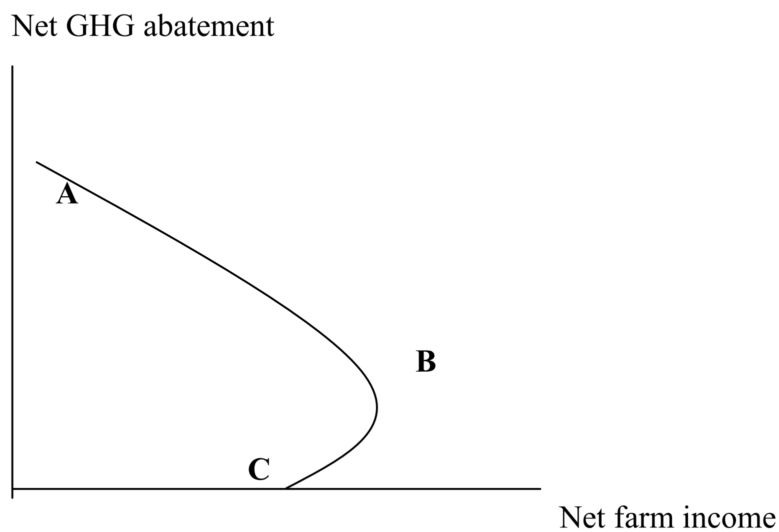
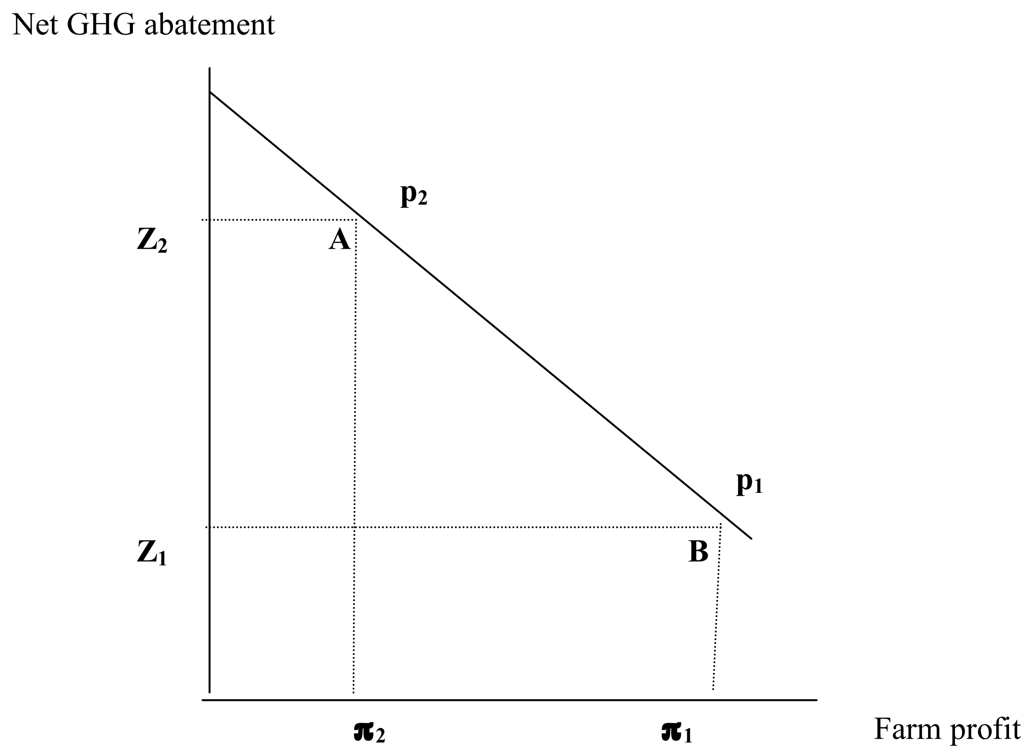



**Figure 3.1 Trade-Off Curve Between Net Farm Income And Net GHG Abatement**
(Source: Antle *et. al.,* 1998 b)

The key features of the trade-off curve are its *location* in the quadrant and its *slope* at a point along it (Figure 3.2). Figure 3.2 shows that on the trade-off curve, when $\pi_1$ units of net revenue are being made, net GHG abatement is $z_1$ under conventional tillage management $p_1$. When a change to, for example, reduced tillage management is taken $p_2$ , hypothetically, one may expect net GHG abatement to increase to $z_2$ and net revenue to possibly decline to to $\pi_2$. The slope of the trade-off curve from B to A thus represents the opportunity cost of increasing net GHG abatement in terms of forgone net GHG abatement.




(Source: Antle *et. al.,* 1998 b)
**Figure 3.2 Trade-off Curve Reflecting Farm Profitability And GHG Emission Abatement**

The information provided by these tradeoff functions can help policy makers assess the cost of environmental improvement in terms of foregone net farm revenue (or agricultural production, if that were the measure used on the horizontal axis). The preceding discussion makes simplifying assumptions that the production technology is deterministic. For example, a given production technology combines a certain amount of land, labour, and capital to produce a given amount of output (Antle *et al.,* 1998 (b)). However, production in the real world is stochastic, so that a given amount of inputs may produce variable amounts of output or environmental quality due to uncontrollable factors such as a pest infestation that could decrease production well below average, while high rainfall could raise it (up to a particular upper limit for water use by the crop).

It is important to consider that GHG abatement should capture both on-farm and off-farm benefits. The on-farm benefits are those related to soil C sequestration; the improvement in soil fertility associated with greater SOC, improvement in soil N, P and moisture, reduction in soil salinity improvement and improvement in soil tilth and structure and also the reduction in wind and water related erosion. These on-farms changes may increase yields and reduce yield variability or production risk over the long term. These changes in productivity would likely be captured by the net farm profit axis of the trade-off curve if the trade-off is analysed over the long term. There may also be an implicit benefit to the farmer of knowing they have higher quality soil and in the process are abating GHG emissions. These factors will not be captured by the net farm profit function. The off-farm benefits (co-benefits) of GHG abatement includes benefits to society at large in mitigating climate change. As well, co-benefits like water quality improvement and recreational value of water is not captured by the net GHG abatement indicator. Such co-benefits may be considered separately and evaluated in separate trade-off curves from net farm profit.

### 3.3 The Simulation Model

Having discussed the role that TOA can play in the present research it is important now to discuss the role for a simulation model and the procedure in developing or adapting an appropriate simulation model to provide data to develop the trade-off functions. The key benefit is that a model that has been parameterised for this region could be used to easily and economically depict what would otherwise take years of controlled field experiments to study. The model enables one to look beyond the short-term benefits such as the studies already done for periods of less than five years, but also look at how the endogenous benefits such as soil conservation could be internalised into net revenue over 30 years or more. Moreover, the model could change the exogenous factors to reflect imminent climate change and perform 'what if' simulations on the farm system.

The simulation model specifies the relation between the endogenous variables (net revenue and net GHG abatement) and the exogenous factors (variable and fixed inputs and output prices and technology). The model used in this research was based on a simulation model developed at the University of Saskatchewan (see Belcher *et. al.,(*2003); Belcher (1999)) The model was developed using with the STELLA version 7.0.2 modelling software for a Windows platform[11]. For descriptive purposes the model is divided into three components; an environmental model, an economic model and an emissions model. Each of these component models will now be discussed individually.

### 3.3.1 Environmental Model

The Crop production function described by Belcher *et. al.,* (2003) represents the biophysical relations between crop production and three production input variables representing soil moisture and available soil nitrogen (N) and phosphorus (P). The model assumes that annual crop yields are determined exclusively by the availability of these three inputs. Available water, N and P are partially determined by SOMC stocks which are dependent on yields from previous years. In addition, the model assumes that farmers can apply synthetic N and P fertilizer as influenced by available soil moisture and available soil N and P nutrients. Hence, the crop production function is dynamic since it is a function of prior year production and weather. The production function is:

$$y^t_{ij} = Y_i * Xns^t_{ij} * Xps^t_{ij} * Xws^t_{ij} \qquad (3.5)$$

where;

$y^t_{ij}$ = yield of crop i in rotation j in year t (kg/ha)

[11] STELLA is software that provides an environment for constructing and interacting with models in a graphical programming language. Also used was Microsoft Excel 97 for analysing the standard deviation of determinant variables of economic profit and net GHG abatement obtained through STELLA.

$Y_i$ = unconstrained maximum potential yield for crop i when moisture and nutrients are optimal (kg/ha)

$Xns^{t}_{ij}$ . $Xps^{t}_{ij}$ . $Xws^{t}_{ij}$ = indices for N, P and water sufficiency, respectively. These indices fall between zero and one, with one representing unconstrained conditions.

The model shows complementarity of production inputs by virtue of its construction. At higher levels of any one of the yield contributing factors (N, P or water) any of the other remaining factors (N, P or water) would contribute toward a higher marginal output. For example, the marginal product with respect to a given supply of nitrogen would be greater when moisture levels are higher, provided that none of these factors are limiting. The balance of the environment model is focused on simulating the availability of N, P and water over time given the management history and the biophysical conditions of the target area (eg. soil texture, precipitation etc.). For more complete details of the model structure refer to Belcher et al. (2003).

### 3.3.2 Economic Model

The economic model computes net farm income from the proceeds of the sale of crop net the cash costs of inputs such as fertiliser, pesticides, seed, labour, management, land, transport and overhead. Included in this calculations are the returns to equity and are calculated annually per hectare for each of the simulated rotations. The crop yields and N and P fertiliser rates applied are endogenously derived by the crop environmennt model. The other input costs and output prices are exogenous and these inputs (seeds, labour, herbicides etc.) are combined in fixed proportions. The input and output prices are assumed fixed through the simulation period and were derived from data published by Saskatchewan Agriculture, Food and Rural Revitalisation (SAFRR, 2004). The annual net farm income per hectare for each rotation is defined in equation 3.6 below.

The production inputs, pesticides, seed, land rent and overhead are assumed to be used in fixed proportions in the model (eg. each ha of land in each crop imposes a fixed input cost). This assumption of fixed proportions for the fixed inputs is a strong assumption but does facilitate the modeling process. The quantity of fertiliser used is endogenously determined by the model based on available soil N, P and soil moisture and assumes the farmers soil test to obtain soil N and P information. The economic model is parameterised using a farmer survey along with baseline data provided in the Crop Planning Guides published by SAFRR (2004) for the Black soil zone of Saskatchewan. Chapter 4 is dedicated to describing the survey while chapter 5 to describes the parametrising of the model. Although it is acknowledged that tillage systems can be used to produce a broad range of crop rotations[12], the rotation used for the tillage systems in this research reflects the commonest rotation surveyed under that tillage system. Hence, it could be argued that the rotation is 'integral' to that tillage system and further, the subject of interest is the tillage system and not the rotation.

$$\prod{}_{\mathrm{j}}^{t} = \frac{\sum_{i=1}^{\mathrm{n}}\left(\mathrm{Pr_i}\, y_{ij}^{t} - w_{ij} - s_i y_{ij}^{t} - rNf_{ij}^{t} - gPf_{ij}^{t}\right)}{\mathrm{n}} \qquad (3.6)$$

where:

$\prod{}_{\mathrm{j}}^{t}$ = the average annual profits for rotation j at time t ($/ha/yr)

n = the number of crops (i) in rotation j

$\mathrm{Pr_i}$ = the fixed farm gate output price for crop i ($/t)

$w_{ij}$ = a vector of fixed production costs (pesticides, seed, fuel, labor and management,rent, overhead) for crop i in rotation j ($/ha/yr)

$s_i$ = fixed transportation costs for crop i ($/t)

r,g = the respective fertiliser prices doe N and P ($/kg)

$Nf_{ij}^{t}, Pf_{ij}^{t}$ = the N and P fertiliser application rates (kg/ha/yr), respectively, for crop i in rotation j at time t

### 3.3.3 Emissions Model

The Emissions model uses the endogenously determined crop yield and fertiliser quantities of the Environmental model to determine the C sequestration and soil $N_2O$ emissions respectively. Further, the Emissions model makes use of other inputs quantities (herbicides, machinery) from the Economic model to estimate emissions in the manufacture of them. Such emissions are termed 'frugal emissions' under IPCC (1996), but this study uses the term 'embodied emissions'.

The rudimentary relationships between the three sub models are illustrated in Figure 3.3. The figure illustrates that the relationship between the respective components is bi-directional or unidirectional (or involve a feedback mechanism or not). Within the environmennt model, the exogenous variables weather, initial soil biophysical conditions and cropping systems (tillage and crop rotation) influence endogenous variables including subsequent soil biophysical conditions, which influence fertiliser quantity to be applied which influence crop yield which in turn influence subsequent soil biophysical conditions to complete the feedback cycle. The feedback mechanisms envisaged between economic and environmennt components are where output and input price changes, change input demand. The feedback mechanisms envisaged between the emissions and environmennt components might be where conditions impacting soil $N_2O$ emissions coefficients change crop growth. Further, one may argue that these management decisions are considered influenced by profitability, risk and agronomic suitability and would most likely change during long time periods. To a lesser extent the farmer's long-term concern for the environment could also be considered (Maqbool,1999).

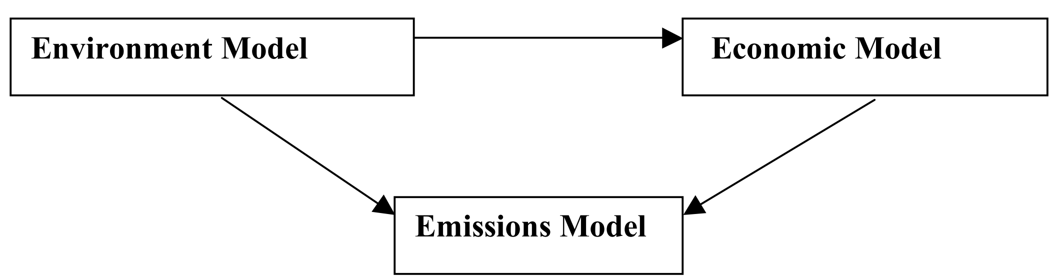



**Figure 3.3 Rudimentary Relationships of the Model**

### 3.4 Temporal and Spatial Considerations.

The simulation model depicts a farmer's decision to apply fertiliser, pesticides and other inputs at every cycle that the simulation is run. The duration of each cycle within the model is one year. However, such management decisions in farming can be taken at shorter intervals. The timing of the application of these inputs or the frequency of the application could change the outcome of the model, such as crop yield and SOC abatement. For example, the impact that application date of fertilizer and pesticides has on yields is not captured by the model. In addition, the model can not capture within year environmental effects such as intra-year precipitation variability. In general, the model assumes that inputs are used at the correct time and precipitation comes when needed. As a result the crop yields produced by the model are often at the high end of the distribution for the target area.

Another factor that should be considered is the fact that the simulation model must combine environmental and economic data. Environmental data sets often have a higher temporal resolution than those of economic/market sets (Belcher, 1999). As a result, there must be recognition of the inconsistent time horizons. For example, environmental models are frequently designed to capture processes that occur over long-time horizons encompassing over 25 and sometimes a 100 years, economic theory assumes that future shocks and adjustments are impossible to predict and restrict analysis to five to ten years (Belcher, 1999). As a compromise the simulation model is run for 30 year time horizons.

### 3.5 Summary

TOA defines the choices that aid in making policy. The policy outcomes can be represented by indicators that are functions of factors of production used on the farm, input and output prices as well as a random weather component: The chosen indicators were net GHG abatement and net economic profit, which are simulated by a model.

This chapter defined the concept behind this simulation model. The model was parametersied using a survey and secondary data. The survey will be discussed in the following chapter.

# CHAPTER 4
# THE SURVEY

## 4.1 Introduction

For the model to simulate the economic and environmental trade-off outputs for the Black soil zone, it needs to be parameterised with economic and biophysical data from the Black soil zone. The economic model was parameterised using both regional level secondary data published by the provincial agriculture branch (SAFRR) and data gathered using a survey of farmers from the target region. The subject of the current chapter is this survey and focuses on the process used to conduct the survey and provides a summary of the survey data.

## 4.2 The Sampling Process

The survey population was located in the Black soil zone, of the northeast agricultural region in Saskatchewan. The map in appendix A depicts the Black soil zone with respect to the other soil zones in the province. The sample population was located across this region with representatives from a number of the rural municipalities (Table 4.1).

