

Sustainable Horticultural Crop Production in Canada

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Introduction.

Canada is one of the largest countries in the world when measured by land area. It has a stable government, a strong economy, and carries worldwide influence. It is both a major importer and exporter of agricultural products. The country has historically grown grain crops but more recently has seen a rising trend in greenhouse vegetable production. In the face of an extremely cold climate, Canada has found agricultural and horticultural success, making it valuable to study the country's production practices.

Country Profile.

With 9,984,671 sq km of land and water area, Canada is the second largest country in the world. This compares to Russia, the largest at nearly double the area, and the United States and China which are both just slightly smaller. Situated in the northern regions of North America it shares its southern border with the US (8,893 km), and is bound by the Pacific Ocean on the west, the Atlantic Ocean on the east, and the Arctic Ocean to the north. The country has 202,080 km of coastline (Central Intelligence Agency, 2010).

There is great variation in Canadian geographic and environmental conditions due to its large size. The southern areas of the country have a temperate climate, the middle regions have a subarctic climate, and the most northern areas have an arctic climate. The land is dominated by plains, but there are sizable mountains in the west, and lowlands in the southeast. As of 2005, 4.57% of the country was arable land, with only 0.65% in permanent crops. There is an estimated 7,850 sq km of irrigated land, and as of 1985 an estimated 3,300 cu km of renewable water

sources. In total 44.72 cu km/yr of freshwater is withdrawn, 12% of that being for agricultural use (Central Intelligence Agency, 2010).

As a result of Canada's geography there are a couple interesting affects. First, northern development is extremely hindered due to the arctic climate; 90% of the population lives within 160 km of the southern border shared with the US. Second, air patterns from the oceans and continental US lead to the majority of rain and snow being produced east of the (western) mountains (Central Intelligence Agency, 2010).

The entire population is currently around 33,487,208, ranking 36th in the world. However, the population is only slowly growing at about 0.817%, and there is a net migration rate of about 0.006%. Roughly 80% of the population lives in metropolitan communities. The urbanization of the population followed a similar pattern to that of the United States. Following World War II the formerly dominant agricultural sector began to be replaced by industrialization, manufacturing, mining, and service sectors. Although these industries have seen a downturn, the country's vast natural resources have enabled continued economic prosperity. Canada is the greatest foreign supplier of energy (oil, gas, uranium, and electric power) to the US. This wealth of resources has carried the country from the 1990s through today, even holding the country fairly stable through the current worldwide financial slump (Central Intelligence Agency, 2010).

Canada's estimated 2009 GDP (official exchange rate) is \$1.390 trillion Canadian dollars, (\$1.319 trillion US dollars). This is comprised of 69.6% from the service sector, 28.4% from industry and just 2% from agriculture. Within the agriculture sector, the main products include: wheat, barley, oilseed, tobacco, fruits, vegetables, dairy products, forest products and fish (listed in general order of importance). Additionally, Canada is a major exporter of plastics, fertilizers, wood pulp, natural gas, electricity, and aluminum, as well as a major importer of electricity (these lists are not complete but are items related to sustainable agriculture), (Central Intelligence Agency, 2010).

As a nation that became self governing in 1867 much of their development has paralleled the United States and often but unfortunately economic and technologic gain came at the expense of negative environmental situations. The country suffers from air pollution (from vehicles, coal burning, metal smelting, etc.) and acid rain. Ocean contamination is becoming more problematic and is partially blamed on agricultural practices. However, the country is an active party in many international environmental initiatives, focusing on but not limited to: air quality, water quality, and biodiversity. Based on such involvement, Canada is self-aware of its environmental condition and seeks to maintain and improve it (Central Intelligence Agency, 2010).

Defining Sustainability.

As a nation, Canada lacks a single, formal definition for the term "sustainability". Rather, a sampling of recent activity and explanations give a sense of the term.

In 1995 the Auditor General Act established the office of the Commissioner of the Environment and Sustainable Development. This branch of government may have the farthest reach regarding sustainability, as it requires government departments to prepare sustainable development strategies for presentation to the Canadian Parliament. The Sustainable Development's remarks on a definition include, "...Development is essential to satisfy human needs and improve the quality of human life. At the same time, development must be based on the efficient and environmentally responsible use of all of society's scarce resources - natural, human, and economic..." (SDInfo, 2006).

Held in Toronto, a 2002 International Horticultural Congress symposium focused on sustainability and development for sustainable horticulture for the future. With input from many nationalities and professional backgrounds, sustainability was identified as a balance of ecology, economics, and social values, and then further refined as "people-planet-profit" (Bertschinger et al., 2004).

Agrium is a major producer and supplier of agricultural products, primarily focused on fertilizers. With corporate headquarters in Calgary, this 'non-production' horticulture company

has a heavy hand in the broader industry. Agrium formally defines sustainability as, "The enduring well-being of interacting economic, environmental and social systems" (Agrium, 2010).

In an effort to merge academia and British Columbia's horticulture industries, Kwantlen Polytechnic University formed the Institute for Sustainable Horticulture in 2004. The Institute aims to work in horticulture, silviculture, forestry, and urban landscapes to promote greater environmental responsibility. Their idea of sustainable horticulture includes four main tenants, "Resources are kept in balance through conservation, recycling and or renewal. Practices preserve horticultural resources and prevent environmental degradation to the site of use as well as off-site land. Production, profits and incentive remain at acceptable levels. Community is an integral part of the system" (Institute for Sustainable Horticulture, 2010).

