Rate of Return to the Research and Development Expenditure on Zero Tillage Technology Development in Western Canada (1960-2010)

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Executive Summary

The widespread adoption of zero tillage technology has profoundly transformed agriculture in western Canada over the past few decades. Zero tillage technologies have allowed farmers to increase cropping intensity, diversity and yields, while reducing fuel and labour requirements. These benefits of zero tillage technology led to widespread producer adoption. The result has been a substantial increase in productivity accompanied with a substantial reduction in soil erosion and a rebuilding of the soil organic matter. The extent of the shift away from the tillage based, summerfallow, cereal rotations that dominated in the mid- 1970s toward the direct-seeded, continuously cropped, diversified cropping systems of today is illustrated in Figure 1. The profound success of these technologies also led to the development of a significant manufacturing industry, which developed and manufactured seeding equipment not only for the domestic market but also the global market as the technology has been adopted elsewhere. Given the extent of the transformation, the development and adoption of zero tillage cropping systems is perhaps the most important agricultural innovation of the past fifty years.

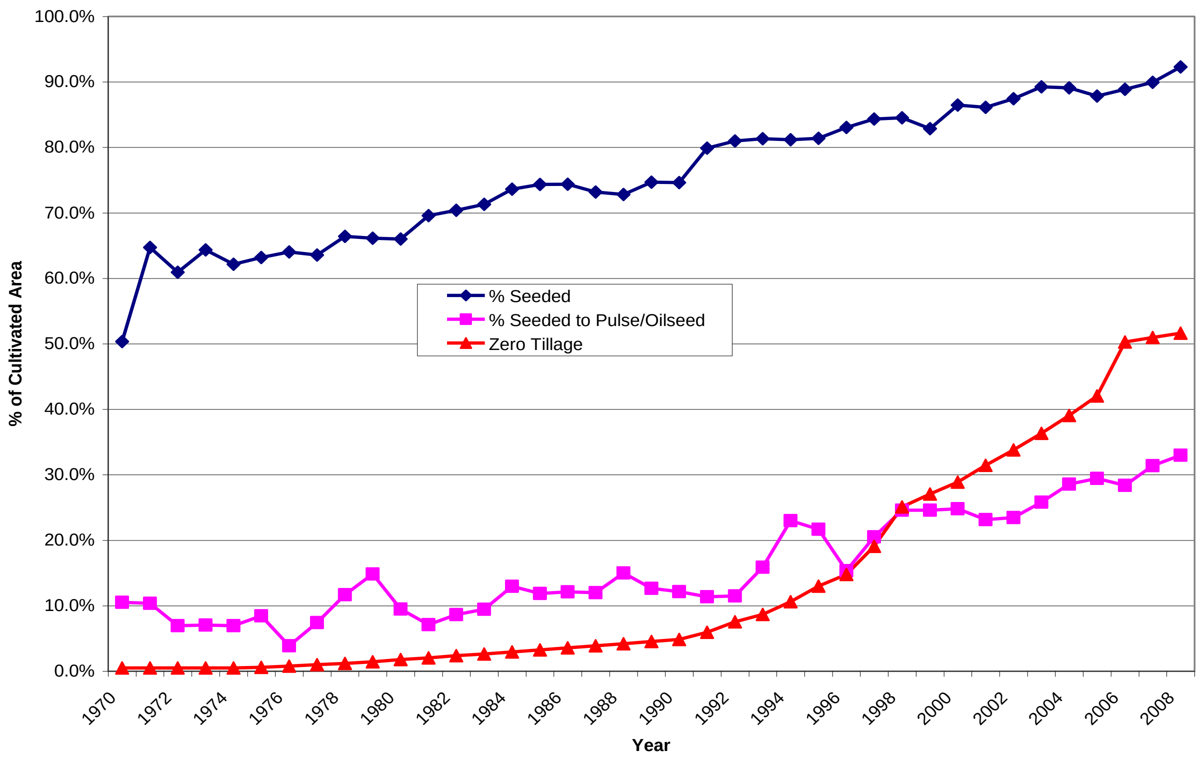

Figure 1: Percentage of Area Seeded and Area Seeded to Pulse/Oilseed

Source: Base data from Statistics Canada Table 001-0010

The development of zero tillage cropping systems did not result from a single act of genius, but rather involved many types of innovation that co-evolved over three or four decades. Initially driven by the need to control soil erosion in the 1960's a few public researchers and some mechanically minded farmers began to work on machinery to address their needs[1]. These machinery technologies, some seemingly unrelated at the time, eventually lead to the technical package of the zero tillage system. This was combined with agronomic research, mostly public that investigated the conservation of the soil resource and crop production combined with reduced tillage to develop the zero tillage cropping systems. The end result was a complete package that could be adapted to the range of soil/climate regimes in western Canada. In the early years public and private funds were used in the development of the zero tillage technology with only a vague sense of the final product that would coalesce in the early 1990s leading to the adoption of zero tillage on a wide scale. This investment has generated considerable monetary and non-monetary benefits accruing to farmers, tillage and herbicide manufactures, and society to name a few. Also, spillovers from the RD&E of zero tillage affected the cropping practices of minimum tillage, continuous cropping and fallow practices.

Objective

The purpose of this report is to quantify the benefits and cost that have arisen from investment in zero tillage related Research Development and Extension (RD&E). The quantification of the benefits and costs of research investment is important because many forms of knowledge are non-excludable and take place in the public domain funded by tax payers. As such, policy makers need evidence to continue to make these investments. While there are hundreds of studies that have examined the benefits and cost of RD&E and have shown high rates of return, to out knowledge none have examined the development of zero tillage.

Results

A return of $52 dollars for every dollar invested in zero tillage RD&E research by public, NGOs and private sector was estimated which generated an internal rate of return of 34% to the direct and indirect RD&E investment. Approximately, 50% of the $3.4 billion net benefit of the research was captured directly by farmers in terms of fuel, labour, machinery and other input cost reductions. The RD&E expenditure by zero tillage machinery manufacturing businesses of $60.5 million generated $121 dollars in sales for each dollar invested of which $61 of those dollars was value added.

Report Outline

Section 1.0 is a description of the "Factual" what actually happened in the development and adoption of zero tillage and the "Counter Factual" what possibly would have happened if the investments in RD&E were delayed or did not happen.

Section 2.0 quantifies the net benefits defined as the difference between the Factual and Counter Factual. Differences in the amount of carbon sequestration, nitrous oxide emissions, carbon emissions, fuel, labour, tractor hours, wind erosion, salinity and net costs are quantified and assessed a value. The net benefit of the investment in zero tillage research is in Section 3.0.

Section 4.0 is an estimate of the cost of research and development effort by public and private institutions in developing the zero tillage technology. Federal and provincial governments either directly through departments of agriculture or indirectly through funding agencies and tax policy expended funds to develop and promote zero tillage. Private companies involved in equipment manufacture, herbicide manufacture, and retailing farm inputs funded RD&E and extension activities. NGOs such as Ducks unlimited, Saskatchewan Soil Conservation Association and zero tillage associations promoted direct seeding. Adopters of zero tillage technology also invested in the physical capital and human capital needed for successful adoption.

Section 5.0 is an estimate of the return on the investment of equipment manufacturers in the development and promotion of zero tillage in western Canada. The implications of these results are presented in Section 6.0.

Acknowledgement

The authors wish to acknowledge the help and support of the many individuals who contributed comments and suggestions which helped in the daunting task of undertaking such a project; to name a few; Elwin Smith, Bob Zentner, Wayne Lindwall, Blair McClinton, Darwin Anderson with special thanks to Jim Halford and Kathy Larsen.

Table of Contents

Tables

Figures

1.0 Factual and Counter Factual Scenarios of Zero Tillage Development

1.1 Introduction

Basic research, applied research and extension activities over several decades starting in the 1960s have led to the high rates of adoption of zero tillage technology currently experienced in the Prairie Provinces. Basic and applied research carried out in various public and private institutions led to the development of equipment (hard technology) used in the zero tillage system. Soft technologies (i.e. knowledge in combining the pieces) were developed at public and private institutions which aided in the adoption of the zero tillage cropping system. Basic and applied agronomic research primarily performed by public institutions developed the concept of a workable cropping system using zero tillage technology. Extension activities were carried out separately or co-operatively by Agriculture Canada Research Centres, provincial departments of agriculture, non-governmental organizations and private industry (chemical and machinery). Milestones in the development of the zero tillage cropping system in western Canada in relation to the rate of adoption of zero tillage are presented in Figure 2. The dates as shown are not specific in terms of introduction, full development or complete adoption of a technology. It is not until the last half of the 1990s that significant yearly rates of adoption start to occur. This is a period where all the pieces of the equipment technology/cost competitiveness puzzle come together combined with agronomic research into clearly defining the zero tillage cropping system along with the reduction in the price of glyphosate and the significant extension effort of the early nineties.

Until a well defined “cropping system” using zero tillage technology was achieved the rate of adoption would remain low. A flexible base model such that producers could adapt it to their own operation needed to be in place before rapid adoption could occur. Just as conventional tillage practices vary considerably across the prairies to achieve success, the same would be true for zero tillage cropping. The adoption of zero tillage prior to 1996 was primarily in the Brown and dry Dark Brown soil zones of the Prairie Provinces using technology and agronomics developed for the semi-arid Great Plains Region of North America. It wasn’t until the last half of the 1990s that significant rates of adoption occurred in the moist Dark Brown and thin Black regions then in the Black and Gray soils of the Parkland region. The breakthrough came by combining zero tillage moisture conservation with labour saving air seeder technology and land saving continuous cropping that enabled the adoption.

Ground opener research and development to obtain consistent depth of placement and separation of seed and fertilizer is one of the critical elements in achieving a one pass direct seed operation. Residue clearance of the frame and crop residue flow along with developments to insure even seed placement (floating hitch, walking axle) were important developments enabling seeding into standing stubble. Dove tailing into the machinery development is the agronomic research, primarily weed control strategies needed to eliminate the tillage operations.

Economic and environmental pressures are also major influences on the rate of adoption as the cost of fuel, reduced availability of labour, high capital cost of renewing a conventional tillage system and soil degradation all affected the decision to adopt. These factors along with declining real commodity prices pushed producers to consider alternative crops and cropping practices. The data seems to support a link between high commodity prices (1996 & 2007) resulting in higher rates of adoption while major droughts of 1988 and 2001-02 have very little immediate affect. This suggests that capital constraints may have slowed the rate of adoption especially in the early 1990s.

In order to assess the impact of the research and development and extension activities on the return to funds invested the factual situation (what actually occurred) has to be compared to the counterfactual situation. The counterfactual is the hypothetical case that would have existed in absence of research and development funding in Western Canada. We argue that in this counterfactual situation, zero till systems would have eventually developed but the development and adoption process would have been substantially delayed[2]. In some cases development of key aspects of zero tillage technology would have been delayed resulting in reduced rates of adoption. However, research spillovers and cross fertilization due to RD&E expenditures from other related and non-related activities such as soil conservation effort, crop development research and some aspects of tillage equipment innovation would have occurred regardless of the rate of development of zero tillage technology. In Figure 3 the factual rate of adoption is presented along with the rates of adoption that would have occurred if the zero tillage technology was delayed by 5 or 10 years. The hypothetical cases of no agronomic and extension and no equipment RD&E are presented in Figure 4. In these two cases the uptake of zero tillage is reduced substantially in the Parkland region relative to the historic levels of adoption (pre 1996). Brown and Dark Brown soil zones rate of adoption is reduced somewhat from the historic as zero tillage air seeding equipment would not be available. The development of zero tillage drills in the United States would be the main technology used which would limit its use in the higher moisture regions of western Canada. Here we argue that the agronomic and technology development would have limited or delayed adoption of zero tillage in the Parkland region. Therefore, it seems reasonable to use a delay of 5 years as an approximation of the counterfactual.

