Sustainably Increasing Crop Production in Alberta: Land Use, Nutrient Management, Greenhouse Gas Emissions, and Economics

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EXECUTIVE SUMMARY

The purpose of this study was to provide an analysis of the sustainability and economic effects of increasing crop production from the existing land base rather than bringing new land into production through improved nitrogen management in the Alberta.

To meet this purpose, the literature regarding tradeoffs between increasing crop production through intensification in land use vs generating increased production through extensification and land conversion was reviewed, along with the agronomy literature outlining the prospects for increased crop yields through increased nitrogen application and associated adjustments in management. Based on this, scenarios representing low intensification (baseline) medium, and high intensification were developed. These scenarios were analyzed based on nitrous oxide emission and economic efficiency.

Findings

- Agricultural land use in Alberta has evolved through a shift from an extensive land use system to increasing intensification over time. This is evident in increased yields and increasing crop production over time, on what has been essentially a constant agricultural land base. Shifts have occurred toward annual crops from pasture, accompanied by increased use of fertilizers and pesticides. This evolution has been accompanied by refinements in practices for sustainability of the production base; for example, in a short period of time, direct seeding/zero-till systems have become heavily adopted in Alberta.
- The literature clearly shows that extensive land use results in improved sustainability on a unit area basis. More intensive management employs relatively more inputs to obtain higher yields on relatively less land. When these higher yields are factored in, intensive management is found to be more sustainable (in terms of greenhouse gases, nutrient application, etc) on a unit output basis than extensive management. The reality of a limited land base thus suggests that intensification of existing agricultural land is more sustainable than converting land from other uses to agricultural production as a means of increasing output.
- The agronomy and crop management literature provides the scientific basis for fertility management that can generate significantly increased yields in a western Canadian environment. However, to be efficacious, this requires the selection of appropriate cultivars, timely seeding, using appropriate pest management, and assessment of the soil nutrient status through soil testing in addition to increased rates of fertilizer
- Based on this literature, empirical models of yield response to fertilizer, and expert opinion, agronomic scenarios were developed to represent wheat and canola production in Alberta. A baseline scenario representing current practice was developed, along with two BMP scenarios consistent with the NERP that produce higher yields with increased fertilizer use. These were developed for three regions of Alberta- EcoDistrict 791 (South-central Alberta, dark brown soil zone), EcoDistrict 727 (Central Alberta, black soil zone), and EcoDistrict 596 (Peace River region- grey soil zone).
- The scenarios developed envision significantly increased yields. For canola, the BMP scenarios contain yield increases over the baseline range between 32 and 65%. For wheat, the scenarios contain yield increases between 37 and 69%. The BMP scenarios

involve range of changes in seeding rate, weed control, fungicide and growth regulator treatments compared with the baseline to achieve these yield increases as well as increased fertilizer application.

- A GHG lifecycle model was constructed that included field operations and the upstream GHGs associated with manufacture of fertilizer and other agricultural chemicals to evaluate the scenarios. The results showed that overall GHG emissions per hectare increased substantially with cropping intensity. However, emissions per kilogram crop produced were similar at the different levels of intensity- in other words, the increase in yield offset the increase in greenhouse gas emissions. When the GHG emissions from the land base required to produce the same amount of crops are compared there is no substantial difference in the GHG emissions among intensification scenarios. Conversely, increasing production through an extension of the area farmed in lieu of intensification involves conversion of lands from grassland, wetland or forest, which will result in a substantial release of GHGs and the loss of net sequestration capability as well as the other ecological goods and services provided by natural ecosystems.
- An economic analysis compared the BMP scenarios for the two crops and three regions. The analysis considered agronomic costs and returns; other costs such as harvesting, equipment depreciation, etc. were not considered as they do not vary significantly by scenario. Thus the economic analysis estimated agronomic costs, revenues, and margin (revenue less agronomic costs) to evaluate the scenarios. In each case, input and output prices were based upon historical averages.
- The results showed that the margin over agronomic costs increased the BMP scenarios compared with the baseline, with the most intensive BMP scenario providing the largest return over agronomic cost. These are presented in the table below. This was particularly significant for canola which saw an increased margin of up to $188/acre; for wheat the potential increased return per acre under the high intensification BMP was up to $72/acre.

Thus, there appear to be good prospects to significantly increase crop yields and production Alberta on an environmentally and economically sustainable basis, through more intensive management.

Cost, Revenues, and Margins by Intensification Scenarios

		Canola				**Wheat**					
		Yield (bu/acre)	**Price ($/bushel)**	**Agronomy Cost ($/acre)**	**Revenue ($/acre)**	**Margin ($/acre)**	**Yield (bu/acre)**	**Price ($/bushel**	**Agronomy Cost ($/acre)**	**Revenue ($/acre)**	**Margin ($/acre)**
Risk Area 2-ED791	Baseline	34	12.61	148.99	428.64	279.64	42	6.48	104.44	272.06	167.62
	Medium	45	12.61	214.04	567.31	353.27	56	6.48	179.69	362.75	183.06
	High	56	12.61	246.26	705.99	459.73	70	6.48	265.79	453.43	187.64
Risk Area 11-ED727	Baseline	37	12.61	140.25	466.46	326.21	52	6.48	116.27	336.84	220.57
	Medium	48	12.61	206.46	605.14	398.68	69	6.48	178.93	446.95	268.02
	High	60	12.61	242.18	756.42	514.24	87	6.48	271.21	563.55	292.34
Risk Area 19-EI	Baseline	35	12.61	148.99	441.24	292.25	53	6.48	116.27	343.31	227.04
	Medium	45	12.61	211.12	567.31	356.19	71	6.48	187.68	459.91	272.23
	High	55	12.61	241.01	693.38	452.37	88	6.48	285.79	570.03	284.24

Table of Contents

1 Introduction

The demand for crops is increasing worldwide (Tilman et al. 2011). The Royal Society stated in 2009 that increased demand of food can only be satisfied if: "there is also a substantial increase—by between 50 and 100%—over today's levels of production of all major food crops. This increase demands urgent action, with clear short-, medium- and long-term goals." (Davies et al, 2009). At the same time, there are no large tracts of high quality land that can be brought into production to extend the agricultural land base. In fact, globally the extent of the agriculture land base may have already peaked and be in decline (Ausbel et al. 2013). This scenario suggests that any response to increased demand for agriculture products will come largely through intensification of production on a reduced agricultural land base rather than bringing more acres into production.

In the same time frame that the world population is expected to grow from 7 to 9 billion and food demand increase potentially double, Alberta's population is expected to nearly double from the current level of 3.5 million people (Alberta Treasury Board and Public Finance 2013). Furthermore, almost all of the increase will come in urban areas with continuing land conversion from rural to urban further reducing the agricultural land base. This represents an opportunity for rural economic development in Alberta but also present many challenges particularly in the area of conflicting land use.

There is also an enhanced interest and awareness regarding the sustainable use of natural resources used in food and agricultural production to satisfy this growing demand. This relates to greenhouse gases, losses of nutrients and reduced fertility of soils, consumption of water, and other factors. Sustainability is increasingly viewed as an integrated approach that seeks to balance among economic, social, and environmental goals. The economic viability of farms, particularly small and medium farms, is viewed almost globally as an ongoing issue. The main environmental areas of concern are greenhouse gas (GHG) emissions, losses of nutrients and soil degradation, and consumption and pollution of surface and groundwater. Responsible agriculture chemical use in relation to human health and employment conditions for farm workers are examples of social issues often included under the sustainability umbrella.

Increasingly, downstream customers for food products are monitoring and seeking assurances of the sustainability of products they sell. Much of the current focus is on greenhouse gas emissions associated with agriculture products. Major retailers[1] have sustainability programs in place that seek to reduce the GHG all along the supply chain. This is important to the farm segment of the supply chain as retail food members and their intermediate suppliers have made significant commitments to sourcing agricultural products from sustainable suppliers. As a result, the supply chain has become keenly interested in the differences in GHG emissions associated with various farm practices. Since the major greenhouse gases associated with crop production is nitrous oxide, there is particular interest in improving nitrogen fertilizer management of all major crops.

[1] For example Walmart, Pepsico, and McDonalds all have sustainability programs with a strong focus on the energy life cycle and carbon footprint of the products they sell as well as their internal energy efficiencies.

In Alberta, the interests of the agriculture supply chains in reducing GHGs coincides with public policy aimed at reducing GHGs from large final emitters such as power plants. Alberta's Specified Gas Emitters Regulations allow regulated final emitters to use GHG offset credits produced by non-regulated industries such as agriculture. These offsets must be produced using protocols approved by the regulator and trade within Alberta's regulated carbon market. The Nitrous Oxide Emission Reduction Protocol (NERP) is an approved protocol that focuses on improving nitrogen use efficiency and concomitantly reducing nitrous oxide emissions. The mechanism for improving nitrogen use efficiency in NERP is the 4R Nutrient Stewardship Program developed by the International Plant Nutrition Institute (IPNI). The 4R approach seeks to integrate nutrient management practices among four interrelated factors namely the source of nutrients, the rate of application, the time of application, and the placement of the nutrients. The 4R approach is summarized as the right source @ the right rate, right time and right place.

Within the NERP protocol, source, rate, time and place practices known to reduce nitrous oxide emissions are prescribed by a professional advisor and integrated within a 4R Plan. The plan is implemented by the producer and nitrous oxide emissions are estimated based on crop type and nitrogen use using Canada's Tier II inventory methodology developed by Rochette et al. (2008) with modification for use on individual farms.[2] The estimate assumes average baseline practices before application of the 4R plan based on either current year nitrogen application and yields using a dynamic baseline or a three-year historic baseline approach. A reduction coefficient is applied to the current year or project estimate to account for the reductions associated with improved nitrogen management, the magnitude of the reduction varying depending on the suite of practices implemented by the producer. The allowable offsets (expressed as tCO_2e) are calculated as the difference between the baseline condition estimate and the project condition estimate for nitrous oxide. The use of specific practices within a professionally developed 4R Plan provides the assurance of additionality, while a rigorous verification process insures the reduction activities actually took place.

In addition to nutrient management practices, land use change can have a significant impact on GHG emissions associated with crop production. Conversion of land from perennial forage crops to annual crops reduces carbon sequestration and depending on crops grown, tillage practices and nutrient management can change the cropping system from a net sink to a net source of GHG emissions (reference required). Bringing additional acres into production through wetland drainage or clearing of woodlots and/or forested areas not only incurs considerable costs for the producer, it can also change the system from a sink to a source of GHGs mainly through the emission of carbon dioxide associated with oxidation of stored soil carbon and/or burning of woody materials. Land use change also leads to the loss of other ecological goods and services such as water retention and filtering, erosion prevention, wildlife habitat, and recreation. These losses of natural areas can have considerable economic as well as environmental impacts. For example, in a study in Saskatchewan's Upper Assiniboine Watershed, the net benefit of services provided through the region's natural capital was estimated as ranging from $29 to $107/ha/yr with a best estimate at $67/ha/yr (Olewiler, 2004).

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[2] For a more complete explanation of NERP refer to https://www.cfi.ca/_documents/10-10-18_NERP_v1_Protocol_FINAL.pdf.

1.1 Purpose and Objectives

The purpose of this study is to provide an analysis of the sustainability and economic effects from increasing production from the existing land base rather than bringing new land into production through improved nitrogen management in the Alberta.

The specific objectives are:

- To document and review the existing work on the tradeoffs between increasing crop production through intensification in land use vs generating increased production through extensification and land conversion
- To understand the potential for improved nitrogen management in intensification of land use
- To provide an economic analysis enhanced nitrogen management to generate increased crop production
- To communicate results and insights to stakeholders and decision makers

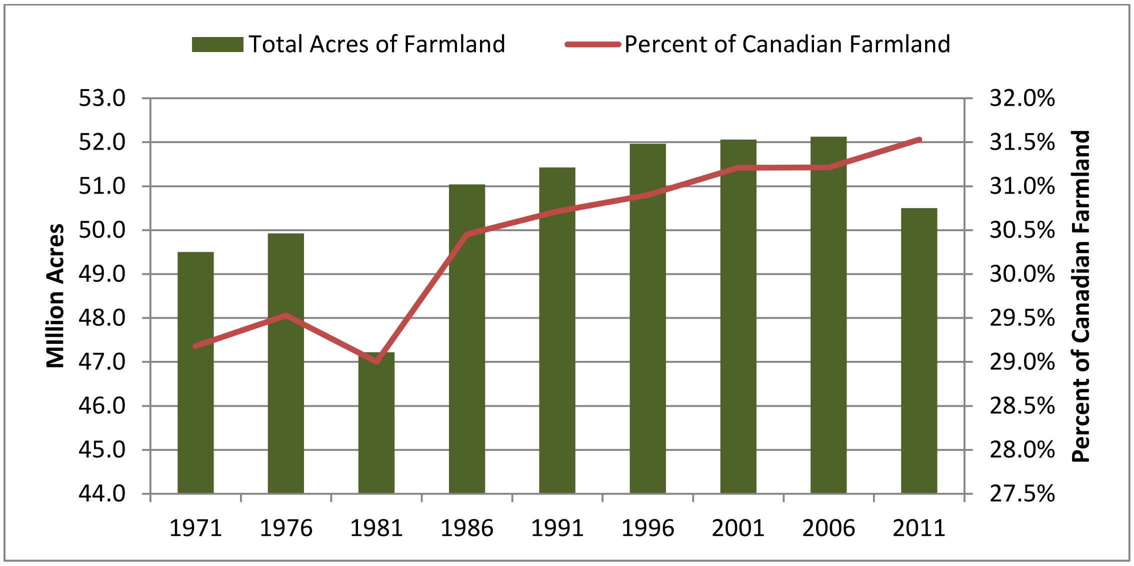
1.2 Organization of the Report

Section 2 below provides an overview of trends in agricultural land use in Alberta. Section 3 reviews the literature of intensive and extensive agricultural land management. Section 4 reviews the literature on intensive crop management to increase yields. Section 5 develops intensification scenarios and evaluates these scenarios based on nitrous oxide emissions and economic feasibility. Section 6 concludes the report.

2 Agricultural Land Use Intensity in Alberta

This section provides an overview of land use and management in Alberta over the past three to four decades. Farmland in Alberta has increased slightly through much of the previous two decades, but total farmland area fell by 3 percent or 1.62 million acres between the 2006 and 2011 census (Figure 2.1). Even with the reduction in farmland in the 2011 census, more than 31% of total farmland in Canada is in Alberta. Agricultural Land as a percent of total land, in Alberta, increased in each census period since 1981, prior to the 2011 census (Figure 2.2)[3].

Figure 2.1 Total Farmland, Alberta



Source: Statistics Canada, Census of Agriculture

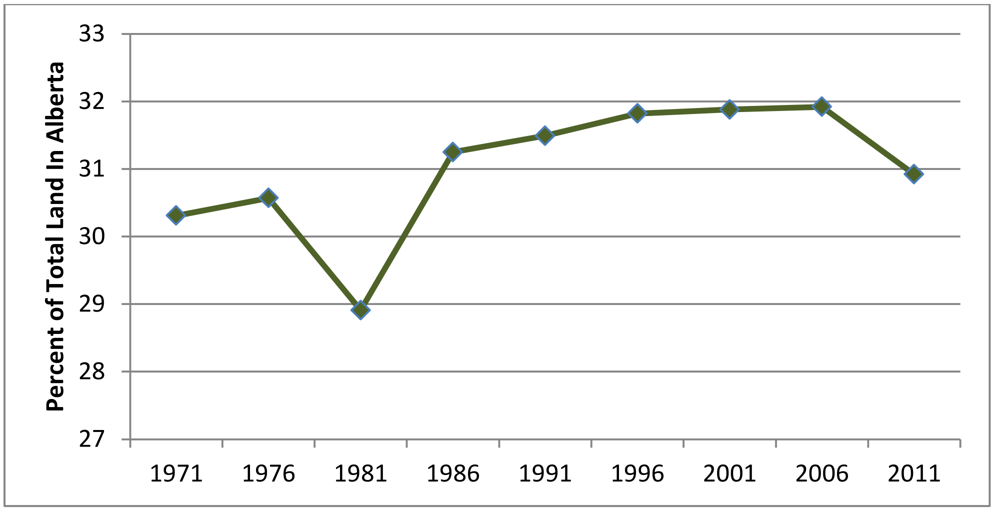
Most of the agricultural land in Alberta is used for crop production (Figure 2.3). Land in crops has been stable over the past decade, increasing 0.03% from 2001 to 2011 and pasture (managed and natural) has been essentially constant. Summer Fallow acreage has declined 59% over the same period. Due to variations in census categories the land use categories do not add to the total acres as shown

Looking at the top 3 field crops back to 1970, total acres in wheat, barley and canola have grown from 8.6 million to 16.9 million acres in 2013 (Figure 2.4). At the same time production has increased at a faster rate than acreage increases for these three crops. Record crop production was produced in 2013, but even using the 5 year average from 2009 to 2013, production of the top three Alberta field crops were 163% greater than in 1970, while acreage was only 97% greater than in 1970. This is evident from the yield data (

[3] Note that land that was not seeded due to abnormally wet conditions in 2010 is included in the data, so the change in acreage cannot be attributed to those conditions.

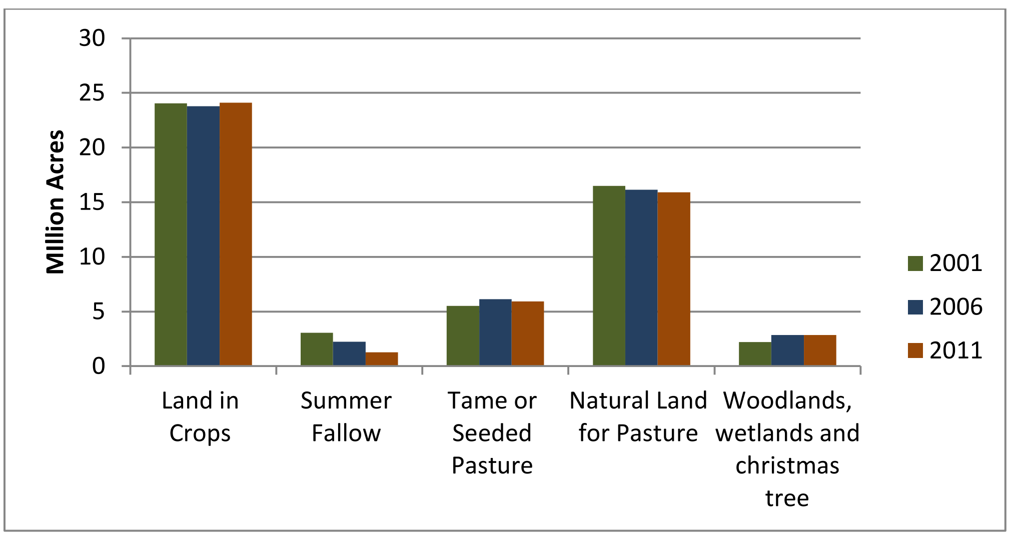
Figure 2.5), showing that the average yields for these crops have increased over time.

Figure 2.2 Agricultural Land as Percent of Total Land, Alberta



Source Statistics Canada, Cansim Table 153-0039; Statistics Canada Census of Agriculture

Figure 2.3 Land Use by Category, Alberta



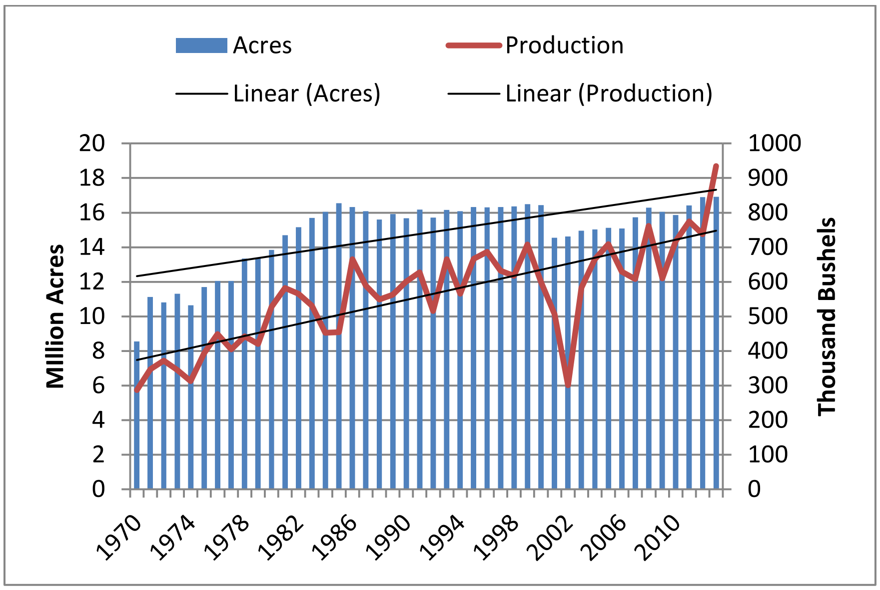
Source: Statistics Canada, Census of Agriculture

Table 2.1 Change in land use between census years

	Percent Change 2006-2011	Percent Change 2001-2011
Land in Crops	1%	0%
Summer Fallow	-44%	-59%
Tame or Seeded Pasture	-4%	7%
Natural Land for Pasture	-1%	-4%

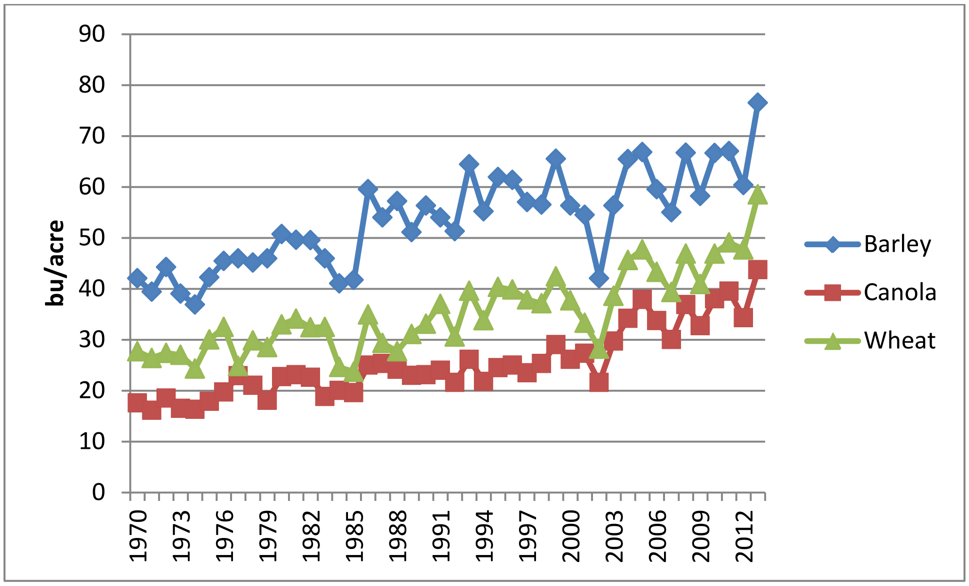
Source: Statistics Canada, Census of Agriculture

Figure 2.4 Seeded Acres and Total Production Top 3 Alberta Field Crops



Source: Statistics Canada, Cansim Table 01-0017

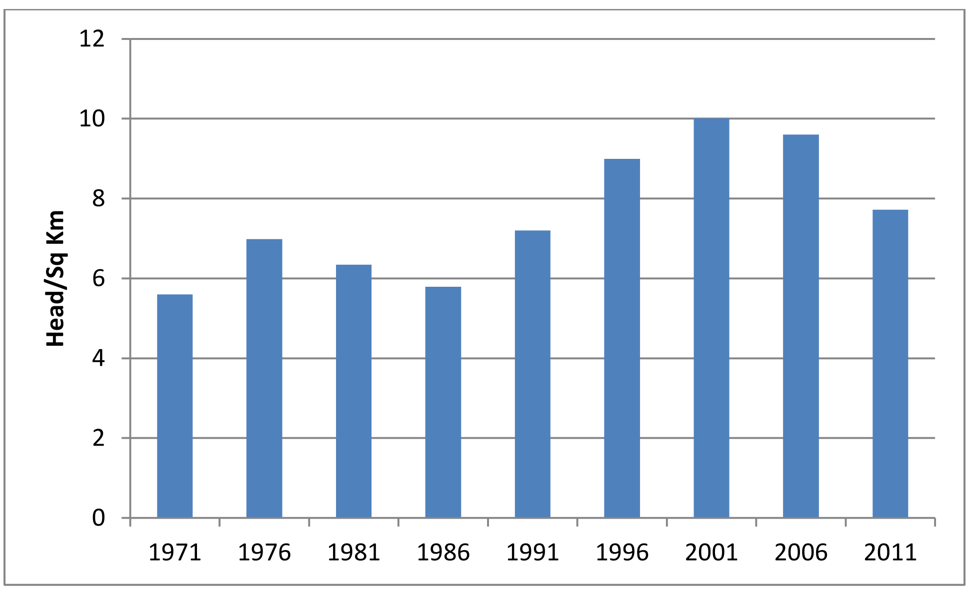
Figure 2.5 Average Yield Top 3 Field Crops



Source: Statistics Canada, Cansim Table 01-0017

Cattle herds per square kilometer in Alberta reached a peak in the 2001 census year, in each of the last two census period cattle volumes and cattle density has decreased (Figure 2.6). However, the general trend in cattle herd density remains upward.

