Changing Demands on Agricultural Land: Are Reforms Urgent?

by Bill Deen, Margaret Graves, Evan Fraser and Ralph C. Martin

Green Paper presented at the Annual Conference of the Alberta Institute of Agrologists, Banff, Alberta, March 27, 2013
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Green Paper for the Alberta Institute of Agrologists

Bill Deen¹, Margaret E. Graves², Evan D. G. Fraser³, Ralph C. Martin⁴

¹ Bill Deen, Ph.D., Associate Professor, Department of Plant Agriculture, Crop Science Bldg. University of Guelph, 50 Stone Rd., Guelph, ON N1G 2W1
² Margaret Graves, M.Sc., 36 Lushs Rd., Conception Bay South, NL A1X 4C7, 709-240-2450, graves.margaret.e@gmail.com
³ Evan Fraser, Ph.D., Canada Research Chair, Department of Geography, University of Guelph, 50 Stone Rd., Guelph, ON N1G 2W1
⁴ Ralph C. Martin, Ph.D., P.Ag., Professor and Loblaw Chair Sustainable Food Production, Department of Plant Agriculture, University of Guelph, 50 Stone Rd., Guelph, ON N1G 2W1
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Abbreviations

4 F’s – Food, feed, fuel and fibre
5th F – ecological system function
AAFC – Agriculture and Agri-Food Canada
ALR – BC’s Agricultural Land Reserve
BMP – beneficial management practices
BSE – bovine spongiform encephalopathy
C – carbon
CH4 – methane
CLI – Canada Land Inventory
CO2 – carbon dioxide
EC – Environment Canada
EFP – environmental farm plan
GHG – greenhouse gasses
GJ – gigajoule
ha – hectares
IEA – International Energy Agency
IPCC – International Panel for Climate Change
IPM – integrated pest management
kg – kilogram
MA – Millennium Ecosystems Assessment
Mt – megatonne
N – nitrogen
N2O – nitrous oxide
OM – organic matter
P – phosphorus
ppb – parts per billion
ppm – parts per million
SOC – soil organic carbon
SOM – soil organic matter
t – metric tonne
TJ – terajoule
USGS – US Geological Survey
Executive summary

Agricultural land produces, at a glance, into four “F’s”: food, feed, fibre and fuel. These are ecosystem “provisioning” services as described by the Millennium Ecosystems Assessment, and projections indicate that demand for these four services will increase over the course of the next forty years and beyond. Projections made by the FAO and cited by many, quoting an increase of 70% in demand for food and feed tend to be based somewhat narrowly, without consideration to other sets of services that agricultural land provides. Not only are fibre and fuel often excluded from evaluations of the world’s ability to feed itself in 2050, services described as regulating, supporting and cultural, provided by both wild and farm ecosystems, are not taken into account. The real-world impact of the trend to disregard diverse ecosystem services is degradation of farmland and damage to surrounding ecosystems at a global scale.

Increasing variability (climate) and volatility (oil and food prices) are symptoms of a narrow focus on food production. According to the IPCC, methane and carbon dioxide emissions from agriculture have contributed to the greenhouse effect. Land use change and the decrease of forest cover due to farming (crops and livestock) have decreased the ability of the global ecosystem to sequester carbon. With ongoing environmental degradation and farm landscape simplification, we risk continuing on our narrow path in a world that is changing, thus becoming less resilient. Resilience, the ability of a system to withstand disturbances without changing its underlying structure, to bounce back when subjected to challenges, is threatened by rigidity. Resilient systems must be able to adapt as circumstances change. Sustainability encompasses resilience. To increase sustainability in the agricultural system in the face of climate variability and price volatility, we can broaden the focus from the provisioning function of agricultural land to make the system more resilient with five F’s, instead of the traditional four.

The fifth “F”, ecosystem function, has been defined by many authors to include temperature and hydrologic regulation, waste treatment, nutrient cycling, pollination, protection against storms, employment, education and recreation. These environmental goods and services are intertwined in the production aspects of agriculture and are associated with its ability to persist.

In order to consider the path of agriculture in Canada and how it has focused on the four F’s of production at the expense of the fifth F of ecosystem functional services, we trace the intensification and increase in productivity in agriculture in the 20th century. Crop production has increased, alongside an increase in cropped land – however, toward the end of the 20th century, cultivated land decreased while crop production continued to increase, showing an increase in intensity of production per area of land. The same trend is shown when comparing the number of farms, which has decreased, to the land area per farm, which has increased. Animal production intensity has also increased with more meat, eggs and milk produced from fewer animals on fewer, larger farms. Intensity of input use has also increased, especially when
considering the use of nitrogen fertilizer, which has increased steadily in absolute terms, as well as when considering fertilizer used per land area and per tonne of crop produced. Energy use, both direct and indirect, has also increased per land area. In some cases, increases in production have outpaced increases in direct energy use, thus increasing energy efficiency. Diversity of crops grown Canada-wide has increased, but in Ontario in particular, crop rotations have simplified over the past forty years. Ontario has seen cultivated land-use change from cereals and forages, to corn and soybean, in an intensification in the cropping system. The Prairies, however, faced with a more acute erosion problem in the early- to mid-1900’s, have diversified their cropping system, taken up conservation tillage practices and increased rotation length, improving soil health and production.

Farming in Canada has intensified over the past century. However, not all players in the agricultural system have taken the same route. Alternative farming systems also play a part in the evolution of farming in Canada; they act as a reservoir for new and different practices, incubating diversity which, in some cases, has not persisted in the mainstream. We argue that both the mainstream, with more weight and influence (conventional agriculture), and the alternative systems, which encompass adaptive options, have much to contribute and are part of a continuum of farming systems which make up the larger agricultural system in Canada.

As mentioned, there are challenges which face agriculture and the use of agricultural land. Some are directly related to the lack of attention paid to ecosystem services and some need to be focused upon to ensure added resilience in the face of climate variability. The challenges are listed and rated in terms of the urgency, as well as the type of change required to address them. The “type of change” rating, which has three levels – incremental, moderate and transformative, refers to the magnitude of change between the current condition of the Canadian agricultural system and the condition of the system in the future, after the challenge has been resolved. It also speaks to the scale of change required. Moderate change, for example, could occur at the landscape scale, such as the reduction of nutrient discharge from entire watersheds, while incremental change might occur at the farm scale. Transformative change is required when the agricultural system or even the food system will be substantially different if the challenge is resolved, as it may require new technology or a paradigm shift. As these changes occur at the systems level, they may have far-reaching impact at a global scale on both the production and consumption of food, feed, fibre and fuel.

We enumerate thirteen challenges facing agriculture in Canada. Challenges that we consider to be urgent in nature include: 1) adaptation to the effects of climate change, 2) increased attention to the fifth-F services and resilience of agro-ecosystems, 3) water quality and 4) the conversion of farmland to non-agricultural uses. Of these, the first two are also considered in this report to require transformative change, meaning that solutions must be enacted quickly to increase the resilience of the farm landscape and the agricultural system to climate variability. Other
challenges that we have rated as requiring transformative change are: 1) the dependence of agriculture on liquid fossil fuels, 2) the loss of both wild and agricultural biodiversity, and 3) the need to reduce waste in the food system.

Finally, solutions to address the thirteen challenges are described briefly, along with additive effects, or any limitations posed by each strategy. A few selected strategies are highlighted for the purpose of discussion, but the use of two tables pares down the solutions and strategies to show how they build upon each other and interact. Key strategies are the diversification of crop rotations (especially when a forage is added), covering the soil by using intercropping, underseeding and cover crops, increasing organic matter return in the form of crop residues, manure and green manures, increasing farm landscape diversity, decreasing erosion and improving water quality by adding and maintaining riparian zones, hedgerows and windbreaks. These changes, if implemented on all farms, could represent a transformative change and address most of the challenges reviewed in this report. Further to changes that farmers can make, there are challenges to be addressed by policy and consumers, by preserving agricultural land, decreasing household food waste and choosing diets higher in vegetable protein, integrating crop and livestock production to close nutrient cycles, and using food waste to feed animals and generate energy.

The agricultural system has the ability to make changes that will retain the current trajectory of mainstream agriculture while incorporating aspects to make it more sustainable and resilient. By the end of the 21st century, the system will have undergone transformative change and the enacted solutions will have brought added efficiency and adaptability to farming and to the food system. There is a case for broadening the current focus of agricultural production to conserve functional agro-ecosystems for generations down the road.

**Introduction**

The demands placed on agricultural land include the provision of Food for people (cereals, corn, potatoes, vegetables, fruit, pulses), Feed for animals which produce meat, milk and eggs consumed by people from grain and forages, Fibre (cotton, wool, animal bedding) and Fuel (biofuels, provide space for wind turbines and solar panels). In Canada, most of our 65 million hectares of farmland are used to produce these “four F’s” and they are indispensible for our economy and way of life.

However, and as we argue throughout this report, alongside the first four F’s, farmland must also provide us with a fifth F: Functional ecosystems. Ecosystem function, also referred to as ecological goods and services, has been the subject of many academic reports. For example, in the early 2000’s the Millennium Ecosystem Assessment (MA, 2005a) conducted an overview of the global environment and used the concept of ecological goods and services as the basic framework used to organize the report. Ecosystem function has been defined and classified by
many authors to include climate regulation and support: treating waste, pollinating crops, storm protection, and cultural, educational and recreational function (Costanza et al., 1997; de Groot et al., 2002; MA, 2005a; Fischer et al., 2009). Agricultural land contributes to these functions because it makes up a considerable amount of the world’s land base (IPCC, 2002).

In maintaining all five “F’s”, the sustainability of our agricultural systems is paramount as the climate becomes more variable and resilience is more important. Many are worried that agro-ecosystems have largely lost their ability to contribute to climate regulation, and provide other services like pollination, soil production and maintenance of ground and surface water quality (IPCC, 2002; MA, 2005a; Kremen et al., 2007; Bilotta et al., 2012). The MA (2005a) concludes that because the market economy fails to value many of the things the environment provides, we tend to undervalue ecosystem functions and this is one reason why farmland often becomes environmentally degraded. Trade-offs have been occurring between the first four F’s and the fifth, and it may be compromising the ability of future generations to sustain themselves (MA, 2005a; Power, 2010).

To address the chronic under-valuing of ecosystem functions, academics have tried to estimate the value of the ecological goods and services around the world. One of the most often cited studies was published in the journal Nature (Costanza et al., 1997). Using market values from the 1990’s, the authors of this study estimated that the total global value of 17 ecological functions was approximately USD 33 trillion. This number is by no means an absolute value of ecosystem functional services, rather a representation of the undervaluation and potential of ecosystems (Costanza et al., 1997; de Groot et al., 2002).

As the world evolves, demands on agricultural lands increase: populations are increasing and diets are changing toward consumption of more energy-intensive foods, like meat and processed food. Projections of a required increase in global food and feed production of 70% are a rough estimation of the change required by 2050 (FAO, 2009). Although projections of this nature are useful, they have been judged by some to be inflated by frequent citation and too narrowly based to be truly indicative of the situation in which the global agricultural system finds itself (Tomlinson, 2011). Volatility in oil prices, environmental concerns and the limited nature of fossil energy supply encourage the search for alternative energy, putting considerable pressure on agricultural systems to produce bioethanol and biomass energy (de Vries et al., 2007; Smith, 2009; Trujillo-Barrera et al., 2012). Growing food, growing energy, using energy to grow and process food – demands on farmland are both increasing and diversifying. Add climate change to the mix and the neglected fifth F becomes more important. Improving the stability of food, feed, fibre and fuel production is necessary to adapt to changing atmospheric conditions and temperatures, and potential variability including more drought, floods and extreme events like storms (IPCC, 2007b). In order to maintain – let alone increase – production of the first four F’s,
and to ensure that the fifth F of ecological Function is provided for, land must be used in a way that is sustainable and resilient.

This report presents a heuristic framework that looks at the question of sustainability in the current agricultural system. Which elements of the system promote resilience and sustainability, and which ones hinder? Is there a pressing need for change in response to some of the barriers to sustainability, and if so, which ones? How can we ensure that the problems which do not require immediate attention are still acted upon incrementally? What are selected strategies to address the challenges agriculture faces?

To answer these questions, the report proceeds in the following fashion. In Chapter 2 the trends in Canadian agriculture are described. In this we demonstrate that productivity has increased substantially over the past century. We are producing more food, on fewer farms with less land and with fewer animals than ever before. But these changes have come at a price. For instance, in many regions in Canada and around the world, the conversion from natural to cultivated land has meant a decrease in biodiversity and an increase in soil degradation. Simple crop rotations (2-year cash crop or continuous cropping systems) have further damaged soil health (one notable exception is in the Canadian Prairies where rotation complexity has increased). But there are alternatives, and Canada also has farm enterprises that focus on small-scale or organic methods. There is a tremendous amount to be learned from these organisations. Hence, we conclude chapter two by arguing that it is the time to see “conventional” and “alternative” as systems on a continuum and with much in common. As we move forward, there are opportunities for farmers and policy makers to recognize the place of small systems within larger agricultural systems: they represent diversity and resilience, incubating new ideas and biodiversity.

The challenges that face Canadian agriculture are then described in Chapter 3. In particular, we explore and assess the large scale sustainability issues that confront Canadian farm enterprises and use the literature to evaluate them. We explore what type of change is required to face the challenges and how urgently each one must be addressed.

