Economic Analysis of Beneficial Water Management Practices in Quebec and Ontario

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By

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ABSTRACT

Concerns are increasing with regard to global warming, suggested to be caused by the increasing greenhouse gas (GHG) emissions. Scientific research emphasizes that high concentrations of GHGs in the atmosphere causes increased temperatures, changes in precipitation patterns, and the occurrence of extreme events, such as floods or droughts. All these phenomena constitute climate change that has become a main concern in the agriculture community around the world (excess moisture or water stress). However, the agricultural sector is also a source of GHGs. According to the most recent estimation reported in 2017, the Canadian agricultural sector accounted for 10% of the total national emissions.

As Canada has committed, through the Paris Agreement, to reduce its GHG emissions by 30% from the level of 2005 by 2030, federal and provincial governments are taking action to reduce agricultural GHG emissions but, at the same time, developing programs to adapt to climate change. Under the Agricultural Greenhouse Gases Program (AGGP) project, responsible agricultural activities are being promoted by supporting, among other areas, the development of technologies in irrigation, drainage and water table management, beneficial management practices (BMPs), which promote efficiency in the use and improvement in the quality of water (environmental performance), and ensure optimal agricultural production to protect the interests of Canadian producers (profitability performance).

Adoption of these BMPs by producers, however, depends entirely on their perception of the new technology and its effect on their farm business. Producers are more likely to adopt innovative practices that translate into an increase in their profits, relative to the pre-investment situation. To investigate this issue, this thesis evaluates the economic effects of adopting BMPs on the farm-level, deriving an incremental cash flow as a result of comparing net flows with and without the practice, in each of the four research farms located in Quebec and Ontario. The economic performance was estimated through the use of several indicators, but mainly the net present value. This thesis has also undertaken simulations on the economic desirability outcomes under changes in various factors that would affect the economics of the BMPs and as possible measures that influence its adoption. Crop yield was considered among these factors, whose variation results from projections into climate change.

The study findings show that the selected BMP technology for each of the four case studies is the most desirable alternative when compared to the base technology. This would imply that producers, may be interested in adopting innovative water management practices. However, depending on whether they are grain or vegetable producers, their interest may change as the results on economic desirability are very sensitive to variations in certain parameters due to uncertainties associated with economic and non-economic events.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAC	Agricultural Adaptation Council
AAFC	Agriculture and Agri-Food Canada
AGDEX	Agricultural Index
AGGP	Agricultural Greenhouse Gases Program
ATC	Average Total Cost
AVC	Average Variable Cost
BCA	Benefit-Cost Analysis
BMP	Beneficial Management Practices
CAD	Canadian Dollar
CRA	Canada Revenue Agency
CRAAQ	Centre de Référence en Agriculture et Agroalimentaire du Québec
ESDC	Employment and Social Development Canada
FADQ	La Financière Agricole du Québec
FCC	Farm Credit Canada
GHG	Greenhouse Gas
GRA	Global Research Alliance
IPCC	Intergovernmental Panel on Climate Change
MAPAC	Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec
MC	Marginal Cost
Mt CO2-eq	Megatonnes of Carbon Dioxide Equivalent
OAG	Office of the Auditor General of Canada
OECD	Organisation for Economic Co-operation and Development
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
OSCIA	Ontario Soil and Crop Improvement Association
PRISME	Productions en Régie Intégrée du Sud de Montréal
PS	Producer Surplus
PV	Present Value
TFC	Total Fixed Cost

TC	Total Cost
TR	Total Revenue
TVC	Total Variable Cost
UNFCCC	United Nations Framework Convention on Climate Change
U of G	University of Guelph
USD	United States Dollar
USDA	United States Department of Agriculture
USGCRP	United States Global Change Research Program
WACC	Weighted Average Cost of Capital
WTM	Water Table Management

Chapter 1

INTRODUCTION

1.1 Background

For the world as a whole, global warming, resulting from an increased amount of greenhouse gases (GHG), has been regarded to be an almost certainty for the future generations (USGCRP, 2017). The global emissions have increased by 1.3% annually from 1970 to 2000, while from 2000 to 2010 period their rate of annual increase has been estimated to be 2.2% (IPCC, 2014). Human activities are regarded to be the major sources of these emissions. According to 2010 estimates, 35% of the total GHGs worldwide were emitted in the energy supply sector, while 24% in agriculture, forestry and other land use (AFOLU), 21% in industrial sector, 14% in transport and 6.4% in buildings (IPCC, 2014). The major gas among these emissions is carbon dioxide (CO_2), which is responsible for about 78% of the total increase in emissions (IPCC, 2014). High concentrations of GHGs in the atmosphere produce increases in temperatures, changes in precipitation patterns and the occurrence of other extreme events, such as floods or droughts around the world (FAO, 2019). All these phenomena constitute climate change that, due to its global warming potential, has become the main concern in all countries around the world (IPCC, 2014).

In 2017, Canada´s total GHG emissions were estimated at 716 megatonnes of carbon dioxide equivalent (Mt CO_2-eq), which were 2% (15 Mt CO_2-eq) less than the 2005 emissions (730 Mt CO_2-eq). The majority of these emissions were in the form of CO_2, being approximately 80% of the total (Environment and Climate Change Canada, 2019a). In the same year, the agricultural sector accounted for 10% (72 Mt CO_2-eq) of the total GHG emissions and, at the same time, being the largest contributor of nitrous oxide (N_2O) and the second-largest contributor of methane (CH_4). These two gases accounted for 77% and 30%, respectively, of the total Canadian agricultural GHG emissions (Environment and Climate Change Canada, 2018).

The GHG emissions in Canada vary greatly by region depending on whether the economic activities that predominate in each of them provide high emission levels. Historically, Ontario had been the province emitting the highest levels of GHGs; however, its emissions have been decreasing steadily, being 22% (45 Mt CO_2-eq) less in 2017 compared to 2005 emissions. Similarly, Quebec has reduced its emissions by 9.8% (8.4 Mt CO_2-eq) during the period 2005-2017 (Environment and Climate Change Canada, 2018; 2019a). The reduction in emissions in both provinces is mainly attributed to the fact that coal plants to generate electricity are being replaced by plants that involve new sources (hydro, nuclear, wind, biomass, etc.) for the generation of the so-called clean or carbon-free electricity (Environment and Climate Change Canada, 2019a; Natural Resources Canada, 2019). Even though great efforts, such as the clean electricity generation, are being made to reach the goal agreed by Canada in 2015 under the Paris Agreement, in which reducing the GHG emissions by 30% from its 2005 level by 2030 was committed (OAG, 2016), meeting such targets is still a long way to go.

In this regard, federal and provincial decision-makers are taking measures aimed at reducing GHG emissions. Actions included here also pertain to the agricultural sector since it is also a source of GHGs (Environment and Climate Change Canada, 2019a). However, at the same time, programs for adaptation to climate change are being developed (OAG, 2016). Crop production is undoubtedly being affected, either positive and negatively, by a higher concentration of GHGs in the atmosphere, since photosynthesis, respiration rate, efficiency in water use, soil potential, among others, depend directly on temperature levels and water availability (He et al., 2018). The yields of some crops such as corn, wheat and soybean increase due to increases in temperature, to a certain extent suitable for them, and because they take advantage of uptaking the high levels of CO2 existing for the development of the plant (Qian et al., 2019). However, in other crops such as vegetables, yields are highly susceptible to decrease as a result of high temperatures, which causes an imbalance in water availability due to evaporation. All this combined with the unexpected periods without rainfall (Tesfaendrias et al., 2010).

Among many other actions, Agriculture and Agri-Food Canada (AAFC), has made a commitment under the Global Research Alliance (GRA) to fund research that leads to lower agricultural GHG emissions by promoting environmentally-friendly agriculture and supporting the development of new technologies (called beneficial management practices or BMPs), and transferring of information in four priority areas: livestock systems, cropping systems, agroforestry, and agricultural water use efficiency (AAFC, 2017a).

The variability of the water resource, in its most extreme cases of floods and droughts, has a significant effect on Canada´s agriculture since the water imbalance is mostly unpredictable (Cherneski, 2018). On many occasions, producers have to deal with excess water during the planting season and very little water during the growth (Bonsal et al., 2019). Seeding in very humid soil leads to underdeveloped roots and greater vulnerability of the plant to droughts and warm temperatures (AAFC, 2019a), while a growing season with moisture deficit could lead to a considerable reduction in crop yields and, consequently, the profitability of the farm (AAFC, 2015a). Thus, the frequency of these events means large impacts on farm producers.

The consequences associated with climate change, especially the availability of water for agriculture and growing season duration, are expected to be more prominent if the same GHG emission scenario continues (Bonsal et al., 2019). In that sense, concerns are justified. The management of agricultural water resources has been and continues to be a subject of study and interest of researchers, decision-makers, and producers, whose aim is principally oriented to promote the efficiency in its use and the improvement of water quality, in order to increase agricultural production (USDA, 2014). However, given that 10 percent of Canada's GHG emissions are from crop and livestock production (AAFC, 2016b), the Canadian government´s priority goes beyond just increasing agricultural productivity. To the Government of Canada, improving efficiency of water use, as well as to control and mitigate GHG emissions through the development of beneficial water management practices is also of paramount importance.

Water management practices in agriculture are basically the application (irrigation) of water to crops when needed and elimination (drainage) of water from croplands when it might be damaging to them. In that sense, the focus is on the various irrigation and drainage techniques. Irrigation water can be supplied using furrow, drip, sprinkle, and subsurface irrigation systems, surface and subsurface drainage systems, as well as the water table management (WTM) systems. The latter consists of controlling groundwater combining drainage and irrigation techniques in order to adjust the water table level of the cropland, in a kind of dual-purpose system (Zimmer et al., 1997; Evans et al., 1996).

All water management systems have relevant characteristics of being beneficial practices. Some such characteristics are: the ability to maximize water use efficiency (i.e., ensuring that the plant covers all its water requirements for better yields and, at the same time, minimizing losses due to evaporation and/or runoff), the control of water table levels according to the needs of each crop, fertilizer application in a safe and controlled manner, among others (OMAFRA, 2003b). Likewise, for beneficial water practices to have promising results, several factors must be taken into account, such as access to a nearby source of water, whether surface or underground, the types of soil on the farm, its drainage capacity, as well as its ability to retain moisture (OMAFRA, 2002).

Humid regions in North America with organic and sandy soils farms have adopted WTM for a long time in order to increase crop yields and reduce agricultural pollution, since the technique reduces the concentration of chemical substances (nutrients and pesticides) in drained water (Madramootoo et al., 1997). The WTM system can take one of the following two forms: controlled drainage and subirrigation. The first occurs when the conventional tile drainage system is modified to permit the water table to be lowered during planting and be higher during growing; however, because of the evaporation and filtration, the water table drops over time and the crop needs irrigation. In the form of subirrigation instead, the level of the water table remains constant because water drained is pumped into the drainage system again when the crop needs water (Zimmer et al., 1997; Evans et al., 1996).

With the existence of the different irrigation and drainage systems mentioned previously, the question needs to be raised whether such practices would be adopted by the farm producers. If the adoption rate is poor, then a secondary question is what economic and social incentives may be offered that may encourage them to adopt such practices. As a starting point, many stakeholders have already been working on the denominated “Agricultural Greenhouse Gases Program project”, undertaken by the partnership conformed by agricultural producers, federal and provincial governments, and universities, who have gathered useful information from about six study sites in eastern Canada, as a result of changes in the conditions of crops in terms of new production systems and innovative water management practices (Madramootoo, 2018).

1.2 Problem Statement

As Canada is a member of the United Nations Framework Convention on Climate Change (UNFCCC) since 1992, it has made commitments about reducing GHG emissions.

Under the Copenhagen Accord in 2009, the agreement was to reduce GHG emissions by 17 percent below its 2005 level by 2020; likewise, in 2015 Canada agreed under the Paris Agreement to reduce GHGs by 30 percent of the 2005 level by 2030 (OAG, 2016). These decisions are consistent with the UNFCCC´s main objectives of limiting global warming and strengthening countries so that they can deal with the effects of climate change (Environment and Climate Change, 2016). In this regard, the government of Canada has called on all sectors of the economy to address the issues and challenges of climate change.

The agricultural sector has not been the exception. For grain, vegetable and fruit production, beneficial water management practices have been developed through research and experimentation under the Agricultural Greenhouse Gases Program (AGGP), besides other measures of the federal and provincial governments (plus producers' actions). These practices have also been evaluated for their effect on the reduction of GHG emissions (Madramootoo, 2018). However, the adoption by producers depends entirely on their perception of the new technology and its effect on their farm business. The development of measures that might encourage producers to adopt these new water management practices is an important issue.

Among other things, producers are likely to adopt a new BMP if it would positively impact their pocketbook. In other words, producers are more likely to adopt innovative practices that mean an increase in their net returns, relative to the pre-investment situation. Studies in this regard are conclusive, for instance, Shekhawat (2007) has concluded that producers need evidence of a financial gain to adopt new opportunities of a subsurface drainage system available, beyond the social benefits that it generates. Similarly, Patil and Poddar (2016) found that lack of subsidies from the government as well as the lack of technical assistance, were the main obstacles for small and marginal producers to adopt a drip irrigation system.

The research on farm producer behaviour by Reimer et al. (2012) used interview data to assess the factors that motivate producers to adopt BMPs. They found that although off-farm benefits, such as clean water and air, are important, they are only a small part of the decision to adopt new practices; likewise, a stewardship attitude is the only motivation for adopting a practice. The same study also stated that it is vital for the producer to have full knowledge of how the technology works and evidence of its operation to create awareness and have a perception of its advantages.

According to the Organisation for Economic Co-operation and Development (OECD), it is necessary for farm producers to understand a wide range of factors so that they may acquire a technological change, the first and most important being financial incentive, although the profitability of new practices will not be enough. There are other elements such as habits, cognition and norms that influence producer´s behaviour, mainly to contribute to the adaptation to climate change (OECD, 2012). The same study also found that heterogeneity in the agricultural sector (specific characteristics of farms such as large-scale agricultural enterprises versus farms managed by families, market targets, etc.) also affect the behaviour of producers towards the adoption of innovative practices, so that political intervention could work to encourage certain sectors that are reluctant to the change.

Based on the previous review, it is important for the adoption of a BMP by producers that its economic effects are estimated and possibly disseminated to them. Additionally, in a context of climate change, the long term economic effects of the BMPs are even more important. According to the latest assessment report on impacts, vulnerability and adaptation by the Intergovernmental Panel on Climate Change (IPCC), it is projected that climate change will impact on the incidence and magnitude of both extreme events: floods and droughts (IPCC, 2014). Those variations are definitely a challenge in the agriculture system around the world, which are expected to have negative effects on crop yields in some parts of the world because of changes in water availability.

Even though there are some crops, such as corn, wheat, and rice, that may benefit from the changing conditions in a projected climate change scenario by 2050 (Ignaciuk, 2015), other projections after 2050 coupled with a higher level of warming between 2° and 4°C, have also been estimated to have a more severe impact on crop yields (IPCC, 2014). Therefore, it is clear that yields would be affected at some point by higher temperature conditions, although some studies mention that warming can be considered a future benefit for the agricultural sector in some cold parts of the world (Ignaciuk, 2015; Vincent et al., 2018, Li et al., 2018). In this regard, the concerns about the harmful effects of climate change on agricultural production are justified and it is important to develop new agricultural techniques. Innovative practices to facilitate water use efficiency are necessary, not only to avoid the increases in GHG emissions responsible for global climate change, but also to guarantee crop yields that ensure profitability at on-farm level.

As noted earlier, the literature suggests that the adoption of new farming practices by producers depends largely on the economic impact on their business, but knowledge about the financial viability of BMP technologies has not been thoroughly investigated, so there is a gap in this field that should be filled. Therefore, the query that emerges is, will the on-farm net benefits that these improved water management technologies yield be attractive enough over time for the producer to be willing to adopt them?.

1.3 Objectives of the Study

The study aims to evaluate the economic effect of adopting BMPs on the farm-level at two locations in Ontario and another two locations in Quebec. The major objectives are:

- Estimate the economic desirability of adopting the selected BMP considering the direct benefits and costs that could have an effect on the producers; and,

- Examine the robustness of the results on economic desirability of the selected BMP by simulating these outcomes under changes in various factors that would affect the economics of the BMPs and as possible measures that influence its adoption. Within these scenarios for assessing the robustness of the BMP's performance, changes in crop yield resulting from projections into climate change are simulated.

1.4 Scope of the Study

The scope of the present farm analysis is restricted to four study sites, two in Quebec – Saint Emmanuel and Saint-Patrice de Sherrington, and two in Ontario – Harrow and Holland Marsh. All case studies comprise of commercial farms that include a study field, with the exception of Harrow, Ontario, which is an experimental farm belonging to the Research and Development Center of the Agriculture and Agri-Food Canada. The farms located at two of the sites, St. Emmanuel and Harrow are grain-producing farms, while the other two study locations, Sherrington and Holland Marsh, comprise of farms that produce vegetables.

Chapter 2

PROJECT BACKGROUND

As noted in Chapter 1, this study involved four research sites where producers have implemented a BMP for water table management or providing water to the crops. Two of these sites were grain-producing while the other two were engaged in vegetable production. In this chapter, the economic characteristics of these crops are described. Major grain crop in the region is corn which is usually grown in rotation with soybean, while carrot and onion are two of the vegetables that are produced together in the same field. Both of these vegetable crops make an important contribution to the economy of the provinces under study, as described in Section 2.1. In addition, in Section 2.2, the most relevant production characteristics of the aforementioned crops in Ontario and Quebec, highlighting their importance in terms of the total produced with respect to the cultivated area, are described. Finally, the BMPs involved in this study are described in detail, as well as their importance and need to delve into how attractive they are to be adopted by the producers (Section 2.3).

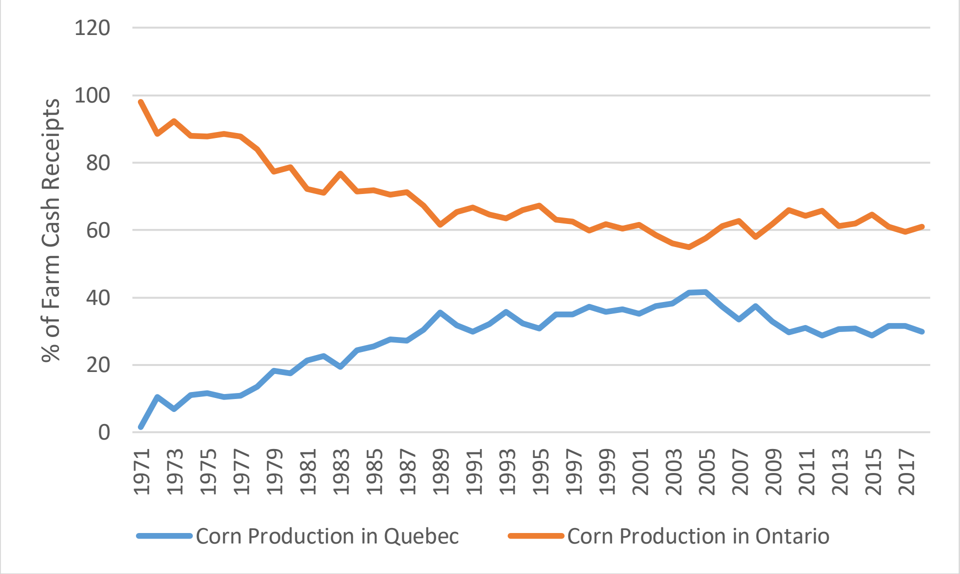
2.1 Economic Contribution of Agricultural Production in Quebec and Ontario

Canadian agriculture is progressing over time and its contribution to the national economy is increasing. During the period 2012-2016, the gross domestic product (GDP) in the agriculture and agri-food system grew by 11%, compared to the Canadian economy as a whole, which grew by 7.8% during the same period (AAFC, 2017b). In 2016, the Canadian agriculture and agri-food sector accounted for 6.7% of the total Canadian GDP, that is, around $111.9 billion. Of this total, grains and oilseeds production contributed $25.3 billion (AAFC, 2018a), while fruits and vegetables contributed $6.2 billion (AAFC, 2017b). Moreover, regarding the labor force, the agricultural sector accounted for 12.5% of total national employment in 2016, employing approximately 2.3 million people (AAFC, 2017b). Of the total, 807,291 workers (35%) were employed in Ontario (OMAFRA, 2019a) and 509,344 (22%) in Quebec (MAPAQ, 2017); which means that the two provinces are an important source of agricultural employment in Canada as they offer approximately 57% of agricultural jobs nationwide.