Figure 2.6 Cattle Herd Density, Alberta



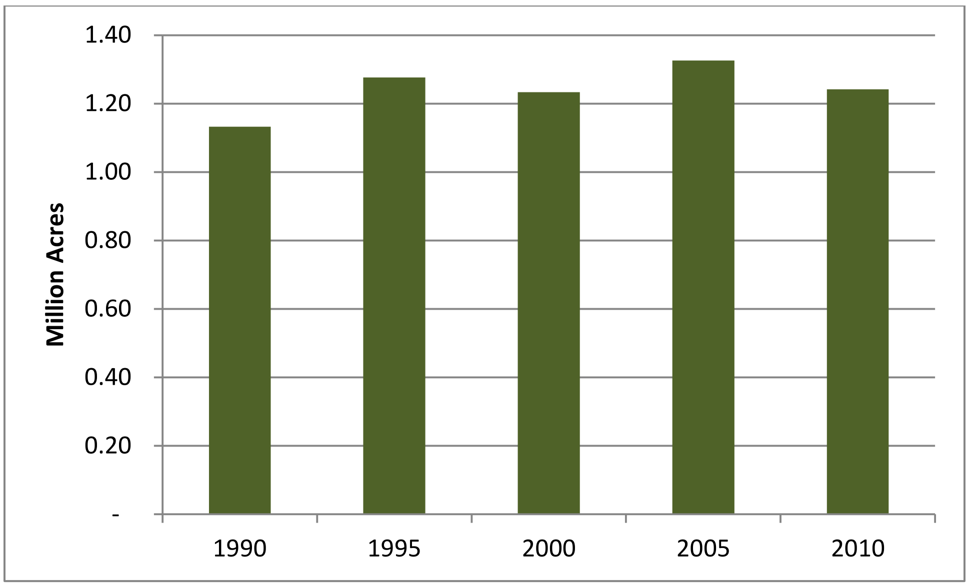
Source: Statistics Canada, Cansim Table 153-0039; Statistics Canada Census of Agriculture

2.1 Environmental Management Practices in Alberta

Irrigation

Irrigated land in Alberta occupies less than 6% of the arable land base while accounting for 19% of primary agriculture production (Alberta Water Portal 2014). In 2010, 1.24 million acres of farmland were irrigated, down from 1.33 in 2005. Most of the irrigated land in 2010 (73%) was seeded to field crops. Alberta accounts for the majority of irrigated farmland in Canada, at 65% in 2010. The long-term trend over the past 20 years has been a slight increase in irrigated land (Figure 2.7). Intensity of irrigation in Alberta varies significantly depending mainly on growing season precipitation and in some cases irrigation water availability. For example, in 2010, a year when all Alberta irrigation districts received well above average precipitation, irrigation levels, at 1,350 cubic meters per hectare, were slightly above the Canadian average of 1,334 for field crops (Statistics Canada, 2014)

Figure 2.7 Land under Irrigation

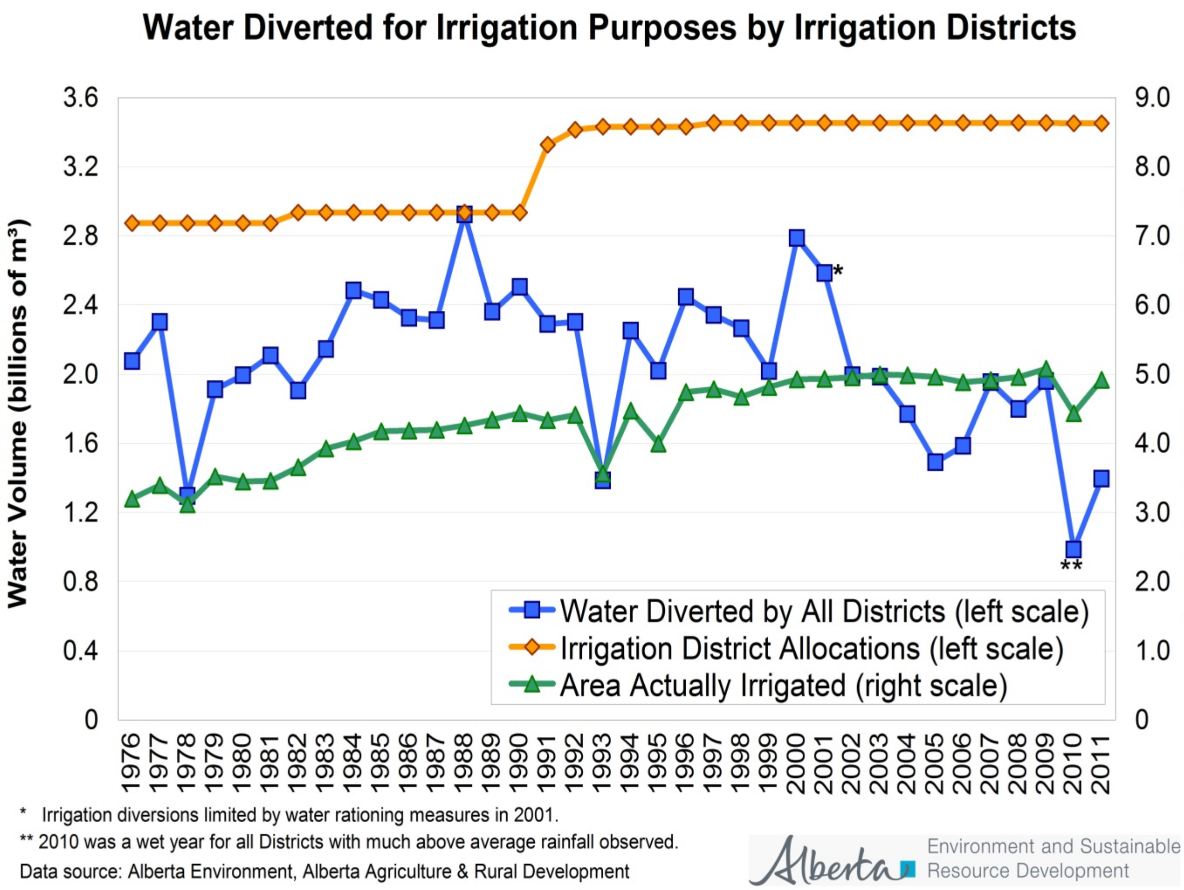


Source: Statistics Canada, Census of Agriculture

By comparison in 2012, a near normal precipitation year in most irrigation districts, intensity of water use for irrigation of field crops in Alberta increased to 3,280 cubic meters per hectare, and 3,040 cubic meters per hectare for all crops (Statistics Canada, 2013). Both of these values were above the national average of 2,093 for field crops, and 2,863 for all crops.

Although there is significant annual variation, the actual water volumes diverted by the irrigation districts in Alberta shows a modest downward trend (Figure 2.8). This downward trend in total water volume combined with the slight increase in irrigated acres over the same time period suggests water use efficiency has improved. A number of technology factors such as lower transmission losses (improved canal linings), improved application methods (pivots replacing flood and wheel moves), and more accurate irrigation scheduling techniques have contributed to higher efficiency. Improvements in the water use efficiency of crops and enhanced nutrient management have also contributed to this trend.

Figure 2.8 Water Diverted for Irrigation Purposes by Alberta's Irrigation Districts



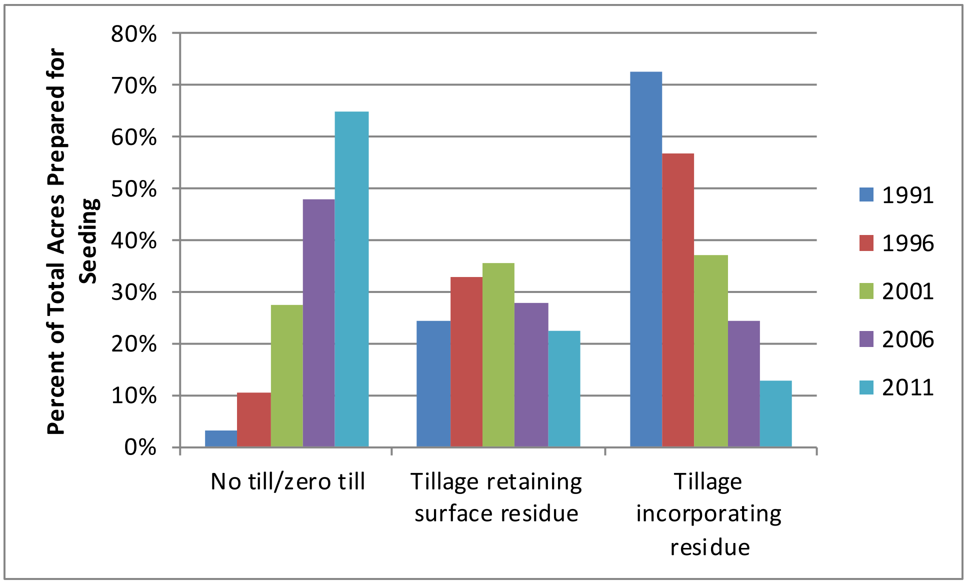
Source: Alberta Environment and Sustainable Resource Development

Tillage Practices

There has been a consistent move towards no till/zero till practices in field preparation in Alberta and away from tillage practices that incorporate crop residues into the soil (Figure 2.9). In 1991 only 3% of land was prepared for seeding using no till/zero till methods. In 2011, 65% of fields were prepared with no till/zero till, consistent with ongoing improvements in direct seeding technology. This is much higher than the national average for no till/zero till in 2011 at 41%.

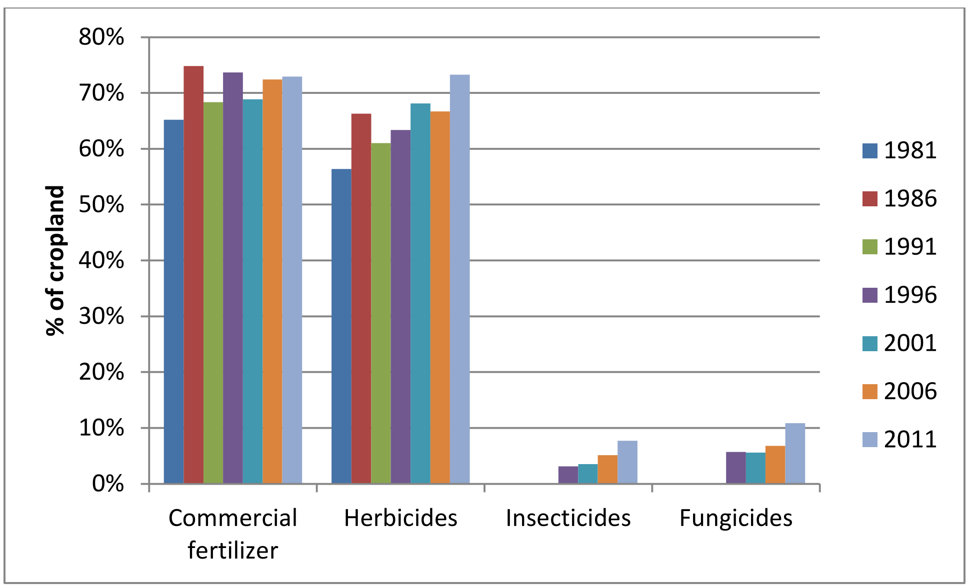
In addition to conserving seedbed moisture and preventing wind and water erosion, reduced tillage systems tend to sequester more carbon than systems that use intensive tillage. In Alberta, net carbon dioxide removals from the atmosphere on land under reduced tillage regimes have been eligible for carbon offset under the Reduced Tillage Protocol (2008-2012) and more recently its replacement the Conservation Cropping Protocol. Total credited emission reductions under these protocols were in excess of 2.3 $MtCO_2e$ and accounted for

Figure 2.9 Tillage Practices on Alberta Cropland



Source: Statistics Canada, Census of Agriculture

Figure 2.10 Pest and Weed Management Practices on Alberta Cropland



Source: Statistics Canada, Census of Agriculture

approximately 45% of total credits generated through approved protocols as of 2011.[4] These values illustrate the substantial contribution that can be made to reducing GHG when appropriate agricultural practice changes are broadly applied.

[4] Data presented at the 2013 AESRD Industry Update.

Pest and Weed Management

Most of the crop land in Alberta is treated with both commercial fertilizer and pesticides (Figure 2.10). This is consistent with relatively more land in crop production, and with the development and adoption of herbicide resistant varieties of canola. Insecticide and fungicide use on Alberta farms has also increased. While the data do not speak to this, the nature of fertilizer and pesticide use has changed over time, as new pesticide chemistries have been developed, as well as new fertilizer products such as urease treated nitrogen fertilizers. One of the major factors that contributed to the increased use of herbicides was the switch from tillage to chemical weed control as producers converted to reduced and zero till systems. No till along with the adoption of herbicide tolerant varieties has made glyphosate the most widely applied active ingredient in Alberta as well as the rest of Canada. Insecticide and fungicide use on Alberta farms has also increased partly in response to higher commodity prices. Wide spread adoption of high clearance sprayers has also contributed to higher use as they reduce application time and enable later season applications.

Increased pesticide use over the past three decades reflects the shift towards more intensive crop production practices. Poor handling and application practices can result in pesticides having significant negative impacts on the ecosystem. For herbicides, this needs to be balanced against their role in reducing soil erosion and increasing yields. Fungicides are used to maintain quality as well as increase yield, as are insecticides. When pesticide use results in significant yield increases there tends to be a concomitant drop in GHG emissions per unit of crop produced. This is because the increase in GHG emissions from manufacture, transport, and application that contribute to the numerator tend to be relatively small relative to the increased mass of crop in the denominator. The obvious corollary to the above is that applications that do not raise yield or result in only minor yield gains increase GHG intensity per unit of crop. Economically pesticide applications must increase crop value beyond the cost of the application to increase net revenue. With respect to GHG intensity per unit of crop produced, reduced environmental impact can be convergent with improved economic performance when pesticides are used appropriately.

2.2 Observations

The evolution of Alberta agricultural land use is characterized by a shift from more extensive land use agriculture toward more intensive management and land use consistent with a dry prairie climate. This is evident in several respects. In a relatively short period, the use of fallowing has declined dramatically in favour of land management that allows continuous cropping. Similarly, in a short period of time, tillage practices have shifted with minimum tillage and direct seeding technologies. Agricultural land has experienced subtle shifts toward annual crops from pasture, accompanied by increased use of fertilizers and pesticides. Irrigated acreage is stable to increasing.

This is illustrated in the data and discussion throughout this section. In the 5 year average from 2009 to 2013, production of the top three Alberta field crops were 163% greater than in 1970, while acreage was only 97% greater than in 1970. In addition, the general trend in cattle herd density is upward. Alberta accounts for the majority of irrigated farmland in Canada. When it comes to intensity of irrigation, application rates tend to be slightly above the Canadian average for field crops. Irrigated land accounts for 6% of total arable acres in the province but produces 19% of total primary production suggesting that irrigation farming is already considerably more intensive than dry land farming in the province. These figures also illustrate that available water tends to be an important limiting factor in dry land production.

This evolution is consistent with the development of more intensive agricultural production systems, particularly in relation to land use. However, the benefits and tradeoffs associated with more intensive land use vs. extensive land use systems in which production increases occur primarily through increases in land are need to be better understood. The improvement in the management of nutrients that can both meet increasing demands for product and meet sustainability expectations is a core element of this tradeoff, and thus a key issue for ongoing agricultural development in Alberta.

3 Agricultural Intensification, Extensification and Land Sparing

This section provides a brief review of studies in which the sustainability effects of agricultural intensification versus extensification in agricultural land use are evaluated.

3.1 Intensification vs. Extensification in Land Use

A growing world population has led to an increased use of non-land resources such as improved genetics, fertilizer and pesticides to produce farm products and food. The effect has been to increase output through improved agricultural technology and increased yields on existing farmland, and to leave other lands in a more pristine state. Intensification in agricultural land use can also have unintended consequences, such as increased GHG emissions per hectare, decreased diversity in crops, and regional concentration of farms (Bos et al. 2013). Agriculture is estimated to be responsible for 14-24% of global greenhouse gas emissions (Vermeulen et al. 2012). Concerns have been raised that agricultural intensification can lead to lower soil fertility, reduced biodiversity, increased soil erosion, accelerated eutrophication of lakes and rivers, and adverse climatic effects (Matson et al. 1997). According to Foley et al. (2011), the irrigated cropland area in the world has approximately doubled in the last 50 years, where 70% of global freshwater withdrawals are devoted to irrigation. Over the same time period global fertilizer use increased by 500% (over 800% for nitrogen alone). However, it must be acknowledged that some of the adverse environmental effects could also occur under extensification in which increased production comes from increasing the agricultural land base. Thus, we look to the broad literature on agricultural sustainability for insight.

Burney *et al.* (2010) estimated the net effect on global GHG emissions of historical agricultural intensification between 1961 and 2005. Fertilizer production and land application emissions have increased over this time frame. However, because of higher yields, the net effect has been to avoid emissions of up to 161 gigatons of carbon (GtC) (590 GtCO2e) since 1961. The authors estimated that in comparison to 1961 technology, each dollar invested in agricultural yields has resulted in 68 fewer kgC (249 kgCO2e) emissions (1961: $14.74/tC, or ~$4/tCO2e), which avoided essentially 3.6 GtC (13.1 GtCO2e) annually. The authors concluded that crop yield gains should rank high among a portfolio of strategies to reduce global GHG emissions. They observed that "Our results demonstrate the importance of land use change emissions over direct emissions of methane and nitrous oxide from agricultural systems, and suggest that the climatic impacts of historical agricultural intensification were preferable to those of a system with lower inputs that instead expanded cropland to meet global demand for food". Extending from Burney *et al*, recent work by Stephenson *et al* (2013) found that genetic improvements in major field crops between 1965 and 2004 prevented the need for between 18 and 27 million hectares of land conversion into agricultural use.

The environmental impacts of meeting global food demand will depend on how global agriculture expands. Tillman et al (2011) focus on a shift from extensification of land in less developed countries to moderate intensification of existing agricultural land. They estimate that the impact of continuing current intensification in rich countries and extensification in poor countries would result in about 1 billion ha of land cleared by 2050, approximately 3 Gt per year CO_2-C equivalent greenhouse gas emissions and about 250 Mt per year Nitrogen use. The alternative of moderate intensification of existing land, paired with continued current intensification of agricultural land in developed countries would result in only about 0.2 billion ha of land cleared, 1 Gt per year CO_2-C equivalent greenhouse gas emissions and 225 Mt per year nitrogen use.

Baker at al.(2013) conducted an empirical analysis on U.S. historical agricultural growth rates, investigating different scenarios for future changes in agricultural productivity. The authors found that, based on observed yield growth from 1960-2009, increased crop productivity in the United States was land-saving and thus directly greenhouse gas emission reducing. However, the downstream relationships of crop productivity are complex. Increased feed grain yields decrease feed grain prices, resulting in increased livestock production with its associated greenhouse gas output.

The environmental effects of intensification are thus diverse and not entirely unequivocal. Increasing yields per acre initially increase profitability, but can also have a secondary effect of decreasing prices. This has been hypothesized to result in a secondary effect of decreasing agricultural land use (or land “sparing”). However, this has generally not occurred. For example, Rudel *et al* (2009) used global data from 1970 to 2005 and national data from 1990 to 2005 for 10 crops to determine whether intensification had reduced the agricultural land base. For the most part land “sparing” due to increases in yields and decreases in prices were not observed; however, the authors noted a number of other contextual changes that help explain this- such as increased trade, growth in livestock demand, political shifts, etc. In noting that empirical studies indicate that biodiversity protection is more effective under land sparing over land “sharing” (managing land less intensively to provide for both agricultural production and biodiversity) Ramankutty and Rhemtulla (2012) point out that it is unclear whether land sparing has ever actually reduced acreage under agricultural use, because a reliable baseline has never been established.

Kastner *et al* (2012) found that potential land savings through intensification and agricultural yield increases, were generally offset by increasing populations and dietary change. Change in technology such as increased use of fertilizers, pesticides, fossil fuels and infrastructure, globally was estimated to decrease farmland requirements by 654 million ha between 1963 and 2005, almost 60% of this decrease is attributed to the period between 1963 and 1984. In North America, technology was estimated to reduce land requirements by 42 million ha, with 57% of this occurring between 1963 and 1984. However, total land requirements between 1963 and 2005 to meet dietary needs increased 267 million ha globally, and 5 million ha in North America, as the result of population and dietary shifts.

More than half of the additional land requirement was the result of increased livestock production, and vegetable oils along with coffee, tea and cocoa were also noted as categories that contributed to increased agricultural land requirements.. These results indicate that intensification of current agricultural land is not wholly sufficient to prevent extensification at current rates of technological change and adoption, as the global population increases and dietary preferences are also significant influences. They also note that stagnant population growth is usually accompanied by economic development that results in dietary shifts, which has resulted in an increase in land requirements for food production.