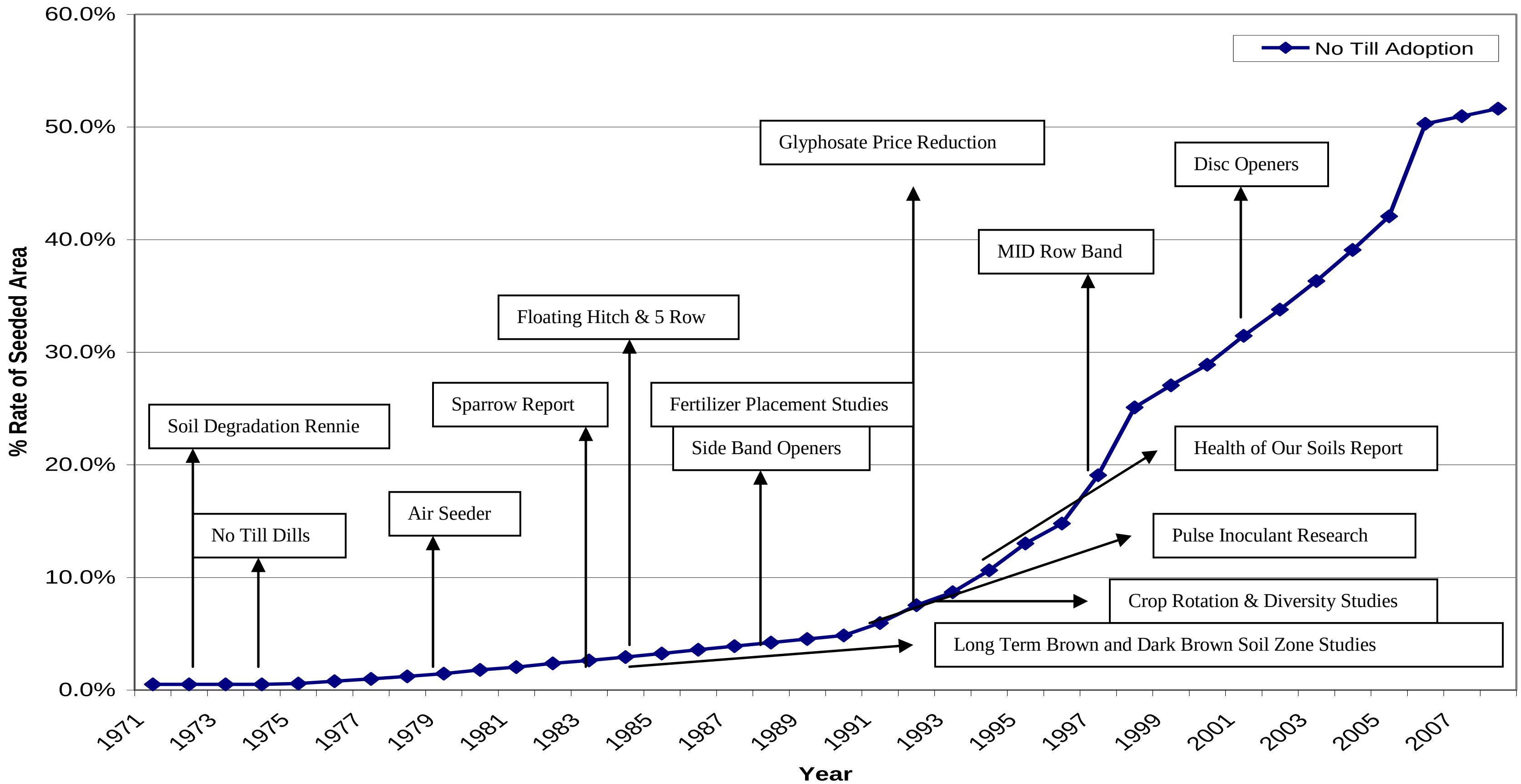

Figure 2: Milestones in the Adoption of Zero tillage Cropping Systems

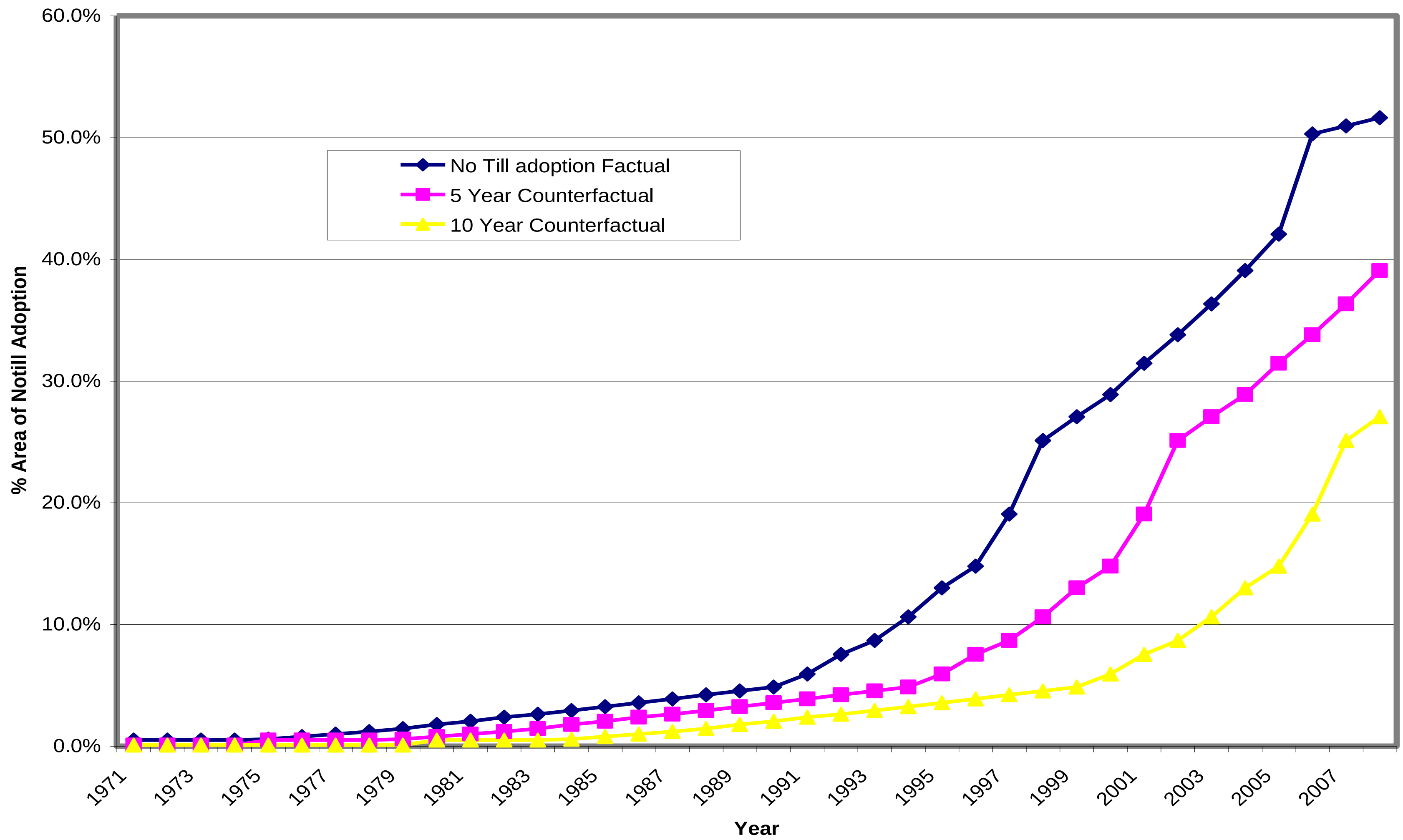

Figure 3: Comparison of Factual Zero Tillage Adoption Rates with Possible 5& 10 year Counterfactual

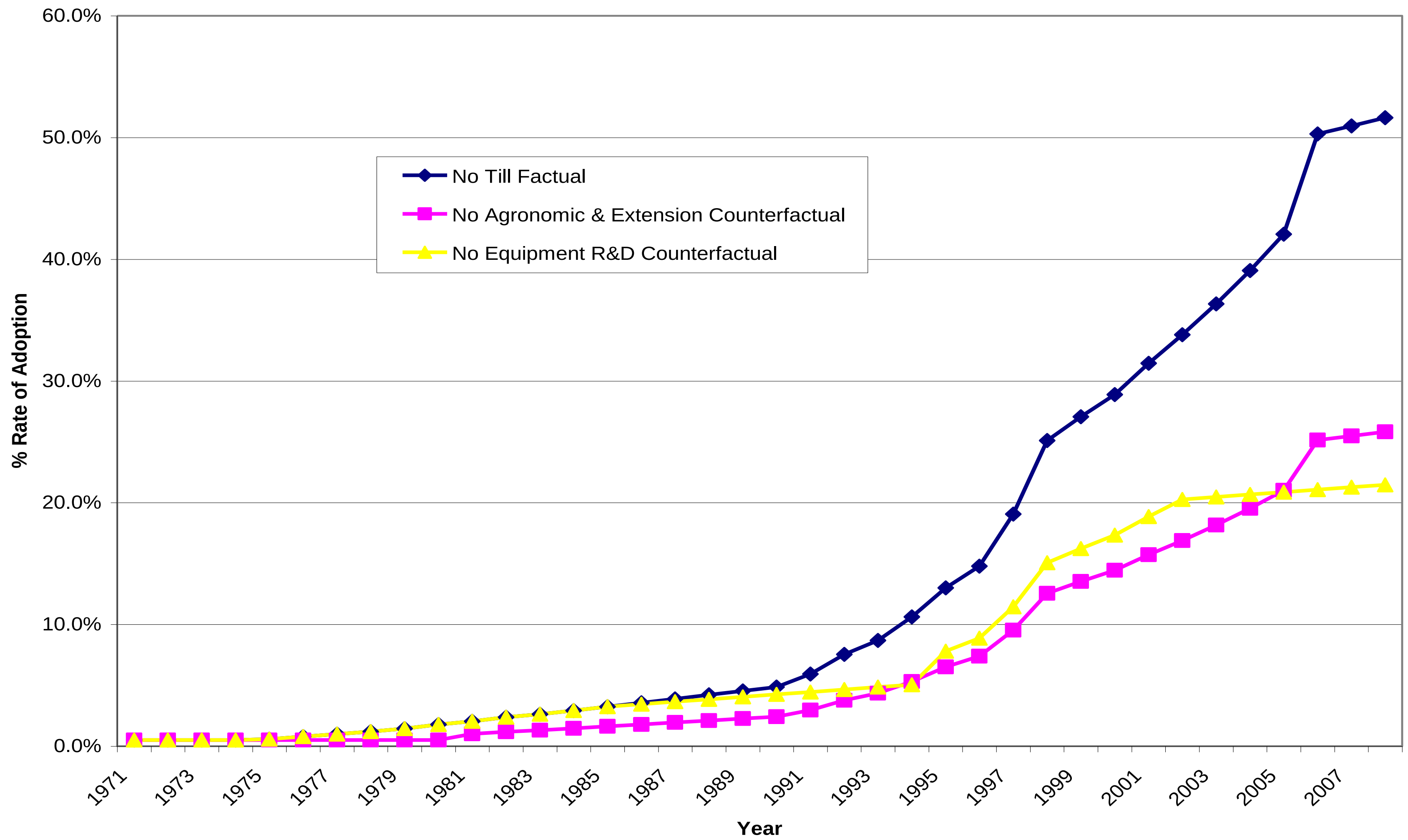

Figure 4: Rate of Adoption Zero tillage Hypothetical No Agronomic & Extension and No Equipment RD&E

2.0 Benefits and Costs Associated with Zero tillage in Western Canada

2.1 Introduction

The Prairie Provinces of western Canada comprise a range of soil/climate zones which affects the types of cropping practices used i.e. tillage system, crop rotation, fertilizer application methods and amounts applied. These in turn affect the net benefits associated with the adoption of zero tillage in terms of carbon sequestration, nitrous oxide emissions, erosion reduction, salinity, fuel use, labour use, tractor hours and net benefits/costs.

The data that is available for the adoption of tillage practices is by crop district from Statistics Canada for the census years of 1991, 1996, 2001 and 2006. Carbon sequestration coefficients for the adoption of reduced tillage practices and reduction or elimination of summerfallow have been developed for the range of soil/climate zones in the Prairie Provinces. The soil/climate zones used are the Brown, Dark Brown, Black and Gray in terms of applying the carbon sequestration coefficients. Differences in nitrous oxide emissions, erosion reduction, salinity, fuel, labour, tractor hours and net costs are by tillage system.

2.2 Rate of Adoption

The adoption of zero tillage seeding practice for the 1980 – 2006 period is estimated from the rates of adoption from Statistics Canada Agricultural Census years 1991, 1996, 2001 and 2006 plus industry surveys (various years) from Monsanto and Stratus Agri-Marketing Inc. (Figure 5). Because of the wording of the question for the 1991 and 1996 Census, farmers incorrectly responded by including direct seeding using a discer as zero tillage. Saskatchewan crop districts 2A, 2B, 7A and 7B have rates of adoption from the 1991 and 1996 Censuses that are inconsistent with the 2001 Census and private industry surveys. Therefore, rates of adoption of zero tillage for these crop districts were adjusted by using the rate of adoption of adjacent crop districts for crop districts 2A, 2B, 7A and 7B. McClinton 2009 suggests that the rate of adoption of zero tillage in western Canada in 1980 was zero rising to the 1990 level.

The projected rate of adoption of zero tillage cropping systems to 2020 given the current level of adoption in western Canada would indicate a reduced rate. Current Manitoba rates of adoption lag behind the other two Prairie Provinces specifically in crop districts 3, 4, 5 and 6 which all have levels of adoption of less than 10% (2006 Census). Conventional tillage levels in these crop districts range from 53.8% to 60.2% which is the highest in the Prairie Provinces. These crop districts typically have soil which is clay to clay loam combined with more growing season precipitation relative to the semi-arid region of the prairie. Alberta crop districts 5, 6, and 7 have levels of zero tillage adoption of less than 35% while Saskatchewan's lowest rates are in crop district 4 and 5 of 53.8% and 49.8%, respectively. With the exception of Saskatchewan crop district 4, these crop districts are in the sub-humid Parkland region. The Alberta crop districts have generally short growing seasons especially the Peace River region (CD 7).

