ORGANIC AND CONVENTIONAL AGRICULTURE: ASSESSING SYNERGIES BETWEEN AGRICULTURAL APPROACHES

by

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Abstract

Organic agriculture (OA) and conventional agriculture (CA) represent two polar approaches to farming, both of which employ their own methods and farming practices. OA and CA both hold their own challenges and implications within the global food chain, particularly with respect to the impending global food crisis coupled with climate change. These issues present pressing agricultural questions leading us to ask how our farming methods will adapt to feed the world's burgeoning population while maintaining the viability and health of the world's ecosystems. This study performed a literature review type of examination on three crops grown in Canada: wheat (*Triticum* spp.), corn (*Zea mays*) and canola (*Brassica napus* L.). Three categories of farming methods were observed (use of fertilizers, use of pesticides and levels of soil tillage) as farming methods characterising OA and CA. Using yields as an indicator of method success, new farming systems combining various method approaches were extrapolated while bearing in mind the scale at which farming occurs in Canada, the GHG emissions associated with the use of conventional fertilizers, and the need for yield. Ultimately, this project aims to reconcile OA and CA farming practices in the best interests of human well-being and the environment from a Canadian perspective.

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List of Common Abbreviations

CA	Conventional Agriculture
CT	Conventional Tillage
GHG(s)	Greenhouse Gas(es)
GM(O)	Genetically Modified (Organism)
IPM	Integrated Pest Management
NT	No Tillage
OA	Organic Agriculture
RT	Reduced Tillage

1. Introduction and Literature Review

1.1. The Food Crisis and Climate Change

The world's population currently stands at just over 6.7 billion people and is projected to surpass 9 billion by 2050 (UN 2006). The picture becomes increasingly grim as the world's resources continue to be depleted at an unsustainable rate and as the level of greenhouse gases in the atmosphere continues to rise correspondingly. One of the concerns tied to population growth is food and how to feed a burgeoning population. The matter goes on to question how this will be done while ensuring that crop farming doesn't continue to erode the health of the Earth's ecosystems.

The evolution of agriculture can be thought of as an assisted growth process using human interventions in plant growth conditions to maximize yield for sustenance. Over time, these activities have become the standard set of methods and practices employed, with variations from culture to culture and from food system to food system. However, it can already be witnessed that traditional methods of food production are failing to provide a solution to the expected food shortage (Iqbal 2010). Current degradation rates of the planet's natural resources and use of arable land for farming holds serious implications for resource management and need for increased food production (Warner *et al*. 2010). The literature suggests a growing sense of concern over the matter with evidence in an increasing number of studies experimenting to refine farming methods to maximize crop yields on local scales. Studies describe planting crops in narrower and denser rows while continuing to refine levels of fertilizer applications to maximize crop yields tailored to geographical conditions (Bootsma *et al*. 2005, Kaut *et al*. 2009, Mason *et al*. 2007, Parent *et al*. 2007, Wen *et al*. 2003).

Plants and crops sequester carbon naturally for their growth and development with a naturally net to negative carbon footprint. However, agriculture in Canada still produces 8% of the country's total GHG emissions (AESA 2004). The GHGs emitted from energy-intensive farming agriculture and transportation are inevitable contributors to the greenhouse effect spurring climate change. Agricultural emissions could be of greater concern than any other sector because of the range of GHGs agriculture produces. Over a time scale of twenty years, methane and nitrous oxide have global warming potentials 72 (IPCC 2007) and 296 greater (UNESCO-SCOPE 2007) than carbon dioxide, respectively contributing proportionally more to global warming per unit of emission.

The health of the planet's ecosystems becomes increasingly compromised (Lynch 2009), and inextricably linked to human health and well-being, as the resource-intensive approach to agriculture continues to exercise several of its methods (Dyer and Desjardins 2009). For example, farms that irrigate crops or extract groundwater as methods of crop watering merits associated concerns on freshwater availability (Rosegrant *et al*. 2009). In the meantime, farms that grow genetically modified (GM) crops should consider their impacts on regional ecosystem health and the preservation of genetic diversity (Benton *et al*. 2003, Lynch 2009). These practices help to ensure a steady yield of nutritionally valuable food but produce climate-changing GHGs as a by-product of such intensive energy use.

The way by which most of modern agriculture is exercised and distributed, and the scale at which it is done, presents a system vulnerable to collapse under surmounting socioeconomic pressures (Fraser 2006). It will play directly into how the global food system, built on an environmental equilibrium that has already started to tip (Godfray *et al*. 2010, Rosegrant *et al*. 2003), will approach the social and ethical pressures of ensuring that the world's population is nourished at an economically affordable rate. Food prices have risen globally (Hertel *et al*. 2010, Wise *et al*. 2009), indicating that the combination of these issues is greater than the total sum of its parts. For Canada, this means that most households should be expecting a minimum 6% increase in food prices by the end of 2011 (Grant 2011). The World Bank recently reported a 29% increase in their food price index; a clear indication of a stressed food system and the pressing need for an objective look at how food is produced (Waldie 2011).

1.2. Conventional Agriculture

Modern agriculture has been working within the global food system to feed the world's urbanized masses via a gamut of advents in farming practices (Fraser *et al*. 2005) to become what is now known as industrial agriculture. The mass production of food through the techniques that define modern agriculture has led to the conventionalization of agriculture in a technocratic approach to agriculture (Fraser, personal communication). The intensive farming that characterizes modern agriculture uses a higher amount of labour and chemicals per unit area than any other approach to farming. Much of this labour is mechanised to allow for a much more efficient use of land, providing a higher yield-output to human labour-input ratio. However, this conventional and mechanized form of agriculture is extremely energy intensive, requiring fossil fuels to power the machines that allow humans to farm on such a large scale (Pimentel *et al*. 1973, Pimentel *et al*. 2005).