The definitions above are pulled from four sectors, (government, the international scientific community, corporate business, and higher education), each of which have the ability to influence horticultural practice. Although driving interests are very different among these four sectors, there are recurring themes in each definition of sustainability. At heart, it seems that sustainability should provide for current needs without harming future needs, and is a theory that can be applied to all behaviors and all industries.

Slightly more troubling than defining sustainability, is an effective way to measure and evaluate its current condition and future progress. Many times sustainable actions appear positive by one measure, but are at the expense of another. Some indicators that can be monitored for horticultural sustainability include levels of inputs, energy and water consumption rates, soil quality and water quality.

Historical Production Practices.

Prior to European arrival in North America many Indian tribes practiced primitive farming, and grew such crops as maize, beans, sunflowers, tomatoes, and peppers. When early settlers arrived in the 1600s land was held in a seigniorial system, which guaranteed a landlord-tenant agricultural relationship. It only took 200 years for all the arable land to be possessed. As

the territory expanded into the early 1800s settlers found the land suitable for cereal farming and many immigrants used the same cultivation methods that they did back home in Europe. Wheat and flour were the dominant crops, and in combination produced over 27,000 tons by 1802. Before the end of the 19th century gold lured the population westward, causing an increase in agricultural demand, and therefore production. However, the western settlers noticed that the land was unlike where they had come from (Ontario, Manitoba, or Europe) and agricultural methods became more experimental (Government of Canada, 2001, and Dick and Taylor, 2010).

The need for new agricultural practices was an important incentive in the founding of the Department of Agriculture in Canada in 1868. Two experimental crop stations were started in the late 1880s to study necessary field crops (grains and also livestock), as well as non-essential plant material that was brought in from the United States and Eurasia. Irrigation studies were conducted for potential cultivation in dry regions. In 1915 the first research station dedicated to horticulture crops (fruits, vegetables and ornamentals) was opened in Morden, Manitoba. Additional research and horticultural development was carried out by Canadian Pacific Railway (because of a large land interest), as well as universities, a few smaller nurseries and individuals concerned with cold-tolerant cultivars (Dick, 1996).

Large scale horticultural production has really developed over the last 100 years and is reliant on greenhouses. Greenhouse vegetables started in two separate regions in Ontario and used low, free standing structures with very simple heating. Coal-fired burners were common until the early 1970s, when the energy crisis resulted in a switch to natural gas heat. As more greenhouses were built the most common glazing material used was double inflated poly. However, researchers Papadopoulos and Gosselin suggest that the two most important changes were in the late 1970s and early 1980s. One, the adoption of soil-less production methods allowed growers to produce a better crop, especially tomatoes. Whereas tomatoes previously were pinkish, they could now grow redder, higher yielding cultivars without suffering rot diseases. The second change was not a technology innovation, but the implication of government

regulation - the adoption of the North American Free Trade Agreement. NAFTA allowed the vegetable market to expand beyond Ontario to include all of North America, thus providing an instant opening in the marketplace (Papadopoulos and Gosselin, 2007). Interestingly, NAFTA has been generally well received by Canada, and beyond the horticulture industry one if five Canadian jobs is related to international trade (Government of Canada, 2009).

In a 1995 paper by Gauthier, the author discuss the value of an automated or computerized system for use in the greenhouse. The need for a program with wide control and monitoring abilities for items such as light, CO₂, temperature, humidity levels, water and feeding regimens, etc., was identified. However, at the time the author was not concerned that the technology would be unachievable, but instead that compatibility and collaboration within the industry would be preventative (Gauthier, 1995).

Current Production Statistics.

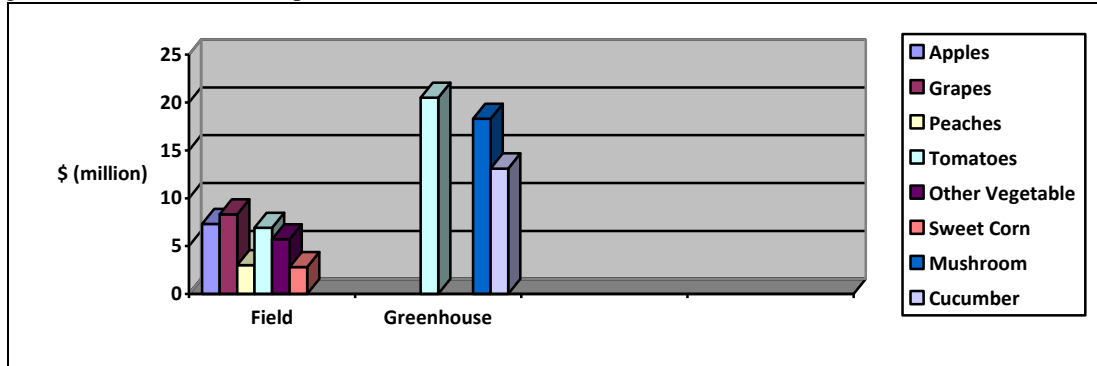
Analysis of current trends will focus on the truly recent 21st century. Canadian agriculture uses only 0.18% of their country's renewable water sources, while for comparison India uses nearly 30% and Mexico just under 20%. From 2001-2006 in each region of the country no-till practices have become more common (and is thought to be a best management practice because of reduced fuel and fertilizer costs). In 2006 in the Prairies over 40% of farms reported no-till. The Canadian federal government has allocated 24% of agricultural spending towards research and inspection, indicating an interest in advancing good practices (Agriculture and Agri-Food Canada, 2008).