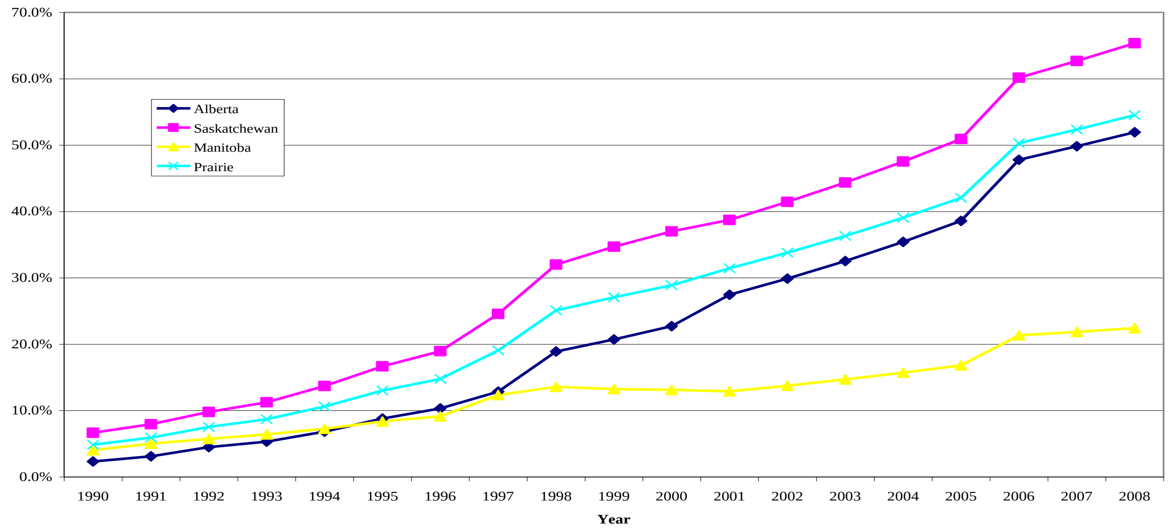

Figure 5: Percentage of Area in Zero tillage by Province

Source: Statistics Canada Agricultural Census 1991 to 2006, Monsanto, Stratus Agri-Marketing Inc.

Reduction in fuel costs would be a major incentive to the adoption of reduced tillage in the 2010 to 2020 period if oil prices rise appreciably without a corresponding rise in the prices of agricultural commodities. If western Canada experienced drier (wetter) than normal precipitation over a number of years higher (lower) zero tillage adoption would be expected. In any given crop year a dry (wet) fall or spring would result in less (more) preseed tillage relative to a normal year. Since, airseeders have become almost universal as the seeding implement of choice in western Canada the marginal cost of conversion would be relatively small especially if sideband or mid-row band is already used. Demand for biomass used in green energy production and green products would be a market for crop residues which could result in more zero tillage adoption to preserve the remaining stubble (McConkey et al. 2008). Also, a market for sequestered carbon would be an incentive for further adoption of zero tillage depending on the contract specifications.

The projected average annual rate of zero tillage adoption for the three Prairie Provinces based on the annual rates as calculated from the 2001 and 2006 Census is presented in Table 1. The 2010-20 annual rate of zero tillage adoption is half the 2001 to 2006 annual rate while the 2007-09 rate is the 2001-06 average rates for Alberta and Manitoba while the rates for Saskatchewan vary depending on the level of adoption in a crop district. The level of adoption from industry surveys for the period 2007-09 were used to estimate the rate of adoption by crop district for this period. The estimates of the adoption of zero tillage for the 2010-2020 period are low because we hold technology development of zero tillage at 2009 rates.

Table 1 : Projected Rates of Adoption of Zero tillage by Crop District

CD	Actual Average Annual Rate			Projected	
SK	**1991 to 96**	**1996 to 01**	**01 to 06**	**2007-09**	**2010-20**
1	3.1%	4.3%	1.1%	1.1%	0.6%
2	2.8%	4.6%	0.8%	1.2%	0.4%
3	2.4%	4.1%	1.1%	0.9%	0.5%
4	0.9%	2.2%	1.1%	0.9%	0.5%
5	1.4%	2.8%	1.2%	1.4%	0.6%
6	2.1%	4.7%	0.9%	1.3%	0.4%
7	3.0%	4.2%	0.9%	1.1%	0.5%
8	0.9%	4.4%	1.4%	1.2%	0.7%
9	2.6%	3.4%	1.3%	0.9%	0.6%
AB	**1991 to 96**	**1996 to 01**	**01 to 06**	**2007-09**	**2010-20**
1	1.1%	3.0%	1.1%	1.1%	0.6%
2	1.6%	4.6%	1.0%	1.0%	0.5%
3	1.2%	3.3%	0.9%	0.9%	0.4%
4A	1.7%	3.6%	1.3%	1.3%	0.7%
4B	1.9%	5.3%	1.3%	1.3%	0.7%
5	1.0%	2.0%	3.7%	3.7%	1.8%
6	1.0%	2.1%	3.2%	3.2%	1.6%
7	1.4%	2.0%	2.8%	2.8%	1.4%
MB	**1991 to 96**	**1996 to 01**	**01 to 06**	**2007-09**	**2010-20**
1	1.8%	2.3%	3.1%	3.1%	1.5%
2	0.7%	0.2%	2.7%	2.7%	1.4%
3	0.2%	-0.2%	0.4%	0.4%	0.2%
4	0.1%	0.1%	0.7%	0.7%	0.4%
5	0.3%	-0.3%	0.1%	0.1%	0.0%
6	0.3%	-0.5%	1.1%	1.1%	0.6%

Source: Author's calculations from Statistics Canada Agricultural Census

2.3 Sequestration Coefficients

The coefficients for carbon sequestration for each cropping activity using zero tillage were developed using the following published estimates. Campbell et al 2005a in a review of Canadian studies of carbon sequestration using zero tillage on the prairies found that the rate of soil carbon change for cropping frequency between 50% to 66% and continuous crop in the semiarid prairie was between 0.18 and 0.37 tonnes CO_2e $ha^{-1}year^{-1}$, and 0.92 tonnes CO_2e ha^{-1} $year^{-1}$, respectively. In the sub humid area of the prairies the rate of carbon sequestration varied from 0.18 to 0.28 tonnes CO_2e $ha^{-1}year^{-1}$ for cropping frequencies less than 75% with 0.92 tonnes CO_2e $ha^{-1}year^{-1}$ when continuously cropped. Adequate fertilization when using zero tillage was also found to be a significant factor in the rate of carbon sequestration. McConkey et al. 2000 report the rates of carbon sequestration for the elimination of fallow for the various soil zones (Table 2) and states that "the adoption of several carbon sequestration practices appears to be approximately additive". The model uses the same rates for carbon emissions if there was an increase in summerfallow.

Table 2 : Carbon Sequestration Coefficients (tonnes CO_2e ha^{-1})

	Elimination of Fallow[a]	Zero tillage Fallow greater > 25%[b]	Zero tillage Continuous Crop[b]
Brown	0.73	0.83	0.83
Dark Brown	1.10	0.83	0.83
Thin Black	1.83	0.18	0.92
Thick Black	2.20	0.18	0.92
Gray	2.20	0.18	0.92

a. Source: McConkey et al. 2000.
b. Source: Campbell et al 2005a.

To obtain the rate of carbon sequestration for a crop district the rates are adjusted for the percentage of soil class in a crop district as presented in Table 3.

Table 3: Percentage of Soil Class by Crop District

CD	Brown	Dark Brown	Thin Black	Thick Black	Gray
AL1	100%				
AL2	20%	80%			
AL3		10%	70%	20%	
AL4		44%	46%	10%	
AL5			10%	80%	10%
AL6				20%	80%
AL7					100%
SA1		33%	67%		
SA2	3%	86%	11%		
SA3	84%	16%	0%		
SA4	100%				
SA5		1%	30%	56%	14%
SA6		84%	16%		
SA7	43%	54%	3%		
SA8		9%		38%	53%
SA9		1%		52%	47%
MB 1			90%	10%	
MB 2		5%	35%	40%	20%
MB 3				100%	
MB 4			10%	90%	
MB 5				100%	
MB 6				70%	30%

Source: Authors' calculation from soils maps.

The base coefficients used to estimate the level of carbon sequestration are presented in Tables 4 for Alberta, Saskatchewan and Manitoba. The model will give an estimate of the amount of carbon sequestered using zero tillage plus an amount for the change in fallow practices from the previous year.

Table 4: Carbon Sequestration Coefficients (tonnes CO_2e ha^{-1} $year^{-1}$)

CD[a]	Zero tillage Fallow[b]	Zero tillage Cont[c]	Fallow Reduction[d]
AL1	0.84	0.84	0.73
AL2	0.84	0.84	1.03
AL3	0.26	0.92	1.83
AL4	0.48	0.88	1.54
AL5	0.18	0.92	2.16
AL6	0.18	0.92	2.20
AL7	0.18	0.92	2.20
SA1	0.40	0.88	1.58
SA2	0.77	0.84	1.17
SA3	0.84	0.84	0.81
SA4	0.84	0.84	0.73
SA5	0.18	0.92	2.09
SA6	0.73	0.84	1.21
SA7	0.81	0.84	0.95
SA8	0.22	0.92	2.09
SA9	0.18	0.92	2.20
MB 1	0.18	0.92	1.87
MB 2	0.22	0.92	2.02
MB 3	0.18	0.92	2.20
MB 4	0.18	0.92	2.16
MB 5	0.18	0.92	2.20
MB 6	0.18	0.92	2.20

Source: Authors' calculations.

a. CD – crop district.
b. Zero tillage Fallow – change in soil organic carbon for rotations with fallow.
c. Zero tillage Cont – change in soil organic carbon for continuous crop rotations.
d. Fallow Reduction – change in soil organic carbon do to reducing fallow area.

Campbell et al. 2005b state that straw yields reflect the precipitation received and can account for the change in soil organic carbon, as carbon sequestration has generally mirrored the production of straw. However, Campbell et al. 2005a note that the relationship between straw yield and changes in soil organic carbon are not linear suggesting that adequate fertilizer is also required. The carbon sequestration coefficients were adjusted for the amount of crop residue produced by each crop, which was determined as a function of the yield of the crop. The result was that with the adjustment for crop residue the model was better able to account for the high grain yields in 1996 and the drought reduced yields through 2001 to 2003 in Saskatchewan and Alberta. Also, the increased fallow in south-eastern Saskatchewan due to excessive spring moisture and the drought in north-eastern Saskatchewan in 1999 are also accounted for in the model.

2.4 Nitrous Oxide Emissions

Duesenbury et al. 2008 found no significant differences in N_2O emissions between conventional and zero tillage cropping systems for the semiarid northern Great Plains. However, Lemke et al. 1999 and Lemke et al. 2002 report that N_2O emissions were similar to lower for zero tillage compared to conventional till at several sites in Alberta. N_2O emissions regardless of cropping system tend to be higher in regions that are more humid; i.e. Parkland region 4.0 kg N ha^{-1} yr^{-1} compared to Brown soil zone of 0.5 kg N ha^{-1} yr^{-1} (Lemke et al. 1999). Heavy rainfall and freeze/thaw events; type of N product (urea, anhydrous ammonia, ammonium nitrate, nitrogen solution) along with application method (seed placed, broadcast, broadcast and incorporated, banded, sidebanded); fall, spring, seed, incrop application period all affect the N_2O emissions from applied nitrogen. Since, 1970 there has been increased use of nitrogen fertilizer as the area in summerfallow declined (Figure 6). As limits to the amount of seed placed N were reached N needed to be applied by alternative means. Broadcast, and broadcast and incorporated were the dominant application methods used in the 1970s. Development and adoption of the airseeder in the 1980s has led to greater amounts of urea being used. Since, 1997 urea has been the dominant product used in the Prairie Provinces (Figure 7).