Chapter 4 builds on Chapter 3, presenting solutions and specific strategies to the challenges outlined. In addition, we introduce a time scale for addressing problems in today’s agriculture, taking into account the risk-averse nature of the industry. Finally we reflect on how we can make adjustments to our current land-use trajectory in order to optimize its sustainability and production capacity in the face of increasing variability. The solutions are intertwined and can be addressed within the current system. Transformative changes are necessary, but they can be effected over time and will support increased yields and efficiency in the agricultural system.
Chapter 1. Resilience and sustainability in agro-ecological systems

Our discussion on Canadian farmland’s ability to continue producing the five F’s must be framed by an understanding of both sustainability and resilience. As Costanza and Patten (1995) put it, a sustainable system is one that persists. In the three chapters that follow, we will be assessing Canadian agriculture to see if it can persist in providing the food, fibre, feed and fuel while maintaining ecosystem function.

To help us decipher these issues, we can use works such as a paper by Yunlong and Smit (1994) that describes three different types of sustainability; ecological, economic and social. All three are important in the discussion of Canadian agriculture and land use. Social sustainability considers the needs of human beings: not only the less tangible aspects of the 5th F such as recreation and spiritual needs, but also the basics of food, shelter and clothing (the first three F’s), and societal requirements like education and jobs. Finally, we can draw on the classic definition of sustainability: to provide for current needs without compromising the ability of future generations to meet their own needs (Brundtland, 1987).

From these definitions, we conclude that agricultural activities should contribute to – not be solely responsible for – these functions. Ecological sustainability encompasses hydrology, climate, and soil health. When soil health decreases, necessitating higher inputs to maintain yields, ecological sustainability is compromised. Finally, economic sustainability is the ability of a system to be profitable over time and is measured by variable costs and gross margins.

Is it possible to account for social and ecological sustainability by focusing on economics? At first glance, the answer is yes. We ought to be able to set values to education, recreation, food, and productive soil and then invest effort to promote these more valuable resources. But some authors argue that there are services provided by agricultural ecosystems that cannot be traded for man-made capital (Seghezzo, 2009; MA, 2005a). Take for example the value of old-growth forest. A monetary value can be assigned to the resource, but that money can never bring the forest back. We will consider this as we assess the sustainability of our food system. Is it sufficient to consider the trade-offs for high production in the framework of economic sustainability, or are they too large to put a value on?

Other important aspects to this discussion are those of scale and time (Costanza and Patten, 1995). For instance a country’s food system is made up of many small systems, from a legume’s root nodule, to a small research plot, to a field, to a farm, to an industry, to a region. For the purposes of this paper, we consider Canadian agriculture as a whole, but with an eye on the global situation, and with consideration that within the country there are many different interacting systems. We consider that the Canadian agricultural system comprises not only the mainstream but also organic farming and other options, which are sometimes viewed as different systems entirely. Although we touch upon the Canadian food system on a few occasions in this
paper (for example, while discussing household food waste and the impact of consumer choice upon the production of farm goods), the discussion centres on farming. In order to focus upon the current agricultural system we consider a time scale of the 20th and 21st centuries, the evolution of production and productivity in Canadian agriculture, and lay out time frames up to 2100 during which changes can be made to increase its sustainability.

Another aspect of sustainability relevant to this discussion is resilience. The concept of resilience originates in ecology (Carpenter et al., 2001) and can be directly transferred to agricultural systems from natural systems. Resilience is the opposite of vulnerability and can be broadly defined as the ability of a system to withstand disturbances without changing the underlying structure of that system (Milestad and Darnhofer, 2003). Agricultural systems are resilient when they can maintain productivity in face of shocks or challenges, such as drought or pest pressure (Brundtland, 1987), and bounce back after such a challenge. Resilience, like sustainability, must be measured within time and space (Carpenter et al., 2001) since shocks or challenges vary from year to year and within and across regions. Finally, resilient systems are often described as having the ability to learn and adapt as circumstances change (Milestad and Darnhofer, 2003).

Agricultural resilience has direct implications for food security (Frison et al., 2011) as well as the landscape’s ability to provide feed, fibre, fuel, and ecosystem function. There is evidence that climate variability will increase (IPCC, 2007b) and this represents a potential increase in shocks to agro-ecosystems. Consideration needs to be given to whether existing production systems will be resilient to increasing shocks.

In practical terms, resilience means that average yields of food, feed, fibre and fuel are maintained in stressed situations (Simelton et al., 2012). Yields in vulnerable systems will decrease when subjected to stresses. For example, if corn yields are on par with average yields during a drought year, we can say that that system in that year was resilient. Inter-annual yield stability can be used as an index of resilience. However, when evaluating the agricultural system as a whole for sustainability and resilience, it is important that we consider more than yields (of the first four F’s) but also that we evaluate ecological function. In fact, without a functional ecosystem, the four F’s of production may decline. Input efficiency and effectiveness, particularly of N, P, and pesticides, must be considered because of their impact on the environment and on farmers’ variable costs. Degraded soil stores fewer nutrients as they are discharged into the environment and soil erosion pollutes waterways. Over time, maintenance of yields is not sustainably productive if it must be accompanied by a climb in inputs to offset soil degradation (Brady and Weil, 1996). Energy and nutrient use efficiency can be assessed (Castoldi and Bechini, 2010). A system that depends on finite resources will need to adjust in order to persist. Finally, soil health is an important way of assessing the sustainability of agricultural systems (Kibblewhite et al., 2008; Castoldi and Bechini, 2010; Govaerts et al., 2009). The aspects we have already mentioned (nutrient and pesticide inputs, yields, energy use,
ecosystem services and economic gain) are all intertwined. Thus, a sustainable agricultural system must be based upon all five F’s, where the fifth F of ecosystem goods and services essentially represents resilience. Once the agro-ecosystem can maintain fifth-F function of primary productivity, soil production, nutrient cycling and water quality, its capacity to produce (four F’s) is protected by the ability to absorb shocks; a resilience imparted by a functional ecosystem.

Chapter 2. Canada’s agricultural trajectory

2.1 Trends toward intensification in Canadian agriculture

Canadian agricultural systems have changed dramatically over the past hundred years. Generally the trend has been towards system intensification as measured by production per unit area, per animal, or per farm and by intensity of inputs used per unit area, per unit of crop or animal product produced, or per farm.

2.1.1 Production

Major crop production, in terms of tonnage, is led nationally by wheat production, mostly for export, and hay for livestock production (Figure 1). Since around the year 2000, soybean and canola production have increased, whereas production of more traditional crops has plateaued (Figure 1). Figure 2 shows that canola, in particular, has seen an increase in seeded area while wheat area has decreased since the mid 90’s. Area seeded to corn has remained relatively static while production has increased (Figure 1; Figure 2).
Figure 1. Historic production of major crops in Canada, thousands of tonnes, 1908-2012. Source: Statistics Canada, CANSIM database 2013

Figure 2. Historic seeded area of major field crops in Canada, area of summerfallow and total area of cultivated land (total land in crops, summerfallow and tame hay), thousands of hectares, 1908-2012. Source: Statistics Canada, CANSIM database 2013

Animal production has also increased. Figure 3 shows the increase in total annual beef and veal production (from 631,000 t in 1960 to 1,154,000 t in 2012), while Figure 4 shows the increase in annual chicken meat production (from 89,480 t in 1941 to 1,053,216 t in 2012) and in egg production (112,148 thousand dozens in 1920 to 643,810 thousand dozens in 2012).
Figure 3. Number of beef farms, total beef cows (hundreds) and total beef and veal production (tens of tonnes), in Canada 1960-2012. Source: Statistics Canada, CANSIM database 2013.
2.1.2 Production by land area

Figure 2 shows historic land use by major field crop and summerfallow land. For most of the past century, cultivated land\(^1\) area has increased, including an increase of 40% in cropped land\(^2\) from 1951 to 2011 (calculated from CANSIM, 2013). That trend has reversed and the area of cropped and cultivated land has decreased since 2001, due in part to the conversion of agricultural land to other uses (Hofmann et al., 2005). Nonetheless, as seen in Figure 1, crop production continues to increase, indicating an increase of intensity of use of agricultural land, particularly as summerfallow has fallen substantially since peaking in 1972 (Figure 2).

Productivity of Canadian agricultural land rose over the past century, with corn exceeding a 200% increase in yield (kg/ha) since 1910 (Figure 5). Veeman and Gray (2010) analysed the increase in crop productivity since 1960 and found that wheat, barley, field peas and canola in Canada exhibited statistically similar trends in productivity, with yields per hectare of land increasing approximately 60%.

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\(^1\) Cultivated land; defined by Statistics Canada as total land in crops, summerfallow and tame hay (CANSIM, 2013).

\(^2\) Land in crops; defined by Statistics Canada as the sum of land used for cultivation of field crops, vegetables, fruits, nursery crops and sod (CANSIM, 2013).
Figure 5. Historic yields of major crops in Canada, kilograms per hectare, 1908-2012. Source: Statistics Canada, CANSIM database 2013.

Although the increased productivity of land use has mitigated any loss of production from the decrease in agricultural land, Canada’s land mass is only 5% dependable agricultural land (Class 1, 2 and 3 land; CLI, 2008) – a limited resource. Since 1951, Canada has lost 1.8 million hectares of dependable agricultural land to urbanisation, transportation and utility infrastructure, and rural housing, the worst of which has occurred in Southern Ontario (Hofmann et al., 2005). Cultivated land has been in excess of available dependable agricultural land in Canada since the mid 90’s, sparking concern about the risk of soil degradation on farmed marginal land (Class 4-7; CLI, 2008; Hofmann et al., 2005). The loss of agricultural land in Southern British Columbia caused the initiation of the Agricultural Land Reserve in 1973, protecting over 4.5 million hectares while the same problem in Ontario resulted in the creation of the Ontario Greenbelt in 2005. The Green Belt protects 720,000 ha of land around the fast-growing Greater Golden Horseshoe area (Friends of the Greenbelt, 2012). In addition to the Greenbelt, the province of Ontario has developed the Places to Grow policy that creates incentives to ensure that urban development outside of the Greenbelt accounts for environmental and agricultural land uses (Caldwell and Hilts, 2005).

Other important trends in Figure 2 are the recent decline in area seeded to wheat and to tame hay while area of more intensive crops, canola, soybean and corn, have increased. During the 1900’s, agriculture decreased natural biodiversity through large-scale cultivation of a few staple grain crops – wheat, corn, soybean (MA, 2005b). Although crop rotation is an accepted method of pest control and a promoter of soil health, farmers are often driven to intensify and simplify rotations by financial necessity (Knowler and Bradshaw, 2007) – the short term cash benefit of a cash crop each year can validate the tradeoff. In the U.S. in 2012, 52% of land in field crops was in corn and soybean, whereas in Canada 48% was in wheat and canola (CANSIM, 2013; USDA, 2013).

One way to assess and compare trends in crop diversity over time is to use the Shannon Index, which is commonly used by ecologists working to evaluate species richness and diversity. Shannon Indexes return a higher value for landscapes that are relatively more diverse (e.g. each species in a landscape is present in a relatively similar amount). We used this approach on Statistics Canada data that show the proportion of different provinces’ farmland made up of different crops. Provinces with more diverse cropping landscapes have a Shannon index of close to 4 while the more uniform landscapes have values closer to one (Table 1). Because the diversity index takes into account the number of species, it is important to note that the analysis is based on Statistics Canada data, which may have been less thorough in 1908 than in 2012. Also shown in Table 1 is the Shannon evenness index which describes the equality of species in a population; a value of 1 describes a population with all species present in equal quantity while
a value closer to 0 represents few species which are predominant in a population of many (Magurran, 2004).

Both Canada-wide and in the Prairie Provinces, we note that crop diversity has increased since 1908 overall, as well as over the past three decades (Table 1; Figure 6). In the Prairies, this is due to rotations that are more complex (less use of fallow; thus more production on the same amount of land) and diversified (more pulses, oilseeds and forages; Acton and Gregorich, 1995; Padbury et al., 2002; Statistics Canada, 2012). Since 1976, Prairie summerfallow land decreased 80% to about 2 million ha fallowed in 2011, and over 80% of prepared land was under conservation tillage (calculated from CANSIM, 2013).

However, in Ontario, since 1982, crop diversity has decreased and is now similar to 1908 (Table 1; Figure 6). In Ontario, corn-soybean-wheat rotations are common, and an upward trend in shorter rotations (corn-soybean or continuous corn or soybean) is suggested since the mid-1980’s (Eilers et al., 2010). A closer look at Figure 6 for Ontario shows that while area seeded to corn has remained fairly static since 1982 (7% increase), soybean production has increased by 684,000 ha (188%), mostly at the expense of mixed grains, barley and oats (average decrease in seeded area 82% each, a total of 780,000 ha since 1982) and, to a lesser extent, hay, which decreased 31% over the past thirty years (calculated from CANSIM, 2013). Trading cereal area for a more input-intensive row crop (soybean) indicates that rotations in Ontario are simplifying in order to intensify cash crop production.