One of the defining methods that CA employs is the use of conventional fertilizers (Crews and Peoples 2004). Applied conventional fertilizers come in various standard N-P-K ratios for application on a crop. Fertilizers provide renewed applications of nutrients onto the soil, effectively removing consider long-term strategies to retain and replenish soil nutrient and soil organic carbon. Fertilizers are also the cause of one of the primary concerns of CA. Methane and nitrous oxide emissions are respectively the second and third most important GHGs after carbon dioxide (UNESCO-SCOPE 2007), and their emissions from agricultural fields has been greatly increased with the application of ammonium-based

Environmental problems that have arisen from the use of conventional fertilizers highlight the disjunction between intensive industrial farming and care for natural ecosystem processes. For example, conventional fertilizers are used to provide an abundant amount of nutrients in biochemically available forms, but the scale at which fertilizers are applied coupled with the natural water cycle has led to nutrient-loaded runoff that feeds into aquatic systems (Goetz and Zilberman 2000). The loss of dissolved oxygen driven by nutrient-laden waters has led to the eutrophication of coastal regions and lakes throughout North America, altering ecosystem dynamics of entire aquatic systems (Carpenter *et al*. 2009).

The post-World War II Green Revolution produced another example showcasing the large divide between CA development and environmental considerations. The first suite of synthetic pesticides was produced, leading overtime to the refined synthesis and common applications of pesticides to eradicate pest insects, weeds, and other undesired organisms. Pesticides are used to control natural biological processes that disrupt the homogeneity and production efficiency of industrial crop farms by disrupting the natural chemical functions (Hussain *et al*. 2009) of unwanted organisms in the farm system. The problem herein lies in the chemical selectivity of the pesticides and the biological evolution of tolerance and resistance to these pesticides, rendering them ineffective and biochemically obsolete. Furthermore, human consumption of foreign and synthetically produced chemicals is an aspect of agriculture that the general public is none to comfortable with (Dunlap and Beus 1992).

The introduction of GMOs presented a technocratic solution to the biological problems associated with excessive pesticide use. GMOs gave farms the ability to grow masses of phenotypically and genotypically monocultured crops, fitting into the CA system by allowing the creation of machines specialized to handle vast quantities of single crop types. Such a precise specialization of crops delivers an even higher yield output per unit of energy input (Gardner 2003), resulting in less land required for farming and leaving more natural land intact.

As a whole, the mechanization of farming in today's conventionally industrial agriculture has brought about an approach to farming that is disconnected from the earth and the people it feeds. The growing number of links in the food chain renders it harder and harder to see firsthand the ecological impacts that conventional farming has (Cone and Myhre 2000), facilitating the ease with which we can forget its connection to climate change and food security.

1.3 Organic Agriculture

The ecological impacts of CA have been called into question, allowing for the emergence of organic agriculture (OA) as an alternative approach to farming. OA is seen as a holistic approach to food production, basing its principles of practice on sustainability by focusing on the importance of long-term ecosystem health by excluding or limiting the use of conventional fertilizers, pesticides and GMOs (Pimentel *et al*. 2005). Because of the strict limitations on OA, many regulatory bodies exist to ensure that organic farms uphold to certain standards in order to sell their products as certified organic. The demand for sustainably farmed and chemical-free foods has provided organic foods with a price premium.

OA has had to adapt to maintain yields that are competitive with CA yet remain in line with its sustainability principles. Many farming techniques used by organic farmers have come about as a method of remaining competitive while adhering to the organic farming standards placed upon them (Cranfield *et al*. 2009, Grey 2000). One common concern with farming is the gradual depletion of soil nutrients and soil organic carbon with each passing year of growth on farmland. Where CA would apply conventional fertilizers abundant in nutrients and organic carbon, OA relies on techniques such as crop rotation and the application of manures.

An organic farmer can opt to use animal manures which retain nutrients more effectively and reduce overall runoff (Pote *et al*. 2003), or the farmer can choose to plant leguminous cover crops in a crop rotation to fix nitrogen and replenish its bioavailability in the soil (van Kessel and Hartley 2000). Unfortunately, legumes may present competition for resources. Crop residues from previous growths may be cycled back into the soil as another alternative to the use of conventional fertilizers. In the case of phosphorus and potassium, organic farmers may also use mineral powders from rock phosphate and potash to provide the two remaining macronutrients, respectively (Pelletier *et al*. 2008).

Typically, OA tills the soil as a method of weed suppression and control as well as for soil nutrient rotation (Barberi 2002) provided from one of the alternative sources discussed above. Other methods organic farmers may use to physically control weeds include standard mowing or flame weeding to burn weeds and their seeds (Perruzzi *et al*. 2007). Badgley *et al*. (2007) argued that OA can feed the world yet it was counter-argued in a response that tillage in OA of corn is observed to be more detrimental to the condition and nutrition of the soil. This difference in the utility of tillage in OA is just one example of how little is known of its potential as a farming system to feed the world.

Pests cannot be addressed with the exclusive use of pesticides in OA, leaving organic farmers to use integrate multiple approaches to pest control in what is now known as Integrated Pest Management (IPM). IPM aims to control pest populations through constant crop monitoring to maintaining healthy crops and avoid diseased crop plants and physical involvement with pest removal on the crops. In worst-case scenarios, minimal amounts of chemical pesticides are used after having tried biological controls in the form of other organisms or natural plant compounds to deter pests (US EPA 2011).

These practices demonstrate that OA is centred around sustainability and long-term health. OA farms are typically associated with Farmer's Markets and Community Shared Agriculture movements, shortening the food chain and illustrating the relationship between the farm and the plate (Cone and Myhre 2000, Dupuis and Gillon 2009, Grey 2000, Smithers *et al*. 2008). However, achieving the same yield as a CA system requires much more energy input per unit of land or per unit of yield, energy input that would typically come in the form of time or human labour.

OA commands a higher price premium than CA because of its appeal to consumers who desire chemical-free foods and because of the labour costs associated with the farming efforts required (Jansen 2000). So while OA may provide a much more ecologically sound approach to agriculture, with minimal use of GHG-emitting machines and long-term natural farming strategies, it is still lagging in its competitive ability to yield enough food to feed the growing population at an affordable rate (Connor 2007).