Snyder et al. (2009) conducted a review of available scientific information on the effects of nitrogen timing, source, rate and placement, in combination with different cropping and tillage practices on greenhouse gas emissions. Intensification of agricultural land with effective and efficient nutrient uptake to achieve high yields was found to be the main approach to reduce GHG emissions and meet demands for crops. According to Snyder et al. (2009), GHG emissions per unit of crop or food production do not necessarily increase under intensive crop management systems; rather, natural areas are spared from cropland conversion, or can be converted back to forests for GHG mitigation. Other conclusions derived from the literature reviewed included: a) BMPs for nitrogen fertilizers are important to reduce residual soil nitrate, which decreases the risk of nitrous oxide (N2O) emissions; b) soil organic carbon levels increase if tillage practices that reduce soil disturbance and maintain crop residue on the soil surface can, and if crop productivity is maintained or increased, c) proper nitrogen fertilizer use helps to increase biomass production, which helps to restore and maintain soil organic carbon levels; and site- and weather-specific conditions determine differences among fertilizer N sources in N2O emissions (Snyder et al., 2009).

Organic farming has been promoted as a more extensive method of farming that is aimed at reducing the environmental impact of agriculture. Tuomisto et al. (2012) conducted a meta-analysis of European studies that investigated whether organic agriculture reduces environmental impacts in comparison to conventional agriculture. The results generally showed that, compared with conventional farming practices, organic farming practices had positive environmental impacts per unit area, but not necessarily per unit of product. For example, the results show that, based on median response ratios, nitrogen leaching per unit area was 31% lower for organic farms (because of lower levels of nitrogen inputs applied) but 49% higher per unit product, due to lower yields on organic farms.

Firbank et al. (2013) sought to identify examples of sustainable intensification among British farmers, by conducting 20 case studies. The authors considered a farm to be practicing sustainable intensification if none of the predetermined environmental variables deteriorated while the food production per unit area increased during the study period. A single variable was chosen from the following ecosystem services: "agricultural production, biodiversity, climate regulation, regulation of air quality and regulation of water quality" to present the whole farm area. Three of the 20 farms were found to have increased production while enhancing biodiversity and reducing pollution. Producers that increase meat and milk yields were not able to achieve sustainable intensification in the study. Most sustainability efforts were undertaken to increase profits, by reducing inputs and increasing production. Over 85 percent of the farmers used payments from agri-environment schemes to support the enhancement of biodiversity on their farms.

3.2 Biodiversity

Intensification by nature leads to a reduction in biodiversity on agricultural land. However, many studies do not consider the accompanying secondary gains when habitat is spared from conversion to agricultural land. For example, Benton et al. (2003) state that agricultural intensification leads to a loss of farmland biodiversity with the main cause being homogeneity of agricultural habitats caused by simplification of crop rotation, increasing size of farm machinery, crop breeding and advances and agricultural policy (using the example of the EU's agri-environment schemes). According to Benton et al. (2003) conservation management should ensure heterogeneity of farmland to secure biodiversity.

The meta-analysis by Tuomisto et al. (2012) found that organic farms have on average 50 percent higher abundance of organisms and a 30 percent higher species richness. However, this finding differed widely among the studies analyzed and some studies even found a negative biodiversity effect of organic farming. The question still remains if conventional farming with targeted species protection practices can result in even higher levels of species richness than organic farming systems.

Some of the best evidence on biodiversity relative to agricultural land use comes from developing countries where new land has recently been converted to agricultural use on a significant scale. Phalan *et al* (2011) compared the densities of tree and bird species according to varying levels of agricultural intensity in India and Ghana. They found that more species were negatively impacted by agriculture than benefitted from it, indicating a benefit to intensifying the land base and leaving other lands undisturbed. Similar effects were observed by Guitierrez-Velez *et al* (2011) in oil palm production in Peru, and across a range of crops in tropical countries by Phalan *et al* (2013).

Matson and Norris (2005) argue that wildlife-friendly farming is not the only land use strategy that can be used to conserve biodiversity and to research alternative options such as land sparing. There is also a need for social scientists and ecologists to bring their approaches together, so that land use change and its consequences can be investigated in a more holistic way." According to Phalan et al. (2011), a number of trade-offs between biodiversity and yield are prevalent. A large proportion of wildlife species will not exist "even in the most benign farming systems". It is therefore important to keep wild land to ensure the survival of these species.

3.3 Observations

The literature that relates to the environmental impact of intensification in agricultural land use is voluminous, and a complete review is well beyond the scope of this study. However, this review of recent studies suggests the following. More extensive land use results in improved sustainability on a unit area basis. This is not at all surprising as increasing production through extensification involves lower inputs per acre of land managed. More intensive management employs relatively more inputs on relatively less land to obtain higher yields. When these higher yields are factored in, intensive management is found to be more sustainable (in terms of greenhouse gases, nutrient application, etc) on a unit output basis than extensive management. This perhaps most evident in the literature estimating the environmental benefits of the green revolution and the implied saving of land and emissions. It is somewhat more equivocal regarding biodiversity- although it does seem that attempting to modify agricultural practices to provide habitat appears to be generally less effective than more intensively managing farmland and allowing other lands to be focused on supplying biodiversity habitat.

The broad implication of these observations seems fairly clear. In a world that is stretched to produce sufficient farm products and food, the most sustainable means to do this by using land more intensively. This is implied by Foley et al (2011) in arguing that “to meet the world’s future food security and sustainability needs, food production must grow substantially while, at the same time, agriculture’s environmental footprint must shrink dramatically”.

The arguments supporting extensification must thus relate to the specifics of technologies employed to implement more intensive production; this is explicit in the case of organic production. This reflects a concern toward, and focus on, the potential for unintended consequences and offsite effects associated with agricultural technologies used to increase yields. This focus on the efficacy and safety of specific agricultural technologies is appropriate, and critical to supporting intensive management; but this should not diminish the broader point- using land more intensively is more sustainable than extensive land use.

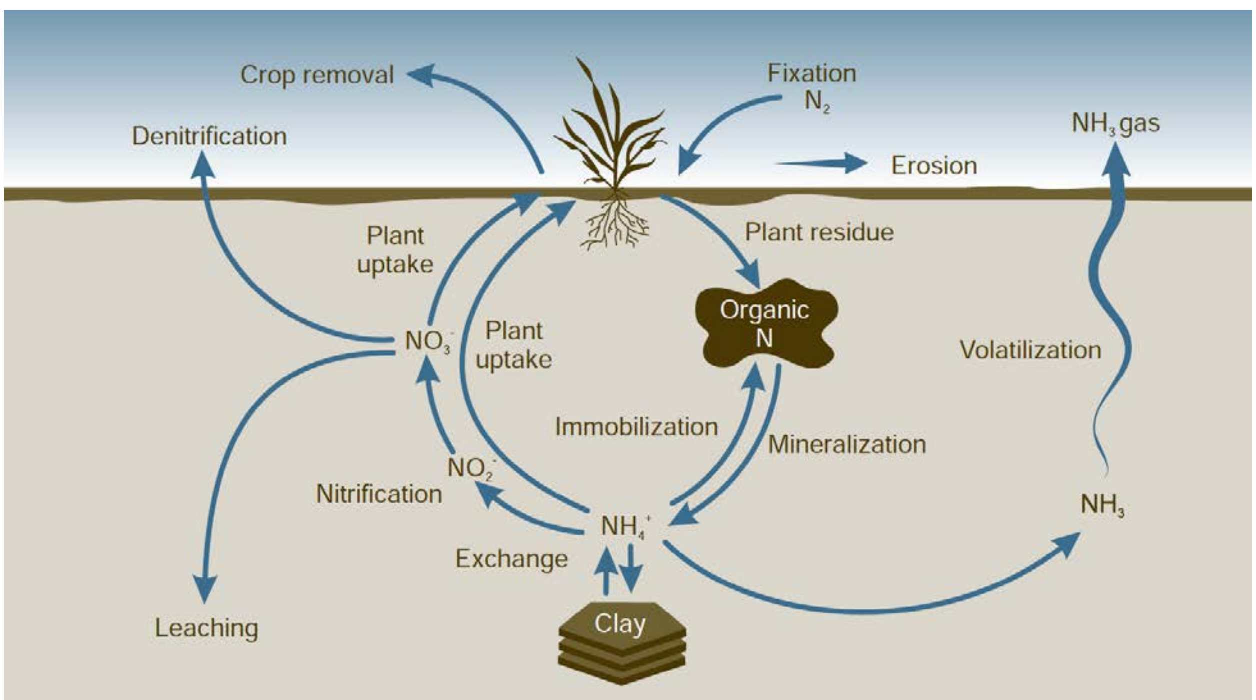
4 Nitrous Oxide Emissions from Fertilizer, Source, Rate, Time and Place Effects

4.1 Introduction

Intensification of crop production has often been approached simplistically with producers increasing inputs in hopes of reaching maximum yield. This goal has often been pursued without regard for the collateral damage that the maximum yield approach can have on a producer's overall economic and environmental performance. A more intelligent approach to intensification involves increasing productivity within a framework of economic optimization of input resources and minimization of environmental impacts. Practices that result in simultaneous agronomic, economic, and environmental benefits are referred to as sustainable or best management practices (BMPs). These BMPs can be developed for all aspects of crop production including crop and variety selection, tillage management, pest management and nutrient use.

In Canadian prairie agriculture, fertilizer expenditures typically represents the largest proportion of the variable costs in crop production with significantly more dollars spent on nitrogen than the other nutrients. Consequently, improving nutrient use efficiency in general and nitrogen use efficiency in particular is an important tool in the profitable intensification of crop production. Poor nitrogen management practices result in losses of nitrogen from the cropping system that not only reduce a producer's economic efficiency they also impair air and water quality. Nitrogen losses occur through surface runoff and deep leaching as well as gaseous emissions from the

Figure 4.1. The Nitrogen Cycle



Source: Nutrient Management Planning Guide. Alberta Agriculture and Rural Development soil surface (Figure 2.1). One of the gases emitted is nitrous oxide (N_2O), a potent green house gas (GHG) with a global warming potential (GWP) about 300 times greater than carbon dioxide. Nitrous oxide contributes more than half of the global warming potential attributable to Canadian cropping systems (Janzen et al. 2008). Consequently, reducing nitrous oxide is an important part of balancing economic and environmental outcomes within intensive cropping systems.

Nitrous oxide is lost directly from the cropping system through the processes of nitrification and denitrification. Other nitrogen loss pathways also contribute nitrous oxide indirectly. Ammonia (NH_3) lost through the process of volatilization and nitrate (NO_3^-) lost through runoff and leaching are eventually deposited in terrestrial or aquatic ecosystems where a small proportion will be converted to nitrous oxide. Nitrogen that is taken up by the crop is in the short-term removed from the pathways that lead to nitrous oxide emissions. Managing nitrogen source, rate, time and place decisions in ways that prevent nitrate accumulation, reduce loss and improve crop uptake reduces nitrous oxide emissions.

The purpose of this section then is to examine the recent scientific literature with respect to nitrogen management practices. This was not intended as a comprehensive review of nitrogen management rather the literature was filtered through the lens of 4R Nutrient Stewardship and the Nitrous Oxide Emission Protocol (NERP). Although a wide range of literature was examined, the studies reported here involved experimental or modeling work where nitrogen source, rate, time and place practices were manipulated and data on yield and nitrogen use efficiency and/or nitrous oxide emissions were measured. The approach used was to find recent review articles or articles where meta-analysis was used to examine recent work on a particular set of nitrogen management practices or technologies. If a practice or technology appeared to have merit in reducing nitrous oxide emissions and improving productivity, a deeper exploration was undertaken to find studies that were relevant to the crops and climates of the Canadian Prairies. The end purpose was to use the recent scientific literature to:

- ❖ Identify or verify nitrogen management practices that achieved the desired results of improving nitrogen use efficiency, increasing yield and/or reducing nitrous oxide emissions and were likely applicable within Alberta’s crop production systems.
- ❖ Examine the magnitude of nitrous oxide reductions reported for various practices and combinations of practices and compare them to the current reduction coefficients used in the NERP protocol.
- ❖ Examine whether the current suite of practices prescribed for the different levels of NERP should continue to be viewed as effective in reducing nitrous oxide emissions and whether the current list is too restrictive or needs to be more restrictive in prescribing BMPs.

The focus for the purposes of this report as described above was relatively narrow. For a broader perspective and more thorough review of nitrogen management and nitrous oxide emissions refer to Snyder et al. (2007, 2009); Asgedom and Kebreab (2011); and Snyder and Fixen (2012).

4.2 4R Nutrient Stewardship and the NERP

The International Plant Nutrition Institute (IPNI) developed 4R as a principle-based and evidence-driven approach that is applicable to any cropping system (Bruulsema et al. 2008). 4R is built on a foundation of sustainable agriculture and aims to help crop producers balance among economic, social, and environmental goals. Within 4R, nutrient management is organized into four interconnected sets of decisions with the idea that by adopting locally appropriate practices for nutrient source, rate, time, and place, crop managers can optimize nutrient use. The central principle of 4R is captured in the axiom *the Right Source @ the Right Rate, Time and Place*. One of the key principles of 4R is site-specific management in which farmers adjust their nutrient management practices to match the nutrient requirements and manage environmental risks at the individual field or sub-field level as required.

The NERP was developed as a science based tool for driving adoption of nitrous oxide reducing nitrogen management practices and quantifying those reductions as fungible offset credits within Alberta's regulated carbon market (Climate Check, 2008). The quantification of nitrous oxide and other greenhouse gas emissions associated with nutrient management is based on life cycle analysis and an adaption of Canada's Tier II inventory method for nitrous oxide developed by Rochette et al. (2008a,b).

NERP uses a 4R Nutrient Stewardship Plan as the vehicle for promoting farmer adoption of management practices that reduce nitrous oxide emissions. Since the main driver of these emissions is additions of nitrogen, particular attention is paid within a NERP project to nitrogen management practices that increase nitrogen use efficiency by the crop and subsequently reduce nitrous oxide emissions. While there is an emphasis on nitrogen management on NERP project farms, nitrogen cannot be effectively managed independently from other required nutrients. So even within the rather narrow confines of a NERP project, 4R is expected to improve overall nutrient management and provide better economic, social, and environmental outcomes.

NERP uses a comprehensive approach to accounting for nitrogen additions and nitrous oxide emission pathways within the cropping system. Fertilizer, manure, compost and any other sources of added nitrogen are accounted for through direct quantification. Nitrogen returns through crop residues are estimated from harvested yield and average nitrogen concentration values taken from the literature. Direct emissions from the cropping system through the two major processes responsible, nitrification and denitrification, are captured using an emission factor specific for the ecodistrict containing each field.[5] Indirect emissions from ammonia loss are estimated using a volatilization fraction (partitioning coefficient) to quantify the proportion of added nitrogen volatilized and then applying an emission factor to the lost nitrogen. Leaching is handled in a similar manner using a leaching fraction to estimate leached nitrogen and an emission factor to quantify nitrous oxide emissions from the leached fraction. The leaching fraction is ecodistrict specific to account for regional variability in precipitation, evapotranspiration, and soil type. Irrigated crops are treated as a separate case and appropriately higher factors are applied to account for the increased direct and indirect emissions.

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[5] Ecodistricts, the smallest units of area within Canada's National Ecological Framework, are differentiated on the basis of regional landform, local surface form, permafrost distribution, soil development, textural group, vegetation cover/land use classes, range of annual precipitation, and mean temperature. Ecodistrict size is a function of regional variability of these defining attributes. Minimum size is approximately 100,000 ha (250,000 acres).

Table 4.1. NERP BMP Performance Levels for the Drier Soils in Canada[1]

Performance Level	Right Source	Right Rate	Right Time	Right Place	Reduction Modifier
Basic	Ammonium-based formulations.	Apply N according to 4R Plan, using annual soil testing and/or N balance to determine application rate.	Apply in spring; or split apply; or apply after soil cools to 10^{0}C.	Apply in bands / Injection	0.85
Intermediate	Ammonium-based formulation; and/or use slow /controlled release fertilizers; or inhibitors.	Apply N according to qualitative estimates of field variability (landscape position, soil variability) as outlined in the 4R Plan	Apply fertilizer in spring; or split apply; or apply after soil cools to 10^{0}C.	Apply in bands / Injection	0.75
Advanced	Ammonium-based formulation; and/or use slow / controlled release fertilizers; or inhibitors; or stabilized N	Apply N according to quantified field variability (e.g. digitized soil maps, grid sampling, or satellite imagery).	Apply fertilizer in spring; or split apply; or apply after soil cools to 10^{0}C using slow / controlled release fertilizer or inhibitors / stabilized N.	Apply in bands / Injection	0.75

[1] Relevant examples for Alberta shown for complete and current details of required BMPs at each performance level consult the most current version of the protocol.

Estimating reductions in nitrous oxide emissions, the basis for generation of carbon credits or offsets in NERP, is done on an intensity basis (Δkg N_2O/kg crop). The reduction is calculated as the difference between a baseline value, average emissions for each crop on the project farm using three years of historic data on nitrogen application and yield, and a project value, the emissions for the current year. The project value is corrected using a reduction modifier that reflects the suite of BMPs applied (Table 4.1) and then subtracted from the baseline.

The values used for the reduction modifiers were set conservatively based on the best available evidence at the time the NERP was developed and are subject to periodic review. A useful way to view the reduction modifiers is that unlike strictly nitrogen rate driven approaches, NERP produces an initial rate based emission and then adjusts it for the mitigating effects of right source, time and place practices. Adopting BMPs that optimize nitrogen rate is an important strategy both economically and environmentally. Optimizing source, time and place practices maximizes nitrogen efficiency and yield while minimizing nitrous oxide emissions at whatever rates are used. Adoption of right source, time and place BMPs will lead to further rate adjustments as producers seek to continuously improve productivity, profitability, and environmental performance. These ongoing adjustments may be to increase or to decrease rates depending on the production potential and environmental risks for each field on the farm.

An important principle to keep in mind when applying NERP is that it is designed to achieve 'accuracy in aggregate'. NERP is not intended to achieve the site-specific predictive capability of a full process model nor does it require the detailed and time stepped data required to run a full process model. As a farm based tool, NERP can provide an important metric for tracking environmental benefit that is easily understood and can be initiated using data farmers collect routinely to improve their crop management decisions. As a compliance option within a regulatory framework like Alberta's, the uncertainties of quantification at the farm field level are minimized as the NERP is applied over a large number of fields.

4.3 4R Best Management Practices

The right source @ the right rate, time and place expresses the synergy that can be obtained through integration of practices. Determining the quantitative effects of this synergy is challenging. The peer review literature contains reports on numerous experiments where one or two 4R factors are manipulated while holding the remaining 4R factors constant. This is necessary as performing a fully integrated experiment on the 4Rs even for a single crop at a single site rapidly becomes unwieldy both operationally and statistically. For example, comparing three urea nitrogen sources (urea, polymer coated urea, urease inhibited urea) at four rates (check, below-recommended, recommended, above-recommended) using the three most common placements (broadcast, surface banded, subsurface banded) and two timings (spring and fall) would require seventy-two treatments. Given these limitations, the synergistic effects when all 4Rs are combined into a nutrient management system must to a large extent be inferred from multiple datasets through tools such as modeling and meta-analysis as they cannot realistically be measured directly.

Right Source

The most commonly used conventional nitrogen fertilizers sources in Western Canada are in order of nitrogen applied: urea, anhydrous ammonia, urea-ammonium nitrate (UAN), and ammonium sulfate (Canadian Fertilizer Institute, 2014). All these sources when used with appropriate management practices increase yield of small grains and oilseeds on the prairies about equally well per unit of nitrogen applied (Johnston et al. 1997; Grant et al. 2002). Agronomists and farmers have approached source selection within the paradigm of a pound of N is a pound of N. Choosing the right N source has generally been based on price; grower preferences for placement equipment; and blending, storage, safety, and handling characteristics.

Different conventional sources may in some circumstances vary in nitrous oxide emissions. Halvorsen et al. (2014a) found that UAN produced lower emissions than urea in irrigated cropping systems in Colorado. Tenuta and Beauchamp (2003) compared sources in laboratory and field studies and found that emissions ranked urea > ammonium sulfate > ammonium nitrate. Urea has been reported to lower emissions compared to anhydrous ammonia in rain-fed corn production systems in Minnesota (Venterea et al. 2010). On the other hand, Burton et al. (2008) found no difference between urea and anhydrous ammonia in Manitoba. Decock (2014) in a recent review and meta-analysis of nitrogen management practices in mid-west corn systems, found that source differences can have a considerable impact on fertilizer induced emissions. In her analysis, conventional sources ranked anhydrous ammonia > UAN > ammonium nitrate > urea when emissions were compared per unit of nitrogen applied, with emissions from urea being on average less than half of those from anhydrous ammonia.

At present, there is insufficient evidence to indicate which conventional sources and under what circumstances might produce lower emissions in Alberta cropping systems. While there has been considerable work done in the past decade comparing conventional and enhanced efficiency fertilizers for yield and nitrous oxide emissions, there has been very little focused directly on comparing emissions from conventional sources.

The gradual improvement of enhanced efficiency fertilizer has been the major development in nitrogen source over the past two decades. One approach to enhanced efficiency is to physically control release of nutrients out of granular products with a membrane or coating. Polymer coated urea sold by Agrium as ESN™ has been available commercially in Western Canada for a decade and is being increasingly adopted by producers. The price premium relative to uncoated urea has narrowed considerably as ESN has become a more mainstream product and is currently 10-20%. ESN can be applied alone but there is a growing trend to apply it in blends with uncoated urea. One of the benefits of ESN is increased seed safety relative to uncoated urea when seed row applied (Hadelein et al. 2001; Malhi and Lemke, 2013; McKenzie et al. 2007). Another may be preventing early season nitrogen uptake by weeds (Blackshaw et al. 2011).

Yield benefits from ESN appear to be variable depending on the cropping system and site-specific conditions of the experiments. Haderlein et al. (2001) in their comparison of seed-placed ESN to side-banded conventional urea at multiple rates reported no yield advantage. But seed-placed ESN did consistently increase nitrogen uptake. Grant et al. (2012), in a multiple site, multiple year study in W. Canada, found no consistent improvement in yield relative to uncoated urea when ESN was side-banded in spring. McKenzie et al (2007) measured no yield differences relative to uncoated urea when ESN was side-banded at time of seeding on winter wheat in S. Alberta but substantial positive differences when it was seed-placed. In later experiments, they found ESN banded at seeding increased yield slightly but was comparable to other forms when spring broadcast (McKenzie et al. 2010). Beres et al. (2010) also working with winter wheat in Southern and Central Alberta, reported ESN side-banded at seeding consistently outperformed conventional urea broadcast in spring. Working in Northern Alberta and Saskatchewan over a four year rotation, Malhi et al. (2010) reported enhanced yield and nitrogen recovery in crops receiving ESN in wetter than normal years. Blackshaw et al. (2011) found canola yield with ESN was similar to urea in 14 of 20 site-years and increased canola yield in 4 site-years. In a Minnesota study, ESN blends showed positive protein and yield benefits in spring wheat production under warm moist spring conditions while yield decreased and protein increased under cool dry spring conditions (Farmaha and Sims 2013).

Khakbazan et al. (2113) estimated net revenue differences among treatments using the data from Grant and colleagues and found that overall ESN provided no economic benefit. Interestingly when spring banded, the most common application method on the Canadian Prairies, at the recommended rate was broken out, ESN provided equal (19) or better (1) net revenue relative to urea in 20 of the 24 site-years where a statistical comparison was provided.