Although the dominant agriculture crops include cereals and oilseeds, the Canadian agricultural census measures horticulture by 5 categories: fruit, berries and nuts; vegetables (excluding greenhouse); sod; nursery products; and greenhouse products. Last reported in 2006, fruit, berries and nuts had 110, 069 hectares, and 5.4% of total farms. Vegetables had 125,181 ha and 4.1% of total farms. Sod was produced on 27,960 ha and 0.2% of total farms. Nursery

products were on 24,953 ha and 1.7% of total farms. Greenhouse products were on .0021 ha and 2.4% of total farms (see Appendix 1 for details), (Statistics Canada, 2008).

The numbers within each category can be broken down a little further to represent the situation in Ontario (See Figure 1). The 2008 farm value of fruit crops included (\$ Canadian): apples \$7,300,000, grapes \$8,309,000, and peaches \$3,043,300. The 2008 farm value of vegetables included: tomatoes \$6,971,400, other \$5,704,800, and sweet corn \$2,800,000. The 2008 farm value of greenhouse vegetables included: tomatoes \$20,457,900, mushrooms \$18,295,700, and cucumber \$13,065,900 (Mailvaganam, 2009).

Figure 1 - 2008 Value of Crops in Ontario (million \$ Canadian)



Total greenhouse sales in Canada in 2008 (\$ Canadian) were \$208,868,000, with ornamentals and plant sales making up \$127,550,500 and vegetables comprising \$81,317,500. (See Appendix 2 for details). Cut flowers were dominated by Tulips and Gerbera, while potted plants were dominated by 'other', geraniums, and spring hanging baskets (Mailvaganam, 2009).

Current Production Practices.

Modern Canadian agriculture is reliant on the import/export market, and export opportunities are necessary for continued growth. Canada was the 4th largest exporter and 6th largest importer of agriculture and agrifood products in the world (in 2007). Despite the high rankings Canada recognizes that today's consumers are demanding more variety and higher quality than ever before. The trend for fewer-but-larger farms that came with the onset of

automation has been countered by a recent increase in smaller, more diversified farms. These new groups of farms are more likely to focus on organic or eco-friendly production methods, which will help them stay globally competitive. Growers have also been affected by rising input costs, primarily crude oil, but also other inputs such as pesticides, which serve as encouragement to find alternative methods of production (Agriculture and Agri-Food Canada, 2008).

Perhaps most important to current horticulture practice is the increase in Canadian greenhouse production. Despite the overall small market share that greenhouses hold, there is great opportunity here because of year round production in a cold climate. It is this possibility which fuels innovation and provides incentive to improve industry standards. Business and research alike both desire the latest technology in such factors as glazing materials, house layout and use of space, lighting, heating and cooling, and general crop management (often in regard to automation of irrigation and fertilization).

The best greenhouse glazing material is highly debatable. Over the last 20 years, many houses have used double inflated polyethylene, which showed a greater cost savings in construction and maintenance, (as much as \$500 million based on research in Ontario). However, as the economy began to change in 2004 the price gap narrowed, year round production demand increased, and Canada saw a return to glass houses instead of poly. In 2004, 47% of 62 ha of new greenhouses were built with glass. The caveat is using a thermal curtain with the glass to obtain an equivalent efficiency level to the double polyethylene (Papadopoulos and Gosselin, 2007).

A very popular trend in house layout is the conversion to raised troughs (also known in Europe as gutters). Under this system, crops are grown in raised beds, usually anywhere from 30 to 100 cm off the ground that allows for greater air circulation and less strenuous labor due to the waist height workspace (Papadopoulos, 2007). SunTech Greenhouses Ltd. has adopted such a system and is pleased to have no high-humidity dead zones, as well as happier workers who prefer a leaf blower to a broom (SunTech Greenhouses Ltd, 2010).

Due to geography, short winter days, and prolonged cloud cover of winter storm systems, lighting is a very important factor to Canadian greenhouse production. A typical December day provides a greenhouse with an average PAR (photosynthetically active radiation) between 0.8 and 1.6 MG m⁻² while a typical July day may provide an average PAR between 7.3 and 8.0 MG m⁻² (Papadopoulos, Demers, and Theriault, 2002). Therefore supplemental lighting is highly crucial to (year round) greenhouse production, and is thought to be essential for profitability, particularly from October to March. In order to maximize natural light conditions growers typically start their first (tomato) crop in January for harvest in mid summer, and then start a second (tomato) crop for harvest in late fall to early winter. An added benefit of using supplemental lighting is the heating contribution to the greenhouse. A double-polyethylene house in Quebec showed that between 25-41% of their heat was provided by artificial lights, as a typical high pressure sodium (HPS) lamp will convert 20% of energy to light, and 80% of energy to heat (Papadopoulos, Demers, and Theriault, 2002).