1.4 Research Question

The importance of food production and the methods by which we approach agriculture will only continue to become more and more intertwined with the planet's health and human well-being. OA and CA present two alternative principles, and thus approaches, to farming. This research project aimed to examine the literature for any evidence that could suggest a combinatory and synergistic approach to agriculture for yield optimization using three commonly grown crops in Canada: wheat, corn, and canola. To lay the foundation for such an examination, two research questions were posed:

1. Assuming that OA and CA can be combined, can there be a new set of farming practices and methods based on the those already employed?
2. Can the combination of OA and CA methods and practices be analyzed and compared critically using crop yield as a measure of success?

As a response to the research questions, it was hypothesized agricultural synergies can be achieved by combining both OA and CA practices and methods to increase yields for human benefit while trying to mitigate agricultural effects on climate change.

2. Comparative Analysis: Laying Down the Groundwork

Above all else, a definition of OA and CA were required to provide a defined project framework for an effective comparative analysis. Rather than focusing on the standard definitions of OA and CA provided by food regulatory bodies such as the Canadian Food Inspection Agency and United States Department of Agriculture, definitions were based on the actual farming methods and practices employed by organic and conventional farmers (Table 1, below).

The project was approached as being similar to a literature review, allowing the bulk of the data to be acquired from the available literature through the Queen's University library databases. Further data was acquired from information available on the Statistics Canada database, with most of the information originating from the 2006 Census of Agriculture. Where observations from the literature were qualitative (e.g.. Pelletier *et al.* [2008] mention that OA yields of corn are 5% lower than CA), values from Statistics

Table 1. Farming methods used in conventional and organic agriculture. For the purpose of this analysis, the **x** denotes that the farming practice is allowed for the specified agricultural approach.

	Agricultural Approach	
Farming Practice	Conventional	Organic
IF	**X**	
OF		**X**
NF	**X**	**X**
Pesticide	**X**	
CT	**X**	**X**
RT	**X**	**X**
NT	**X**	**X**

IF – inorganic fertilizer
OF – organic fertilizer
NF – no fertilizer
CT – conventional tillage
RT – reduced tillage
NT – no tillage

Canada provided baseline values allowing values to be benchmarked and awarded to the qualitative information. Once all the data was acquired, it was placed into a spreadsheet, recording yields, farming methods described and used, how studies defined their trials as conventional or organic, study crop(s), and any other relevant information.

Yield in tonnes per hectare (t/ha) were used as indicators of a crop's success under the different farming regimes to quantify the effectiveness of fertilizer usage, pesticide usage and the level of soil tillage. Conventional farming systems can exercise many more combinations of farming practices so long as inorganic conventional fertilizer is used and/or pesticides. Organic farming cannot allow either except under specially regulated circumstances. The types of fertilizers applied to each system was evaluated as inorganic fertilizer, organic fertilizer (animal manure, green manure, or the use of leguminous crops), or no fertilizer treatment. To accompany that, tillage was evaluated at three different levels to compare the intensities of their usage: CT (conventional tillage), RT (reduced tillage), and NT (no tillage). As a farming practice, tillage was used as a means to evaluate the amount of mechanized labour used. Figure 4 illustrates crop yields in weighted means to provide each recorded yield equal weight for each crop and farming type. Where crop yields are indicated as 'N/A', the data on methodology was incomplete by failing to discuss which how crops were or were not farmed. Without the exclusion of said data, no safe assumptions could be made without skewing the remainder of the collected data. Thus, it is equally likely that any corn trials observed had or had not undergone a no-tillage growth regimen, or for any other incomplete field data.

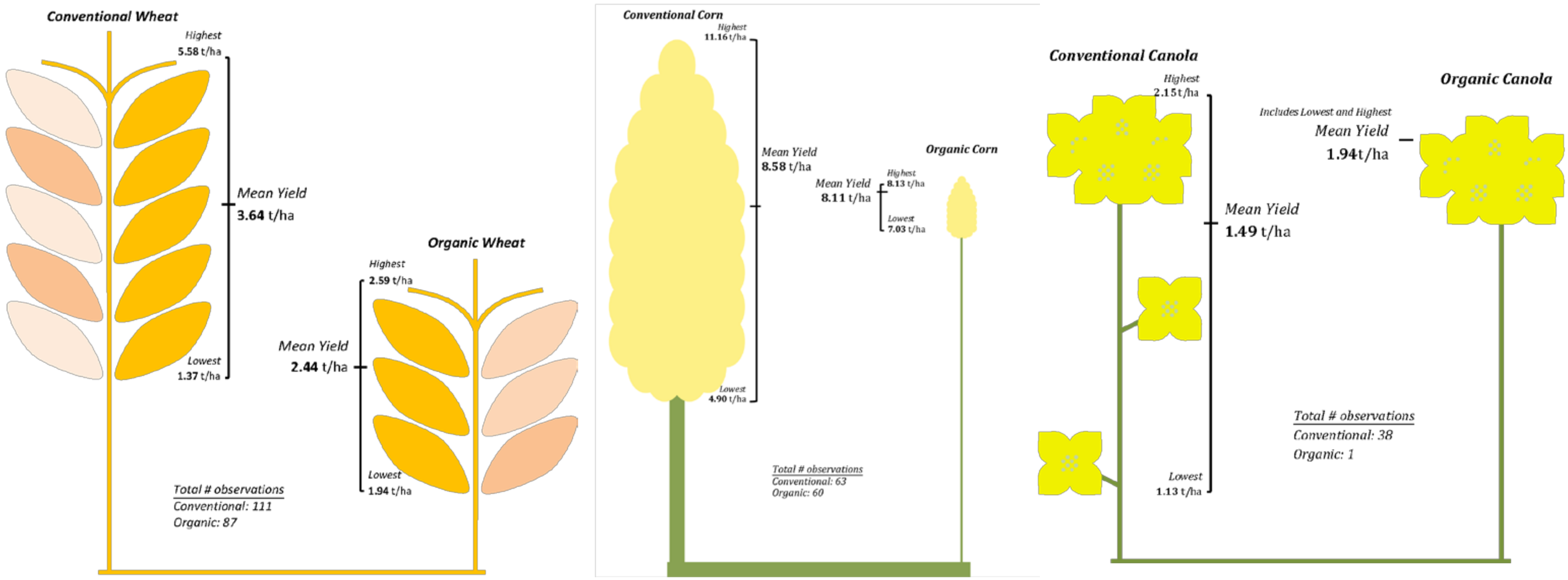

Figure 1. Observed yield ranges for conventionally and organically grown wheat, corn and canola, as well as the total number of observations for each crop.