This suggests there may be situations where realizing the environmental benefits of ESN may be revenue neutral for the producer.

A second approach to enhancing efficiency is by adding chemical inhibitors to the fertilizer source. The principle behind these products is to slow conversion of urea to ammonium and reduce the rate of volatilization and/or limit the conversion of ammonium to nitrate through nitrification and prevent nitrate accumulation, potentially reducing denitrification and leaching. Use of these stabilized nitrogen sources reduces risk of loss and when timed appropriately can synchronize supply with crop demand. Since nitrification and denitrification are the major processes responsible for direct nitrous oxide emissions and volatilization and leaching the processes contributing to indirect emissions slowing the conversions potentially lowers nitrous oxide contributions from fertilizer.

The most commonly used urease inhibitor is N-(n-butyl) thiophosphoric triamide (NBPT), has been extensively field and laboratory tested in North America and elsewhere with well over a thousand individual trials completed to date (Saggar et al. 2013). In Canada NBPT is sold under the brand names Agrotain™ as a stand-alone product or in combination with the nitrification inhibitor dicyandiamide (DCD) as Agrotain Plus™. These products can be added to granular or liquid urea containing fertilizers. Urea pre-treated with urease inhibitor and DCD is also available under the trade names SuperU™. In Western Canadian soils, NBPT has been shown to prevent losses through ammonia volatilization when urea is surface applied (Rawluk et al. 2001). This has not consistently resulted in agronomic benefit. Experiments on the use of NBPT to improve seed-row safety in Western Canada have met with mixed results. Research showing improved seedling emergence with NBPT treated urea on wheat, barley, or canola has been reported by Xiaobin et al. (1995); Grant and Bailey (1999); Malhi et al. (2003); and Karamanos et al., (2004). More recently, Malhi and Lemke (2013) found no benefit on seedling emergence in a three-year study on canola and wheat. Grant (2014) found NBPT was not effective in increasing grain yield of spring wheat when applied with urea but did have some positive effects when used with UAN in broadcast (spray) applications. McKenzie et al. 2010 measured small yield increases with NBPT treated urea relative to ESN when broadcast in early spring on winter wheat but no difference relative to urea. He concluded that the negligible improvements were likely due to the low risk of nitrogen loss in the S. Alberta study area.

Treating nitrogen fertilizer with nitrification inhibitors is the third approach to creating an enhanced-efficiency fertilizer. There are three nitrification inhibitors that are commercially available in North America: nitrapyrin, dicyandiamide (DCD), and ammonium thiosulfate (ATS). Nitrapyrin is the active ingredient found in the DOW® product N-Serve® and Instinct®. Nitrapyrin was initially registered for the US market in 1974. Although tested in Canadian soils in the 1970's and 80's, it was never registered. Nitrapyrin is quite effective even at relatively low rates. Originally nitrapyrin was difficult to handle and only available for use with anhyrous ammonia (N-Serve). More recent microencapsulated formulations (Instinct and Instinct II) can be used with UAN and granular products as well as liquid manure. Dow Agrosciences is currently conducting field tests on nitrapyrin in Canada. Dicyandiamide (DCD) is the active ingredient in nitrification inhibitors such as Agrotain Plus®, SuperU®, and Guardian®. Dicyandiamide is required at a significantly larger concentration to be effective. Ammonium thiosulfate is used as a sulfur source in fluid fertilizer blends.

Akiyama et al. (2010) performed a meta-analysis on the effectiveness of enhanced-efficiency fertilizers as mitigation options for nitrous oxide emissions using 113 datasets from 35 studies. They found nitrification inhibitors and polymer coated urea reduced nitrous oxide emissions 38% and 35% respectively. Reductions varied with cropping system and soil type. The results were more equivocal for urease inhibitors, which over all showed little or no effectiveness in reducing nitrous oxide emissions in the study. Three of the six data sets analyzed for NBPT were from a site at Brandon, Manitoba where nitrous oxide emissions from treated urea, untreated urea and the zero nitrogen control were similar in two out of three years (Burton et al 2008). In a recent summary of experiments on irrigated corn systems in Colorado performed over multiple sites and multiple years, Halvorson et al. (2014a) found that controlled release and stabilized nitrogen sources consistently reduced direct nitrous oxide emissions during the growing season relative to untreated urea and UAN. The controlled release source ESN, reduced nitrous oxide emissions by 42% compared with urea and 14% compared with UAN in no-till and strip-till systems but had no effect in a conventional tillage system. Granular urea treated with both a urease and a nitrification inhibitor (SuperU) emitted 46% less nitrous oxide than urea and 21% less than UAN. A UAN source similarly stabilized with urease and nitrification inhibitors (UAN+Agrotain Plus) reduced nitrous oxide emissions by 61% compared with granular urea and 41% compared with UAN alone. Interestingly, UAN reduced nitrous oxide emissions by 35% compared with urea in their studies.

In an Alberta study focused on canola production systems, nitrous oxide emissions across three sites and three years were reduced by an average of 20% for spring side-banded ESN compared to uncoated urea on canola (Li et al 2012). Soon et al. (2011), in a study in Dark Gray soils, compared emissions from fall and spring banded urea and ESN at two sites over three years. They concluded that ESN can increase available N during the growth period and reduce nitrous oxide loss in some years compared with urea. Other studies from cool dry regions in the interior plains generally show a reduction of direct emissions with enhanced efficiency sources in a range of soil types and cropping systems (Burton et al. 2008; Hyatt et al. 2010; Venterra et al. 2011). In more humid climates, enhanced efficiency sources may have little or no positive benefits on direct emissions and may actually increase emissions depending on the timing and intensity of rainfall events (Sistani et al. 2011; Parkin et al. 2014).

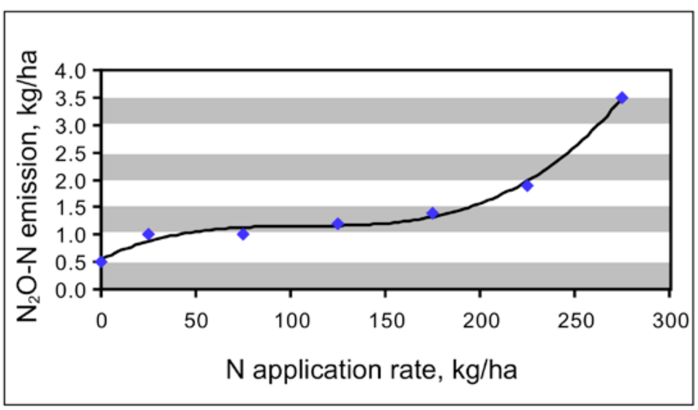
Experimental work in cool dry areas shows that the positive effects of enhanced efficiency fertilizers are site specific. The use of these sources does not consistently result in yield increases and in some cases can result in lower yields relative to conventional sources. They typically increase fertilizer use efficiency and reduce nitrous oxide emissions. Overall the enhanced efficiency sources have a modest potential of improving yield and return on fertilizer dollars and a substantial potential for reducing nitrous oxide emissions. The challenge going forward will be to provide producers and agronomists with tools to identify the circumstances where enhanced efficiency fertilizer will have a high likelihood of providing both economic and environmental benefits. If that can be accomplished they will be an important technology for managing nitrous oxide emissions under intensified productions regimes.

Right Rate

Nitrogen fertilizer is the major yield driver for non-leguminous field crops in the Northern Great Plains, followed by phosphorus, potassium, sulphur and to lesser extent micronutrients, in particular copper and chloride depending on crop and region (Karamanos et al. 2010). Fertilizer costs are typically the largest single variable expense for cereal and oilseed producers with the majority of fertilizer dollars spent on nitrogen (MAFRI 2014). Growers in Alberta are generally sensitive to nitrogen costs and are becoming increasingly aware that fertilizing for the economic optimum involves lower rates than those required to achieve maximum yield. The focus in this discussion is the relationship between fertilizer rate, production and nitrous oxide emissions. But keep in mind that insuring a balanced nutrient supply is a BMP for sustainable production. Cropping systems that are inadequately supplied with other nutrients will not make efficient use of nitrogen resulting in higher emissions, lower yields and greater quantities of residual nitrate (Snyder et al. 2009, Johnson et al. 1997).

Economic optimization of fertilizer rates requires consideration of expected growing conditions, crop prices, and fertilizer costs. Of these only fertilizer cost is usually known with certainty at the time of making the rate decision. Crop yield response to nitrogen fertilizer typically follows a pattern of near linear response giving way to a diminishing return and finally a plateau as rates increase. Since return on nitrogen fertilizer is maximized at the rate where marginal revenue from the extra crop produced and marginal cost of the nitrogen are equal, under or over fertilizing in any given year results in reduced profit suboptimal economic performance. Finding the economic optimum nutrient rate (EONR) is difficult with so many unknowns but one thing that is know is that it is by definition less than the minimum rate required to achieve maximum yield or agronomic optimum nutrient rate (AONR) (IPNI 2012).

Figure 4.2. Median Nitrous Oxide Emissions as a Function of Fertilizer Rate.

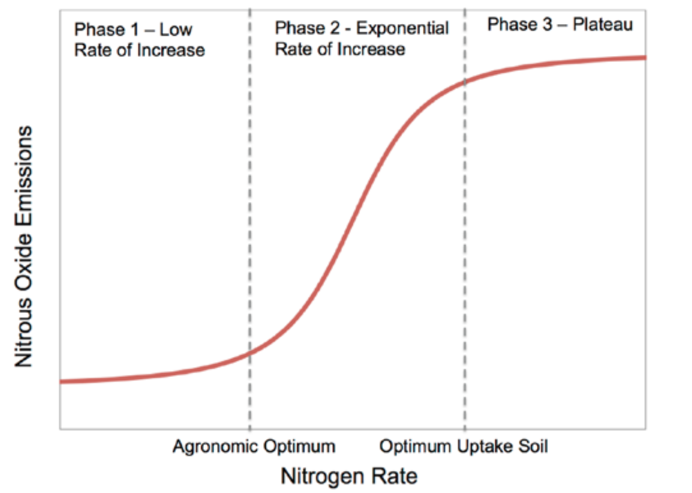


Source: Snyder et al (2007) adapted from Bouwman et al. (2002) review of nitrous oxide emission from cropping system experiments.

In the studies examined in this review, there was almost invariably a yield response to added nitrogen. The few exceptions involved experiments where environmental conditions, such as lack of moisture, placed limitations on crop growth. Several authors have theorized that the rise in nitrous oxide emissions in response to fertilizer rates is relatively moderate until the nitrogen uptake capacity of the cropping system is exceeded (Bouwman et al. 2002, Grant et al. 2006, and Snyder et al. 2007) (Figure 4.2).

In a recent meta-analysis, Kim et al. (2013) examined 26 published datasets where at least four different levels of N input had been applied. They found the relationship of direct nitrous oxide emission to N input was nonlinear (exponential or hyperbolic) in 18 datasets while the relationship was linear in four datasets. They proposed based on their analysis a general sigmoidal model with a lag or low rate of increase phase, an exponential phase, and a plateau or steady state phase with the cross over point from low to exponential increase occurring at the optimal N uptake by vegetation (Figure 4.3). The optimal uptake rate for vegetation will typically be the same or very close to the agronomic optimum nitrogen rate in cropping systems as shown in the figure.

Figure 4.3. Three Phase Emission in Response to Nitrogen Rate



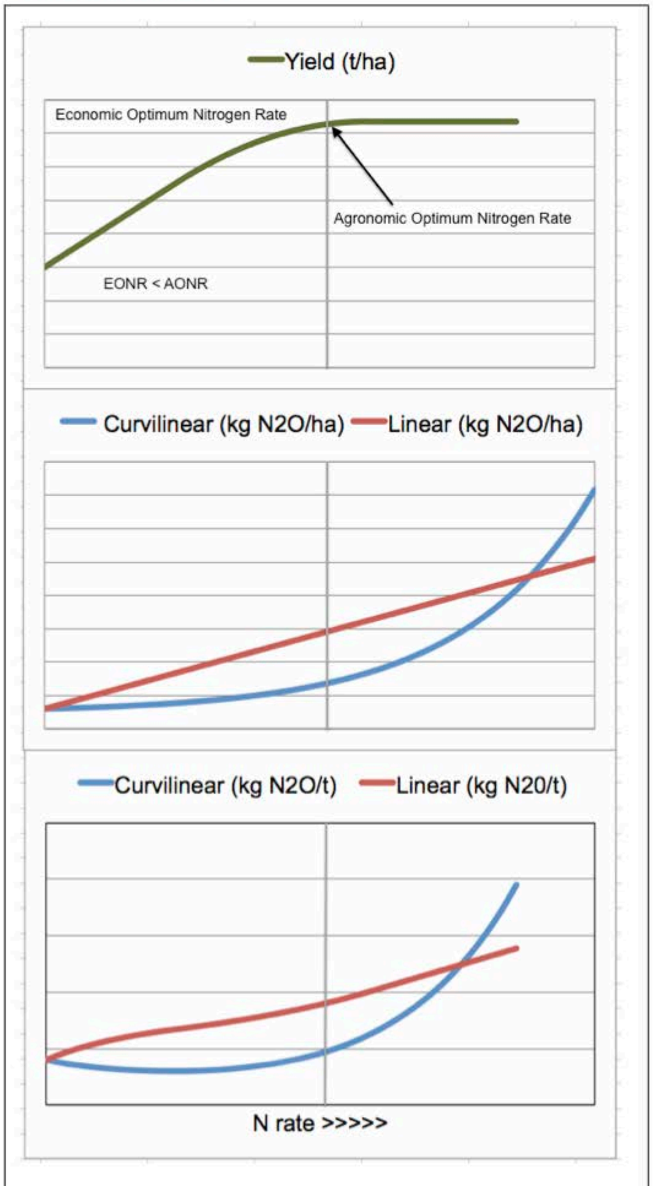
Source: Adapted from Kim et al. 2013.

The field studies that supported this model were largely from temperate cropping systems. For example, Hoben et al. (2011) working with corn in Michigan reported that nitrous oxide emissions increased substantially once the optimal rate was exceeded. Working with corn in Ontario, Ma et al. (2010) found that rates over 90 kg N/ha substantially increased nitrous oxide emissions but not yield. In a Manitoba potato study, Gao et al. (2013) found that emission were linear overall but in their study, optimum yield as measured by marketable tubers was reached at the lowest fertilizer nitrogen rate.

While there is a large degree of variability among sites and years in the reported experimental data the emerging trend appears to be that direct N_2O emission factors increase markedly at N input rates above plant uptake capacity. This would suggest that while nitrous oxide emissions per unit of land may go up with increasing nitrogen rates, the emissions intensity (kg N_2O/kg crop) is not likely to increase substantially as long as rate are kept below the agronomic optimum (Figure 4.4). If the aim of sustainable production is to find the balance point among economic, environmental and social goals, then economic optimization of nitrogen rates will result in maximum return to the producer on their nitrogen expenditures and reduction in nitrous oxide emissions relative to the over fertilization inherent in a maximum yield approach.

Over fertilization can occur for a number of reasons. One of the more common ones in prairie agriculture systems is lower than expected precipitation during the growing season. Several relevant studies have shown that nitrous oxide emissions tend to be driven by high moisture (for example, Gao et al. 2013; Soon et al. 2011). Consequently, excess nitrogen as a result of water limitations does not immediately result in higher nitrous oxide emission. However, excess nitrogen additions in a dry year generally end up as residual nitrate at the end of the growing season and contribute to subsequent direct and indirect emissions. The second common reason for over application of fertilizer is driven by growers' desire to maximize yield. While the idea that economic optimum rates are less than the agronomic optimum or maximum yield rate is widely understood by agronomists, fertilizer recommendations based on maximum yield are common and maximizing yield is still widely encouraged in the industry.

Figure 4.4. Nitrogen Rate, Yield, and Nitrous Oxide Emissions.



Source: Adapted from Van Groenigen et al. (2010) and Kim et al. (2013).

Under application of N rather than over application is more likely the norm in prairie cropping systems as evidenced by the difference between average reported yields and yields achieved under higher fertility regimes.[6] There is little current data available on farmer used nitrogen rates in Alberta and unlike phosphorus and potassium which are largely conserved within the cropping system, gross nitrogen balances based on total fertilizer use and crop removal are essentially meaningless.

Technologies available for optimizing nitrogen rates for Alberta growing conditions include optimizations programs such as AFFIRM[7] which take in account fertilizer and crop prices and provide an estimate of the economic optimum rate under different moisture probabilities. Unfortunately AFFIRM and many of the recommendation system like it are driven from out dated data that doesn't fully reflect advances made in both genetics and management factors such as direct seeding. For example, Smith et al. (2010), found major differences in the nitrogen response functions between older open pollinated canola varieties and hybrid canola varieties.

Furthermore, AFFIRM and other programs like it generally depend on soil test nitrogen as an input variable. While soil test use remained the same in Saskatchewan and rose substantially in Manitoba, it appears to have declined by approximately 30 in Alberta in the period 2000 to 2010 (IPNI 2010). Soil test nitrogen is considered one of the important variables for determining right rates for nitrogen on a field specific basis under Alberta growing conditions. In a 2012 survey of production practices in Western Canada, canola growers that soil tested reported on average a

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[6] See Section 5 for discussion of intensification potential and nitrogen use.

[7] Alberta Farm Fertilizer Information and Recommendation Manager, Available from Alberta Agriculture and Rural Development as a free download at www1.agric.gov.ab.ca.

2 bu/acre advantage over those that didn't (Smith 2013). NERP prescribes soil testing as a best management practice at all levels of application of the protocol.

Variable rate fertilization is another technology that has the potential to optimize nitrogen rates by more closely matching nitrogen inputs to spatial differences in crop uptake requirements and soil supplying power. Little direct work has been done in Western Canada on using variable rate to mitigate nitrous oxide emissions.

Suboptimal economic performance of nitrogen can result from both under and over application. Over application results in economic inefficiency and increased risk. Under application may result in lower emissions per unit of land and potentially better environmental, if not economic performance, of a given cropping system. Keep in mind, however, that in a market with increasing demand, the reduced production would likely be made up in similar cropping systems. There is likely no GHG advantage overall in reducing nitrogen rates and yield on one piece of land if it is only to be made up on another piece of land. There may in fact be considerable disadvantage, if the new piece is brought into production from alternative uses that are GHG sinks under their current management regime. Whether this occurs locally or in another region is immaterial to the global balance between food production and GHG reduction. Since under fertilization also reduces total production, it also works against global society's requirement for increased food production on existing land.

Right Time and Place

Nitrogen timing and placement can have significant effects on yield, nitrogen use efficiency and nitrous oxide emissions. In Alberta, most nitrogen is spring applied at or just before seeding (Korol 2004). Fall-application appears to be declining as producers have adopted single pass seeding systems. Use of split-application, with some of the nitrogen applied at or before seeding and the remainder in crop, is increasing but is still a minor practice.

Fall nitrogen application reduces workload during the seeding window and takes advantage of lower fall fertilizer prices. Many producers have solved the price differential by purchasing in fall and storing on-farm. Fall application also avoids the seedbed drying that can occur as a result of spring tillage to incorporate broadcast or subsurface band fertilizer, an important consideration in the drier brown and dark brown soil zones of S. Alberta.

The choice of fall over spring application timing can reduce nitrogen use efficiency and yield response particularly in finer textured soils and moister regions. Placement interacts strongly with timing and site conditions in determining the relative efficiency but there is a considerable body of evidence demonstrating that in prairie cropping systems spring-applied N generally out performs fall (Harapiak 1979; Nyborg and Leitch 1979; Bole et al. 1984; Malhi et al. 1984; Ukrainetz 1984; Nyborg and Malhi 1986, 1992; Malhi et al. 2001). The ranking from most to least effective under conventional tillage can be summarized as spring banded > fall banded > spring broadcast > fall broadcast (Table 4.2). The table suggests correctly that fall-application performs about equally well to spring application in drier regions under normal moisture conditions. Under wetter than normal conditions, overwinter losses of fall-applied nitrogen can occur in all regions of the province.

Table 4.2. The relative effectiveness of methods and time of nitrogen application for increasing crop yield.

Time and Place	Soil Moisture			
	Dry	Medium	Wet	Irrigated
Spring Broadcast and Incorporated	100	100	100	100
Spring Banded	120	110	105	110
Fall Broadcast and Incorporated	90	75	65	95
Fall Banded	120	110	85	110

Dry = Well drained soils that are seldom saturated during spring thaw. Medium = Well to moderately drained soils that are occasionally saturated during spring thaw for short periods. Wet = Poorly to moderately drained soils that are saturated for extended periods during spring thaw. Irrigated = Well drained soils in southern Alberta that are seldom saturated during spring thaw.

Source: Adapted from Alberta Agriculture and Rural Development, Agdex 542-11 (revised 2013), Fall-applied nitrogen risks and benefits. http://www1.agric.gov.ab.ca

The common fertilizer nitrogen sources used in Alberta, either contain nitrogen in the ammonium form or convert to ammonium following application. (The notable exception is UAN with nitrate-N accounting for 25% of its nitrogen content.) The subsequent conversion of ammonium to nitrate is temperature dependent and early fall application allows formation of more nitrate prior to the soil freezing and increases the potential for losses prior to crop uptake the following growing season (Malhi and Nyborg 1979; Malhi and McGill 1982; Malhi et al.1984; Malhi and Nyborg 1983; Monreal et al. 1986; Malhi and Nyborg 1990a,b; Nyborg et al.1990; Nyborg et al. 1997).

The risk of overwinter loss and reduced yield response varies regionally largely dependent on soil moisture and the probability of spring saturation. Research conducted largely in the wetter black, dark gray and gray soil zones generally indicates large reductions in efficiency that can only be partly overcome by band placement, use of inhibitors and late fall timing (Malhi and Nyborg 1979; Malhi and Nyborg 1984; Monreal et al. 1986; Malhi and Nyborg 1988a,b; Yadvinder-Singh et al. 1994; Malhi et al. 2001). Results from the brown and dark brown soil zones indicate lower risk of overwinter loss, which can be largely overcome at least in most years by banding (Bole et al. 1984; Kucey 1986; Kucey and Schaalje 1986; Malhi et al. 1992b; Malhi et al. 2001).

Site-specific factors can substantially modify these regional trends. Grant et al. (2001, 2002) found in black soils in Manitoba that grain yields with fall-applied urea and UAN tended to be lower than spring-applied on a finer textured soil but similar on a coarser textured soil. In these studies, the two sites were approximately 50 kilometers apart. Efficiency of fall application can also vary markedly with landscape position in the same field. Tiessen et al. (2005, 2006) reported grain yield and apparent recovery of fertilizer N were significantly greater for spring and late fall applications at low landscape positions, when compared with early and mid-fall applications but found no difference at high landscape positions.

The potential for loss is higher when fertilizer nitrogen is fall-applied. Denitrification during the the spring thaw can account for a substantial portion of annual nitrous oxide emissions from soils subject to freeze thaw cycles (Risk et al. 2013). This makes it likely that nitrous oxide emissions are higher with fall compared to spring fertilizer timing. However, experimental results have varied. Burton et al. (2008) found that cumulative emissions from fall-applied nitrogen were marginally greater than spring applied over a three-year study in Manitoba. Soon et al. (2011) found significantly greater emissions from fall-applied plots in some site years but not others. They did, however, report large apparent losses of nitrate that may have contributed to indirect emissions.