Table 1. Shannon diversity index and Shannon evenness index (Magurran, 2004) for 1908 and every ten years from 1982 til present, for the Prairie Provinces, Ontario and Canada. Also noted is the percent change from 1982-2012. Source: calculations made from Seeded area (ha) in CANSIM data table Table 001-0010, Statistics Canada 2013

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<td>1.678</td>
<td>1.922</td>
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<td>0.0966</td>
<td>0.1111</td>
<td>0.1034</td>
<td>+6.26%</td>
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<tr>
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<tr>
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</tr>
<tr>
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<td>0.1254</td>
<td>0.1205</td>
<td>0.1117</td>
<td>-12.16%</td>
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<tr>
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<tr>
<td>Diversity</td>
<td>1.760</td>
<td>1.951</td>
<td>1.947</td>
<td>2.236</td>
<td>2.125</td>
<td>+8.92%</td>
</tr>
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2.1.3 Production by animal

In livestock, productivity increases have been substantial. Since 1976, average hog cold trimmed\(^1\) weight increased 28\% (CANSIM, 2013). This increase in meat production per animal does not factor in the increase in number of pigs per litter and growth rates which have contributed to improved pig production (Veeman and Gray 2009). Average cattle cold dressed weight\(^2\) has increased by 45\% since 1976 (CANSIM, 2013). In poultry production, eggs per thousand birds have doubled since 1941 (calculated from CANSIM, 2013). Over the same period, total number of broiler chickens in Canada has increased by seven times while the quantity of chicken meat produced has increased 12 times (Figure 4). Dairy productivity, with the majority of Canadian dairies (75\%) registered in milk recording programs, rang in at 9,774

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\(^1\) Hog cold trimmed weight is a measure of meat production per hog, not including edible offal (CANSIM, 2013).

\(^2\) Cattle cold dressed weight is a measure of meat production per beef cow (not calves for veal), not including edible offal (CANSIM, 2013).
kg milk per 305-day lactation in 2011. This represents an increase in productivity of 32% since 1990 (CDIC, 2012a). Globally, Canada is second only to the US for milk produced per lactation (CDIC, 2012b).

2.1.4 Production by farm unit
From 1941, the number of Canadian farms has decreased by 70% and farm size has more than tripled, from 96 ha in 1941 to 315 ha in 2011 (Figure 7). To compare crop production per farm unit, total production of principle field crops¹ was divided by total farms reporting field crops from the Statistics Canada CANSIM database (CANSIM, 2013). Since farms generally produce more than one field crop, there were overlapping responses and more “total farms” than in reality; thus these numbers are used for comparative purposes only. In 1956, farms reporting field crops produced an average of 66 tonnes per farm and in 2011 farms produced an average of 304 tonnes per farm, a five-fold increase.

Average animal production per farm has also increased (Figures 3, 4 and 8). Average number of cattle and calves per farm rose from 17 animals in 1951 to 149 in 2011 (Figure 3). Over the same period, annual hog inventory per farm increased from 14 to 1,720 animals (Figure 8). When chicken meat and egg production is divided into farms reporting hens and chickens, as a comparative tool, there was an increase of 300 to 51,000 kg chicken meat produced per farm and from 682 to 31,200 dozen eggs produced per farm, from 1951 to 2011 (calculated from CANSIM, 2013). Alongside economies of scale, government regulation, and especially health legislation, has made it difficult for small scale livestock farmers to stay in business (Winson, 1992), partially driving the increase in farm size.

¹ Principal field crops include barley, dry beans (all), borage seed, buckwheat, canary seed, canola, caraway seed, chick peas, coriander seed, corn for both grain and fodder, fababean, flaxseed, lentils, mixed grains, mustard seed, oats, dry peas, rye (all), safflower, soybeans, sugar beets, sunflower seed, tame hay, triticale, and wheat (all).
Figure 7. Number of Canadian farms (thousands) and average farm area (hectares), 1921-2011. Source: Statistics Canada, CANSIM database 2013
2.1.5 Input intensity

Globally, agriculture has approximately doubled the influx of nitrogen into the elemental cycle, not only with synthetic fertilizer (since World War II), but with fixation by cultivated legume crops (Smil, 1999; Erisman et al., 2008). The increase in N flow played a large part in intensification during the 20th century. Figure 9 shows N fertilizer use (red line) alongside indicators of intensity of fertilizer use. Canada’s N usage has increased more than 7 times since 1967 while cropped land in 2011 had increased by a quarter of its 1967 area. In 2011, farmers applied N fertilizer to 60% of cultivated land in Canada at an average of 53 kg/ha. In 1971, 10 kg/ha N fertilizer was applied on 22% of cultivated land (calculated from CANSIM, 2013). By dividing the quantity of N in fertilizers used annually, by the total production of Statistics Canada’s list of “principal field crops”, we can obtain a general idea of the amount of fertilizer used per tonne of crop produced: in 1966 farmers used 4.5 kg N/t of principal crops, which increased steadily to 2011, when 22.6 kg N/t was used (Figure 9).

Figure 9. Total quantity of nitrogen used in fertilizer in Canada, quantity of fertilizer per tonne of principal crop produced and per hectare of cultivated land, 1966-2011. Principal field crops include barley, dry beans (all), borage seed, buckwheat, canary seed, canola, caraway seed, chick peas, coriander seed, corn for both grain and fodder, fababean, flaxseed, lentils, mixed grains, mustard seed, oats, dry peas, rye (all), safflower, soybeans, sugar beets, sunflower seed, tame
hay, triticale, and wheat (all). There are crops which do not appear on this list, such as potatoes, to which N fertilizer is applied, so the measure of total N fertilizer used by the agriculture industry by tonnes of crops produced is only used here as a comparative, not an absolute measure. Cultivated land includes total land in crops, summerfallow and pasture. Source: Statistics Canada, CANSIM database 2013


Agriculture and Agri-Food Canada (AAFC, 2012a) estimate that since 1961, productivity in the agriculture industry (total factor productivity index) grew by an average of 1.6% per year and made up over two thirds of economic growth in agriculture during that time. The input index, measuring increase in agricultural inputs, showed slower growth at 0.7% per year. Thus inputs are being more efficiently used while productivity continues to grow.

The use of tractors and other farm equipment has also changed the way Canadians farm over the past century. In 1921 only 6% of farms had tractors, while in 1951, 55% did. In 2011, 92% of farms had tractors and these farms had an average of between three and four tractors each (calculated from CANSIM, 2013). Technological “lock in”, which occurs once a farmer invests in specific technology and then obliges them to continue growing bigger for financial reasons, partially drives this growth (Winson, 1992). Use of farm machinery allows operations to be larger and employ fewer people. A diminishing labour force and rising productivity have given Canada one of the highest agricultural labour productivities in the world (Arizpe et al., 2011).

The availability of fossil energy has allowed agriculture to develop over the past century, in terms of machinery and equipment (trucks, tractors, combines, dryers, irrigation systems), heating/cooling, lighting and indirect energy use for the manufacture and transport of fertilizers, chemicals and feed. Direct energy use in primary agriculture is shown in Figure 10. In 2011 agriculture used a total of 272 thousand terajoules of direct energy inputs in Canada, 44% of which came from diesel fuel (Figure 10). Energy use per farm increased 120% from 1981 to 2011 while energy use per hectare of farmland increased 50% over the same period (Figure 11).
Figure 10. Direct energy demand in primary agriculture in Canada (total and by energy type, in terajoules), 1978-2011. Source: Statistics Canada, CANSIM database 2013

Figure 11. Direct energy demand per farm and per hectare of cultivated land in Canada, 1981-2011. Source: Statistics Canada, CANSIM database 2013
Indirect energy use in agriculture, particularly crop production, is largely dependent on synthetic N fertilizer use (Davis et al., 2012) as its manufacture is energy-intensive. In Canada in 2011 the manufacture of fertilizer (excluding potash) used 5.4 GJ of energy per tonne of fertilizer produced: a total of about 39 thousand terajoules were used to manufacture the fertilizer used in Canada that year.

While the trends just noted show that energy use has increased on Canadian farms, a somewhat different story emerges when we view energy use per unit of food produced or in terms of the amount of energy use per unit of economic wealth created. Specifically, Statistics Canada measures energy use intensity in gigajoules of direct and indirect energy used per thousand dollars produced by industry and reports a 50% drop of energy used per thousand dollars of primary agriculture product from 1990 to 2008 (calculated from CANSIM, 2013). Direct energy use in Canadian agriculture increased 42% from 1978-2011, while total principle field crop production increased 26% and total meat production (chicken, beef and veal, mutton and lamb and pork) increased 92% (calculated from CANSIM, 2013).

2.2 Factors influencing agricultural intensification

Intensification is related to increased availability of N and P, plant breeding (Tester and Landridge, 2010), crop protection (Oerke and Dehne, 1997; Jaggard et al., 2010), biotechnology (van Alfen, 2004; Duvick, 1995; Dunwell, 2011), irrigation (Gornall et al., 2010), labour productivity and mechanisation of farm practices. From a Canadian point of view, irrigation has a small role; only 1.2% of cultivated land in the country is irrigated (calculated from CANSIM, 2013).

Increases in livestock productivity have been largely due to improved genetics for feed conversion, carcass composition and fecundity (Veeman and Gray, 2009), and management practices such as precise ration formulation, artificial insemination and movement toward high-grain diets for ruminants. These factors have resulted in reduced land use per unit of animal production.

In addition, the 20th century saw the emergence of low food prices in industrialized countries, related to consumer demand and food policy (Hodges, 2005; Guthman, 2010). In 2009 Canadians spend 9.8% of household income on food, compared to France at 13.4% and developing countries at upwards of 40% (AAFC, 2012a; Anker, 2011). In 1991, Canadians spent 11.3% of household income on food (AAFC, 2012a). However, Canadian consumers have become more demanding toward agriculture. They expect farmers to be stewards of the environment as well as to produce healthy food, feed, fibre and fuel that does not violate animal welfare, and some are willing to pay for those benefits. In response to concerns about environmental issues and community connectivity, people are more likely to choose local food; recently published data suggest that 43% of Canadians will pay more for locally grown products.
Organic production has increased in response to consumer demands, with an increase from 2230 to 3713 certified organic farms from 2001 to 2011 (Statistics Canada, 2012). Considering that Canada’s Standard for Organic Agriculture was only initiated in 1996 (PWGS Canada, 2012), there has been a definite evolution since the early 1990’s.

Finally, centralised food retail and processing, which themselves are driven by improved food storage and transportation favour large scale producers (Connor and Shiek, 1997; Fraser, 2006). Trade is central to this aspect and has shaped the type and scale of markets we cater to. In 2010 we exported 45% of agricultural production compared to only 5% in the EU (AAFC, 2012a) where food policy has been more focused on self-sufficiency (Angus et al., 2009). Not only does Canada export large quantities of agricultural produce, we import nearly as much: Canada was the world’s fifth largest agricultural exporter in 2010 at CAD 35.5 billion of agriculture and agri-food exports, and the sixth largest importer of agriculture and agri-food goods at CAD 28 billion (AAFC, 2012a). There was a 33% increase in the value of exports as a share of total primary agriculture GDP from 1992 to 2007 (CSLS, 2011). Canada exports particularly high proportions of grains, oilseeds and red meat. The production of these commodities, therefore, is highly dependent on international markets, mostly the US; about half our agricultural exports are destined for American markets. Agricultural exports to the US peaked at 67% of total exports in 2002 (AAFC, 2012a). This has been a source of instability in the past, for example the crippling blow of BSE to the Canadian beef industry, due to the US ban on live cattle imports from 2003-2005 (Clark and Cechura, 2011).

2.3 Where are we now: The agricultural systems continuum

The trends discussed in section 2.1 describe the mainstream of Canadian agricultural production, usually termed “conventional” agriculture. There exists also a departure from the mainstream in a variety of alternative methods practiced by small numbers of farmers. These may be driven by desire to change farming practices away from the mainstream or by economic motivation to target a niche market. Alternative farming systems can have multiple components that define them.

Alternatives for farm management include decreasing inorganic input use (organic or ecological management), often because of health or environmental concerns, decreasing mechanisation in favour of a higher labour intensity (and lower energy use), and increasing diversity as a management strategy. The latter can be through genetic diversity such as increasing crop rotation diversity, using heritage varieties or breeds, or by managing for greater wild species diversity by providing land for habitat. Farms can also be “alternative” in terms of scale, by sourcing inputs and by marketing locally (decreasing food miles and closing nutrient cycles), or by keeping operations small – striving for operational sustainability rather than growth. Finally, there are farms that pursue economic alternatives: direct marketing, family- or community-owned and managed operations, decreased “marketedness” (the degree to which the farm reacts to market conditions)
to market signals), and the inclusion of value-added products. Alternative farms target niche market products for which consumers are willing to pay more. The potential of higher farm-gate prices draws farmers to alternative farming systems, as well as the underlying principles of the systems as described. For a brief review of these issues refer to Renting et al. (2003), Marsden et al. (2000), Morgan et al. (2006), Blay-Palmer (2008) and Kloppenburg et al. (2007). Proponents of alternative systems have been critical of the mainstream for its lack of attention to the fifth F, leading to a purposed lack of resilience (e.g., Badgley et al., 2007; De Schutter and Vanloqueren, 2011). However the alternative systems exist on a small scale and are very difficult to compare to one another and to the mainstream.

While proponents of “conventional” and “alternative” agriculture may seem entrenched in mutually exclusive camps, we need to move beyond simplistic divisions. In particular, we must engage in dialogue between proponents of the different systems which recognize that there exists a continuum of farming systems (NAS, 2010) and that so-called conventional and alternative farms all play a part in the ongoing evolution of agriculture.

Another way to look at this continuum is to imagine a plot of soil – the larger agricultural system – with many shoots of different sizes, representing different farming systems. The biggest and strongest of course is mainstream, input-intensive farming, while the smaller ones run the gamut; perhaps the organic shoot is quite strong and beginning to resemble the mainstream, and other shoots are dying off. Many different shoots, all contributing to the system on our plot of soil as their roots interact and co-mingle, and the alternatives (smaller shoots) forming a reservoir of diversity, of new ideas, a testing ground to provide options in case circumstances shift, so that former niche approaches provide useful new mainstream practices. Instead of looking at the mainstream as inelastic, it can be seen to encompass alternative systems – all the roots of these individual shoots are intertwined – which in fact lend it a greater adaptability (Thirsk, 2001; NAS, 2010).