**Table 4.1 Number of Respondents under Each Rural Municipality (R.M)**

| R.M. Number | Number of Respondents | R.M. Number | Number of Respondents |
|---|---|---|---|
| 271 | 4 | 218 | 1 |
| 3 | 1 | 459 | 1 |
| 92 | 1 | 430 | 1 |
| 428 | 2 | 307 | 1 |
| 187 | 1 | 91 | 1 |
| 471 | 2 | 367 | 1 |
| 427 | 2 | 429 | 1 |
| 244 | 1 | 461 | 1 |
| 245 | 2 | 429 | 1 |

| R.M. Number | Number of Respondents | R.M. Number | Number of Respondents |
|---|---|---|---|
| 216 | 1 | 275 | 1 |
| 460 | 1 | 308 | 2 |
| 187 | 1 | 157 | 3 |
| 400 | 4 | | |

The farmers interviewed were selected from databases of farmer contact information. Only farmers located in the Black soil zone were contacted. They were contacted by telephone, informed of the objective of the survey, the structure of the questionnaire, the approximate time that the questions would take and their entitlement to privacy as well as other information that was required to be provided by the ethics review committee of the University of Saskatchewan. Before contacting the farmers a trial survey was conducted with farmers attending the Saskatchewan Soil Conservation Association Conference in Regina, Saskatchewan in February of 2004 and faculty at the University of Saskatchewan. The feedback from this pilot indicated that it would be ineffective to request cost data for each input for each year due to the extensive time requirement of each of the respondents. Therefore, it was decided that response rates would be much better if the survey focused instead on quantifying the relative change in input use after converting from the old management practice. Between ten and 15 farmers did not answer the telephone calls and an approximately equal number answered but did not provide consent to respond to the survey. The final sample population of 40 respondents were evenly divided between the adopters of zero tillage and minimum tillage. There were only two farmers contacted who used conventional till which was too small to be used as a representative population so it was decided to use the secondary data on farm input costs provided in the Crop Planning Guide for the Black soil zone published annually by SAFRR (2004). The data from the Crop Planning Guide was used to parameterise the economic component of the model for conventional tillage. To parameterize the cost component of the economic model for minimum and zero tillage management this conventional cost data was adjusted using the relative change data collected through the survey.

### 4.3 Structure of the Survey

The format of the survey questions is provided in Appendix B. The order in which the questions were asked and their intended purpose was as follows. First, the cultivated acreage or acreage under tillage was elicited. Then they were asked if they were practising zero till, defined as a single pass operation, minimum till (a two pass operation) or conventional till (with greater than two passes). Next, they were asked how long ago they had changed their management practice, if they were practising one of the reduced till operations. Following this, they were asked if summer-fallow was practised. These questions on management along with their crop rotation helped determine the exogenous variable of tillage management practise (the model assumes that the tillage technique used is independent of other variables within the model and hence is considered an exogenous variable in the simulation model). Next, questions were asked on how much cultivated acreage, average crop yields and crop rotations changed after conversion to reduced till. Similarly, how variable inputs such as fertiliser and pesticide application rates, along with fuel use change was elicited. The responses to these questions would determine how most input factors of production changed, with the exception of machinery and owner operator opportunity cost of time spent on the field. With respect to machinery, the farmer was asked what machinery he/she bought and when and what machines he/she sold and when. The data gathered from these questions is considered somewhat suspect since many of the respondents found it too tedious to recall dates and values. Therefore, secondary data was used for the costs related to machinery investment. Next, they were asked by what proportion the owner/operator’s time on field operations had changed.

Following the first section of the survey which focused on more quantitative estimates of the cost changes associated with the change from conventional to minimum and zero tillage the next part of the survey focused on qualitative benefits. Specifically, the participants were asked whether ground water and surface water quality improved, worsened or left unchanged as a result of the change. The respondents were also asked for their impression on the effect that the reduced tillage management had on soil quality and soil erosion and the effect on weed species populations.

### 4.4 Responses of the Survey

The survey responses are presented in the following four sub-sections: first, the cultivated acreage and acreage change; second crop fallow and crop rotations; third, changes in farm inputs; fourth, changes in qualitative benefits.

#### 4.4.1 Cultivated Area and Change in Cultivated Area

The first section of the survey focused on the size of cultivated area and then the change in size of cultivated area since adopting the reduced tillage management practice. Table 4.2 depicts these results having excluded both the highest and lowest values. The important information gleaned from this table is that the size of farms surveyed are larger than the mean farm size of 425 ha used by SAFRR (2004) in their crop budgets which were used to parameterise the simulation model in this study. As a result, economies of size associated with the larger reduced tillage systems will not be captured in the simulation results.

**Table 4.2 Cultivated Area and Change in Cultivated Area**

| Cultivated Area (Ha) | | |
|---|---|---|
| | Mean | Range of Responses |
| Minimum till | 2,466 | 1,000 to 6,700 |
| Zero till | 2,194 | 900 to 4,000 |
| Change in Cultivated Area (Ha) | | |
| | Mean | Range of Responses |
| Minimum till | 794 | 0 to 2,400 |
| Zero till | 537 | -600* to 1,900 |

Note:*The negative value for change in area reflects that some producers reduced the size of their fields after converting from conventional to zero till.
(Source: Survey)

#### 4.4.2 Summer Fallow and Crop Rotations

Of the sample of 40 farmers, 20 practiced zero till and 20 practiced minimum till, today. Of the above 20 minimum till farmers, five included summer fallow in their rotation until the mid 1990's and today they do not include summer fallow. Of these same 20 minimum till farmers, another five still include summer fallow in their rotation. Thus, 15 of the minimum till farmers surveyed (or the majority) do not include summer fallow in their rotation, today. Of the 20 zero till farmers no one includes summer fallow in their rotation. The most common crop rotation among both reduced tillage systems was wheat/ pea/ barley/ canola and therefore this rotation will be simulated in the model.

### 4.4.3 Input Use Change

It is reasonable to assume that the use of farm inputs such as pesticides, fertiliser, labour and fuel would change after the conversion of the tillage system. The survey elicited to what proportion these inputs had changed since the conversion (Table 4.3). The responses for fertiliser use change, fuel use change, owner/operator time on field are reported in percentage change. Glyphosate use is reported in litres per hectare (glyphosate is assumed not to be used in conventional tillage and this is supported by SAFRR, 2004). Machinery investments were represented net of machinery sold, adjusted at a discount rate of three percent to arrive at a net present value. A negative value on an input indicates that the cost of the input had reduced after the change.

**Table 4.3 Input Use Change after Conversion of Tillage System**

| | Mean | Range of Responses |
|---|---|---|
| N fertiliser percent change (in kg/ ha) | | |
| Minimum till | +10% | 0 to +39% |
| **Zero till** | +18% | -20% to +80% |
| | | |
| P fertiliser percent change (in kg/ ha) | | |
| Minimum till | 0 | - |
| Zero till | +4% | 0 to +50 % |
| Glyphosate use after conversion of tillage system (l/ ha) | | |
| Minimum till | +2.48 l/ ha | 0 to +3.7 l/ ha |
| Zero till | +2.57 l/ ha | 0 to +3.1 l/ ha |
| Fuel use change after conversion of tillage system (l/ ha) | | |
| Minimum till | -18 % | 0 to -66 % |
| Zero till | - 42 % | -10% to -80 % |
| Operator opportunity cost (hours on field) change after conversion of tillage system | | |
| Minimum till | - 24 % | 0 to -30 % |
| Zero till | - 43 % | -8% to -75 % |
| NPV of machinery investment after conversion of tillage system (dollars invested) | | |
| Minimum till | +161 $ | 0 to +514 $ |

| | | |
|---|---|---|
| Zero till | +82 $ | -73* to +258 $ |

Note: The negative value in NPV of machinery investment after conversion to zero tillage indicates that some producers actually benefited by selling surplus machinery that was not needed anymore like a second tractor or old conventional seeding equipment

### 4.4.4 Ancillary Benefits in Reduced Tillage

The survey was used to collect information on changes in other components of the farm environment such as changes in water quality and soil quality (Table 4.4). It is noteworthy that these benefits are apparent to a greater proportion among zero till farmers compared with minimum till farmers. This is interesting because the practice of zero tillage could be considered the opposing end of the scale from conventional tillage with respect to the least disturbance to the soil. Nearly, half the zero till farmers improved surface water quality (a third for minimum till farmers). A majority of both groups noticed an improvement in soil quality. Quite a few zero till farmers use cattle manure. A large proportion of both reduced till farmers groups felt there was a change in weed species where some weed species has reduced in the population and other had increased. As a response a greater proportion increased their use of herbicides (but not insecticides although this was elicited as one question) which has become a greater cost component. As well, approximately half of them said they are able to seed earlier after having reduced the tillage operations. Seeding earlier allows the crop to benefit from a longer crop growing period before the onset of winter.

**Table 4.4 Perceived Change in Farming System Attributes**

| | Farms with improvement in surface water quality |
|---|---|
| Minimum | 35% (n=17) |
| Zero | 53% (n=19) |
| | Using cattle manure |
| Minimum | 8% (n=12) |
| Zero | 43% (n=14) |
| | Change in weed species |
| Minimum | 59% (n=17) |
| Zero | 100% (n=12) |
| | change in pesticides |
| Minimum | 40% (n=15) |

| | |
|---|---|
| Zero | 47% (n=19) |
| | improvement in soil quality |
| Minimum | 82% (n=17) |
| Zero | 95% (n=19) |
| | reduced soil erosion |
| Minimum | 62% (n=13) |
| Zero | 100% (n=18) |
| | able to seed crop earlier |
| Minimum | 47% (n=15) |
| Zero | 58% (n=19) |

Note: n = number of responses to the question

### 4.5 Summary

This chapter explains where and how the sample was selected for the survey as well as the structure of the survey and finally tabulates or summarises the responses of the survey. These responses will be used to parameterise the economic component of the model, which is the subject of the following chapter. The following chapter discusses how this survey data will be used to parameterise the model and how the emissions component of the model are parameterised.

# CHAPTER 5
# ANALYTICAL FRAMEWORK

## 5.1 Introduction

The fourth chapter discussed how the survey was conducted and presented the specific data collected using the survey. This information is necessary to parameterize the simulation model so that it may be used to generate the appropriate data for the development of the trade-off functions. This chapter focuses on developing the empirical foundations of the simulation model and specifically details the data that was used to parameterize the environmental, economic and emissions components of the model. The chapter begins with a description of the biophysical properties of the Black soil zone with respect to its soil properties and climate characteristics within the rural municipalities encompassed in the study (section 5.2). The discussion then moves on to describe the how to parameterise the individual components of the model environmental, economic and the emissions sub-model (sections 5.3, 5.4 and 5.5 respectively).

## 5.2 Black Soil Zone

This research focused on the Black soil zone because of the relatively high adoption rate of reduced tillage practices over a relatively longer period of time in this region relative to the other soil zones in the province. This ensured a better availability of both biophysical and economic data relevant to these targeted management alternatives. In addition, the simulation model being used in this study has been validated for the Black soils (Belcher *et. al.,* 2003)

The Black soils were formed under grassland vegetation, although trees and shrubs have expanded onto the grasslands as a result of the elimination of such landscape scale forces as large prairie fires and the herds of bison that once roamed them. The natural climax community in this region is mid to tall grass prairie with some tree and shrub communities interspersed in areas with wetter soils, such as wetlands and riparian zones along streams and rivers. In the current period annual crop production, predominantly cereals and oilseeds, and livestock production (the area has the highest cattle numbers per farm in Saskatchewan) dominate the landscape. Soils in this soil zone tend to have higher organic matter (SOM) stocks. Since SOM contains both organic carbon and mineralizable N, the greater availability of SOM implies more mineralizable N. As well, SOC has a greater water holding capacity and thus the Black soil zone is not as constrained with soil moisture and hence farmers in this soil zone are less compelled to summer fallow. Practices like zero tillage or extended rotations, when combined with adequate fertiliser increases crop yields which leaves behind greater crop residues. These crop residues produce greater SOM that conserve more moisture even under dry conditions. Specific details of the landscape are provided in Table 5.1 and a map of the Black soils with respect to its position in the province is depicted is Appendix A

### 5.3 Parameterising the Environmental Model

The agronomic processes of the sub model are parameterised to the Black soil zone. All tillage systems in the model are parameterised using values representing the biophysical and climatic conditions of an area near Yorkton, in the eastern part of the province of Saskatchewan (Table 5.1). Precipitation values are based on historic- 1973 to 2003- growing season (May to July) and non-growing season (April to August) precipitation data from the Yorkton weather station.

**Table 5.1 Biophysical Characteristics of the Black Soil Zone**

| | |
|---|---|
| Growing season precipitation [a] (cm) | 20.18 |
| Winter precipitation [b] (cm) | 24.9 |
| Mean daily temperature ($^{0}$C) | 20 |
| Mean daily temperature (days) [c] | 2 |
| Growing degree-days [d] | 1420 |
| Soil texture | Clay loam |
| Initial Solum (cm)[e] | 130 |
| Initial SOC (t/ha)[f] | 80 |

| | |
|---|---|
| Initial surface trash (t/ha) | 4.2 |

notes:
a- growing season precipitation is from May through July
b-winter precipitation is from August through April
c-mean daily temperature days represents the number of days within a growing season where the mean daily temperature exceeds 24 $^0$C
d- growing degree days using a base temperature of 5 $^0$C
e – depth of A and B horizon
f-total stock to a depth of 20 cm
(Source: adapted from Belcher, *et.al.,* 2003)

A complete description of the environmental component of the simulation model is found in Belcher, (1999) and Belcher *et. al.,* (2003). The model is parameterised with three categories of biophysical data; soil type (texture and thickness), weather (growing season temperature and precipitation), and initial soil stocks (surface residue, soil N, soil P and SOC). Based on these initial stock values the sub-model simulates crop yields (wheat, canola, pea and barley); bio-physical soil properties (SOC, soil N, soil P and soil moisture); under the different crop rotations. The rotations modelled in this study are the wheat-pea-barley-canola for both zero tillage and minimum tillage and wheat-barley-fallow-canola for conventional tillage. These rotations were selected based on information collected in the survey that indicated that they represented the more common rotations used by farmers in the area.

Crop yields are estimated by the model based on Liebig's concept of the Law of the Minimum (Belcher *et. al.,* 2003): The maximum potential yield (Ymax) decreases in proportion to the most limiting growth requirement; soil moisture, soil N or soil P. It should be noted that the model assumes that moisture is received at the correct time and inputs are used at the optimal levels such that yields are not negatively impacted by weeds, insect pests and disease. The mathematical expression of yield (kg/ha) for crop i, under rotation j at time t is calculated using the following mathematical relationship:

$$y_{ij}^{t} = Y_i * Xn_{ij}^{t} * Xp_{ij}^{t} * Xw_{ij}^{t} \quad (5.1)$$

where:

$y^t_{ij}$ = yield for crop (i) in rotation j at time t (kg/ha)

$Y_i$ = an exogenous variable reflecting the maximum potential yield (unconstrained for the margin) (kg/ha)
$Xns^t_{ij}$ . $Xps^t_{ij}$ . $Xws^t_{ij}$ = indices for N, P and water sufficiency, respectively. The indices fall between zero and one, with one representing unconstrained conditions**.**

The sufficiency indices have been parameterised using empirically derived relationships (Belcher *et. al.,* 2003). The primary function of the environmental component of the model is to simulate the quantity of soil N, P and water available to the crop at each time step thereby determining the magnitude of the sufficiency values. The availability of soil N, P and soil moisture is, among other variables[13], determined by the SOC stock. SOC (kg/ha to a depth of 20 cm) at a point in time is determined by the equation 5.2:

$$SOC^{t}_{ij} = SOC^{t-1}_{ij} + (R^{t-1}_{ij} - D^{t-1}_{ij}) \tag{5.2}$$

where:
$SOC^{t}_{ij}$ = soil organic matter carbon for the i[th] crop in the j[th] rotation at time t
$R^{t}_{ij}$ = the annual rate of crop residue additions to soil (kg/ha/yr) which, in turn, is a function of crop type and crop yield
$D^{t}_{ij}$ = the annual rate of residue decomposition (kg/ha/yr) due to microbial decomposition and respiration of $CO_2$ which , in turn, is a function of the tillage factor and growing degree days.

The annual rate of crop residue additions to the soil is a function of crop type and crop yield:

$$R^t_{ij} = Y^t_{ij} * C_i * HI_i \tag{5.3}$$

where:

[13] Such other variables as precipitation, fertiliser application, placing of legumes in the crop rotation

$C_i$ = the carbon content of the added biomass

$HI_i$ = harvest index (kg residue/kg grain defined by crop in Belcher et. al., (2003))

It should be noted that, as discussed earlier, since the model assumes that crop yields are constrained only by N, P and water, crop yields tend to be overestimated by the model. As a result, organic residue added to the soil also tends to be overestimated with SOC stocks also overestimated. This situation will also have implications for yields in later periods of the simulation with higher SOC stocks resulting in greater levels of available N, P and water in the future.

The annual rate of residue decomposition due to microbial decomposition and respiration of $CO_2$ which is a function of the tillage factor and growing degree days:

$$D^{t}_{ij} = R^{t}_{ij} \cdot EXPf(N_i, G_j, k, GDD) \quad (5.4)$$

where:

$N_i$ = the N content of the crop residue

$G_j$ = a tillage factor which increases with the frequency of tillage

$k$ = a general decomposition coefficient calculated as 1/cumulative degree days

$GDD$ = the annual growing degree days above $5^{0}$C

A key factor to consider from the above equations is that greater tillage frequency increases the rate of residue decomposition by increasing soil disturbance, temperature, aeration and available N (Belcher et al., 2003). The quantity of available soil N is based on the SOMC content, and the rate of N mineralization (Belcher *et.al.,* 2003). N mineralization is positively correlated with soil temperature and soil water and, as such, is rotation and time specific. The quantity of N available to the crop is the sum of available soil N plus fertiliser N. Fertiliser N is constrained, in the model, so that total N does not result in a sufficiency value greater than one for each crop (in other words the farmer does not apply more fertiliser than required). Fertiliser N is further adjusted based on available soil water to reflect the fact that farmers will be more willing to invest in fertiliser inputs in years when water will be less likely to be constraining to crop growth.[14]. Available soil P is a function of the stock of P in the previous time period plus P released from mineral, organic and fertiliser sources, minus the quantity of P taken up by the crop and exported with grain. Fertiliser P is constrained using the same procedures as for N fertiliser.