Furthermore, during the same year, more than 55% of the total GDP contributed by the agriculture sector was generated in the provinces of Ontario and Quebec, representing 33.4% and 21.9%, respectively, for primary agriculture and food processing (AAFC, 2017b). Both provinces have more diversified production compared to other provinces, with the grain, oilseed and horticultural commodities representing the majority of their agricultural market revenues (AAFC, 2018a).

In as far back as the census of agriculture in 2011, approximately 92% of corn in Canada grew in those provinces. Ontario accounted for 61.7% and Quebec for 30.2%, while the remaining was shared between Manitoba and to a lesser extent in Alberta (AAFC, 2015b). Historically, trends in the contribution of corn production to farm cash receipts in both provinces have been different. Figure 2.1 shows that in the 1970s, Ontario was the only province producing corn, while Quebec's corn production was insignificant; however, that has been changing over the years until it stabilized from the 90s to the present at an average of 62%

and 33% of the Canadian farm cash receipts for the crop, respectively. In 2018, corn for grain production at the national level was reported at 13.9 million tonnes (Statistics Canada, 2018a), valued at $2.26 billion (Statistics Canada, 2019a), with Ontario accounting for 8.8 million tonnes (63.3%), valued at $1.4 billion, and Quebec accounting for 3.6 million tonnes (25.9%) valued at $674.5 million.

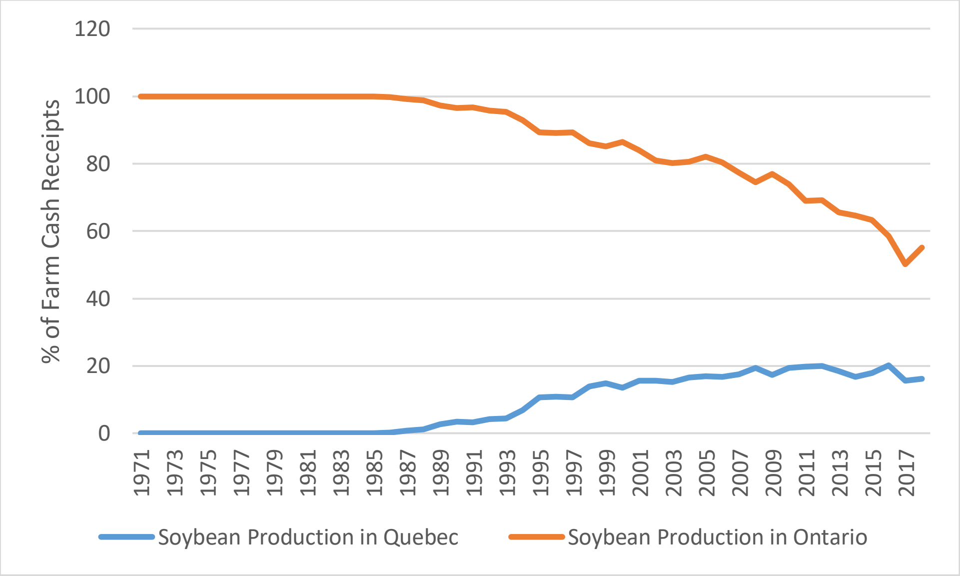


Source: Statistics Canada (2019a)

Figure 2.1. Contribution of Corn Production in Ontario and Quebec to Total Canadian Farm Cash Receipt for Corn, 1971-2018

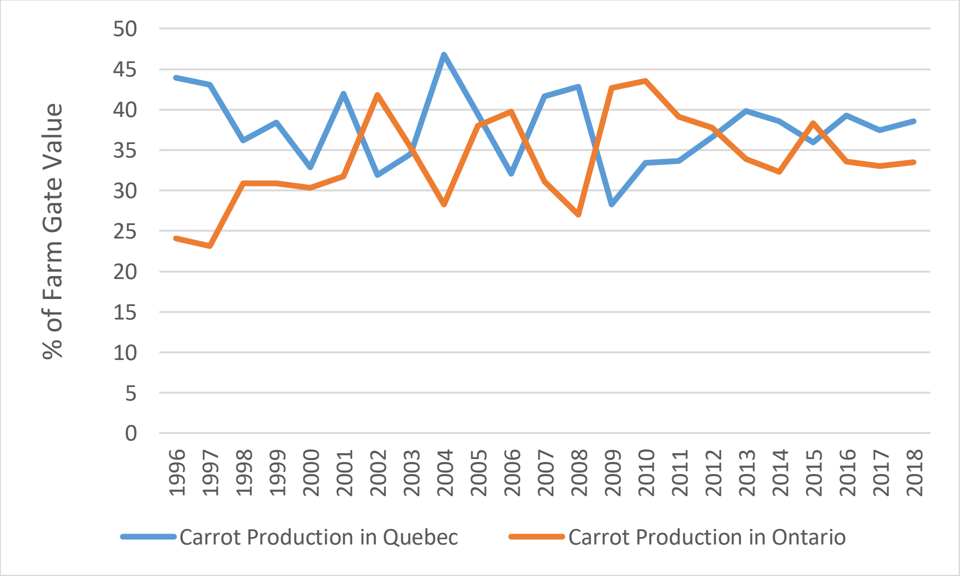
Until 1985, soybean was only produced in Ontario. As shown in Figure 2.2, its contribution in this province has been declining over the years, although it is still quite significant, being above 50% of the total farm cash receipts for the crop. Likewise, from 1985 to the present, the contribution of Ontario and Quebec together always exceeded 65% of the total farm cash receipts for the crop, which shows the importance of the soybean in these two provinces. In 2018, Canada produced 7.3 million tonnes of soybean, distributed among Ontario, Manitoba and Quebec (Statistics Canada, 2018a), representing $3.05 billion of farm cash receipts (Statistics Canada, 2019a). Production in Ontario was 4.2 million tonnes (57.5%), valued at $1.68 billion; in Manitoba was 1.9 million tonnes (26.1%), valued at $720.5 million; while Quebec produced 1.2 million tonnes (16.4%), valued at $493.4 million.

In 2018, the total production of field vegetables nationwide was 2.4 billion tonnes, with a farm gate value of $1.2 billion (Statistics Canada, 2019b). Of this total, 90.9% of the vegetable production was distributed between Ontario (44%), Quebec (38%) and British Columbia (8.9%) (Statistics Canada, 2019c). In the same year, carrots were the most produced vegetable at 382,877 tonnes in Canada, generating a farm gate value of $129.9 million. Of this total carrot production, 198,674 tonnes (values at $43.5 million) were produced in Ontario and 111,845 tonnes (valued at $50.1 million) in Quebec. In the last decade, the combined contributions of both provinces to the farm gate value for carrot production have remained constant at about 72% of their combined farm level receipts for carrot (Figure 2.3).



Source: Statistics Canada (2019a)

Figure 2.2. Contribution of Soybean Production in Ontario and Quebec to Total Canadian Farm Cash Receipt for Soybean, 1971-2018



Source: Statistics Canada (2019b)

Figure 2.3. Contribution of Carrot Production in Ontario and Quebec to Total Canadian Farm Gate Value for Carrot, 1996-2018

Dry onion crop was the third most-produced vegetable after tomato in Canada in 2018[1]. Total Canadian onion production was 251,836 tonnes, totalling $94.6 million of the farm gate value, with Ontario accounting for 101,885 tonnes (valued at $34.8 million) and Quebec accounting for 98,040 tonnes ($35.1 million) (Statistics Canada, 2019b). Figure 2.4 shows that historically both provinces together have contributed on average combined total around 80% to the total farm gate value for fresh dry onions.

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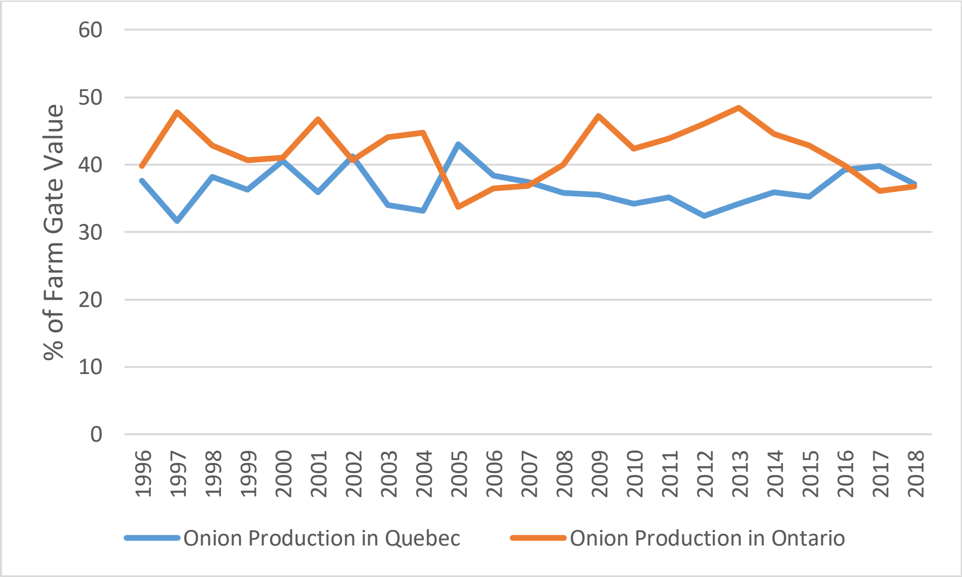
[1] Whenever "onion" is mentioned in this study, reference is made to "dry onions".



Source: Statistics Canada (2019b)

Figure 2.4. Contribution of Onion Production in Ontario and Quebec to Total Canadian Farm Gate Value for Onion, 1996-2018

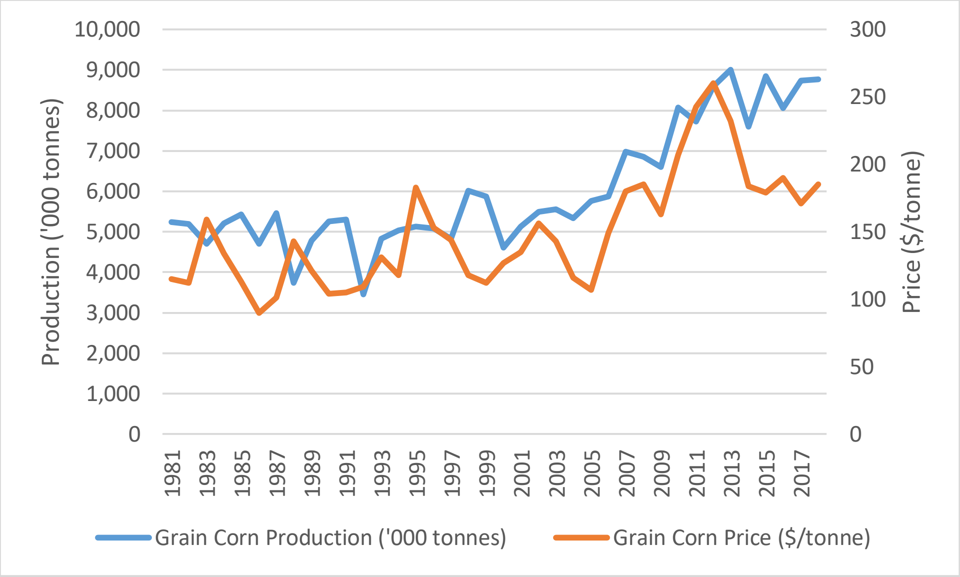
2.2 Grain and Vegetable Production Characteristics

Although Canada’s population is growing, there is a trend towards urban expansion. As technology and rural-urban migration change, smaller farms disappear and that bring forth a decrease in the total number of farms. From 2011 to 2016, farms have reduced by 5.9%, from 205,730 to 193,492 farms (Statistics Canada, 2019d). However, in the same period, the number of farms producing grains, oilseeds and vegetables have increased in response to growth forecasts and significant contribution to farm receipts of the mentioned crops. Farms dedicated to the production of grains and oilseeds increased from 61,692 in 2011 to 63,628 in 2016, and farms that produce vegetables increased from 4,822 in 2011 to 5,514 in 2016, the latter increased significantly by 14.4%. This increase occurred mainly as producers changed agricultural practices, improved marginal lands, cleaned and drained to make them suitable for crop production (Statistics Canada, 2017).

2.2.1 Grain and Vegetable Production in Ontario

According to the 2016 census of agriculture, Ontario has a total cropland of 3,650,789 ha (Statistics Canada, 2019e). Of this total, in 2018, the proportion of this under corn for grain was 23% (841,746 ha), with a total production of 8,767.9 million tonnes (OMAFRA, 2019b). Historical data show that although with some oscillations between 1981 and 2018, corn production in the province has shown a growing trend (Figure 2.5). As shown in this figure, this trend was maintained even though prices had significant variations, such as their sharp falls in 2004, 2008 and 2014, when corn prices fell by 28, 24 and 27%, respectively, with respect to the prices of the prior year (Zuba & Borman, 2015).

Corn production is mostly concentrated in the southern region of Ontario, which has accounted for approximately 45.9% of the total production in 2018 (OMAFRA, 2019b). This region is comprised of Chatham-Kent, Middlesex and Oxford counties, and on average produces about 51% of corn production in the southern region and 25% of total corn production in the province, during the 2008-2018 period (OMAFRA, 2019b). Western Ontario is also a region with significant corn production as well, predominantly Huron County. In 2018, 30.9% of total provincial production came from the western part of the province.



Source: OMAFRA (2019b)

Figure 2.5. Average Production and Prices of Corn in Ontario, 1981-2018

Usually, corn producers in Ontario try to plant it in late April or the first half of May to prevent a reduction in crop yields due to damage from an early fall frost or from other adverse weather during harvest (OMAFRA, 2017). According to the target dates provided by OMAFRA, the planting day should be May 5 and the growth process should take place from May 16 to September 18, which is the target date where the plant reaches physiological maturity (OMAFRA, 2017). The warmth of the season determines the optimal germination and emergence of corn, which is very susceptible to cold conditions. Temperatures between 20°C and 30°C are required for optimum growth. According to estimates in southern Ontario, there is a new leaf in the corn plant every 2 to 3 days with temperatures of 30°C during the day and 20°C at night. With lower temperatures of 20°C during the day and 10°C at night, a new leaf appears every 5 or 6 days (OMAFRA, 2017).

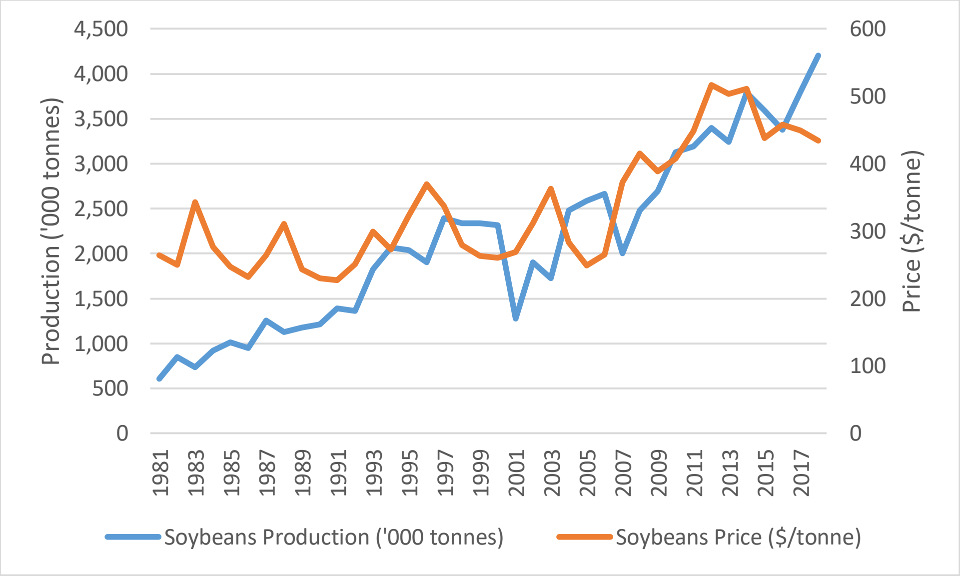
The amounts of different types of fertilizers (containing N, P, K) used for corn production differ depending on the type and characteristics of the soil based on guidelines developed by OMAFRA. Their ranges are between 9 and 211 kg N/ha, 20 and 110 kg P/ha, and 30 and 170 kg K/ha (OMAFRA, 2003a). Stress due to excess and water shortage is also faced by the corn crop in Ontario. If there is a flood in the first stage of growth, the plants die in 5 days due to the lack of oxygen in the root, while flooding during the growth generates a reduction in the filling of the grain. On the other hand, drought can reduce pollination and lack of silk appearance (Jacques, 2014).

Corn producers face two important decisions regarding production, one is to achieve the right soil texture for planting and the other is to choose crop rotation. In early spring, the soils of southern Ontario are generally saturated and rapid drying is necessary for timely planting, which is usually achieved with tillage that loosens the soil and allows rapid evaporation. The soils in this region are generally sandy, loamy and sandy loams (OMAFRA, 2017). Many fields in that region have poorly drained soils that, if not properly addressed, can generate planting delays. This has motivated some producers to install subsurface (tile) drainage system to ensure a normal period of growth (AAFC, 2006a).

Proper crop rotation can help to avoid some problems related to conservation tillage, such as soil compaction and perennial weeds (Roth, 1996), and sometimes can even replace tillage in fields where there is good drainage and there are no soil compaction issues (OMAFRA, 2017). Corn and soybean rotations are commonly used practices in both Ontario and Quebec, sometimes even combined with a small grain such as wheat (AAFC, 2006a). This practice allows, among others, weed control and breaking pest cycles that might appear in continuous crops (Statistics Canada, 2018b). However, what is of most interest to the producer is the economics of crops in response to the potential yield by rotation. Deen et al. (2016) found that adding wheat to a corn-soybean rotation has an additional profit of $115 per acre mainly due to the increase in yields of all the crops involved (4% in corn and 11% in soybean on average). Another reason for better returns is that inputs and fixed costs are divided or shared among all crops within the rotation (Deen et al., 2006; Roth, 1996).

The soybean acreage in Ontario in 2018 was 1,216,080 ha, which represented a significant 33.3% of Ontario´s total cropland (3,650,789 ha), with a total production of 4,200.4 million tonnes (OMAFRA 2019c). Since 2014 it has become the largest row crop by acreage in the province with more than 1 million ha annually. This crop has become attractive to producers due to the development of its early maturing varieties, a wide selection of herbicides and the low cost of production in comparison with corn and other crop fields (OMAFRA, 2017). Historical data show that although with some oscillations between 1981 and 2018, soybean production in Ontario has shown a growing trend. Prices have had a steady rise from 2005 to 2014, then a slight decrease began (Figure 2.6). Like corn, soybean production is concentrated in the south region of Ontario, which has accounted for approximately 50.3% of total production in 2018, followed by the western area that has accounted for 28.2% (OMAFRA 2019c).

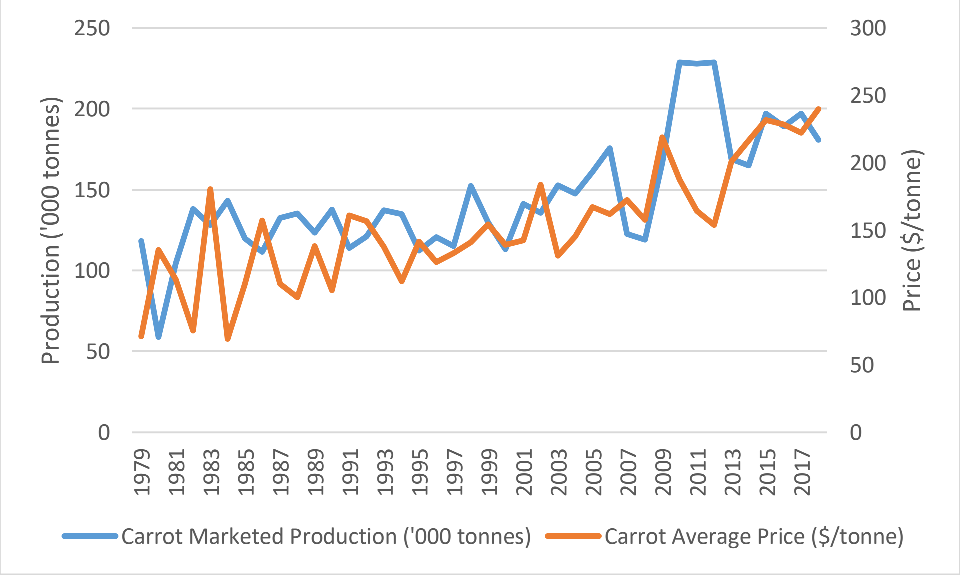
Soybeans can be sown later than corn; however, producers choose to plant before mid-May, if weather conditions allow, to ensure the highest yield. Generally nitrogen fertilizers are not used in soybeans if the seeds have been previously inoculated; however, in western Ontario, there has been evidence that up to 50 kg N/ha have been applied (OMAFRA, 2017). According to the guidelines developed by OMAFRA, a range between 20 to 80 kg P/ha and 30 to 120 kg K/ha are required, depending upon types of soil to grow soybean (OMAFRA, 2003a). As noted previously, Ontario producers generally grow soybean in rotation with corn or wheat, since it is not advisable to grow soybeans for more than two consecutive years because it might present root diseases (AAFC, 2006b).