**Chapter 3. Challenges facing the agricultural system and their urgency**

In this section, we attempt to provide a very quick summary of the literature on the major threats and challenges to agriculture, to review the urgency of each and to postulate on the type of change required. Both the urgency and the type of change ratings are specific for Canada. If the challenge, globally, is at a different level, it is described as such in the text (Challenges 1 through 13). The urgency rating has three levels; urgent, medium and eventual, and are based on our assessment of the state of the literature. More specifically, challenges are referred to as 1) **urgent** if changes are required in the next ten years; 2) **medium** if changes are required in 15-20 years; and 3) **eventual** if changes are required in 30-50 years. The type of change refers to the difference between the current condition of the Canadian agricultural system (defined in Chapter 2) and the future condition of the system after the challenge has been resolved.
There are also three levels in the rating for “type of change”. Change is designated as \textit{incremental} when the literature indictsates that the resolution to the problem can be achieved with small changes using existing practices, or is already moving forward substantially. Incremental change can also refer to change at a small scale, and targets continuing action individual farms can take to enhance their sustainability. Changes could be improvements in efficiency or adhering to a beneficial management practice (BMP) that has been previously set out for the farm. \textit{Moderate} change is required when modification to the existing system is necessary to resolve the challenge but the tools needed are largely available or in development. Moderate change could occur at the landscape scale, such as the reduction of nutrient discharge from entire watersheds. \textit{Transformative} change is required when the agricultural system or even the food system will be substantially different if the challenge is resolved, as it may require new technology or a paradigm shift. As these changes occur at the systems level, they may have far-reaching impacts at a global scale on both the production and consumption of food, feed, fibre and fuel.

\textbf{Challenge 1: Limited liquid energy supply}

Type of change: Transformative  
Urgency: Eventual

The possibility of future oil price increases and the ultimate unavailability of fossil fuels have been used as a reason for advocating that transformative system changes are needed. The concept of an oil crisis due to limited supply has gained acceptance among the public, although perhaps has yet to trigger societal change (Bardi, 2009). The International Energy Agency (IEA) blames oil and gas subsidies for slowing development of energy alternatives and encouraging wasteful consumption of fossil energy – global subsidies to fossil fuel consumption in 2010 were USD 409 billion (IEA, 2011). The world has certainly seen oil price volatility\textsuperscript{1}, due largely to political instability, not limited oil reserves (Smith, 2009). Of course, volatility in the price of oil and the resulting volatility in food prices impact the vulnerable and poor across the globe, as we saw in 2008 (Headey and Fan, 2008).

Increased fossil fuel costs would affect mainstream agriculture in a number of ways but in particular through the high level of inputs that rely on oil and gas for production (i.e. N fertilizer). Canada used over 5 thousand megalitres of refined petroleum products in agriculture in 2011 and 1.4 thousand megalitres of natural gas for fertilizer manufacture. Add the cost of transporting our globalized foods long-distance by air and road (Coley et al., 2011), and we are

\textsuperscript{1} [Crude oil price volatility] has led to the US attempting to reduce their energy dependence on other countries – in part by subsidizing biofuel production (Trujillo-Barrera et al., 2012). In terms of energy independence, Canada is in a fairly good situation: currently the sixth-largest producer of crude oil in the world at 169 Mt or 4.2% of global crude production in 2011 (70% of which was exported to the U.S) and the third-largest producer of natural gas (NEB, 2011a; NEB, 2011b; IEA, 2012).

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looking at a system which would not hold up well to a significantly restricted oil flow. In the long term, the agricultural system needs transformative change away from dependence on oil for energy and/or from such energy-dependent agricultural methods (De Schutter and Vanloqueren, 2011; Giovannucci et al., 2012).

Despite the apparent seriousness of this issue, media, academia and industry are in conflict as to when peak oil will happen (or if it already has; Hirsch et al., 2005; Deffeyes, 2008; Borger and Elliott, 2012). The USGS is still reporting domestic and international reserve growth at a total of 697 billion barrels of oil, 1720 trillion cubic feet of natural gas and 26 billion barrels of natural gas liquids in 2012 (USGS, 2012a; USGS, 2012b). It is unlikely, therefore, that severe shortages or sustained peaks in oil prices will happen in the next decade (Smith, 2009; Anderson, 2010). Alongside emerging technologies such as shale gas extraction and bitumen extraction from the oil sands, other sources of energy like coal and hydropower, mitigate the immediacy of an energy crisis stemming from peak oil. It seems that we have time to make incremental change to build toward the transformation that will be required for energy use in agriculture when oil is no longer a viable fuel source. Fossil fuel use should continue to become more efficient and alternatives should be developed.

**Challenge 2: Energy, pesticide and nitrogen fertilizer use and climate change mitigation (reducing GHG)**

Type of change: Moderate
Urgency: Medium

Although we are apparently not about to run out of fossil fuels, these energy sources are certainly causing problems for the environment. Fossil fuel use accounted for nearly 57% of anthropogenic GHG emissions in 2004 and agriculture was responsible for 13.5% of total emissions (IPCC, 2007a). Agriculture accounts for 8% of Canadian GHG emissions, not including emissions due to land use changes/deforestation (EC, 2012). The IPCC (2007a) states with over 90% certainty that global increases in methane (CH$_4$) and nitrous oxide (N$_2$O) have been due to agriculture and fossil fuels. Both CH$_4$ and N$_2$O are GHG’s with substantially more global warming potential than CO$_2$, at 25 and 298 CO$_2$-equivalent 100-year warming potential (Forster et al., 2007). N fertilizer use emits N$_2$O by volatilisation under moist conditions, intensive tillage emits CO$_2$ from soil organic carbon (SOC), ruminant animals produce large amounts of CH$_4$, and farm machinery and processing equipment run on fossil fuels, emitting CO$_2$.

Agriculture can play a large role in mitigating GHG emissions, and we can use existing methods to enact change, such as reduced tillage, increased rotation diversity, increased energy use efficiency strategies like precision agriculture and nutrient management planning (Meyer-Aurich et al., 2006b; Smith et al., 2007; Hillier et al., 2009). Over the next 17 years, using available
technologies, the IPCC estimates that agriculture will be able to mitigate a minimum of 2.3 Gt CO₂-eq emissions per year globally (Smith et al., 2007), but this is dependent on estimations of potential sequestration of carbon in soils, which tend to be variable. SOC may increase initially only to reach a threshold or saturation point, after which carbon sequestration potential will be limited (Stockmann et al., 2013). From 2005 to 2010, Canada’s agricultural emissions decreased by 2.4%. The reduction was partially because farmers in the Prairies have engaged in a large-scale adoption of conservation tillage and reduction of summerfallow over the past few decades, which has had the effect of adding an average of 86 kg SOC/ha to Western soils in 2006. This resulted in Canadian soils becoming a net carbon sink at over 11 Mt CO₂/year. But the same cannot be said for the Eastern provinces where data suggest average soil losses of 90 kg SOC/ha due to high levels of soil erosion in 2006 (Larney et al., 1997; Eilers et al., 2010).

Changes agriculture makes to reduce GHG emissions will create synergies to positively impact other challenges in agriculture: the eventuality of limited gas and oil supply, the need for improved soil stewardship by extending soil rotations or increasing reduced-till management, reducing discharge of nutrients into water systems when they are applied more efficiently. By no means should agriculture be alone in decreasing GHG emissions, but to take a leadership role by continuing to sequester carbon in soils and to take up new practices would look very good for the industry. Change, therefore, the development of which is already underway, needs to fall somewhere between transformative and incremental.

**Challenge 3: Climate change adaptation**

Type of change: Transformative
Urgency: Urgent

While mitigation of climate change is required, there is an increasing urgency to adapt because the effects of less predictable weather are already here (IPCC, 2007b). Atmospheric CO₂, which stimulates C3 crop growth and contributes to the greenhouse effect, is causing global temperature increases. At the global level, atmospheric CO₂ levels were at 390 ppm in 2010 (Stocker, 2010) and are predicted to rise to 550 ppm by 2050 (Prather et al., 2001). Atmospheric ozone levels are also rising and can be detrimental to plant growth. Increased temperatures may stimulate yields (longer growing seasons) or hamper them (early maturity). The IPCC (2007b) predict that increases in temperature will have an overall detrimental effect on crop yields in low-latitude developing countries but may stimulate yields in mid- to high-latitude developed countries. Li et al. (2009) estimate that global risk of drought will double by 2050 and heavy

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1 Background ground-level ozone (O₃) in the Northern Hemisphere is currently at about 20-40 ppb, with peaks at 200 ppb (occasional peaks with appropriate weather in polluted areas), and has seen an average 5 ppb increase since 1980 even in some rural areas (Royal Society, 2008). Jaggard et al. (2010) estimate that over 25% of land globally is exposed to levels higher than 60 ppb O₃ in the summer, which can restrict crop growth (Feng and Kobayashi, 2009; Hayes et al., 2010).
rainfall events also seem to be on the rise (Gornall et al., 2010). Inefficiency of input use during drought years is more problematic since lower yielding crops take up fewer nutrients; this reflects more danger to the ecosystem as residual soil N is higher in those years (Eilers et al., 2010). With uncertainty and variability of weather events, our agricultural system must crucially be able to adapt and bounce back. Changes in weather and climate may affect the incidence and severity of insect pests, pathogens and invasive species (Dukes et al., 2009), especially in agriculture as pests are not limited by food supply (Adamo et al., 2012).

Adaptation strategies to climate variability and shifting attention to ecological sustainability in agriculture require transformative change away from simple corn-soy rotations so common in North America. Varieties resistant to various stresses need to be developed and made available to farmers. Drought resistance is built through soil stewardship and using hardy varieties while a resilient agro-ecosystem comprises greater diversity including set-aside areas, greater integration of farming systems and expanded crop rotations.

**Challenge 4: Agro-ecosystem resilience, fifth-F ecological function**

Type of change: Transformative
Urgency: Urgent

Although the resilience of the agro-ecosystem is closely tied to climate change adaptation there are some differences. In particular, according to the Millennium Ecosystem Assessment, the production of crops and livestock has involved diminishing ecosystem functions such as water availability, water quality, biodiversity, pollination and forest cover (MA, 2005a). Today, this means that declines in ecological functions (the fifth F) now threaten the resilience of agro-ecosystems on which our food production relies. Many are worried that we are coming to a threshold in which we must face the historic lack of attention to ecological function (Rockstrom et al., 2009).

Apart from climate variability, but due in part to a lack of ecological regulation, we are facing a loss of wild-lands and of agro-ecological systems that are of use for: nutrient and water cycling, soil formation and primary production, and those which are of value to society: recreation, tourism, education and inspiration (MA, 2005a). All these ecosystem services reinforce resilience in agro-ecosystems, but they have not traditionally been assigned a monetary value. There is no doubt that they are of value, but assigning actual numbers is a topic of debate (Costanza et al., 1997; de Groot et al., 2002; Power, 2010). Canada boasts nearly a million square kilometres of protected land (FPTGC, 2010), but some argue that this is not sufficient to sustain biodiversity and ecosystem function. The practice of setting aside large tracts of land for wild function while intensifying farming practices on less land has been promoted as “land sparing” by ecologists, a way in which to preserve all five F’s (Green et al., 2005). However, more recent assessments conclude that to a certain extent, “land sharing”, in which farming
leaves room for wild ecological function on a farm scale, is more realistic and must form part of the solution (Tscharntke et al., 2012).

On farms, ecological function can be preserved by taking care of the soil (increasing soil organic matter; SOM, keeping the soil covered, using perennials especially on marginal land) providing set-aside areas such as shelterbelts, hedgerows, windbreaks, woodlots and riparian zones, and increasing commodity diversity. Canadian farms used some conservation practices in 2006: 34% of farmers used perennial forages on marginal land, 23% used cover and companion crops, 60% had riparian setbacks but only 32% limited livestock access to waterways (Eilers et al., 2010). These numbers represent a good start, but to diversify the ubiquitous corn-soy landscape that dominates so much of our agricultural landscape, a transformation is required; conservation practices need to be used on 100% of farms. Natural areas off-farm also need to be conserved and protected (this will be discussed more in Challenge 11 - Biodiversity).

**Challenge 5: Phosphorus supply**

Type of change: Incremental

Urgency: Eventual

The challenges presented by finite supplies of inorganic P are similar to that of fossil fuels in that both are non-renewable; but unlike fossil fuels there are currently no alternatives to rock phosphate for fertilizer. Nevertheless, recycling P from sewage and other organic wastes is possible. At current usage, reserves could last 300-400 years, or less if P demand increases (Syers et al., 2011; Norton, 2012). By 2100 global rock phosphate supply could stand at anywhere from 50-90% of the total resource base (Van Vuuren et al., 2010). Thus, we conclude that P use needs to become more efficient (Smil, 2000), but that this can be achieved over medium time frames and using relatively incremental changes. In the long-term (over the course of centuries) we need to find another solution to the rock phosphate consumption for agriculture: about 90% of global production (191 Mt of phosphate rock) is used for fertilizer and animal feed supplements (Cordell et al., 2009; Jasinski, 2012). Livestock are inefficient metabolizers of P, consuming inorganic P only to excrete it in manure, which cannot be used efficiently as fertilizer because of transportation expense and the distribution of livestock and crop operations. The world’s farmers apply about 18 Mt P/year to their crops in the form of inorganic P fertilizer (average of 12 kg P/ha of global agricultural land; FAO, 2003; Syers et al., 2011). The application is not equally distributed: China, Northern India, the US and Western Europe apply nutrients at much higher rates than the rest of the world (Foley et al., 2011). Short-term, incremental efficiency improvements are quite feasible; global P crop uptake efficiency is estimated at 41-45% (Smil, 2000). Solutions for increased P recycling include adding the enzyme phytase to monogastric livestock diets to increase P utilization and improving technologies for safely reusing P from wastewater (Kebrab et al., 2011; Cordell et al., 2011).
Low-phytate crop varieties may also become a viable alternative (Kaufman and Kalaitzandonakes, 2011).