Apart from available N and available P, within the model, crop yields are largely determined by the availability of soil water. Soil water, in turn, is determined by the precipitation received during the growing season (May- July) and non-growing season (August-April). The pattern of precipitation is based on actual precipitation data for the past 30 years, for Yorkton. The proportion of total precipitation that is available to the crop in each time step is determined by the infiltration rate, recharge rate, and water storage capacity of the soil. It is assumed that there is no carryover of soil water following crop production and that 30% of the water stored in the soil during a summer-fallow year is available in the subsequent year. In this part of the environmental sub model, the output parameters of SOC as well as inorganic fertiliser and other factors of production like pesticides are used to calculate net GHG sequestered in the emissions sub model. As well, the output parameter crop yield is used to determine revenue in the economic component of the model. The crop rotations of this model were selected to represent those most closely resembling the survey respondents'.

### 5.4 Parameterising the Economic Component of the Model

The output of the Environment component is used in the economic and emissions components of the model. The measures taken to parameterise the Economic component of the model are described here. The economic component calculates net income ($/ha) for the three different tillage systems based on economic data for an average farm size of 425 hectares from the Crop Planning Guide for the Black soil zone published by SAFRR (2004). The Crop Planning Guide arrived at such cost data by conducting cost surveys of farms in the Black soil zone with an average farm size of 425 ha. However, the cost and revenue results are projected on a per hectare basis. Net

[14] Optimum rates (N sufficiency = 1) are applied only when soil water is greater than 50% above average for the region. The model assumes when available soil water is at or below average, farmers are less willing to invest in fertiliser inputs, as there is a higher risk that yields will be limited by water availability.

farm income is the revenue from the sale of crops (gross revenue) above the cash costs of farm expenses (described in equation 3.6 in chapter 3). Gross revenue is the product of farm gate crop prices and yields. Crop prices were fixed at farm gate levels (SAFRR, 2004) (Table 5.2). Crop yields are endogenously determined by the environmental sub model.

**Table 5.2 Farm Gate Market Prices (Black Soil Zone, 2004)**

| Crop | Price ($/t) |
|---|---|
| Wheat | 146.98 |
| Pea | 156.19 |
| Barley | 88.18 |
| Canola | 275.58 |

(Source: SAFRR, 2004)

The input costs used to parameterise the economic component of the model were based primarily on SAFRR, (2004) data with some adjustments made to the costs for zero and minimum tillage based on the survey data (Table 5.3). Land rent was fixed at $42/ha/year for the entire simulation period for each of the tillage systems SAFRR (2004). However, one may argue that lands under reduced till may capitalise the value of improved soil and the rent maybe greater (Kulshreshtha, 2004 (b)). The Third assessment Report of the IPCC (2001) states that land prices may change (e.g., increase) as a consequence of competition between crops for food and crops for mitigation strategies. Nonetheless, for the purpose of this analysis a fixed land rent value will be assumed. The cost of the herbicide Glyphosate was the product of the price of $7 per litre (SAFRR, 2004) and the mean application rates of 2.48 l/ha and 2.57 l/ha for minimum till and zero till respectively, which are values that were elicited from the survey. The cost of the other pesticides were as reported by SAFRR, (2004). Owner operator opportunity cost is arrived at using the labour costs provided for conventional tillage (SAFRR, 2004) and then discounting them by the proportion of owner operator time saved after the conversion of tillage system, as elicited by the survey. Fuel costs were calculated the same way. Machinery costs were as reported by SAFRR (2004) and included machinery investment, repairs and depreciation. Seed costs were also determined using SAFRR, (2004).

**Table 5.3 Summary of Annual Cost Components ($/ha)**

| Component | CT | MT | ZT | Source |
|---|---|---|---|---|
| Land | 42.82 | | | (SAFRR, 2004) |
| Glyphosate | n/a | 17.36 | 18.00 | (SAFRR, 2004) for price and survey for usage |
| Other pesticides | | | | (SAFRR, 2004) |
| *spring wheat* | 49.47 | 49.47 | 49.47 | |
| *canola* | 55.70 | 55.70 | 63.87 | |
| *barley* | 44.35 | 44.35 | 50.95 | |
| *peas* | n/a | 61.38 | 61.38 | |
| *fallow* | 6.84 | n/a | n/a | |
| Labour | | | | SAFRR (2004)for CT and discounts from survey for MT & ZT |
| *spring wheat* | 15.44 | 11.73 | 8.80 | |
| *canola* | 10.50 | 7.98 | 5.98 | |
| *barley* | 10.50 | 7.98 | 5.98 | |
| *peas* | 8.65 | 6.57 | 4.93 | |
| *fallow* | n/a | n/a | n/a | |
| Machinery | | | | SAFRR (2004) |
| *spring wheat* | 95.31 | 95.31 | 83.77 | |
| *canola* | 95.31 | 95.31 | 83.77 | |
| *barley* | 95.31 | 95.31 | 83.77 | |
| *peas* | n/a | 118.44 | 106.33 | |
| *fallow* | 49.13 | n/a | n/a | |
| Fuel | | | | SAFRR (2004) for CT and discounts from survey for MT & ZT |
| *spring wheat* | 18.90 | 15.50 | 10.96 | |
| *canola* | 20.01 | 16.41 | 11.61 | |
| *barley* | 18.90 | 15.50 | 10.96 | |
| *peas* | 21.13 | 17.33 | 12.26 | |
| *fallow* | 11.12 | 9.12 | 6.45 | |
| Seed | | | | SAFRR (2004) |
| *spring wheat* | 19.25 | 19.25 | 19.25 | |
| *canola* | 62.57 | 62.57 | 62.57 | |
| *barley* | 18.80 | 18.80 | 18.80 | |
| *peas* | n/a | n/a | 48.93 | |
| *fallow* | n/a | n/a | n/a | |
| Other costs | | | | SAFRR (2004) |
| | 36.05 | 36.05 | 36.05 | insurance premium + utilities.+ interest on variable expenses & miscellaneous |
| | 74.14 | 74.14 | 74.14 | all machinery related |
| Summer Fallow Expense | | | | SAFRR (2004) |
| *spring wheat* | 146.96 | n/a | n/a | |

| Component | CT | MT | ZT | Source |
|---|---|---|---|---|
| *canola* | 146.96 | n/a | n/a | |
| *barley* | 146.96 | n/a | n/a | |
| *peas* | 146.96 | n/a | n/a | |
| *fallow* | - | - | - | |

Net revenue per hectare (derived using equation 3.6 in chapter 3) are evaluated per crop rotation. The rotation chosen was the most popular crop rotation among survey respondents for the tillage system. The fact that two tillage systems being compared employ different crop rotations is not a concern because the study attempts to study the tillage system with the crop rotation that is most popular with that tillage system. This facilitates an evaluation of the management systems and not a particular crop. The economic profit of each tillage system is evaluated as a 10 and 30 year cumulative expected yield, mean return and risk (keeping prices constant).

**5.5 Emissions Sub Model**

The three largest components of net GHG abatement in agriculture are the quantity of carbon sequestered as SOC, soil $N_2O$ emissions and emissions associated with farm fuel use. A less significant source of emissions are those resulting from the manufacture of other farm related inputs including fuel, fertiliser, and agro-pesticides. These emissions are referred to as 'embodied emissions'. The purpose of the emissions sub-model is to estimate the net GHG emissions from the simulated management systems by calculating the above-discussed emission levels for each rotation and management. Each of these categories will be discussed in more detail in this section.

Soil organic carbon sequestration is derived from the environment component of the model. The model simulates conversion of crop growth to crop residues and crop residues to either sequestered SOC or emitted as $CO_2$. Crop residues enter the soil as surface trash. The amount of carbon in the surface trash is a function of crop yield, reflecting biomass production, and crop type, reflecting type of residue. The rate of change in the SOC stock is determined by the rate of SOC formation and the rate of decomposition, which in turn are determined by soil N and soil moisture (Belcher, 1999). In the simulation model the initial value of SOMC is set at 80 tonnes per hectare and surface trash at 4.2 tonnes per hectare. The trade-off analysis measures net GHG sequestered in $CO_2$ equivalent, hence the carbon sequestered would be multiplied by the ratio of molecular weight of $CO_2$ to the atomic weight of carbon, 3.667.

In accounting for soil $N_2O$ emissions, the Emissions component of the model follows the accounting system recommended in the IPCC Guidelines (1996), which are divided into direct and indirect emissions (from atmospheric deposition of $NH_3$ and NOx). Direct emissions are where $N_2O$ is emitted directly to the atmosphere from cultivated soils and fertilized and/or grazed grassland systems. Indirect emissions result from transport of N from agricultural systems into ground and surface waters through drainage and surface runoff, or emission as ammonia or nitrogen oxides and deposition elsewhere, causing NO production. Both direct and indirect emissions in the simulation model are a function of the (endogenously determined) inorganic nitrogen fertiliser added and their respective direct and indirect emissions coefficients. To calculate direct emissions all the N input to the soil, through N-fixing crops, crop residue and from additions of synthetic N ferilizer, are estimated. The N input to the soil from N-fixing crops ( kg N/ha) is calculated as follows:

$$F_{BN} = 2 * Crop_{BF} * Frac_{NCRBF} \qquad (5.5)$$

Where:

$F_{BN}$ - N input to the soil from N-fixing crops (kg N/ha)

The factor 2 converts crop production to total crop biomass (IPCC, 1996)

$Crop_{BF}$ – Dry pulses and soy beans produced (kg/ha/yr). In case dry biomass is unavailable, multiply yield by 0.85 (IPCC Guidelines, 1996)

$Frac_{NCRBF}$ – Fraction of N in N-fixing crop (0.03 kg N / kg dry biomass – IPCC,(1996))

The N input to the soil from crop residue (kg N/ha) is calculated as:

$$F_{CR} = 2 * Crop_o * Frac_{NCRO} * (1 - Frac_R) * (1 - Frac_{BURN}) \qquad (5.6)$$

*note: substitute* $Frac_{NCRBF}$ *for* FracNCRO *if the crop is a legume*

where:

$F_{CR}$ - N input to the soil from crop residue (kg N/ha)
The factor 2 converts the crop production to total crop biomass (IPCC, 1996)
$Crop_O$ – Dry production of other crops (kg/yr). In case dry biomass is unavailable, multiply yield by 0.85 (IPCC Guidelines, 1996)
$Frac_{NCRO}$ - Fraction of N in non N-fixing crop (0.015 kg N / kg dry biomass for non-N-fixing crops and 0.03 fro N-fixing crops –IPCC Guidelines, (1996))
$Frac_R$ – Fraction of crop residue removed from field as crop (0.45 –IPCC Guidelines, (1996))
$Frac_{BURN}$ - Fraction of crop burned (0.1 in developed countries-IPCC Guidelines, (1996))
The N input from synthetic fertiliser are calculated as:

$$F_{SN} = N_{FERT} * (1 - Frac_{GASF}) \quad (5.7)$$

where:
$F_{SN}$ - N input from synthetic fertiliser excluding emissions of $NH_3$ and NOx (kg N/ha)
$N_{FERT}$ – total (endogenous) synthetic fertiliser (kg N / yr)
$Frac_{GASF}$ - Fraction of synthetic fertiliser N volatilised as NOx + $NH_3$ (0.1 kg NH3-N + NOx-N per kg of fertiliser N applied – IPCC, 1996))

It should be noted that this part of the calculation does not consider emissions of $NH_4$ and $N_2O$ (Kg N/ha). All three sources of N addition to the soil contribute to direct $N_2O$ emissions from the soil (tonnes $CO_2$ equivalent/ ha), which is calculated as follows:

$$N_2O = \frac{EF_1 * (F_{BN} + F_{CR} + F_{SN}) * 44 * 310}{28 * 1000} \quad (5.8)$$

where:
$EF_1$ - $N_2O$ emission factor for direct emissions (0.0125 kg N2O N/kg N input (IPCC, 1996))

$F_{BN}$, $F_{CR}$ and $F_{SN}$ are as discussed above

310/1000 converts kg $N_2O$/ha into tonnes $CO_2$ equivalent /ha

44/28 is the ratio of the molecular weight of $N_2O$ to the molecular weight of $N_2$

The indirect emissions (from atmospheric deposition of $NH_3$ and $NO_x$) is comprised of emissions from leaching and emissions from volatilisation which are both functions of inorganic N fertiliser, and of their relevant emission coefficients. The quantity of fertiliser N that leaches from the soil (kg N/ha) is calculated as follows:

$$N_2O = N_{FERT} * Frac_{LEACH} \tag{5.9}$$

where:

$N_2O_{(L)}$ - the quantity of fertiliser N that leaches (kg N/ha)

$N_{FERT}$ – total (endogenous) synthetic fertiliser (kg N/ha/ yr)

$Frac_{LEACH}$ = Fraction of fertiliser that leaches (0.3 kg N/kg fertiliser applied – IPCC Guidelines, 1996)

The quantity of fertiliser N that volatilises (kg N/ha/yr) is calculated as follows:

$$N_2O_{(G)} = N_{FERT} * Frac_{GASF} \tag{5.10}$$

where:

$N_2O_{(G)}$ – Quantity of fertiliser N that volatilises (kg N/ha)

$N_{FERT}$ – total (endogenous) synthetic fertiliser (kg N/ha/yr)

$Frac_{GASF}$ - Fraction of synthetic fertiliser N volatilised as NOx + $NH_3$ (0.1 kg NH3-N + NOx-N per kg of fertiliser N applied-(IPCC , 1996))

The fraction of N that volatilises may not necessarily be in the form of $N_2O$. It could be in any other gaseous form of N. A fraction of these nitrogenous gases would be converted $N_2O$. When both, the N that leaches and the N that volatilises are calculated, these values are added and multiplied by their respective emission coefficients to calculate the total Indirect $N_2O$ emissions as follows:

$$N_2O_{(I)} = \frac{310 \ x \ 44 \ x \ [(N_2O_{(G)} \ x \ EF_4) + (N_2O_{(L)} \ x \ EF_5)]}{1000 \ x \ 28} \tag{5.11}$$

where:

$N_2O_{(I)}$ = Indirect $N_2O$ emissions from leaching and volatilisation (kg/ha/yr)

$EF_4$ = Emission factor for N volatilised. 0.01(0.002 –0.02) kg $N_2O$-N per kg $NH_3$-N emitted (IPCC,1996)

$EF_5$ = Emission factor for N leached 0.025 (0.002 – 0.12) kg $N_2O$-N per kg N leached or runoff per year

44/28 is the ratio of the molecular weight of $N_2O$ to the molecular weight of $N_2$

310/1000 converts kg $N_2O$/ha into tonnes $CO_2$ equivalent /ha.

It should be noted that due the extreme temporal and spatial variability in $N_2O$ emissions and therefore the high degree of uncertainty associated with $N_2O$ emissions from agriculture, the coefficients for $N_2O$ emissions from N that leaches and volatilises are subject to wide variation (IPCC, 1996 and Desjardins and Riznek, 2000).

With respect to IPCC (1996), energy based emissions related to agriculture refer solely to on farm fuel based emissions (eg. emissions of $CO_2$, $CH_4$ and $N_2O$ that arise only from burning fuel on farm machinery). The quantity of total on-farm emissions in the model is the product of the fuel use and the individual emissions coefficients for $CO_2$, $CH_4$ and $N_2O$. The quantity of fuel used, which is exogenous in the model, is taken from the economic component of the model. How the individual emission coefficients were derived is described below. The emission coefficient for $CO_2$ arising from the on farm use of fuel ($CO_2$ tonnes /L) is calculated as follows:

$$CO_2 = \frac{(NCF * CEF * 99\% * 44/12)}{VOL} \tag{5.12}$$

where:

$CO_{2(F)}$ = The emission coefficient for $CO_2$ arising from the on farm use of fuel ($CO_2$ tonnes /L/year)

NCF = Net Calorific Value (43.33 Tera joules/ 1000 tonnes diesel -IPCC Guidelines, 1996))

CEF = Carbon Emission Factor of diesel (20.2 tonnes C / Tera joule of diesel -IPCC Guidelines, (1996))

99% = percentage of C that is oxidised (IPCC Guidelines, 1996)

44/12 = molecular weight of $CO_2$/ atomic weight of C

VOL = volume of 1000 tonnes of diesel ($10^6$ x 0.85 )

The emission coefficient for $CH_4$ emissions arising from the on farm use of fuel is calculated as follows ($CH_4$ tonnes / L):

$$CH_{4(F)} = \frac{(NCF \times CH_4EF)}{VOL} \qquad (5.13)$$

where:

$CH_{4(F)}$ - The emission coefficient for $CH_4$ arising from the on farm use of fuel ($CH_4$ tonnes /L)

$CH_4EF$ = CH4 Emission Factor (5kg $CH_4$/ Tera joule of diesel –IPCC, 1996))

The emission coefficient for $N_2O$ emissions arising from the on farm use of fuel is calculated as follows ($N_2O$ tonnes /L):

$$N_2O_{(F)} = \frac{(NCF \times N_2OEF)}{VOL} \qquad (5.14)$$

where:

$N_2O_{(F)}$ - $N_2O$ emissions arising from the on farm use of fuel ($N_2O$ tonnes /L)

$N_2OEF$ = $N_2O$ Emission Factor (0.6 kg $N_2O$ / Tera joule of diesel – IPCC , 1996))

The emissions sub-model calculates the total emissions from energy use using these estimates. The IPCC Guidelines do not consider embodied emissions, or those generated during the manufacture of fertiliser, fuel, machinery and pesticides, under emissions accounting for the agriculture sector. This study includes them to provide a more complete picture of total agricultural and induced emissions. Embodied emissions are estimated by the emissions sub-model by multiplying the specific input use value (quantity) by the respective emission coefficients obtained from Sobool and Kulshreshtha, (2004) (Table 5.4).