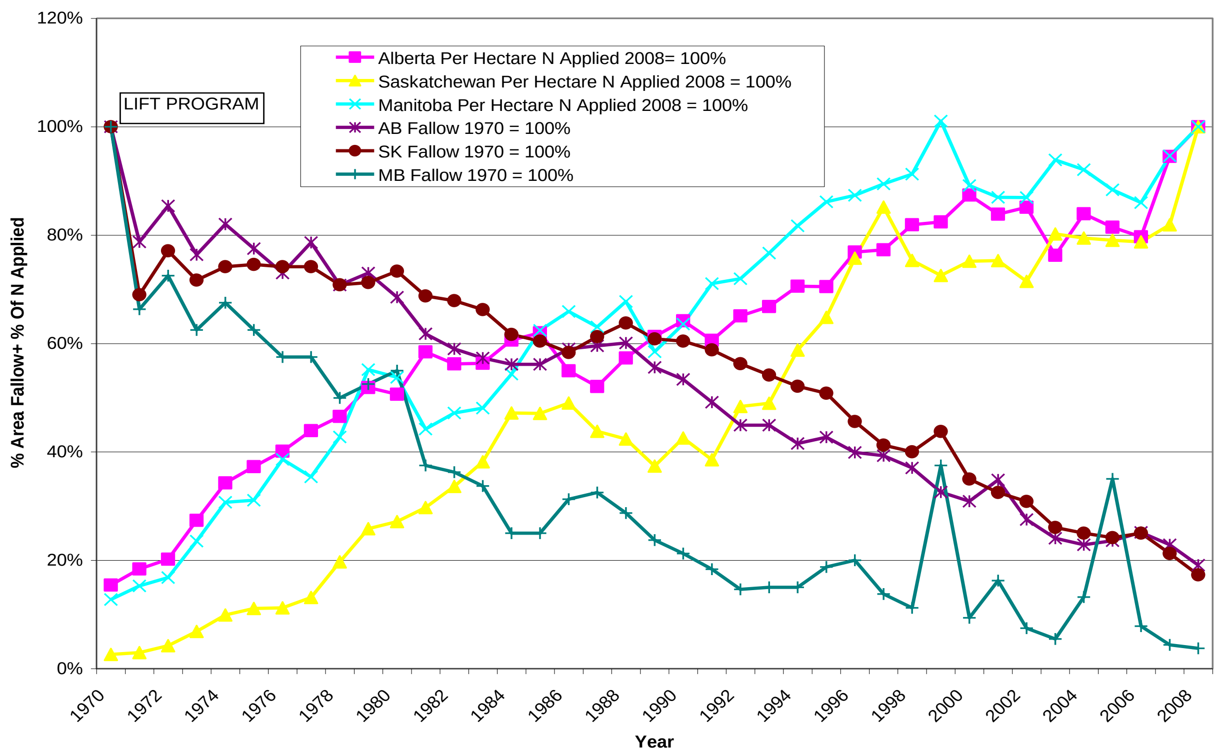

Figure 6: Fallow Area and Commercial Nitrogen Application

Source: Base data from Statistics Canada, Agriculture and Agri-Food Canada and Canadian Fertilizer Institute.
1. Lower Inventories for Tomorrow Program (LIFT) resulted in an increase in fallow area in western Canada that was significantly above 1960s levels.

The main problem in assessing N_2O emissions from the different cropping systems is that there is no data on the type of nitrogen product used or the method of application by cropping system. By definition zero tillage is a one pass seed fertilize operation, however information on product used and placement does not exist. Rochette et al. 2008a estimate the base fertilizer induced emission factors for the semi-arid Brown and sub-humid Black soil zones at 0.0016 and 0.008 kg N_2O-N kg^{-1} N, respectively. They estimated the emission factors for zero tillage adoption in western Canada to be 20% less than the base from research plot data. Rochette et al. 2008b estimated the 1990 to 2005 yearly reduction in N_2O-N from nitrogen fertilizer in the Prairie Provinces over the 1990 to 2005 period (Table 5).

Table 5: Estimate of N_2-O-N yearly Emissions from Fertilizer (Gg N_2-O-N)

	Alberta	Sask	Man
Mean	5.97	6.14	4.88
Min	3.59	1.73	2.97
Max	8.33	11.04	7.59

Source: Rochette et al. 2008b

The method used to estimate the difference in N_2O-N emissions from fertilizer application uses the provincial nitrogen fertilizer allocated to the crop district level to account for the variation in N use overtime and by crop. The amount of nitrogen used at the provincial level is from Agriculture Canada's publication Canadian Fertilizer Shipments, Consumption and Trade, 1980 to 2002 and Canadian Fertilizer Institute 2003 to 2009. The N_2-O-N coefficients from Rochette et al. 2008a for conventional, minimum and N-Till are used to estimate the emissions.

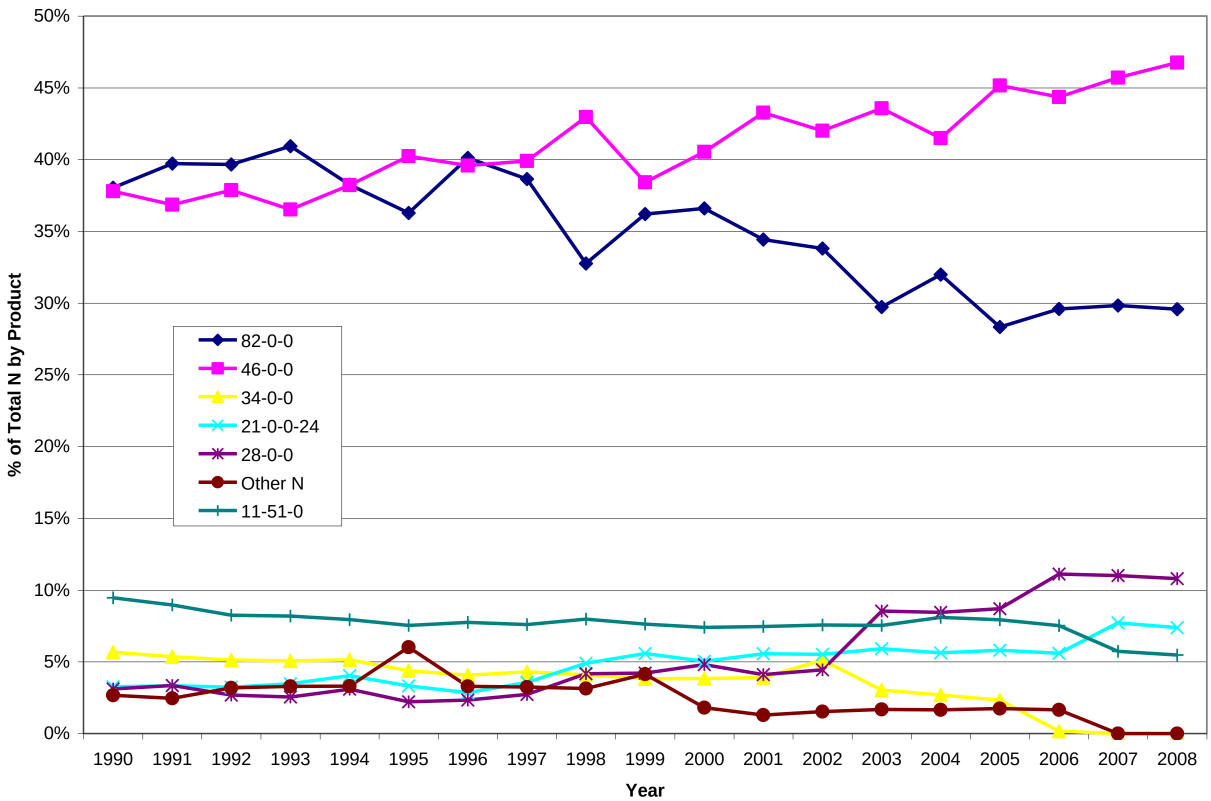

Figure 7: Percentage of Total N by Product Type (Prairie)
Source: Agriculture and Agri-Food Canada and Canadian Fertilizer Institute.

There is also a reduction in nitrous oxide and carbon dioxide emissions due to reduced diesel fuel use as zero tillage is adopted. The estimated reduction in diesel fuel use is multiplied by the GHG coefficient for emissions from tractors combines and swathers from Neitzert et al. (1999). The estimated GHG sink and emission reductions for western Canada due to the adoption of zero tillage are presented in Table 6. The sequestration and fuel use amounts by province reflect the cultivated area and adoption rates in each province. Fertilizer GHG emissions reflect the higher rates of nitrogen applied in Alberta and Manitoba relative to Saskatchewan.

Table 6: Estimated GHG Sink and Emission Reductions

	Sink	Fertilizer	Fuel
	tonne CO2E		
AL	17,851,298	435,229	920,463
SK	35,205,180	531,887	2,168,292
MB	5,793,814	235,918	324,833
Total	58,850,292	1,203,034	3,413,587

Source: Author's calculations.

2.5 Soil Health

Campbell et al. 1997 found that the elimination of fallow had the greatest impact on total organic C, N, and microbial biomass. There were no significant differences due to tillage system after 12 years if fallow was eliminated in the Brown soil zone. Lupwayi et al. 2009, Liebig et al. 2006, and Lupwayi et al. 1999 show significantly higher soil microbial biomass and diversity (Lupwayi et al., 1998) relative to conventional tillage. The difference between the tillage systems being in the top few centimetres of soil which has more crop residue and moisture creating a suitable microbial environment. Clapperton et al. 1997 report significant differences in earthworm populations between zero tillage and conventional tillage in a 25 year wheat –fallow rotation. The difference in soil health between zero tillage and conventional tillage should be reflected in greater N and P availability which would present itself in higher yields and quality (protein).

2.5.1 Nutrient Runoff (Wind, Water and Tillage Erosion)

Selles et al. 1999 found that under zero tillage continuous wheat cropping system in the Brown soil zone the concentration of organic P near the surface was significantly different than compared to tillage systems. Therefore, surface water quality may be affected by runoff from zero tillage fields.

Erosion due to wind and water is a function of crop residue, soil health and weather events. Tillage affects the amount of crop residue that is available to limit erosion either from high wind, snow pack melt and high rainfall events. Tillage also affects the erodibility of the soil by increasing the amount of aggregates that are susceptible to erosion. Also, the permeability of the soil affects the amount of runoff from a field. Drought affects the amount of crop residue and tillage of a dry soil creates higher amounts of small aggregates. Elimination of fallow plays a major role in reducing erosion. Chem fallow and Chem/Till fallow are less prone to erosion than tillage fallow.

Tillage erosion is a function of the number of tillage passes, type of implement and terrain. Reduced tillage on hilly or rolling landscapes limits the amount of soil that moves from the hilltops. Typically the area affected is from 20% to 30% (Govers et al. 1999).

Gregorich and Anderson, 1985, de Jong and Kachanoski, 1988 estimate that erosion is responsible for 45% to 55% of the carbon loss in prairie soils. Dumanski et al. 1986 estimated the area of the Prairies (including B.C. Peace) affected by water and wind erosion to be 4.64 and 6.31 million ha, respectively. Where erosion is defined as moderate or severe such that losses exceed 10 tonnes per ha per year.

The amount of residue needed to control wind erosion given the soil type and water erosion by slope is presented in Table 7. The crop residue for each crop in each crop district is calculated from the crop yield and by the reduction in residue due to tillage operations. If the crop residue falls below the acceptable levels required to mitigate erosion then those hectares are susceptible to erosion. The model is used to calculate the area susceptible to wind erosion for the fall and spring periods. The assumption used is that conventional tillage has a post harvest and a spring preseed tillage operations. Minimum tillage would have a banding operation either post harvest or preseed.

Table 7: Crop Residue Levels to Mitigate Erosion (tonnes per ha)

	Conventional Tillage			**Minimum Tillage**			**N-Till**		
	Cereal	**Oilseed**	**Pulse**	**Cereal**	**Oilseed**	**Pulse**	**Cereal**	**Oilseed**	**Pulse**
Sandy	1.96	3.05	3.63	1.23	1.49	2.95	0.13	0.20	0.12
Loam	1.00	1.60	1.82	0.64	0.66	1.45	0.13	0.20	0.12
Clay Loam	1.05	1.67	1.91	0.73	0.71	1.52	0.13	0.20	0.12
Heavy Clay	1.31	2.04	2.38	0.84	0.95	1.94	0.13	0.20	0.12

Source: Adapted from McConkey and Panchuk, 2009.

Van Kooten et al. 1989 estimate the cost of erosion as the present value of the yield loss discounted at 5% resulting in a per ha cost of $5.63. This is compared with the PFRA estimate of $33.76 per ha using yield loss and the cost to replace nutrients. Using the amount of land that would be subjected to wind erosion as estimated in the model, the value of reduced wind erosion due to zero tillage can be estimated following the methodology in Van Kooten et al. 1989. First the yield loss per hectare due to wind erosion is estimated. For much of western Canada the annual wind erosion is less than 6 tonnes per hectare (National Agri-Environmental Health Analysis and Reporting Program). Larney et al. 1995 estimated the average loss of yield per cm of soil loss is 110 kg per hectare for wheat in western Canada. Since, one cm of soil on a hectare is approximately 100 tonnes, the yield loss is 3.3 kg per hectare using an annual soil loss of 3 tonnes per ha per year. The per hectare value of lost yield is adjusted for cropping frequency for each province to account for fallow. The net present value of the yield loss using actual farm gate wheat prices from 1980 to 2008 with a 10 year moving average to 2020 and a 5% discount rate is $11.62, $6.56, $12.72 per ha for Alberta, Saskatchewan and Manitoba, respectively. The estimated value of the reduction in wind erosion is 3.4, 0.5 and 0.6 billion using PFRA, Van Kooten et al. 1989 and our estimate, respectively (Table 8). The cost of wind erosion using our estimate of yield loss given the price of wheat appears to give a credible, conservative estimate.