**Challenge 6: Water quality**

Type of change: Moderate
Urgency: Urgent

High-input agriculture also has a negative impact on water quality. In particular, nutrient (N and P) discharge from agricultural sources into rivers, lakes, oceans and groundwater causes high nitrate levels, algal blooms, eutrophication and dead zones. Excess application of N and P from fertilizers and manure – about 50% more than required to maintain soil fertility with annual nutrient removal by crops – is common in high-input systems, presenting a health risk as well as a serious threat to ecosystems (Smil, 2000; Janzen et al., 2003; Smil, 2012).

Intensive animal operations may produce large volumes of manure containing high levels of N, P and coliform bacteria. In the absence of regulations, land application rates may be high on land in close proximity to the facility where the manure is produced, since high transportation costs may preclude land application to more distant fields (Zebardt et al., 1998; Eilers et al., 2010; Van Horn, 2002). High nutrient and coliform loading rates can increase risk of discharge while good storage facilities can decrease risk, by preventing leaching and volatilisation of ammonia-N into the atmosphere (Bourque and Koroluk, 2003; Peterson and Sommer, 2011). From the Farm Environmental Management Survey in 2001, Statistics Canada compiled data on manure storage and application and found that while most manure storage systems in Canada were insulated against nutrient leaching with concrete or steel, over 75% of liquid manure storage systems did not have covers (Bourque and Koroluk, 2003; Beaulieu, 2004). In addition, 40% of the largest hog farms used feeding strategies or feed additives to decrease nutrient loading in manure.

Storage capacity on most farms with manure storage systems was between 250-400 days, showing a certain capacity to store manure until conditions for application are good (Bourque and Koroluk, 2003). However there is no guarantee that sufficient cropped land will exist close enough to a large operation to safely apply all the manure produced.

Increasing non-point source (runoff) P pollution has been reported throughout the Great Lakes-St. Lawrence River ecosystem, particularly in Lake Erie, which has been experiencing algal blooms for the first time since strict water quality controls were put in place during the 1970’s (Great Lakes Commission, 2012). In Ontario’s Lake Simcoe, P loading was partially due to the conversion of land around the Holland River to intensive agriculture, and increased from the mid 1800’s to a peak in the 1940’s. Oxygen levels have decreased in the lake and it no longer sustains breeding fish populations (Evans et al., 1996).
In British Columbia’s highly populated Sumas River watershed in the Fraser River Lowland, and the Abbotsford aquifer, nutrient loading increased from 1954 to 1994 and is blamed upon non-point source pollution from manure and fertilizers, both of which have increased substantially in the area (Zebarth et al., 1998; Berka et al., 2000). Estimated N surplus from farms in Abbotsford was 245 kg/ha in the early 90’s, and up until 2004 there was no demonstrated improvement in groundwater nitrate levels (Zebarth et al., 1998; Chesnaux et al., 2007).

Environment Canada assesses environmental N contamination risk by measuring residual soil N (not taken up by the crop), because it is likely to move through the soil, ending up in the environment. In PEI 100% of farmland had over 40 kg/ha residual N in 2006, representing a huge environmental threat and cost to the environment (Eilers et al., 2010). Pesticides have a lower risk of being discharged to the environment, in part due to a strong federal pesticide regulatory system, but may still threaten human and ecosystem health (e.g., from land in potatoes; Boutin et al. 1999; Eilers et al., 2010; Xing et al., 2012). In PEI, pesticide run-off from the same land with high level of residual soil nutrients have resulted in multiple occurrences of anoxic events and fish kills (PEI Department of Environment, Labour and Justice, 2012; Xing et al., 2012). A recent OECD publication describes gross N balance (difference between N inputs and N uptake by crops) and shows that there was an 80% increase in residual N in Canada’s farmland between 1992 and 2004 (Parris, 2011). Figure 8 in Chapter 2 tells a similar story, demonstrating that fertilizer N applied per hectare has increased faster than N used per tonne of field crops produced. This is a problem for our ecosystems.

The water quality issue can be addressed by installing riparian zones around waterways, improving timing and methods of applying manure, inorganic fertilizer and pesticides as well as using crops with high nutrient uptake and minimizing P in animal manure – these are moderate changes for which current technology provides adequate solutions. In addition, environmental farm plans (EFP), which were only initiated on a national level in Canada in 2003, have seen considerable adoption and are considered an industry standard that can improve focus on nutrient loading issues (Brouwer et al., 2013). At present, however, they are voluntary and as of 2006 there were still 67% of Canadian farms without an EFP. Increased adoption of EFP’s would improve the water quality situation, especially the increased efficiency of nutrient application to farmland (Eilers et al., 2010; AAFC, 2011; ARDCORP, 2011).

**Challenge 7: Water supply**

Type of change: Incremental
Urgency: Medium

A global water crisis has been the focus of considerable discussion in recent years (Vorosmarty et al., 2000). Globally, agriculture accounts for over 60% of water use and in the US, about 34%
Increasing pressure from non-agricultural use is a serious concern as is the depletion of groundwater. The huge Ogallala aquifer, underlying eight American states, has been severely depleted by irrigation (McGuire, 2009), putting producers under pressure to modify their practices. Similar problems are evident in China, where serious ground water depletion is observed, and in Asia and Africa where farmers rely on surface water and glacial melt (Rockstrom et al., 2007; Biazin et al., 2012). Luckily, the picture is somewhat different in Canada (which is why we have only assessed the urgency of this problem as medium): only 9% of total water withdrawals in Canada were for agriculture in 2001, 92% of which was used for irrigation (Beaulieu et al., 2001). Improvements in efficiency are underway, discarding use of flood irrigation in favour of drip nozzle systems (Eilers et al., 2010). Grassini et al. (2011) estimate that by switching to pivot irrigation from surface irrigation, conservation tillage, and improving irrigation schedules, water use could be decreased by 32% per year, while maintaining yields. These changes are driven by both the acknowledgement of a need for water conservation and by a desire to be more energy efficient (thus more financially efficient), and indicates that continuing incremental changes are feasible. In terms of urgency, therefore, we believe that Canadian water use efficiency practices must improve, but that we are not threatened by an imminent water crisis.

**Challenge 8: Soil degradation**

Type of change: Moderate
Urgency: Medium

Globally, soil degradation is an urgent problem (Lal, 2011). Soil losses due to erosion by wind, water or tillage are substantial. Recent estimates for Europe rate soil erosion losses to be 3-40 times greater than soil formation, at a greatly variable average of 10 t soil/ha/year (Verheijen et al., 2009). Soil salinization, where mineralized groundwater (or irrigation water) evaporates leaving behind salts and infertile soil (this can be due to soil water deficit in cropped soils; Kovda, 1983; Wiebe et al., 2007), and desertification (Eswaran et al., 1999; MA, 2005c) are also problems worldwide. The decline of SOM and thus, SOC, can also be the result of insufficient organic matter returned to the soil from crop residues, manure or compost, or green manures and cover crops (Loveland and Webb, 2003). In this case, the harvested crop removes nutrients from the soil and carbonaceous matter is not incorporated or left on the surface of the soil to replace it. This process weakens soil structure and can make it more susceptible to soil erosion (Brady and Weil, 1996).

In Canada, soils are in a generally “good health”, as defined by Environment Canada (Eilers et al., 2010). Nine percent of Canada’s cultivated land lost more than 11 t soil/ha/year in 2006, much due to water erosion, while 80% lost less than 6 t/ha/year (Eilers et al., 2010). Improved practices over the years in response to the Dust Bowl conditions of the 1930’s have been important for soil conservation across the North American Great Plains (Baveye et al., 2011).
The Western provinces have taken steps to mitigate the effects of wind erosion, to which their land is susceptible, by changing practices away from summerfallow and toward conservation or reduced tillage (36% increase in land prepared with conservation tillage from 2001 to 2011; calculated from CANSIM, 2013). Soil erosion is more prevalent in Eastern Canada and is mostly associated with intensive crops such as potato, sugar beet and horticulture, in short crop rotations. Some soils particularly in the Atlantic Provinces and Southern Ontario have low and decreasing soil organic carbon (Eilers et al., 2010). For example, in New Brunswick, potato cultivation on slopes from 2-17% gradient caused an average loss of 13.6 t soil/year from 1990 to 2005. From 1981 to 2006, the percent of Ontario soils which lost more than 22 t soil/ha/year remained fairly static at 46% in 1981 and 41% in 2006 (Eilers et al., 2010). This situation requires attentive management especially under intensive row crops susceptible to water erosion (Miller, 1985).

SOM is a central element of sustainable soil stewardship. SOM moderates soil function by providing aeration, increasing water infiltration, holding soil moisture and acting as a substrate for soil biota, contributing to fertility and stability (Brady and Weil, 1996). It is a balancing act to maintain active SOM, which breaks down and releases nutrients necessary for crop growth, while maintaining passive SOM, which sequesters carbon and can contribute to soil structure (Loveland and Webb, 2003; Janzen, 2006). The active fraction is quickly depleted, provided there is sufficient N, if not “fed” by adding carbon-based material: crop residues. In simple rotations, fertilizer N can maintain or increase soil organic carbon (SOC) over time when it increases crop residue return (Gregorich et al., 2001; Loveland and Webb, 2003). The effect is greater when manure and/or a forage rotation are added (Hofmann et al., 2009; Ladha et al., 2011). For example, VandenBygaart et al. (2003), summarize literature that indicates that the net SOC gain from adding a legume rotation to continuous corn could be 14.4 t/ha/year. Especially in systems which are dependent on synthetic inputs, it is not prudent to remove crop residues which are crucial for maintaining SOM (Loveland and Webb, 2003).

Moving toward long-term sustainability of Canadian soils, the East needs to implement practices to control soil degradation using emerging strategies and longer rotations, particularly including forages. When forages and manuring are incorporated into cropping systems, SOM increases, indicating that livestock-crop integration can be a beneficial soil stewardship practice (Davis et al., 2012). Concentrating on residue cover and return, cover crops and intercropping, addition of manure and perennial forages to protect soil from erosion will ensure that agricultural soils can continue to provide the five F’s into the future. Sensitive soils (Class 4-7; CLI, 2008) should not be put in intensive row crops in order to avoid soil erosion and degradation. Effective soil management is not dependent on farming system (conventional, organic); instead it is the responsibility of each farmer to make ongoing changes to improve the health of their soil.
**Challenge 9: Food production increase needed to match projected demand increase**

Type of change: Incremental  
Urgency: Eventual

Global food demand increase is usually cited at more than 50% by 2050, requiring production increases to match (FAO, 2009; Jaggard et al., 2010). Agriculture also faces increased demand for fuel and fibre, although those are not generally included in production projections. Estimates show that an increase of production by 2050 can be achieved by closing gaps between potential and actual crop yields, especially in developing countries, by using conventional breeding and biotechnology to improve yields in both traditional and novel crops, and by improving input use efficiency (Fischer et al., 2009; Jaggard et al., 2010; Tester and Landridge, 2010). In this sense, global agriculture is moving forward to be able to meet projected demand. Since methods like increasing rotation diversity will increase yields (e.g., Gregorich et al., 2001; Munkholm et al., 2013) and increase fifth-F ecological function, synergies will be put in place to meet diverse and increased demand for the four F’s. With great certainty we can state that agricultural land must stay in production to begin to meet future demand, especially when factoring in biofuels, bioproducts and expanded requirements of ecologically functional farmland.

Other authors argue that the estimates of increased demand are based too broadly and cited irresponsibly (Tomlinson, 2011). The assumption that with increased income comes increased meat consumption is questioned by some, for example in the case of India, where most of the population is vegetarian. Nevertheless, it is clear that meat consumption is rising, particularly amongst urban populations and even in countries like India where a vegetarian diet is more culturally established. The assumption that increased demand requires increased production does not take into account that 30-50% of food produced ends up not as human sustenance, but in the waste stream (see Challenge 12: Food waste). Reducing food waste would substantially increase the food-provisioning capacity of our land base. Most importantly, the food system currently fails to provide for the global population, regardless of caloric production worldwide (Cirera and Masset, 2010; Tomlinson, 2011). When this outlook is taken into account, the question of increasing food production to feed the global population is an oversimplification of a disparity issue that is beyond the scope of agronomy to address (Giovannucci et al., 2012).