Source: OMAFRA (2019c)

Figure 2.6. Average Production and Prices of Soybean in Ontario, 1981-2018

In 2018, the harvested area of carrots in Ontario was 3,439 ha, which accounted for about 42% of the total carrot harvested area in Canada (8,133 ha), with a total marketable production of 198,674 tonnes (Statistics Canada, 2019b). Carrot production is mostly concentrated in southern Ontario, which has accounted for almost 50% every year (OMAFRA, 2018a), specially Chatham-Kent county. The other half of the carrots production comes from the area known as the Holland Marsh, which covers 40% of York Region and 60% of Simcoe County, in central western Ontario. Figure 2.7 shows historical data from 1979 to 2018 that indicate a steady rising trend, both in carrot production and its price, although with some oscillations noted in both.

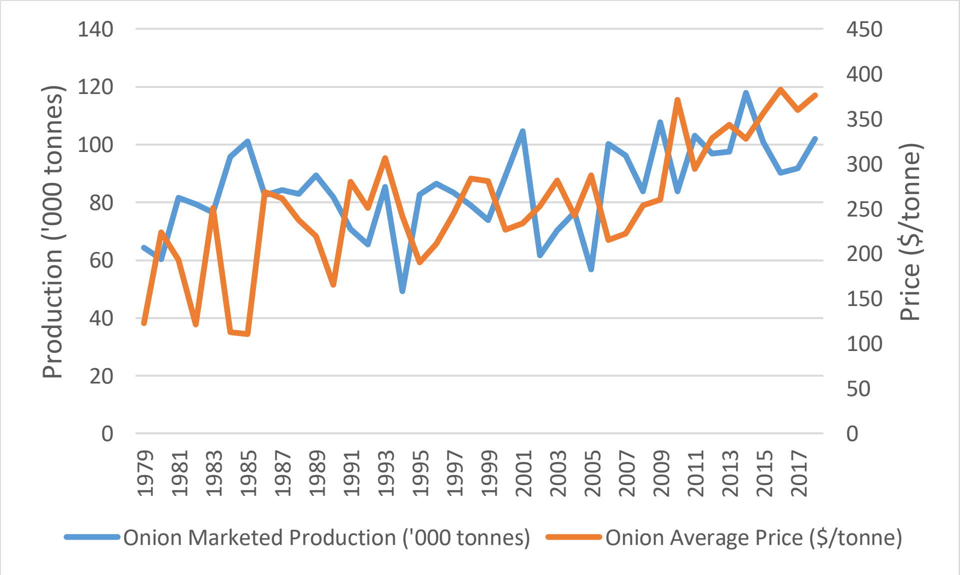


Source: OMAFRA (2018a)

Figure 2.7. Average Marketable Production and Prices of Carrot in Ontario, 1979-2018

Carrots tend to adapt to long and cold growing seasons. A large number of crops in Ontario grow in muck soils (60%), although there are increasingly more varieties of carrots that are growing in non-organic and mineral soils, which are generally destined for the processing industry (Telfer, 2017). The optimum temperatures for growing good-quality carrots in this region are between 16 and 21°C (Tesfaendrias et al., 2010), even though they also respond well with minimums of up to 12°C and maximums of up to 24°C (AAFC, 2004). In southern Ontario, planting is usually from mid-April to late May, and it takes between 6 to 21 days to germinate and between 70 to 120 days to mature. Harvesting starts in mid-August until October approximately (Telfer, 2017). Soil moisture has a determining role in carrot production, as the optimum soil water content is 54.6% (White, 1992). In the muck soil region, the carrot fields are usually rainfed; however, in recent years, they are being irrigated up to two times to stimulate seed germination when soils are dry during spring (Tesfaendrias et al., 2010). Producers apply fertilizers as the crop needs and follow the guidelines issued by OMAFRA (AAFC, 2004).

In 2018, the harvested area of dry onions in Ontario was 2,291 ha, with a total marketable production of 101,885 tonnes. This area accounted for around 42% of the total dry onion harvested area in Canada (Statistics Canada, 2019b). The Holland Marsh area each year produces between 65 and 75% of total onion production in Ontario (Tesfaendrias et al., 2010). Production has fluctuated greatly between 1979 and 2005 with minimums of approximately 50,000 and maximums of more than 100,000 tonnes. However, from 2006 to the present it has not dropped from 80,000 tonnes per year; prices have also had an increasing trend according to the historical data shown in Figure 2.8.



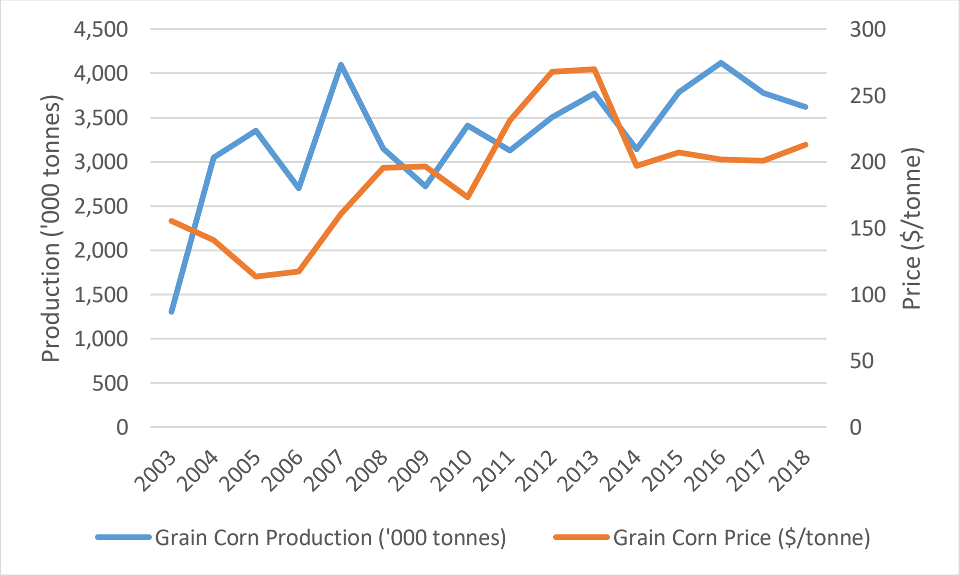
Source: OMAFRA (2018b)

Figure 2.8. Average Marketable Production and Prices of Onion in Ontario, 1979-2018

Onions have a standard growing season that begins late in April and mid-May and ends in September (Tesfaendrias et al., 2010), with an average ripening time of 85 to 115 days after planting. Direct seeding is the most common method in Ontario, although sometimes transplants are also performed (Tayviah, 2017). Since onions have surface roots, the rainfall that varies annually between 313 and 398 mm in the Holland Marsh region is usually sufficient and no extra irrigation is required (McDonald et al., 2017). The fertilizer is applied during the preparation of the land before planting (Tayviah, 2017), following guidelines developed by OMAFRA for the type of soil and location.

2.2.2 Grain and Vegetable Production in Quebec

In 2016, Quebec had a total cropland of 1,866,829 ha (Statistics Canada, 2019e). In 2018, corn for grain was grown in about 45% (383,400 ha) of this area, which accounted for a total production of 3.6 million tonnes (Statistics Canada, 2019f). Historical data in Figure 2.9 shows an increasing trend in corn production between 2003 and 2018, although subject to many periods of price fluctuations. Much of Quebec's corn production, about 61% of the total production, takes place in the northeast and southwest Montérégie region, located in the southwest of the province (CRAAQ, 2018a). Although grain and fodder corn are produced in the province, only the former was included in the data set to elaborate Figure 2.9.



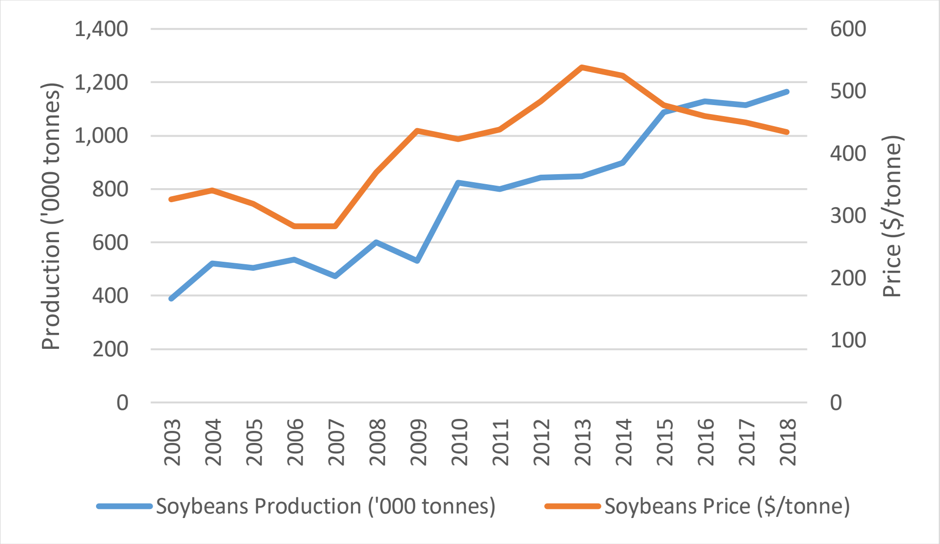
Source: Institut de la Statistique Quebec (2019a) and Statistics Canada (2019f)

Figure 2.9. Average Production and Prices of Corn in Quebec, 2003-2018

The 1.2 million tonnes of soybeans produced in Quebec in 2018 were cultivated in a total area of 369,400 ha (Statistics Canada, 2019f). This area represents 20% of the total cropland in Quebec (1,866,829 ha) (Statistics Canada, 2019e). From 2003 to date, the soybean has been showing a steady growth despite the fact that since 2013 prices have been declining (Figure 2.10). The majority of soybean production comes from the northeast and southwest regions of the Montérégie region, representing around 50%, followed by the Center-du-Québec, which represents 15-20% every year (Institut de la Statistique Quebec, 2019b).

The cultural practices for the production of corn and soybean in Quebec are similar to those listed formerly for Ontario. The only exception is that the planting of corn should not be later than May 10 in southwestern Quebec since the delay can result in yield losses of 1% for each day of delay (Mycogen Seeds, 2012). Additionally, the fertilizer application in Quebec for corn is 120 to 170 kg N/ha and for soybean is 20 kg N/ha. These are based on the reference rates developed by the Centre de Référence en Agriculture et Agroalimentaire du Québec

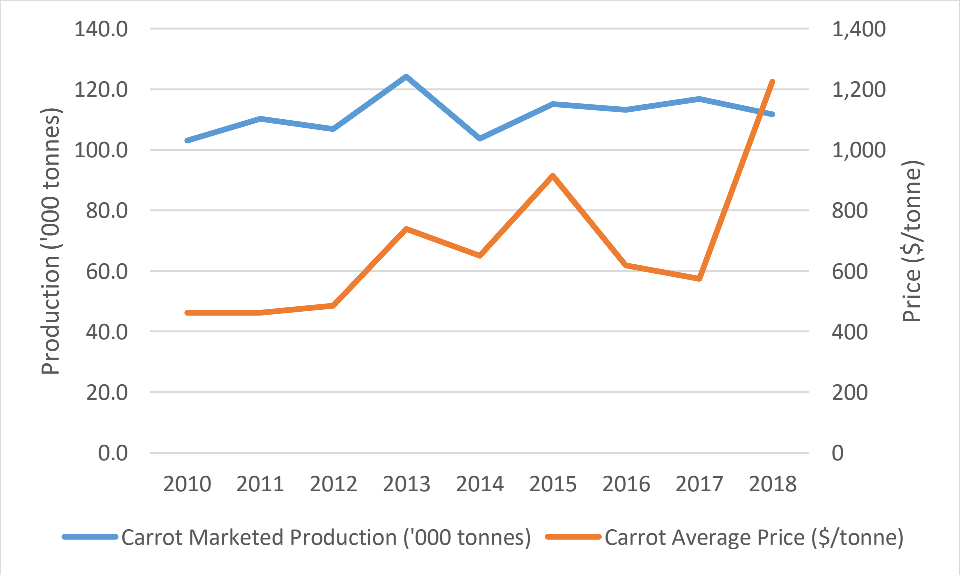
(CRAAQ), although these may vary according to the previous crop has been as well as if manure was applied (CRAAQ, 2018a; CRAAQ, 2018b).



Source: Institut de la Statistique Quebec (2019b) and Statistics Canada (2019f)

Figure 2.10. Average Production and Prices of Soybean in Quebec, 2003-2018

In 2018, the harvested area of carrots in Quebec was 2,939 ha, with a total marketable production of 111,845 tonnes (Statistics Canada, 2019b). Figure 2.11 shows that during the last decade carrot production has remained constant with values between 100,000 and 120,000 tonnes per year, despite pronounced price fluctuations. According to the 2016 census of agriculture, more than 60% of the production is located in the Montérégie region, concentrated in the area of the black lands of Jardins de Napierville (Statistics Canada, 2017).

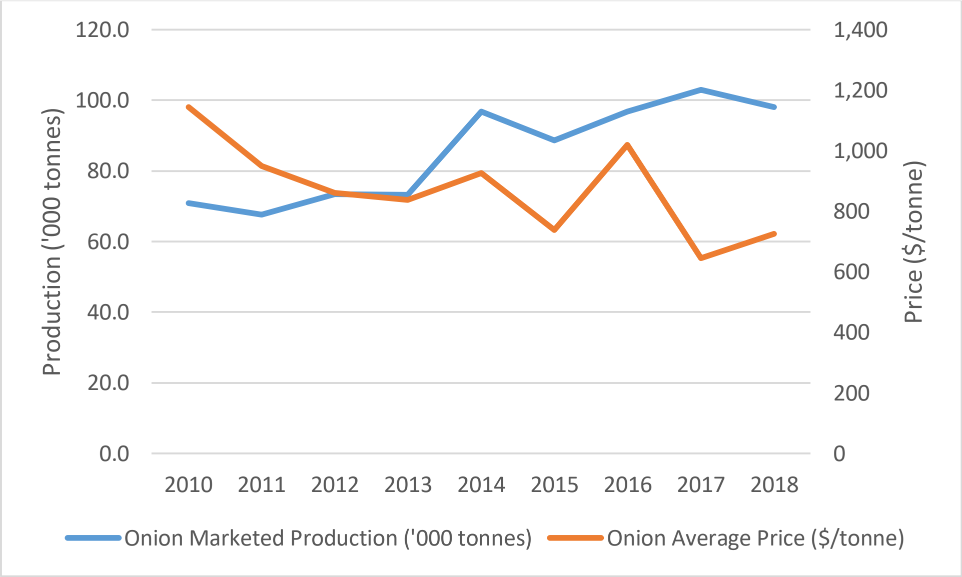


Source: OMAFRA (2018a)

Figure 2.11. Average Marketable Production and Prices of Carrot in Quebec, 2010-2018

Planting carrots in Quebec takes place from the end of April until mid-July, germination could take between 7 and 10 days, although in cold conditions it sometimes could be up to 20 days. The harvest lasts from the beginning of August until the end of October or the beginning of November (PRISME, 2019a). The CRAAQ recommends fertilizer contributions based on soil analyses. The requirement is usually low nitrogen and enough potassium.

The harvested area of dry onions in Quebec was 2,105 ha, with a total marketable production of 98,040 tonnes in 2018 (Statistics Canada, 2019b). Onion production in Quebec shows a growing trend in recent years despite the fact that prices are fluctuating and downward (Figure 2.12). According to the 2016 Census of Agriculture, more than 80% of Quebec onion production is located in the Montérégie, in the Jardins de Napierville, similar to carrot production (Statistics Canada, 2017).



Source: OMAFRA (2018b)

Figure 2.12. Average Marketable Production and Prices of Onion in Quebec, 2010-2018

Production is frequent in the muck soils of the province due to the great soil organic matter content, which makes them highly fertile with a high capacity to retain water. Onions are the beneficiaries because they require constant humidity at the time of bulb formation (Lloyd, 2016). In recent years, irrigation is becoming a frequent practice in southern Quebec (Rekika et al., 2014). Planting occurs between mid-April and early May, and the growing season lasts until around September 17 (Équiterre, 2009). The CRAAQ recommendations regarding the use of fertilizer are made based on soil analysis. Producers generally choose a carrot-onion rotation or alternate with other vegetables such as lettuce and spinach. Larger farms adopt an intercropping system as well (PRISME, 2019b).

2.3 Beneficial Management Practices

2.3.1 Need for Development of Beneficial Management Practices

Climate change is particularly affecting Canada´s farming sector because its rate of warming is faster than the global rate (Li et al., 2018). Over the period 1948-2016, the annual mean temperature in Canada has increased by 1.7°C (varying between 1.1 and 2.3°C depending on the region[2]), which is almost double the increase in the global mean temperature of 0.8°C during the same period (Zhang et al., 2019). This warming is having and probably might have adverse effects on crop yields, so the challenge of studies and research today is to develop adaptation technologies so that crops are not affected by future warming (Qian et al., 2019).

Many studies indicate that under future conditions of global warming, there will be longer growing seasons and increase of crop heat units (CHU), which would be beneficial for the production of some crops, such as corn and soybeans, that are resistant to heat (Qian et al., 2019; Vincent et al., 2018, Li et al., 2018). In southern Canada, an increase in the growing season of more than 20 days is projected at a warming level of 2.1°C above the current temperature (Li et al., 2018). However, even though yields are expected to increase in this scenario, production may be affected by moisture stress due to accelerated evaporation and the subsequent low water availability. Water resource variability and extreme events, such as floods and droughts, will have a significant effect on Canadian agriculture in terms of crop yields decline since water imbalance is mostly unpredictable (Cherneski, 2018). Projections indicate that crop yields accustomed to growing at high temperatures in southern Canada would start to decrease when the warming level exceeds 2.0°C above the current temperature (Qian et al., 2019).

The high temperatures that have been projected for the future and its consequences, such as the longer duration of growing seasons and the probable shortage of water in the farmland, indicate the need to adjust practices in the agricultural sector of Canada. The Pan-Canadian Framework on Clean Growth and Climate Change, adopted in 2016, aims to ensure that all sectors of the economy have a plan to stimulate economic growth along with a resilience plan to the impacts of climate change at the federal, provincial and territorial government level (Environment and Climate Change Canada, 2019b). Adaptation measures to reduce the effect of climate change in Canada's agricultural sector include beneficial management practices and alternative crop choices.

Federal and provincial governments are responsible for taking an important role in adaptation practices. The government of Ontario, for its part, has been supporting a set of initiatives to deal with such problems. The provincial Ministry of Agriculture, Food and Rural Affairs (OMAFRA) has implemented cost-share programs to help carry out the best management practices through the Ontario Soil and Crop Improvement Association (OSCIA). In Quebec, the programs are carried out and managed through the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Quebec (MAPAQ). In both cases, practices that provide solutions to water quantity and quality problems are supported.