**Table 5.4 Embodied Emission Coefficients**

| Agriculture Induced Emission Input | Embedded Emission Coefficient and Unit |
|---|---|
| P fertiliser manufacture coefficient | 1.33E-03 t $CO_2$ equivalent/ kg P in fertiliser |
| N fertiliser manufacture coefficient | 1.836E-03 t $CO_2$ equivalent/ kg N in fertiliser |
| Machinery manufacture coefficient | 3.841E-04 t $CO_2$ equivalnt/ $ machinery |
| Pesticide manufacture emission coefficient | 4.677E-06 t $CO_2$ equivalent/ $ pesticide |
| Fuel manufacture emission coefficient | 4.98E-04 t $CO_2$ equivalent/ litre diesel |

(source: Sobool and Kulshreshtha, 2004)

## 5.6 Summary

This chapter described how the empirical aspects of the model were parameterised with respect to the Black soil zone. It begins by briefly describing how the model is initiated with the bio-physical properties of the Black soil zone and then continues by describing how the three sub components of the model are parameterised to reflect the farming practices of this soil zone. The three sub components included in the environmental component, an economic component and end emissions component. The next chapter describes how the model simulations results are used and an analysis of these results.

# CHAPTER 6
# SIMULATION RESULTS

## 6.1 Introduction

Having discussed the survey data and the parameterisation of the model in the previous chapter the current chapter will present the data provided by the simulation model and provide a discussion of the implications of these results. Across many provinces reduced tillage and summer-fallow are known to reduce $CO_2$ emissions, increase N fertiliser use which is associated with an increase in soil $N_2O$ emissions and increase soil C sinks. The policy of selecting from options of different tillage practices that would be both beneficial to GHG abatement and farm income. The primary objective of this study is to look at the net effects, the long-term effects on farm income and capacity to abate GHG abatement. The chapter commences by comparing the components of GHG abatement (section 6.2), components of net income (section 6.3), TOA between net abatement and net income (section 6.4) and economic risk (section 6.5) and discussing the implications for policy throughout.

## 6.2 Components of Net GHG Abatement

The model was used to simulate a 30-year time horizon for the identified crop rotations and tillage management options. The simulation output included each of the discussed GHG sources (fuel, soil and embedded emissions) and the carbon sink (SOC sequestration) components of the simulated farming systems. Each replication includes a stochastic weather component that results in different SOC and yield values that in turn creates a random distribution around an expected value of net income and net GHG abatement. Therefore, the 30-year simulations were run for 30 separate times in order to generate a distribution of output values. The following compares the expected values of the sources and the sink

Carbon sequestered in the soil was a function of such factors as crop yield, crop type, tillage, and the growing degree days. All three tillage systems started with 80 tonnes of soil organic carbon and were subject to the same biophysical and climatic conditions (growing degree days and thirty year historic precipitation), with the exception of mean daily temperature, which was the stochastic weather parameter mentioned earlier, the effect of which will be discussed in this section. Hence, all three systems commenced with the same exogenous climatic conditions and stocks such as soil organic matter carbon, surface trash, soil depth, and minerals.

### 6.2.1 Soil C Sequestration

Throughout the simulation period of 30 years, SOC sequestration was greatest for zero tillage, second for minimum tillage and lowest for conventional tillage (Table 6.1). This divergence kept increasing throughout the simulation period (Table 6.1 and Figure 6.1). The SOC stocks show an almost linear increase over time (Figure 6.1) and the increase seems associated with an increasing, albeit cyclical trend (which may be attributable to the precipitation trend(Figure 6.3)), in crop yield (Figure 6.2). This result that reduced till is able to sequester greater SOC agrees with the literature with respect to western Canada generally and specifically to Saskatchewan (Agriculture and Agri-Food Canada, 2000). More SOC is retained under reduced tillage because of the slower decomposition of crop residue and organic matter. Equation 5.2 states that SOC addition to the soil is positively influenced by crop residue addition to the soil and negatively influenced by crop residue decomposition. Now, equation 5.3 states that crop residue addition to the soil is positively influenced by crop yields and should crop yields be greater with reduced tillage this will contribute to greater SOC addition. Moreover, equation 5.4 states that crop residue decomposition is positively influenced by tillage intensity, hence, by reducing the intensity of tillage the rate of residue decomposition could be retarded and hence SOC addition increased. In general the reduced tillage cropping systems till have greater annual crop yields which result in greater crop residue additions to the soil which results in larger SOC stocks. In addition, reduced tillage frequency reduces residue decomposition rate which helps keep SOC stocks higher. Moreover, in the Black soil zone more crop residue is added to the soil because of greater crop yields. However, a greater increment in SOC sequestration was expected of reduced till from the Black soil zone of Saskatchewan  Agriculture and Agri-Food Canada, 2000; Soon and Clayton, 2002). The smaller than expected difference may be due to the fact that the model assumes that only N, P and water availability have an impact on annual crop yield.  The simulation assumes that all precipitation values used in the model were available at the correct time of the growing season, whereas in reality such precipitation could have been experienced at a time in which it did not contribute to crop growth. Further, the model does not capture any yield losses that may be attributed to early or late frosts or insect, weed or disease infestations. Such imperfections may contribute to an underestimate of the difference between SOC sequestered in reduced tillage systems as compared to conventional tillage systems. However, as previously discussed (in Chapter 2) the SOC sequestration with reduced tillage is labile and is easily oxidised if the farmer changes tillage practices from reduced tillage to conventional tillage systems. In argument for giving western Canadian soils recognition for such ephemeral C sinks one could suggest that most countries that have not considered soil conserving tillage practices are still in the stage of moving from A to B of Figure 2.4.  In defence of the reduced till strategy providing only labile C sinks, one may argue that restoring the lost SOC is what warrants merit. If society is concerned about the possibility of farmers returning to conventional tillage and oxidising the C sequestered incentives may be put in place to motivate the farmers to maintain appropriate management even after the soil reaches its carrying capacity. For example, to meet this objective a program that provides ongoing incentives even after reaching carrying capacity or require that the producer purchase C credits from another producer for oxidising the C thereby imposing a disincentive to mobilizing the soil carbon stock.

**Table 6.1 Mean SOC Stock At Every Fifth Year With Standard Deviation In Parentheses (t C/ Ha)**

| years | Conventional | Minimum | Zero |
|---|---|---|---|
| 5 | 85 (0.2) | 86 (0.2) | 87 (0.3) |
| 10 | 87 (0.3) | 89 (0.3) | 91 (0.3) |
| 15 | 89 (0.3) | 91 (0.3) | 94 (0.4) |
| 20 | 91 (0.3) | 95 (0.4) | 98 (0.4) |
| 25 | 92 (0.4) | 96 (0.5) | 101 (0.5) |
| 30 | 96 (0.4) | 99 (0.5) | 104 (0.5) |

Note:

Under a gamma distribution Belcher et al., (2003) came up with the following SOC annual sequestration values for conventional, minimum and zero till respectively: 0.19, 1.00 and 1.2 tonnes carbon per year after 50 years of simulation. This study gives 0.53: 0.63 and 0.80 tonnes carbon per year respectively for the same tillage systems but with 9 cm less of annual growing season precipitation and a 30-year simulation

### 6.2.2 Fuel Emission

The model was parameterised so that fuel use was exogenous in the model. The model was parameterised for each crop and cropping system as summarised in Table 6.2. It should be noted that peas were not a crop in conventional tillage cop rotation and summer-fallow was not used in minimum or zero tillage crop rotation. Fuel use has no stochastic component in the simulations, hence, there would be no variability within the 30 simulations. The 30-year cumulative $CO_2$ emission from fuel use for the three cropping systems were 3.2; 3.0 and 2.2 tonnes/ha $CO_2$ equivalent for conventional, minimum and zero tillage respectively. The literature suggested that lower fuel emissions were an advantage of reduced tillage to which was consistent with the survey results. That lower energy use as a result of reduced tillage is associated with the scaling down of tillage operations due to the change in practice. Under conventional tillage the farmer would have made three or more passes with tillage equipment to break up and bury the vegetative stubble from the previous crop and to break down soil clumps to ensure higher seed germination followed by the seeding operation as compared to reduced tillage systems where the farmer would make one or two passes where seeding is done directly into the stubble.

### 6.2.3 Soil $N_2O$ Emissions

The discussion in chapter 3, where the emissions sub-model was analysed, explained that soil $N_2O$ emissions from crops are a function of inorganic nitrogen fertiliser quantity, crop nitrogen content (a function of crop type), yield, tillage system, residue management and a vector of emission coefficients. The coefficients have temporal and spatial variability such that the values discussed below for soil $N_2O$ emissions should be interpreted with caution, since there is a high degree of uncertainty associated with these coefficients. A discussion of the other variables that these emissions are a function of will precede an estimate of soil $N_2O$ emissions.

The quantity of inorganic fertiliser applied to annual crops largely helps to determine the nitrogen input to the soil that would be available for emission from the soil as $N_2O$ (Table 6.2). The quantity of N fertiliser to be applied is negatively influenced by SOC available, because SOC itself contains N. The results indicate that within the first ten years total cumulative fertiliser added to the soil in zero tillage and minimum tillage was almost 20 kg greater than for conventional tillage. In the second ten-year period this difference, though reduced, was still evident. At first, this difference was thought to be attributable to either the difference in crops in the rotation (as the conventional till rotation does not have a legume whereas the two reduced till rotations do not leave their land fallow) or it was thought to be attributable to difference in tillage intensity, or both.

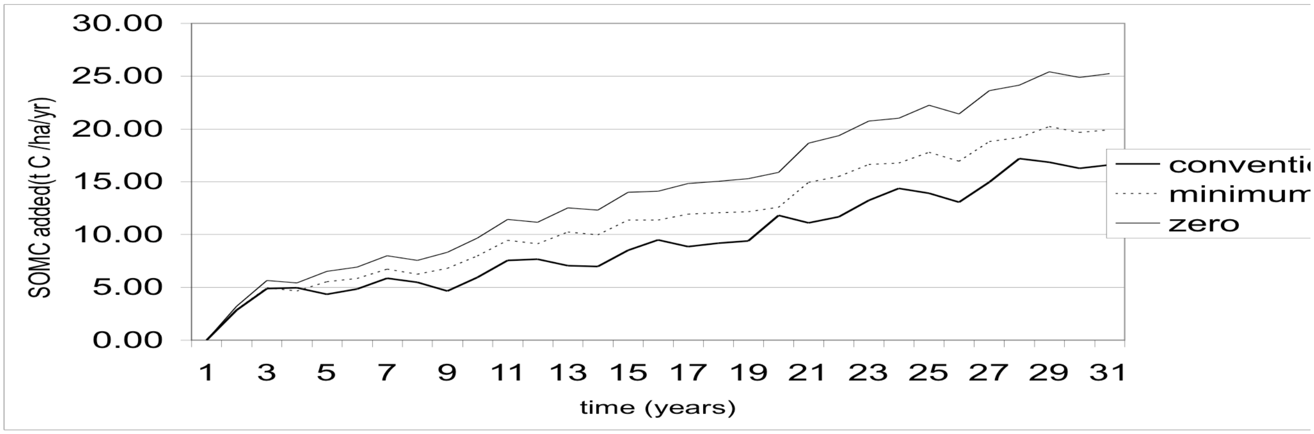



**Figure 6.1 SOC addition by tillage system over time**

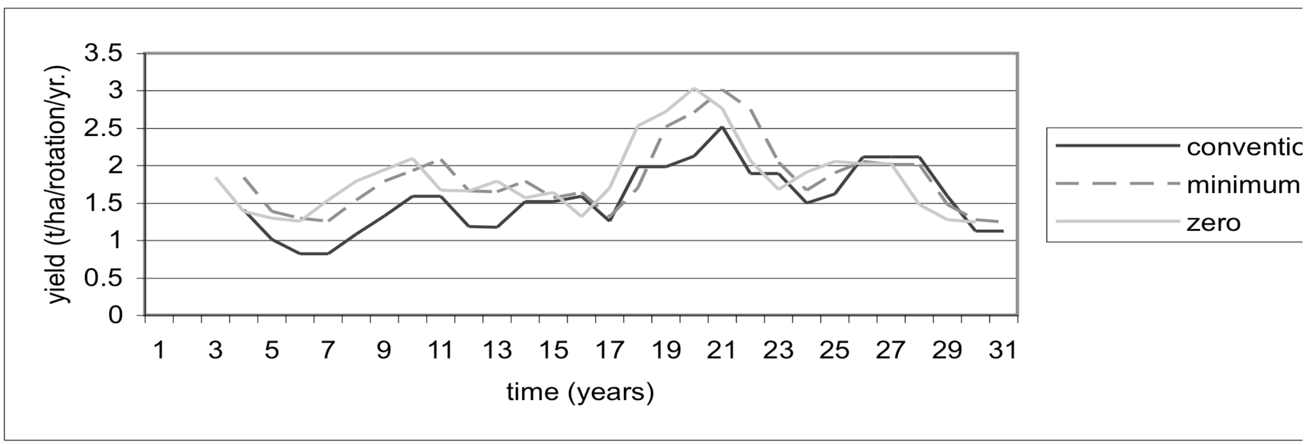



**Figure 6.2 Simulated Annual Rotational Crop Yield**

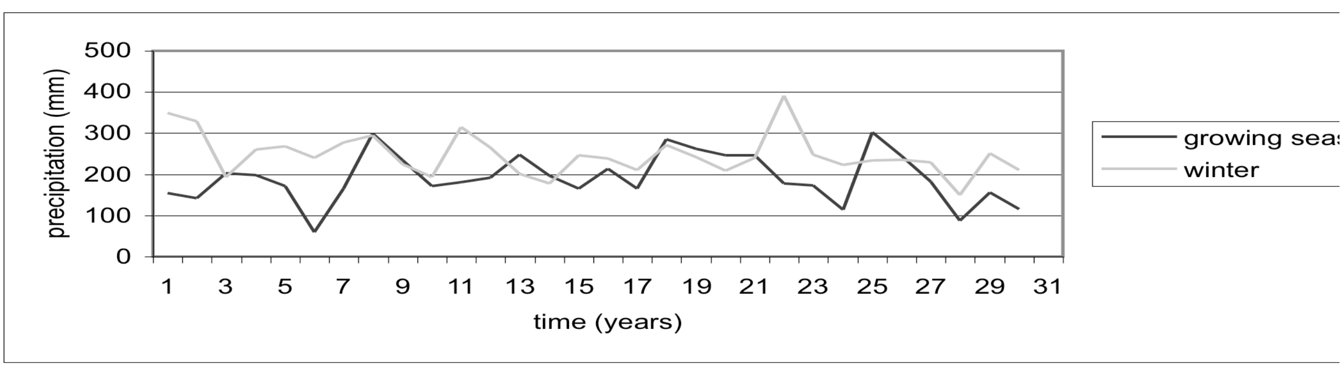



**Figure 6.3 Annual Precipitation 1971-2001 from the Yorkton weather station**

However, difference in tillage intensity could be ruled out, at least for the first 20 years, since the minimum till and zero till rotations (which have different tillage intensities) still had the same fertiliser quantity applied. Hence, it is believed that the difference in fertilizer input during the first 20 years was attributed to the difference in crop rotation. This difference in fertiliser use between conventional till and reduced till has been explained by Desjardins et. al., (2002) as follows; the conversion to reduced tillage has reduced the need to summer-fallow[15], and the reduced area under summer fallow has increased the area under cultivation (intensification of cropping system). Intensification of cropping systems has led to both the increased need for nitrogen fertiliser and increased legume crop production, which adds greater quantities of nitrogen to the soil. The addition of greater quantities of nitrogen to the soil *may* subsequently enhance $N_2O$ emissions[16]. Reduced tillage rotations include a legume, which is capable of fixing nitrogen. The legume in the reduced till rotation is capable of fixing enough N that it compensates for the greater quantity of N fertiliser applied because of the intensification in land use,

**Table 6.2 Cumulative N Fertiliser Used with Time, Crop Type and Cropping System for 30 Years. (Kg /ha/year)**

| Year | Crop | Conventional | | Crop | Minimum | | Zero | |
|---|---|---|---|---|---|---|---|---|
| | | Mean | s.d.* | | Mean | s.d. | Mean | s.d. |
| 1 | wheat | 100 | 0.00 | wheat | 100 | 0.00 | 100 | 0.00 |
| 2 | barley | 100 | 0.00 | legume | 100 | 0.00 | 100 | 0.00 |
| 3 | fallow | 176 | 0.00 | barley | 176 | 0.00 | 176 | 0.00 |
| 4 | canola | 254 | 0.00 | canola | 254 | 0.00 | 254 | 0.00 |
| 5 | wheat | 338 | 0.00 | wheat | 338 | 0.00 | 338 | 0.00 |
| 6 | barley | 338 | 0.00 | legume | 338 | 0.00 | 338 | 0.00 |

15 Because reduced tillage has shown to as good as conventional till (and in the Black soils) at conserving soil moisture than summer fallow.