**Challenge 10: Conversion of agricultural land to other uses**

Type of change: Moderate  
Urgency: Urgent

Canada, for a geographically large, food exporting nation, has proportionally little agricultural land; 7% of our land mass is suitable for agricultural production and only 5% is dependable agricultural land (Class 1, 2 and 3 land; Hofmann et al., 2005). Although Canada has an
excellent network of protection mechanisms for farmland (Francis et al., 2012), we have lost nearly 8% of that dependable agricultural land to urbanisation, rural settlements and other uses like landfills. In Ontario, 11% of Class 1 land is under pavement (Hofmann et al., 2005; OFT, 2004). Some land in Canada, like the fruit-producing areas in the Okanagan Valley and the Niagara Peninsula, are so valuable for niche agricultural production that even small losses are problematic (Krueger and Maguire, 1985; Krueger, 2000; Beesley, 2010; Hofmann et al., 2005). Farmers who are retiring, or whose businesses are struggling, sell parcels of land for non-agricultural use (Caldwell and Weir, 2002; Caldwell and Hilts, 2005; Beesley, 2010) – in Canada this practice is much more common than in France, England and in some American states, where retired farmers’ principal income is from social security and private pensions (Lobley et al., 2010).

Keeping land in agricultural use can stimulate the economy by providing an economic multiplier effect of up to three times direct earnings from agriculture. However, this is not always apparent in decision-making, and development of agricultural land can be more immediately profitable (Francis et al., 2012). Strong initiatives like the Agricultural Land Reserve (ALR) in the Lower Mainland of Vancouver and the Greenbelt in the Greater Golden Horseshoe in Ontario need to be expanded and emulated (Smith and Haid, 2004; Friends of the Greenbelt, 2012). Where urban development is allowed to expand into farm land, it must do so in a way that supports agricultural and food systems, for example, by including facilities for market gardening and local food processing. Land trust programs also exist across the country and should be supported. Examples are the Ontario Farmland Trust, the Genesis Land Conservancy in Saskatchewan, the New Brunswick Community Land Trust and the Land Conservancy of BC (Caldwell and Hilts, 2005; Gorsuch and Scott, 2010). The loss of some dependable agricultural land from the ALR (35,000 ha) in the Okanagan, Vancouver Island and the Lower Mainland indicates that even protected areas are not entirely safe (Smith and Haid, 2004; Campbell, 2006).

Challenges

Challenge 11: Biodiversity

Type of change: Transformative
Urgency: Medium

Biodiversity is a difficult fifth-F service to quantify, thus it has been unaddressed by some researchers in mainstream agricultural production (MA, 2005a). Academia and organisations such as USC Canada have been advocating for the preservation of Canadian and global biodiversity (Frison et al., 2011; USC Canada, 2013). The agricultural system, by focusing on production of just a few commodities, has promoted simplicity and homogeneity over diversity as described in Section 2.1.2. There has been some promotion of a land-sparing concept, in which land is set-aside for biodiversity and functioning ecology, balancing high-intensity productive land (Green et al., 2005). An example lies in the American Conservation Reserve Program, in which 12 million hectares are set aside for ecological function and the eventualty of
extra land being pushed into food production (Cain and Lovejoy, 2004). The problem lies in scale: farmers as decision-makers are looking to maximize their economic success on a farm scale, and will usually only make ecologically-motivated choices when driven by legislation (Knowler and Bradshaw, 2007) or incentives. In Canada, wild protected areas cover 9.4% of total land area and are managed for conservation of natural biodiversity, recreational and cultural uses (FPTGC, 2010).

With rising land costs, increase and diversity of demand (four F’s), there is a risk farmers may seek to increase crop area by removing hedgerows and riparian zones. These are integral parts of the farm landscape and maintain fifth F natural biodiversity, water quality and climate regulation – for example, while only 13% of wildlife species in Canada can subsist on cropped land, 75% can subsist on “other” land: riparian, woodland, wetland or pasture (Silva et al., 2005; Eilers et al., 2010). In Canada, EFP’s have encouraged farmers to put riparian zones in place and consumers are becoming more likely to choose food based on a low environmental impact (AAFC, 2012a), but these are relatively small contributions. A food system that increases heterogeneity by increasing rotation complexity, set-aside areas for wild species and natural habitat (on-farm: hedgerows, windbreaks, woodlots, riparian zones; off-farm: nature conservation areas), and closed nutrient cycles by bringing livestock and crop production closer together, would be different from the one we have today.

Challenge 12: Food waste

Type of change: Transformative
Urgency: Eventual

Food waste, which includes agricultural waste from harvest and pest damage, through the marketing chain and into the home, accounts for 30-50% of food produced every year (Gustavsson et al., 2011; IMECE, 2013). In developing countries, post-harvest and storage losses are problematic, whereas in developed countries, post-consumer waste is the issue (Parfitt et al., 2010). Globally, Kummu et al. (2012) estimate that consumption waste could be decreased by 86%, and that if minimal losses were attained in all areas of food waste, current resources could feed an additional billion people. This strategy would also result in improved water quality and water use. In Canada, food waste is estimated to be 40% along the value chain and it costs the Canadian economy $27 billion per year (Gooch et al., 2010). Food waste varies over an estimated 20% for dairy, to 44% for vegetables, of food available for consumption. Most losses are at the household level (AAFC, 2012a). This is comparable to the picture in other developed countries (Godfray et al., 2010). In Canada, household food waste has been attributed to marketing strategies that encourage consumers to buy more than they need (Gooch et al., 2010). Although food waste is a challenge to measure and estimates difficult to compare, there remains no doubt that changing the way we process and consume food would change the system
dramatically. Also certain: addressing the food waste problem is important for reducing pressure on agricultural production and increases our ability to meet demands for all five F’s.

Tied in with the concept of waste in the food system is that of nutrients that were used to produce the wasted food. We have already discussed that N uptake efficiency of crops averages around 50% (Smil, 2000; Janzen et al., 2003). Why, then, does Smil (2012) estimate that the global food system has an N efficiency of only 15%? Inefficient use of N and P can also be considered a form of food waste. A great deal of N inefficiency in the food system is accounted for by livestock systems, which some authors include in measuring food waste: N that is taken up by crops is then consumed by animals, which in turn excrete much of that N. Pimental and Pimental (2003) estimate that it takes 6g of plant protein to grow 1g of animal protein; much of the plant protein used is directly consumable by humans. This is the basis of the food vs. feed debate: much human-edible food is used for feed – 2/3 of grain in developed countries goes to animal feed, representing a vast drain on the system’s efficiency. Alongside a diet high in animal protein – Canadians consumed about 95 kg of meat per person in 2010 (AAFC, 2012a) – has come overconsumption: more than 1000 extra kilocalories per day in developed countries (Smil, 2004). Transformative change to decrease the use of human-edible food products as animal feed could substantially increase the quantity of food available. Consumption of edible food (mostly corn and soybean) by livestock allows us to exploit economies of scale, but ruminants in particular are suited to eat grass, forage legumes and small grains (Oltjen and Beckett, 1996). Forage-based livestock systems may require more land (marginal or otherwise) but may also decrease inefficiencies surrounding animal production such as nutrient import and export, and have a positive impact on soil health if well-managed. These changes would require an increase in the amount of vegetable protein consumed by people in developed countries (Pimental and Pimental, 2003; Aiking, 2011).

**Challenge 13: Shortage of farm labour and decreased land ownership**

Type of change: Moderate
Urgency: Medium

Canada, like other developed countries, faces a shortage of people willing to work in agriculture. Labourers in primary agriculture account for only 1.6% of the workforce, compared to over 75% in developing countries (FAO, 2009). In a labour market survey by the Canadian Agricultural Human Resource Council, Canadian farms reported 9% vacancy rate and 20% vacancies for seasonal positions. 58% of farms across Canada reported difficulty hiring (CAHRC, 2009). Farming is neither attractive nor high-paying enough to hire or keep workers, especially when in competition with the oil and gas industry. Both issues require transformative change: when rural populations have largely migrated to cities and household expenditure on food is less than 10% (AAFC, 2012a), how do we maintain farming as a way of life? The workforce in primary agriculture is aging; in 2011 farm operators over 55 years made up 48% of the total, compared to
32% in 1991 (Statistics Canada, 2012). Migrant labour is beginning to fill some gaps (CAHRC, 2009) but change is needed in order to keep Canadian farms running. With older farmers and agricultural workers retiring, there is danger of a skill gap – this could be felt across the industry, not only in primary agriculture.

Bringing young farmers into the industry has significant benefits, not only to the sustainability of farming itself, but to the environment: young farmers, often with fresh education and ideas, are more likely to adopt environmental farm plans (AAFC, 2012a). Succession planning is currently supported by provincial agriculture bodies (e.g., MAFRI, 2012; OMAFRA, 2012) and financial institutions. Young farmers are supported through Canadian 4-H Council, Canadian Young Farmers Forum and the Outstanding Young Farmers’ Program which are funded by AAFC (AAFC, 2012b). However new farmers face significant barriers to entrance into farming such as lack of capital for land, equipment and quota, and heavy student loan burdens that would decrease their ability to handle increased risk and debt associated with getting into farming (AAFC, 2010).

Alongside a decline in labour, there is an increase in farming rented land by almost 5% in the past ten years (Statistics Canada, 2012). This may be related to the expense of purchasing land (AAFC, 2012a) and the increase in retired farmers who may wish for their land to remain farmland but are unable to work it themselves. Unfortunately, decreased ownership may mean decreased stewardship (Fraser, 2004), especially when considering practices with medium- to long-term effects such as riparian zones and strip cropping (Soule et al., 2000). It turns out that farm families with generations-long commitment to their land tend to implement soil conservation practices more often.
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<tr>
<th>Challenge</th>
<th>Type of change required (Incremental, Moderate, Transformative)</th>
<th>Urgency (Urgent, Medium, Eventual)</th>
<th>Comments</th>
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<tbody>
<tr>
<td>1. Limited liquid energy supply (running out of fossil fuels)</td>
<td>Transformative</td>
<td>Eventual</td>
<td>- Fossil fuel supply is exhaustible and prices may increase as reserves are depleted. This could theoretically cause food costs to rise, but volatility in oil and food prices have been due to political instability, not a shortage of oil reserves (Smith, 2009; Anderson, 2010). Technologies such as shale gas constantly extend supply estimates and a shortage does not seem imminent (Borger and Elliott, 2012) - Subsidies may be causing global inertia in seeking renewable alternatives to fossil fuel (IEA, 2011). The agricultural system is dependent on fossil energy and should begin to find renewable sources and become more energy efficient (De Schutter and Vanloqueren, 2011; Giovannucci et al., 2012)</td>
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<td>2. Energy, pesticide and nitrogen fertilizer use and climate change mitigation (reducing GHG)</td>
<td>Moderate</td>
<td>Medium</td>
<td>- Mainstream agriculture is dependent on energy intensive inputs that emit GHG and exacerbate climate change (N fertilizer, imported animal feed and mechanised farming practices). The agriculture sector emits 8% of Canada’s GHG’s and should increase input efficiency use to contribute to societal climate change mitigation efforts (EC, 2012) - SOC⁴ sequestered in agricultural soils have potential to help mitigate climate change (Smith et al., 2007; Stockmann et al., 2013)</td>
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<tr>
<td>3. Climate</td>
<td>Transformative</td>
<td>Urgent</td>
<td>- Increasing volatility in weather conditions, including drought</td>
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<td>Challenge</td>
<td>Type of change required (Incremental, Moderate, Transformative)</td>
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<tr>
<td>1. Climate and floods, changing temperature patterns, modified pest challenges and increasing CO₂ and ozone levels are predicted (Royal Society, 2008; Dukes et al., 2009; Li et al., 2009; Gornall et al., 2010). These may compromise the sustainability and resilience of the current agricultural system unless adaptive changes are implemented</td>
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<td>2. Agro-ecosystem resilience, 5th-F</td>
<td>Transformative</td>
<td>Urgent</td>
<td>- Independent of climate change effects, declines in ecological function have occurred as a result of prioritization on food, fuel, feed and fibre production. Decline in climate regulation and ecosystem supporting function have compromised the sustainability and resilience of agricultural systems. (MA, 2005a; Power, 2010) -Conservation practices, both on and off the farm, are important to maintain productivity of agro-ecosystems (Eilers et al., 2010; Tscharntke et al., 2012)</td>
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<tr>
<td>3. Phosphorus supply</td>
<td>Incremental</td>
<td>Eventual</td>
<td>-Current P reserves suggest that running out of P is not an immediate concern but currently, there is no alternative for rock phosphate in agriculture. This may be an issue in the future (Smil, 2000; Cordell et al., 2009; Van Vuuren et al., 2010)</td>
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<tr>
<td>4. Water quality</td>
<td>Moderate</td>
<td>Urgent</td>
<td>- Fertilizer, manure, and tillage systems interact and have resulted in numerous examples of water quality reductions due to nutrient loading and soil erosion. Examples of negative</td>
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<td>Challenge</td>
<td>Type of change required (Incremental, Moderate, Transformative)</td>
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<tr>
<td>7. Water supply</td>
<td>Incremental</td>
<td>Medium</td>
<td>- Globally, water scarcity is a growing concern, with altered precipitation patterns already resulting in reduced water supply (Vorosmarty et al., 2000; McGuire, 2009; Biazin et al., 2012). In Canada the situation is not as severe, but there is room for improved water use efficiency (Grassini et al. 2011)</td>
</tr>
</tbody>
</table>
| 8. Soil health | Moderate | Medium | - Global soil degradation is a severe problem with soil loss from erosion, soil salinization and desertification. Lack of organic matter returned to the soil causes a decrease in SOM\(^5\) and SOC, which maintain soil health, fertility and structure (Janzen, 2006; Wiebe et al., 2007; Verheijen et al., 2009; Lal, 2011)  
- Optimum levels of active SOM are crucial for sustainable stewardship of land and maintenance of productivity (Gregorich et al., 2001; Loveland and Webb, 2003; Hofmann et al. 2009)  
- The Canadian Prairies have implemented regionally-specific conservation tillage strategies which have decreased the risk of soil erosion by wind and tillage but Eastern Canada is faced |
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<tr>
<td>9. Food (and feed, fuel, fibre) production increase needed to match projected demand increase</td>
<td>Incremental</td>
<td>Eventual</td>
<td>-Food demand projections of 50-70% increase by 2050 are contested and are based upon distribution mechanisms that are inefficient and inequitable (Tomlinson, 2011)</td>
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<td>-Even with potentially inflated estimates of future demand, studies indicate that adjustments to the food system could be made to produce sufficient quantities of the first four F’s (Fischer et al., 2009; Jaggard et al., 2010; Tester and Landridge, 2010)</td>
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<tr>
<td>10. Conversion of agricultural land to other uses</td>
<td>Moderate</td>
<td>Urgent</td>
<td>-The loss of high-quality (Class 1, 2 and 3 land) to non-agricultural use permanently decreases our ability to maintain all five F’s (Hofmann et al., 2005; Francis et al., 2012).</td>
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<td>-Urbanisation and the sale of farm lots for residential use are major drivers for the conversion of agricultural land out of farming (Caldwell and Weir, 2002; Lobley et al., 2010)</td>
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<tr>
<td>11. Biodiversity</td>
<td>Transformative</td>
<td>Medium</td>
<td>-Biodiversity encompasses wild species biodiversity and on-farm diversity, and has been diminished by large-scale intensive production of crops and livestock (MA, 2005a; FPTGC, 2010)</td>
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<td>-With rising cost of land, farmers may be motivated to increase profit by removing areas with biodiversity function, like hedgerows, windbreaks and riparian areas in favour of</td>
</tr>
<tr>
<td>Challenge</td>
<td>Type of change required (Incremental, Moderate, Transformative)</td>
<td>Urgency (Urgent, Medium, Eventual)</td>
<td>Comments</td>
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<td>greater area for production. They may also decrease rotation complexity to produce more cash crops in fewer seasons. These practices are detrimental to biodiversity in the soil, on the farm and in the landscape and may impact soil health and water quality (Silva et al., 2005; Knowler and Bradshaw, 2007; Frison et al., 2011)</td>
</tr>
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</table>
| 12. Food waste                                                           | Transformative                                                   | Eventual                           | -Food waste includes post-harvest losses, wastage in retail stores and in the home (Hodges et al., 2011; Parfitt et al., 2010). 30-50% of all food is wasted and it costs the Canadian economy about CAD 27 billion every year (Gooch et al., 2010; Gustavsson et al., 2011)  
 -The use of human-edible food for animal feed is inefficient and causes nutrients to be imported and exported into systems which may not be able to absorb them. Plant protein may have lower external costs (Pimental and Pimental, 2003) |
| 13. Shortage of farm labour and decreased land ownership                | Moderate                                                        | Medium                             | -Canada faces a labour shortage in agriculture, an aging workforce and barriers to new entrants into agriculture research, industry and farming (CAHRC, 2012)  
 -The practice of farming on rented land is increasing (AAFC, 2012a) and may decrease soil stewardship (Fraser, 2004)                                                                                                                                                                                                                                    |