A new heating technology that seems beneficial to growers in the cold northern climate of Canada is carbon dioxide recovery/hot water storage. The idea is to feed plants the carbon dioxide that is created by running the boilers during the day (even when heat is not necessary), store the heat in insulated tanks and then use it to heat the greenhouse at night. Although research on this method has been limited, proponents claim that costs can be recovered in 1-3 years for an 8 ha operation (Papadopoulos and Gosselin, 2007).

In their 2007 industry review Papadopoulos and Gosselin suggest that small changes in crop management have reaped big rewards. Modification of the plant root zone, particularly by using soilless media, has increased overall yield and reduced the need for input quantities, and therefore produces overall energy savings. They also credit improvements in watering technology with the ability to improve crop production while reducing waste. One method is the Harrow Fertigation Manager, a computerized irrigation and fertilization system that can provide

more precise water and nutrient delivery. Another example is the recycling and reuse of nutrient solutions by hydroponic lettuce growers.

Integration of Practices - historic and current

Canadian crop production has transgressed from primitive farming to field production, and is slowly starting to incorporate greenhouse production. In order for the country to remain competitive in the market (in the face of Southern growers), greenhouse operations may become more important and will need to assume a more prominent position in the industry. For that reason, a comparison of sustainable qualities of cropping methods will target the changes and choices in greenhouse production, rather than the less relevant comparison of field versus greenhouse production. Although greenhouse production is representative of *Solanum lycopersicum* (tomato), *Agaricus bisporus* (mushroom), and *Cucumis sativus* (cucumber), tomato is the dominant crop.

Vegetable and floriculture production have inspired the review of many aspects of controlled environment growing - but whether or not new trends are sustainable is not always clear. Canada's most common greenhouse trends and their aspects of sustainability are outlined in Table 1 below.

Table 1 - Greenhouse Trends and their Aspects of Sustainability

Practices	Cons / Non-Sustainable Attributes	Pros / Sustainable Attributes
Glass Glazing	-Poor insulation, and therefore extra heat loss. -Prone to breakage which requires replacing material and added expense. -Lifespan is still short in the big picture. -Expensive	-High light transmission reduces the need for supplemental lighting. -Longer lifespan (30+). -Better for year-round production of crop. -Thermal curtain increases efficiency.
Double Inflated Poly	-Short lifespan, needs to be replaced every 2-6 years. -Poor light transmission	-Inexpensive and cost effective. -Resistant to tears and breakage.
Coal-fired Burners	-Higher emissions	-Plentiful and therefore cheaper
Natural Gas Heat	-More expensive	-Cleaner, with fewer CO2 emissions.
Supplemental Lighting	-Increase energy consumptions	-Light contributes heat and reduce need for other heat

		sources.
Raised Troughs / Gutters	-Expensive to install.	-Greater air circulation leads to healthier crops. -Better physical working environment for employees.
Soilless Media: Rockwool	-Disposed of in landfills and is non-degradable.	-Good for plant production

The use of glass versus polyethylene for Canadian greenhouse glazing will come down to individual circumstance. Glass is strong (although subject to shattering) and allows good light transmission, but is expensive. Heat loss can be minimized with the use of a thermal curtain. Alternatively, polyethylene is much more inexpensive, but needs to be consistently replaced. Heat loss is dramatically reduced when using double layer poly, particularly when inflated with air. Due to the many other factors in greenhouse production that can be manipulated, the sustainable choice of glazing material is very elusive.

Choosing a heating element is a difficult question of balance. There are 10 billion tonnes of coal reserves in Canada, which exceeds the amount of energy the country has in oil, natural gas, and oil sands combined. Bearing in mind a definition of sustainability's reference to community, the coal industry in Canada supports thousands of jobs and contributes an estimated \$5 billion (Canadian) to their economy. New technology, such as coal gasification, is also resulting in cleaner coal which burns at efficiencies near natural gas. (The Coal Association of Canada, 2006). On the other hand, natural gas is the preferred choice by some advocates. It is traditionally thought to be relatively clean-burning, safe and efficient. Although Canada has significant natural gas reserves, estimated at 1.66 trillion cubic meters in 2006, prices have been climbing due to US demand (Natural Resources Canada, 2010).

The use of supplemental lighting has both positive and negative aspects regarding sustainability. It is very beneficial to producing a more efficient crop and can reduce other heating costs and inputs, but on the contrary, supplemental lights require extra energy, which particularly adds up at 16 hours a day...or longer. Additionally, light energy is wasted if not programmed correctly or if it is left on during sunny times, when plants may already be receiving

their maximum irradiance. Further, supplemental lighting needs are affected by light transmission of the glazing material. Despite the importance of light to plant growth, a relatively small number of greenhouses report using supplemental lighting; for example, only 130 of 604 growers in Quebec report using supplemental lights (Dansereau and Menard, 2002). Dansereau's research suggests that while lighting is very valuable to the grower, more studies need to be conducted on combining it with the best temperature and fertilization practices to optimize sustainability.