2.3.2 Water Use and Management

Historically, the development of new agricultural technologies has been aimed at taking control of the quantity and quality of water in the crop field to increase productivity. Water quantity management refers to its efficient use, which is reaching a higher level of production

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[2] The annual average temperatures have increased by 2.3°C in northern Canada (Yukon, Northwest Territories, Nunavut, Nunavik and Nunatsiavut), 1.9°C in Prairies and British Columbia regions, 1.3°C in Ontario region and 1.1°C in Quebec and Atlantic regions, over the period 1948-2016 (Cohen et al., 2019).

with less water. On the other hand, increasing crop yields while protecting the environment is also of predominant interest today (OMAFRA, 2003b). The development of beneficial water management practices is an approach to conserving a farm's water resource without sacrificing productivity. The provincial government of Ontario through OMAFRA encourages producers to irrigate their crops with a schedule, but not before conducting a water table level evaluation suitable for the crop (OMAFRA, 2003b). Although according to some studies, producers rely more on their experience to realize the water needs of their crops (Bernier, 2008), this may lead to a possible overestimation of water needs.

During the growing season, average rainfall in Ontario is approximately 70 mm each month; however, evapotranspiration is often high, which means that only 65% of the water requirements of the crops are met by natural sources for optimal yields (OMAFRA, 2019d). As a result, many crops require irrigation at least in the most critical period of their growth. For example, in the case of onions, it is in the bulb formation and enlargement stage that moisture is critical (Tesfaendrias et al., 2010). Carrots have a low tolerance to drought, as they are most sensitive to moisture stress during root enlargement and seed germination (AAFC, 2004). At the same time, the amount of water provided through irrigation also depends on the water retention capacity of the soil (OMAFRA, 2002).

There are several types of irrigation systems used for plant growth in Ontario, including: hand-moved, travelling-gun, center-pivot and lateral sprinklers, in addition to drip (trickle) systems. Of these methods, the hand-moved sprinkler irrigation system is the most popular, representing 70% of all types of irrigation systems in use (Bogdan, 2019). This system is least expensive, although its workforce requirements are higher because the lateral pipes have to be moved along the ground to have a uniform level of irrigation. Irrigation in the region is also used for frost protection (OMAFRA, 2019d; OMAFRA, 2002). According to 2018 statistics, the total irrigated area in Ontario is 35,684 ha, of which 61.4% corresponds to field crops, 26% to vegetables and the rest, 12.6%, to fruits (Statistics Canada, 2019g). Since water is essential to produce optimal corn yields and rainfall can be unpredictable, other technologies, such as the subirrigation system, are being adopted. Such systems allow the right amount to be maintained in the field for good yields (ATCC, 2015). These systems handle the water table adequately to provide optimum moisture at each stage of corn growth (OMAFRA, 2002).

Ontario producers need a permit for the use of more than 50,000 litres of water per day, taken from either surface or underground irrigation sources. Permission is issued by the Ministry of the Environment and Energy (OMAFRA, 2019d). In general, any work involving stream channels or shorelines requires a permit from the Ontario Ministry of Natural Resources (OMAFRA, 2003b). Water for irrigation comes from different sources. Producers mostly use on-farm water resources, such as rivers or streams, lakes, ponds (filled by streams or groundwater), wells where rainwater accumulates, and municipal water (OMAFRA, 2002). The rest is taken from sources outside the farm. In 2016 in Ontario, 80% of the irrigation came from on-farm surface water, about 16% from on-farm groundwater, while 4% came from off-farm water sources (Statistics Canada, 2019h).

Likewise, the management of drainage of crop fields is of considerable importance in the province. Approximately 32% of the cropland in Ontario is tile-drained (Kitchen and

Kitchen, 2017). The subsurface drainage system or tile system has been installed in the early 1900s and since then it is supported by OMAFRA, which licenses contractors for an adequate plan, design and installation of the agricultural tile drainage system according to the type of soil, crops, requirements of each farm, as well as environmental and legal regulations. OMAFRA, in cooperation with the Ministry of Natural Resources, has a geo-spatial digital system with which it locates the fields drained by tiles. Each licensed contractor must accurately report the location of the workplace using a global positioning system (GPS), so the information is stored in a database (OMAFRA, 2013).

In Quebec, the total irrigated area was 17,228 ha in 2018, less than 50% than in Ontario (35,684 ha) of which, only 21.2% was allocated to field crops, 26.3% to fruits and 52.5% to vegetables (Statistics Canada, 2019g). It was estimated that only 10-35% of vegetable farms use sprinkler irrigation (Bogdan, 2019). Water for agriculture is handled in a similar way as in Ontario. In 2016, 84% of the irrigation came from on-farm surface water and about 15% from on-farm groundwater (Statistics Canada, 2019h). Agricultural water consumption, obtained from rivers, lakes and groundwater, is high compared to other economic sectors (AAFC, 2016c). Regarding the management of excess water, large-scale subsurface drainage systems began to be installed in Quebec in the 1970s to help increase crop yields from poorly drained soils during wet periods (Ritter et al., 1995). Around 40% of the total cropland in the province has installed a tile drainage system (Essien, 2016).

In general, the management of water in agriculture is an objective also marked from the point of view of pollution by livestock activity, as well as related to the leakage of fertilizers from the cropland. The subsurface drainage system is not sufficient to control the concentration of chemical pollutants and to flow to water collection sources (Ritter et al., 1995). In that sense, it is necessary to adopt water management practices that reduce the chemicals in the drained water. Practices called controlled drainage and subirrigation fulfill that purpose not only by controlling phosphorus discharges that create eutrophication and nitrate concentration in the water, but also by allowing adequate internal drainage of the soil and controlling the water table to improve crop yields by minimizing water stress (Madramootoo et al., 2001; Evans et al., 1996).

A controlled drainage system restricts water discharges from the main tile line of the subsurface drainage system, resulting in a higher water table. For this purpose, an underground control structure, with two inlet and outlet pipes and with stoplogs inside, is installed right in the outlet drain tile, so that the producer can raise and lower the stoplogs according to the desired level of water table. In periods of drought, the stoplogs are placed to retain the water in the crop field, while in periods of excessive rainfall, the stoplogs are simply removed and the water drains in the conventional way to remove excess water (Figure 2.13[3]). From the control structure, water can drain into a river, stream of surface water, lake, etc. or it can be stored in a well. This water can be pumped through the control structure back into the subsurface tiles

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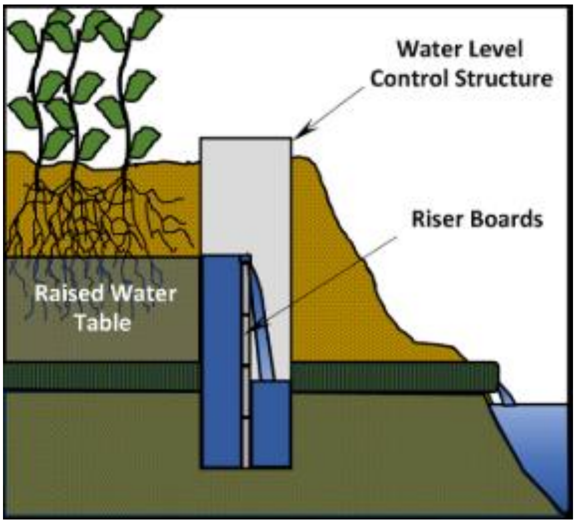
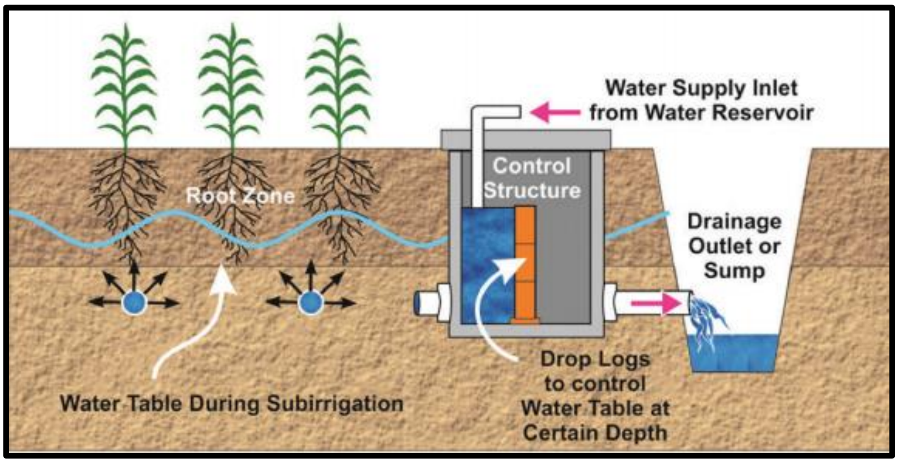
[3] The “riser boards” shown in Figure 2.13 are the stoplogs mentioned in the text above, the latter is the technical name used by Agri Drain Corporation (2019).

to keep the water in the field at a desired water table (Figure 2.14[4]). This practice is called the subirrigation system (Zimmer et al., 1997).



Source: Elshemy (2017)

Figure 2.13. Controlled Drainage System



Source: Irmak (2017)

Figure 2.14. Controlled Drainage with Subirrigation System

Research is being carried out on the new water management technologies performance that prevent agricultural drained water from continuing to transport contaminants. In order to reach the environmental goals of the government, it is necessary that such systems are adopted by producers. This raises the question of whether producers are willing to adopt them.

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[4] The "drop-logs" shown in Figure 2.14 are the stoplogs mentioned in the text above, the latter is the technical name used by Agri Drain Corporation (2019).

Chapter 3

LITERATURE REVIEW

This chapter reviews the work of researchers in the study of water management systems, which emerged as a need to increase crop yields and reduce fluctuations that production may have due to water shortage or excess moisture in the soil. The major objective of the review was to understand what water management system is the most adequate to guarantee, in addition to sustainable yields, better efficiency in water use and at the same time avoid negative impacts on the environment. Therefore, particular emphasis is placed on the water table management techniques, which intend to reduce agricultural pollution by reducing the loss of chemical substances from drained water (as presented in Section 3.1). In Section 3.2, a description of studies that have analyzed the economic effects of different water management systems: irrigation, subsurface drainage, and controlled drainage with and without subirrigation, on the farm-level is provided. This review is inclusive of how profitable they are, as well as their findings and conclusions. Included here is also the suitability of financial analysis in the evaluation of agricultural projects.

3.1 Water Management Practices

3.1.1 Need for Water Management Practices

The importance of increasing crop yields, as well as the quality of the product, is paramount for producers. Some studies have linked the adoption of different water management practices to these two factors. Al-Jamal et al. (2001) compared three different practices: sprinkler, furrow, and drip irrigation in onion crops and concluded that the last irrigation system is the best to upgrade onion yield since it keeps the soil moist but not wet during growth. Li et al. (2004) found that the efficiency of water use is principal to increase crop yields, especially in semi-arid regions during periods of drought. They found that the adoption of an irrigation practice (along with the inclusion of fertilizers) to the spring wheat during dry periods helps rapid growth and maintenance of the root system, that is important for the plant to absorb all the water that it needs, even from a deeper soil layer, which leads to an increase in the crop yield (Li et al., 2004).

Water management practices in agriculture could be related to good production and high product quality due to the timely application of water that enhances the plant nutrition in the root zone of the crop (Van der Werf and Petit, 2002; Ayars et al., 2015). Helyes et al. (2012) studied the effects of different irrigation procedures on the yield characteristics of tomato, as well as on its quality in terms of nutritional value. The study was carried out by comparing regular drip irrigation in some plants, drip irrigation only up to 30 days before harvest in other plants, and rainfed tomato plants. It concluded that the number of marketable tomatoes per hectare has increased with both the irrigation treatments, as well as their weight and size were augmented in comparison to rainfed yield. Thompson et al. (2009) referred to a higher quality of cotton and vegetable crops as a result of the adoption of the subsurface drip irrigation method in Arizona, USA. Additionally, the practice of subsurface drip irrigation helps to keep the plant healthy because it prevents the proliferation of fungi in the plant canopy, since there is no constant humidity in the soil surface and improved weed control (Thompson et al., 2009; Ayars et al., 2015).

Several studies (Phocaides, 2007; EPA, 2003) suggest that it is necessary to closely monitor the proper design and application of water management practices to avoid negative impacts on the environment as well as to make efficient water use. When the amount of water from precipitation or irrigation is greater than the amount of water that the soil is able to absorb, surface runoff may occur, which has negative consequences for the environment, not only because of the transport of sediments, pesticides, and nutrients to nearby water sources, but also because removal of soil particles may cause soil erosion and deep percolation (EPA, 2003; Hatfield, 2015).

Nutrient pollution is one of the reasons why managing water in farmland is of great importance because it causes the eutrophication of aquatic habitats. Eutrophication is a process of algae growth in water bodies, which eventually reduces oxygen creating matter decomposition and water toxicity, leading to unhealthy conditions for ecosystem development involving animals and humans (De Sena, 2017). It is through this process, although indirectly, that the loss of nutrients via runoff contributes to the emission of GHG since the anoxic conditions in the affected water generate the death of all living beings and their decomposition is an important contribution of methane (CH_4) released into the atmosphere (Beaulieu et al., 2019).

Additionally, when there is a shortage of water in the soil or dryness, the microbes that live on the surface where there is concentration of crop residue, use oxygen as a source of energy (aerobic conditions) and CO_2 is produced, which is released into the atmosphere; however, as water is added to the soil through irrigation or precipitation, then the amount of oxygen decreases and less CO_2 is produced, which in part may be sequestered in the soil and plant (Lloyd, 2016). However, an increase in soil moisture also leads to an increase in the emissions of the GHG nitrous oxide (N_2O), especially in mineral soils, because anaerobic conditions (less oxygen due to the presence of water) stimulate the reduction of nitrates to nitrogen gas (N_2) and N_2O, this process is known as denitrification. Although, on the other hand, denitrification helps reduce soil nitrates that could reach a body of water through runoff (Edwards, 2014).

The use of pipes instead of channels for irrigation and drainage of farm land, is a highly accepted alternative to address the above potential issues. For example, drip and sprinkler irrigation techniques would be more efficient than surface methods because the application rate of water through these techniques was found to be equal to the infiltration rate of the soil, resulting in no over-application and no runoff (EPA, 2003; Van der Werf and Petit, 2002; Al-Jamal et al., 2001; Thompson et al., 2009; Biswas et al., 2015). Ayars et al. (2015) attributed a better efficiency in the water use to subsurface drip irrigation technique (in comparison with sprinkler irrigation) because of reduction of runoff and deep percolation in California, US. There has been a long history of water management innovations in this region. Also, subsurface drainage and water table control could be successfully used depending on the characteristics of the cropland (EPA, 2003; Madramootoo et al., 1997). Some fields when flooding for a long time have higher emission levels than when they flood and drain rapidly (Lstiburek, 2006).

Recently, studies have been evaluated performance of agricultural water management practices to mitigate GHG emissions, either by reducing emissions or by increasing retention (sequestration). Essien (2016) and Lloyd (2016) found differences between the emissions from two types of drainage (controlled drainage with subirrigation compared to subsurface drainage) and irrigation (sprinkler irrigation compared to dry land) systems, respectively in each study. They observed high variability in emissions that were collected over two growing seasons and concluded that the differences between the water management systems were not statistically significant; although the BMP technology produced less emissions. Furthermore, Sun (2019) has undertaken a life cycle assessment (LCA) during the entire crop production process (from raw material production to harvesting) under the controlled drainage with subirrigation and subsurface drainage technologies, based on a three-year corn-soybean rotation system (2012-2014), in order to estimate the difference of environmental impacts between both technologies. The study has found significant reductions in GHG emissions (CO_2, N_2O and CH_4) under the BMP technology, along with other environmental improvement aspects.

3.1.2 Techniques for Water Table Management

Water table management (WTM) refers to the control of groundwater level by regulating water flows with either drainage or subirrigation, this dual-purpose system has already been described previously. Successful WTM is generally carried out on flat terrain with a slope of no more than 1%, and on soils with moderate to high hydraulic conductivity (Lstiburek, 2006). The WTM systems has been adopted by the humid regions of North America, especially on organic and sandy soils with the objective of increasing crop yields and reducing agricultural pollution by reducing the loss of chemical substances from drained water (Madramootoo et al., 1997).

Ng et al. (2002) and Elmi et al. (2004) reported that the controlled drainage system improved nutrient efficiency by retaining fertilizers in the cropland the time necessary for their use and, consequently, improved yields. Both of these studies were conducted on a sandy loam soil in Ontario and Quebec, respectively. Madramootoo et al. (1997) used controlled drainage and subirrigation and found that higher water table in organic and sandy soils improved denitrification (which causes nitrate leaching to be reduced), as well as that water conservation in the soil helped to cover the needs of plant uptake through upwards (from the root), allowing adequate transpiration. Additionally, corn and soybean yields grown in eastern Canada have increased by 10 to 15% due to subirrigation.

Other studies referred that the controlled drainage with subirrigation system, by raising the water table during the growing season, allows retaining nitrate and other nutrients close to the root zone, which allows better crop yields (Ballantine and Tanner, 2013; Tan et al., 1999; Drury et al., 1996). Drury et al. (1996) work was conducted on a Brookston clay loam soil. His finding was that WTM could reduce average annual nitrate losses by 43%, compared to conventional treatments. Tan et al. (1999) found tomato and corn yield increases of 11 and 64%, respectively, in comparison with the conventional tile drainage. On the other hand, the impacts that the water management practices have on producers are related to changes in labor patterns. According to Madramootoo et al. (1997), the operation of a BMP related to WTM requires greater attention by the producer than a conventional drainage system, since the installation and management of the equipment is not at first sight and it is necessary to supervise it in several points during the crop growth period.

3.2 Farm-Level Analysis of Beneficial Management Practices

Any program that intends to encourage the adoption of agricultural management practices among producers will be successfully accepted only if they observe a high profitability and sustainable production possible (Cole et al., 1997). Therefore, several studies have analyzed the economics of crop production with different water management practices to compare the economic viability of investment in new and existing practices.

3.2.1 Irrigation

Irrigation practices generally improve production by reducing the variability of yields and therefore, increases the profitability of the farm, but choosing the right technology can be complex and quite expensive (Amosson et al., 2011). Luhach et al. (2004) assessed the economic worth of investment in a sprinkler and surface irrigation systems in croplands with sandy soils. The net present value results provided evidence that the sprinkler system is the most viable economically when compared to the surface irrigation system. The results showed increases in the average net returns of almost 20% because of the reduction of operational costs and a decrease in labor requirements of about 78% per hectare. Additionally, the results showed that the sprinkler system was able to reduce the waste of irrigation water during delivery, uniform distribution and higher infiltration rates.

Hoffmann and Willett (1998) evaluated the economics of four irrigation systems: wheel-line, center pivot, linear-move and gated pipe furrow irrigation. This comparison was made in terms of investment cost, along with fixed and operational costs of growing alfalfa, wheat and oat in a rotation. The results indicated that the linear-move system is the most economic method due to its lower labor cost and a significant reduction in water use.

3.2.2 Subsurface Drainage

Several studies have stated that the subsurface drainage technique has other important benefits beyond the increase in yields. These include: (i) earlier planting, that is more efficient for the producer in terms of time and money (Jin et al., 2003; Fore, 2010; Hofstrand, 2010; Mukkannawar, 2011); (ii) the ability of the crop to compete against weeds (Fore, 2010); (iii) reduced soil compaction (Fore, 2010; Hofstrand, 2010); (iv) greater development of the roots due to soil aeration (Jin et al., 2003; Hofstrand, 2010); (v) facilitation of tillage, planting, and harvesting, because machinery no longer slides due to excessively wet soil (Jin et al., 2003); (vi) better water use (Jin et al., 2003; Fore, 2010; Hofstrand, 2010); and (vii) less fluctuating yields (Fore, 2010). However, the biggest disadvantage of subsurface drainage alternative is the high investment cost for the producer (Fore, 2010). Hofstrand (2010) pointed that even when the investment is large and expensive, the producer must take into account the long-term benefits; for example, the fact that less fluctuating yields will reduce financial risks and at the same time will increase the sale value of the land.

Mukkannawar (2011) analyzed the economic feasibility of the subsurface drainage system in two study sites where the fields were strongly affected by salinity and waterlogging -- negative externalities of irrigation. The study found that the said technology fulfilled its objective because it resulted in an improvement of crop yields by more than 100% mainly in corn; moreover, it concluded that investments in subsurface drainage systems are financially feasible at both study sites, and producers are highly encouraged to adopt it. Similar results were obtained by Shekhawat (2007), who assessed the financial viability of a subsurface drainage system installed in a pilot area located in India, where the land was completely waterlogged. The study resulted in well-established indicators for the financial feasibility of the project, the benefit-cost ratio being 2.44 and the net present value Rs.[5] 34,275 per ha.