Subsurface band placement tends to increase nitrogen use efficiency and more effectively increase yield than broadcasting nitrogen. Placing N fertilizer in bands also reduces volatilization losses, lowers the risk of immobilization, and slows the rate of nitrification of fertilizer N to nitrate in the fall, which reduces the risk of overwinter loss (Yadvinder-Singh et al. 1994). Reduction of ammonia volatilization and leaching infers reduction of indirect nitrous oxide emissions. Whether banding (fall or spring) results in lower emissions overall is still unclear. Burton et al. (2008) found little difference in direct emissions between broadcast and banded urea in two Manitoba soils. Based on their meta-analysis of emission measurements from experiments comparing tillage and placement, Van Kessel et al. (2013) concluded that deep placement (>5 cm) of nitrogen was an effective strategy for reducing emissions in no-tillage and reduced tillage systems. Banding urea can increase ammonia volatilization on dry acidic soils compared to surface placement (Rochette et al. 2009) and ammonia losses contribute to indirect nitrous oxide emissions. However, practices that reduce direct emissions but increase ammonia emissions may still be important mitigation strategies depending on the balance between the two processes. A kilogram of volatilized ammonia-N would have a GWP of approximately 4.87 kg CO_2e, while a kilogram of N lost through direct emissions of nitrous oxide results in a GWP of 487 kg CO_2e.[8]

Banding after the soil has cooled below 10°C is considered a BMP for fall nitrogen application under NERP at the basic level. Use of an enhanced efficiency fertilizer with fall-banded N is a BMP at the advanced level. The inclusion of fall application timing as an appropriate BMP under NERP will need to be reconsidered once results from some of the research currently underway become available. Early indications are that switching from fall to spring application may be one of the more effective practice changes growers can make for both improving nitrogen use efficiency and reducing nitrous oxide emissions.

The other main timing consideration in prairie agriculture is whether to apply all nitrogen at or before seeding, after seeding, or use a split application approach. Agronomically there are a number of reasons to use split applications including reducing the fertilizer volume handled at seeding, managing risk of low moisture in dryland cropping, matching application to uptake timing, and fine-tuning of nitrogen rates with growing conditions. Holzapfel et al. (2007) reported no yield reduction in canola from split application, but yield was depressed in wheat when little

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[8] Based on the default IPCC emission factor for redeposited ammonia of 0.01 kg NO_2-N/kg NH_3-N and a the GWP conversion of 310 currently used in NERP.

precipitation was received after N application. Karamanos et al. (2005) suggested that applying N post emergent was higher risk than applying all N at the time of seeding and that adding a significant portion of nitrogen at seeding was required to reduce that risk. Split application that places a third to half the nitrogen at or before seeding, more in drier and less in wetter conditions, combined with timely in-crop application yield about equally well under normal moisture conditions and provide growers with a tool to avoid over or under application (Lafond et al. 2008, Malhi et al. 2001).

NERP allows in-season or split application of fertilizer provided a band placement is used. This currently eliminates broadcasting either urea or spraying UAN as a BMP in NERP project fields. The protocol is not clear whether the post emergent application portion of a split application needs to be subsurface banded using granular or fluid through a coulter or can be surface banded using granular urea or streamer bars and UAN. The stream bar approach is an attractive option to growers as they increasingly adopt high clearance sprayers, while a coulter system requires specialized equipment including guidance to ensure correct placement and minimize crop damage.

There appears to be little difference in yield between in-soil and surface banding using UAN under prairie conditions (Holzapfel et al. 2007). Grant (2014), working in no-till wheat production in Manitoba, compared surface application techniques applied immediately after seeding. She found that concentrating surface application in a band increased yield when UAN was the source but yields were comparable when broadcast urea was compared to surface banded urea.

Split application using surface banding or in-soil bands both appear to be viable options agronomically but little work has been done comparing nitrous oxide emissions from the different placements. Halvorson et al. (2012) measured nitrous oxide emissions from ESN, SuperU, UAN+Agrotain Plus compared to subsurface banded ESN, surface banded UAN, and surface banded urea in irrigated strip-till and no-till corn systems in Colorado. They found that all sources and placements produced the same yield but sources varied significantly in cumulative growing season emissions. Surface banded UAN and SuperU reduced cumulative emissions by approximately half compare to surface applied urea, while UAN+Agrotain Plus reduced emissions by 67%. Interestingly surface banded ESN, while reducing emissions by 53% relative to urea, also had 38% lower emissions than subsurface banded ESN.

Split-applications have the potential to be a useful BMP for nitrous oxide emission in Alberta cropping systems. They may be particularly effective in areas of the province where growing season precipitation is more variable and applying all nitrogen at seeding represents a financial and environmental risk. In all likelihood the mechanism of nitrous oxide reduction would be a lower nitrogen application rates in years when the in-crop application was not applied or applied at a reduced rate. Split application is an allowable practice in NERP but producers may not have the equipment necessary to subsurface band in crop. Surface banding using UAN or UAN+Agrotain Plus appears to have relatively low emissions compared to broadcasting or surface banding urea and fits with the growing use of high clearance sprayers in cereal and oilseed production. The use of enhanced efficiency fertilizers in-crop can be an agronomic issue if it significantly delays conversion or release and uptake by the crop and needs to be approached with caution but does warrant more attention as a possible BMP under NERP.

4.4 Observations

A significant body of work examining the effects of the 4Rs on nitrous oxide emissions has been completed since the original scientific review of the NERP in 2008. This new work generally supports the conceptual framework and suggested BMPs found in the NERP while at the same time pointing out areas where benefits can be increased by reconsidering practices at the different levels. The most important points and recommendations are as follows:

- Conventional nitrogen sources do not appear to vary much in agronomic performance but can differ markedly in emissions when compared side by side. These differences need to be further clarified and recognized within the framework of NERP BMPs at the advanced level.
- The efficacy of enhanced efficiency fertilizers in increasing yield and reducing nitrous oxide emissions is highly site specific and interacts strongly with time and place. Further efforts should be made to provide agronomists and growers with guidance to their appropriate use as both agronomic and environmental BMPs.
- Nitrous oxide emissions are not linear with respect to nitrogen rate but increase exponentially once sufficient nitrogen has been applied to maximize yield. Since the economically optimal rate is less than the rate required to maximize yield, a strategy of economic rate optimization will generally improve economic performance and reduce emission intensity. Furthermore, the newer rate research supports the use of economic rate optimization in conjunction with a yield based intensity approach to calculating offsets.
- Fall-application is agronomically inferior to spring in the higher moisture areas of Alberta. Nitrous oxide emissions during spring thaw can be a considerable portion of annual emissions and work nearing completion in Alberta shows that switching from fall to spring application would significantly reduce overall emissions. The inclusion of fall-application as a BMP in the moister ecodistricts at the advanced level of NERP should be reconsidered.
- Split application has potential to help growers improve economic performance and mitigate emissions by avoiding over application. Presently cereal and oilseed growers require specialized equipment to subsoil band in-crop. Existing research suggests that source selection can significantly reduce emissions from surface banding. Allowing in-crop surface banding with specified sources as part of a split-application or on forages should be considered for inclusion as a NERP BMP.
- Researchers often found application of source, rate, time, and place BMPS reduce emissions more than the current reduction modifiers of 15% for basic and 25% for intermediate and advanced NERP. The newer research supports the view that the reduction modifiers are conservative. A reduction modifier of 30-35% is scientifically supportable for the advanced NERP with revisions to the required BMPs.

Overall the research supports the concept that optimization of nitrogen fertilizer use is an important part of a strategy to sustainably intensify production on existing crop land and using a 4R approach can ensure that any increases in nitrous oxide emissions per unit of crop produced are minimized.

5 Intensification Scenarios GHG Emissions and Economics

5.1 Introduction

The purpose of sections 3 and 4 of this report was to examine the issues involved in increasing total production through higher output on existing acres (more intensive production) relative to increasing the acreage of land under production (more extensive production). Central to this discussion was the concept of land sparing, can land be kept out of agriculture use and serve alternate purposes such as delivery of ecological goods and services particularly carbon sequestration that provide environmental and social benefit. The other main theme is the role of nitrogen fertilizer in increasing productivity of Alberta's cropping systems and what effect changes in nitrogen management will have on nitrous oxide emissions.

Section 4 examined the recent literature on nitrous oxide emissions from cropping systems and identified technologies and practices that would help support intensification within a framework of sustainable agriculture with a major focus on the impact of 4R based fertilizer management on GHG emissions.

The purpose of this section is to first examine the question of whether is further intensification possible given Alberta's biophysical resource base. A second purpose is to quantify the discussion on the potential for intensification using economic analysis and projected greenhouse gas emissions. Third, for comparative purposes, to examine the costs and change in GHG emissions associated with intensification to the costs and GHG emissions associated with the land use changes required to bring more land into annual crop production.

5.2 Climate and Intensification

Alberta's climate can be challenging for crop production. The moisture regimes in the major crop production areas range from sub-arid to sub-humid with mean annual precipitation ranging from 300 to 600 mm (Figure 5.1). There are normally significant growing season moisture deficits ranging from 380 mm in the southeast near Medicine Hat to 25 mm in cooler west central areas. Rain fed crop production is significantly water limited within the Prairie ecozone and while water limitations are less in the Boreal Plain region of Northern Alberta, there are significant limitations due to insufficient heat units and shortness of

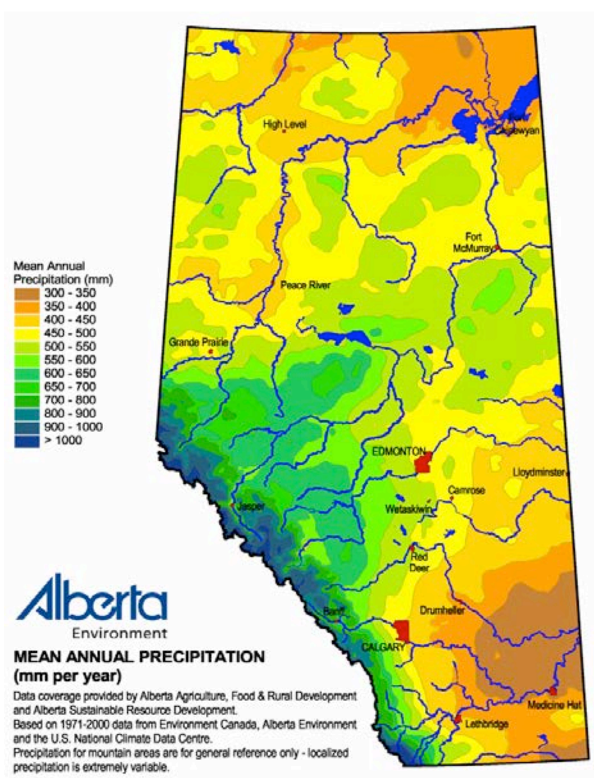


Figure 5.1. Alberta's Mean Annual Precipitation

the frost-free period (Figure 5.2). Within Alberta's current and projected future climate is there room for further intensification of crop production? If so what are the fertilizer management practices that will allow this intensification?

What are the costs associated with intensification on existing arable land and how do those costs compare to bringing new land into production? Finally, what are the environmental risks associated with intensification on existing acres compared to bringing land currently in alternate uses into annual or perennial crop production?

Within the framework of these questions this report will focus on the role of improved nutrient management in the intensification of crop production. Where intensification is defined as an increase in units of harvestable product per unit of land area or more simply put increased yield. Greenhouse gas emissions are the main environmental risk of interest. Since the GHG of most interest in cropping systems is nitrous oxide, the role of nitrogen management in improving crop yields is of particular interest.

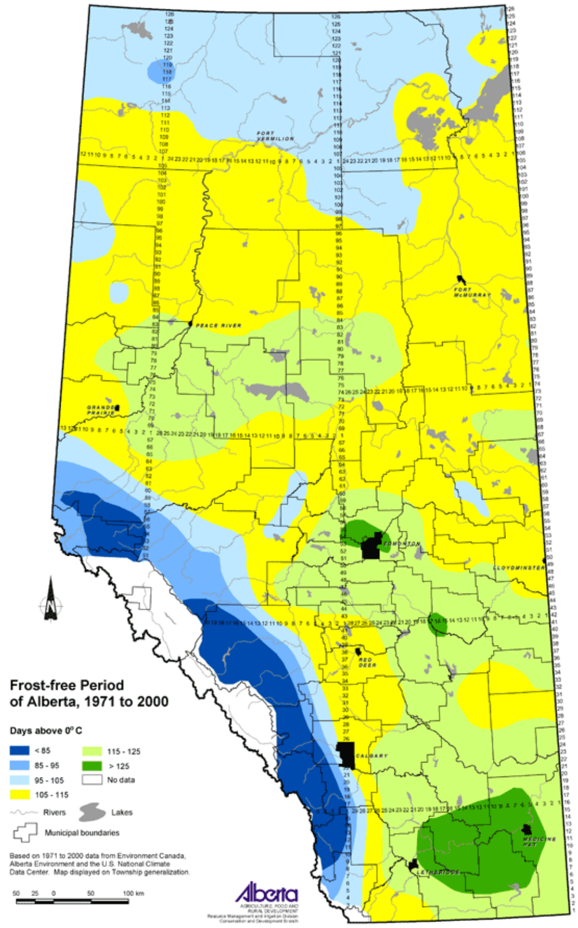


Figure 5.2. Alberta's Frost Free Period

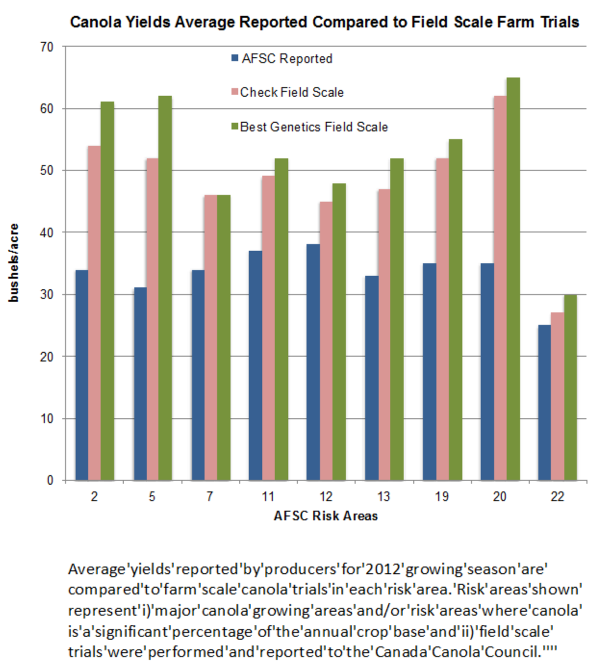
5.3 Potential for Intensification in Alberta

The potential for intensification, within the context of this report, is defined as increased production per unit area of land or yield increase. The potential for intensification can be illustrated in several ways. Using canola as an example and 2012 as a base year[9], comparison of average reported yields for Agriculture Financial Service Corporation crop insurance purposes (AFSC 2013) to yields achieved on field scale test plots set up by the Canada Canola Council suggests that even with current genetics and technology, yields might be considerably increased (Figure XX2). The comparisons are only for those risk areas where a significant acreage of canola is grown and field scale trials were successfully taken to yield for the 2012

[9] The year 2012 was chosen as the base year because it is recent enough to reflect current practices and genetics and had closer to normal growing season conditions across the province than either 2011 or 2103 when growing conditions were considerably better than normal. Several factors significantly impacted canola yield in certain areas during the 2012 growing season including high temperatures during canola flowering and aster yellows. None-the-less yields were above the 10-year average in most regions. For greater detail refer to the publication *Yield 2013* on the AFSC website.

growing season. Since AFSC yields are reported by variety and acres harvested, the reported yields shown are the area weighted means in the risk area. The AFSC yields are compared to the top performing and check varieties in the field scale trial. The field scale trials were replicated and performed using the farmer's equipment and current practices. Canola varieties turn over fairly rapidly in Western Canada, in these trials the checks were widely grown herbicide tolerant hybrids.

The difference between reported yields and the field scale trial yield using the top yielding varieties in each trial is considerable in all risk zones except Zone 22. The increases range for a low of 5 bu/acre in Zone 22 to a high of 31 bu/acre in Zone 5. The latter value is double the reported average for the zone. Complete details of the practices used at the individual trial sites were not readily available; however, field notes taken at each site by either the grower or a local agronomist show generally higher fertilizer rates, above average weed control, as well as the use of fungicides were typical practices.



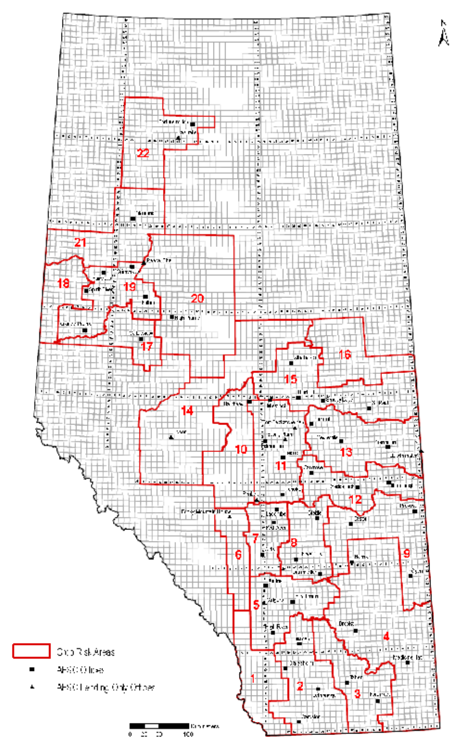


Figure 5.3 – Canola Yields by AFSC Risk Areas

Comparable regional data based on field scale trials are not readily available for other major crops but looking at small plot variety trials shows a similar trend to canola at the provincial level (Table 5.1). Small plot trials tend to yield 10-15% higher than what is achievable at field scale under similar growing conditions and optimal management. Even with discounting at the 15% level the results achieved are above average AFSC reported yields for 2012. Well above for trials performed at high productivity sites. The comparison with older genetics (varieties that are no longer widely grown but included in the trials for continuity and to enable comparisons across years) that were included in the 2012 cereal variety trials suggests that the potential for improvement is more than just the selection of superior varieties. While these old varieties did not perform as well as best genetics, they still yielded well above the reported averages in all cases. High yield at a specific site is not simply a product of high fertility but depends on complex interaction among genetic, environmental and management factors. However, nutrients must be in adequate supply for superior genetics, optimal growing conditions and management factors to produce high yields. It is safe to say that the higher yields illustrated in the data below were realized under high fertility regimes in particular high nitrogen fertility even if the source of that nitrogen is not known with certainty.

Table 5.1. Cereal Yields at High Test Sites Compared to AFSC Provincial Averages

Crop	AFSC Averages[1]		Alberta Variety Trials 2012 Averages			
	10 Year	2012	Overall Check[2]	High Test[3] Check	High Test[3] Best Genetics	High Test[3] Old Genetics
	bu/acre[4]					
HRS Wheat	41	46	58	79	90	77
HRW Wheat	44	57	76	118	119	104
Durum	35	48	65	95	98	87
Barley	59	61	100	133	153	130
Field Peas	34	40	175[4]	----	----	----

[1] Farmer reported yields for crop insurance purposes.
[2] Check variety averages over all sites.
[3] Averages from trials at high productivity sites.
[4] Pea trials check variety averaged over multiple years.
Source: Derived from AFSC Yield Alberta 2013, Varieties of Cereals and Oilseed Crops for Alberta (Agdex 100/32 2013), and Varieties of Pulse Crops for Alberta (Agdex 142/32-1 2013).

While the comparisons shown above are not scientifically rigorous in the strictest sense, the differences between yields reported by growers and those achieved under more intensive management regimes in the same region in the same year illustrate the current productivity gap between average and high end growers. The other pertinent observation is that while continued improvements in genetics and technology will open the way for future productivity gains, there is considerable potential for increasing productivity by wider adoption of currently available genetics and practices. The proviso is that there will be situations were inherent productivity issues like soil salinity will severely limit yield regardless of practices used.

5.4 Quantification of Nitrous Oxide Emissions

To quantify intensification, scenarios were developed with canola and wheat (the two largest acreage annual crops grown in Alberta) using the 2012 growing season as a model year. The scenarios were developed as a matrix of the two crops in three agroclimatic areas of Alberta using a representative ecodistrict from what are commonly referred to as the Dark Brown, Black and Dark Gray-Gray Peace regions of Alberta.

These scenarios were developed to fall well within the range of yields discussed in the previous section. Namely at the current yield levels as reported by ASFC, an advanced level of intensity representing the yields that could be achieved with optimal management including increased fertility, pest management and superior genetics. Finally at an intermediate level of intensification that would include better management practices than are currently used but not the complete optimization of the advanced scenario.

The yields chosen for canola for the current levels were the yields reported for the AFSC risk area that contained the representative ecodistrict. Since the approximate location of the field scale canola trials was available and could be placed within a specific ecodistrict, the intense scenarios used yields in the high end of the range achieved in the plots using best available genetics. The intermediate scenario yields were the midpoint between the two (Table 5.2).

Table 5.2. Scenarios for Canola Production Economics and GHG Emissions.

AFSC Risk Zone	Representative Ecodistrict	Ecodistrict Name	AFSC Reported	Intermediate	Intense[1]
			bushel/acre		
2[2]	791	Vulcan Plain	34	45	56
5	798	Delacour Plain	31	46	62
7	737	Red Deer Plain	34	40	46
11	727	Leduc Plain	37	48	60
12	731	Daysland Plain	38	43	48
13	728	Andrew Plain	33	42	52
19	596	Dunvegan Plain	35	45	55
20	612	Heart River Upland	35	45	65
22	587	Boyer Plain	25	28	30

[1] Yields based on best available genetics from field scale canola trials in 2012.
[2] Scenarios shaded in grey were used in the economic and GHG analysis.

Since no comparable field scale data was available for wheat, the percent improvement of the provincial best genetics yields in the 2012 small plot variety trials relative to the provincial AFSC average reported yield in 2012 was used as a starting point for estimating yields under high intensity. This relative improvement was applied to the AFSC reported yield for the risk zone containing the representative ecodistrict to estimate the upper yield limit. The upper yield limit was discounted by 15% to account for the difference between small plot and field scale yields under optimal management. The midpoint between the low and high yield scenarios was assigned for the intermediate level (Table 5.3).

AFSC Risk Zone	Representative Ecodistrict	Ecodistrict Name	AFSC Reported	Intermediate	Intense[1]
			bushel/acre		
2[2]	791	Vulcan Plain	42	56	70
11	727	Leduc Plain	52	69	87
19	596	Dunvegan Plain	53	71	88

Table 5.3. Scenarios for HRS Wheat Production Economics and GHG Emissions.

[1] Intense yields based on best available genetics from small plot trials in 2012 adjusted for ecodistrict.

Nitrogen fertilizer requirements to meet the yield goals were estimated using an N balance approach where the nitrogen deficit was calculated as the required crop uptake for canola or wheat minus soil test nitrogen and the expected nitrogen mineralization from soil organic matter. Soil test nitrogen for all cases was assumed to be 40 lbs N/acre to a depth of 24 inches, a fairly typical value found under stubble. Soil organic matter release was based on the estimated nitrogen release equations used in the AFFIRM software using the average soil organic matter values for the appropriate soil zone. The fertilizer nitrogen requirement was the nitrogen deficit adjusted for fertilizer use efficiencies of 50, 60, and 65% respectively for the low, medium and intense scenarios to reflect improvements in nitrogen management practices (Table 5.4).