Table 8: Reduced Cost of Wind Erosion 1980 to 2020

	PFRA	**Van Kooten**	**Author's**
AB	748,303,912	124,791,203	196,073,156
SK	2,304,466,704	384,305,318	341,118,801
MB	396,597,531	66,138,747	104,986,078
Total	3,449,368,147	575,235,269	642,178,035

Source: Author's estimated from model generated area of wind erosion estimates of wind erosion cost from PFRA 1983 and Van Kooten et al. 1989.

2.5.2 Salinity

Saline seeps are caused by cultural practices since settlement, summerfallow and crop water use over the growing season compared to native vegetation have been identified as major factors. Therefore, reduction in fallow and use of annual and perennial crops that match the timing of growing season precipitation with plant growth are the major mitigation activities. To the extent that the adoption of zero tillage reduces fallow and increases the diversity of crops grown, the affect of saline seeps will be reduced (Ag Canada 2000). Yield reductions at low salt levels have been estimated at between 10% - 20% (Stepphun 1996) with pulse crops > cereal & oilseed > barley in yield loss. The area of primary and secondary salinity resulting in a maximum of 25% decline in productivity is estimated at 0.65, 1.34, and 0.25 million ha for Alberta, Saskatchewan and Manitoba, respectively (VanderPluym & Harron 1992). A further 10 million ha have been estimated to be slightly salinized in western Canada (Stepphun 1996).

The adoption of zero tillage and reduction in fallow will lower the severity of the salinity problem however the full impact is not likely to be immediate (2-5 years) with most of the benefit on slightly to moderately saline land. The reduction in the levels of salinity will impact production by increasing the yields for the crops grown and shift crop production from a lower valued crop of barley (greater salinity resistant) to higher value lower volume crops such as pulses and oilseeds. Since, the demise of the crow benefit in 1996 this latter factor would have become more valuable to the farmer. The benefit of using zero tillage as a management tool to deal with salinity relative to other options including doing nothing

To estimate the benefit of the adoption of zero tillage in the reduction of salinity the percentage of the area of primary and secondary salinity is applied to the difference in area of zero tillage (factual – counter factual) delayed 5 years. The percentage of cultivated area that is affected by salinity by province is 9.3%, 9.7% and 6.2% for Alberta, Saskatchewan and Manitoba, respectively. An estimate of spring wheat yield on stubble for the 1980 to 2008 period plus a 10 year moving average to 2020 is multiplied by 10% to get the yield increase. The farm gate price of wheat adjusted for inflation is used to estimate the dollar value of the benefit. The estimated benefit of reduced salinity due to the adoption of zero tillage over the 1980 to 2020 period is $59,975,597, $128,879,364 and $21,037,973 for Alberta, Saskatchewan and Manitoba, respectively.

2.5.3 Water storage capacity/ Water Use Efficiency

Lafond et al. 1992 found a zero tillage cropping system to have 9% more spring soil water content than conventional tillage resulting in increased yield of spring wheat, flax and field pea in a four year rotation by 21%, 23% and 9%, respectively. Lafond et al. undated found that water infiltration rate was best correlated with organic matter content with a 1% increase in organic matter resulting in a 9 mm increase in the cumulative infiltration. They found an almost linear relationship between years in zero tillage and the rate of increase in organic matter of 0.2% per year of zero tillage.

The yearly average yield of wheat (1980-2009) for each province is used as the basis to estimate the foregone yield. To account for a cost of learning the new system Year 1 -8% less yield; Year 2 – 6% less; Year 3 – 4% less; Year 4 – 2% less; Years 5-10 same; Years 11 – 20 a 1% per year increase; Year 21-30 a 0.5% per year increase; Year 31-40 remains at 115% of average. Wheat prices are the actual farm gate prices from Saskatchewan Statistics Handbook 1980 to 2008 then a rolling average to 2020, deflated to 2009 dollars. The NPV discounted at 5% is $148.30 per ha.

2.6 Cropping System Costs and Benefits

2.6.1 Crop Inputs

The cost savings associated with the adoption of zero tillage technology are dependent on the type of seeding technology in use at the time of conversion. The tillage systems are defined as conventional – two or more tillage operations prior to seeding along with post seeding harrow/packer operation, weed control is achieved through tillage and incrop herbicide application; minimum tillage – one preseed tillage operation mainly associated with nitrogen fertilizer application, weed control is a combination of tillage and herbicides; zero tillage – no preseed tillage operations, one pass seed fertilizer operation, chemical weed control preseed burn off, incrop and post harvest. Further complication is that seeding technologies and practices used have changed over time for all seeding systems not just for zero tillage.

2.6.2 Labour

The labour savings due to the adoption of zero tillage combined with a reduction in summerfallow frees up labour for increased management activities, crop diversification, alternative on-farm enterprises and off-farm opportunities. Thus the valuation of the "freed up" labour becomes problematic as the net per hour value of the options has a wide range and changes over time. Non-farm economic activity in a region and the proximity of large urban centres will affect the cost of on-farm labour and the opportunity cost of a farmer's labour.

Work rates, fuel consumption and labour use for field operations using average size equipment are presented in Table 9. The work rates used are the effective field time as inefficiencies due to field size, geometry and un/loading time are accounted for in the number of turns and turning time. Field operations not only include the time spent doing the operation but also the maintenance, repair, management and travel time expended. These factors range from 10% to 20% of the work rate of the field operation.

Table 9: Work Rates, Fuel Consumption & Labour for Field Operations

	Size	Work rate	Fuel	Labour
Operation	**M**	**Ha hr^{-1}**	**L ha^{-1}**	**Hr ha^{-1}**
Disc Press Drill (pre worked)	12.4	7.8	2.628	0.128
Hoe Press Drill (pre worked)	12.4	7.8	4.038	0.128
One Way Disc	11.0	6.6	3.849	0.152
Air Seeder Sweeps	12.2	8.3	4.746	0.120
Air Seeder Zero tillage	12.2	6.8	4.466	0.147
Harrow Packer	15.2	10.0	1.652	0.100
Heavy Duty Cultivator (Primary)	12.1	6.3	6.028	0.159
Heavy Duty Cultivator (Secondary)	12.1	8.6	4.345	0.116

Source: Nagy 1999.

The net labour savings for zero tillage as compared to conventional tillage seeding system is presented in Table 10.

Table 10: Net Labour Savings Zero Tillage Compared to Conventional

		Pre Seed Passes			Seed	Post	Total	Difference
System	**Seeding System**	**Hr ha^{-1}**						
Conventional	Disc Press Drill	0.159	0.116	0.1	0.128		0.503	0.274
	One way Discer	0.159		0.1	0.152	0.1	0.511	0.282
	Hoe press Drill	0.159	0.116	0.1	0.128		0.503	0.274
	Air Seeder w sweeps	0.159		0.1	0.12	0.1	0.479	0.250
Zero tillage	Air Seeder side band	0.082			0.147		0.229	0

Source: Author's calculations from Nagy 1999.

2.6.3 Fertilizer

The comparison of the use of nitrogen fertilizer in zero tillage cropping systems to conventional systems is complicated by the differences in the amount of fallow and soil moisture availability between the two systems. The mineralization of nitrogen in summerfallow can reduce the need for commercial nitrogen application. If a farmer wants to maximize the available soil moisture in a zero tillage system more nitrogen will be required relative to a conventional tillage system. Or conversely to attain a target yield, less N will need to be applied when using zero tillage relative to conventional tillage (McAndrew undated). Therefore, the metric used for comparison of commercial nitrogen fertilizer use in the literature is kilograms of output per kilogram of nitrogen input.

Nitrogen use efficiency generally increases with type of placement and nearness to crop uptake; in order of increasing efficiency broadcast, broadcast and incorporated, fall banded, spring banded, seed placed, sidebanded. If farmers who use zero tillage sideband nitrogen to a greater extent than conventional tillage, then zero tillage would have greater nitrogen use efficiency. This should be seen in higher yield per kilogram of nitrogen input for zero tillage. Sidebanded nitrogen in the zero tillage system is superior to sideband nitrogen in conventional tillage (McAndrew undated).

Lupawyi et al. 2006 report no significant difference in dry matter and N added to the soil for continuous crop zero tillage and conventional although, crop residues from zero tillage added between 5.1 and 9.4 kg more N ha^{-1}. Lafond et al. undated found significant differences between long term and short term zero tillage in the availability of mid and end of season nitrogen to affect yield and protein of wheat.

2.6.4 Pesticides

The substitution of herbicides for tillage operations results in more herbicide use in zero tillage cropping systems compared to conventional tillage. Typically a preseed spraying operation is used to control weeds in a zero tillage cropping system consisting of one or more herbicides depending on the weeds to be controlled and the weed population. Glyphosate has been the main broad spectrum herbicide used since it was reduced in price in the early 1990s. Narrow spectrum herbicides that are used in combination with glyphosate or alone are 2,4-D, MCPA, dicamba, bromoxynil, florasulam, and tribenuron methyl.

The costs of herbicides used in the preseed application for zero tillage are presented in Table 11. Pre 1992 herbicide cost difference between conventional and zero tillage cropping systems is significantly greater if glyphosate was used. Weed species and population changes with the adoption of reduced or zero tillage compared to conventional tillage (Gill et al. 1994). Weeds that are adapted to the tillage regime will become problems however; the net difference in incrop herbicide application in terms of amount and types of herbicides would be insignificant.

Table 11: Zero Tillage Herbicide Cost

	Rate		Cost		
	Low	**High**		**Low**	**High**
Herbicide	**L ha^{-1}**		**\$ L^{-1}**	**\$ ha^{-1}**	
Glyphosate[a]	0.74	2.47	8.30	6.15	20.50
2,4-D[a]	0.57	1.43	10.15	5.77	14.54
MCPA[a]	0.49	0.99	7.90	3.90	7.81
Bromoxynil	0.49	0.99	20.00	9.88	19.76

Source: 2009 Guide to Crop Protection Saskatchewan.
a. 360 g L^{-1} formulation; 700 g L^{-1} formulation; 600 g L^{-1} formulation

2.6.5 Fuel

The savings in diesel fuel due to the substitution of spraying for cultivator operations to control weeds in summerfallow is presented in Table 12.

Table 12: Chem Fallow vs. Tillage Net Fuel Use

	Litres of Diesel ha^{-1}		
# of Tillage Passes	**Tillage**	**Spraying**	**Net**
1	6.0	0.7	5.3
2	10.8	0.7	10.1
3	15.7	0.7	14.9

Source: Author's calculations from Nagy 1999.

The net fuel savings due to the adoption of zero tillage are presented in Table 13. The difference in fuel use between seeding systems is dependent on the number of field operations and the draft requirements of the operation.

Table 13: Net Fuel Savings Zero Tillage compared to Conventional

		Pre Seed Passes			Seed	Post	Total	Difference
System	**Seeding System**	**L ha^{-1}**						
Conventional	Disc Press Drill	6.028	4.345	1.652	2.628		14.653	9.454
	One way Discer	6.028		1.652	3.849	1.652	13.181	7.982
	Hoe press Drill	6.028	4.345	1.652	4.038		16.063	10.864
	Air Seeder w sweeps	6.028		1.652	4.746	1.652	14.078	8.879
Zero tillage	Air Seeder side band	0.733			4.466		5.199	0

Source: Author's calculations from Nagy 1999.

2.6.6 Management

The adoption of zero tillage technology requires a change in the management of farm activities as weed control using herbicides replaces tillage operations. Also, technical knowledge of the seeding equipment to attain proper seed placement in a range of soil/stubble conditions needs to be acquired as these are significantly different from conventional tillage practices.

2.7 Capital Requirements

2.7.1 Seeding Equipment

The zero tillage seeder along with the sprayer are the main pieces of equipment in the zero tillage cropping system. The difference in the capital cost of changing equipment is influenced by the seeding equipment that is being replaced. For the period of the 1970s to early 1980s disc press drills, one way discers and hoe drills were the main seeding equipment used. The introduction of the airseeder in the late 1970s and early 1980s became the seeding system of choice in the 1990s when replacing seeding equipment. If the equipment being replaced is at the end of its useful life the capital recovery charge will be zero. The capital costs for a number of options to convert to zero tillage are presented in Table 14.

Table 14: Capital Cost of Converting to Zero Tillage ($/m of seeder width)

Upgrade[1]	Used Zero tillage[2]	New Zero tillage[3]
495 to 2100	3000-4000	6000-8000

Source: Nagy and Schoney 2001.

1. Upgrade existing equipment to seed and fertilize in one pass.
2. Cost of used zero tillage seeding equipment, no allowance for the value of the trade.
3. Cost of new zero tillage seeding equipment, no allowance for the value of the trade.

Hours of use of the main tractors declines significantly when switching to zero tillage. This can result in the elimination of unused capacity or longer period over which the tractors can be keep before productivity/reliability declines. Lower hours of operation can result in higher trade in value relative to equipment used in conventional tillage.