1 The type of change refers to the difference between the current condition of the Canadian agricultural system (defined in Chapter 2) and the future condition of the system after the challenge has been resolved. Incremental change: resolution can be achieved with small changes using existing practices, or is already moving forward substantially; Moderate: modification to the existing system is required to resolve the challenge
but the tools needed are largely available or in development; Transformative: agricultural system will be substantially different if the challenge is resolved, may require new technology or paradigm shift

2 The urgency rating is specific for Canada. Urgent: changes required in the next ten years; Medium: changes required in 15-20 years; Eventual: changes required in 30-50 years

3 GHG, greenhouse gasses

4 SOC, soil organic carbon

5 SOM, soil organic matter
Chapter 4. Selected strategies for adaptation

4.1 Solutions and strategies

Chapter 4 shows there are clear solutions to the challenges discussed previously, which will make the agricultural system more robust. We have given each type of strategy a specific focus and a timeframe. The type of change required and the urgency of the challenge, described in Chapter 3, are used to assign the timeframes, although in many cases the strategies address more than one challenge. For example, in solution 4, “increase farming system complexity and stratify land use to decrease risk of soil degradation, loss of farmland and increase land devoted to fifth F”, the strategy “increase landscape-scale commodity diversity” is given a timeframe of medium. This is despite the fact that increasing landscape diversity addresses biodiversity (transformative; urgent), water quality (medium; urgent) and soil health (medium; moderate). It also addresses the issue of food price instability that falls under two challenges: fossil fuels and increased demand for the first four F’s. Given that implementing increased landscape-scale farm diversity is a transformative change; stating that change could happen in the “immediate”-term (initiate the strategy within three years for measurable change this decade) is unrealistic. Giving a medium timeframe (inception within eight years for some measurable change by 2028), takes into consideration the layers of decision-making and associated change that go along with modifying the agricultural system’s land use.

Timeframes of medium or eventual (change in 2028-2050) do not mean that attention should not be paid to these issues immediately; it simply means that the implementation may be slower. For example, the issue of food waste and changing diets will require transformative change and will not happen overnight, thus the timeframe of execution has been defined as “eventual”. But education and awareness, which have already begun on the food waste and diet efficiency issues (e.g., Mayer, 2012; Tuttle, 2012) must be built upon steadily in order to effect that eventual change.

4.2 Increase rotation complexity

Timeframe: Immediate

Crop rotation complexity in some regions of Canada has significantly declined. In regions such as Ontario, more complex rotations have been replaced by corn- and soybean-based rotations. This decline has occurred in spite of the numerous benefits that are associated with more complex rotations: increased yield, increased yield stability, increased SOM, improved soil quality, reduced erosion, increased resource use efficiency, increased success of reduced tillage systems and greater opportunity for sustainable biomass removal (e.g., Copeland et al., 1993; Drury and Tan, 1995; Lemke et al., 2010; VandenBygaart et al., 2010; Campbell et al., 2011).
Increased crop rotation complexity can significantly contribute to the sustainability and resilience of agricultural production systems. Inclusion of winter wheat into corn-soybean rotations has been shown in Ontario to increase yield (Meyer-Aurich et al., 2006a), improve soil quality (Munkholm et al., 2013) and reduce GHG emissions (Meyer-Aurich et al., 2006b). Under stress environments the benefits of rotation complexity appear to be accentuated. In 2012, in a long-term rotation trial at the Elora Research Station, University of Guelph, under below-average precipitation levels, inclusion of winter wheat into corn-soybean rotation resulted in approximately twice the average yield benefit observed over the history of the trial (Deen, data unpublished). Given increasing concerns of precipitation extremes due to climate change, importance of rotation complexity could increase in the future.

Simplification of rotation is generally the result of producer perception that simple rotations are more profitable. Such perceptions may or may not be true, as suggested by Meyer-Aurich et al. (2006a). To encourage rotation complexity Canadian producers require economic incentives. These incentives could take various forms and could include: 1) economic analysis of data on simple versus complex rotations to address possible misconceptions growers have regarding relative profitability, 2) incorporation of rotation effects on yield and yield stability into crop insurance programs and 3) direct economic incentives to producers who use complex rotations, perhaps through mechanisms such as the EFP, where the incentives are based on environmental goods and services provided to society by crop rotation.

4.3 Secure land tenure

Timeframe: Medium

Having secure land tenure is generally expected to lead to good agricultural management (Panayotou, 1993) because growers who use long-term soil conservation practices may forego immediate revenue for the promise of better fertility and production in the future. As there are no guarantees that growers who rent land will benefit in the long term, farmers who rent are assumed to use strategies that promote short-term production even if this reduces long-term soil fertility. For instance, Gillis et al. (1992) point out that different land tenure agreements can impact on productivity as proprietors who own their land know that investment should pay off with better income. Based on research from Thailand, Praneetvatakul et al. (2001: 103) argue that, “…insecure land tenure may result in reduced incentives to improve land productivity.” Research from China leads to the conclusion that ambiguous property rights often encourage the “…irresponsible use of land resources” (Hu, 1997:175). Nowak and Korschning (1983) and Schertz and Wunderlich (1981) both conducted studies showing that farmers who own land use a broader number of management strategies and use more best management practices than renters. Ervin (1982)’s data confirms this, illustrating that erosion rates for owned fields are lower than rented fields (however, it is unclear whether this decline is due to land tenure or intervening site-specific variables). Fraser (2006) indicates that long-term leases are not a substitute for
ownership in a study that compared management practices on fields with different lease lengths and owned fields in the Fraser River Valley. Crop rotations were relatively simple on rented farmland regardless of lease length, with crop choices varying considerably between even 16 year leases and owner-operated land.

While the literature is clear that secure land tenure is necessary, there remains the problem of how to achieve this goal. In the developing world, many countries lack the legal frameworks to ensure land tenure for farmers is stable or even achievable (Ubink et al., 2009). This represents a major policy gap in many parts of Asia, South America and Africa. In Canada, the main reasons that farmers may feel they do not have secure tenure is when they rent their land or when they feel their farmland is likely to be absorbed by urban development. In both cases, there are ways that policymakers can help. Right to Farm legislation, which ensures that farm activities are given priority over urban or other uses, is one approach that has been tried in BC (BC Laws, 1996). Similarly, the ALR, Ontario's Greenbelt and Places to Grow legislation are designed to ensure that farmland has a long term future (Caldwell and Hilts, 2005). But these are only half measures. Until farming is an economically viable industry on the outskirts of Canada's cities, competitive with development for housing and retail, supported with an appropriate processing and retail industry, then there will be inadequate security for Canadian farmland.

4.4 Incentivize good soil stewardship

Timeframe: Medium

SOM is arguably a societal good and its maintenance or increasing proportions in soil is crucial to retaining productive capacity of food, feed, fibre and fuel (Janzen, 2006). The variability of climate change may result in too little or too much moisture at the wrong times (Li et al., 2009; Gornall et al., 2010) and soils with relatively high levels of SOM are expected to be more resilient (Kibblewhite et al., 2008).

SOM levels could be evaluated on each field by calculating inputs of C from manure, crop residue, cover crops, digestate and other sources. The annual C balance calculations as part of a nutrient management plan would also include assessments of C removal in crop products, crop residues and soil erosion. Another option for evaluating SOM is to measure the active fraction of SOM every five years, on each field. This may currently be considered to be too expensive and/or time-consuming with concerns about sampling density and sampling the same exact locations each time.

Incentives could be available to farmers who manage soil to maintain or improve SOM levels, even on rented land, by linking crop insurance premiums to SOM levels. As C balance calculations or regular measurements, for each field, indicate that SOM is increasing, premiums could decrease and similarly if SOM levels decrease, premiums could increase. These incentives
could be cost neutral to government, if C balance calculations or regular measurements are a condition for a farmer to obtaining crop insurance coverage on any given field. It is conceivable that over time, such a program would affect the sale value of farm land.

4.5 Paying more for food

Timeframe: Eventual

Some argue that consumers should pay more for food, incorporating externalities like indirect energy use costs into the price (Pollen, 2006). Many issues in agriculture could be improved upon by allowing consumers to pay full costs of food, which would incorporate costs to the environmental and the health care system: agricultural land might be more competitive with land for development, discouraging the loss of agricultural land; there might be more skilled agricultural labour; and substantially less food waste. Currently, Canadians spend an average of 9.8% of household income on food (AAFC, 2012a).