Table 5.4. Fertilizer Nutrient Rates Used in the Different Intensification Scenarios[1]

Ecodistrict	Intensity	Canola				Wheat			
		N	P_2O_5	K_2O	S	N	P_2O_5	K_2O	S
		lbs/acre							
Vulcan Plain 791	Low	65	20	0	20	44	20	0	0
	Med	106	25	0	25	87	25	0	0
	High	145	25	0	30	115	30	0	0
Leduc Plain 727	Low	50	20	0	20	60	25	0	0
	Med	93	25	0	25	90	20	0	0
	High	138	25	0	30	120	35	0	0
Dunvegan Plain 596	Low	65	20	0	20	60	25	0	10
	Med	101	25	0	25	105	30	0	15
	High	136	25	0	30	145	35	0	15

[1] N and S assumed to be broadcast prior to seeding in the low intensity scenario and midrow banded at time of seeding in the medium and high scenarios. P was placed close to the seed using an appropriate opener in all scenarios. Sources of N, P, and S were assumed to be urea, monoammonium phosphate, and ammonium sulfate respectively.

Phosphorus, potassium and sulfur rates were assigned based on standard sufficiency recommendation tables based on soil test values and yield goals. The recommendations assumed low soil test values for phosphorus, sufficient values for potassium, and marginal values for sulfur. These assumptions resulted in phosphorus and sulfur but not potassium recommendations for canola. For wheat, phosphorus but not potassium recommendations were included in all scenarios but sulfur was included only in the scenarios for the Dunvegan Plain ecodistrict. Most Alberta soils are well supplied with potassium but are deficient in phosphorus. Sulfur levels tend to be highly variable in the landscape, often ranging from less than 5 to over a 1,000 lbs/acre in the same field. Applying sulfur to canola is standard practice regardless of soil test values. The Gray and Dark Gray Luvisolic soils of the Peace River region tend to be lower in available sulfur and application to cereals is a more common practice than elsewhere in the province. Micronutrient deficiency in cereal and oilseeds is relatively rare in Alberta with the exception of copper (Karamanos et al. 2010).

Intensification goes beyond increased fertilizer rates and generally includes practices such as increased seeding rates and improved crop protection. These practices tend to work together with increased fertility and superior genetics to increase yield. The assumption was that all crops were grown in a no-till system, as direct seeding into no-till is common practice in Alberta and typically gives superior economic and environmental performance than conventional tillage systems. The general approach used in creating these scenarios was to move to higher seeding rates for wheat, more effective weed control, and improved disease management through the use of fungicides as the scenarios moved from low to medium to high. The model for the medium and high canola intensity scenarios were based on the *Canola Growers Manual* (Canada Canola Council, 2014) and discussions with agronomists working directly with intensive growers. The wheat medium and high intensity scenarios were modeled after the agronomic practices used in the currently underway *Wheat 150 Project* (Dr. Sheri Strydhorst pers. comm.) and in discussions with agronomists working with intensive growers. The scenarios are fully described in Appendix A.

5.5 Nitrous Oxide Emissions and Cropping Intensity

Estimation of Greenhouse Gas Emissions

Nitrous oxide emissions for the different scenarios were estimated using the equations from the NERP, which are derived from the National Inventory Methodology developed by Rochette et al. (2008a). For the medium and high scenarios, the assigned practices meet the threshold for the basic and advanced NERP respectively so the appropriate reduction modifiers of 15 and 25% were applied to reflect the impact of an integrated 4R Plan on emissions. NERP only accounts for GHG emissions associated with in-field nutrient management practices that affect nitrogen and ignores baseline emissions from soil and field operations that occur under both baseline and project conditions. Since one of our objectives was to compare the relative difference in GHGs required to grow equivalent amounts of grain extensively versus intensively a more complete GHG lifecycle was constructed that included field operations and the upstream GHGs associated with manufacture of fertilizer and other agricultural chemicals. The emission factors used for fuel, fertilizer, and pesticides used in the different scenarios were obtained from various sources (Table 5.5). Downstream emissions associated with grain transport off farm was not included on the basis that the comparisons among systems were on equal amounts of grain produced and emissions from transporting a tonne of grain grown extensively would be no different than intensively.

The assumption was that all crops were grown in a zero tillage direct seeding system and were actively sequestering carbon. The carbon sequestration coefficients, with adjustment for yield differences to reflect higher residue inputs, were approximated from values for dry prairie (ED 791) and moist parkland (ED 727 and ED 596) developed for the Canadian agriculture national inventory method by VandenBygaart et al. (2008) and are similar to values from Campbell et al. (2005). The carbon sequestration values were subtracted from the gross emissions to calculate the final net emissions.

The calculation of nitrous oxide based carbon credits followed the NERP methodology. Since medium and high intensity scenarios involved extra trips of the sprayer across the field relative to the low or baseline scenario, the carbon dioxide equivalents associated with estimated fuel consumption by the additional sprayer operations were subtracted from the initial estimate of credits. Carbon credits per Alberta's Conversation Cropping Protocol (CPP) were not calculated but would be similar in magnitude to the sequestration values at low intensity in each ecodistrict. All scenarios would meet the no-till criteria for CPP, where as only the medium and high scenarios include the practices required for NERP eligibility. The CPP and NERP protocols do not overlap and can be applied to the same field provided the BMP criteria for each is met.

Table 5.5. Emission Factors Used in Calculating GHG Emissions for Intensity Scenarios.

Inputs	Emission Factor[1]	Units	Souce
Seed	0.734	kg CO_2e/kg	Biograce
Urea	3.31	kg CO_2e/kg N	Ecoinvent
Ammonium Sulphate	2.87	kg CO_2e/kg N	GHGenius
Monoammonium Phosphate	1.29	kg CO_2e/kg P_20_5	Ecoinvent
Pesticides	10.16	kg CO_2e/kg a.i.	Ecoinvent
Diesel	2.86	kg CO_2e/L	NERP Appendix G

[1] For emission factors used in calculation of nitrous oxide emissions from added fertilizer refer to the Quantification Protocol for Agriculture Nitrous Oxide Emission Reductions (NERP), 2010.

Offset Credits Generated under NERP through Adoption of 4R.

Growers currently using or willing to adopt an integrated set of right source @ right rate, time, and place BMPs as described in the protocol are eligible for NERP offset credits. The 4R practices are incorporated within a 4R Nutrient Stewardship Plan. The medium and high intensity scenarios in this study assumed nutrient management practices that would make them eligible in Alberta for generation of carbon offset credits under NERP. These BMPs included ammonium based N sources, rates based on soil testing and nitrogen balance (variable rate for the high intensity scenario), spring application timing, and narrow band placement (see Table 4.1). Under NERP the plan is developed for the farm enterprise with the involvement of an Accredited Professional Advisor (APA) with credentials such as Certified Crop Advisor (CCA) and/or Professional Agrologist (PAg) and certification in NERP through training provided by the Canadian Fertilizer Institute. Offset programs must be additional or beyond business as usual to be recognized internationally. The additionality requirement is met in NERP through creation and implementation of the 4R Plan. NERP is not retroactively applicable. Sign-off of the 4R Plan by the APA initiates eligibility for the current cropping year and a project can run for up to eight years. At present, offsets generated in Alberta under NERP can be traded in the regulated Alberta market.

The NERP approach calculates offsets on a yield-basis rather than an area-basis using the difference between intensity of emissions (kg N_2O/kg crop) in a baseline and a project condition. As explained earlier, the project emissions are corrected for the emission reducing effect of 4R by applying a reduction modifier (RM) prior to subtraction of the baseline. Once the difference is converted to carbon dioxide equivalents and converted from an intensity to a mass basis by multiplying by the total kilograms of crop produced, the value is corrected for any additional emissions from field operations in the project that were not part of the baseline operations.

$$kg\,CO_2e_{credit} = \left(\frac{kg\,N_2O_{baseline}}{kg\,crop_{baseline}} - \left(\frac{kg\,N_2O_{project}}{kg\,crop_{project}} \times RM \right) \right) \times \frac{310\,kg\,CO_2e}{kg\,N_2O} \times kg\,crop_{project} - \Delta CO_2e_{operations}$$

The NERP credits and their nominal value over the life of an 8-year project at different levels of carbon are shown in Table 5.6. For the purposes of this table, we used a dynamic baseline approach that uses current year data for both baseline and project. This provides a conservative estimate of credits for the scenarios. The dynamic baseline approach is currently being considered as a flexibility mechanism in NERP. Using this approach would allow growers with insufficient records to develop a baseline using the 3-year historic approach to participate in offset projects while they collected baseline data.

Table 5.6. Nominal Value of Carbon Offset Credits Generated through NERP for the Medium and High Intensity Scenarios.[1]

	Units[2]	Ecodistrict and Production Intensity					
		791		727		596	
		Medium	High	Medium	High	Medium	High
Offset Credits	tCO_2e/ha/yr	0.109 (0.044)	0.242 (0.098)	0.171 (0.069)	0.389 (0.157)	0.165 (0.067)	0.364 (0.147)
Credit Dollars @ $15 Cap & $10.00 to Farmer[3]	$/ha/yr @ $10.00 tCO_2e	1.09 (0.44)	2.42 (0.98)	1.71 (0.69)	3.89 (1.57)	1.65 (0.67)	3.54 (1.47)
Credit Dollars @ $25 Cap & $16.65 to Farmer	$/ha/yr @ $16.65 tCO_2e	1.82 (0.74)	4.04 (1.63)	2.85 (1.15)	6.48 (2.62)	2.74 (1.11)	6.07 (2.46)
Credit Dollars @ $35 Cap & $23.30 to Farmer	$/ha/yr @ $23.30 tCO_2e	2.53 (1.02)	5.62 (2.28)	3.97 (1.61)	9.02 (3.65)	3.82 (1.55)	8.45 (3.42)
	Offset Credit Revenue on 1000 ha (≈2500 acre) Farm over an 8 Year Project Life[4]						
Credit Dollars @ $15 Cap & $10.00 to Farmer	$ @ $10.00 tCO_2e	$8,728	$19,393	$13,704	$31,116	$13,168	$29,143
Credit Dollars @ $15 Cap & $10.00 to Farmer	$ @ $16.65 tCO_2e	$14,533	$32,289	$22,817	$51,808	$21,925	$48,523
Credit Dollars @ $15 Cap & $10.00 to Farmer	$ @ $23.30 tCO_2e	$20,250	$44,991	$31,793	$72,189	$30,550	$67,612

[1] Values shown are average of canola and wheat.

[2] Values shown in brackets, for example (0.05) are tonnes or dollars per acre per year.

[3] Cap is the price per tonne final emitters can pay to the Emissions Management Fund as an alternative to meeting their targets through operational reductions or offset purchases.

[4] Under the Alberta regulations offset projects can initially run for 8 years.

At present, the price per tonne for offsets in Alberta is effectively capped by the regulator allowing large final emitters that cannot meet their reduction targets to pay $15/tonne into the Emissions Management Fund.[10] Since fund payment is a no risk solution to regulatory compliance, offsets are generally discounted relative to the fund cost. In the calculation shown, we used a price point of $10.00/tonne to the farmer as a starting point.[11] The price to farmers was then increased using the ratio of 0.67:1 as the fund price was raised from $15 to $25 to $35/tonne.

The estimates show that at medium and high intensities the offsets fall in the range of 0.1 to 0.5 tCO_2e/ha/yr and are higher in the ecodistrict representing the more productive black soil zone (727) than in the drier dark brown soil zone (791) or cooler dark gray Peace (596). At the current cap of $15, revenue per acre generated through NERP would likely cover the farms marginal cost of participation in a project such as 4R Plan development and sign-off and improved record keeping but not the cost of agronomic practice changes. The real value of implementing the 4R Plan as part of NERP would come through improved agronomic and economic efficiency of fertilizer, other inputs, equipment, and land. The economic analysis of intensification in this report approximates what those gains might be as a producer moved from low to medium to high intensity production. The higher level of accuracy for farm metrics such as yield required by NERP as well as the high standard for farm records imposed by the verification requirements of the protocol would provide farmers with better data records to use in decision making.

Since the offsets and revenue shown were calculated using the conservative dynamic baseline approach, the question arises how much higher could they be if the 3-year historic baseline approach were used. The answer depends on the level of improvement in nitrogen use efficiency and the consequent improvement in emission intensity (kg N_2O/kg crop) from baseline to project. Without improvement in yield per unit of nitrogen applied the difference between the dynamic and 3-year historic baseline approached would be minimal. With improvement it would increase substantially. The value would be unique for each crop on each farm but can be explored using our scenarios. To illustrate, the value of offset credits over the life of an 8-year project were calculated with nitrogen rates held constant and baseline yields set at 100, 95, and 90% of project yield in the medium and high scenarios (Figure 5.4).

The calculated yield increases baseline to project for the 95 and 90% baselines are 5.3 and 11.1% respectively. The estimated increase in offset credit revenue with these yield improvements ranged from a low of $2,173 to a high of $10,671. The revenue increases were similar in Ecodistricts 727 and 596 and on average 78% higher than the matching case in Ecodistrict 791. Whether the yield increase took place at time of project implementation or was

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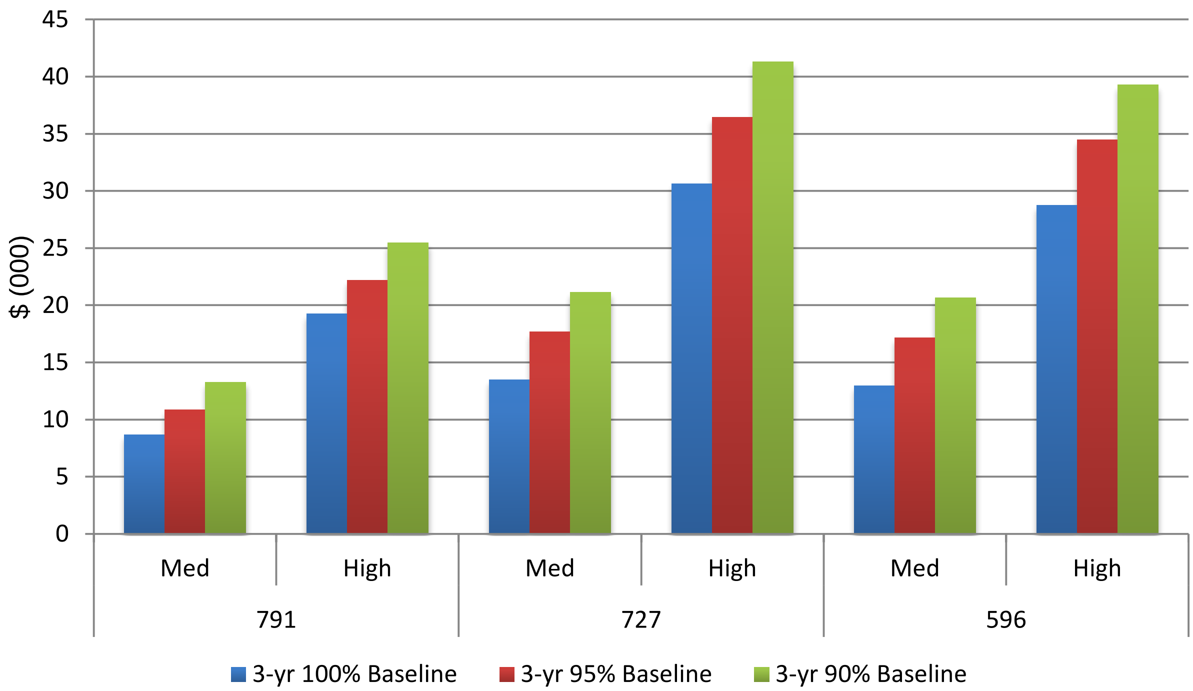
[10] The Emissions Management Fund is administered by the Climate Change and Emissions Management Corporation at arms length from the Alberta Government. Funds collected under the regulations are reinvested in research and development projects aimed at developing new technologies for reducing GHG emissions.

[11] Offset credits are aggregated in large projects that might involve dozens of farms and tens of thousands of hectares before sale to a final emitter. The prices contracted for offsets between farmer and aggregator and aggregator and final emitter are not regulated or reported. Prices to farmers for conservation tillage credits within the same market appear to have ranged from $6 to $12/tonne over the past 5 years.

the average yield increase achieved over the life of the project through annual incremental improvements is immaterial to the nominal revenue values.[12] Although, the nominal value is not affected, the future value would increase substantially if the increase occurred at time of project implementation rather than gradually.

Figure 5.4. Impact of Yield Improvement on Nominal Offset Dollars Generated on a 1000 ha (2500 acre) Farm over 8-year NERP Project.



Production Intensity and Greenhouse Gas Emissions

Estimated greenhouse gas emissions per hectare increased markedly with cropping intensity (Figure 5.5). Proportionally the increases range from 29 to 53% for medium intensity relative to low and from 47 to 83% for high intensity relative to low. The largest source of these increases was nitrous oxide released from the cropping system attributable to incremental fertilizer nitrogen additions followed by the upstream GHGs from the manufacture of the additional fertilizer (Appendix Table A2). The contributions from additional use of chemicals and fuel in the medium and high scenarios relative to the baseline were comparatively minor. Total emissions differed by ecodistrict for the same crop at the same level of intensity. These are mainly attributable to the differences in nitrogen rate and the emission factors used to calculate direct and indirect emissions of nitrous oxide.

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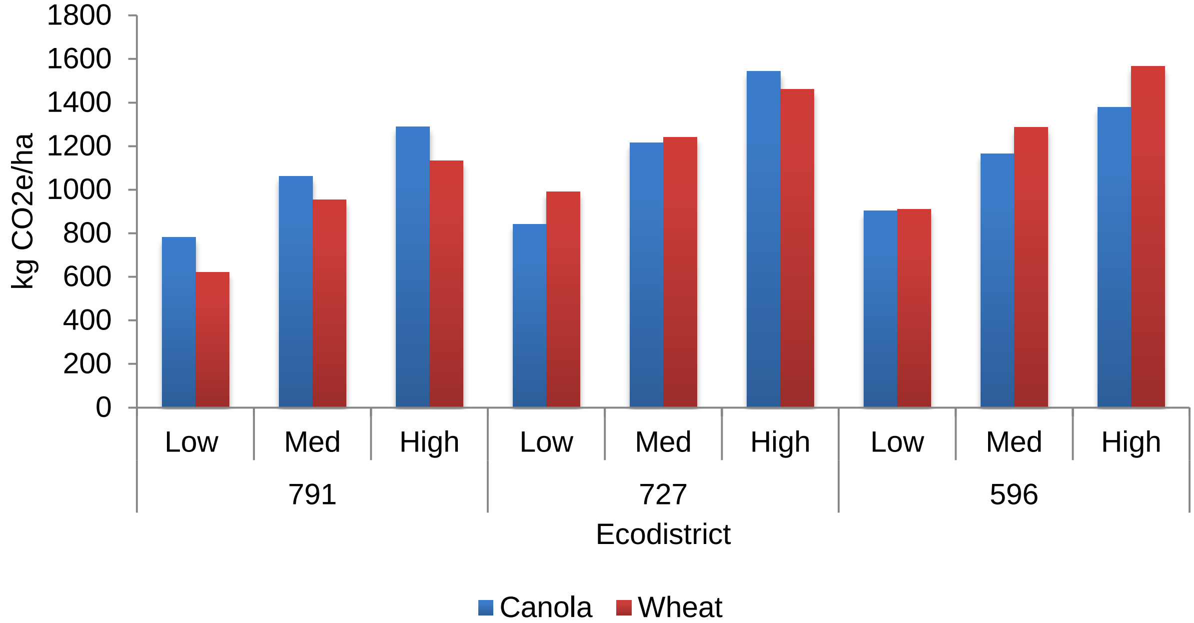
[12] To be clear a 10% average yield increase over an 8-year project would require annual yield increase of approximately 2.1% per year and the yield at project end would be approximately 18% higher than baseline.

Figure 5.5. Emissions at Different Cropping Intensities Area Basis



Comparison among cropping intensities based on yield-based emissions expressed per kilogram of crop produced shows a completely different trend (Figure 5.6). Change in yield-based emissions relative to the baseline scenario varies from a reduction of -11% to an increase of 13%. The dampening of yield-based emissions with increased cropping intensity is in part due to the reduction modifiers used in calculating nitrous oxide emissions for the medium and high scenarios and in part to the increased yield projected for higher intensity. The reduction modifiers incorporate the effect of improved nitrogen management through implementation of 4R, while the increased yields reflect the higher nitrogen rates plus the assumed effects of better weed and disease management.

Since it takes less area to grow equivalent amounts of crop, when emissions are expressed on the basis of the area required to grow the same quantity of canola or wheat produced under the low scenario (equivalent area basis), there is little difference in emissions with intensity or among crops (Figure 5.7). The equivalent areas varied slightly by ecodistrict and crop but averaged out to 0.76 ha to grow the equivalent amount of crop at medium intensity and 0.61 ha under high intensity.