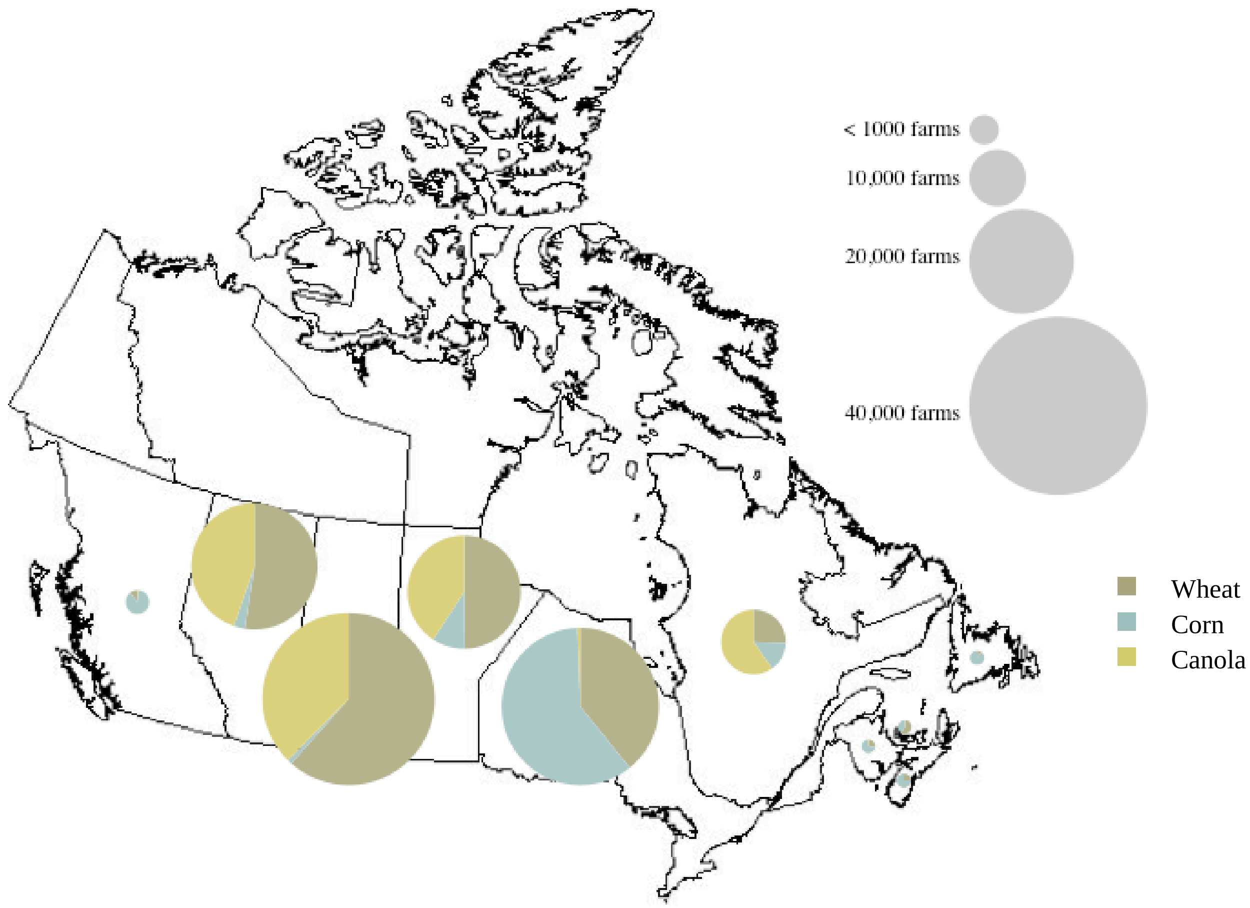

Figure 2. Farms across Canada devoted to wheat, corn and canola farming as of 2006. No data was available for the Yukon, the Northwest Territories and Nunavut. Refer to Appendix A for the raw data in each province and crop type.