As mentioned above, changes in greenhouse design and crop management have great potential, but are also countered by problems. Although raised trough systems promote air circulation and ease labor, they can be expensive to install. Papadopoulos claims that rockwool is the most widely used growing medium in Canada, but it is non-degradable and must be disposed of in landfills. Also, while good water and nutrient technology exists, it has yet to be widely employed by growers. In the Harrow Fertigation Manager example, although there are water and fertilizer savings, the recirculation has also led to the quick spread of root pathogens.

The resulting sense is that no production element can be ranked explicitly above another, as each element is neither wholly sustainable nor non-sustainable. In the future, production practices need to be taken into consideration as a group to determine the ability of the system overall. There needs to be continued research and exploration in all topics mentioned: glazing material, heat source, supplemental lighting, and cropping systems. The knowledge, tools, and funding available to future researchers will determine the most effective area to study. Advances in glazing material, heat sources, and lighting may require academic knowledge and/or funding held by government agencies or large corporations. Smaller players have a better chance to improve greenhouse layout and design, media use, or even crop choices. Future research should focus on tomato production due to its prominence as Canada's top greenhouse crop.

Sustainable Development Strategies

Integrating sustainable production methods into Canada's horticultural markets comes with a host of challenges, rewards, cost-effectiveness issues, and frustrations. Perhaps one of the

toughest challenges is the paradox of production itself – greenhouses are key for the country to maintain market presence, yet the structures are generally input intensive. Adoption of improved greenhouse technology could reduce negative environmental impacts, allow for more goods to be sold, and for production to continue year-round. These qualities can be labeled as sustainable. However, the structures are expensive to build, suffer heat loss, require high heat inputs, often require supplemental lighting, and potentially use non-recyclable growing media. This second set of qualities is generally unsustainable. Yet, if the challenges can be diminished, the rewards are great. The primary reward would be economic, whereas more greenhouses means more production and therefore more sales. Naturally, as sustainable elements of the greenhouse improve then environmental rewards also increase. For example, better light transmission from the glazing material would allow for less supplemental lighting needs. Cost effectiveness is another very real concern with greenhouses, particularly in the short term. The initial cost of building a greenhouse can be quite expensive, and using environmentally friendly materials often only adds to the cost. So while the technology may be available to create more responsible houses, the costs can simply be too inhibitive for growers to implement. Finally, there are no identified standards in greenhouse development in Canada. From one aspect this is good, and may somewhat ease the entry process into the greenhouse industry. Alternatively, frustration can ensue, as no regulation provides no guidelines, gives little direction for establishment, and creates no accountability for environmental standards.

In order for greenhouse production to become a more common option, overall efficiency needs to increase. This may include improvements to heating technology, energy usage, light transmission, media choice, use of space, or crop selection. Further, the market needs to continue to drive demand and support the shift to greenhouse production. The cost of entering the greenhouse industry and the research involved in improving its sustainability will always come back to financial sense. For example, if Canadian consumers are willing to pay for tomatoes grown locally, then more growers should be willing to use greenhouse production in order to

provide the product, and in turn more research money should be made available to support the rising industry.

Aside from opportunities to improve technology, there are two gaps in the progress of the greenhouse industry. One is physical location and the centralization of greenhouses in the country. As of 2003, over half of vegetable greenhouses were located in Ontario. In fact, the largest concentration of greenhouses in all of North America is in the Leamington area in southwest Ontario, close to the Toronto and American markets. Alternatively, British Columbia recorded about 30% of the greenhouses and Quebec only 12% (Purdy, 2005). The second gap is limited winter production, especially for tomatoes. When the natural temperatures and light levels are at their lowest in December and January, the extra heat and light required to produce a winter crop is often preventative. Although Canada has cutting-edge technology and well-respected research facilities (such as Harrow Research Station), winter production remains elusive.

Although researchers in both Canada and internationally are taking steps to improve greenhouse sustainability, studies are primarily focused on growing methods and building materials. These advances are at the heart of improving environmental and business practices. However, it would be beneficial to Canada to also research the gaps mentioned above. First, how could the Canadian greenhouse industry expand beyond Ontario? This question should examine the environmental conditions in the country that could support a greenhouse operation. It may consider locations that have reasonable access to trade routes and transportation means. Further, it may identify markets that are ignored or simply missed. Second, how can winter production be improved? This is much more supported by current 'technology' research, as the solution may lay in improved materials or construction methods. It should also address crop choice and crop timing. Perhaps a crop with lower light and temperature needs would in fact be feasible in the winter. Alternatively, a vegetable with a shorter production schedule may allow more harvests

than tomatoes, while still avoiding deep-winter operation. See Table 2 for potential research questions, and their associated advantages and disadvantages.