Researchers in the area of subsurface drainage are also aware that the results are not absolute and can change depending on climate variations and soil types (Fore, 2010; Hofstrand, 2010), or other factors that affect the profitability and adoption decisions of producers. These factors need further research (Nistor and Lowenberg-DeBoer, 2007). For instance, Jin et al. (2003) reported that the crop yields of corn, wheat, and sugar beet decreased when the water table during the growing period remained above about 60 to 80 cm depth for just a few days; furthermore, they concluded that the effectiveness of the subsurface drainage system depends on the spacing of the tiles according to the properties of the soil.

The economic analysis by Hofstrand (2010), about the investment in the subsurface drainage system, showed that the yield improvement proportion is the most important for the adoption of the technique because it means an increase in the returns by the same proportion. This is of course, after deducting the costs of inputs and maintenance needed for the installed new system. The study suggested the net present value and pay-back period as the two principal ways to compute the economic returns. Additionally, Fore (2010) tested subsurface drainage at two study sites in Northwest Minnesota, on the same type of soil and planted at the same time. He found significant increases in crop yields at only one of the sites, due to the fact that the other study site was in an area with a good internal drainage. This study recommended taking into account several factors, such as the hydrology of the area, before making the decision to invest in any drainage system. Likewise, the economic analysis of the investment in subsurface drainage by Fore (2010) concluded that the lower the amount invested and the longer technology´s useful life, the higher would be the internal rate of return and the lower the pay-back period.

3.2.3 Controlled Drainage with/without Subirrigation

Although studies on subsurface drainage have widely recommended the adoption of the system in poorly drained soils, since it mostly resulted in an increase in crop yields, environmental problems have also emerged. These have included a reduction in soil quality, for example, due to the loss of nutrients (Allerhand et al., 2013; Sahani, 2017). As a consequence, researchers have begun to test also the efficiency of reducing the effect of these issues in the context of controlled drainage. The study by Nistor and Lowenberg-DeBoer

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[5] Rs: Rupee, currency unit for India, equivalent to 0.0185 per CDN $.

(2007) concluded that controlled drainage could be attractive for producers to adopt because of its favourable effects on yields (corn-soybean crop rotation). Their study assessed the economics of said technology by using the Purdue Crop/Livestock Linear Programming model and concluded that the returns with and without subsidy were 10% and 8% higher, respectively, as compared with the situation with the conventional tile drainage. Likewise, the results were the same when a sensitivity analysis was carried out by taking into account a percentage increase in the price of fuel. However, the analysis of crops with controlled drainage reported greater demand for labor, and higher variable costs due to the increase in production (Nistor and Lowenberg-DeBoer, 2007).

Evans et al. (1996) compared the net returns of the subsurface drainage, controlled drainage and control drainage with subirrigation systems. The study concluded that the subsurface drainage is more profitable than the controlled drainage with and without subirrigation technologies due to the higher cost of the control structure; however, if it is assumed that yields are higher than 2%, then, the controlled drainage is the most economical alternative. The increase in the yields was recorded only in the soils that have high drainable porosity, so the use of a controlled drainage is good and could increase the crop yields up to 20%. Crabbé et al. (2012) found that a controlled drainage system is more profitable in corn and soybean production than a subsurface drainage system assuming a useful life of 20 years. The study estimated that crop yields are 3 and 4%, respectively, higher with controlled than with conventional subsurface drainage.

Allerhand et al. (2013) reported that the increases in yields using controlled drainage systems would be high enough to compensate for the high costs of investment and implementation. Their study concluded that controlled drainage technology is highly profitable for the farm with respect to the subsurface drainage system. However, this would only occur under certain favorable conditions that were tested during the study with a break-even analysis in different scenarios. Examples of these include: (i) growing season should alternate between wet periods and medium-long dry periods, (ii) design of the system should allow deep tiles, and (iii) control structures should have constant adjustment during the growing period. The researchers also realized that more research is required since their study obtained some results that were not entirely conclusive.

Sunohara et al. (2016) tested the benefits of using a controlled drainage system, compared to a subsurface drainage system that already existed in various regions of Ontario. The major characteristic of these regions was a humid climate. The comparison was made only during the growing season of corn and soybean crops, finding significant increases in the yields of both. Studies related to controlled drainage with subirrigation, although not many, are also associated with significant increases in yields. For example, Allerhand et al. (2013) evidenced a 64% increase in soybean crops with controlled drainage with subirrigation compared to controlled drainage systems only.

Mejia et al. (2000) concluded that it is possible to obtain higher yields from crops with higher water tables, since there is a greater water absorption by the root. This study evaluated the effects of applying subirrigation systems on corn and soybean crops in eastern Ontario, finding significant increases in yields with water tables 50 and 75 cm below the soil surface, compared to the free drainage that maintains the water table at 1 meter below the ground surface. According to Mejia et al. (2000), there are several reasons why the subirrigation technique would be more efficient than any other irrigation technologies in a field with subsurface drainage technology installed. These include: (i) loss of water by evapotranspiration is minimal; (ii) water is evenly distributed throughout the field; (iii) there is less water consumed; and (iv) the technology requires less labor. At the same time, for the water table management systems to work, it is necessary that the croplands have a flat topography and that the soils have a coarse texture. Studies indicate that most of the cropland in Ontario and Quebec meet these characteristics (Mejia et al., 2000). Essien (2016) studied the economic impact of adopting a controlled drainage with subirrigation system by comparing it with the results of the conventional tile drainage technology in a corn growth experimental field in Quebec. The study obtained on-farm financial indicators concluding that the conventional subsurface drainage system is the best option in this case because of higher net returns under different discount rates.

There are several studies that highlight the positive impacts on the yield of crops that have the WTM technologies -- some highlight their ability to control salinity and waterlogging, soil quality, etc., while others focus on the fact that investment costs are high and that it requires more labor. However, there are few studies that have comprehensively studied the financial feasibility or the economic impact of these technologies.

3.3 Suitability of the Financial Analysis for Agricultural Projects

A financial analysis deals with net cash inflows and outflows over the lifespan of the project in order to provide practical resources for the evaluation of the profitability of investment (Sell, 1991). The determination of the costs and benefits at the farm level of adopting water management technologies is an important tool in the adoption decision-making by the producer and his willingness to invest (Selvavinayagam, 1991), regardless of the impacts on society since these are of concern the producer and included in the received cash returns (Van Kooten, 2019). The main purpose of using financial analysis in technological agricultural projects is to determine their financial viability. This is done not only considering the benefits and costs of all projects, but also assuming that these projects are alternates (OECD, 2006). Also, taking into account the importance of the project in its entire useful life through the discount rate and analyzing the cash flows of the investments in terms of its present value to have an accurate comparison evaluation today (Boardman et al., 2018). These characteristics of financial analysis make it an adequate tool to analyze the economics of water management technologies.

Chapter 4

THEORETICAL FRAMEWORK

When deciding about new projects to implement or new investment decisions to be made, it is natural to think in terms of costs and benefits. Such evaluations have their groundings in welfare economics, particularly the allocative efficiency and Pareto Optimality. In this chapter, Section 4.1 is dedicated to the general project evaluation criteria used for such decisions. Then, the concept “with and without” the project is highlighted in Section 4.2, which is a consideration that plays an important role in the decision-making process of adopting a particular project. This chapter also describes the project analysis from a private accounting stance as the main criterion for carrying out the financial analysis in Section 4.3. In the fourth section (Section 4.4), the theory behind project analysis is addressed by describing the welfare economics as a theoretical framework for the financial analysis. Finally, the seven steps for undertaking the financial analysis are discussed, starting with identifying what benefits and costs need to be included in the evaluation of the project from a private point of view. The financial desirability of the investment can be compared through different indicators, such as net present value, benefit-cost ratio and pay-back period.

4.1 Project Evaluation Criteria

A project involves investment decisions in which financial resources are allocated to create capital assets that could produce benefits for a definite period of time and at a specific geographic location. For an agricultural project, the definition above is applied to various activities related to the farm, such as: irrigation, livestock, land settlement, tree crops, agricultural machinery and equipment, agricultural education, among many others (Gittinger, 1982). The evaluation of a project is carried out by deducting the stream of investment and production costs of an agricultural firm from the flow of benefits that are produced over a given number of years, resulting in net benefits.

Two methods are used in project evaluation for assessing the economic desirability of an investment project depending upon the accounting perspective of the researcher – individual investor or the society as a whole. These analyses are called, respectively, financial analysis and benefit-cost analysis (BCA). The BCA has some commonality in terms of methodology with financial analysis. However, on financial analysis, only the private perspective of the project evaluation is considered (Van Kooten, 2019). Typically the BCA can be built upon the financial analysis, and thus could be thought of complementing each other. Financial analysis estimates the impact of the benefits and costs attributable to the project on the cash flow of the private stakeholder, referred to as the producer or farmer in an agricultural project, which in the long run is a component of social costs and benefits (Gittinger, 1982).

The BCA requires the reassessment of the financial inputs and outputs considered from the private perspective. There might be times when decision-making in the private sector could make sufficient arguments to affirm that a project is worthwhile, and the evaluation from the social point of view is no longer necessary. However, it should be noted that this case can occur only if there are no externalities involved in the execution of the project that can influence decision-making (Van Kooten, 2019). This is unusual in public projects since costs and benefits that have direct (private stance) consequences with the profitability of the project are not able to measure the externalities in order to reflect the impact (benefit or not) to the society (Sell, 1991).

Even though the financial analysis and BCA have similar characteristics, they differ not only in the accounting stance – private versus societal, respectively, but also with respect to exclusion of externalities in the financial analysis, as well as in the evaluation of benefits and costs of a project. While financial analysis uses market prices to undertake the investment viability, the BCA uses shadow prices, which are corrections or conversions of market prices for market failure in such a way that represent and improve the benefit or cost indicator, those that usually goes with policies (Sell, 1991). Besides, while a tax payment means a cost in the financial study, on the BCA side it is an income for the public treasury, and with the subsidies, the opposite happens (Gittinger, 1982). Taxes and subsidies are considered transfer payments and not economic costs in the BCA. Taxes are costs to consumers offset by benefits to government and subsidies are benefits to consumers and producers offset by costs to taxpayers (Backhaus and Wagner, 2004).

Furthermore, discount rates are different in both methods, BCA uses a social discount rate while financial analysis uses a private discount rate. The former is usually lower than the private discount rate for several reasons including the fact that the individual´s consumption and saving decisions are not the same as the government decisions with regard to time preferences. Society is immortal and at any point in the future will have positive net benefits, however, individuals have finite operation outlook and value current decisions differently than what they would act collectively in society (Edwards-Jones et al., 2000). Therefore, the risk that comes from the investment is greater for the individual and the discount rate reflects those levels of risk (Trautman et al., 2012).

Taking these considerations into account to undertake investment analysis with each method, the difference is obvious regarding the criterion for selecting a project. On the one hand, the BCA is typically carried out for the evaluation of policies and public projects, which allows policy-makers to know if society as a whole is improving its welfare status (Pearce and Nash, 1981). On the other hand, the financial analysis is undertaken to provide input in the investment decision-making process, whose criterion for selecting a project is based on the change in the economic welfare of the decision-maker or investor (Selvavinayagam, 1991).

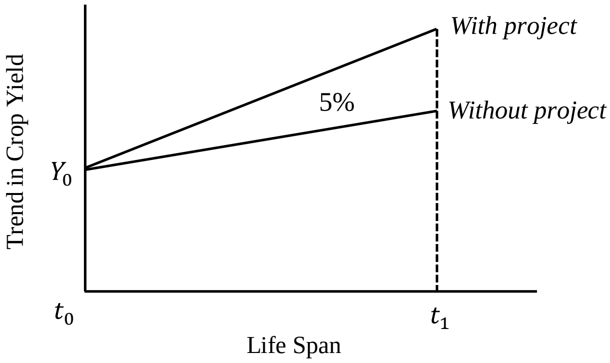
4.2 Project Analysis Using With and Without Framework

The project evaluation methodology is built under the principle "with and without" the project, which is very important as it makes possible to separate the changes that the proposed project might produce from those changes that could occur even if the project was not carried out, and which could be incorrectly attributed to it (Edwards-Jones et al., 2000). This principle allows an analysis of the project by comparing the benefits and costs that arise with the project with those benefits and costs that arise when the project has not been undertaken. The difference between both (with-minus-without) results in the incremental net benefit that the investment in such a project implies (Gittinger, 1982).

It is pertinent to point out that “with and without” the project principle is not the same as making a comparison using “before and after” the project since, as noted previously, it is not possible to identify the situations that may arise regardless of whether the project is carried out or not, which could lead to erroneously considered them as benefits or costs to the proposed project (Gittinger, 1982). Therefore, the right thing to do is measure the impact of the project on the net changes (incremental net benefits), which will correspond to those attributable to the project only (Edwards-Jones et al., 2000).

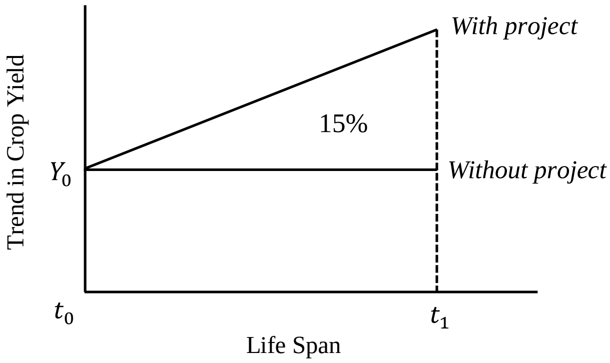
Let us take an example of an agricultural investment project in irrigation technology. Assume that irrigation is projected to increase crop yield by 15% over its life span that starts at year t_0 and ends at year t_1. By applying the “with and without” principle, this project will be evaluated by comparing it with the situation in which the investment was not made, over the same period of the project´s life. Then, if crop yields are assumed to be subject to what may happen in three hypothetical scenarios: (i) an increase in crop yield by 10% was projected due to the regional forecast reported a temperature increase by 1°C during the period $t_0 - t_1$ that would favour the growth of that particular crop; (ii) crop yield was projected to stay constant during the period $t_0 - t_1$; and (iii) a decrease in crop yield by 10% was projected because an increase in the temperature of 3°C was predicted in the region that would end up damaging the crops.

In the first scenario, the impact attributable to the project is associated with a yield increase of only 5%, which represents the incremental net yield as is shown in Figure 4.1. By omitting the ‘with and without’ criterion, an error would be made in measuring the impact of the project in terms of increased yields. Figure 4.2 shows that, in the second scenario, where no change in yield is expected, the project´s performance is associated with the 15% increase in crop yield. It is noted that the incremental net yield in this scenario is the same as the prospect for increasing crop yield "with" the project, that is, the impact on yield is entirely attributable to the project. Finally, the third scenario is represented in Figure 4.3. The impact attributable to the project is a yield increase of 25% since a decrease in crop yield was expected. In this case, the impact of the project is twofold because it not only prevents yield losses but also helps increase those yields. As in the first case, by omitting the "with and without" principle, it would not be possible to identify the benefit obtained from avoiding the yield loss.



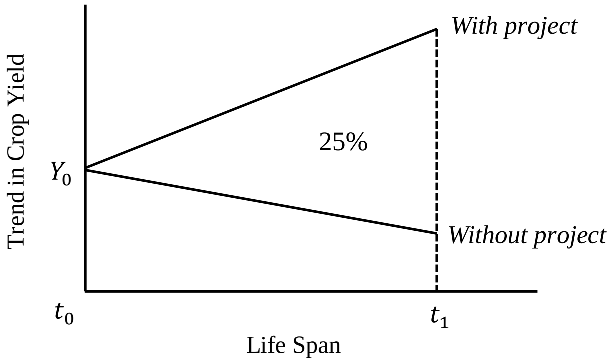
Source: Adapted from Edwards-Jones et al. (2000)

Figure 4.1. “With and Without” Project Criterion – Scenario 1



Source: Adapted from Edwards-Jones et al. (2000)

Figure 4.2. “With and Without” Project Criterion – Scenario 2



Source: Adapted from Edwards-Jones et al. (2000)

Figure 4.3. “With and Without” Project Criterion – Scenario 3

4.3 Analysis from a Private Accounting Stance

As noted earlier in this chapter, the private perspective of project evaluation is used in the financial analysis. A proposed project has effects on the individual participants (stakeholders) through the changes in net returns that the project may produce; therefore, an investment project will be financially viable if it has positive net benefits and is profitable for the investor. In an agricultural project, the main participant is the producer; thus, an investment project will be financially viable if it is profitable for the farm undertaking it (Townley, 1998).

Financial analysis calculates the incentive to invest by using a cash flow evaluation. Whatever the type of investment, it all starts with a cash outflow in the initial period, followed by periods of cash outflows of operating costs and cash inflows from revenues (Selvavinayagam, 1991). For the private analysis, market prices are used to value the benefits and costs. Thus, the evaluation of the project´s effects on the investor is made through the accountable money flows during the life span of the project. Moreover, financial analysis uses discounting techniques for project evaluation by converting each benefit and cost in each year of the project´s life into a present value. From the comparison of the discounted flows, the net economic benefits that result from the adoption of a new project are estimated (Townley, 1998).

In the analysis from the private accounting stance, the decision-making ignores the impacts that this decision would have on other members of the society, and instead focuses mainly on knowing whether the producer will have sufficient net returns from an investment that has been made (Van Kooten, 2019). This whole process raises in-depth the question related to the way in which the welfare of the decision-maker changes with the decision to invest in a particular project.

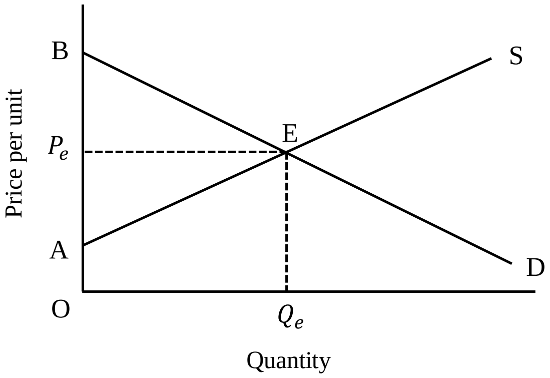
4.4 Measures of Economic Welfare

The methods of assessing the economics of a project emerged in an attempt to construct the guidelines for evaluation of policies from the point of view of an efficient allocation of resources in accordance with social objectives (Pearce and Nash, 1981). The objective of allocation efficiency, referred to Pareto efficiency, provides the conceptual basis by which the modern welfare economics and project evaluation criteria are built. The notion that an alternative policy that would make at least one of the persons better off without making any one else worse off, leads to think that this policy has positive net benefits (Boardman et al., 2018).

The practical basis for undertaking project evaluation comes from the concept of potential Pareto principle (Kaldor-Hicks criterion of compensation), from which it follows that in order to measure the benefits and costs of a policy, it is necessary to consider the concept of willingness to pay to value the outputs of a determined policy and the concept of opportunity cost to value the inputs required to implement the policy (Boardman et al., 2018). Therefore, the difference of both valuations (benefits and costs) results in the net benefits of the policy for the society. This means, when the total amount of what people who are worse off with the policy are willing to accept for adoption (cost) is subtracted from the total amount of what people are willing to pay for the benefit provided by the policy (benefit). If the result is positive, then there is a Pareto efficient outcome, and therefore, a positive change in the society´s welfare.

Regarding the financial analysis specifically, it was noted previously that it is an analytical tool that contributes to private decision-making with respect to investment and assess the implications of that decision on individuals (Townley, 1998). The way to determine whether investing in a proposed project would enhance or diminish the individuals' well-being is through the welfare properties of market equilibrium, taking into account that the market is characterized by private ownership of resources (Backhaus and Wagner, 2004). This is usually illustrated in a supply and demand diagram where the supply curve measures the marginal cost of the proposed project and the demand curve measures the benefit of the project (Townley, 1998). Figure 4.4 shows such a diagram of the market in which P_e and Q_e are equilibrium prices and quantity, respectively, in this market.