16 A caveat has to be expressed here as the effect of less disturbed soil and greater mulch cover may help counter this – there is insufficient information to express the net effect

| | | Conventional | | | Minimum | | Zero | |
|---|---|---|---|---|---|---|---|---|
| 7 | fallow | 422 | 0.00 | barley | 422 | 0.00 | 422 | 0.00 |
| 8 | canola | 528 | 0.26 | canola | 529 | 0.24 | 528 | 0.26 |
| 9 | wheat | 615 | 0.26 | wheat | 616 | 0.24 | 615 | 0.26 |
| 10 | barley | 615 | 0.26 | legume | 616 | 0.24 | 615 | 0.26 |
| 11 | fallow | 708 | 0.26 | barley | 709 | 0.24 | 708 | 0.26 |
| 12 | canola | 786 | 0.26 | canola | 787 | 0.24 | 786 | 0.26 |
| 13 | wheat | 872 | 0.26 | wheat | 873 | 0.24 | 872 | 0.26 |
| 14 | barley | 872 | 0.26 | legume | 873 | 0.24 | 872 | 0.26 |
| 15 | fallow | 950 | 0.26 | barley | 951 | 0.24 | 950 | 0.26 |
| 16 | canola | 1027 | 0.26 | canola | 1028 | 0.24 | 1027 | 0.26 |
| 17 | wheat | 1100 | 0.26 | wheat | 1100 | 0.24 | 1100 | 0.26 |
| 18 | barley | 1100 | 0.26 | legume | 1100 | 0.24 | 1100 | 0.26 |
| 19 | fallow | 1196 | 0.26 | barley | 1195 | 0.24 | 1196 | 0.26 |
| 20 | canola | 1274 | 0.26 | canola | 1273 | 0.24 | 1274 | 0.26 |
| 21 | wheat | 1365 | 0.26 | wheat | 1365 | 0.24 | 1365 | 0.26 |
| 22 | barley | 1365 | 0.26 | legume | 1365 | 0.24 | 1365 | 0.26 |
| 23 | fallow | 1446 | 0.26 | barley | 1446 | 0.24 | 1446 | 0.26 |
| 24 | canola | 1506 | 0.26 | canola | 1503 | 0.24 | 1506 | 0.26 |
| 25 | wheat | 1609 | 0.26 | wheat | 1606 | 0.24 | 1609 | 0.26 |
| 26 | barley | 1609 | 0.26 | legume | 1606 | 0.24 | 1609 | 0.26 |
| 27 | fallow | 1687 | 0.26 | barley | 1684 | 0.24 | 1687 | 0.26 |
| 28 | canola | 1737 | 0.26 | canola | 1729 | 0.24 | 1737 | 0.26 |
| 29 | wheat | 1815 | 0.26 | wheat | 1807 | 0.24 | 1815 | 0.26 |
| 30 | barley | 1815 | 0.26 | legume | 1807 | 0.24 | 1815 | 0.26 |
| 31 | canola | 1904 | 0.26 | canola | 1896 | 0.24 | 1904 | 0.26 |

Note:* standard deviation of fertiliser use among 30 simulations

Other factors that influence the quantity of inorganic N being added to the soil in the simulation model are crop yield, crop type and residue management. These three factors affect the size of the SOC stock, which consists of N, and hence has an impact on the quantity of N fertiliser required. The Emissions component of the model considers the aforementioned three factors and the nitrogen entering the soil through fertiliser and makes an $N_2O$ emission estimate (Table 6.3) with the use of a set of emission coefficients recommended by the IPCC (1996). As expected the emission estimates are positively correlated with the quantity of N fertilizer added to the soil and the stock of N in the soil. The reduced till cropping system emitted greater quantities of $N_2O$ during the first 20 years, but the reduced tillage cropping systems have greater emissions in the last 10 years of the 30-year simulation horizon. These results are consistent with results from comparable studies in the literature. For example, Six et. al., (2004) reported that over a period of 20 years the soil $N_2O$ emissions were less for reduced till than for conventional till. However, their study was for soils in the temperate climatic zone.

**Table 6.3 Cumulative Simulated Soil $N_2O$ Emissions (t $CO_2$ e. /ha)**

| Years | Conventional | Minimum | Zero |
|---|---|---|---|
| 10 | 6.6 | 6.8 | 6.8 |
| 20 | 12.9 | 13.1 | 13.1 |
| 30 | 18.7 | 18.2 | 18.3 |

Note: Boehm, (2004 c) indicates that Saskatchewan farmland emit soil $N_2O$ emissions of approximately 0.3 tonnes $CO_2$ equivalent per hectare per year. Based on IPCC coefficients this simulation produces approximately 0.6 tonnes $CO_2$ equivalent per hectare per year.

### 6.2.4 Embodied Emissions

The previous section discussed the *on-farm* emissions resulting from the consumption of fuel and fertiliser. This section discusses the emissions that result from the manufacture of fuel, fertiliser, machinery, pesticide inputs used in the farm operations. Fertiliser based embodied emissions are the product of the total quantity of both N and P based fertiliser and their respective emission coefficients as discussed in section 6.2.3. The quantity of fertiliser based embodied emissions is consistent, primarily with the quantity of N fertiliser applied. The fertiliser based embodied emissions are displayed on Table 6.4.

**Table 6.4 Fertiliser use and Embodied GHG Emissions (30-year)**

| | Conventional | Minimum | Zero |
|---|---|---|---|
| Cumulative N fertiliser Use (kg N/ ha) | 1,940 | 1,896 | 1,904 |
| Cumulative P fertiliser Use (kg P/ ha) | 68 | 105 | 106 |
| N fertiliser - Embodied Emissions (t $CO_2$ e. /ha) | 3.6 | 3.5 | 3.5 |
| P fertiliser - Embodied Emissions (t $CO_2$ e./ha) | 0.1 | 0.1 | 0.1 |
| Total fertiliser - Embodied Emissions (t $CO_2$ e./ha) | 3.7 | 3.6 | 3.6 |

Notes:
- P fertiliser embodied emission coefficient =0.00133 t $CO_2$ e./ kg fertiliser P/ ha (Sobol and Kulshreshtha, 2004)
- N fertiliser embodied emission coefficient=0.00184 t $CO_2$ e./ kg fertiliser N/ ha (Sobol and Kulshreshtha, 2004)

None of the literature reviewed specifically indicated how embodied emissions were effected by tillage practices. The discussion in chapter 5 of the present study explained how the fuel based embodied emissions were the product of fuel consumed and the fuel based embodied emission coefficient, the former being elicited from interviews and the latter from Sobool and Kulshreshtha (2004). The emission coefficients are constant and hence fuel based embodied emissions have a linear relationship with fuel use. As expected, farm fuel embodied emissions are proportional to on-farm fuel emissions (Table 6.5). However, fuel embodied emissions represent only about 15% of the total GHG emissions associated with fuel use (Table 6.8).

**Table 6.5 Fuel Based Embodied Emissions**

| | conventional | minimum | zero |
|---|---|---|---|
| Total 30-year fuel consumed (litres/ha) | 1,181 | 1,120 | 795 |
| Cumulative fuel based embodied emissions (t $CO_2$ e. /ha) | 0.6 | 0.6 | 0.4 |

Note:
Embodied fuel emission coefficient 0.000498 t $CO_2$ e./litre diesel/ ha (Sobol and Kulshreshtha, 2004)

Farm machinery, aside from the fuel use component already discussed, does not give rise to direct on-farm emissions, however, the machinery manufacturing process requires energy giving rise to GHG emissions. The method of calculating machinery based embodied emissions in this model is the product of the dollar value of machinery and the embodied emission coefficient (Sobool and Kulshrestha, 2004). Moreover, reduced till may involve greater machinery requirements resulting in greater machinery based embodied emissions. The cumulative emissions by cropping system indicate that minimum tillage has greater machinery expenditure and hence higher embodied emissions (Table 6.6). Machinery based embodied emissions are the second largest embodied emission component after fertiliser based embodied emissions, but however, are small compared to the on-farm fuel emissions like fuel and fertiliser (table 6.8)

**Table 6.6 Machinery based Embodied Emissions**

| | conventional | minimum | zero |
|---|---|---|---|
| Total 30-year machinery investment ($/ha) | 2,513 | 3,140 | 2,191 |
| Cumulative 30-year machinery based embodied emissions (t $CO_2$ e./ha) | 1.08 | 1.32 | 1.01 |

Note:
embodied machinery emission coefficient 0.000384127t $CO_2$ e./$ machinery/ ha (Sobol and Kulshreshtha, 2004)

The manufacture of farm pesticides requires energy, just as all the other farm inputs. Pesticide based embodied emissions are computed as the product of pesticide cost and an emission coefficient, which was discussed in chapter 5 . The results indicate zero till had the highest and conventional till the lowest pesticide embodied emissions related to the pesticide requirements for each of these systesm.

**Table 6.7 Pesticide Based Embodied Emissions**

| | Conventional | Minimum | Zero |
|---|---|---|---|
| Total 30-year glyphosate cost ($/ha) | - | 247 | 256 |
| Total 30-year other pesticide cost ($/ha) | 1,195 | 1,631 | 1,741 |
| Cumulative 30-year pesticide based embodied emissions (t $CO_2$ e./ha) | 0.006 | 0.009 | 0.009 |

Note:
embedded pesticide based emission coefficient 4.67704E-06 t $CO_2$ e./$ pesticide/ ha (Kulshreshtha, 2004(a))

### 6.2.5 Simulated Net GHG Abatement

Having discussed the components used to calculate baseline net GHG abatement for the three tillage systems, they are now summarised and presented together in this section (Table 6.8). Total net GHG abatement is the size of GHG sinks after netting off sources, expressed in $CO_2$ equivalent. The simulation results indicate that net GHG abatement is greatest in zero till, followed by minimum till and conventional till. The reason for the greater abatement in the reduced tillage systems is primarily due to the larger quantity of C sequestered in reduced tillage systems. The lesser soil $N_2O$ emission with reduced tillage, both direct and embodied, was the result of reduced N fertiliser being required with reduced tillage. The reduced fuel emission with reduced tillage was also the result of reduced fuel use. The Table 6.8 provides perspective of the components of net GHG abatement. It shows that the largest influence on net GHG abatement comes from SOC sequestration. Thus, it may be most effective to direct policy toward enhancing SOC sequestration. Following SOC sequestration, as a distant second in importance is soil $N_2O$ emission reduction, which should receive importance in policy direction second only to SOC sequestration. Next, in importance are fuel emissions and embodied emissions in the manufacture of fertiliser. The other embodied emissions are not a large influence on net GHG emissions.

**Table 6.8 Simulated Net GHG Abatement For The Three Management Systems (T $CO_2$ E. / Ha / 30 Years)**

| | conventional | minimum | Zero |
|---|---|---|---|
| C sequestration* | 59 | 70 | 88 |
| On-farm fuel emissions | - 3.2 | - 3.0 | - 2.2 |
| Soil $N_2O$ emissions** | - 18.7 | -18.2 | -18.3 |
| Embodied emissions | | | |
| - fertiliser | -3.7 | -3.6 | -3.6 |
| - fuel | -0.6 | -0.6 | -0.4 |
| - machinery | -1.08 | -1.32 | -1.01 |
| - pesticides | -0.006 | -0.009 | -0.009 |
| Net GHG Abatement* | 32 | 43 | 62 |

Note:

* differences among expected net GHG abatement values among tillage systems were statistically significant ($p < 0.05$)

## 6.3 Net Income

The previous section disaggregated and aggregated the first of the two components of the study, net GHG abatement, now the study begins to focus on simulated results of the second component of the study, the economic component. The economic indicator used is net income from the sale of crops produced, net of cash costs, per hectare, and per crop rotation. The simulated mean annual gross revenue was larger for reduced till because of a greater annual crop yield per rotation compared with conventional till. Crop yields were approximately 18 per cent greater for both reduced tillage systems compared with conventional. These values are consistent with values collected during the farmer survey which revealed yield advantages associated with reduced tillage of between six and 20 percent. Further, a study by Lafond et al. (1993) reported yield advantages in the Black soil zone of between 10 and 20 percent. Further, Gray et al. (1996) reported yield advantages for reduced tillage systems over conventional tillage of between zero and 18 percent in the Indian Head Saskatchewan area (Black soil zone). The impact of including high value crops such as field pea and flax in crop rotations combined with improved yields under reduced tillage resulted in a more favourable economic return in these studies (Lafond et. al., 1996).

Despite the fact that the zero and minimum tillage systems had higher yields in the simulations these systems had lower average net income than the conventional rotation by $45 and $18 respectively (per rotation, per hectare, per year). This lower income for the reduced tillage systems was largely due to pesticide costs that were on average $22/ha/yr and $15/ha/yr higher for the zero and reduced tillage systems respectively. An important production cost difference between the conventional and reduced tillage systems in the simulation was pesticide costs, and in particular the costs of glyphosate. Based on the simulation results it was estimated that herbicide costs would need to decline by 58% and 28% for minimum till and zero till, respectively, for these systems to be at least as profitable as conventional till. At this point it is not difficult to understand why the simulated minimum tillage system was so unprofitable.

To use the reasoning by Lafond et. al., (1993) while the minimum tillage management practice still has to retain machinery that is needed for some limited tillage ,and perhaps partial burying of stubble in the soil, the minimum tillage practice does still require nearly as much herbicide as the practise of zero tillage does .

In addition, input costs associated with machinery were potentially an important factor in the relative profitability of the simulated tillage systems. SAFRR (2004) budgeted machinery costs, based on a 425 ha farm, for minimum tillage and zero tillage that were on average \$20/ha/yr and \$5/ha/yr greater than conventional till, respectively (Table 6.9). The survey indicated that farmers had expanded their land after converting to reduced tillage, although this may not be a significant indication that reduced tillage farming systems are generally larger than conventional till farming systems. However, it was evident from the survey that reduced till helps reduce the farm (hired and owner/operator) labour required. Thus, it is safe to assume that the reduced farm labour required may enable the farmer to cultivate more land with the same labour as before the change to reduced tillage. There is likelihood that larger farm size may provide economies of size that makes reduced till more profitable or at least competitive with conventional till. Based on the simulated results of net income, to be at least as profitable as conventional tillage, in the (30-year) long-term simulation, minimum tillage and zero tillage would require machinery costs to be reduced by 20% and 35% respectively. However, reduced tillage did not produce large savings with respect to fuel (between \$1 and \$5 per ha.) or for labour (between \$0 and \$3 per ha.) for minimum till and zero till, respectively. Besides the caveat expressed with respect to economies of size that have not been factored in to the profitability calculations, another caveat is that the costs derived from SAFRR are derived from the farmers who used the highest level of inputs and are likely not representative of the average farmer (Schoney, 2004 b).

### 6.3.1 Returns to Size

As discussed earlier, returns to size may be an important factor influencing the production costs of the reduced tillage systems simulated in this research. The production costs that would most likely be influenced by returns to size would be fixed costs and overhead such as farm machinery, farm buildings, labour and management.

**Table 6.9 Simulated Average Farm Production Costs And Average Net Income ($/Ha/Rotation/Year)**

| | Conventional | Minimum | Zero |
|---|---|---|---|
| Average Gross Revenue | 211 (5) | 249 (5) | 250 (5) |
| Fuel cost | 17 (0) | 16 (0) | 12 (0) |
| Labour cost | 9 (0) | 9 (0) | 6 (0) |
| Machinery cost | 82 (0) | 101 (0) | 89 (0) |
| Land | 43 | 43 | 43 |
| N fertiliser cost | 50 (0) | 49 (0) | 49 (0) |
| P fertiliser cost | 2 (0) | 3 (0) | 3 (0) |
| Glyphosate cost | - | 8 (0) | 8 (0) |
| Other pesticide cost | 39 (0) | 53 (0) | 56 (0) |
| Transport cost | 84 (1) | 97 (1) | 97 (1) |
| Seed cost | 22 (0) | 37 (0) | 37 (0) |
| Other cost | 102 (0) | 107 (0) | 107 (0) |
| Total Cost of Production | 450 | 523 | 507 |
| Net revenue* | -239 | -274 | -257 |

Note:
* expected net revenues are significantly different ($p<0.05$)
Standard deviation in parantheses

Variable costs such as fertiliser, pesticides and seeds would not be as influenced by returns to size. It was assumed in the simulation model that the size of the farms containing the simulated systems were consistent with the characteristics of those surveyed by SAFRR for the Black soil zone with a mean size of 425 hectares. The SAFRR (2004) data used to parameterise the model involved input cost data such as machinery, herbicide, and labour. It is likely that although some input costs like herbicide and seed costs remain unchanged other costs such as labour and machinery may differ by the size of the farm. Therefore, while returns to size may be an important factor in production costs it has not been factored into the model. Economies of size may result in minimum till and zero till farmers investing in larger equipment and decreasing tillage time thereby enabling them to complete greater areas of farm operations which may enable farmers to expand farm size and use their machinery on such expanded farms. Within the survey performed in this research project there were only three farmers with less than 425 hectares among the minimum till farmers surveyed and just one among the zero till. In fact in the survey population the mean size of farms was 1,000 ha for minimum tillage and 1200 ha for zero tillage.

The net worth (per ha) of machinery for minimum tillage and zero tillage could be lower than conventional tillage under two more conditions:

1. If the farmer is making the change towards the end of the life cycle of the machinery when he was going for machinery replacement anyway.
2. The difference between the existing tillage practice and the envisaged tillage practice is small.