Field operations; such as seeding, in-crop weed control, swathing, and combining; are essentially similar regardless of intensity. It may take more fuel to combine a higher yielding crop but the incremental GHG emissions are small relative to the total emissions for the system and more than compensated for by the increased yield when emissions are expressed per unit of crop produced. Intensity does add additional operations, in our scenarios fungicide and plant growth regulators, but these operations generally involve relatively low emission equipment like

Figure 5.6. Emissions at Different Cropping Intensitities Production Basis

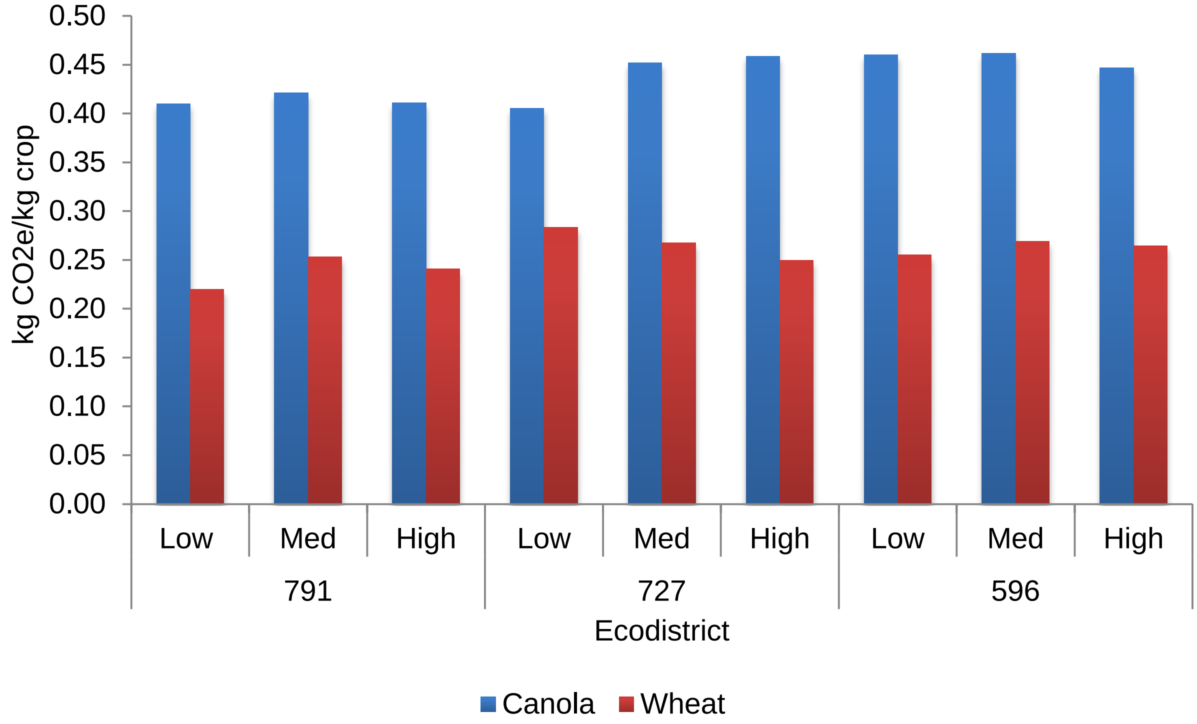
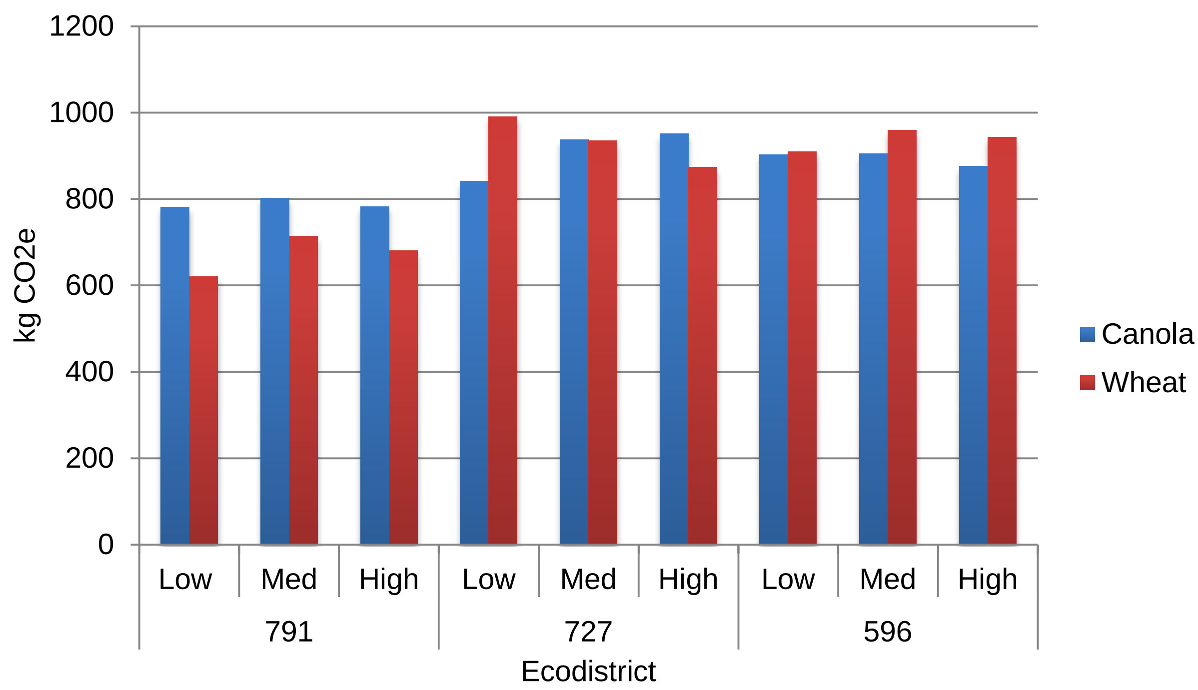


Figure 5.7. Emissions from Producing Equal Quantities of Crop Under Different Intensities



high clearance sprayers. Approaches like enhanced crop protection that maintain yield close to its full potential with only minor concomitant increases in GHGs tend to minimize yield-based emissions in intensive management systems. To be fully effective economically and minimally damaging to the environment, crop protection practices need be incorporated within integrated pest management systems (IPM). There is considerable opportunity for synergy between 4R and IPM in developing cropping systems with high yield and low GHG emission intensity.

While some of the leveling out among scenarios comes from equipment travelling over less hectares to produce the same amount of crop, it is the nitrogen applications that have the major dampening effect on GHG emissions. Using wheat for an example, the average nitrogen rate at low, medium and high scenarios were 61, 105, and 142 kg N/ha. When adjusted on an equivalent area basis quantity of nitrogen applied remains at 61 for the low intensity scenario but drops to 79 and 85 on average under the medium and high intensity scenarios. There is a decrease in the nitrous oxide quantities proportional to the reduction in the land footprint when equivalent areas are compared.

The emission values obtained are a result of the assumptions, crop input and yield values used in setting up the scenarios, consequently different assumptions or field derived input data for nitrogen use and yield would result in somewhat different results. One of our assumptions was to use yields associated with normal moisture conditions. Below normal moisture would have a significant depressing effect on yield particularly in the dark brown soil zone containing Ecodistrict 791 where the moisture deficit tends to be greater. Similarly above normal moisture would tend to increase yields more in the dark brown soil zone than in black or dark gray zones containing ecodistricts 727 and 596. Available moisture poses a significant limit to intensification and inter-year variability likely imposes greater risk in drier areas.

The values obtained are estimates of the marginal change in emissions associated with intensifying production. The scenarios while synthetic rather than based on a comprehensive experimentally derived data set are reasonable and the outcomes illustrative of likely trends in field situations. In that sense, the increased emission per hectare with increased intensity comes as no surprise. Perhaps more surprising was the much smaller differences among cropping intensities when the comparison is made on a GHG emissions per kilogram crop produced or equivalent area basis. That the intensity of emissions did not necessarily increase with higher levels of inputs is reflective of the field research on the mitigating effects of BMPs reviewed in Section 4. This suggest that when intelligently pursued intensification of cropping systems can be relatively neutral or beneficial in terms of GHGs and the total food supply. This will become particularly apparent in the next section when the GHG footprint of the alternative to intensification, bringing more land into cereal and oilseed production, is examined.

Greenhouse Gas Emissions Associated with Land Use Change

Globally demand for crop products is rising and will continue to rise in response to population growth. Increased production to meet this demand has the potential to place considerable additional strain on the environment. Increased primary production is not the entire solution to rising demand. For example, Foley (2014) recently suggested five steps necessary to increase food supply while reducing environmental impacts. They included no further expansion of agriculture land, shifting diets away from animal protein, reducing food waste, more efficient resource use, and intensification. Although a comprehensive approach can reduce, it cannot eliminate the need for increasing primary production. Increasing total crop production will be a major factor in meeting human food requirements.

The alternative to increasing total crop production through intensification is by increasing the area under cultivation. Whether considered locally or globally, extending the cropping area brings land into production that may be better suited for other uses and typically reduces or eliminates the ecological goods and services provided by the converted land. These services include sequestration and storage of atmospheric carbon through the uptake of carbon dioxide. Conversion of natural areas or perennial crops to arable agriculture can result in significant release of carbon dioxide and other GHGs and turns lands that are currently sinks into sources.

In the scenarios used in this study, up to one third more land area was required to grow an equivalent amount of canola or wheat under low compared to medium intensity systems and up to two thirds more under low compared to high intensity (Table 5.7). In Alberta, there are two

Table 5.7. Area Required to Grow Equivalent Amount of Grain at Different Intensities

Crop	Ecodistrict	Low/Low	Low/Medium	Medium/High	Low/High
		hectares			
Canola	791	1	1.32	1.24	1.65
	727	1	1.32	1.25	1.62
	596	1	1.32	1.22	1.57
Wheat	791	1	1.33	1.25	1.67
	727	1	1.33	1.26	1.67
	596	1	1.33	1.24	1.67

sources of additional land for annual crop production. One is conversion of seeded forage land to annual cropping either through reducing the perennial component of crop rotations or changing land that was used exclusively for perennial crop production to exclusively annuals. The other is the conversion of native grassland, forest or wetland to annual crops through cultivation, clearing, and drainage. Development of any new annual or cropland through conversion of natural lands can result in significant transitional releases of GHGs. The objective of this section is to examine the relative GHG emissions when natural land is converted relative to intensification on existing cropland.

Conversion of natural lands for arable agriculture in Alberta initially involved plowing under native grasslands in the prairie ecozone and clearing of aspen parkland and boreal forest in the boreal plain ecozone. Subsequent conversions have included draining wetlands and removal of woodlots considered obstacles within existing arable parcels. High grain and oilseed prices relative to the value of forage for cattle has driven more recent trends in conversion of hay and pasture lands for annual crops. These practices continue as well as the clearing of aspen parkland and boreal forests for agriculture in Northern Alberta.

Land use change from native vegetation to annual crops can result in large losses of soil organic carbon. Guo and Gifford (2002) performed a meta analysis of research projects where changes in soil carbon stocks were measured with land use changes. They found that on average soil carbon stocks declined with conversion of native forest or grassland to crop by 42% and 59% respectively. Much of the soil carbon loss is through increase carbon respiration and release as carbon dioxide although erosion can also be a significant factor. Forested land, whether in plantation or natural forest, tend to be net sinks of GHGs (Goodale et al. 2002; Luyssaert et al. 2008). For example, Robertson et al. (2000) reported that hybrid poplar plantations in Michigan had net negative emissions of 1050 kg CO_2e/ha/yr.

Stinson et al. (2011) estimated that forests in the semiarid prairie, subhumid prairies, and boreal plain contain approximately 150, 200, and 220 Mg C/ha with about half of the total carbon above ground. While clearing practices vary in Alberta, bulldozing trees and brush into windrows and burning the windrows is still common. Even with incomplete combustion (charcoal formation can be high as 40% of the original carbon), the oxidation of half of the above ground carbon to carbon dioxide would likely result in GHG emissions in excess of 135 tCO2e/ha for all forest types. Harvesting the useable above ground biomass, depending on end use of the harvested biomass, would change the net GHG balance but still result in substantial direct emissions if the residual slash were then burned on-site. Putting the above ground debris or slash following forest harvest at 25-50% of total pre-harvest material, burning the slash on-site would results in approximate direct emissions in the range of 20 to 60 tCO_2e/ha depending on the initial density of carbon present above ground. These values are one to two orders of magnitude higher than the values estimated for high intensity cropping systems in the last section but are still much lower than those used in Canada's national GHG inventory estimates that set forest conversions release at approximately 360 tCO2e/ha. However, that figure accounts for all conversions not just conversions to agriculture (National Inventory Report 1990–2011: Greenhouse Gas Sources and Sinks in Canada, Part 1).

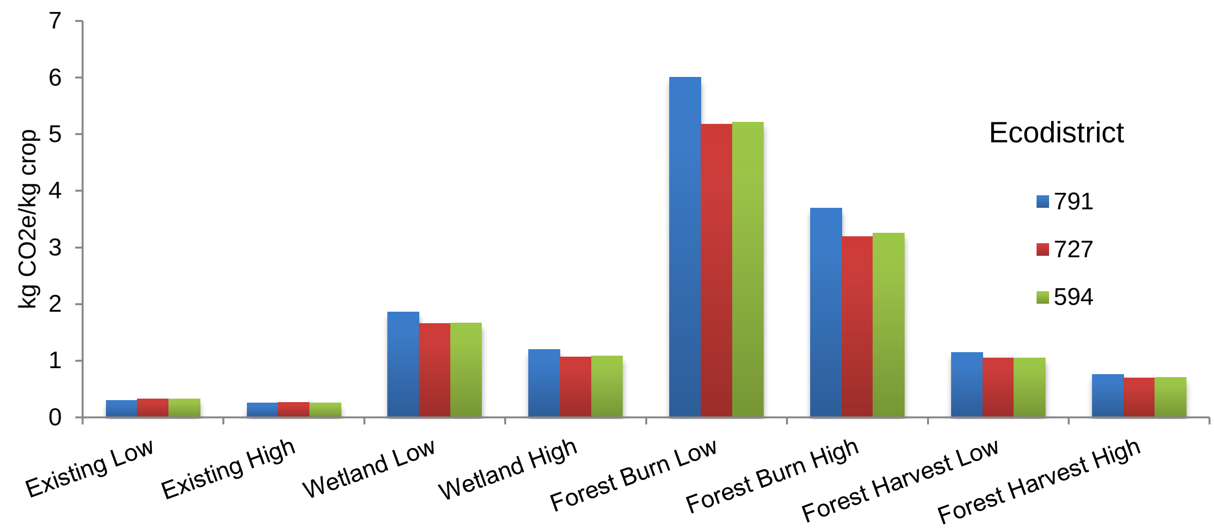
Conversion of wetlands to croplands also results in change from a net sink to a net source as the soil carbon that has accumulated during development is exposed to air and mineralized. Euliss et al. (2006) estimated that wetland conversion in the prairie pothole region of North America has resulted in an average carbon loss of 10.1 Mg C/ha on over 16 million hectares of wetlands. This would be equivalent to as much as 37.1 tCO_2e/ha if the average carbon loss was converted to carbon dioxide. Soil carbon losses through wetland conversion approaching 90 Mg C/ha were estimated by Bedard-Haaughn et al. (2006) and Badiou et al. (2011). Losses of this magnitude through oxidation to carbon dioxide once the soil carbon is exposed to air would result in emissions in excess of 300 tCO_2e/ha. While wetlands can sequester carbon they also release nitrous oxide and methane, so net effect on GHGs for any individual wetland can be variable depending on water chemistry, pond hydrology, landscape position, climate, and vegetation (Philips and Berri, 2008; Pennock et al. 2010). Bridgham et al. (2006) in reviewing the literature on wetland emissions concluded that although uncertainty was high, freshwater mineral soil wetlands (the type commonly found on agricultural lands in Alberta) were likely net sinks for GHGs. Other author's have been more positive in their assessment of wetland maintenance and/or restoration as a GHG mitigation strategy. Badiou et al. (2011) estimated that restored wetlands in the prairie pothole region of Canada could sequester carbon at a rate of approximately 9.9 tCO_2e/ha/yr with a net sink effect of 3.25 tCO_2e/ha/yr after accounting for methane and nitrous oxide emissions. Wetlands in the prairie pothole region also provide many other ecological goods and services such as water filtering, flood mitigation, biodiversity, wildlife habitat, and recreation (Gleason et al. 2008).

The conversion of tame hay or pasture or grassland into cropland under conventional tillage results in soil carbon loss and increased carbon dioxide emissions. Forage production tends to sequester up to twice as much carbon as no till (see Hutchinson et al. 2007 for a review). Whether the effect is one of reduced sequestration rather than net loss of soil carbon when a forage system is converted to zero tillage, conversion results in higher emissions. Gelfand et al. (2011) estimated the GHG balance immediately following conversion of Conservation Reserve Grasslands in the states to corn or corn- soybean rotations for bioenergy production. The carbon debt from conversion, which included the net reduction in sequestration potential, was estimated at 68 tCO_2e/ha for conversion to no-till corn and 222 tCO_2e/ha for conversion to conventional tillage corn. The payback period representing the time required for net credits for biofuel displacement of fossil fuel from the corn equaled the GHGs released on conversion was 40 years for no-till and 123 years for conventional till.

While conversion to annual crop will reduce net sequestration, it should be remembered that forage crops and grasslands are primarily used for ruminant livestock production. Beef production systems in Alberta, have net GHG emissions in the range of 13 kg CO_2e/kg beef on a live weight basis (Beauchemin et al. 2010). In contrast, a recent life cycle analysis found that GHG emissions for Alberta produced canola varied from 0.259 to 0.409 kg CO_2e/kg canola (Canola Council of Canada, 2014). Forage land is an important sink for atmospheric carbon but the life cycle of the production system needs to be considered when deciding if maintaining forage land is a GHG mitigation strategy.

Land conversion of grasslands, forests, and wetlands to annual crops results in considerable short-term release of GHGs through carbon oxidation associated with change processes. On an on-going basis what was once a sink for GHGs becomes a source. These short-term emissions due to land conversions tip the balance strongly in favor of intensification as a strategy for maintaining low emissions per kilogram of crop produced. To illustrate, GHG emissions per kilogram of crop produced at low and high intensity cropping scenarios are shown with the GHGs from various conversion included (Figure 5.8). The quantity of additional direct emissions was set at 37, 135, and 20 tCO_2e/ha for wetland conversion, forest conversion with on site disposal of the trees, and forest conversion with tree harvest with low residuals to be disposed of on site respectively. The additional GHG emissions from conversion were averaged over 10 years of subsequent canola and wheat production from our low and high intensity scenarios.

Figure 5.8. Emission Projections on Converted Land at Different Cropping Intensities.



These projections used fairly modest values for the GHG release with land conversion and don't take into account the loss of ongoing sequestration if the land was left in its natural state. Several trends stand out. First, the order of magnitude difference between projected emission intensity on existing compared to converted land. Second, low intensity production on converted land results in a higher intensity per kilogram of crop produced than high intensity production. This latter observation points out that converting land for low intensity cropping is an extremely poor strategy in relation to minimizing GHGs per unit of crop produced.

Observations on Greenhouse Gas Findings

In our scenarios, GHG emissions per hectare increased substantially with cropping intensity while emissions per kilogram crop produced were similar at the different levels. The substantial dampening of the increase in the medium and high intensity scenarios resulted from application of the reduction modifiers from NERP. These modifiers are conservative estimates of the impact of integrated 4R practices on GHG emissions.

Use of other agronomic practices that increase or preserve yield; such as superior genetics, increased seeding rates, improved weed control, and disease management with fungicide; add little to GHG emissions per hectare while substantially dropping the GHG emissions per kilogram of crop. There are issues with agriculture chemical use that must be addressed going forward but their impact on GHG intensity is typically positive.

Reducing inputs, in particular nitrogen fertilizer, can reduce emissions per hectare. However, if the end result is simply extension of acreage, there has been little or no gain in terms of emissions per unit of production. Extension of area will invariably involve conversion of lands from grassland, wetland or forest, which will result in a substantial release of GHGs and the loss of net sequestration capability as well as the other ecological goods and services provided by natural ecosystems. Whether the extension occurs in Canada or elsewhere is immaterial. An intelligent approach to intensifying crop-based agriculture needs to be enacted globally using all the tools in the toolbox. The 4R approach can provide the global framework for nutrient stewardship that increases productivity per hectare while minimizing GHG emission intensity per kg of crop produced.

5.6 Economics of Intensification in Alberta

As identified above, the intensification scenarios broadly involve higher rates of input use (fertilizer, seed, crop protection products) as well as additional passes over the field. On this basis, intensification creates additional costs. At the same time, intensification can significantly increase yields and thus revenues. The purpose of this section is to provide an evaluation of these costs and benefits from intensification.

The procedure for the economic analysis follows that employed in Mussell and Heaney (2013). The per acre agronomic costs (inputs and application) are calculated under the baseline and intensification scenarios. These are then combined with revenues under the alternative scenarios to give a per acre margin (revenue less agronomic costs). This approach focuses on the differences between the scenarios, rather than on total of production costs, including elements that do not vary according to intensification scenarios, such as machinery depreciation and interest expenses.

5.6.1 Data

In order to estimate costs and returns under the baseline and intensification scenarios, data on fertilizer prices were obtained from Alberta Agriculture, Food and Rural Development (AFRD)[13]. These were the following:

- Mono-Ammonium Phosphate (11-52-0), 2010-2013 monthly average price ($715/tonne),
- Urea (46-0-0), 2010-2013 monthly average price ($591/tonne).

Other values were assumed based on industry information:

- Ammonium Sulphate (21-0-0-24) priced at $425/tonne,

Data on custom rates were also obtained from AAFRD[14]. These were generally presented as a range, and the approximate midpoint of the range was used.

- Double depth soil testing, complete nutrient analysis $160/field (interpreted as $1/acre)
- Spraying costs at about $7/acre (observed range was $3.25/acre to over $9/acre)

Advanced soil testing with VRT map building was assumed at $8/acre based on industry information.

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[13] http://www.agric.gov.ab.ca/app21/rtw/surveyprices/graph.jsp?groupId=5&dataId=39

[14] http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/inf14269

Estimated costs of pesticide products used in the baseline and intensification scenarios were obtained from industry sources. These are presented in Table 5.8 below. Where possible, product prices for individual products were obtained; in other cases the combined product costs of common tank mixes were estimated. The costs in the table do not include application costs.

Table 5.8 Crop Protection Product Cost/Pricing Assumptions

Chemical Name	**Trade Name**	**Estimated Product Cost/litre**	**Product Cost/acre at recommended rate**
Glyphosate 360 g/L	Roundup	5.4	2.7*
Glufosinate ammonium	Liberty	7.7	8.47
Glyphosate+ Carfentrazone	CleanStart	14.7	7.35
Clethodim + Penflufen + Trifloxystrobin+ Metalaxyl	Prosper EverGol	158	9.95
Prothioconazole	Proline	162	22.71
Clethodim	Centurion	158	3.95
Florasulam	PrePass	13.04	6.6
2,4-D		12.5	3.75
Pyraclostrobin	Headline	108	25.93
tebuconazole	Prosaro	55.78	17.85
ethephon	Etherel	20	8
Clodinafop+propargyl,Bromoxynil + MCPA tank mix	Horizon + Buctril M tank mix		15
thiencarbazone-methy+Pyrasulfotole+Bromoxynil	Velocity M3		27
Florasulam + clopyralid+ MCPA, Pinoxaden tank mix	Spectrum + Axial tank mix		35

* .5 L/acre rate

Alberta prices for canola and wheat were obtained from AAFRD[15]. For canola, an average of Alberta daily price quotes delivered to crusher from January 2012 to late March 2014 were used to develop a price reference. For canola, the price quote delivered to a crusher was used. Alberta-basis wheat price quotes were not available for the same period. Instead, #1/2 Canada Western Red Spring Wheat quotes were obtained from AAFRD for the first week of the months of March 2013, June 2013, September 2013, December 2013 and March 2014 and averaged.

5.6.2 Results

To evaluate the intensification scenarios relative to the baseline, the agronomic costs associated with the alternative fertilizer management scenarios were computed and compared

[15] http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sdd6248

with the associated revenue, given the specifics of the scenarios described above and presented in Appendix A. Based upon this, the margin over fertility cost (fertilizer ingredients plus application/agronomy cost) was calculated.

To do so the basic nutrient requirements were obtained from the scenarios and the fertilizer costs were calculated by balancing the requirements for P_2O_5 with mono-ammonium phosphate (MAP) and requirements for sulfur with Ammonium Sulfate. The nitrogen content of these ingredients were credited against nitrogen requirements, and the remaining residual nitrogen requirements provided by urea. Based on the per acre requirements of these fertilizer ingredients and the prices of fertilizer ingredients, the implied costs of fertilizer per acre were calculated. This is illustrated below in Table 5.9. Under the "Low" intensity or baseline scenario, fertilizer costs range between about $45 and $54/acre for canola, and between $39 and $50/acre for wheat. Under increased intensification, nitrogen use rates increase up to about 145 lbs/acre for both canola and wheat, increasing fertilizer costs up to over $100/acre.