The $OBEQ_e$ area, below the demand curve D, indicates the maximum amount that consumers are willing to pay for Q_e units of the good, but what they actually pay in total is $P_e * Q_e$, represented by the OP_eEQ_e area. So, if what consumers really pay is deducted from what they would be willing to pay, the result is the so-called consumer´s surplus -- the BEP_e area in Figure 4.4. On the other hand, the $OAEQ_e$ area below the supply curve S denotes the minimum amount of money that producers are willing to accept for producing Q_e units of the good; however, what they receive is really OP_eEQ_e (what consumers actually pay for the same amount of the good). Then, if subtracts what producers are willing to accept from what they actually receive for producing the good, the result is the producer's surplus, denoted by the P_eEA area in Figure 4.4.



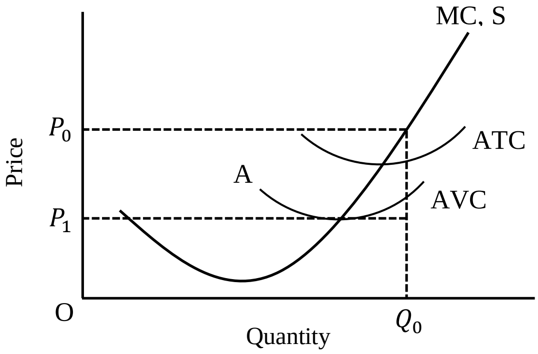
Source: Adapted from Backhaus and Wagner (2004)

Figure 4.4. Consumer and Producer Surplus

Consumer surplus is one of the basic concepts used in the financial cost-benefit analysis to measure the change in the well-being of the individual. Changes in consumer surplus are a measure of the benefits to consumers of investing in a project (Boardman et al., 2018). The effect is mainly measured when, as a result of the project, changes in the market price of some goods are experienced. Although the analysis of the consumer surplus is an important part to measure the well-being of the individual when carrying out a project, the consumers in a context of perfect competition are unaffected since the market prices remain unchanged as a result of the investor's decision to go ahead with the project. Therefore, what is of interest at this point is the other measure of welfare – producer surplus.

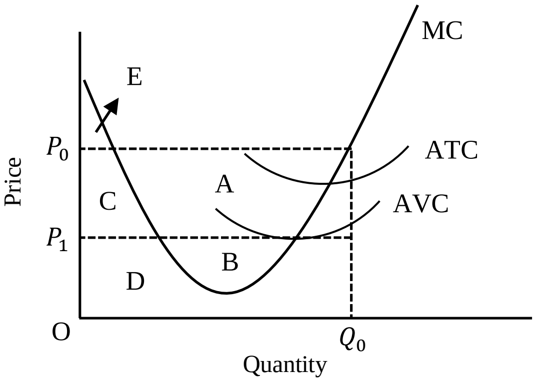
One of the ways to measure the producer´s welfare is through variations in profit, defined as total revenue minus total costs (total variable costs plus total fixed costs); however, variations in profit will exist if there are variations in prices (Just et al., 2004). The most common way to measure changes in producer´s welfare is through net benefits, defined as the excess of the total revenue that the producer receives for any product produced over the additional cost incurred at produce that product. They are determined by the area above the short-run supply curve and below price (Just et al., 2004). The definition of net benefits refers to the quasi-rent or producer surplus noted previously, which constitutes a measure of welfare by estimating the returns from fixed factors of production and investment decisions made by the producer (Van Kooten, 2019). In general, the producer surplus is determined by the difference between total revenue and total variable cost at a given level of output of the project.

There are different ways of measuring profits or changes in producer welfare, as shown in Figures 4.5 to 4.7. The most common and easy to illustrate is using a firm´s diagram in the short run. Figure 4.5 shows the average total cost (ATC) curve, the average variable cost (AVC) curve and the marginal cost (MC) curve of the firm. As the firm maximizes its profits by producing Q_0 at the price P_0 (total revenue is equal to $P_0 * Q_0$), and the supply curve S in the short term is the portion of the MC that is above P_1 (since at a price lower than P_1 the firm would cease operating), then the producer surplus is the area represented by A in Figure 4.5. Another way to measure producer surplus is described in Figure 4.6. The total revenue (TR) of the firm $P_0 * Q_0$ is defined by the areas $A + B + C + D$. In addition, the total variable cost (TVC) is measured as the areas $C + D + E$; therefore, the producer surplus will be calculated as the difference $TR - TVC$, i.e. the areas $A + B - E$.



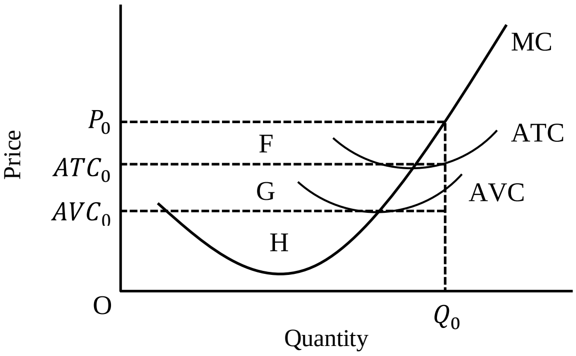
Source: Adapted from Just et al. (2004)

Figure 4.5. Producer surplus – Approach 1



Source: Adapted from Just et al. (2004)

Figure 4.6. Producer surplus – Approach 2



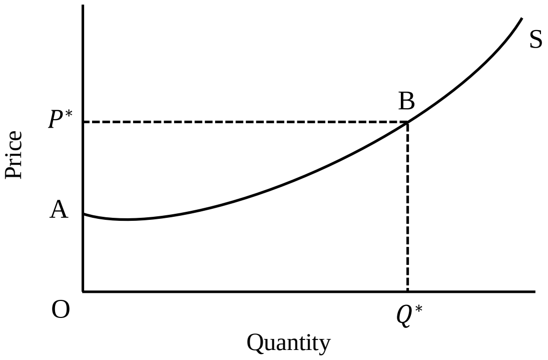
Source: Adapted from Just et al. (2004)

Figure 4.7. Producer surplus – Approach 3

Figure 4.7 suggests another way to calculate producer surplus, where the total revenue $P_0 * Q_0$ is given by the area $F + G + H$. Since $TVC = AVC * Q$, then it is possible to calculate the total variable cost as the amount produced that maximizes the profit Q_0, multiplied by the average variable cost at that level of production (AVC_0), which would become the area H ($AVC * Q_0$). The producer surplus in that sense would be given by the area $F + G$, which is the same as saying $(P_0 - AVC_0) * Q_0$. In this form of calculation, it is also possible to determine what part of the producer surplus would correspond to the firm's fixed costs. By definition, the total costs (TC) are given as the product of the total variable cost and the quantity produced ($ATC * Q$), then the total fixed costs will be given by $TFC = TC - TVC =$

$(ATC - AVC) * Q$. At the production level Q_0, where the total average cost is ATC_0, the total fixed cost is given by area G.

The measure of producer welfare is also better visualized by analyzing the supply of all producers together in a competitive market. Figure 4.8 shows the supply curve in a supposed agricultural market. It is assumed that this curve is derived from the horizontal sum of the individual supply curves of all farms that offer a product in this market, and also that each farm operates with the only purpose of profit maximization (Boardman et al., 2018).



Source: Adapted from Boardman et al. (2018)

Figure 4.8. Market Supply Curve

The market price is P^* (in Figure 4.8), to which the farms offer Q^* units of the product; therefore the area OP^*BQ^* corresponds to the total revenue that the farm would receive from the market, as it is the result of the product of the price by the total amount offered: $P^* * Q^*$. On the other hand, the $OABQ^*$ area represents the total variable cost (TVC) of producing Q^* of the product, which is located just below the supply curve, or marginal cost. Therefore, the difference between these two areas constitutes the producer surplus:

$$PS = P^* * Q^* - TVC \tag{4.1}$$

The TVC can also be understood as the minimum total revenue that the firms must receive before they would be willing to produce Q^* (Boardman et al., 2018). In that sense, the producer surplus will measure the net benefit that the use of factors of production or a new investment gives the firm, by subtracting the minimum total income that firms in the market should receive before willing to produce Q^* at a given price of P^* from the actual revenue. The resulting benefit, when positive, is also a positive change in the welfare of the producer when a new project is adopted. Consequently, any change in the net return that producers receive would affect their investment decisions (Van Kooten, 2019).

4.5 Undertaking Financial Analysis

To carry out a financial analysis, it is necessary to properly identify all the cost and benefit streams over the project life span, distinguishing between capital cost stream, operating cost streams and revenue streams. The financial analysis includes the following steps:

i. Determine project costs
ii. Determine project benefits
iii. Calculate annual project net benefits
iv. Determine the appropriate discount rate
v. Calculate the incremental net benefits
vi. Estimate the financial net present value
vii. Undertake sensitivity analysis

4.5.1 Project Costs

Private costs to the firm are usually classified as those related to land, labor and capital. These costs are estimated quantitatively and at market prices. The following types of capital costs can be distinguished: buildings, equipment and machinery, working capital, replacement of fixed assets, among others (Gittinger, 1982). The costs of investing in a project are generally associated with: initial installation costs, such as labor and materials; annual operating costs, such as fuel; and maintenance and repair costs (Van Kooten, 2019).

In agricultural projects, the costs to be estimated for an investment analysis are of two types: (a) capital costs: land, buildings, equipment and machinery, plant infrastructure, installation or replacement of fixed assets, etc.; and (b) production costs: farm inputs (seed, fertilizer, pesticides, lime, etc.), labor, energy, fuel, electricity, custom work, repairs and maintenance costs, crop insurance, marketing costs, depreciation, land rent, etc. The production costs can be further classified into variable and fixed costs for financial analysis. The latter are costs that are not linked to production levels (amortization, depreciation, rent, insurance, etc.), while variable costs are subject to the operation of the farm. They generally increase when production increase (Selvavinayagam, 1991).

4.5.2 Project Benefits

Private benefits to the firm can be given in two ways: as an increase in the value of production and as a reduction in costs, when investing in a project (Gittinger, 1982). The way to measure the value of production on a farm is through the estimation of its revenues, calculated as the product of yields and its price in the market (Selvavinayagam, 1991). On the other hand, the reduction of costs through mechanization is associated with benefits experienced by farms that invest in new machinery or innovative technologies that may not increase production, but do reduce the use of inputs or labor costs. Additionally, some assets, such as equipment, machinery and other components, have a salvage value at the end of the project's life. This value is considered a negative cost at the end of the useful life of the project, so it is also a benefit (Van Kooten, 2019).

4.5.3 Net Benefit

Subtracting the total costs from the total benefits attributed to the project results in the net benefit. A positive net benefit might mean that the investment scheme is worthwhile; however, under the “with and without” the project principle, it is necessary to estimate the difference between the net benefit with the project and the net benefit without the project to have certainty about the viability of the proposed project. Subtracting the second from the first results in the incremental net benefit, which, as noted previously, is a preferable indicator for decision-making (Townley, 1998).

4.5.4 Discount Rate

It is very important to deal with time when a financial analysis is carried out. The financial feasibility of the project is assessed by adding the costs and benefits streams at the same point in time, regardless of when they occur throughout the life of the project. This is done by using the discount rate (Sell, 1991). Discounting is necessary to know exactly the costs and receipts that the producer will have with the implementation of the project because it is known that receiving a dollar next year or the year after, is not the same as receiving a dollar today. Any money that can be spent now is worth more than that money that one has to wait until tomorrow to be able to spend it (Boardman et al., 2018). Therefore, converting inflows and outflows into the same unit of measure to make it comparable is a delicate task.

In project evaluation, a year to compare the costs and revenues streams is chosen, for convenience, as the year in which the project begins commonly denoted as year zero ($t = 0$), that is, the point in time in which the investment is made (Townley, 1998). Therefore, the present value of the inflows and outflows are calculated multiplying each value by the discounting factor: $DF = 1/(1 + r)^t$, once the respective discount rate (r) for the firm has been estimated (Sell, 1991). The discount rate that is typically used in financial analysis to assess the financial viability of a project is calculated as the weighted average cost of capital (WACC).

The WACC represents the cost that the firm incurs at the time of raising the capital necessary to implement the project. Since most firms use several sources of capital with different returns, the WACC is calculated as the weighted average of the cost after-tax of each source of capital (Olson, 2011). The most common assumption is to establish two sources of capital: equity and debt, then the WACC (discount rate: d) is calculated as a linear combination as in equation (4.2):

$$d = K_e W_e + K_d (1 - t) W_d \tag{4.2}$$

Where, K_e is the rate of return on equity capital, W_e is the proportion of equity capital, K_d is the interest rate on debt, t is the income tax rate, and W_d is the proportion of debt. If there are more loans, then the interest rate on debt should be the weighted average of the loans (Boehlje and Eidman, 1984).

The proportion of equity capital W_e is represented by the equity/asset ratio, interpreted as "the percent of the business´value owned by the owners" (Olson, 2011). This ratio measures the amount of capital that the owner has in his business compared to the total value of the asset. On the other hand, the debt/asset ratio is used to represent the proportion of debt W_d. The debt/asset ratio measures the amount of the firm´s debt compared to the total value of the asset. It is interpreted as "the percent of the business´ total value owed to creditors" (Olson, 2011). These ratios are solvency measures of firms to measure their financial position and performance. The sum of both equity/asset plus debt/asset will always be equal to one (Selvavinayagam, 1991).

4.5.5 Financial Criteria

The most important information for the decision-making process from the private accounting stance is the result of the evaluation of the profitability of the project throughout its useful life. The purpose of the financial analysis is to evaluate the financial viability of the proposed project from the point of view of the firm (Townley, 1998). For this purpose, it is important to properly determine the streams of costs and revenues at market prices, as well as their respective projection over the life span of the project, and the rate at which costs and revenues will be discounted. With all this information, once it is defined that the total revenue stream exceeds the total cost stream, then it is determined through the performance indicators that the investment is feasible (Van Kooten, 2019).

Regarding how this process applies to the producer's decision-making of investing in a new project. The determination of how attractive the investment project is to the farmer depends on the evaluation of the effects of the project on farm income. For this purpose, the analysis that is generally carried out involves a partial budgeting technique, which is a convenient tool to be used in the financial analysis of a project because it allows observing the marginal cost of the investment and comparing it with the marginal benefit of the same to estimate the profitability that this new activity related to the project will bring, and the occurrence of incremental benefits (Gittinger, 1982).

For a proper decision-making regarding the project and to show that it will be more valuable to the firm, it is necessary to use analysis methods or criteria that lead to the conclusion that the proposed project will help the firm maximize the present value of its future benefits. These include: $PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t}$ and the present value of its costs: $PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$, where B_t and C_t are the benefits and costs streams, respectively, that occurred in the time period t at a r discount rate (Selvavinayagam, 1991). Further evaluation criteria (such as net present value, benefit-cost ratio and pay-back period) can be constructed from these estimates.

4.5.5.1 Net Present Value (NPV)

The NPV procedure is the most commonly used indicator to evaluate the economic desirability of investments (Boardman et al., 2018). This procedure discounts annually all future cash flows to the present value by using an appropriate discount rate. Cash flow projections must include all relevant costs and benefits; then, the NPV will be the sum of the discounted benefits minus the sum of the discounted costs of the project over the project life span. To affirm the financial viability of a project and take the decision to invest, the result of subtracting the present value of costs from the present value of the benefits should be greater than zero (Boardman et al., 2018). While in the evaluation of two or more projects, the decision will be made to invest in the project that has the largest NPV (Van Kooten, 2019).

4.5.5.2 Benefit-Cost Ratio (BCR)

The BCR is another indicator commonly used for the analysis. It is calculated by dividing the present value of benefits by the present value of costs. A result greater than one indicates that the benefits outweigh the costs and the project is worthy of investing. The decision criterion indicates that the higher the BCR, the more attractive the project is (Gittinger, 1982).

4.5.5.3 Pay-back Period

In addition to the previous two indicators (NPV and BCR), another indicator could be used to assess the economic desirability of a project. This indicator is called the pay-back period or break-even time (BET), which is the length of time required for the discounted net returns generated by a project to equal its initial cost of investment. The pay-back period is not a measure of the economic worth of a project, but it usually helps to compare investments. The investment that is preferred is the one with the shorter pay-back period. This indicator is calculated by adding the discounted net benefits stream year by year until the accumulated sum exceeds the initial cost, and that year is chosen; then, the portion of the net benefit of the year following the one chosen is estimated to calculate exactly the time needed to recover the initial investment. Finally, the pay-back is the period of time until the chosen year plus the fraction of the following year (Olson, 2011).

4.5.6 Sensitivity Analysis

A financial analysis is based on estimates and the sensitivity analysis is used in this framework to deal with the uncertainty. The sensitivity analysis is carried out by identifying and changing the values of each of the economic or non-economic parameters in which uncertainty is considered apparent and the influence on the financial viability conclusions of the project is probable (Edwards-Jones et al., 2000). It may involve variations in market prices, investment costs, discount rates, length of project, among other critical costs and benefits. Sensitivity analysis provides important additional information for investment decision-making, and shows the robustness of the decision.

4.6 Summary of the Chapter

A financial analysis framework was described in this chapter which can be used to estimate the net economic benefits that result from the adoption of a selected BMP. This analysis is undertaken with a “private” accounting stance using a comparison of “with and without” criterion. The latter means deriving an incremental cash flow as a result of comparing net flows with and without the project. The economic performance of investing in a new project is estimated through the use of several financial indicators, including: Net present value (NPV), benefit-cost ratio (BCR), and pay-back period. As long as financial benefits over the lifetime of the project exceed its costs, the private investor determines the investment to be economically desirable.

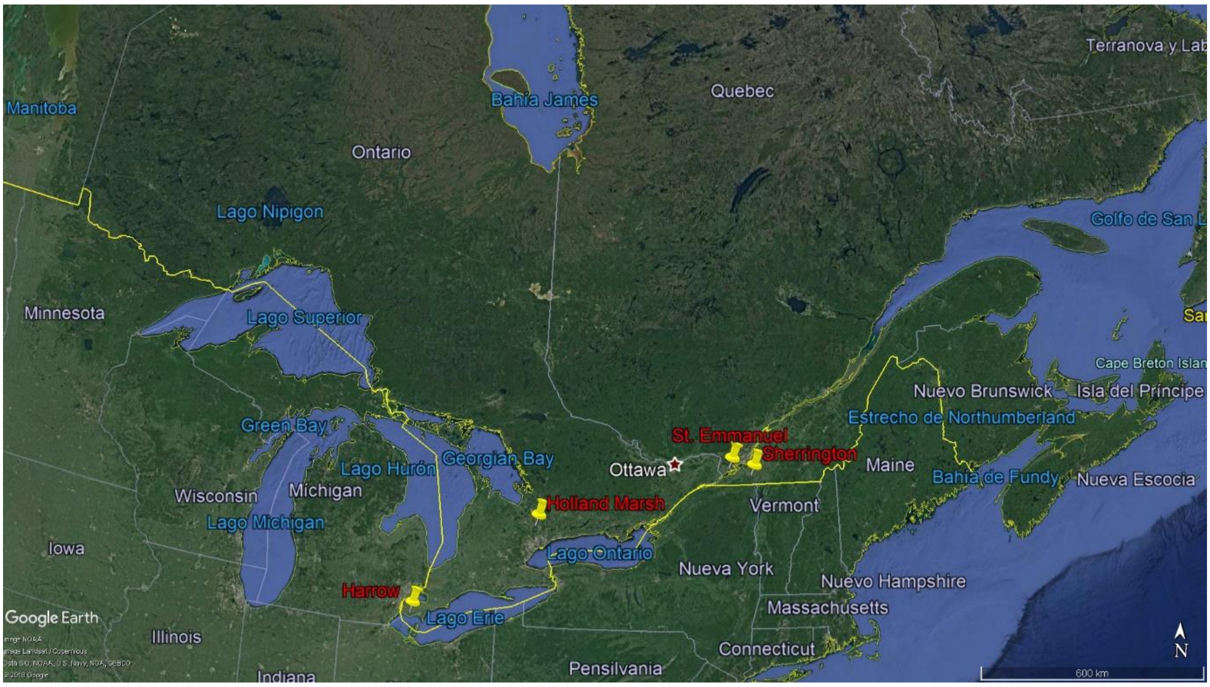
Chapter 5

ANALYTICAL FRAMEWORK

This chapter describes in detail the development of the methodological approach used in this thesis to assess the impacts of beneficial management practices on the study farms. Information regarding the location and production characteristics of the four research fields are addressed, as well as the Base and the BMP Technologies taken into account for each case study. Moreover, details about the procedures followed for data collection and sources of data are provided, followed by a description of components and methods associated with the financial analysis of each BMP and its sensitivity analysis.