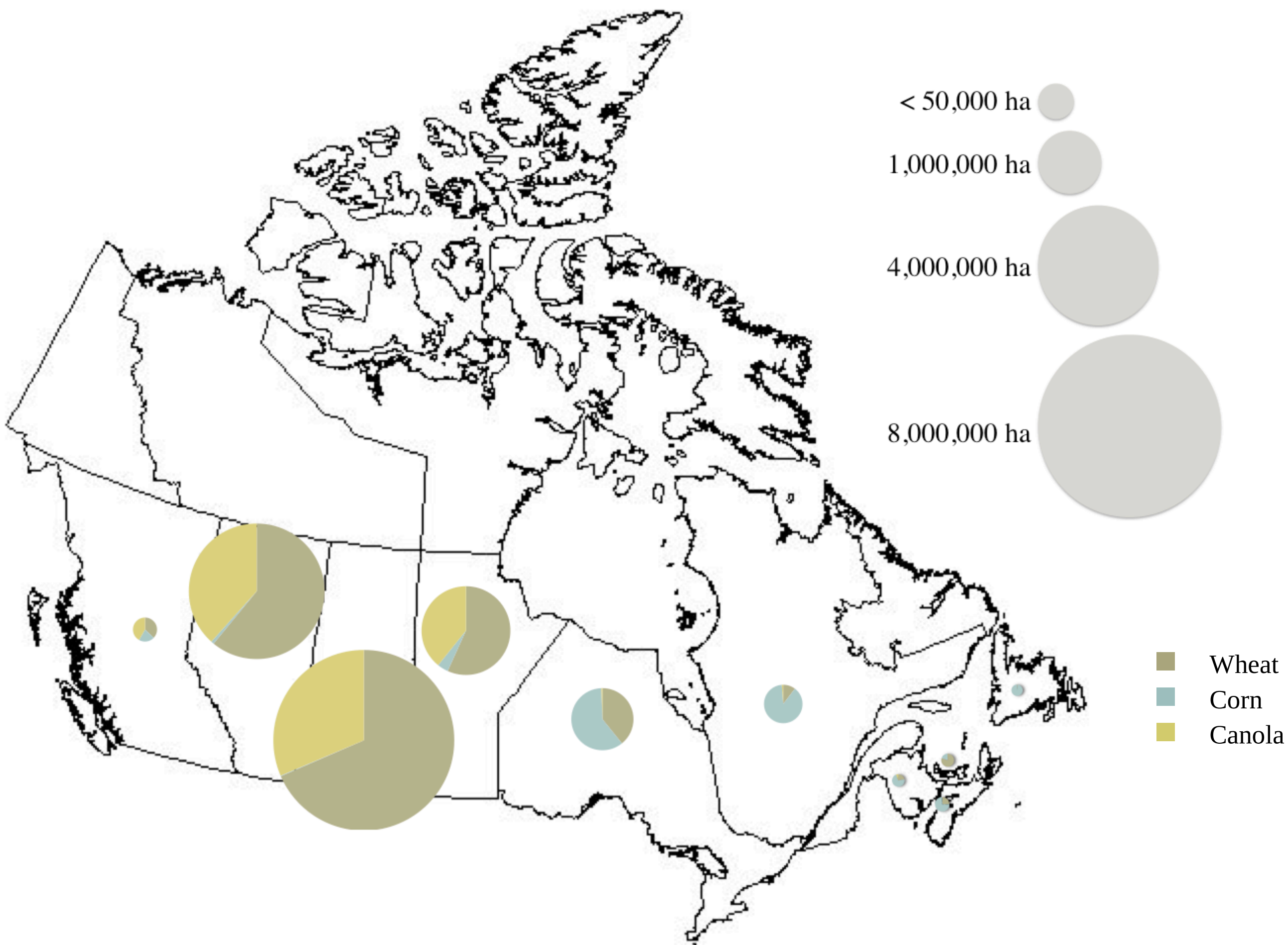

Figure 1. Provincial production of wheat, corn and canola by hectare in 2006 within Canada. No data was available for the Yukon, the Northwest Territories and Nunavut. Refer to Appendix A for the raw data in each province and crop type.

2.1 Study Crops

Wheat (*Triticum* spp.), corn (*Zea mays* L.) and canola (*Brassica napus* L.) were chosen to the three crops of study since they represent over 10% of Canada's farms, major constituents of Canadian agronomy (Statistics Canada 2006). Wheat and corn are major cereals that make up a large portion of the human diet while canola is a Canadian-bred type of oilseed (Source: MGCA). With the prospects of biofuel as an alternative energy source, large and consistent yields of corn and canola are being sought for biofuel production (Singh and Kumar 2011), playing a large part in the diversion of food crops to biofuel crops and the subsequent rise in corn-based food prices (Koning *et al*. 2008).

Wheat has a multiple strains and cultivars, being bred and cross-bred with one another on a regular basis for the selection of geographically-specifically high performance crops. In Canada, the focus is placed on four major types of wheat, durum (*Triticum durum*) for the production of pasta products being high in protein and gluten (Liu *et al*. 1996), common wheat (*Triticum aestivum*) for breads, and spring and winter wheats combined for all-purpose flours used in a variety of baking products (Johansson *et al*. 2001). Each of these types of wheat can be planted at different at different times of the year.

Corn is one of the first crops to have been domesticated by humans, originating from Central America and spreading outwards throughout the world over time. It is a staple food for many people globally, edible in many forms, and a major source of complex carbohydrates. As mentioned, corn biomass is increasingly being used as an alternative energy source with the production of ethanol. The high cost of traditional oil has led to a greater demand for ethanol, inadvertently resulting in new economical cost dynamics for corn (Singh and Kumar 2001).

As an oilseed crop, canola is an extremely versatile crop. Canola seeds produce oil that is low in erucic acid, a known toxin (Busch *et al*. 1994, Parke and Parke 1997), giving canola oil a common usage as a cooking oil as well as an ingredient in a variety of other products, including biofuels. Although not as advanced as corn-based ethanol production, canola seeds' naturally high oil content at 43% (Canola Council 2007) gives it great potential as an alternative energy source. Canola is also the crop of much contention, being farmed largely as a GM crop rendering it difficult to be farmed organically. A popular case of GM canola and GM patents causing problems in Canada involves the corporation Monsanto and its legal battles with a Canadian farmer, Percy Schmeiser, regarding its GM RoundUp Ready canola crops (Semal 2007). Canola merited inclusion in this analysis for its major role in Canadian agriculture regardless of how it is farmed.

2.2. Conventional Agriculture

CA is extremely flexible in the types of farming practices and methods it can choose to use on any given crop (Table 1), the advantage lying in its ability to use synthetic fertilizers, pesticides, and its choice of tillage regimen. As a result of this mixed approach, mean CA yields for all types of farming practices employed by each of three study crops are higher than those used by OA (Figure 1).