Table 2 - Future Research Questions and Associated Advantages and Disadvantages

	<u>Question</u>	<u>Advantages</u>	<u>Disadvantages</u>
Greenhouse Location Expansion	What locations are environmentally suited for greenhouse production Canada?	The industry could easily expand if new geographies are identified. Resources may be more available/cheaper in other locations.	It is possible that the best location for production is in Ontario and that there is little benefit to other areas.
	Is transportation suitable for horticultural products?	Major trading routes lower expenses for the grower and consumer.	New locations not near transportation could increase the cost of production, as well as increase environmental footprint.
	What consumer markets have been ignored by Canadian greenhouse production?	Identifying new markets can mean greater income. Positioning greenhouses near their market will reduce transportation needs	Potential markets may not be in areas feasible for greenhouse growing. Collecting data may be inaccurate and costly.
Winter Efficiency	How can greenhouse materials be improved to increase winter efficiency?	Advances to materials such as glazing or heat source could greatly reduce the input need and allow for winter growing. This is beneficial for the environment and could be less expensive for the grower.	New technology may be more expensive for the grower. Even if a low-cost resource is found it may still require high input levels.
	Are there alternative crops that can be produced under lower light requirements, cool temperatures, or a shorter production period?	This would afford year-round production, while using less heat and supplemental light. Multiple harvests could be sold throughout the year, while still not requiring winter production.	Market demand for such a crop may not be as high as for tomatoes. Even at lower input levels than those needed for tomatoes, any input is greater than no input (in the case of no winter operation). Alternate crops may have other production problems (pests, disease, etc).
	Can genetic improvement to tomatoes increase their hardiness or speed production?	If the market does not support alternative crops and greenhouse technology does not change, then genetic improvements in tomatoes would make the crop more profitable.	Research of genetic improvement in tomatoes may be extremely costly or very time consumptive.

Design of a Future Sustainable, Controlled-Environment Production Facility

If limited to proceed on only one of the two main proposed research areas, efforts should be aimed towards improving winter efficiency. Testing for physical expansion of the Canadian greenhouse industry would require a host of preliminary research prior to constructing test facilities. Once ready to build, the number of research greenhouses required throughout the country for adequate experimentation would likely be quite expensive. Alternatively, building a greenhouse for winter production would be more logical. There are already a number of research-based facilities in Canada, and the industry would benefit from a complementary house that focused on efficient winter cropping, of tomatoes or alternative crops.

The 'Winter Efficiency Research Greenhouse' should be built in Ontario, in the Leamington area, at the heart of the greenhouse tomato industry. Located on the 42 Parallel, the area is known as the Sun Parlor of Canada. With the same climate and growing conditions as existing producers, this location would provide relevant research results and would deal with similar market and transportation realities. The WERG should be designed with the consultation of professional greenhouse engineers. In initial construction, the ability to test different glazing materials and different light levels is important. To that end, the WERG should consist of connected houses. The more combinations of material the better, but that will naturally be limited by funds. In addition to glazing material (and thereby light transmission), a variety of supplemental lighting should also be installed. If possible, install multiple heat sources to include natural gas, coal, or new experimental technology. Space use and bench layout will also be important and standard rolling metal benches as well as raised troughs should be used. Providing a house(s) with options for flexible experimentation in bench and layout design would be very valuable. This may include floor growing or vertical systems. Aside from these fixed features,

the WERG needs to be able to accommodate changing production processes. It should account for variability in crop choice and media selection and storage.

A benefit of the WERG would be the ability to run a variety of experiments; three examples follow. A first experiment could test a newer idea for cold weather greenhouses, - operable insulation shutters. Used in Wisconsin, US (at a more northern location), this technique serves to insulate the southern side of the greenhouse at night, while reflecting sun off the snow on bright days (Gunderson). The experiment should grow a winter tomato crop and measure the heat losses as well as required heat inputs on shuttered and non-shuttered houses. A cost analysis of the shutter system should also be completed. A second experiment could focus on alternative crop choices to tomatoes for winter production. Spinach or kale may be feasible alternatives, which naturally prefer cooler temperature, require lower light levels, and grow on a slightly shorter schedule. Experiment with variations of crop spacing and bench design to produce the greatest leafy harvest, while keeping heat input to a set minimum and no supplemental lighting. Complementary research on alternative crops would also look to the consumer market to measure demand. A third experiment would employ a plant breeder to identify hardiness traits in tomatoes. This experiment would involve fewer specifications to the greenhouse itself, and instead would focus on superior knowledge of the tomato crop to make good selection and crossing choices. To represent typical industry houses, no new or investigational greenhouse technology should be used in genetic tomato studies.

As inferred, tomatoes are a warm temperature and high light crop. Night temperatures need to remain between 60-62°F to enable normal pollination and fruit set. For this reason, cropping from December through February is generally not recommended. In addition, extremely hot temperatures (greater than 95°F) can have a negative affect on foliage, fruit, and root growth. Therefore, the primary harvest should target spring sales. Spring generally provides the best environmental conditions, lower heat costs, and a good sales price from consumers (Anderson).

For a spring crop sowing *may* begin as early as November (if growers are willing to pay for extra inputs), set in the greenhouse in January and harvested from March to July. If growers do not handle the crop correctly early on in winter, then vegetative growth may be stunted or fruit set will be too high. But as discussed, most growers may wait to seed a few months later, to avoid the cost and slow growth rates of winter. The standard schedule for fall tomato crops is seeding in the end of June, set in the greenhouse in August, with fruit to market from October to December (Papadopoulos, 1991).

Crop schedule experiments at the WERG may take on any variation of the above protocols, while technology based experiments (shutter systems), alternative crops (spinach and kale), and even genetic improvement to tomatoes, must be conducted in the winter with seeding in November. Due to the nature of testing winter production, experiments are limited by season. Research findings may be shared after 3 years, but would be validated after 5 or more years.