5.1 Study Sites

As noted previously, the on-farm economic analysis conducted in this study was carried out in four study sites located in Quebec and Ontario, which are shown in Figure 5.1. Two of these sites – St. Emmanuel and Sherrington, are located in Quebec, while the other two sites – Harrow and Holland Marsh, are located in Ontario. The farms located at two of the sites, St. Emmanuel and Harrow are grain-producing farms, while the other two study locations, Sherrington and Holland Marsh, comprise farms that produce vegetables. Further discussion of these sites is provided in the next two sub-sections.



Source: Google Earth (2019)

Figure 5.1. Map Showing the Study Sites in Quebec and Ontario, Canada

5.1.1 Grain Production Sites

St. Emmanuel, Québec

St. Emmanuel study site is located in Coteau-du-lac, Monteregie, Quebec. The family farm has a total area of 100 ha, within which lie the experimental field consisting of 4.2 ha (or about 10 acres). The soil at this farm is fine sandy loam with 0.5% of slope (Jiang et al., 2019). The production is mainly corn every year, only in some years in the past there was a rotation with soybean and very occasionally in recent years, peas were grown (Ekwunife, 2019).

The 40-year average rainfall calculated for this region is about 546.1 mm (Ekwunife, 2019). This makes the study site located in the humid area of St. Lawrence lowlands of Quebec and Ontario. In this area, it is necessary to remove excess water to allow crop growth, which is why most of the fields have subsurface drainage systems installed; however, drought conditions are very frequent during the summer due to the low rainfall and high evapotranspiration (Mejia et al., 2000), making irrigation a needed practice. This region has mostly sprinkler irrigation systems installed (Singh, 2013).

Harrow, Ontario

Harrow study site is located in Essex county, Ontario. This experimental site is located on the Research and Development Centre of Agriculture and Agri-Food Canada (AAFC). This centre manages the Honourable Eugene F. Whelan Research Farm, at Woodslee, in southwestern Ontario, which has a total area of 77 ha. The soil at this farm is Brookston clay loam type with 0.1-0.4% slope and is characterized by poor natural drainage. This type of soil is the most common in that region of Ontario (Tan and Zhang, 2016; Zhang et al., 2017). The experimental crop field of interest for this study had an area of 1.6 ha, further broken down into sixteen experimental plots of 1005 m^2 (67 m x 15 m) each (Abbasi et al., 2018; Soultani et al., 1993; Tan et al., 1993; Drury et al., 2009), where the impact of water management systems, detailed in Section 5.2, on corn and soybean crops was studied.

5.1.2 Vegetable Production Sites

Sherrington, Québec

The experimental field in the Sherrington, Montérégie, Québec, study site belongs to a commercial farm located in southern Quebec, 60 km south of Montreal. The farm is approximately 607 ha (~1500 acres), of which approximately 142 ha (~350 acres) are occupied by the study fields that are of interest to this study (Bogdan, 2019). The fields are characterized as having muck soil, which is an organic soil with high content of organic matter and nutrients. This type of soil is appropriate for growing vegetables (Tesfaendrias et al., 2010; Lloyd, 2016). On this farm, the following crops are rotated: spinach, lettuce, onions, and carrots (Dube-Laberge, 2019). The rotation is usually changed every year to avoid diseases (Lloyd, 2016). Moreover, the practice is to use an intercropping system such as carrot - onion or lettuce - spinach in a given year, which is generally used for a complimentary sharing of resources between different crops, such as nitrogen or water (what one crop does not need is used by another). The intercropping carrot-onion is of interest to this study, which consists of rows of carrots and rows of onions alternate in the same field during the growing season. On this farm, the fields were irrigated using a hand moved sprinkler system only once a year regardless of whether it is a dry or wet growing season (Lloyd, 2016; Bogdan, 2019).

Holland Marsh, Ontario

The research fields in the Holland Marsh study location belong to two commercial farms of 4.05 ha and 6.07 ha each. The Holland Marsh region is considered one of the most productive areas for vegetables, not only in Ontario but also in Canada (Planscape, 2009; OMAFRA, 2019e). Its soils are muck soil type classified as a terric humisol, with an organic matter content of about 70-80%, and drain poorly and have a humic texture (De Sena, 2017, Planscape, 2009). The Holland Marsh´s fields comprise about 7,000 acres, in which more than 60 vegetables are grown. A partial list includes: carrots, onions, celery, garlic, mixed greens, beets, cabbage, and other Asian vegetables, with a variety of cultivars each. However, the most predominant crop rotation is carrot-onion, whose crop areas together represent more than 70% of the total area for vegetable production in the Holland Marsh (Planscape, 2009; Tesfaendrias et al., 2010).

The typical growing season for carrots is from May to October and for onions is from May to September (Tesfaendrias et al., 2010; Wilton Consulting Group, 2018). These crops in the Holland Marsh region are mostly rainfed, but since a few years ago, occasional irrigation during the growing season is also provided, particularly during the period of extreme drying of the field. In this condition, the carrot crop needs watering in the spring to help germination of the seed, and the onions need to be irrigated during the time of formation and filling of the bulb (Tesfaendrias et al., 2010). However, due to the characteristics of soil type of these fields, draining is usually required (Planscape, 2009). Many crop fields in the region have the subsurface (tile) drainage system installed. In fact, approximately 32% of the arable land in Ontario is tile-drained (Kitchen and Kitchen, 2017).

5.2 Description of Beneficial Management Practice

5.2.1 St. Emmanuel

For this study site, a subsurface drainage system was installed in the 4.2 ha of the farm's study field. Under this system, tiles were installed approximately 1 m deep from the ground surface and spaced 15 m apart. These tiles constitute the laterals of the system and are basically 100 mm diameter plastic PVC pipes with 2 mm holes spaced around 5 cm along the entire length of the tube. At each end of the lateral 5 m long non-perforated pipes were installed, all of which are connected to a 150 mm diameter PVC pipe called main tile (Essien, 2016).

The water management system analyzed in this site is the controlled drainage with subirrigation that was implemented in half of the total field. The system is mainly used in the growing season to maintain the adequate water table at between 60 and 75 cm from the ground surface (Jiang et al., 2019). The system consists of a water level control structure that is a 6 feet high and 150 mm diameter high-density polyethylene (HDPE) shaft, which contains stoplogs adjustable at different heights; moreover, it has 150 mm diameter pipe extensions at the bottom (Agri Drain Corporation, 2019). One of these extensions is connected to the main tile line, while the other one leads directly to a deep well. When rainfall occurs and the water level exceeds the height of the stoplog, then the water drains into the well and is stored for use during a period when there is no rainfall. During this period, water is pumped back, with a 1 horsepower pump (suitable for pumping at least 4 ha), to the drainage pipes through the control structure (Jiang et al., 2019).

5.2.2 Harrow

Most of the studies undertaken for the Harrow experimental site have compared the use of subsurface tile drainage, controlled tile drainage, and controlled drainage with subirrigation. These experiments were planned to measure and analyze, among other things, the loss of nitrate and phosphorus from a continuous corn cropland through subsurface drain outflow using water samples collected daily (Soultani et al., 1993), the differences in water efficiency, measuring change in agricultural water quality with both free and controlled drainage (Ng et al., 2002). In addition, the responsiveness of crop yields to these treatments in continuous corn and in a corn-soybean rotation was also estimated (Tan et al., 2007; Drury et al., 2009; Tan and Zhang, 2016). Some of these studies found increases in corn productivity with controlled drainage with subirrigation system by up to 64% compared to subsurface drainage (Ng et al., 2002).

The experimental crop field, used in this study, comprised of 16 plots of 1005 m^2 (67 m x 15 m) each, which were isolated from each other with a 1.2 m deep plastic curtain, to prevent surface and subsurface water movements from one plot to another. Each plot was implemented with a subsurface tile drainage system that consisted of installation of two perforated tile lines of 104 mm in diameter, spaced at 7.5 m at an average depth of 0.6 m.

To implement the water management systems (controlled drainage and controlled drainage with subirrigation), some plots were chosen randomly and were installed with a water level control structure. This structure consisted of a plastic chamber with two 104 mm holes at the bottom. In one of the holes, the tile was connected and in the case of the other one, a 104 mm diameter corrugated non-perforated drain pipe (outlet) plus a plug was installed. When the plug was closed, the water increased to the desired water table level and was pumped to return through the same tiles for the subirrigation to occur. When the plug was opened, the water drained freely from the field through the outlet pipe to a central instrumentation building (Tan et al., 1993; Drury et al., 2009).

5.2.3 Sherrington

The BMP analyzed for the Sherrington site involved providing water to the crop using irrigation, and compare it against no irrigation situation. On the study farm, as mentioned previously, some plots were irrigated using the sprinkler method, while other plots were not irrigated at all. The irrigation system consisted of a hand moved type, better known as the overhead sprinkler system (Lloyd, 2016). This consisted of 3 inches (~76 mm) aluminum lateral pipes with 30 feet (~9 m) in length, which were arranged on the surface of the land, and sprinkler heads for each lateral pipe. Water was supplied through an underground 3 inches diameter PVC pipeline system that brought water from a deep well. This underground system had a 6-inch diameter aluminum (~152 mm) main pipe, with a length of 37 feet (~11 m) length. Water was obtained using two 200 hp and 60 hp electrical pumps (Dube-Laberge, 2019;

Bogdan, 2019). The main feature of the sprinkler irrigation system was, except for underground pipes, perfectly movable (Dube-Laberge, 2019).

This farm used this system to irrigate 12.7 ha (or 31.3 acres) at a time; however, the same system was used to irrigate 142 ha (or 350 acres) -- the entire field. The base design consisted of 14 main pipelines, 1200 lateral (15 rows of 80 laterals each) and 1200 sprinklers, covering an area of 720 m (80 laterals x 9 m) long by 154 m (14 main pipelines x 11 m) wide (Bogdan, 2019). Another characteristic of this system was that the sprinklers were installed in such a way that they throw water into the air in a circular pattern, which falls to the ground in an overlapping manner (Lloyd, 2016). This is done to ensure an uniform watering, and not an irrigation method where the greatest amount of water falls on the radius near the sprinkler only (Ortiz et al., 2006; De Oliveira et al., 2016; Tam and Petersen, 2014b; Martin et al., 2007).

The financial evaluation in this study site involved a comparison of the hand moved sprinkler irrigation system as the BMP and a non-irrigation (dryland) as the Base Technology. Moreover, it was assumed that onions and carrots are grown in an intercropping[6] system every year.

5.2.4 Holland Marsh

For this study site, two commercial farms in the Holland Marsh area were included. Both of these had tile drainage (subsurface drainage system), typically consisting of 100 mm diameter perforated plastic pipes that form the lateral tile lines, connected in parallel to a main tile drain which consists of a 150 mm diameter plastic pipe. Since drainage is accomplished by water infiltration in the soil, it enters the lateral tile lines, which then transfer the flows to the main tile (Singh, 2018). This main tile at both farms transfers water to a well, from where it is pumped into a municipal surface ditch, and subsequently to the Holland River which finally flows into Cook´s Bay of Lake Simcoe (De Sena, 2017; Planscape, 2009).

One of these farms (Farm I) maintained the subsurface drainage as described, which is considered as the Base Technology in this study. This field area was 6.07 ha (~15 acres) with a main tile drain of 397.5 m long, and the lateral tile lines spaced at 16 m apart. The length of the lateral drainage perforated pipe was estimated by interpolating the value from the guide shown in Table 5.1.

Table 5.1. Length of the Lateral Drainage Pipe per a Given Drain Spacing

Lateral Drain Spacing (m)	**Drainage pipe required (m/ha)**
6	1,640
9	1,090
12	820
15	655
18	545

Source: Simundsson et al. (2016).

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[6] The intercropping system type in this research site involves the cultivation of different crops (carrots and onions) in adjacent rows.

For the estimation of the amount of lateral pipe, a spacing of 16 meters is of interest to this study site. This length was obtained using the average growth rate of the values according to the following formula $r = \left(\sqrt[n]{M/C}\right) - 1$, where M is the final value in the data series, C is the initial value in the data series, and n is the number of periods between the final and initial value, thus $r = \left(\sqrt[13]{545/1640}\right) - 1 = -0.0813$. Then, using the value of the previous immediate position (15 m) and the average growth rate, the length of pipe needed for 16 m spacing was estimated at: $655 * [1 + (-0.0813)] = {\sim}601.75$ m/ha (or 244 m/acre). This was the amount of perforated lateral tile used in Farm I.

In addition to the tile drainage system described previously, the other commercial farm (Farm II) had installed a control structure for the management of the water table. This structure was installed at the end of the main tile line, just before the well from which water was usually pumped to control the flowing out of the farm. The control structure consisted of a 300 mm diameter high-density polyethylene (HDPE) shaft, with 150 mm diameter pipe extensions at the bottom. One end of the extension was connected to the 150 mm diameter tile mainline and the other led to the well. The structure was fitted with two guides, opposite each other on the walls of the structure, which accommodated several stackable gates (stoplogs) within the structure. The gates acted as a blockage and prevented water from free flowing out of the farm and their height installed regulated the water table within the field (De Sena, 2017; Singh, 2018).

It is important to note that this field (Farm II) is of 4.05 ha (~10 acres) in size, with a main tile drain of 265 m long and nineteen lateral tile lines which were spaced at 9 m apart (Singh, 2018). The length of the lateral pipe needed was estimated using data provided by Simundsson et al. (2016) (as shown in Table 5.1). The result was that the length of the lateral pipe needed was 1090 m/ha (~441 m/acre). The difference between this farm and the Farm I was that an additional two hundred meters more of pipe per acre was used in this field. This difference was considered in the analysis, to rule out that the impact on the efficiency and profitability of the BMP is due to the installation of the side tiles closer together.

In this study site, since both farms were tile-drained, the subsurface drainage system was considered as the Base Technology. On the other hand, the installation of the control structure for the water table management converted the system into a controlled drainage, which was considered as the BMP in this study. Both study farms grew several types of vegetables but the pattern of crop rotation of each farm in recent years was carrot-onion in different cycles (Grenon, 2019); therefore, it was assumed that in Farm I (Base Technology), carrots and onions are grown in a three-year cycle rotation (two consecutive years of carrot followed by one of onion), while in Farm II (BMP), there is a four-year cycle (three consecutive years of carrot and followed by one year of onion).

5.3 Sources of Data

This thesis was conducted based on information gathered from the literature on the particular technologies for each research site (see summary in Table 5.2). Investment costs were estimated after learning about the design of the technologies in each experimental field and then calculating the cost of its components, installation, preparation of land and retrofitting, according to current market prices. Some prices were obtained from the direct quotation provided by suppliers, while others from publications of agricultural material costs (for Quebec, it was from CRAAQ, and in Ontario from OMAFRA). If these sources did not have the needed data, other studies were consulted.

Table 5.2. Summary of Research Sites

Study Site	Crop Rotation	Base Technology	Selected BMP Technology
St. Emmanuel (Quebec)	Corn-Soybean (5-year cycle: CCCCS)	Subsurface Drainage	Controlled Drainage with Subirrigation
Harrow (Ontario)	Corn-Soybean (2-year cycle: CS)	Subsurface Drainage	Controlled Drainage with Subirrigation
Sherrington (Quebec)	Carrot-Onion (Intercropping)	No Irrigation	Hand Moved Sprinkler Irrigation
Holland Marsh (Ontario)	Carrot-Onion (3-year cycle: CCO / 4-year cycle: CCCO)	Subsurface Drainage	Controlled Drainage

Like investment costs, crop yield data were also obtained from various sources. These included: previous research developed under the Agriculture Greenhouse Gases Program: Phase I; results of previous studies carried out on-site; other information through direct communication with researchers from McGill University; as well as publications of average annual yields of each crop by province through CRAAQ, OMAFRA, La Financière Agricole du Québec (FADQ), etc. Commodity prices were obtained from provincial publications through OMAFRA, CRAAQ, MAPAQ, and Infohort (wholesale vegetable price report[7]) managed by AAFC.

Operating costs related to inputs (seeds, fertilizer, pesticides, machinery and equipment, etc.)[8], as well as fixed costs (crop insurance, depreciation of existing capital, taxes, etc.) were obtained from the field crop budgets that the provinces of Ontario and Quebec have developed. These were available from CRAAQ for Quebec and OMAFRA for Ontario. Those budgets corresponded to the average cost estimated for a profitable farm with good performance. Labor-related costs were obtained from the provincial reports based on Statistics Canada tables and the 2016 agricultural survey. The data sources used in this study are detailed by each site in Table 5.3, while the estimates carried out with the data obtained are displayed in Section 5.4.

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[7] Quoted prices are provided by a select group of surveyed wholesalers that operate in the vegetable market specifically.

[8] The cost of water was not considered in this study. It was estimated that 80 and 84% of the water for irrigation in Ontario and Quebec, respectively, comes from on-farm sources (Statistics Canada, 2019h). In this study, therefore, it was assumed that water is available locally on the farm in all four case studies.

Table 5.3. Summary of Data Sources of Costs and Benefits Included in the Analysis

Data / Research Sites	St. Emmanuel	Harrow	Sherrington	Holland Marsh
Revenues:				
▪ Crop Yield	- Ekwunife (2019) - Mejia et al. (2000)	- Tan et al. (2007) - Drury et al. (2009) - Abbasi et al. (2018)	- AGDEX 200/850 by CRAAQ (2019b)	- De Sena (2017)
▪ Commodity Price	- FADQ (2018)	- OMAFRA (2019b) - OMAFRA (2019c)	- AGDEX 202/855 by CRAAQ (2019a) - AAFC (2019b)	- OMAFRA (2018a)
Costs:				
▪ Investment Costs:				
- Components (piping and fittings, water control structure, well, pump, fittings)	- AGDEX 752 by CRAAQ (2010) - Agri Drain Corporation (2019)	- Soleno.Inc. (2019) - Agri Drain Corporation (2019) - AGDEX 752 by CRAAQ (2010)	- AGDEX 753 by CRAAQ (2016) - AGDEX 258/821 by CRAAQ (2008)	- Soleno.Inc. (2019) - Agri Drain Corporation (2019) - AGDEX 752 by CRAAQ (2010)
- Installation	- Kitchen and Kitchen (2017)	- Kitchen and Kitchen (2017)	- AGDEX 753 by CRAAQ (2016)	- Kitchen and Kitchen (2017)
- Land Preparation/Retrofitting	- AGDEX 752 by CRAAQ (2010)	- AGDEX 752 by CRAAQ (2010)	- AGDEX 753 by CRAAQ (2016)	- AGDEX 752 by CRAAQ (2010)
▪ Fixed Costs (repair and maintenance, depreciation on existing capital, insurance, among others)	- Essien (2016) - ESDC (2019)	- OMAFRA (2019f) - ESDC (2019)	- AGDEX 258/821 by CRAAQ (2008) - Martin et al. (2007) - ESDC (2019)	- AGDEX 258/821 by CRAAQ (2008) - ESDC (2019)
▪ Operating Costs (seed, fertilizer, pesticide, farming operations such as planting, fertilizer application, harvesting, etc., drying, storage and ventilation, crop insurance, fuel, electricity, land rent, among others)	- AGDEX 111/821b by CRAAQ (2018a) - AGDEX 141/821 by CRAAQ (2018b) - Essien (2018)	- OMAFRA (2019f)	- AGDEX 258/821 by CRAAQ (2008) - Bogdan (2019) - ESDC (2019)	- Stokes Seeds.Inc (2019) - Van Dyk (2019) - U of G (2018) - OMAFRA (2018c) - AGDEX 258/821 by CRAAQ (2008)

5.4 Analysis of the Beneficial Management Practices

Although some of the sites were actual farms while others were experimental sites, to maintain comparability, for all sites it was assumed that the producer made the investment in the BMP Technology.

5.4.1 St. Emmanuel, Quebec

At the St. Emmanuel study site, the economic desirability of the controlled drainage with subirrigation system was evaluated as the BMP, and contrasted with the conventional subsurface tile drainage system called the Base Technology. Several studies (see Madramootoo et al., 1993; Mejia et al., 2000; Singh, 2013; Essien, 2016; Jiang et al., 2019) have been conducted in St. Emmanuel site to establish mainly the benefits of adopting the BMP Technology against the conventional free subsurface drainage system. In addition, some of these studies have evaluated their impact on nitrate pollution reduction, greenhouse gas emissions and crop yields increase. The study by Essien (2016) evaluated the economic impact of adopting the BMP on the farm profitability by comparing the net returns under the subsurface drainage and the controlled drainage with subirrigation in corn production. The raw data reported in the Essien study were used for the present analysis, in terms of the components and characteristics of both the technologies placed in the study field.