Table 15: Cost Reduction due to Reduced Tractor Hours

	Reduced	Cost Reduction	
	Hours	$/hour	Total
AB	8,041,606	33.22	267,142,137
SK	14,849,385	33.22	493,296,572
MB	3,645,567	33.22	121,105,730
Total	26,536,557		881,544,438

Source: Authors' estimates

2.7.2 Harvest Equipment

To the extent that the adoption of zero tillage changes the diversity of crops in a rotation harvest equipment will have to be acquired to process these alternative crops.

2.7.3 Cost Estimation

Fuel energy use by tillage system and crop, which accounts for all fuel energy used to the farm gate are from the Prairie Crop Energy Model (PCEM) is used to estimate fuel use. Labour coefficients for tillage system and crop are used to estimate the amount of labour used. Costs are also estimated for fixed, repair, seed, fertilizer, operating interest and chemical use by tillage system and cropping activity.

3.0 Net Benefit/Cost of Zero tillage

3.1Model Description

The model used to estimate the carbon that is sequestered in the Prairie Provinces is developed from a version of the Prairie Crop Energy Module (PCEM). Available cultivated area is allocated to 122 cropping activities for each of the 22 crop districts in the Prairie Provinces. The cropping activities consist of the eight major grain crops, plus summerfallow, alfalfa, hay and three “other” categories for pulse, oilseed and other annual crops that are new or limited in area. Each of the cropping activities maybe produced by one of three tillage management methods (conventional, minimum or zero tillage) and each can be grown after fallow (conventional, chem.-till, chem-Fallow), cereal, pulse, oilseed, alfalfa, hay or green manure. However, not all combinations of the Crop/Tillage/Previous Activity are included as cropping activities in all regions for agronomic reasons.

Seeded area and crop yield by crop district and year for 1979 to 2009 are from Statistics Canada and agriculture statistics from provincial departments for the eight major grain crops and from 1987 for the specialty crops. The crop yield and seeded area for the 2010 to 2020 period is projected using a 5 year moving average.

The model is used to estimate the carbon sequestration/emission, nitrous oxide emissions from fertilizer use, erosion risk, fuel use, labour use and net cost for the factual case (what actually happened and is likely to happen in the 2010-2020 period). The model is then run with the adoption rates delayed by 5 years to obtain the counter factual case. The difference between the factual and counter factual is the benefit of RD&E zero tillage research in western Canada.

3.2 Results

The benefits of the RD&E into zero tillage technology are presented in Table 16. The major benefit is the reduction in fuel use amounting to $929 million dollars with the reduction in tractor hours adding a further $881 million. Reduction in labour results in a $318 million dollar benefit while the cost difference results in a $372 million dollar benefit. The benefit of sequestered carbon and reduced nitrous oxide emissions when valued at $5.00 per tonne of CO_2E gives a benefit of $294 million and $6 million, respectively. A further benefit is the reduction in cultivated area at risk of erosion of 49.8 million and 76.6 million hectares for the fall and spring, respectively over the 1980 to 2020 period; estimated benefit of $575 million. Reduced affect of salinity was estimated at $209 million. The net benefit of the RD&E of zero tillage is estimated at 3.60 billion.

A second scenario was run where the sink would be full after 20 years, by subtracting the carbon sequestered 20 years earlier from the current year to 2020. The results are presented in Table 17. The net result is a reduction of $176 million in the value of carbon sequestered resulting in a net benefit of the RD&E of zero tillage estimated at 3.48 billion.

Table 16: Net Benefit from RD&E Zero tillage Research in Western Canada

	SINK	Emissions		SAVINGS			Soil Resource			
	CO2	Fertilizer	Fuel	Fuel	Labour	Tractor	Salinity	Wind		Net
	@$5 per	@$5 per	@$5 per	@$.85	@$10	Hours		Erosion	Cost	Benefit
	tonne CO_2E			per litre	per hour	$	$	$	$	$
MB	28,969,069	1,179,590	1,624,164	88,467,747	43,746,802	121,105,730	21,037,973	66,138,747	22,662,195	**394,932,016**
SK	176,025,899	2,659,435	10,841,459	590,531,271	178,192,621	493,296,572	128,879,364	384,305,318	210,723,957	**2,175,455,896**
AL	89,256,492	2,176,143	4,602,314	250,686,777	96,499,267	267,142,137	59,975,597	124,791,203	139,572,932	**1,034,702,861**
Total	**294,251,460**	**6,015,168**	**17,067,937**	**929,685,795**	**318,438,689**	**881,544,438**	**209,892,934**	**575,235,269**	**372,959,084**	**3,605,090,773**

Table 17: Net Benefit from RD&E Zero tillage Research in Western Canada (Sink Full)

	SINK	Emissions		SAVINGS			Soil Resource			
	CO2	Fertilizer	Fuel	Fuel	Labour	Tractor	Salinity	Wind		
	@$5 per	@$5 per	@$5 per	@$.85	@$10	Hours		Erosion	Cost	Total
	tonne CO2E			per litre	per hour	$	$	$	$	$
MB	16,361,267	1,179,590	1,624,164	88,467,747	43,746,802	121,105,730	21,037,973	66,138,747	22,662,195	**382,324,214**
SK	101,816,734	2,659,435	10,841,459	590,531,271	178,192,621	493,296,572	128,879,364	384,305,318	210,723,957	**2,101,246,731**
AL	58,113,128	2,176,143	4,602,314	250,686,777	96,499,267	267,142,137	59,975,597	124,791,203	139,572,932	**1,003,559,497**
Total	**176,291,130**	**6,015,168**	**17,067,937**	**929,685,795**	**318,438,689**	**881,544,438**	**209,892,934**	**575,235,269**	**372,959,084**	**3,487,130,443**

Liang et al. 2005 developed a model to estimate C sequestration in the Prairie Provinces. Using census data for 1996 and 2001 they estimated the sequestration amount due to the adoption of zero tillage for these years at 1.23 million Mg C and 1.72 million Mg C, respectively. Our model estimates for 1996 and 2001 are .606 million Mg C and .777 million Mg C, respectively. The Liang et al. 2005 estimate uses the average yield which would understate carbon sequestration in 1996, a high yield year and overstate it in 2001 a drought year.

4.0 Estimate of the Research, Development and Extension Activity

4.1 Introduction

There were many different firms, organizations and institutions that were involved in the research and development of zero tillage technology and extension effort in western Canada.

Firstly, small private machinery manufacturers in western Canada most of which originated as sole proprietors or family run businesses in connection with their farming operation developed much of the zero tillage hard technology. These firms through mostly private RD&E effort developed the seeding technology and through the patent process would have been able to capture most of the benefits of this effort. Several of the firms were able to access Federal government tax credits on RD&E to help offset some of the cost of this investment. Also, there was some testing and RD&E of zero tillage technology by or in co-operation with PAMI, ATC, and Agricultural Engineering Departments at the Universities. In contrast, the intellectual property of the soft technology of zero tillage could not be captured by these firms due to the soft technology not being tied to the hard technology, and the complexity and cost of establishing credible research trials.

This is where federal and provincial funding through a number of institutions and funding agencies played a role. Agriculture Canada Research Centres across western Canada were critical in developing the soft technologies that would contribute to the high rate of zero tillage adoption in western Canada. There were many parts to the development of soft technologies with basic research on some aspects of the puzzle starting in the 1950s. Over the years there were a number of federal and provincial funding programs that funded public, NGO, and private, RD&E and extension activities.

NGOs which were mainly provincially based were farmer run soil conservation or zero tillage associations. Their main involvement was in extension activities such as zero tillage conferences, field days and field trials. Federal and provincial funding, either directly or through funding programs, along with private companies and farmer memberships or levies were their source of funds. Ducks Unlimited were a major contributor to the development of winter wheat with the major emphasis on low disturbance seeding into standing stubble.

Several private companies supported zero tillage extension activities as it fit with their corporate goals. Chemical companies such as Dow and Monsanto, farm input retail suppliers such as Alberta and Saskatchewan Wheat Pools and Westco fertilizer sponsored conferences, field days etc in co-operation with NGOs. Also, some research was carried out on how zero tillage would fit with the products they produced or sold. TransAlta also funded extension activities and some RD&E due their interest in carbon sequestration.

The adoption of zero tillage technology also required farmers to invest in human capital by attending conferences, field days and field trials etc.

The purpose of this section is to estimate the cost of the RD&E and extension activities carried out in western Canada for zero tillage.

4.2 Estimation of RD&E Expenditure and Rate of Return

Public and private research and development expenditures from various levels of government, NGOs and private corporations are estimated in this section. To accomplish this, a number of data sources were used to construct as complete a database as possible by minimizing duplication while trying to estimate the effort of the major players.

The main source for expenditures on zero tillage RD&E came from the Inventory of Canadian Agri-Food Research (ICAR) database from Canadian Agri-Food Research Council (CARC). The database contains projects funded by the public sector (Federal, Provincial, Municipal), nongovernmental organizations (i.e. Ducks Unlimited), universities and the private sector (i.e. pesticide companies) on agri-food related research. The start date, funding organization, person years by staff category (professional, research, technical staff), and co-operating organizations are supplied with the title of the project. The process involved identifying the zero tillage related projects, the funding organization(s) and the person years for each labour category. The month of the project start date was used to adjust the person years for the first year of a project. Zero tillage related projects were identified over the period of 1960 to 2009 as having direct application to zero tillage adoption or indirectly contributing to the general base of knowledge. The person years for each project were then allocated to the sector categories as determined by the funding organization as direct or indirect RD&E. The categories used were Agriculture Canada, Universities, Industry, Other Public (i.e. Environment Canada, NGOs), Alberta Department of Agriculture, Saskatchewan Department of Agriculture and Manitoba Agriculture Food and Rural Initiatives. The RD&E was then estimated by taking the person year totals of each labour category multiplied by 100% for direct and 10% for indirect and the yearly salary estimate to arrive at an expenditure on RD&E for each sector category. The yearly salary estimates were $100,000 for project lead, $65,000 for professional and $35,000 for technical support. Graduate students were included in the technical support category with a maximum of 0.5 for PhD and 0.3 for MSc. person year per year of project. An estimate of the overhead and supplies used in the RD&E was arrived at by adding 15% and 10% of the labour total for overhead and supplies, respectively[3].

One problem encountered for the years 1998 to 2006 was the increase in the number of mixed public, NGO and private sources of funds for a project. Since, no percentages of the funding share by project participant were given for a project; the project was allocated to the Other Public category. The number of projects that required this process was very small since, after 2004 there are very few zero tillage related projects compared to the 1990s.

Another major source used to identify zero tillage projects was the database of Agricultural Development Fund (ADF) projects from the Saskatchewan Ministry of Agriculture. The database contained the dollar value spent on the projects funded by ADF. Relevant projects on zero tillage were identified as the direct RD&E expenditures by the Saskatchewan government. Since, this database was used for Saskatchewan the values generated from the ICAR database for Saskatchewan Agriculture direct RD&E was not used. The yearly dollar values from the ADF database were converted to constant 2009 dollars.

Seventeen federal government programs that were in operation over the period of zero tillage development were identified as possible sources of funding for RD&E. Only one program supplied data on expenditures. Since, the ICAR database had several of these funding programs as the funding organization of many of the projects dealing with zero tillage development it is felt that this sector is sufficiently covered.

Seven NGOs were identified and contacted for their expenditures on zero tillage RD&E and extension activities. Of the NGOs contacted only the Saskatchewan Soil Conservation Association (SSCA) was able to provide their complete expenditures for their activities of RD&E and extension. The sources of funds for SSCA from public and private sectors were identified and subtracted from the contribution made by these organizations to limit double counting. Several NGOs were listed as the funding organization or as a co-operating partner in the ICAR database so that their activities are accounted for. Extension activities of Alberta Conservation Tillage Society (ACTS) and Manitoba North Dakota Zero Tillage Farmers Association were estimated based on holding a yearly conference/workshop. Most of the funds used to hold these conferences/workshops came from government or private companies. Since, no detailed account for these events could be obtained no amount was subtracted from these sources of funds.

It should be noted that many of the projects were identified as having a direct zero tillage component meaning that zero tillage was part of a larger research project. Therefore, not all of the research benefits would have accrued to zero tillage as other practices and cropping systems would have benefited directly or indirectly. The type of direct zero tillage engineering RD&E included design and assessment of ground openers, packers, residue management, and fertilizer placement. Zero tillage direct agronomic RD&E included weed control (preseed and incrop), cropping sequence, stubble height, soil moisture and temperature, residue management and crop fertilization. Zero tillage related projects were identified on carbon sequestration estimation which included research on the soil carbon and nitrogen cycles and other processes occurring in the soil. Indirect zero tillage RD&E included general agronomic research on weed control, fertilization and cropping practices. This type of research would have been performed even if zero tillage had not been developed. The allocation of 10% of the total indirect RD&E for these activities to zero tillage would account for the cost of the benefit derived to zero tillage.