Research results can be greatly affected by natural variations in weather. With no perfect solution, this will be accounted for my running experiments for 5 or more consecutive years. Another potential problem is that any technology failure, scientific error, or miscellaneous glitch that occurs will have great impact on all data, being limited to one season per year. This may require extension of studies beyond their initial end date. Finally, a universal concern is the continuation of funding throughout an entire experiment. All studies proposed in this paper, as well as those not proposed, are expensive. The economy is in continual flux and offers no true guarantee. Well-planned budgets and initial funding should be secured before research begins.

Conclusion

Canada has seen rapid growth in greenhouse vegetable production, particularly tomatoes. The country employs cutting-edge technology, but still has room for improvement in sustainability. The greenhouse system should be analyzed as a whole, including heat source, glazing, light, crop choice, and use of space. Improvements to the greenhouse system may

complement the two areas in need of future research – increased winter efficiency in production and geographic expansion of the industry.

Literature Cited

- Agriculture and Agri-Food Canada (AGR). 2008. Overview of the Canadian Agriculture and Agri-Food System, Economic Market Information, website. <http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1177676316971&lang=eng>. Accessed 3/18/2010.
- Agrium. 2009. Website. http://www.agrium.com/sustainability/mission_statement.jsp. Accessed 3/15/2010.
- Anderson. N.D. Greenhouse tomato production practices. University of Kentucky, Extension Horticulture, website. http://www.uky.edu/Ag/HLA/anderson/gh_tom.htm. Accessed 5/9/2010.
- Bertschinger, L., J.D. Anderson, N.D. Groot, D. Granatstein, R. Habib, K. Mullinix, D. Neilsen, F. Pomares Garcia, F.P. Weibel, and G. Zinati. 2004. Conclusions from the 1st Symposium on Sustainability in Horticulture and a declaration for the 21st century. *Acta horticulturae* 638:509-512, http://www.actahort.org/books/638/638_65.htm.
- Central Intelligence Agency. 2010. The World Factbook website. <https://www.cia.gov/library/publications/the-world-factbook/geos/ca.html>. Accessed 3/15/2010.
- Coal Association of Canada, The. 206. The Coal Association of Canada website. http://www.coal.ca/content/index.php?option=com_content&task=section&id=9&Itemid=55. Accessed 3/25/10.
- Dansereau, B., and Menard, C. 2002. "Floriculture - The Canadian Greenhouse Industry with Special Emphasis on Lighting". *Acta Hort.* (ISHS) 580:25-28, http://www.actahort.org/books/580/580_1.htm.
- Dick, L. 2010. The Greening of the West: Horticulture on the Canadian Prairies, 1870-1930. *Manitoba History*, #31 spring 1996. http://www.mhs.mb.ca/docs/mb_history/31/prairiehorticulture.shtml.
- Dick, L. and Taylor, J. 2010. The Canadian Encyclopedia, "Agriculture, History of", website. <http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1ARTA0000077>. Accessed 2/16/2010.
- Gauthier, L. 2007. A Multi-Agent Approach for the Dynamic Optimization of Greenhouse Environments. *Acta Hort.* (ISHS) 399: 61-72, http://www.actahort.org/books/399/399_5.htm.
- Government of Canada. 2001. Agriculture and Agri-Food Canada, "One Hundred Harvests – Research Branch, Agriculture Canada 1886-1986", website. <http://epe.lac-bac.gc.ca/100/205/301/ic/cdc/agrican/pubweb/hs27cover.asp>. Accessed 3/24/10.
- Government of Canada. 2009. Foreign Affairs and International Trade Canada, "Fast Facts: North American Free Trade Agreement", website. http://www.international.gc.ca/trade-agreements-accords-commerciaux/agr-acc/nafta-alena/fast_facts-faits_saillants.aspx?lang=eng. Accessed 5/6/10.
- Gunderson, R. N.D. Solar Cold Climate Greenhouse (SCCG), website. <http://www.mwt.net/~roald/solargh.html>. Accessed 5/9/10.
- Institute for Sustainable Horticulture. 2010. Kwantlen Polytechnic University website. <http://www.kwantlen.ca/ish/about.html>. Accessed 3/15/2010.0

- Mailvaganam, S. 2009. Ontario Ministry of Agriculture Food & Rural Affairs, Horticultural Statistics, website. http://www.omafra.gov.on.ca/english/stats/hort/fruit_value_area.htm. Accessed 2/16/2010.
- Natural Resources Canada. 2010. The Government of Canada, Natural Resources Canada website. <http://www.nrcan.gc.ca/eneene/sources/natnat/index-eng.php>. Accessed 3/25/10.
- Papadopoulos, A.P. 1991. "Growing greenhouse tomatoes in soil and soilless media". Agriculture Canada Publication 1865/E, Harrow Research Station.
- Papadopoulos, A.P., D.A. Demers, and J. Theriault. 2002. "The Canadian Greenhouse Vegetable Industry with Special Emphasis on Artificial Lighting". Acta Hort. (ISHS) 580:29-33, http://www.actahort.org/books/580/580_2.htm.
- Papadopoulos, A.P., and Gosselin, A. 2007. "Greenhouse Vegetable Production in Canada". Chronica Horticulturae, 47-3:23-28, <http://www.actahort.org/chronica/pdf/ch4703.pdf>.
- Purdy, J. 2005. High-tech vegetables: Canada's booming greenhouse vegetable industry. VISTA on the Agri-Food Industry and the Farm Community, Catalogue no. 21-004-XIE. SDInfo: The Government of Canada's Sustainable Development Information System. 2006. Government of Canada website. http://www.sdinfo.gc.ca/s1_e.cfm. Accessed 3/15/2010.
- Statistics Canada. 2008. Statistics Canada, 2006 Census of Agriculture, Area of fruit, berries and nuts, vegetables, sod, nursery and greenhouse products, by province, website. <http://www40.statcan.gc.ca/101/cst01/agrc31a-eng.htm>. Accessed 2/11/2010.
- SunTech Greenhouses Ltd. 2010. Website. <http://suntech.ca/index.php?section=growingmethods>. Accessed 3/15/2010.