There is, unfortunately, a significant downside to a potential increase in food prices. The average percent of household income spent on food in Canada hides the fact that families in lower income brackets are spending proportionally more on food: from 13-16% of their income (AAFC, 2012a). They are also more likely to be food insecure: 29-48% of those lower income families were defined as food insecure by Health Canada (2007), meaning that they failed to access ample, quality food. If food prices were to increase, these families, and their children, would be even more at risk of hunger or insufficient nutrition, as we have seen on a global scale recently (Redwood, 2010). Suggestions to address the dual issue of cheap food and hungry people in Canada include the implementation of a national food policy which would include a school lunch program (FSC, 2011) or other ways to target those in need of assistance.
Table 3. Solutions and strategies for addressing challenges in the agricultural system. Solutions are broad while strategies are specific. Central concepts of each strategy are in italics.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Strategy</th>
<th>Timeframe of execution</th>
<th>Description</th>
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<tbody>
<tr>
<td>1. Decrease dependence on fossil fuels</td>
<td>Develop alternative, low-emission energy sources</td>
<td>Eventual</td>
<td>-Continue work on <em>improving and scaling-up alternative energy sources</em> (De Vries et al., 2007), while <em>increasing efficiency of current production and food system operations</em> to decrease fossil fuel use (Burgess et al., 2012). -Biodiesel can be made from used cooking oil, reducing food waste (Ma and Hanna, 1999).</td>
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<tr>
<td>2. Maintain/increase production in variable conditions while leaving more space for natural biodiversity</td>
<td>Decrease yield gaps</td>
<td>Eventual</td>
<td>-Identify and encourage <em>locally specific BMP’s</em> (nutrient management, timing of seeding, variety selection, weed, pest and disease control) which narrow gaps between farm yields and potential yield identified by researchers (Grassini et al., 2011; Hochman et al., 2012; Van Ittersum et al., 2012) -Breeding efforts focused upon hardy crops with <em>efficient N utilization, resistant to drought, flooding, new pest challenges</em> and pollutants like ozone are important (e.g., Comeau et al., 2010). -Exploit opportunities related to CO₂ fertilization and rising temperatures (Jaggard et al., 2010; Tester and Landridge, 2010). -Continuous breeding efforts to improve yield may prove fruitful as yield ceilings have, by some accounts, not been reached (Reynolds et al., 2009; Jaggard et al., 2010) -“Orphan” crops like plantain and cassava warrant more effort, as their genetic potential for breeding has received very little attention (Prochnik et al., 2012; Varshney et al., 2012) -Investment into education and funding the work of plant breeders (Tester and Landridge, 2010; Varshney et al., 2012) -Animal breeding for increased feed efficiency, to decrease footprint</td>
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<th>Solution</th>
<th>Strategy</th>
<th>Timeframe of execution</th>
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| 3. Sequester CO₂, improve soil health & water quality by increasing soil organic carbon | Keep the soil covered | Medium | - Inter/under-seeding, cover cropping, extended rotations that include perennial forages are ways to increase SOM³, sequester carbon and increase yields (VandenBygaart et al., 2003)  
- The quality of organic matter returned to the soil may be as influential as quantity, with deep-rooted forage grasses and legumes contributing more, and less quickly degradable, SOC⁴ than corn (Gregorich et al., 2001; Gal et al., 2007; VandenBygaart et al., 2011) |
| | Constrain OM³ removal and encourage OM returns | Medium | - Residue removal, *i.e. large-scale use of residues for biomass energy, threatens soil health and production potential*. Crop residues are an important source of SOM; their removal threatens already-tenuous maintenance of soil fertility, structural efficacy, water-holding capacity and a diverse soil biota (Franzluebbers, 2002; Janzen, 2006; Kibblewhite et al., 2008)  
- Crop residue retention with conventional tillage can promote a healthy, productive soil, while reducing tillage provides additional soil structural quality (by limiting break-down of soil C in the plow layer; Govaerts et al., 2007)  
- Leave residues on the soil surface when possible (Larney et al., 1997; Eilers et al., 2010)  
- In Eastern Canada no-till may not have the same benefits as in the Prairies, and may need to be combined with other strategies of residue management (Angers et al., 1997; VandenBygaart et al., 2002; VandenBygaart et al., 2003) |
<p>| | Reward farmers with increasing or high SOM | Medium | - <em>Policy should encourage soil stewardship</em> as well as commodity production (Olmstead and Brummer, 2008). |</p>
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<tr>
<th>Solution</th>
<th>Description</th>
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<tbody>
<tr>
<td>Encourage land ownership</td>
<td>-Land which is owned instead of rented is managed with a longer-term focus and soil stewardship is encouraged (Soule et al., 2000; Fraser, 2004; expanded in Section 4.3)</td>
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<tr>
<td>Increase rotation complexity</td>
<td>-Perhaps the best strategy for improving soil health and increasing soil organic matter is to increase rotation complexity – the effect of a forage legume rotation influences soil carbon more than N fertilization. Just adding a forage rotation to continuous corn, or corn-soybean rotation, can significantly increase soil health and yields (Gregorich et al., 2001; Davis et al., 2012, data from Ontario described in Section 4.2)</td>
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<tr>
<td>Reinforce EFP to more strongly encourage ecological function on-farm: riparian zones, hedgerows, windbreaks</td>
<td>-EFP’s prove quite effective in promoting the use of conservation strategies like riparian zones (Rajsic et al., 2012; AAFC, 2012a) but do not sufficiently encourage other “wild” areas like shelterbelts, windbreaks and hedgerows</td>
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<tr>
<td>Increase landscape-scale commodity diversity</td>
<td>-When seeking to optimize economic resilience, diversity on a landscape scale is important; to facilitate this, farmers could share resources (Abson et al., 2013) By increasing landscape diversity, nutrient cycles close (decrease the distance between livestock and crop operations), pest challenge could decrease and costs in pest prevention could be reduced, as well as water contamination by pesticides (Meehan et al., 2011)</td>
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<td>Solution</td>
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<td></td>
<td>Limitations on use of marginal land for row cropping</td>
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<td></td>
<td>Enhancement of policy protecting agricultural land</td>
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</table>
| 5. Close nutrient cycles | Change dynamics of food-feed production | Eventual | - Forage-based livestock systems and the use of human-edible food for food, not feed, increases efficiency of nutrient use – at the same time changing the nature of animal production (Krausmann et al., 2008; Tomlinson, 2011) Feeding animals food that has been rejected by humans and would otherwise go into the waste stream tackles part of the waste issue – the
<table>
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<th>Solution</th>
<th>Strategy</th>
<th>Timeframe of execution</th>
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<tbody>
<tr>
<td>54</td>
<td>Solution Strategy Timeframe of execution</td>
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<td></td>
<td>Decrease impact of large livestock operations by incorporating livestock into cropping systems and improving nutrient use efficiency</td>
<td>Eventual</td>
<td>-Moving toward more integrated crop-animal systems will ease the problem of manure storage and transportation (Davis et al., 2012). -Crop and animal breeding and feed additives can increase the efficiency with which livestock metabolize nutrients (Steinfeld et al., 2006; Kereab et al., 2011)</td>
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<tr>
<td>6. Improve efficiency in food system to mitigate GHG, increase production, decrease energy use and improve water quality</td>
<td>Increase adoption of EFP and implementation of BMP</td>
<td>Immediate</td>
<td>-Environment Canada indicates that NMP and EFP have been effective in decreasing nutrient loading in water (Eilers et al., 2010). -EFP’s increased implementation of beneficial management practices in manure, fertilizer and pesticide application, riparian management, soil erosion control including increasing rotation complexity and wastewater management (AAFC, 2011). -On the other hand, there are areas such as the Abbotsford aquifer which have not seen measurable improvement in water quality due to NMP (Chesnaux et al., 2007)</td>
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<td>Fine-tune nutrient and pesticide applications and irrigation</td>
<td>Immediate</td>
<td>-Follow BMP’s such as soil and manure testing prior to nutrient application, calibrating sprayer equipment, use of a licensed custom pesticide applicator and improving timing of nutrient and pesticide application (e.g., ARDCORP, 2011) -Use precision agriculture technology to optimize farm operations (Gebbers and Adamchuk, 2010) and use inputs more strategically, combined with diversified rotations (Davis et al., 2012) -Switch to pivot or trickle irrigation and improve irrigation schedules</td>
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<td>Solution</td>
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<td>Timeframe of execution</td>
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<tr>
<td>Improve education, outreach and extension for farmers and the public</td>
<td>Medium</td>
<td>(Grassini et al., 2011)</td>
<td>- Improving farmers’ access to information, especially using ICT⁹ (Meera et al., 2011), narrows the production-research gap and allows farmers to make more informed decisions. - Public awareness about agricultural issues increases consumer pressure on the agricultural industry to improve 5th-F services (Daily et al., 2009; NAS, 2010)</td>
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<tr>
<td>Decrease consumer waste in the food system</td>
<td>Eventual</td>
<td></td>
<td>- Education and awareness to reduce food waste and to change retail and consumer habits such that blemished, small and large fruit and vegetables are accepted, promotions encourage buying some now and picking up bonus food later, consumers prepare the exact amount of food to be consumed and/or develop plans to consume leftovers (Parfitt et al., 2010; IMECHE, 2013) - Find alternate uses for food and processing waste, such as composting or animal feed (Godfray et al., 2010; Gustavsson et al., 2011) - Increased food prices¹⁰ would increase the efficacy with which people use their food (IMECHE, 2013)</td>
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<tr>
<td>Change eating habits by diversifying protein sources and eating whole foods</td>
<td>Eventual</td>
<td></td>
<td>- Nutrient excesses and CH₄ emissions from livestock limited by decreased meat consumption, allowing for diversified farming systems and more crops available for direct human consumption (Smil, 2000; Pimental and Pimental, 2003; Aiking, 2011) - Less livestock would mean fewer CH₄ emissions from ruminant metabolism and manure storage, and ruminants facilitate more forage production, which improves soil quality and stores SOC (Hindrichsen et al., 2006; Hofmann et al., 2009)</td>
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<tr>
<td>Solution</td>
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<td><strong>immediate</strong>: within three years for measurable change this decade, <strong>medium</strong>: within eight years for some measurable change by 2028, <strong>eventual</strong>: within 30 years for large-scale/transformative change by 2050-2100</td>
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<td><strong>immediate</strong></td>
<td>Eating whole foods to move away from energy-intensive food transport and processing, minimize processing waste and excess caloric intake (Pollen, 2006)</td>
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<tr>
<td>7. Sustain the agricultural workforce</td>
<td>Support young farmers</td>
<td>Medium</td>
<td><strong>Enhance policy regarding succession planning and young entrants</strong> into farming, including relief from student debt (AAFC, 2010)</td>
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<td></td>
<td>Increase competitiveness with other industries</td>
<td>Medium</td>
<td><strong>Promoting agriculture as a positive and dynamic career choice</strong> may draw educated, engaged individuals to fill a skill gap left by retirees (CAHRC, 2009).</td>
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<td>-Increasing the cost of food, direct marketing and targeting niche markets: farm employers might be more competitive with high paying industries like oil and gas if the price of food went up. Farmers can sometimes get the same effect by cutting out the middle man or exploiting alternative markets (RTI International, 2007)</td>
</tr>
</tbody>
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1. Recommended time frame of action for a strategy’s inception is a) immediate: within three years for measurable change this decade, b) medium: within eight years for some measurable change by 2028, or c) eventual: within 30 years for large-scale/transformative change by 2050-2100
2. BMP, beneficial management practice
3. SOM, soil organic matter
4. SOC, soil organic carbon
5. OM, organic matter
6. EFP, environmental farm plan
7. CLI, Canada Land Inventory
8. NMP, nutrient management planning
9. ICT, information computer technology
10. There are significant problems with the idea of increasing food prices as a solution to agricultural challenges; see the comments in Section 4.5
4.5 Strategic synergies

Table 4 shows the relationship between the challenges described in Chapter 3 and the solutions in Table 3. The seven categories of strategies are on the far left in vertical writing followed by the strategies themselves. For example, the strategy “increase EFP adoption” has checkmarks to describe what challenges it is addressing; if more farmers were to adopt EFP’s and put in place BMP’s accordingly, fossil fuel supply would be affected by the more efficient energy use when applying fertilizer and pesticide (using soil tests, IPM or a certified pesticide applicator), at the same time mitigating climate change by decreasing emissions from chemical/manure application and by increasing soil stewardship and on-farm set-aside areas to sequester carbon. Climate change adaptation would be addressed by increasing soil health for better resilience during drought and floods, P supply by increasing P use efficiency (better application practices), water quality by riparian and nutrient management, soil health as described, increased 4-F demand by improving soil quality and carefully monitoring fertility to increase yields, and biodiversity by using soil conservation strategies and set-aside areas, increasing soil biota diversity, crop rotation diversity and wild species diversity for the animals that use hedgerows, perennials and riparian areas for habitat.

We have discussed how a focus on production of the four F’s has historically degraded agro-ecosystem function. By also focusing upon the challenges, the areas of vulnerability which impact the fifth F, the agricultural production system will be reinforced, made more adaptable and reactive to shocks and threats.
Table 4. Which strategies (first two columns) will positively affect the challenges (top row)?

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Fossil fuel supply</th>
<th>Climate change mitigation</th>
<th>Climate change adaptation</th>
<th>P supply</th>
<th>Water quality</th>
<th>Water supply</th>
<th>Soil health</th>
<th>Increased demand for 4 F’s</th>
<th>Loss of farmland</th>
<th>Biodiversity</th>
<th>Food waste</th>
<th>Ag. labour &amp; land tenure</th>
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<tbody>
<tr>
<td><strong>Fossil fuels</strong></td>
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<tr>
<td>Develop alternative energy sources</td>
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<td><strong>Production</strong></td>
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<tr>
<td>Decrease yield gaps</td>
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<td>Crop &amp; animal breeding</td>
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<tr>
<td>Cover &amp; companion cropping, perennials</td>
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<td>Retain crop residues</td>
<td>√</td>
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<td>Reward high SOM²</td>
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1 SOC, soil organic carbon  
2 SOM, soil organic matter  
3 EFP, environmental farm plan
Conclusions

Narrowly emphasizing production of food, feed, fuel and fibre can be detrimental to ecological functional services and can lead to reduced resilience in the agro-ecosystem. In Canada, agriculture has intensified, which has resulted in high levels of production but has also had some negative impact on the supporting ecosystem. Alternative systems address some of the problems on a small scale. These alternatives should be incorporated into our view of the agricultural system as a whole, in order to make use of the ideas and biodiversity that reside in alternative agriculture.

Addressing challenges in agriculture, such as poor water quality, loss of biodiversity, degraded soils, food waste and greenhouse gas emissions, will create synergies over time to maintain or increase food production in a variable climate, decrease fossil fuel use, conserve P and water, and improve agriculture’s image. Transformative changes are required in the short- and medium-term to adapt to climate variability (increase resilience) and promote biodiversity, and to decrease food waste in the long-term. Water quality can be addressed with more moderate magnitude of change but needs urgent attention. Soil health and water supply, while representing serious issues globally, are less urgent in Canada due to good soil stewardship in the Prairies and limited use of irrigation across the country. Soil health in particular cannot be ignored particularly in areas where crop rotations are becoming less complex (Ontario) and there is demand for crop residues for biomass energy. The action taken in the Prairies to conserve soil and improve soil health with conservation tillage, alongside diversified crop rotations, has also increased yields – an excellent example of the synergies suggested above. By shifting our focus to ecological functional services provided by agriculture, and the resilience they provide, we increase adaptability and sustainability in the agro-ecosystem while continuing to promote a highly productive system.
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