The amount of RD&E expenditure in western Canada by institution that has been identified through the methodology described is presented in Table 18. Given a $3.4 billion dollar estimated net benefit of the adoption of zero tillage in western Canada, the return for each dollar of public investment in direct zero tillage research would have been $69 while including indirect RD&E would return $52 for each dollar invested. The return for the net savings in fuel and labour are $35 and $26 for direct and both indirect and direct RD&E, respectively. Undoubtedly, not all the research and development on zero tillage that occurred in western

Canada and certainly not all of the extension activity has been estimated. However, the estimates include the major players and most of the projects and extension activities that would have contributed to the expansion of zero tillage in western Canada. Further, since most of the projects that were identified as having a direct zero tillage component were allocated to zero tillage at 100% of the cost when the direct benefit to zero tillage development ranged from ~ 10% to 100%, the cost of zero tillage direct RD&E would be overstated.

Table 18: Estimated RD&E Expenditure on Zero Tillage (2009 $)

Institution/Funding Program	Direct	%	In Direct	%
Saskatchewan Agriculture				
ADF	6,636,253	13.3%		
FROM ICAR DATABASE			372,566	2.4%
Alberta Agriculture				
FROM ICAR DATABASE	2,765,547	5.5%	663,851	4.0%
Manitoba Agriculture				
MARC	346,752	0.7%		
ARDI	10,007	0.0%		
FROM ICAR DATABASE	297,813	0.6%	161,527	1.0%
Agriculture Canada				
Research Branch (From ICAR DATABASE)	26,231,568	52.4%	12,065,749	73.2%
Federal Programs/NGOs/Private Industry				
ACAAFS	86,613	0.2%		
FROM ICAR DATABASE[1]	1,792,214	3.6%	2,734,402	16.5%
NGOs				
SSCA[2]	10,008,643	20.0%		
Alberta Reduced Tillage Society	857,888	1.7%		
MANDAK	428,944	0.9%		
Universities				
U of Manitoba Engineering	15,388	0.0%		
FROM ICAR DATABASE	567,698	1.1%	515,373	3.0%
TOTAL Public RD&E Expenditure	**50,045,327**		**16,513,468**	
	Direct		**Direct + Indirect**	
Estimated Return to RD&E per $ invested	**$69.68**		**$51.77**	

Source: Inventory of Canadian Agri-Food Research (ICAR) database Agriculture Canada
Agricultural Development Fund (ADF) Saskatchewan Ministry of Agriculture
Manitoba Agriculture Food and Rural Initiatives
Agriculture Canada
Saskatchewan Soil Conservation Association

Notes:
1. Includes funds from Federal Government Departments other than Agriculture Canada; Federal-Provincial Programs i.e. Canada-Saskatchewan Agri-Food Innovation Agreement; NGOs i.e. Ducks Unlimited; Private Industry i.e. pesticide and fertilizer, manufactures and retailers i.e. WestCo, Monsanto, BASF, DOW; Alberta Barley Commission, Western Grains Research Foundation, Canadian Wheat Board.
2. Includes direct funding from Federal and Provincial governments and Monsanto.

The internal rate of return (IRR) was estimated for the direct RD&E investment and for the direct plus indirect RD&E investment in zero tillage; the estimates are 68.5% and 34.4%, respectively. The IRR was calculated for the indirect investments starting in 1960 and direct investments in RD&E starting in 1964, both to 2020. The modified internal rate of return (MIRR) was estimated where the cost of finance for investments and the interest on reinvestment is used in the calculation of the internal rate of return. Using a cost of finance of 8% and an interest rate on reinvestment of 10% the MIRR for direct RD&E investment was 20.7% and for direct plus indirect 16.5%.

5.0 Return to Equipment Manufacture Research and Development

5.1 Introduction

Eight manufacturers of zero tillage equipment in western Canada were identified and interviewed. Three of the eight supplied actual expenditure on RD&E and one on federal government RD&E tax credits. Seven of the eight companies supplied the number of employees working on RD&E and years worked. An estimate of the employee, materials, overhead RD&E per employee was used to calculate the amount of RD&E expenditure for the four companies that gave no actual expenditure. For the company that gave no information as a proxy a percentage of the expenditure of RD&E from a company that produces similar zero tillage products was used.

Statistics Canada has data on farm machinery manufacturing by province from 1992 to 2009 and all machinery manufacturing from 1981 to 1997. An estimate of farm machinery manufacturing for 1981 to 1991 is obtained by applying the percentage of the farm machinery manufacturing in 1992 divided by all machinery manufacturing in 1992 to the Statistics Canada 1981 to 1991 all machinery manufacturing data. This series is then adjusted for inflation to arrive at $31.9 billion in 2009 dollars of farm machinery manufactured from 1981 to 2009 for the Prairie Provinces. An estimate of the amount of zero tillage equipment manufactured in the Prairie Provinces is obtained by multiplying the yearly percentage of area in zero tillage by the annual farm machinery production. The result is $7.5 billion in zero tillage machinery production over the 1981 to 2009 period

It is estimated that over the 1976 to 2009 period the RD&E expenditure on developing zero tillage equipment by firms in western Canada was $60.5 million with an estimated $4.3 million in RD&E tax credits all in 2009 dollars. Given that the sales of zero tillage equipment were estimated at $7.3 billion this would mean that on average a manufacturer generated $121 in sales for every dollar invested in RD&E.

Fuglie et al. 2011 report the R&D effort of second tier farm machinery manufactures in high income countries averaged 2.4 percent with a range of 1% to 4% of machinery sales. Given our estimate of zero tillage sales by western Canadian companies of $6.2 billion over the 1981 to 2009 period the amount of R&D expenditure in Canada would have been approximately 1% of sales. This is on the low end of the range which could reflect the limited product line of western Canadian companies.

5.2 Western Canadian Investment in Zero Tillage Equipment

The additional machinery needed for zero tillage is estimated following the methodology in Gray and Scott 2003. An estimate of the marginal per ha investment in machinery required to adopt zero tillage is obtained from Saskatchewan Agriculture "Farm Machinery Custom and Rental Rate Guide (various years). The marginal difference is calculated as the cost of a zero tillage seeder for the year minus the cost of a conventional tillage seeder. This difference is divided by a standard farm size of 607 seeded ha and adjusted by the CPI to arrive at 2009 real dollars yearly machinery investment. The estimate of the yearly adoption of zero tillage in western Canada is used to calculate the yearly new investment in zero tillage machinery and the yearly replacement investment in zero tillage machinery. Where new investment is the difference between the current year and previous year's rate of adoption times the per ha yearly machinery investment. And replacement investment is the current year's zero tillage adoption area times 10% (to reflect replacement every 10 years) times the yearly machinery investment. To obtain the yearly sales of zero tillage machinery in western Canada by western Canadian manufactures the yearly sales figures are adjusted by their share of the western Canadian market (Table 19). Kulshreshtha and Thompson 2005 estimated the value added by the farm machinery manufactures in Saskatchewan from $395.6 million in sales over the 1998 to 2002 period to be $233.6 million. This 59% of manufacturers' sales as value added is likely to be consistent over the 1980 to 2020 period and across the three Prairie Provinces. The value added amount is calculated as 59% of the western Canadian manufacturers' sales to reflect that most of the iron and rubber along with the fabricating machinery would come from outside this region.

Table 19: Western Canadian Manufacturers Zero Tillage Market Share

Year(s)	Market Share %
1981-83	10%
1984	20%
1985	30%
1986	40%
1987-92	50%
1993	60%
1994-96	70%
1997-98	80%
1999-2009	90%

Source: Author's estimates

An estimate of the marginal and total investment in zero tillage machinery by farmers and an estimate of western Canadian manufacturer's sales and value added is presented in Table 20. Therefore, given an RD&E investment of $60.5 million by the zero tillage equipment manufactures in western Canada over the 1980 to 2009 period returns $61 in value added for every dollar invested.

Table 20: Western Canadian Farmer Investment, Manufacture's Sales & Value Added

	Marginal	Total
New Investment ($)	45,200,283	4,520,028,290
Replacement Investment ($)	31,092,806	3,109,280,612
Total Investment ($)	**76,293,089**	**7,629,308,902**
Western Canada Manufacturers' Sales	62,514,538	6,251,453,825
Western Canada Value Added ($)	36,883,578	3,688,357,757

Source: Author's estimates

6.0 Conclusion

Zero tillage was one of many soil conservation options that were developed as a direct result of the major soil erosion events of the 1930s and the research funding that resulted. Agriculture Canada and the PFRA developed many soil conservation options such as in field tree windrows, strip cropping, and stubble strips. Basic research on chemical fallow, reduced tillage, preserving crop residue were also carried out. The extent to which this concern resonated in the farm community lead farmers to try a number of these options. However, the persistent loss of soil organic matter from the technology in use was recognized as a serious problem by soil scientists. In the absence of zero tillage development these other options may have become more prevalent, however the net benefits would have been significantly different. Also, the adoption of zero tillage does not preclude the adoption of these other strategies.

The return to the investment of $66.5 million in zero tillage RD&E research by public, NGOs and private sector amounts to $52 dollars for every dollar invested. Inclusion of the RD&E expenditure by machinery manufactures of $60.5 million with the $66.5 million zero tillage RD&E returns $27 for each dollar invested. An internal rate of return of 34% to the direct and indirect RD&E investment was estimated. Approximately, 50% of the $3.4 billion net benefit of the research was captured directly by farmers in terms of fuel, labour, machinery and other input cost reductions. The total benefit of reduced fuel use over the estimation period of 1980 to 2020 is equivalent to the current volume of agriculture fuel used for one year in western Canada. The value of the carbon sequestered by farmers has been realized by some farmers who have adopted zero tillage technology but it has not been universal. The yearly advance in soil quality due to reduced wind erosion or losses due to salinity are not likely to be associated with improvements in the bottom line by farmers.

The RD&E expenditure by zero tillage machinery manufacturing businesses of $60.5 million generated $121 dollars in sales for each dollar invested of which $61 of those dollars was value added. The effect of the estimated $4.0 million in investment tax credits for RD&E research from the federal government was not estimated in this report. The tax credits at the very least may have reduced the time for product development.

Several benefits arising out of the adoption of zero tillage were not estimated in this study. The adoption of zero tillage provided societal benefits of freeing up resources such as fuel and labour which could be used in other activities within the region or exported. The value to future generations of the preservation of the soil resource was not estimated. Also, the change in the amount of public funds needed for crop insurance during a drought or due to low rainfall was not calculated. Finally, the private sector benefits accruing to the herbicide manufacturers, specifically the makers of glyphosate were not estimated.

The nature of most of the research carried out by the public sector was such that the knowledge or soft technology developed was not patentable or tied to any hard technology such that rents could be captured. This combined with most of the zero tillage equipment manufactures being relatively small operations compared to the major manufactures meant that the agronomic RD&E would not have been done. Therefore, the public investment in RD&E substantially aided in the adoption of zero tillage technology. Specifically, in answering the questions about residue management, seeding depth and soil temperature that farmers were concerned about.

Of the public, NGOs and private sector research dollars estimated in this report, Agriculture Canada Research Branch accounted for 52% of the direct and 73% of the indirect RD&E expenditure on zero tillage. The major role that the Research Branch played in the development of zero tillage in undertaking primary research and interaction with farmers and equipment manufactures is one of the reasons for the high adoption rates obtained.

References

Acton, D.F. and L.J. Gregorich, 1995. The Health of Our Soils: Toward sustainable agriculture in Canada. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Canada. Publication 1906/E. Pp 129.

Agriculture and Agri-Food Canada, 2000. Prairie Agricultural Landscapes: A Land Resource Review. Minister of Public Works and Government Services, Canada.

Campbell, C.A., V.O. Biederbeck, B.G. McConkey, D. Curtin and R.P. Zentner, 1999. Soil quality- Effect of Tillage and Fallow Frequency. Soil Organic matter Quality as influenced by tillage and fallow frequency in a silt loam in southwestern Saskatchewan. Soil Biology and Biochemistry, 31:1-7.

Campbell, C.A., H.H. Janzen, K. Paustian, E.G. Gregorich, L. Sherrod, B.C. Liang, and R.P. Zentner, 2005a. Carbon Storage in Soils of the North American Great Plains Effect of Cropping Frequency. Agronomy Journal, 97:349-363.

Campbell, C.A., R.P. Zentner, F. Selles, R. Lemke, B.G. McConkey, and B.C. Liang, 2005b. Effects of crop Rotation on C Trends in a Brown Chernozem. Agriculture and Agri-Food Canada Research Branch.

Campbell, C.A., R.P. Zentner, V.O. Biederbeck, F. Selles, R. Lemke, and B.G. McConkey, 2005c. Effects of Crop Rotation and Fertilization on Soil Carbon Sequestration in the Semiarid Prairie. Agriculture and Agri-Food Canada Research Branch.

Campbell, C. A., Selles, F., De Jong, R., Zentner, R. P., Hamel, C., Lemke, R., Jefferson, P. G. and McConkey, B. G. 2006. Effect of crop rotations on NO3 leached over 17 years in a medium-textured Brown Chernozem. Can. J. Soil Sci. 86: 109–118.