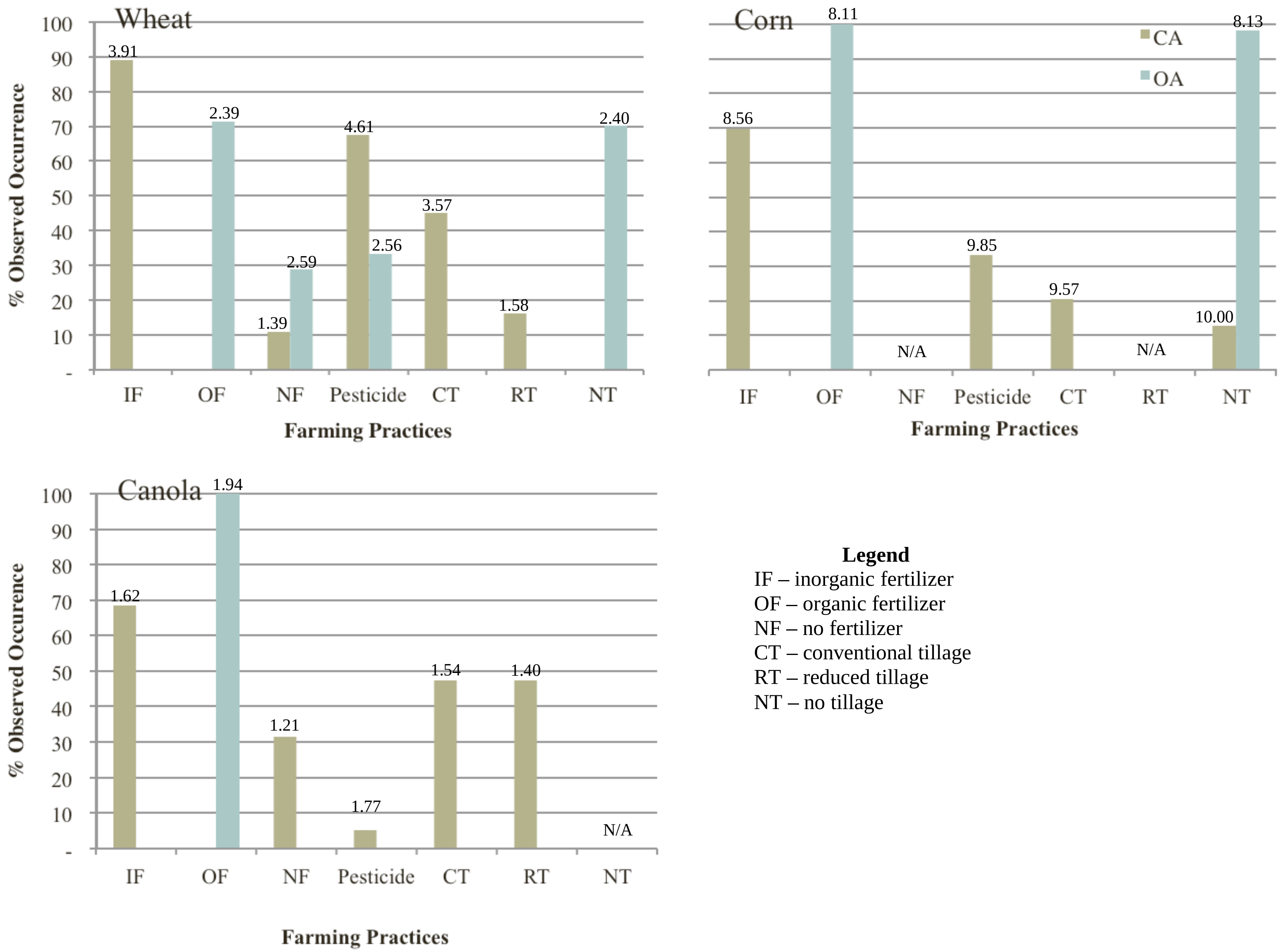

Figure 1. The total percentage of observed occurrences for each time of farming practice as defined in Table 1. The numbers atop each bar indicates the weighted mean yields (t/ha) of the observations that used the farming practice noted while the numbers centered within the bars denote their % of observed occurrence. N/A marks uncertainty in the data where it had failed to mention whether or not the farming practice had been used.

2.2.1. Wheat

Wheat is commonly farmed using conventional methods, and was reported to be farmed in 60,743 farms across Canada (Figure 2), 982,011 hectares of land (Figure 3), taking up 5.3% of the total farms in Canada (Statistics Canada 2006). The calculated Canadian average yield of conventionally grown wheat of 2.54 (Statistics Canada) t/ha is a smaller mean yield than the mean yield observed in Figure 1 of 3.64 t/ha.

In striving for yields, Figure 4 shows that the inclusion of pesticides in 68% of the 111 conventional observations produces the greatest mean yield at 4.61 t/ha (Figure 1). Although this sits below the highest observed CA wheat yield (Figure 1), it does produce a large enough yield to display the benefit of CA's use of pesticides. Interestingly, the second highest mean yield of 3.91 t/ha comes from the use of conventional inorganic fertilizers in 89% of the observations (Figure 4).

Notably, Figure 4 displays a large difference of 1.99 t/ha in CA systems employing CT and RT, representing almost half of the potential yield range observed in Figure 1. No observations opted for a NT approach to CA of wheat, which may have produced an excessively low yield given the sharp decrease in conventional yield with a decrease in tillage.

2.2.2. Corn

Observed conventional corn displays the largest range in yield, from 4.90-11.16 t/ha (Figure 1). The average yield across Canada in 2006 was calculated to be 7.40 t/ha (Statistics Canada 2006) from 29,707 farms (Figure 4), comprising 1.6% of Canadian farms and 139,210 hectares of land (Figure 3). The observed yield in Figure 1 is higher than the

2006 mean Canadian yield at 8.11 t/ha with conventional farming practices all yielding weighted means above the observed average (Figure 4).

In decreasing order of mean yield production, CA of corn using NT (10.00 t/ha), pesticides (9.85 t/ha), CT (9.57 t/ha), then inorganic fertilizers (8.56 t/ha) even though the percentage of their observed occurrences is almost reversed: inorganic fertilizers (70%), pesticides (33%), CT (21%), and NT (13%) (Figure 4). Expectedly, CA of corn did not opt to employ fertilizer-free techniques. There were no observed occurrences of RT CA corn.

2.2.3. Canola

Grown for its oil and not for much else of its biomass, canola is grown *en masse* through CA among less than 4.5% of Canada's farm, yielding a mean of 2.16 t/ha. Figure 1 shows that, as with corn, the mean of the observed canola yielded less (1.49 t/ha) than the Canadian 2006 mean.

The observed trials that included the use of pesticides yielded the highest mean at 1.77 t/ha. Comparisons between the use of inorganic fertilizer and no fertilizer display a large difference in yield,(1.21-1.62 t/ha) (Figure 4), spanning almost the entire observed range of 1.13-2.15 t/ha. Organic fertilizers were not employed (Figure 1). With no observed occurrences of NT, there appears to be no major difference in the % of observed CT or RT occurrences, nor any differences in their corresponding yield, with (CT: 1.56 t/ha, RT: 1.40 t/ha) (Figure 4).