Both of the above are supported anecdotally by Gray et al., (1996) who ran simulations for zero tillage assuming that machinery costs could at times be less than and other times greater than conventional tillage. The survey findings indicated that farmers adopting reduced tillage had little or no need to own cultivators, tandem disks and harrow packer bars obviously because their was no need to cultivate the soil, turn stubble over or pack the soil. Extra equipment such as extra tractors were sold because these tractors were previously used to run the cultivators and disks to cultivate the soil. Moreover, the adoption of reduced tillage may allow a producer to expand the land base farmed. This study has not included the impact of these economies in the simulation parameterization. As well, the time savings could be valued as opportunity cost of time spent with family or recreation (Gray et. al., 1996). There may also be pecuniary economies in purchasing other inputs that have not been captured. Pecuniary economies refer to the discounts that could be obtained when greater quantities of inputs such as seeds and fertiliser are purchased than previously. Although such returns to size have not been captured in the analysis particularly with respect to machinery, management and labour, a series of sensitivity analyses was performed using the simulation model to estimate the impact of these factors on the results. Specifically, sensitivity analysis was performed on machinery costs. The next section highlights the insights gained from this sensitivity analysis.

### 6.4 Scenarios and Sensitivity Analysis

The results that have been presented up to this point have been based on the specific assumptions of historic weather patterns, time horizons and emission coefficients. One of the strengths of simulation models in the type of analysis that is presented in this study is the flexibility to relax some of these assumptions to provide insight into function of the agricultural system. Therefore, the analysis previous to this section represents a baseline scenario. By changing the assumptions of baseline parameters sensitivity analysis can be performed on specific parameters. The specific scenario selected for this sensitivity analysis include changes in the relevant time horizon for net abatement analysis, changes in the IPCC $N_2O$ emission coefficients, a parameter with a high degree of uncertainty, and changes to the climate parameters to reflect climate change conditions (Table 6.10). The remainder of this section will present the TOA for the baseline scenario as well as each of the alternative scenarios highlighted in Table 6.10. In general the results are normalized to the conventional rotation such that the analysis focuses on the relative performance of the reduced tillage systems in the target landscape.

#### 6.4.1 Baseline Simulation and TOA

The baseline simulation assumed that historic weather for the Black soil zone would continue into the future and also that a mid value of IPCC (1996) soil $N_2O$ emission coefficients are appropriate.

The studies done for the economics of tillage systems (discussed in the literature review) in Saskatchewan have been focusing on the impacts that take place only after 5 to 10 years after the change in the practice. This study looks beyond the economic impact of 10 years, it looks at the impact after 30-years.

**Table 6.10. Characteristics Of The Baseline Simulations And The Sensitivity Analysis Simulations**

| Simulation | Description |
|---|---|
| 1 | A ten-year simulation, with historic weather and midpoint soil $N_2O$ emission coefficients (Direct [a] 1.25 %, Leaching [b] 1%, and Volatilisation [c] 1%). |
| 2 | A 30-year simulation, with historic precipitation (as simulation 1) and a midpoint of soil $N_2O$ emission coefficients (as simulation 1) (Baseline Simulation) |
| 3 | A 30-year simulation, with historic weather (as simulation 1) and the upper range of soil $N_2O$ emission coefficients (Direct 2.25%, Leaching 12%, Volatilisation 12%) |
| 4 | A 30-year simulation, with historic weather (as simulation 1) and the lower range of soil $N_2O$ emission coefficients (Direct 0.25%, Leaching 0.2%, Volatilisation 0.02%) |
| 5 | A 30-year simulation, with dry, warm weather and a midpoint of the range of soil $N_2O$ emission coefficients (as simulation 1) |

The results from the simulation model (Table 6.11) shows three key points with respect to timing of the results

a. Reduced tillage systems are relatively more profitable over the longer term compared to the short term. It is proposed that this is due to positive feed back of SOC, soil N and moisture that improves crop production which again produces greater SOC.

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[a] how much $N_2O$ evolves from the fraction of N that enters the soil through fertiliser, crop residues and legumes

[b] how much $N_2O$ tht evolves from the fraction of N that leaches from the N fertiliser that is applied

[c] how much $N_2O$ that evolves from the fraction of N that volatilises from the N fertiliser that is applied

b. Annual net abatement is relatively larger over the short term than over the longer term simulation. This result is possibly because the soil is reaching its carrying capacity in terms of SOC.

c. The trade-off in income for abatement is not largely different between the long-term and short-term. The trade-off is larger for minimum till than for zero-till.

The empirical trade-off curves are depicted in Figure 6.4. The Figure 6.4 shows the points where expected net revenue and expected GHG abatement for each of the three tillage systems reside, with the two reduced tillage systems being normalised to conventional tillage (conventional till being in the coordinates of zero for both net revenue and net abatement). The trade-off curves for zero tillage and minimum tillage each would be the straight line connecting the point representing each reduced tillage system and the point representing conventional tillage. The reader is advised to refer to the conceptual model of the trade-off curves depicted in Figures 3.1 and 3.2 (in chapter 3). The empirical result conforms to the negative or downward sloping section of the curve in Figure 3.1 or the section between A and B. The negative curve indicates that the two reduced tillage systems (zero till and minimum till each) need to forgo profit to gain abatement, when compared to conventional till.

### 6.4.2. $N_2O$ Emission Coefficients

The model estimates the direct $N_2O$ emissions based on the emission coefficient recommended in the IPCC (1996). Indirect $N_2O$ emissions are comprised of those emissions that are sourced from soil N that has been transported from the soil through volatilisation and leaching. Therefore, indirect emissions captures those $N_2O$ emission from soil N that are not captured in the direct emissions calculation. The model calculates indirect $N_2O$ emissions based on the estimates of leaching and volatilisation of the soil N stock and the emission coefficients for leached and volatised N recommended by the IPCC (1996).

**Table 6.11. Economic And GHG Abatement Performance Of Reduced Tillage Production Systems Relative To Conventional Tillage Under Alternative Emission, Time And Climate Scenarios.**

| | Relative rotation net income ($/ha/yr) | Relative rotation net GHG abatement (t $CO_2$ e/ha/yr) | Relative GHG abatement cost ($/t $CO_2$ e) | Relative C sequestration cost ($/t Carbon) |
|---|---|---|---|---|
| | | Long-term (Baseline) | | |
| Minimum* | -35 | 0.40 | 88 | 24 |
| Zero** | -20 | 1.10 | 18 | 5 |
| | | Short-term | | |
| Minimum* | -56 | 0.80 | 70 | 19 |
| Zero* | -41 | 1.50 | 27 | 7 |
| | | Highest $N_2O$ emission coefficient | | |
| Minimum* | -35 | 0.43 | 81 | 22 |
| Zero** | -20 | 1.10 | 18 | 5 |
| | | Lowest $N_2O$ emission coefficient | | |
| Minimum | -35 | 0.36 | 97 | 26 |
| Zero | -19 | 1.10 | 17 | 5 |
| | | Warmer drier weather | | |
| minimum | -48 | 0.27 | 178 | 48 |
| zero* | -35 | 0.73 | 48 | 13 |

Note: * - reduced till different from conventional till ($p<0.05$)

** - zero till different from both minimum and conventional till ($p<0.05$)

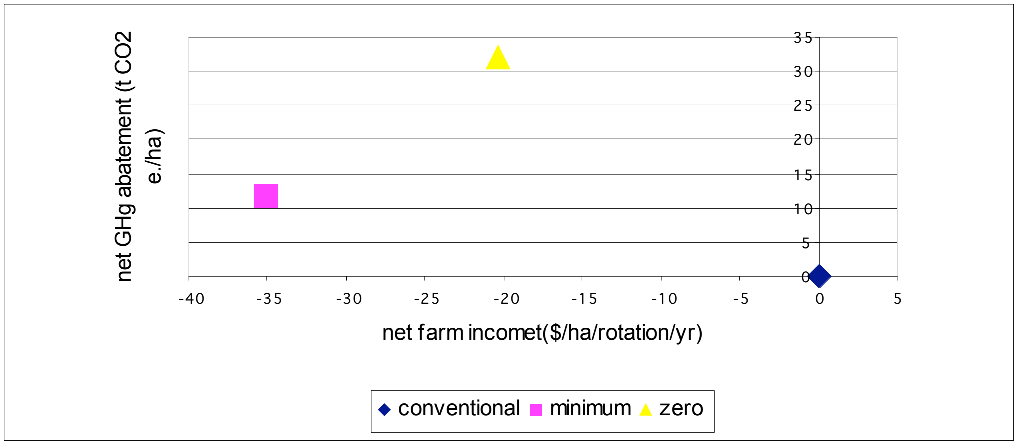



**Figure 6.4 Baseline TOA over 30-years**

It should be noted that $N_2O$ emissions are known to be highly stochastic and therefore the IPCC emission coefficients have a large degree of uncertainty. In response the sensitivity analyses on the emission coefficients to help to understand the impact of this uncertainty on GHG abatement policy. For the initial simulation an emission coefficient was chosen that falls in the middle of this range (as specified by the IPCC for emission accounting: direct emissions 1.25%; volatilisation 1%; leaching 2.5%). The simulation model was run using the highest emission coefficients published by the IPCC (direct emissions 2.25%, leaching 12%, and volatilisation 12%) and the lowest emission coefficients (direct emissions 0.25%, leaching 0.2%, and volatilisation 0.02%) (IPCC, 1996). As before, the reduced till results were normalised to the conventional tillage system to facilitate a relative comparison of the simulation results. The simulation results indicate that changing the emission coefficients seem to have little impact on the relative GHG abatement cost. Therefore, it seems that the TOA analysis is not very sensitive to changes in $N_2O$ emissions within the range specified in the IPCC guidelines (Table 6.12).

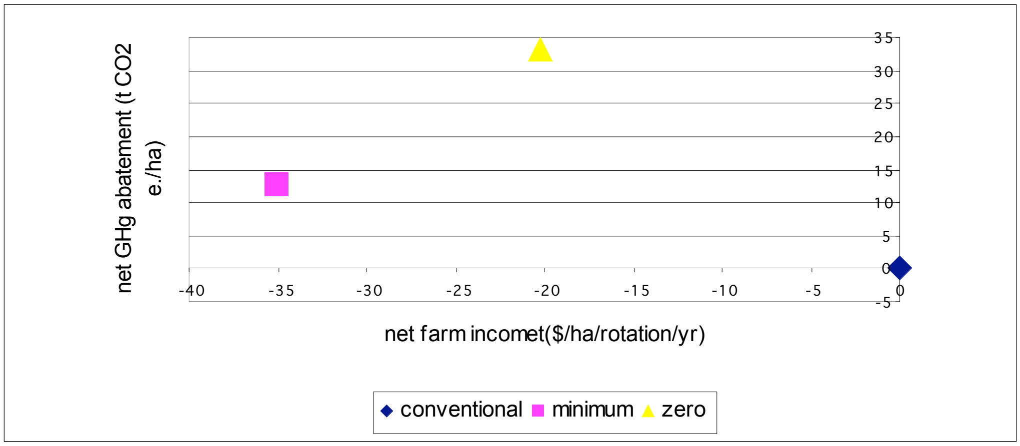



**Figure 6.5 TOA with the Highest Emission Coefficient**

### 6.4.3. Climate Change Weather Patterns

The impact of climatic conditions on the TOA results is also of interest in this study due to predictions of ongoing climate change. To assess the impact of this changing climate on climate change mitigation the simulation model was run using climate data that represents warmer, drier weather with a greater variability in temperature and precipitation. Specifically, growing season precipitation was decreased by 4 cm (to 16 cm), winter precipitation was decreased by 13 cm (to 12 cm) and the standard deviation of precipitation was increased by 2 cm (to 7 cm). In addition, mean daily temperature was increased by 0.2$^{o}$ Celsius to 2.2$^{o}$ Celsius. With these conditions the income and GHG abatement capacity of the reduced tillage systems is negatively impacted relative to the conventional tillage system (Table 6.12). The simulation indicates that under the given climate scenario the costs of GHG abatement increase dramatically relative to the conventional rotation. What does this imply? Encouraging farmers to practice reduced tillage, which is a policy to abate climate change, happens to become a less effective climate change mitigation policy. Thus, in designing policy to mitigate climate change it is important that analysis tools like TOA should not be considered under historic weather alone, but under a pattern of weather that is likely to be seen in the future. Cost of abatement should consider the costs of mitigation as well.

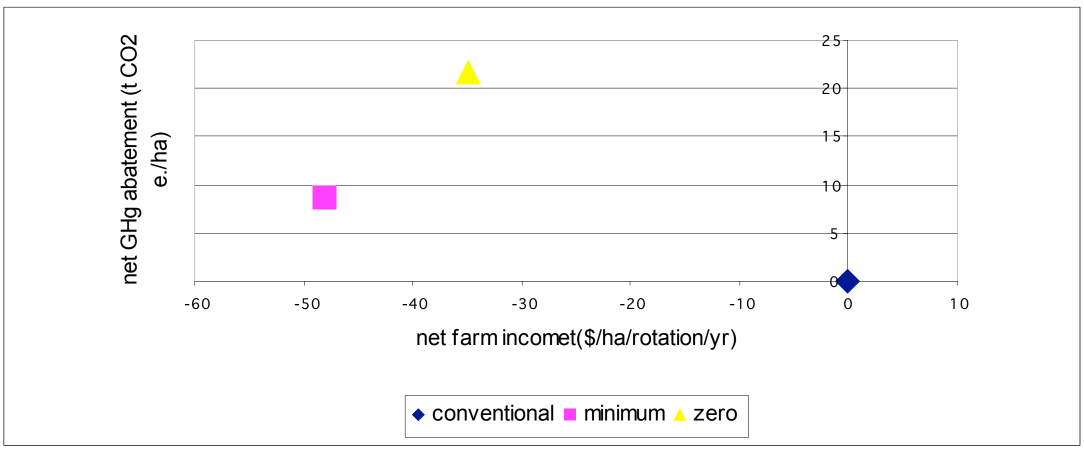



**Figure 6.6 TOA under Warmer Drier Weather**

### 6.5 Risk

The above analysis provided insight into the relative economic and GHG abatement trade-offs associated with reduced tillage annual crop production systems. The results quantified what the opportunity costs are when these production systems are adopted. However, simply compensating the farmer who adopts these alternative production systems such that they receive the same expected net farm returns would not make him/her indifferent between conventional till and reduced till. There must also be explicit consideration of the costs imposed due to the risk of the alternative management practices. Data provided by the simulations showed that the reduced tillage production systems were riskier than the conventional tillage system with the simulated standard deviation in yields for reduced till increased by approximately seven percent, compared with conventional. It should be noted that this is in contrast to some published data. For example Gray et. al. (1996) suggests that the standard deviation of yield would decline by 10 percent for reduced till compared with conventional till. Although, this study took place within the Black soil zone, it was for a shorter time frame, five years or less.

A tool that can be used to evaluate the relative risk and preferences for risky production systems is an evaluation of stochastic dominance analysis (Figure 6.7). In this research the stochastic dominance compares the cumulative probability distribution for each tillage system of net income (normalised to conventional till) after 30 years. The figure shows that the probability of net farm income being less than a given value is always smaller for conventional till and is therefore first order dominant. Hence, producers will choose conventional till over zero till and min till. (The stochastic dominance analysis in this study is not capable of discerning the utility among the risk neutral, risk averse and risk loving individuals). Cumulative probability distributions for the other scenario simulations shows that under short term and warmer drier weather scenarios conventional till is still first order dominant. Moreover, time and risk associated with mastering a new crop production practice was not considered. Hence, the producer considering both expected income and income risk would choose conventional till over a 30-year planning horizon. The policy implications are that in order to encourage a farmer to adopt reduced tillage, the utility gained from expected income and risk should be considered together. It would be of interest to quantify the compensation required for a farmer to view the reduced tillage and conventional tillage as being equivalent.

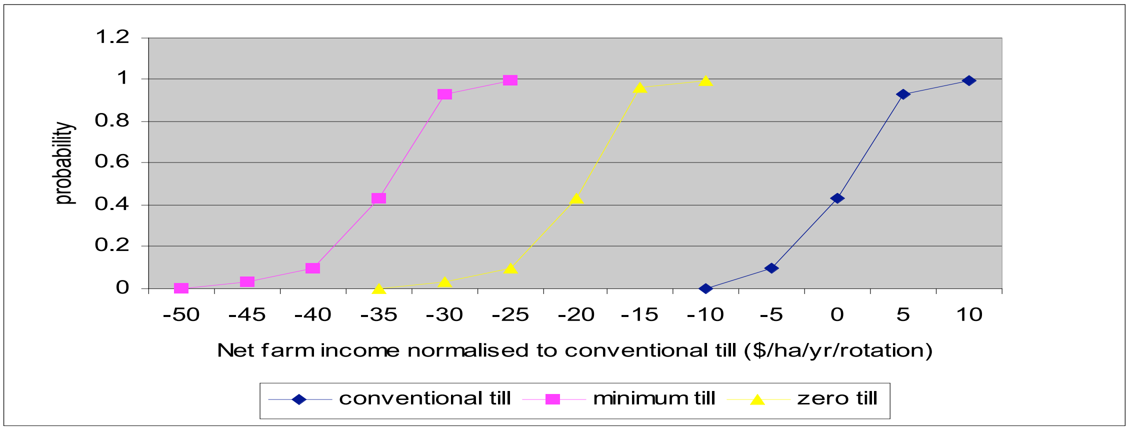



**Figure 6.7 Cumulative Probability Distribution (Baseline)**

The study did a sensitivity analysis to find the magnitude of the value of a tonne of C sequestered that would make a farmer, considering both expected net income and risk, indifferent to the three tillage systems (Figure 6.8). The finding was that deciding to compensate the producer $2.5/tonne of net C sequestered would suffice to make zero till first order dominant and to make a producer prefer zero tillage. The policy implication here is that when attempting to compensate a producer to change to zero till considering producer utility with respect to risk and net income together was cheaper. It is necessary to stress that this analysis does not discern the risk preference of the producer. When the study used TOA (as it did in section 6.4) which considering only income, the compensation required was 5 dollars per tonne C (Table 6.12).