Campbell, C.A., R.P. Zentner, H.H. Janzen and G.P. Lafond, Effect of Cropping Frequency on C storage in Canadian Prairie Soils. Agriculture and AgriFood Canada.

Canadian Agri-Food Research Council (CARC), 2006. Inventory of Canadian Agricultural Research (ICAR). PDF and Excel spreadsheets.

Clapperton, M. J., J. J. Miller, F. J. Larney and C. W. Lindwall, 1997. Earthworm Populations as Affected by Long term Tillage Practices in southern Alberta, Canada. Soil Biol. Biochem. Vol. 29- No. 3/4:631-633.

de Jong, E., and R.G. Kachanoski, 1988. Estimates of Soil Erosion and Deposition for Some Saskatchewan Soils. Can. J. Soil Sci., 68:11-119.

Dumanski, J., D. Coote, G. Lucerek and C. Lok, 1986. Soil Conservation in Canada, *Journal of Soil and Water Conservation*, 41:204-210.

Dusenbury, M. P., R. E. Engel, P. R. Miller, R. L. Lemke and R. Wallander, 2008. Nitrous Oxide Emissions from a Northern Great Plains Soil as Influenced by Nitrogen Management and Cropping Systems. Journal of Environmental Quality, 37:542-550.

Fuglie, K.O, P.W. Heisey, J.L. King, C.E. Pray, K. Day-Rubenstein, D. Schimmelpfenning, S. L. Wang and R. Karmarkar-Deshmukh, 2001. Reserarch Investments and Market Structure in Food Processing, Agricultural Input, and Biofuel Industries Worldwide. ERR-130. U.S. Dept pf Agriculture, Econ. Res. Serv. Pp 147.

Gill, K.S., and M.A. Arshad, 1995. Weed Flora in the early growth period of spring crops under conventional reduced and zero tillage systems on a clay soil in northern Alberta Canada. Soil and Tillage research, 33:65-79.

Govers, D, Lobb, A and Quine, T.A., 1999. Tillage erosion and translocation: emergence of a new paradigm in soil erosion research, Soil Tillage Research. 51:167–174.

Gregorich, E.G. and D.W. Anderson, 1985. The effects of cultivation and erosion on soils of four toposequences in the Canadian Prairies. Geoderma, 36:343-354.

Huffman, E., R.G. Eilers, G. Padbury, G. Wall, K.B. MacDonald, 2000. Canadian agri-environmental indicators related to land quality: integrating census and biophysical data to estimate soil cover, wind erosion and soil salinity. Agriculture, Ecosystems and Environment 81:113–123.

Kharbanda, P., D. McAndrew and S. Werezuk, undated. Zero Tillage Suppresses Barley and Canola Diseases. Alberta Environmental Centre, Agriculture and Agri-Food Canada.

Kulshreshtha, S. and W. Thompson, 2005. Economic impacts of the Saskatchewan Agriculture and Food Cluster on the Saskatchewan Economy. Report prepared for Saskatchewan Agriculture and Food. Pp. 76.

Lefebvre, A., W. Eilers, and B.Chunn (eds.), 2005. Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series – Report #2. Agriculture and Agri-Food Canada, Ottawa, Ontario. Pp 232.

Lafond, G., H. Loepky and D.B. Fowler, 1992. The effects of tillage systems and crop rotations on soil water conservation seedling establishment and crop yield. Can. J. Plant Sci. 72:103-115.

Lafond, G.P., B.E. May, J. McKell, F. Walley, H. Hunter, C. Holzapfel and C. Maule, Undated. Long-Term Implications of No-Till Production Systems: What are the implications?

Lemke, R.L., T.G. Goddard, F. Selles, and R.P. Zentner. 2002. Nitrous oxide emissions from wheat-pulse rotations on the Canadian prairies. In Proc. 4th Annual Canadian Pulse Research Workshop, Edmonton, AB, Canada. 8–10 Dec. 2002. Organizing Committee Canadian Pulse Research Workshop, Edmonton, AB, Canada. p. 95–98.

Lemke, R.L., R.C. Izaurralde, M. Nyborg, and E.D. Solberg. 1999. Tillage and N source influence soil-emitted nitrous oxide in the Alberta Parkland region. Can. J. Soil Sci. 79:15–24.

Liang, B. C., Campbell, C. A., McConkey, B. G., Padbury, G. and Collas, P. 2005. An empirical model for estimating carbon sequestration on the Canadian prairies. Can. J. Soil Sci. 85: 549–556.

Liebig, M., Carpenter-Boggs, L., Johnson, J. M. F., Wright, S. F., and Barbour, N. 2006. Cropping system effects on soil biological characteristics in the Great Plains. Renew. Agric. Food Sys. 21, 36-48.

Lobb, D.A., E. Huffman, D. C. Reicosky, 2007. Importance of information on tillage practices in the modelling of environmental processes and in the use of environmental indicators. Journal of Environmental Management, 82:377–387.

Lupwayi, N. Z., Rice, W. A., and Clayton, G. W. 1998. Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. Soil Biol. Biochem. 30: 1733-1741.

Lupwayi, N.Z., Rice, W.A., and Clayton, G.W. 1999. Soil microbial biomass and carbon dioxide flux under wheat as influenced by tillage and crop rotation. Can. J. Soil Sci. 79: 273-280.

Lupwayi, N. Z., Clayton, G. W., O'Donovan, J. T., Harker, K. N., Turkington, T. K. and Soon, Y. K. 2006. Nitrogen release during decomposition of crop residues under conventional and zero tillage. Can. J. Soil Sci. 86: 11–19.

Lupwayi, N., Y. Soon, G. Clayton, S. Bittman, S. Malhi C. Grant, 2009. Soil microbial response to controlled-release urea under zero tillage and conventional tillage in western Canada. International Plant Nutrition Colloquium, U. of California, Davis, Paper 1242.

McAndrew, D.W. Undated. Nitrogen and Phosphorus Fertilizer Application Rates in Zero-Tillage. Agriculture and Agri-Food Canada. Pp 5.

McClinton, B., 2009. Personal communication.

McConkey, B., Liang, B.C., Padbury, G., Ellert, B., Lindwall, W., 2000. Prairie Soil Carbon Balance Project A System for Quantifying and Verifying Change in Soil Carbon Stocks from Adoption of Direct Seeding and Better Crop Management.

McConkey, B., B. C. Liang, G. Padbury, and W. Lindwall, 2000. Carbon Sequestration and Direct Seeding. Semiarid Prairie Agricultural Research Centre (SPARC), Agriculture and Agri-Food Canada, Swift Current, Saskatchewan.

McConkey, B., S. Kulshrestha, S. Smith, C. Nagy, T. Huffman, R. Gill, B. MacGregor, N. Newlands, L. Townley-Smith, M. Boehm, W. Smith, B. Grant, D. Cerkowniak, M. Bentham, R.

Desjardins, J. Pinter, J. Dyer, T. Martin, B. Saha, R. Bemrose, M. Lindsay, 2008. Maximizing Environmental Benefits of the Bioeconomy using Agricultural Feedstock – PHASE I, Report to the PERD - CBIN Bio-energy project. Pp 252.
McConkey, B., and K. Panchuk, 2009. Securing Low Erosion Risks after Pulses and Oilseeds, Saskatchewan Ministry of Agriculture. Pp 3.

Memory, R., and R. Atkins, Air Seeding- the North American Situation. Pp 7.

Munn, M. D., and R. J. Gilliom, 2001 Pesticide Toxicity Index for Freshwater Aquatic Organisms. U.S. Geological Survey, U.S. Department of the Interior Water-Resources Investigations Report. Sacramento, California. 01-4077.

Nagy, C.N., 2001. An Economic and Agronomic Analysis of Reduced Tillage. Centre for Studies in Agriculture Law and the Environment (CSALE) and Canadian Agricultural Energy End-Use and Data Analysis Centre (CAEEDAC). Pp 26

Nagy C. N., 1999. Energy Coefficients for Agriculture Inputs in Western Canada, CSALE Working Paper Series #2, Centre for the Studies in Agriculture Law and the Environment.

Nagy, C.N. and R.A. Schoney, 2001. An Economic Analysis of Switching from Conventional to Zero Tillage Technology in Saskatchewan. Final Report to Agriculture and Agri-Food Canada. Pp 41.

Nagy, C.N. and R. Gray, 2006. Cost and Benefits of Carbon Sequestration in the Agricultural Crop Land in Western Canada. Prepared for Agricultural Producers Association of Saskatchewan (APAS) and Saskatchewan Soil Conservation Association (SSCA). Pp 77.

Neitzert, F., K. Olsen and P. Collas, 1999. Canada's Greenhouse Gas Inventory 1997 Emissions and Removals with Trends, Environment Canada, April 1999.

Prairie Farm Rehabilitation Administration. 1983. Land degradation and soil conservation issues on the Canadian Prairies. Working Paper. Agr. Can., Regina, Sask. Pp 326.

Rennie, D. A., 1985. Soil Degradation, A Western Perspective. Canadian Journal of Agricultural Economics. 33-1:19-29.

Roberts, T.L., B. Green and J. Farrell, 1998. Fertilizer Use and Grain Protein on the Canadian Prairies, In Wheat Protein Production and Marketing, edited by Fowler, Geddes, Johnston and Preston. University Extension Press, University of Saskatchewan.

Rochette, P., Worth, D. E., Huffman, E. C., Brierley, J. A., McConkey, B. G., Yang, J., Hutchinson, J. J., Desjardins, R.L., Lemke, R. and Gameda, S. 2008a. Estimation of N2O emissions from agricultural soils in Canada. II. 1990-2005 Inventory. Can. J. Soil Sci. 88: 655-669.

Rochette, P., Worth, D. E., Lemke, R. L., McConkey, B. G., Pennock, D. J., Wagner-Riddle, C. and Desjardins, R. L. 2008b. Estimation of N2O emissions from agricultural soils in Canada. I. Development of a country-specific methodology. Can. J. Soil. Sci. 88: 641-654.
Selles, F., B.G. McConkey, and C.A. Campbell, 1999. Distribution and Forms of P under cultivator- and zero-tillage for continuous- and fallow-wheat cropping systems in the semi-arid Canadian prairies. Soil and Tillage Research 51:47-57.

Selles, F., C.A. Grant, and A.M. Johnston, 2002. Conservation Tillage Effects on Soil Phosphorus Distribution. Better Crops, 86-3:4-6.

Science Council of Canada, 1986. A Growing Concern: Soil Degradation in Canada. Science Council of Canada. Pp 22.

Standing Senate Committee on Agriculture, Fisheries and Forestry, Hon. H.O. Sparrow, Chair, 1984. Soil at risk-Canada's eroding future. Senate of Canada, Ottawa, Ont. Pp 129.

Statistics Canada, 2006. Agricultural Census 2006. http://www.statcan.gc.ca/pub/95-629-x/2007000/4123856-eng.htm.

Statistics Canada, 2009. Table 001-0010 - Estimated areas, yield, production and average farm price of principal field crops in metric units, annual.

Statistics Canada, 2010. Statistics Canada data from Crops Small Area Data (22C0005). http://www.statcan.ca

Stepphun, H., 1996. What is Soil Salinity? In Proceedings of the Soil Salinity Assessment Workshop, Alberta Agriculture, Food and Rural Development. Alberta Dryland Salinity Control Association. Prairie Salinity Network, Agriculture Agri-Food Canada. Lethbridge Alberta.

Van Kooten, G. C., W. P. Weisensel and E. de Jong, 1989. Estimating the Costs of Soil Erosion in Saskatchewan. Canadian Journal of Agricultural Economics 37:63-75.

VandenBygaart, A.J., McConkey, B.G., Angers, D.A., Smith, W.N., de Gooijer, H., Bentham, M.J., and Martin, T. (2008). "Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory.", Canadian Journal of Soil Science, 88(5), pp. 671-680.

VanderPluym, H., and B. Harron, 1992. Dryland Salinity investigation procedures manual. Conservation and Development Branch, Alberta Agriculture.

Zentner, R.P., C.N. Nagy, G.P. Lafond, B.G. McConkey, and A.M. Johnston, 2007. Energy Performance of Alternative Cropping Systems and Tillage Methods in Saskatchewan. Pp 13

Zentner, R.P., Selles, F., Campbell, C.A., Handford, K. and McConkey, B.G. 1992b. Economics of fertilizer-N management for zero-till continuous spring wheat in the Brown soil zone. Can. J. Plant Sci. 72: 981-995.

Zentner, R.P., K.E. Bowren, J.E. Stephenson, C.A. Campbell, A. Moulin and L. Townley-Smith, 1990. Effects of Rotation and Fertilization on Economics of Crop Production in the Black Soil Zone of North-Central Saskatchewan, Can. J. Plant Sci., 70:837-851.

End Notes

[1] See the book Landscapes Transformed.
[2] This assumption is deliberately conservative in approach, which will produce somewhat lower but very defendable estimates of the rates of return to this research.
[3] Personal communication with Elwin Smith at the Agriculture Canada Lethbridge Research Station.