2.3. Organic Agriculture

In this case, the observations put into this project's definition of OA renders it so that OA data cannot include the use of inorganic fertilizers in conjunction with pesticides, although a combination of any other set of farming practices is allowed. One exception was allowed for pesticide use in organic wheat, where the Mason *et al*. (2007) stated the use of herbicides to the organic certification standard.

2.3.1. Wheat

Figure 1 indicates that there were fewer observed instances of organic wheat farming, the sum of which provided an observed yield range of 1.94-2.59 t/ha and a mean yield of 2.44 t/ha. The average organic yield of corn in Canada is expected to produce 2.29 t/ha (Statistics Canada 2011), 90% of CA corn (Pelletier *et al*. 2008).

The highest yielding practice of abstaining from fertilizers (2.59 t/ha at 29% observance) sits in contrast to the lowest yielding practices with the greatest percentage of observed occurrences: the use of organic fertilizers at 89% (3.91 t/ha) and no tillage at 70% (2.40 t/ha). Understandably, the exception where pesticides were used produced a competitively high yield, the second highest yield observed at 2.56 t/ha (Figure 4).

2.3.2. Corn

Relative to the CA yield range, OA of corn displays the smallest range at 7.03-8.13 t/ha (Figure 1). Figure 4 shows that, of the observed sources, OA corn applies organic fertilizer in all instances and does not practice tillage to obtain yields near the higher end of the organic corn range at 8.11 t/ha and 8.13 t/ha, respectively. No complete data was available to observe reduced tillage or abstention from fertilizer use.

2.3.3. Canola

The information for organic canola was extremely sparse within the pool of collected data, with nothing substantial with respect to no-till data (Figures 1 and 4). However, the organic canola that was observed from Pelletier *et al*. (2008), where rock phosphate, potash, and green manure were combined for use in the category of organic fertilizer.

Table 2. Potential farming systems based on combinations of farming practices listed according to the greatest potential yield, lowest potential yield, and a yield within range attempting to maximize yield while minimizing the use of certain environmentally undesired practices.

		Farming Practice		
Crop Type	Potential Yield	Fertilizer	Pesticide	Tillage
Wheat	Highest	IF	Yes	CT
	Within range	NF	Yes	NT
	Lowest	OF	No	RT
Corn	Highest	IF	Yes	NT
	Within range	OF	Yes	NT
	Lowest	OF	No	NT
Canola	Highest	OF	Yes	CT
	Within range	OF	Yes	RT or NT
	Lowest	NF	No	RT

IF – inorganic fertilizer
OF – organic fertilizer
NF – no fertilizer

CT – conventional tillage
RT – reduced tillage
NT – no tillage

3. Discussion

3.1. Assessing Synergies

The relative success of conventional fertilizer and organic fertilizers speaks to their importance in plant growth, regardless of soil management strategies. The question has evolved from whether or not to apply fertilizers to what type of fertilizer a farmer should apply. Across each of the three study crops, organic fertilizers provided relatively competitive yields when placed next to fertilizer-free options. Although the yields fell below the total mean yield (Figure 1), they still provide a medium in between the use of conventional fertilizers and lack of fertilizers altogether. Figure 4 implies that organic canola farmers may be the only ones to benefit switching to organic fertilizer. Yet, the large-scale impact of conventional fertilizer use as nutrient-loaded runoff should be considered when observing Figures 2 and 3, seeing the sheer amount of Canadian farmland and number of farms devoted to wheat and corn crops. Even under the assumption that most of the Canada's farms operate using conventional fertilizer, a large-scale switch to organic fertilizers may hold a significant impact on reducing the effects of agriculture of our aquatic systems and amount of GHGs emitted into the atmosphere.

On the topic of scale, the application of pesticides would also be greatly reduced if all farm types were to eliminate its use. Approximately three quarters of pesticides sold for Canadian use are applied onto field crops, which would include wheat, corn, and canola (Nazarko 2004). The data in Figure 4 shows that the use of pesticides holds some influence over crop yield. Nevertheless, the large range between mean yields for organic and conventional wheat systems using pesticides indicates that yield as a function of pesticide use is highly variable and thus does not hold much weight on crop yield. It is unsure if this is also the case for corn or canola since both those crops have a very high yield to percentage of occurrence ratio. Irrespective of pesticide effects on crop yield, in order for traditionally conventional farmland to become organic certified, the land must grow crops for three years without pesticide use (Nazarko 2004).

In 2007, Teasdale *et al*. discussed how no-till conventional systems show 28% greater yields than any other tillage practice. The yields given by Figure 4 present findings that suggest otherwise, with wheat and corn experiencing smaller yields than on systems using conventional tillage. With conventional amounts of tillage, nutrient cycling would provide what is required for crop growth (Daum 1996). When observing the tillage systems in the corn crops, the smallest yield came from the reduced tillage system, which poses some interesting questions about soil dynamics and the nutrient cycling system. It is possible that where conventional tillage provides nutrient cycling, lack of tillage allows soil to settle naturally and assimilate macronutrients without disruption (Kladivko 2001). On the other hand, RT has been found to increase nutrient availability in the shallow soil top layer (Rasmussen 1999), which may not be of much use to canola with its shallow root system.

Table 2 lays out potential farming systems using combinations of farming practices with and without the use of conventional fertilization. Expectedly, the crop systems displaying the best yields are traditionally conventional systems except in the case of canola with an anomalously high yield coming from the use of organic fertilizer. Given the widely regarded detrimental effects of conventional fertilizers with respect to GHG emissions and their effects on climate change, the systems compromising the highest and lowest yields aimed to avoid conventional fertilization.