### 6.6 Policy that Compensates the Change to Reduced Tillage

The common element of the TOA and stochastic dominance analysis discussions have been that they both address the role for compensation. A need to compensate the producer to change from conventional to reduced tillage. The GSD analysis that incorporates both risk and net income appears to be less onerous in terms of dollars per tonne of C sequestered than TOA. However, the analyses are consistent with respect to the fact that a farm of average size of 425 ha, would need to be paid for the C sequestered. How much to compensate should address the greater long-term abatement costs , the long term increase of variability in yields (comparing the simulated results versus other studies done for the region Gray et al.,(1996)). It should also address the cost of mitigation and not TOA under certain historic weather. It should address risk. When to compensate, should address that C sinks are labile and farmer may stop reduced tillage at any time and come back to conventional tillage. Especially if over a long period (30 years) he finds that what he was paid for a tonne of C is not compensating him for his losses. Hence, policymakers should decide if they want to leave their contracts open so that the contract could change its price per tonne of C if events turn to be better or worse or if they want to lock in a price for C at the beginning which does not change regardless of later increases or decreases in opportunity cost of abatement. Another relevant policy question is how to compensate or what policy instruments could be used. The government may decide if they would prefer to include taxes on conventional tillage equipment such as disk ploughs, cultivators, harrowers or subsidies on herbicides like glyphosate and machinery like airseeders. Other instruments may include direct payment per tonne of C sequestered and if it is possible to quantify the other off-farm benefits, such as the improvements to air, water, soil quality and general health benefits that reduced till brings to society at large (section 2.8), then policy instruments may include payment for those benefits. Trade-offs of the same nature as this study between profitability and abatement could be replicated for any of the other co-benefits. These other benefits reduced tillage provides society are what society could re-imburse the producer for such benefits.

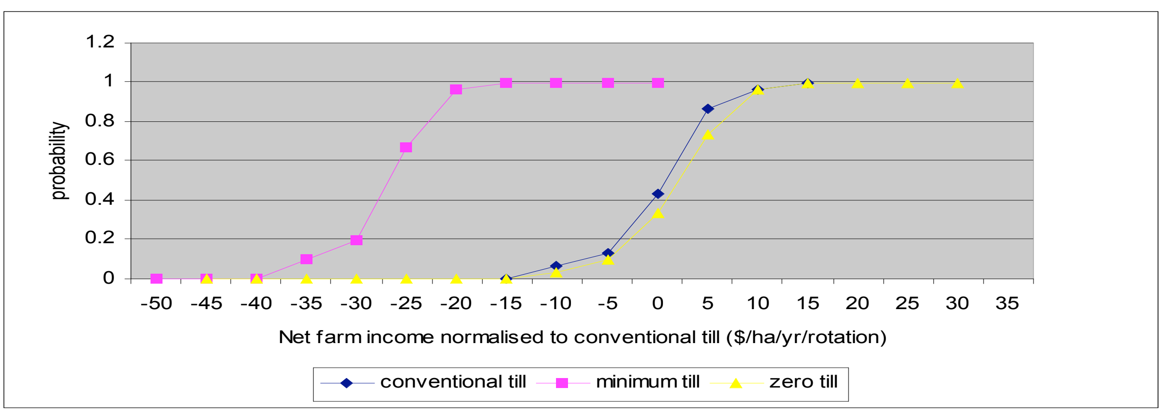



**Figure 6.8 Cumulative Probability Distribution ( $ 2.5/ t. net C abated)**

### 6.7 Summary

The results of the simulations and their implications for policy were the focus of the current chapter. Simulated net GHG abatement and net income were compared. Expected net revenues were greater for conventional tillage than for reduced tillage. Net abatement was greater for reduced tillage than for conventional tillage. The trade-offs between net income and net abatement were also analysed. The TOA, did not change largely between the short and long term. Howoever, the trade-off was greater for minimum tillage than for zero tillage. Different TOA scenarios were also included. Among them were different soil $N_2O$ emission coefficients and a scenario under warmer and drier weather opportunity cost of abatement was not significantly influenced by different soil emission coefficients. Warmer, drier weather made the opportunity cost of abatement significantly greater. The comparison was extended to include a trend analyses and a risk analyses of the tillage systems. The trend analysis showed how closely the SOC sequestration followed average rotational crop production. Risk analysis also showed that reduced tillage would need to be compensated for the producer to be as well of as he would be under conventional tillage. Finally, the chapter discussed the role of financial compensation as a policy tool to meet a climate change mitigation goal.

# CHAPTER 7
# SUMMARY AND CONCLUSIONS

This final chapter provides a summary and conclusion of the entire study. Having previously discussed the results of the study and its policy implications this concluding chapter provides a summary of the entire study and discusses some limitations and suggestions for future study.

## 7.1 Summary

Climate Change has been related to GHG emissions arising from both natural and anthropogenic activities. Soil management and crop management practices (such as reduced intensity tillage and more intensive cropping systems) have a significant impact on the flow of C among it's sources and sinks. Different soil and crop management practices have complex biophysical interactions which have different impacts on net income and net GHG abatement. The focus of this study was to assess the *net* impacts on income and *net* GHG abatement among tillage systems in the Black soil zone of eastern Saskatchewan. Net income and net GHG abatement of tillage practices vary spatially and temporally. Besides tillage and intense cropping systems, net income and net abatement are functions of input costs, commodity prices, biophysical variables (yield and SOC levels) and management system as seen on the farm (tillage intensity, cropping intensity and crop mix). A systems perspective was, thus, employed encompassing tillage intensity, cropping intensity and crop mix. The analysis is multi-disciplinary and TOA was the tool of choice because it depicts impacts on individual indicators for policy makers to make choices. The analysis considered longer-term (30 year) uncertainty of soil $N_2O$ emission coefficients and changes to weather patterns. Since the adoption of reduced till has been a relatively recent development and as such, there is not a lot of long-term biophysical and economic data and hence econometric data analysis would have limited effect. The different scenarios of uncertainty and long-term impacts could be feasibly analysed by use of a simulation model. The study made use of SAFRR (2004) crop budgets and farmer surveys on changes in input use to change the crop budgets to reflect the tillage systems.

### 7.2 Discussion

The distribution of climate change impacts, capacity to adapt and effectiveness of mitigation techniques (reduced tillage) differs from region to region. This site specificity is due to the degree of heterogeneity within regions in terms of climate, ecosystems, and socio-economic characteristics of the systems. Consideration of all such relationships including interactions of climate variability and change with other environmental changes and evolving demographic, social, and economic conditions that affect driving forces of change and resources available for adaptation are desirable but beyond the scope of this study. TOA and the simulation model of this study does not translate impacts into a single metric, but rather retain other physical measures (net income, net GHG abatement). Although, they loose out on comparability the IPCC (2001) recognise that aggregation conceals rather than highlights some of the critical issues and value-laden assumptions at stake. Moreover, because estimates of the monetary costs of impacts span a wide range of values given the many uncertainties and often are value laden, it may be argued that climate change targets should be based on physical or social, rather than economic, indicators.

Since the Kyoto protocol has allowed forest and agricultural sinks to be used by parties to meet their GHG emission reduction commitments there has been much focus on sinks here in North America. Within the agriculture industry, an important part of the sink strategy will be the adoption of reduced tillage production systems (IPCC, 2001). This study shows that reduced tillage has the ability to increase net GHG abatement in the Black soil zone. The social benefit of abatement, in reducing the risks of climate change, goes beyond the farm boundary. While mitigative responses impact beyond the locality of initiation adaptive responses help the locality at which the response was initiated. What this study shows is that while it is important to understand what may be achieved by mitigative and adaptive responses, it is important to know how a mitigative response initiated by one locality may impact the adaptive response of that very locality (a farm in the Black soil zone). The IPCC (1996) TAR states that changes in diurnal and interannual variability of temperature and moisture can result in substantial changes in the mean and variability of wheat yields. The current study only simulated an increased variability and did not simulate decreased variability (in temperature and precipitation). And the results agreed that increased variability of temperature and precipitation results in substantially lower mean simulated yields and its variability. As it is reasonable to assume that many adaptation options will be pursued, this means that the baseline against which mitigation options should be assessed is one with adaptation also occurring (IPCC, 2001).

What was apparent from the TOA was that over the long-term the relative net income of reduced till improved but the relative net abatement declined (closing in on point of saturation). However, because the decline in net abatement was greater than the improvement in net income, the opportunity cost of abatement became greater. The C sinks in reduced tillage are in a labile form, vulnerable to rapid oxidation and release as $CO_2$ if the management system is changed. This implies that even after the soil reaches its carrying capacity in terms of C, reduced tillage needs to be practised in order to prevent the oxidation of SOC and emissions of $CO_2$ again. This may require that reduced-till systems be maintained for an extended period (which also would lengthen the ancillary beneficial aspects of reduced tillage). If the producer is not being compensated after this stage of SOC saturation the economic and ancillary benefits should be sufficient to keep them continuing as seen by the large rate of adoption in the Black soil zone. If not, then compensatory or penalty mechanisms need to be in place. The fact that there were off-site benefits or co-benefits beyond mere abatement may be an adequate justification to continue compensation.

### 7.3 Limitations of the Study

Some of the restrictions this study was under could be relaxed to enable a deeper understanding of the problem such as simulations with changes in commodity prices. The study did not assume price changes due to inflation or technological change. Greater prices among selected crops such as wheat for example with prices other crops remaining unchanged may change the relative trade-offs among tillage systems. Another relaxation of assumptions would be to simulate different scales of farm operations. This would have to consider that either increasing or decreasing returns to size exist with respect to how machinery and labour are used. A further limitation of the model that was discussed before was that it ignored the within year (or inter year) timing of precipitation and other inputs such as fertiliser and pesticides that could effect the other biophysical results. As well, the fact that the SAFRR (2004) factor costs being derived from the farmers who utilised them in the highest quantites also may have affected the accuracy of results.

### 7.4 Further Research

Further research may be interested in deriving a long-term profit function that is able to capture the soil conservation benefit as well as returns to size. Moreover the study could look for an optimising solution with such a profit function. A simulation of reduced till with the inclusion of high value such crops may indicate greater net returns for reduced till. Inclusion of high value crops like flax with the greater yield advantages of reduced till make reduced till more profitable. Moving beyond modelling the farm one could simulate for a watershed where topographical factors are considered. This would consider different leaching levels of fertiliser use and hence different fertiliser use equations and consider off-site impacts as well.

## References


Agriculture and Agrifood Canada, 2000. *Environmental Sustainability of Canadian Agriculture.*Research Branch and Policy Branch, Prarie Farm rehabilitation Administration.

Antle, J.M., J.T. Stoorvogel, C.C.Crissman and W. Bowen. (2000). *Tradeoff Assessment as a Quantitative Approach to Agricultural Policy Analysis.*

Antle, J.M., J.T. Stoorvogel, W. Bowen, C.C.Crissman and David Yanggen. (April 2002). *The Tradeoff Analysis Approach: Lessons Leaned from Ecudor and Peru.*

Antle, J., Capalbo, S., Cole, D., Crissman, C. and Wagenet, R. 1998.a. "Integrated Simulation Model and Analysis of Economic, Environmental and Heath Tradeoffs in the Carchi Potato-Pasture Production System." *Economic, Environmental and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production,* C.C. Crissman, J.M. Antle, and S.M. Capalbo, eds., pp. 243-266. Boston: Kluwer Academic Publishers,.

Antle, J.M., Capalbo, S.M., and Crissman, C.C.1998.b. "Tradeoffs in Policy Analysis: Conceptual Foundations and Disciplinary Integration." *Economic, Environmental and Health Tradeoffs in Agriculture: Pesticides and the Sustainability of Andean Potato Production,* Crissman, C.C., Antle, J.M., and Capalbo, S.M. eds., pp.1-11. Boston: Kluwer Academic Publishers,

Antle, J.M. and Mooney, S. 1999: *Economics and Policy Design for Soil Carbon Sequestration in Agriculture.* Research Discussion paper No.36, Trade Research Centre, Montana State University.

Antle, J.M., J.T. Stoorvogel, W. Bowen, C.C.Crissman and David Yanggen. (October 2002). *The Tradeoff Analysis Approach: Lessons Leaned from Ecudor and Peru.*Proceedings at the International Conference on Impacts of AgriculturalResearch and Development, San Jose, Costa Rica, February 4-7, 2002.

Antle, J.M., J.T. Stoorvogel, C.C.Crissman and W. Bowen. 2001.*Tradeoff Assessment as a Quantitative Approach to Agricultural/Environmental Policy Analysis.* Proceedings o the SAAD III Third International Symposium on Systems Approaches for Agricultural Development, Lima, Peru, November 8-10, 1999.

Azar, C. and Sterner, J. (1996). *Discounting and Distributional Considerations in the Context of Global Warming.* Ecological Economics. 19: 169-184.

Barkin, D. 1996. *Macro Changes and Micro Analysis: Methodological Issues in Ecological Economic.* Ecological Economics. 19: 197-200

Bailey, K.L. 1996. *Diseases under reduced tillage systems.* Canadian Journal of Plant Science. 76: 635-640

Belcher, K. (1999). *Agroecosystem Sustainability: An Integrated Modelling Approach*, Doctoral Thesis, Department of Agricultural Economics Saskatchewan, Canada: University of Saskatchewan.

Belcher, K.W., Boehm, M. aand Zentner, R.P. 2003. *The Economic Value of Soil Quality under Alternative Management in the Canadian Prairies.* Canadian Journal of Agricultural Economics 51:175-196

Belcher, K. 2004. Personal Communications August, 2004

Boehm, M. 2000. *Carbon Sequestration in Agricultural Soils.* Saskatchewan, Canada: University of Saskatchewan.

Boehm , M. 2004. (a)*. Direct seeding and Soil Quality on the Prairies*,. Direct Seeding, The Key to Sustainable Management. Saskatchewan Soil Conservation Association.

Boehm, M. 2004. (b). Personal Communications July, 2004

Boehm, M. 2004. (c). Personal Commuications November, 2004

Boehm, M. 2005. Personal Communications January, 2005

Brandt, S.A. 1992. Zero vs. Conventional Tillage and Their Effects on Crop Yield and Soil Moisture. Can. J. Plant Sci. 72: 679-688.

Brown, K., Emma, T and Adger, W. N.. 2001. *Trade-off Analysis for Participatory Coastal Zone Decision Making.* Overseas Development Group. University of East Anglia.

Bucher, E.H. and Huszar, D.C. 1996. *Project Evaluation and Economic Development-the Use of BCA.* Ecological Economics. 19: 201-203

Campbell, C.A., Zentner, R.P., Janzen, H.H., and Lafond, G.P. (2004) *Effect of Cropping Frequency on C Storage in Canadian Prarie Soils.* Agriculture and AgriFood Canada

Cambell, C.A., Lafond, G.P., Leyshon, A.J., Zentner, R.P., and Janzen, H.H. 1991. *Effect of Cropping Practices on the initial potential rate of N Mineraalization in a Thin Black Chernozem.* Can. J. Soil Sci. 71: 43-53

Changsheng, Li. 2000. *Modeling Impact of Agricultural Practices on Soil C and $N_20$.* Soil Management and the Greenhouse Effect. Lewis Publishers. Boca Raton, Florida. pp101-113.

CBC, August 2004. website: http://www.cbc.ca/news/background/kyoto/

Cihacek, L.J. and Ulmer. M.G. 1995. *Estimated Soil Organic Carbon Losses from Long-Term Crop Fallow I the Nothern Great Plains of the USA.* Soil Management and the Greenhouse Effect. Lewis Publishers. Boca Raton, Florida. pp85-93

Crissman, C.C., Antle, J.M., and Capalbo, S.M. "Introduction and Overview." *Economic, Environmental and HealthTradeoffs in Agriculture:Pesticides and the Sustainability of Andean Potato Production,* Crissman, C.C., Antle, J.M., and Capalbo, S.M. eds., pp.1-11. Boston: Kluwer Academic Publishers, 1998.

Derksen, D.A., Blackshaw, R.E., Boyetchko, S.M. 1996. *Sustainability Conservation Tillage and Weeds in Canada.*Can. J. Pl. Sci. 76: 651-659

Desjardins, R.L. and AgriFood Canada. (2000). "The Kyoto Protocol", *Envitonemental Sustainability of Canadian Agriculture.* Research Branch and Policy Branch. Prarie Farm Rehabilitation Administration. Agriculture and AgriFood Canada.