Table 5.9 Fertilizer Use and Cost by Region, Scenario

		11-52-0 amount (Lbs/acre)	21-0-0-24 amount (lbs/acre)	Actual N amount (lbs/acre)	11-52-0 Cost ($/acre)	21-0-0-24 cost ($/acre)	46-0-0 Cost ($/acre)	Total Fertilizer Ingredient Cost ($/acre)
Canola								
Risk Area 2-ED791	Low	38	83	65	12.32	16.00	25.30	53.62
	Medium	48	104	106	15.57	20.05	46.00	81.61
	High	48	125	145	15.57	24.09	66.17	105.83
Risk Area 11-ED727	Low	38	83	50	12.32	16.00	16.55	44.88
	Medium	48	104	93	15.57	20.05	38.42	74.03
	High	48	125	138	15.57	24.09	62.09	101.75
Risk Area 19-ED596	Low	38	83	65	12.32	16.00	25.30	53.62
	Medium	48	104	101	15.57	20.05	43.08	78.69
	High	48	125	136	15.57	24.09	60.92	100.58
Wheat								
Risk Area 2-ED791	Low	38	41.67	44.00	12.47	8.03	18.09	38.59
	Medium	48	62.50	87.00	15.59	12.05	39.99	67.63
	High	58	62.50	115.00	18.71	12.05	55.71	86.46
Risk Area 11-ED727	Low	48	41.67	60.00	15.59	8.03	26.80	50.43
	Medium	38	62.50	90.00	12.47	12.05	42.36	66.88
	High	67	62.50	120.00	21.83	12.05	58.00	91.88
Risk Area 19-ED596	Low	48	41.67	60	15.59	8.03	26.80	50.43
	Medium	38	62.50	105	12.47	12.05	51.11	75.63
	High	67	62.50	145	21.83	12.05	72.58	106.46

The above costs are exclusive of application, soil testing/analysis, and variable rate technology. Under the baseline or low scenario, nitrogen application is broadcast with phosphorus applied at seeding; in the intensification scenarios all fertilizer application is banded at seeding. Soil testing occurs under both of the intensification scenarios. Variable rate technology is applied under the high intensity scenario.

In order to accommodate this increased fertilizer use and intensity of yields, crop management and protection must adjust. A summary of seed and crop protection adjustments and associated costs is presented in Table 5.10 below. The table shows that seed and crop protection costs are initially (Low intensity scenario) about $87/acre for canola and about $58/acre for wheat. Under more intensive management these increase to about $131/acre for canola and up to $170/acre for wheat.

The output of the above is summarized in terms of total costs, yield, price, revenue, and margin over agronomic costs. This is illustrated in Table 5.11 below. The table shows that total agronomic costs increase significantly with the intensification scenarios. Moving from the baseline (low) scenario, total costs increase in the range of 50% for both canola and wheat under the medium intensification scenario, and the costs for wheat under the high intensification scenario more than double. However, revenues under increased yields with intensification more than offset the increases in costs. Across the board, the highest intensity scenarios gave the highest returns per acre. This was especially the case for canola, but was also the case for wheat.

5.6.3 Sensitivity to Nitrogen Costs

In the spring of 2014, nitrogen fertilizer prices in Alberta have increased. For example, according to Alberta Agriculture urea prices have increased to around $700/tonne, and industry sources suggest ammonium sulphate prices have increased to around $530/tonne. This increases have occurred without a concomitant increase in canola or wheat prices.

To test the impact of higher nitrogen fertilizer prices, the fertilizer pricing assumptions described above were altered to increase urea pricing up to $700/tonne and ammonium sulphate prices up to $530/tonne. All other parameters were held constant.

The results are summarized in Table 5.12 below. Not surprisingly, agronomy costs increase and margins over agronomy costs decrease under higher nitrogen fertilizer prices. The effect on costs per acre is greatest for the high intensity scenarios, since these employ the highest levels of nitrogen fertilizer use. Thus, the higher fertilizer prices decrease the profitability advantage of the intensification scenarios. However, these fertilizer price increases do not influence the profitability rankings of the intensification scenarios; the high intensity scenarios are still the most profitable, followed by the medium intensity scenario, followed by the low (baseline) scenario.

Table 5.10 Seed and Crop Protection Profile by Region, Scenario

		Seed Variety	Seed Rate lbs/ac	Seed Treatment	Seed and seed treatment Cost $/acre	Pre-plant burndown	Pre-plant burndown cost $/acre	In-crop Herbicide	In-crop Herbicide cost $/acre	Growth regulator	Fungicide App 1	Fungicide App 2	Fungicide/Growth Regulator cost $/acre	Post crop burndown	Burndown cost $/acre	Total Seed and Crop Protection
								Canola								
Risk Area 2-ED791	Low	L130	5	Prosper Everglo	58.25	Glyphosate .5L/acre	9.7	Liberty + Centuric	19.42							87.37
	Medium	L130	5	Prosper Everglo	58.25	CleanStart	14.35	Liberty + Centuric	19.42		Proline		29.71	Glyphosate 360	9.70	131.43
	High	L130	5	Prosper Everglo	58.25	CleanStart	14.35	Liberty + Centuric	19.42		Proline		29.71	Glyphosate 360	9.70	131.43
Risk Area 11-ED727	Low	L130	5	Prosper Everglo	58.25	Glyphosate .5L/acre	9.7	Liberty+Centurior	19.42							87.37
	Medium	L130	5	Prosper Everglo	58.25	CleanStart	14.35	Liberty+Centurior	19.42		Proline		29.71	Glyphosate 360	9.70	131.43
	High	L130	5	Prosper Everglo	58.25	CleanStart	14.35	Liberty+Centurior	19.42		Proline		29.71	Glyphosate 360	9.70	131.43
Risk Area 19-ED596	Low	L130	5	Prosper Everglo	58.25	Glyphosate .5L/acre	9.7	Liberty+Centurior	19.42							87.37
	Medium	L130	5	Prosper Everglo	58.25	CleanStart	14.35	Liberty+Centurior	19.42		Proline		29.71	Glyphosate 360	9.70	131.43
	High	L130	5	Prosper Everglo	58.25	CleanStart	14.35	Liberty+Centurior	19.42		Proline		29.71	Glyphosate 360	9.70	131.43
								Wheat								
Risk Area 2-ED791	Low	AC Harvest	86	Rancona	15.394	Glyphosate (0.5 L/acre)	9.7	Horizon+Buctril	22.00					2,4-D	10.75	57.84
	Medium	AC Harvest	108	CruiserMax cereals	19.332	Glyphosate (1 L/acre)	12.4	Velocity M3	34.00		Headline (0.24L/ac)		32.92	Glyphosate (1 L/acre)	12.40	111.05
	High	CDC Go	162	CruiserMax cereals	28.998	PrePass	13.5208	Spectrum + Axial	42.00	Ethrel (0.4 L/acre)	Headline (0.24L/ac)	Prosaro (0.32L/ac)	65.77	PrePass	20.04	170.33
Risk Area 11-ED727	Low	AC Harvest	86	Rancona	15.394	Glyphosate (0.5 L/acre)	9.7	Horizon+Buctril M	22.00					2,4-D	10.75	57.84
	Medium	AC Harvest	108	CruiserMax cereals	19.332	Glyphosate 1 L/acre	12.4	Velocity M3	34.00		Headline (0.24L/ac)		32.92	Glyphosate (1 L/acre)	12.40	111.05
	High	CDC Go	162	CruiserMax cereals	28.998	PrePass	13.5208	Spectrum + Axial	42.00	Ethrel (0.4 L/acre)	Headline (0.24L/ac)	Prosaro (0.32L/ac)	65.77	PrePass	20.04	170.33
Risk Area 19-ED596	Low	AC Harvest	86	Rancona	15.394	Glyphosate (0.5 L/acre)	9.7	Horizon+Buctril M	22.00					2,4-D	10.75	57.84
	Medium	AC Harvest	108	CruiserMax cereals	19.332	Glyphosate	12.4	Velocity M3	34.00		Headline (0.24L/ac)		32.92	Glyphosate (1 L/acre)	12.40	111.05
	High	CDC Go	162	CruiserMax cereals	28.998	PrePass	13.5208	Spectrum + Axial	42.00	Ethrel (0.4 L/acre)	Headline (0.24L/ac)	Prosaro (0.32L/ac)	65.77	PrePass	20.04	170.33

Table 5.11 Cost, Revenues, and Margins by Intensification Scenarios

		Canola				Wheat					
		Yield (bu/acre)	**Price ($/bushel)**	**Agronomy Cost ($/acre)**	**Revenue ($/acre)**	**Margin ($/acre)**	**Yield (bu/acre)**	**Price ($/bushel**	**Agronomy Cost ($/acre)**	**Revenue ($/acre)**	**Margin ($/acre)**
Risk Area 2-ED791	Baseline	34	12.61	148.99	428.64	279.64	42	6.48	104.44	272.06	167.62
	Medium	45	12.61	214.04	567.31	353.27	56	6.48	179.69	362.75	183.06
	High	56	12.61	246.26	705.99	459.73	70	6.48	265.79	453.43	187.64
Risk Area 11-ED727	Baseline	37	12.61	140.25	466.46	326.21	52	6.48	116.27	336.84	220.57
	Medium	48	12.61	206.46	605.14	398.68	69	6.48	178.93	446.95	268.02
	High	60	12.61	242.18	756.42	514.24	87	6.48	271.21	563.55	292.34
Risk Area 19-EC	Baseline	35	12.61	148.99	441.24	292.25	53	6.48	116.27	343.31	227.04
	Medium	45	12.61	211.12	567.31	356.19	71	6.48	187.68	459.91	272.23
	High	55	12.61	241.01	693.38	452.37	88	6.48	285.79	570.03	284.24

Table 5.12 Cost, Revenues, and Margins Under Higher Nitrogen Fertilizer Prices

		Canola					Wheat				
		Yield (bu/acre)	Price ($/bushel)	Agronomy Cost ($/acre)	Revenue ($/acre)	Margin ($/acre)	Yield (bu/acre)	Price ($/bushel	Agronomy Cost ($/acre)	Revenue ($/acre)	Margin ($/acre)
Risk Area 2-ED791	Baseline	34	12.61	157.59	428.64	271.05	42	6.48	109.74	272.06	162.32
	Medium	45	12.61	227.43	567.31	339.88	56	6.48	190.00	362.75	172.74
	High	56	12.61	264.35	705.99	441.64	70	6.48	278.99	453.43	174.44
Risk Area 11-ED727	Baseline	37	12.61	147.24	466.46	319.22	52	6.48	123.17	336.84	213.66
	Medium	48	12.61	218.46	605.14	386.67	69	6.48	189.68	446.95	257.27
	High	60	12.61	259.52	756.42	496.90	87	6.48	284.83	563.55	278.72
Risk Area 19-ED596	Baseline	35	12.61	157.59	441.24	283.65	53	6.48	123.17	343.31	220.14
	Medium	45	12.61	223.98	567.31	343.33	71	6.48	200.04	459.91	259.87
	High	55	12.61	258.14	693.38	435.24	88	6.48	302.08	570.03	267.94

6 Conclusions

Agricultural land use in Alberta has evolved over time on a path toward increasing intensification and away from growth through extensive land use. This is consistent with a world in which land in increasingly scarce, increasingly expensive to convert from alternative uses, and one in which maintaining pristine lands for services such as wildlife habitat, groundwater recharge, and carbon sequestration are seen as increasingly valuable. Within this context there is a recognition that demands for farm products and food are growing, and that increasing food prices amounts to the most regressive form of tax.

This study shows that there is significant further prospect for intensification in agricultural land use to increase output. In a world in which demand forms the binding constraint, the literature finds that intensive management is more clearly sustainable (in terms of greenhouse gases, nutrient application etc) on a unit output basis than extensive management. The reality of a strong demand and limited land base thus suggests that intensification of existing agricultural land is more sustainable than converting land from other uses to agricultural production as a means of increasing output.

Evidence in Alberta exists of significant potential to increase wheat and canola yields through augmented fertility management, coupled with broader changes in seeding and crop protection practices. The increases in yields envisioned are significant, and range well over 50% compared with baseline yields. This, in turn, will require effective management of inputs at higher levels of use compared with existing systems.

This study has provided, in effect, an analysis of the feasibility on increasing output of canola and wheat in Alberta based on more intensive management, from both an environmental and economic perspective. The results show that the intensification scenarios result in little change in nitrous oxide emissions on a unit output basis; when the equivalent alternative means of increasing output by expanding the land base is considered, the intensification scenarios result in a significant benefit.

Intensification also provides significant economic benefits to adopting producers. While the costs of production are much higher on an area basis under intensification, the increased yields and revenue appear to more than offset these increased costs. The implication is for significantly increased profitability for adopting producers.

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8 Appendix A

Table A1. Emission Factors Used in Estimating net GHGs from Cropping Scenarios.

Inputs	Emission Factor	Units	Source
Seed	0.7337	kg CO_2e/kg	Biograce
Urea	3.31	kg CO_2e/kg N	Ecoinvent
Ammonium Sulfate	2.87	kg CO_2e/kg N	GHGenius
Monoammonium Phosphate	1.29	kg CO_2e/kg P_20_5	Ecoinvent
Pesticides	10.16	kg CO_2e/kg a.i.	Ecoinvent
Diesel	2.86	kg CO_2e/L	NERP Appendix Table G1

Table A2. Seed and Crop Protection Inputs for Canola Scenarios of Different Intensities.

Intensity	Seed	Herbicide	Foliar Fungicide
Low	Invigour L130, Liberty Link Hybrid Canola treated with 0.64 L/100 lb/seed Prosper Everglo.[1] Direct seeded at a rate of 5 lbs/acre. Cost: $56.25/acre	0.5 L/ac glyphosate[2] prior to seeding, 1.1 L/ac glufosinate ammonium and 25 mL/ac clethodim in crop. Cost: $15.12/ac	Not included
Med		0.5 L/ac glyphosate and 15 mL/ac carfentrazone-ethyl prior to seeding, 1.1 L/ac glufosinate ammonium and 25 mL/ac clethodim in crop, 1 L/ac glyphosate post harvest. Cost: $25.17/acre	128 mL/ac prothiaconazole at full bloom. Cost: $22.71/acre
High		0.5 L/ac glyphosate and 15 mL/ac carfentrazone-ethyl prior to seeding, 1.1 L/ac glufosinate ammonium and 25 mL/ac clethodim in crop, 1 L/ac glyphosate post harvest. Cost: $25.17/acre	128 mL/ac prothiaconazole at full bloom. Cost: $22.71

[1] Propser Everglo manufactured by Bayer Crop Science is the current standard fungicide and insecticide seed treatment for Bayer's Invigour line of canola. It contains the active ingredients clothianidin 290 g/L, penflufen 10.7 g/L, trifloxystrobin 7.15 g/L, and metalaxyl 7.15 g/L.

[2] Glyphosate rate based on 360 g/L acid equivalent formulation.

Table A3. Seed and Crop Protection Inputs for Wheat Scenarios of Different Intensities.

Intensity	Seed	Herbicide	Foliar Fungicide	PGR
Low	AC Harvest CWRS treated with tebuconazole and metalaxyl at recommended rates. Seeded at 86 lbs/acre (20 plants/ft^2). Cost: $18.10/acre	0.5 L/ac glyphosate[1] prior to seeding, off-patent wild oat and broadleaf control in crop, 0.3 L/ac 2,4-D post harvest. Cost: $21.45/ac	Not included	Not included
Med	AC Harvest CWRS treated with tebuconazole and metalaxyl at recommended rates. Seeded at 108 lbs/acre (25 plants/ft^2). Cost: $22.75/acre	1 L/ac glyphosate prior to seeding, patent wild oat and broader spectrum broadleaf control in crop, 1 L/ac glyphosate post harvest. Cost: $37.80/acre	240 mL/ac pyraclostrobin at flag leaf. Cost: $25.92/acre	Not included
High	CDC Gro CWRS treated with tebuconazole and metalaxyl at recommended rates. Seeded at 140 lbs/acre (30 plants/ft^2). Cost: $30.30/acre	0.5 L/ac glyphosate and 40 mL/ac florasulam prior to seeding, patent wild oat and broader spectrum broadleaf control in crop, 0.5 L/ac glyphosate 40 mL/ac florasulam post harvest. Cost: $48.20/acre	240 mL/ac pyraclostrobin at flag leaf and 320 mL/ac prothioconazole plus tebuconazole at head emergence. Cost: $43.77/acre	0.4 L/ac ethephon at early flag. Cost: $8.00/acre
[1] Glyphosate rate based on 360 g/L acid equivalent formulation.				

Table A4. Yield and Fertilizer Inputs for Scenarios of Different Intensities.[1,2,3]

	Ecodistrict 791				Ecodistrict 727				Ecodistrict 591			
	Yield	N	P_2O_5	S[3]	Yield	N	P_2O_5	S	Yield	N	P_2O_5	S
	bu/acre	*lbs/acre*			*bu/acre*	*lbs/acre*			*bu/acre*	*lbs/acre*		
Canola												
Low	34	65	20	20	37	50	20	20	35	65	20	20
Med	45	106	25	25	48	93	25	25	45	101	25	25
High	56	145	25	30	60	138	25	30	55	136	25	30
Wheat												
Low	42	44	20	--	52	60	25	--	53	60	25	10
Med	56	87	25	--	69	90	30	--	71	105	30	15
High	70	115	30	--	87	120	35	--	88	145	35	15

[1] Fertilizer sources were urea, monoammonium phosphate, and ammonium sulphate.
[2] Nitrogen and sulphur broadcast in spring before seeding in low intensity scenario and midrow banded at seeding in medium and high intensity scenarios. Phosphorus seed placed to maximum safe rate balance placed in midrow blend or broadcast as appropriate for scenario.
[3] All values were converted to metric prior to GHG calculations.
[4] Sulphur is added routinely to canola regardless of sulphur soil tests.

Table A5. Greenhouse Gas Emission Estimate for Field Operations.

Operation	*Canola*								
	Diesel Use		Emissions	Low		Med		High	
	L/ac	*L/ha*	*kg CO_2e/ha*	*Passes*	*kg CO_2e/ha*		*kg CO_2e/ha*		*kg CO_2e/ha*
Fertilizer Broadcast	0.7	1.73	4.95	1	4.96	--	--	--	--
High Clearance Sprayer	0.3	0.75	2.14	2	4.28	4	8.56	4	8.56
Seeder	2.0	4.94	14.13	1	14.13	1	14.13	1	14.13
Swather	1.08	2.67	7.64	1	7.64	1	7.64	1	7.64
Combine Pick-up	4.7	11.61	33.20	1	33.20	1	33.20	1	33.20
	Total Emissions Canola Field Operations				64.2		63.5		63.5
	Wheat								
Fertilizer Broadcast	0.7	1.73	4.95	1	4.96	--	--	--	--
High Clearance Sprayer	0.3	0.75	2.14	3	6.42	4	8.56	6	12.84
Seeder	2.0	4.94	14.13	1	14.13	1	14.13	1	14.13
Combine Direct	3.4	8.40	24.02	1	24.02	1	24.02	1	24.02
	Total Emissions Wheat Field Operations				49.52		46.71		50.99

[1] Diesel use values from ARECA's Energy Efficiency and Conservation Project (www.areca.ab.ca). Diesel conversion factors Appendix Table G1, page 99, NERP 2010 edition (http://www.cfi.ca/_documents/10-10-18_NERP_v1_Protocol_FINAL.pdf).

Table A6. GHG Emissions from Different Cropping Intensities of Canola

Source	Ecodistrict 791			Ecodistrict 727			Ecodistrict 596		
	Low	Med	High	Low	Med	High	Low	Med	High
	kg CO_2e/ha								
Field Operations	64	64	64	64	64	64	64	64	64
Seed Production[1]	12	12	12	12	12	12	12	12	12
Fertilizer Production	219	355	482	170	314	459	219	338	453
Pesticides Production	9	19	19	9	19	19	9	19	19
Soil N_2O 4R[2]	547	704	827	746	1015	1248	759	937	1081
Carbon Sequestration[3]	-70	-93	-115	-160	-208	-259	-160	-206	-251
Net Emissions	782	1062	1289	841	1217	1543	903	1165	1378
	kg crop/ha								
Yield	1905	2522	3138	2074	2690	3363	1962	2522	3082
	kg CO_2e/kg crop								
Intensity	0.410	0.421	0.411	0.406	0.452	0.459	0.460	0.462	0.447
	ha								
Equivalent Area[4]	1.00	0.76	0.61	1.00	0.77	0.62	1.00	0.78	0.64
	kg CO_2e								
Emissions Equivalent[5]	782	803	783	931	1028	1041	993	996	967
Delta	0	21	1	0	97	110	0	3	-27
	kg CO_2e/ha								
NERP Credits[6]	--	118	269	--	173	410	--	159	354

[1] Emissions factors for seed, fertilizer, pesticides from Biograce or Ecoinvent.
[2] Calculated using methodology used in NERP with reduction modifier applied at 0.85 for medium and 0.75 for high intensity scenarios.
[3] Calculated using factors for dry prairie (ED 791) and moist parkland (ED 727 and 596) from VandeBygaart et al. (2008) adjusted for yield.
[4] Area required to produce the equivalent amount of crop produced in the low intensity scenario.
[5] Emissions associated with growing the equivalent amount of crop as the low intensity scenario.
[6] NERP credits calculated for medium and high scenarios using dynamic baseline approach.

Table A7. GHG Emissions from Different Cropping Intensities of Wheat

Source	Ecodistrict 791			Ecodistrict 727			Ecodistrict 596		
	Low	Med	High	Low	Med	High	Low	Med	High
	kg CO_2e/ha								
Field Operations	50	47	51	50	47	51	50	47	51
Seed Production[1]	70	89	115	70	89	115	70	89	115
Fertilizer Production	156	303	398	213	316	418	210	360	496
Pesticides Upstream	16	27	21	16	27	21	16	27	21
Soil N_2O 4R[2]	399	581	666	801	975	1124	725	977	1150
Carbon Sequestration[3]	-70	-93	-117	-160	-212	-268	-160	-214	-266
Net Emissions	621	953	1134	991	1241	1462	910	1286	1567
	kg crop/ha								
Yield	2825	3766	4708	3497	4640	5851	3564	4775	5918
	kg CO_2e/kg crop								
Intensity	0.220	0.253	0.241	0.283	0.268	0.250	0.255	0.269	0.265
	ha								
Equivalent Area[4]	1	0.75	0.60	1	0.75	0.60	1	0.75	0.60
	kg CO_2e								
Emissions Equivalent[5]	621	715	681	991	936	874	910	960	944
Delta		94	60		-55	-117		49	33
NERP Credits[6]	0	100	215	0	170	368	0	170	375

[1] Emissions factors for seed, fertilizer, pesticides from Biograce or Ecoinvent.
[2] Calculated using methodology used in NERP with reduction modifier applied at 0.85 for medium and 0.75 for high intensity scenarios.
[3] Calculated using factors for dry prairie (ED 791) and moist parkland (ED 727 and 596) from VandeBygaart et al. (2008) adjusted for yield.
[4] Area required to produce the equivalent amount of crop produced in the low intensity scenario.
[5] Emissions associated with growing the equivalent amount of crop as the low intensity scenario.
[6] NERP credits calculated for medium and high scenarios using dynamic baseline approach.