The amount of GHGs emitted into the atmosphere from the vast amounts of wheat and corn produced in Canada (Figures 2 and 3) may be reduced greatly from a conversion to organic fertilizers and a no-tillage system while retaining the use of pesticides. Canola is of a similar conclusion, where a system converted to organic fertilizers and pesticides may be of great benefit to the atmosphere but where tillage may be reduced owing to a lack of complete data, or converted to a no-tillage canola system to avoid root system disturbance. The inclusion of pesticides in each system may help to maintain yields similar to those found in conventional systems and may be reconciled by modifying IPM systems.

3.1.1. Additional Observations

The numbers of observed CA and OA corn values were quite similar (Figure 1), suggesting two different dynamics at play. Firstly, the literature is quite focused on biofuel production through corn, most of which would not have any need to account for organic corn production. However, the demand for organic food is evidently providing a counter force on the CA of corn. The growing production of biofuels may be the same dynamic at play with regards to canola, regardless of its highly GM state of farming.

3.2. Project Critique

The inclusion of canola as a study crop was interesting by allowing the study of a crop that seems to hold little value as a directly edible crop. Categorized as an oilseed, canola holds increasing potential as a biofuel crop. Many of the studies focused on measuring the success of canola measured yields in metrics complying with seed yield or dry matter yield (kg/ha), rendering their yield results incompatible with this project's metric system (t/ha). The small amount of usable plant matter from canola crops alone has made it difficult to find valid sources of information with metrics in t/ha. The entire study could have been amended and much more level if it had been approached with dry matter metrics (mg/ha) in mind rather than total bulk yield (t/ha). This approach would have required a calibration and benchmarking of metrics for wheat and corn values. An approach focused on dry matter yields would have accounted for geographical differences in precipitation and soil moisture, regardless of any irrigation practices, and provided a basis for evaluating the importance of climate for crop growth conditions. Figure 3 displays the comparative amounts of land devoted to corn and wheat farming between Eastern and Western Canada, where geographic and climate can vary greatly between the two.

3.3. Further Research

Further expansion on this research topic may include the tracking and analysis of trends in yields, tillage and pesticide use in Canada over time to view how farming systems have changed with respect to each other to increase or decrease yields. An extension into how farming practices have changed with policies and agricultural subsidies may also be of interest when considering an economical context.

This research project was highly qualitative and further research potential lies in the quantifying the proposed results through the actual experimentation of each proposed system. Ideally, these experiments would be laid out to fulfil gaps in the data and expanded to include a better knowledge of crop performance under geographic variability. Plots reserved across various parts of Canada grown under the proposed conditions for several years will aid in determining which systems are best suited to different conditions. From therein, further experimentation may be done in an effort to reduce refine each system to further reduce GHG emissions while maximizing produced yields.

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Summary

1. Each observed crop (wheat, corn, and canola) demonstrated larger yield ranges, with larger observed mean yields in the cases of wheat and corn.
2. There was a great difference in the total number of CA and OA canola observations which may be a result of canola's multi-varied use, although not the case for wheat and corn. This may be attributed to conventional crop growth for biofuel production and the increasing consumer demand for organically-grown food.
3. Differing climates and growth environments across Canada contribute to the variation of crops grown from province to province. This also has an effect on the density of farms per province and farm size.
4. Application of inorganic and organic fertilizers positively influences crop yielding abilities, as does the application of pesticides. The influence of tillage on crop systems may be a function of fertilizer and pesticide use or long-term soil-nutrient dynamics.
5. Highest yielding systems, after analysis, remain to be conventional systems, as defined earlier, except in the case of canola.
6. Potential agricultural synergies may be summarized into farming systems specific to each crop type and long term environmental goals in mind. Special consideration should be taken when weighing desired yields against the GHG emissions of fertilizers and machine fuelling as well as the ecological effects of pesticides.

Appendices

Appendix A: The number of hectares and farms devoted to wheat, corn and canola according to province. Sourced from Statistics Canada 2006.

British Columbia

Crop	Hectares	# of Farms	Ha/Farm
Wheat	23,076	237	97.37
Corn	13,242	137	96.66
Canola	26,018	555	46.88
Total	**62,336**	**929**	**67.10**

Quebec

Crop	Hectares	# of Farms	Ha/Farm
Wheat	54,276	2,031	26.72
Corn	462,609	8,427	54.90
Canola	6,159	224	27.50
Total	**523,044**	**10682**	**48.96**

Alberta

Crop	Hectares	# of Farms	Ha/Farm
Wheat	2,617,356	11,791	221.98
Corn	30,245	636	47.56
Canola	1,646,468	10058	163.70
Total	**4,294,069**	**22,485**	**190.97**

New Brunswick

Crop	Hectares	# of Farms	Ha/Farm
Wheat	1,375	57	24.12
Corn	4500	147	30.61
Canola	359	5	71.80
Total	**6,234**	**209**	**29.83**

Saskatchewan

Crop	Hectares	# of Farms	Ha/Farm
Wheat	5,275,617	24,488	215.44
Corn	8,431	344	24.51
Canola	2,418,916	14,937	161.94
Total	**7,702,964**	**39769**	**193.69**

Nova Scotia

Crop	Hectares	# of Farms	Ha/Farm
Wheat	2,426	111	21.86
Corn	7,258	234	31.02
Canola	10	4	2.50
Total	**9,694**	**349**	**27.78**

Manitoba

Crop	Hectares	# of Farms	Ha/Farm
Wheat	1,334,741	7,156	186.52
Corn	94,192	1,349	69.82
Canola	922,134	5,861	157.33
Total	**2,351,067**	**14366**	**163.65**

Newfoundland and Labrador

Crop	Hectares	# of Farms	Ha/Farm
Wheat	15	3	5.00
Corn	687	27	25.44
Canola	0	0	0.00
Total	**702**	**30**	**23.40**

Ontario

Crop	Hectares	# of Farms	Ha/Farm
Wheat	499,945	14,682	34.05
Corn	768,345	18,275	42.04
Canola	7,517	205	36.67
Total	**1,275,807**	**33162**	**38.47**

Prince Edward Island

Crop	Hectares	# of Farms	Ha/Farm
Wheat	11,279	187	60.32
Corn	2,592	131	19.79
Canola	64	4	16.00
Total	**13,935**	**322**	**43.28**