Dormaar, J. 1986. *Quality and Value of Wind Movable Aggregates in Chernozemic Ap Horizons.* Can.J. Soil Sci. 67: 601-607

Dormaar, J.F. and Carefoot, J.M. 1996. *Implications of crop residue management and conservation tillage on soil organic matter.* Can. J. Pl. Sci. 76: 627-635

Edgar Peter, *The economics of including Annual legumes in Crop Rotations in the Dark Brown Soil Zone of Saskatchewan,* 1998, Masters Thesis, Department of Agricultural Economics, University of Saskatchewan, Saskatoon, Sakatchewan.

Environment Canada Website. 2004. http://www.ec.gc.ca/pdb/ghg/1990_02_report/ann9_e.cfm

Field, D.C., and Olewiler, N.D. 2002. *Environmental Economics* .Second Canadian Edition. McGraw Hill Ryerson. Toronto

Fox, G., Umali, G., and Dickinson, T. 1995. *An economic analysis of targeting soil conservation measures with respect to off-site water conservation.* Canadian Journal of Agricultural Economics. 43: 105-118.

Frank M. Gollop; Mark J. Roberts. Feb., 1985.*Cost-Minimizing Regulation of Sulphur Emissions: Regional Gains in Electric Power*. The Review of Economics and Statistics. 67(1): 81-90.

Fulton, M. 2004. Personal communication, November 2004.

Gray, R.S., Taylor, J.S., and Brown, W.J. 1996. *Economic factors contributing to the adoption of reduced tillage technologies in central Saskatchewan.* Canadian Journal of Plant Science. 76: 661-669

Huggins, D.R., Clapp, C.E., Allmara, R.R., and Lamb, J.A. 1995. *Carbon Sequestration in Corn-Soybean Agroecosystems.* Soil Management and Greenhouse. Effect. Lewis Publishers. Boca Raton, Florida. pp 61-68

Hoosebeek and Bryant, 1992.*Towards Quantitative Modelling of Pedogenesis – aReview.* Geoderma 55:183-210

IPCC. 1996. *Revised IPCC Guidelines for National Greenhouse Gas Inventories.* http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

IPCC 2001a. *Glossary.* < http://www.grida.no/climate/ipcc_tar/wg1/518.htm>

IPCC 2001b. *Third Assessment Report.* < http://www.grida.no/climate/ipcc_tar/>

IPCC 2003: *Introduction to the IPCC.* < http://www.ipcc.ch/about/beng.pdf>

Johnson. M.G., 2000. *The role of soil management in sequestering soil carbon.* Soil Management and the Greenhouse Effect. Lewis Publishers. Boca Raton, Florida. pp351-364.

Jozic, J. and Monchuk, D. 2000. *Uncertainity, Early Action and Soil Sinks.* Climate Change Handbook for Agriculture. Centre for Studies in Agriculture Law and the Environment. University of Saskatchewan.

Katrina Brown, W. Neil Adger, Emma Tompkins, Peter Bacon, David Shim and

Kathy Young. 2001. *Trade-off analysis for marine protected area management.* Ecological Economics. 37: *417-434*

Kowlaski, J. 2000. *Overview.* Climate Change Handbook for Agriculture. Centre for Studies in Agriculture Law and the Environment. University of Saskatchewan.

Kulshestra, S.N., Boehm, M., Bonneau, M., MacGregor, R.J. and Giraldez, J. *Contributions of Canadian Agriculture to Greenhouse Gas Emissions: Preliminary Results of Selected Policy Options,* 1998.World Resource Review 10 (4).

Kulshreshtha, S. 2004 (a). Personal Communications. June 29, 2004.

Kulshreshtha, S. 2004 (b). Personal Communications. December 26, 2004.

Lafond, G.P., Loeppky, H.A., and Derksen, D.A. 1992. *The Effects of Tillage Systems and Crop Rotation Soil Water Conservation, Seeding Establishment and Crop Yield.* Can. J. Plant Sci. 72: 103-115.

Lafond, G. P., Zentner, R.P., Geremia, R. and Derkson, D.A. 1993. *The Effects of Tillage Systems on the Economic Performance of Spring Wheat, Winter Wheat, flax and Field Pea Production in East-Central Saskatchewan.* Can.J.Plant Sci. 73:47-54.

Lal, R. Kimble, J. and Stewart, B.A. 2000 a. “Preface”. *Soil Management and Greenhouse Effect.* CRC Press, Inc. Bota Raton, Florida.

Lal, R. Kimble, J. and Stewart, B.A. 2000 b. “World Soils as a Source or Sink for Radiatively-Active Gases”. *Soil Management and Greenhouse Effect.* CRC Press, Inc. Bota Raton, Florida.

Larsen, B.A. and Tobey, J.A. (1994). *Uncertain Climate Change and the International Policy Response.* Ecological Economics. 11: 77-84

Lemke Reynald. 2000. *Greehhouse Gas Emission Reduction and Cropping Systems.* Climate Change Handbook for Agriculture. Centre for Studies in Agriculture Law and the Environment. University of Saskatchewan.

Lemke, Reynald, McConkey, B., and Janzen H. 2004.*Impacts of Agriculture on Air Quality,*.Direct Seeeding. The 16th Annual Meeting, Conference and Tradeshow of the Sskatchewan Soil Conservation Association. Regina. Sskatchewan.

Li, Changsheng. 1995. *Modeling Impact of Agricultural Practices on SoilC and* $N_20$ *Emissions.* Soil Management and the Greenhouse Effect. Lewis Publishers. Boca Raton, Florida. pp 101-112.

Maqbool , Muhammad . *An Assessment of Sustainable Farming Systems in Saskatchewan,* 1999. Doctoral Thesis, Department of Agricultural Economics Saskatchewan, Canada: University of Saskatchewan.

McConkey, B.G., Campbell, C.A., Zentner, R.P., Dyck, F.B. and Selles, F. 1996. *Long-term Tillage Effects on Spring Wheat Production on Three Soil Textures in the Brown soil zone.* Can.J.Plant Sci. 76:747-756.

Ministry of Agriculture and Forestry, NewZealand. *http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/climate/sinks/climate-07.htm*

Mitchell, D. and Edwards, C.K. 2000. *Market Potential for Emissions Trading.* Climate Change Handbook for Agriculture. Centre for Studies in Agriculture Law and the Environment. University of Saskatchewan.

Munda, G. 1996. *Cost Benefit Analysis in Integrated Environmental Assessment – Methodological Issues.* Ecological Economics. 19: 157-168

Nagy, Cecil. 1997. *An Economic Assesment of Alternative Cropping Systems for the Saskatchewan Parklands.* Masters Thesis, Department of Agricultural Economics Saskatchewan, Canada: University of Saskatchewan.

Natural Resource Canada Website, 2004. http://oee.nrcan.gc.ca/neud/dpa/data_e/SEE03/Gov_operations.cfm?PrintView=N&Text=N

Nyborg, M., Soldberg, E.D., Malhi. S.S., and Izaurralde, R.C. (2000) "Fertilizer N, Crop Residue, and Tillage Alter Soil C and N Content in a Decade". *Soil Management and Greenhouse Effect*. CRC Press, Inc. Boca Raton, Florida.

Plantinga, A.J. and J.Wu. (February 2003). *Co-Benefits from Carbon Sequestration in Forests: Evaluating Reductions in Agricultural Externalities from an Afforestation Policy in Wisconsin.* Wisconsin, U.S.: University of Wisconsin.

Saskatchewan Agriculture and Food (2002): *Agricultural Statistics*. Policy Branch. Regina Saskatchewan.

Saskatchewan Agriculture and Food (2004). *Crop Planning Guide.* http://www.agr.gov.sk.ca/DOCS/Econ_Farm_Man/Production/Cereals/cpgblack04.pdf

Schoney, R. 2004.a. Personal Communications, June 2004

Schoney, R. 2004.b. Personal Communications, November 2004

Six J., Stephen M.O., Breidt J., Rich T.C., Arvin R.M.,and Keith P. 2004. *The potential to mitigate global warming with no-tillage management is only realized when practised in the long term.* Global Change Biology. 10: 155-160

Splash, C.L. (1994). *Double CO2 and Beyond: Benefits, Costs and Compensation.* Ecological Economics. 10 : 27-36.

Sobol D., and Kulshreshtha S. 2004. Greenhouse Gas Emissions from Canadian Agriculture Module. Technical Documentation. Department of Agricultural Economics, University of Saskatchewan, Saskatoon. Saskatchewan. S7N5A8.

Soon, Y.K. and Clayton, G.W. 2002. *Eight years of crop rotation and tillage effects on crop production and N fertiliser use.* Canadian Journal of Soil Science. 82: 165-172

Tucker, M. (1997). *Climate Change and the Insurance Industry: the Cost of Increased Risk and the Impetus for Action.* Ecological Economics. 22 : 85-96.

Shukla P.R. *Greenhouse Gas Models and Abatement Costs for Developing Nations: Critical Assessment.* 1995. Energy Policy. 23(8). 677-687

The United States Department of Commerce .*Current Industrial Reports: Pollution Abatement Costs and Expenditures*.1994. http://www.census.gov/prod/2/manmin/ma200x94.pdf

Tietenberg T. 2002. *Environmental and Resource Economics. Sixth Edition.* Addison Wesley. Toronto

United Nations Framework for Climate Change. http://unfccc.int/resource/docs/sum/can01.htm

United Nations Framework Convention on Climate Change. 2001. Review of the Implementation of Commitments and of Other Provisions of the Convention. Conference of the Parties, 6th session, part two. Bonn, 16-27 July, 2001. www.unfccc.int/resource/docs/cop6secpart/I07.pdf.

Varian, H. 1992. *Microeconomic Analysis. Third Edition.* Norton. New York. N.Y.

Wall, David D. *The Economics of Alternative Crops in the Brown and Dark Brown Soil Zones of Sskatchewan,* 2000. Masters Thesis, Department of Agricultural Economics Saskatchewan, Canada: University of Saskatchewan.

Weersink, A., Walker, M. Swanton, C., and Shaw, J. 1992. *Economic comparission of alternative tillage systems under risk.* Canadian Journal of Agricultural Economics. 40: 199-217

Yanggen, D., Antle J., Stoorvogel J., Bowen W., and Crissman C. 2002. *Trade-off Analysis as a Tool for Integrated Assessment of Economic and Environmental Impacts of Agricultural Research.*

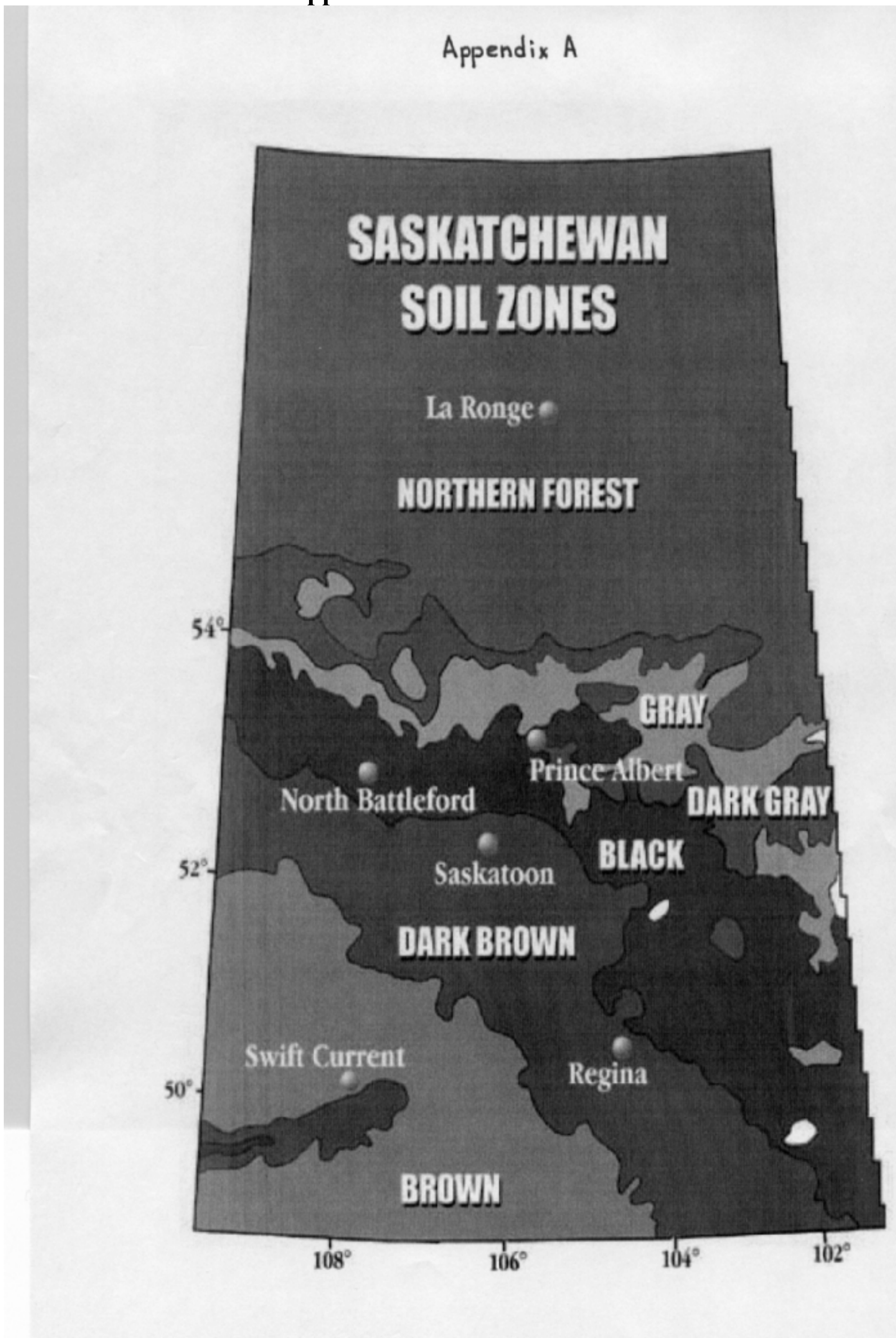
Yiannaka Amalia, Furtan Hartly and Gray Richard. 2001.*Implementing the Kyoto Accord in Canada.* Canadian Journal of Agricultural Economics. 49 :105-126

Yiridoe, E.K., Weersink, A., Hooker, D.C. Vyn, T.J., and Swanton, C. 2000. *Income risk analysis of alternative tillage systems for corn and soybean production on clay soils.* Canadian Journal of Agricultural Economics. 48: 161-174

Young, D.L., Kwon, T.J. and Young, F.L. 1994. *Profit and risk for integrated conservation farming systems in the Palouse.* Journal of Soil Water Conservation. 49:601-606 http://www.encyclopedia.com/html/s1/stripcro.asp

Zentner, R.P., McConket, C.A., Campbell, C.A., Dyck, F.B., and Selles, F. 1996. *Economics of conservation tillage in the semiarid prarie.* Canadian Journal of Plant Science. 76: 697-706.

**Appendix A**


Appendix A
SASKATCHEWAN
SOIL ZONES
La Ronge
NORTHERN FOREST
54°
GRAY
Prince Albert
North Battleford
DARK GRAY
Saskatoon
BLACK
52°
DARK BROWN
Swift Current
Regina
50°
BROWN
108°
106°
104°
102°

**Appendix B**

## Table B.1 Sample Survey Data Grid

| | | | | | | |
|---|---|---|---|---|---|---|
| *L..Name* | *Doe* | | | | | |
| *F.Name & In.* | *John* | | | | | |
| *Address* | *Box 133, Sk.* | | | | | |
| *Phone* | *xxx-xxxx* | | | | | |
| *Acreage* | *2850* | | | | | |
| *R.M.division* | *271* | | | | | |
| *Zerotill: y/n/mintill* | *n* | | | | | |
| *When did you change* | *now changing to zero till* | | | | | |
| *T.fallow: y/n* | *n* | | | | | |
| *Yield change with time* | *steadily rose by 50% in last 10yrs* | | | | | |
| *Acreage change with time* | *75%* | | | | | |
| *Rotation before* | *w/c* | | | | | |
| *Rotation after* | *w/c* | | | | | |
| *Fertiliser change w/ time* | *n use incrsd 20 lb/ac, p by 10, k by 25, s by 15, micronutrients last 5yrs* | | | | | |
| *Herbicide change w/ time* | *no* | | | | | |
| *Fuel use change w/ time* | *no* | | | | | |
| *Equipment* | *bought* | | | *sold* | | |
| | *what* | *how much* | *when* | *what* | *how much* | *when* |
| | *airdrill* | *70000* | *95* | *airseeder* | *30000* | *9* |
| | *high clearnce sprayer* | *69000* | *98* | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| *personal time* | *more due to intense crop plan (spoon feeding , micro nutrients, fungicides)* | | | | | |
| *g.water* | *no* | | | | | |
| *s.water* | *no* | | | | | |
| *soil quality* | *better, nutrient levels increased* | | | | | |
| *hog/cattle manure* | *no* | | | | | |
| *weed species changed* | *no* | | | | | |
| *insec/fungicides changed* | *no* | | | | | |
| *soil erosion* | *no, due to ground cover* | | | | | |
| *seeding date* | *earlier by a wk* | | | | | |
| *wildlife sp.* | *steady* | | | | | |
| *comments* | *changing because soil moisture water use efficiency improves* | | | | | |
| *other contact* | | | | | | |
| *date surveyed* | | | | | | |
| *want an abstract y/n* | | | | | | |