Appendix 1 - (Statistics Canada, 2008)

Area of fruit, berries and nuts; vegetables; sod; nursery; and greenhouse products (Census of Agriculture, 1986 to 2006)

	1986	1991	1996	2001	2006
Canada					
Total number of farms	293,089	280,043	276,548	246,923	229,373
Total fruit, berries and nuts					
Area in hectares ¹	87,317	91,628	99,191	104,504	110,069
Farm reporting	15,191	13,491	14,302	12,158	12,447
Percentage of total farms	5.2	4.8	5.2	4.9	5.4
Average area in hectares per farm reporting	6	7	7	9	9
Total vegetables (excluding greenhouse vegetables)					
Area in hectares ¹	116,573	122,594	127,697	133,851	125,181
Farm reporting	11,758	10,708	11,440	9,829	9,499
Percentage of total farms	4.0	3.8	4.1	4.0	4.1
Average area in hectares per farm reporting	10	11	11	14	13
Sod					
Area in hectares ¹	20,074	26,797	21,964	22,467	27,960
Farm reporting	410	498	422	359	404
Percentage of total farms	0.1	0.2	0.2	0.1	0.2
Average area in hectares per farm reporting	49	54	52	63	69
Total nursery products					
Area in hectares ¹	13,575	19,689	21,521	22,776	24,953
Farm reporting	2,284	3,846	4,844	4,530	3,825
Percentage of total farms	0.8	1.4	1.8	1.8	1.7
Average area in hectares per farm reporting	6	5	4	5	7
Total greenhouse products					
Area in square metres ²	7,188,571	8,438,666	12,740,665	17,933,961	21,963,257
Farm reporting	4,874	4,986	6,422	6,071	5,613
Percentage of total farms	1.7	1.8	2.3	2.5	2.4
Average area in square metres per farm reporting	1,475	1,692	1,984	2,954	3,913
1. Conversion factor: 1 hectare equals 2.471 054 13 acres. 2. Conversion factor: 1 square metre equals 10.763 91 square feet. Source: Statistics Canada, Census of Agriculture. Last modified: 2008-10-29.					

Appendix 2 - (Mailvaganam, 2009)

Greenhouse Industry Statistics,
Ontario and Canada, 2006 to 2008

Item	Ontario 2006	Ontario 2007	Ontario 2008	Canada 2006	Canada 2007	Canada 2008
Glass ('000 sq m)	3,077	3,159	2,998	6,387	6,445	6,611
Plastic ('000 sq m)	8,346	8,361	8,492	14,722	14,547	14,141
Total Area ('000 sq m)	11,423	11,520	11,490	21,109	20,992	20,752
sales to retail florists (\$'000)	83,000	90,500	56,419	175,634	181,731	150,580
sales to domestic wholesalers (\$'000)	240,000	230,000	177,416	332,459	338,339	258,741
sales to mass market chain stores (\$'000)	148,000	200,000	162,521	307,245	367,469	337,473
sales to other greenhouses (\$'000)	60,000	50,000	44,109	97,803	86,274	75,007
exported (\$'000)	100,000	79,500	71,193	166,330	134,061	140,031
direct sales to public ^a (\$'000)	106,000	90,000	84,549	263,686	250,776	229,004
other channels (\$'000)	32,000	34,500	18,116	114,956	119,409	84,669
Total Ornamental and Plant Sales (\$'000)	769,000	774,500	614,323	1,458,113	1,478,059	1,275,505
Total Value of Greenhouse Vegetables (\$'000)	464,725	484,970	475,366	807,259	784,154	813,175
Total Greenhouse Sales (\$'000)	1,233,725	1,259,470	1,089,689	2,265,372	2,262,213	2,088,680
Total greenhouses (no.)	1,115	1,200	1,190	3,095	3,476	3,295
Total employees^b(no.)	18,400	17,300	16,400	42,645	41,980	38,375
Total payroll (\$'000)	279,000	270,000	261,146	539,852	534,908	543,620
Total investment^c (\$'000)	1,800,000	1,820,000	..	3,707,434	3,736,434	..
Total purchase value^d (\$'000)	238,000	251,400	191,881	421,833	448,186	392,318
Total fuel cost (\$'000)	172,300	163,000	146,307	278,372	268,965	244,316

^a Includes roadside stands and owner-owned retail outlets

^b Includes full-time and part-time labour

^c Includes land, buildings, equipment and machinery at fair market value

^d Includes value of flowers, plants, cuttings, seeds and bulbs purchased

.. not available for a specific reference period