Since at the St. Emmanuel site farm, main commodity produced were corn, sporadically alternating with soybeans and peas in some years (Ekwunife, 2019), for this study, it was assumed that corn and soybeans are grown in a five-year cycle rotation, with four consecutive years of corn followed by one year of soybean production. This is similar to the study by Jiang et al. (2019) suggested that the indicated rotation is three years of corn followed by one of soybean.

Investment Costs

As was previously mentioned, the components involved and layout of the system in both Base Technology and BMP Technology were taken from Essien (2016). The costs of investment reported that study was $1,313.40 and $2,080.85 per acre, respectively, the base and BMP Technology, in 2018 prices. Hence, the marginal cost of investing in the BMP Technology was $767.45 per acre. Disaggregated costs and details are summarized in Table 5.4.

The costs of investing in the subsurface drainage and controlled drainage with subirrigation systems were similar except for the costs related to the additional components for the water table control: water control structure, pump and well, as well as the installation and transportation of the control structure. This higher cost is attributed to some of these products being imported from the United States.

With respect to the piping and fittings, the amount used per acre according to the system design was obtained from Essien (2016). The unit costs per type of pipe and accessories, as well as the installation and land preparation costs, were obtained from CRAAQ (2010) and updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019i). The same price index was used to update the costs of the well and the water pump (obtained from Essien (2016)) to 2018 prices. The well had a capacity of providing water to about 20 hectares (~50 acres). The one hp pump was suitable for approximately 4 hectares (~10 acres) (Essien, 2016).

The current price quoted by Agri Drain Corporation (2019) for the water control structure, suitable for an area of 4 hectares, was US $673.72. This cost was converted into Canadian dollars using an exchange rate of 1.296 CAD/USD, which was obtained from the Bank of Canada (2019). The approximate installation and transportation costs of the control structure were obtained from the study carried out in Ontario by Kitchen and Kitchen (2017).

Table 5.4. Cost of Investment for Base Technology and BMP Technology in St. Emmanuel ($/acre)

Item	Unit	Cost ($/unit)	Quantity (per acre)	Total Cost of Base Technology ($/acre)	Total Cost of BMP Technology ($/acre)
Cost of Components:				**781.18**	**1,491.94**
Piping:					
100 mm diameter lateral tile	Metre	2.26	244	549.87	549.87
150 mm diameter main tile	Metre	7.25	27	193.18	193.18
200 mm diameter non-perforated	Metre	12.86	0.6	7.81	7.81
Joints, tees, tapes, etc.	Unit	22.53	1	22.53	22.53
Outlet (250 mm)	Unit	7.79	1	7.79	7.79
Water Table Control:					
Control structure	Unit	872.94	0.1	0.00	87.29
Well [a]	Unit	6,787.34	0.02	0.00	137.40
Pump [a]	Unit	4,860.67	0.1	0.00	486.07
Cost of Installation:				**482.35**	**539.04**
100 mm diameter lateral tile	Metre	1.71	244	416.57	416.57
100 mm diameter main tile	Metre	2.39	27	63.79	63.79
200 mm diameter non-perforated	Metre	3.28	0.6	1.99	1.99
Control structure (Inc. Transport)	Unit	566.92	0.1	0.00	56.69
Cost of Land Preparation:	Acre	49.87	1	**49.87**	**49.87**
Total Investment Cost				**1,313.40**	**2,080.85**

Source: Details and required quantity of the components involved in the technologies from Essien (2016); unit costs of pipe and fittings, installation and land preparation from CRAAQ (2010) and unit costs for components of the water table control system from Essien (2016). Prices were updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019i).

[a] Includes installation costs (Essien, 2016).

Revenue

All available price and yield data were collected from the study site directly. The McGill University team had collected data on corn yields over a 12 years period extending from 1993 to 2018 for both the technologies -- Base Technology and BMP Technology were used (Ekwunife, 2019). With respect to soybeans, the 1995 and 1996 yields were obtained from Mejia et al. (2000)[9]. Annual historical average market prices for both corn and soybean crops were obtained from La Financière Agricole du Québec (FADQ, 2018). A summary of these data is shown in Table 5.5.

Table 5.5. Revenues with Base Technology and BMP Technology in St. Emmanuel ($/acre)

Year	Crop	Price ($/t)	Base Technology		BMP Technology	
			Yield (t/acre)	Gross Revenue ($/acre)	Yield (t/acre)	Gross Revenue ($/acre)
1993	Corn	117.59	3.24	380.86	3.32	390.38
1994	Corn	142.33	3.60	512.85	3.81	541.66
1995	Corn	140.83	4.49	632.88	4.62	649.98
	Soybean	275.50	1.28	353.58	1.45	399.31
1996	Corn	211.22	2.75	581.50	2.96	624.25
	Soybean	301.75	0.96	288.31	1.26	381.16
1998	Corn	155.62	3.56	554.44	2.67	415.83
1999	Corn	131.55	3.93	516.61	3.85	505.96
2001	Corn	128.59	2.79	359.22	3.81	489.37
2002	Corn	141.78	3.08	436.25	4.09	579.75
2008	Corn	195.58	5.06	989.78	4.98	973.94
2009	Corn	196.21	4.57	897.64	4.21	826.15
2014	Corn	197.05	3.87	762.67	3.92	772.24
2018	Corn	215.07	4.45	957.82	4.41	949.11

Source: Corn yield from Ekwunife (2019), soybean yield from Mejia el at. (2000) and corn and soybean historical prices from FADQ (2018).

Fixed Costs

Maintenance and repair of the components of the Base Technology and the BMP Technology, such as piping, control structure and pump, were considered as fixed costs, as well as the depreciation of the existing machinery and equipment on the farm. Depreciation of existing machinery and equipment on the farm was considered as the average amount of an average farm in Quebec, as reported by Essien (2016).

Table 5.6 shows that the total annual fixed cost of the Base Technology was estimated at $30.40 per acre, while the same for the BMP Technology was $41.05 per acre. The difference between them was the cost of repairing and maintaining the water pump and the control structure.

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[9] The experimental field used in Mejia et al. (2000) had exactly the same characteristics and the technologies as in this study; moreover, this farm was located in Bainsville, Eastern Ontario, very close (20 min driving) to the farm in St. Emmanuel, Quebec. For this reason, yields were considered comparable to the study farm.

The maintenance and repair costs of the piping and the water pump were estimated as a fixed percent -- 0.25% and 1%, respectively, of their initial investment cost, as suggested by Evans et al. (1996). In the case of the well, no maintenance and repair costs were assumed (Evans et al., 1996). Agri Drain Corporation (2019) recommends the lubrication of stoplogs as the only maintenance of the control structure. In this study, following Crabbé et al. (2012), this cost was estimated at $5.78 resulting from two lubrications of the stoplogs per year (one when the height is raised in the growing season and the other when it falls after harvesting). This involved two hours of work at $16.72 per hour, calculated as the average agricultural work wage in Quebec obtained from ESDC (2019), plus the lube cost of US $9.41 (in CAD $12.20) per tube for each application. This resulted in the total cost calculated as: (2*16.72+2*12.2=$57.84 per 4.2 ha) equivalent to $5.78 per acre. The reported maintenance costs are shown in Table 5.6 on a per acre basis.

Table 5.6. Fixed Costs under Base Technology and BMP Technology in St. Emmanuel ($/acre)

Item	**Price ($/acre)**	**Base Technology**		**BMP Technology**	
		Quantity (Per acre)	**Total ($)**	**Quantity (Per acre)**	**Total ($)**
Repair and maintenance:					
Piping	1.95	1.0	1.95	1.0	1.95
Well	0.00	1.0	0.00	1.0	0.00
Pump	4.86	0	0.00	1.0	4.86
Control structure	5.78	0	0.00	1.0	5.78
Depreciation on existing capital	28.45	1.0	28.45	1.0	28.45
Total Fixed Costs			**30.40**		**41.05**

Source: Repair and maintenance costs from Evans et al. (1996), Crabbé et al. (2012), Agri Drain Corporation (2019); wage rates from ESDC (2019) and depreciation data from Essien (2016).

Operating Costs

In this study, operating costs under the Base and BMP Technology for the study site were estimated using data obtained from CRAAQ (2018a) and CRAAQ (2018b), which were operating budgets of corn and soybean farms developed by Le Centre de Référence en Agriculture et Agroalimentaire du Québec. The results reported in both publications correspond to the average of existing farms in Quebec that had good technical and economic efficiency in 2018. Table 5.7 shows a summary of the cost of production corresponding to the growing of both crops: corn and soybean, using both technologies.

The transportation for the commercialization of the products was assumed to be zero because in general the sale of cereals is made directly on the farm (CRAAQ, 2018a; 2018b). Likewise, land rent was not included, it was assumed, for convenience, that the farm is wholly owned by the farmers or producers based on the CRAAQ's notes that the rental price is quite variable as a result of several factors, such as regional supply and demand, negotiation between the landlord and the tenant, the number of hectares, among others (CRAAQ, 2018a; 2018b). The rental price of land is not included in the budgets of farm production cost elaborated by either of the two provinces –Quebec and Ontario; however, if this aspect were taken into account, it could be expected that fixed costs would rise considerably. Furthermore, exclusion of rental costs may affect the net present values of each technology, but overall, it does not affect results of financial analysis since both Base and BMP technologies would have the same additional costs, resulting in an unchanged net marginal benefit of the BMP.

Table 5.7. Operating Costs of Corn and Soybean Growth under the Base Technology and the BMP Technology in St. Emmanuel ($/acre)

Item	**Corn**		**Soybean**	
	Base Technology ($/acre)	**BMP Technology ($/acre)**	**Base Technology ($/acre)**	**BMP Technology ($/acre)**
Inputs				
Seed	116.91	116.91	86.49	86.49
Fertilizer (Inorganic N, P_2O_5, K_2O)	157.23	157.23	36.32	36.32
Innoculants	0.00	0.00	7.13	7.13
Limestone	8.60	8.60	3.44	3.44
Herbicides[b]	30.53	30.53	36.03	36.03
Farming Operations[a]				
Tillage (loam, reversible plow)	25.27	25.27	25.27	25.27
Cultivator machine (two times)	9.04	9.04	9.04	9.04
Fertilizer application (tractor only)	1.08	1.08	1.08	1.08
Spreading liquid nitrogen	4.09	4.09	0.00	0.00
Seeder	10.18	10.18	7.20	7.20
Spraying	3.08	3.08	3.85	3.85
Weeding[b]	5.65	5.65	0.00	0.00
Threshing	30.73	30.73	32.44	32.44
Sorting stones (rake and trailer)	0.00	0.00	18.11	18.11
Roller	0.00	0.00	2.52	2.52
Transportation on the farm	6.26	6.26	1.74	1.74
Marketing				
Drying	83.40	83.40	4.93	4.93
Storage and ventilation	1.39	1.39	2.30	2.30
Transportation	0.00	0.00	0.00	0.00
Others				
Crop insurance	12.96	12.96	7.29	7.29
Land rent	0.00	0.00	0.00	0.00
Fuel, electricity	31.89	31.89	31.89	31.89
Additional Labor (Irrigation)	33.44	0.00	33.44	0.00
Total Operating Costs	**571.72**	**538.28**	**350.49**	**317.05**

Source: Operating costs for corn and soybean production from CRAAQ (2018a) and CRAAQ (2018b), respectively; Fertilizer, fuel and electricity costs from Essien (2016); details on irrigation system from Buchanan and Cross (2002) and wage rates from ESDC (2019).

[a] All costs include the operator's salary, maintenance and repair of the machinery involved in each activity, fuel and lubricants (CRAAQ, 2018a; 2018b).

[b] Both herbicides and weeding costs are both included in this budget. It was assumed that the former is related to the cost of the input itself, while the second one is related to the additional labor, machinery and equipment cost for applying herbicides.

In general, the operating costs of the BMP Technology were similar to those of the Base Technology. Even the same amount of fertilizer treatment was used in both cases, according to the experiments carried out at the study site between 2012 and 2014 (Essien, 2018). The only significant difference was related to the irrigation costs that required additional labor when the subsurface drainage system was used, which was excluded in the case of the BMP Technology due to subirrigation component of the controlled drainage system. Furthermore, it was assumed that the irrigation system used under the Base Technology was sprinkler irrigation, which is the most commonly adopted by cereal producers in eastern Canada (Mejia et al., 2000). On average, two hours of work ($16.72/h) per acre per year were considered for sprinkler irrigation (Buchanan and Cross, 2002). Additionally, the fuel and/or electricity costs needed for the operation of the water pump in the Base case for sprinkler irrigation, and for the subirrigation in the case of the BMP Technology, were obtained from Essien (2016) and updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019i).

5.4.2 Harrow, Ontario

The technology used in the Harrow study fields was designed and constructed according to objectives of the experiments to be conducted, without taking into account the investment costs and the economic impact that this may create. For example, taking into account the spacing between tiles (7.5 m apart), this experimental field included twice the amount of pipes than in the case of the farm at St. Emmanuel (15 m apart). This spacing was different from the 18 m apart, which is the technical recommendation for the clay loam type of soil that is found at the Harrow site (Simundsson et al., 2016). Also, Harrow has its own water control structure designed for research purposes. Since this type of system is not affordable by an average producer, in this study, the commercial costs that an average producer would pay in Ontario were calculated based on the data for the commercial producer in St. Emmanuel.

For this study site, as in the previous site, the Base Technology considered was the conventional subsurface drainage and the BMP Technology analyzed was the controlled drainage with subirrigation system. The rotation used on this analysis was a two-year crop rotation with corn followed by soybean.

Investment Costs

Table 5.8 shows detailed initial investment costs associated with both water management systems. The total investment cost was estimated at $1,699.82 per acre for the Base Technology and $2,467.27 per acre for the BMP Technology. As mentioned previously, the cost of investment was derived using the same layout and specification of the case study in St. Emmanuel; thus, to install controlled drainage with subirrigation system on an existing subsurface tile drainage system would cost $767.45 per acre higher than that with the Base Technology. In Harrow, the system costs were higher than those at St. Emmanuel by $386.42 per acre, because of the higher cost of material suppliers (pipes and fittings) in Ontario (compared to Quebec).

The price of the four types of pipes (100, 150, 200 and 250 mm diameter) were obtained from the 2019 retail price list provided through a quote by Soleno.Inc, which is a drainage tile contractor authorized by OMAFRA. The total price of the accessories (joints, tees, tapes, etc.) was estimated at 3% of the piping cost, as suggested by CRAAQ (2010). On the other hand, costs of the components for the water table control (structure, well and pump), and those for installation, transport and the preparation of the land were estimated using the methodology for the St. Emmanuel site.

Table 5.8. Cost of Investment for Base Technology and BMP Technology in Harrow ($/acre)

Item	**Unit**	**Cost ($/unit)**	**Quantity (per acre)**	**Total Cost of Base Technology ($/acre)**	**Total Cost of BMP Technology ($/acre)**
<u>Cost of the components</u>:				**1,167.62**	**1,878.37**
Piping:					
100 mm diameter lateral tile	Metre	3.30	244	803.76	803.76
150 mm diameter main tile	Metre	9.39	27	250.15	250.15
200 mm diameter non-perforated pipe	Metre	19.82	0.6	12.04	12.04
Split couplings, tees, tapes, etc.	Unit	31.98	1	31.98	31.98
Outlet (250 mm)	Unit	69.70	1	69.70	69.70
Water Table Control:					
Control structure	Unit	872.94	0.1	0.00	87.29
Well	Unit	6787.34	0.02	0.00	137.40
Pump	Unit	4860.67	0.1	0.00	486.07
<u>Cost of Installation</u>:				**482.35**	**539.04**
100 mm diameter lateral tile	Metre	1.71	244	416.57	416.57
100 mm diameter non-perforated pipe	Metre	2.39	27	63.79	63.79
200 mm diameter non-perforated pipe	Metre	3.28	0.6	1.99	1.99
Control structure (Inc. transportation)	Unit	566.92	0.1	0.00	56.69
<u>Cost of land preparation</u>:	**Acre**	**49.86**	**1**	**49.86**	**49.86**
Total Investment Cost				**1,699.82**	**2,467.27**

Source: Details and required quantity of the components involved in the technologies from Essien (2016), unit costs of pipe and fittings from Soleno.Inc (2019) and CRAAQ (2010), and unit costs for components of the water table control system from Essien (2016). Prices were updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019i).

Revenue

Revenue from crop production is a product of price by yield of that crop. Details on historical yields were obtained from three different studies carried out at the Harrow experimental site: Tan et al. (2007), Drury et al. (2009) and Abbasi et al. (2018). In all of these studies, the effect of water management technologies on crop yields in a corn-soybean rotation was analyzed. The 13-year yield data were collected over the 1995 to 2015 period, both for the Base Technology and the BMP Technology. The average annual prices of each product were obtained from the publication of historical prices in OMAFRA (2019b; 2019c). A summary of these data along with estimated gross income is presented in Table 5.9.

Table 5.9. Revenues with Base Technology and BMP Technology in Harrow ($/acre)

Year	**Crop**	**Price ($/t)**	**Base Technology**		**BMP Technology**		**Reference Study**
			Yield (t/acre)	**Gross Revenue ($/acre)**	**Yield (t/acre)**	**Gross Revenue ($/acre)**	
1995	Soybean	323.00	1.46	470.12	1.56	504.12	Drury et al. (2009)
1996	Corn	153.00	3.14	480.37	3.24	495.55	
1997	Soybean	337.00	1.28	430.46	1.12	376.57	
1998	Corn	118.00	3.91	461.25	3.54	417.54	
2000	Corn	127.00	2.70	342.59	2.90	367.89	Tan et al. (2007)
2001	Corn	135.00	1.50	202.55	2.86	386.09	
2002	Soybean	312.00	0.90	279.92	1.34	4177.85	
2003	Corn	143.00	3.00	428.71	3.66	522.73	
2004	Soybean	283.00	0.51	145.40	0.61	172.78	
2012	Corn	260.25	5.39	1,403.98	5.32	1,385.01	Abbasi et al. (2018)
2013	Soybean	503.80	1.91	963.75	1.68	844.43	
2014	Corn	183.85	1.92	352.81	1.92	352.44	
2015	Soybean	437.62	1.64	717.56	1.64	717.56	

Sources: Corn and soybean yields from Tan et al. (2007), Drury et al. (2009) and Abbasi et al. (2018); and corn and soybean historical prices from OMAFRA (2019b; 2019c).

Fixed Costs

Fixed costs were estimated as the sum of the cost of maintenance and repair of various components involved in both Base Technology and BMP Technology, plus the depreciation of existing machinery and equipment on the farm and other costs (such as professional advice). The total annual fixed cost associated with the Base Technology was estimated at $54.07 and that for the BMP Technology at $65.07 per acre (Table 5.10). As in the St. Emmanuel case study, the higher cost of the BMP Technology was due to the difference in the cost per acre of pump and control structure maintenance.

The maintenance and repair costs of the pipe system and water pump were estimated in the same way as in St. Emmanuel -- as a fixed percentage, 0.25% and 1% respectively, of the initial investment in each of them (Evans et al., 1996). No cost was assumed for the well[10] (Evans et al., 1996). The maintenance cost of the control structure was also treated in a similar manner; however, for this study site the cost was 36 cents per acre higher than in St. Emmanuel, on account of slightly higher labor cost (on average wage rate in Ontario is $18.50 per hour

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[10] Although the Harrow research station uses a reservoir, it was assumed that a producer would not build such a structure. Similar to the situation in St. Emmanuel, a deep well was assumed to obtain water when needed.

and in Quebec is $16.72, calculated as the average agricultural work in Ontario and Quebec according to ESDC (2019)).

Depreciation of the existing machinery and equipment on the farm was obtained from the budgets developed by OMAFRA (2019f) for an average corn and soybean producing farm in Ontario. Other fixed costs included insurance, professional costs, and land costs such as property tax (OMAFRA, 2019f).

Table 5.10. Fixed Costs under Base Technology and BMP Technology in Harrow ($/acre)

Item	Price ($/acre)	Base Technology		BMP Technology	
		Quantity (Per acre)	**Total ($)**	**Quantity (Per acre)**	**Total ($)**
Repair and maintenance:					
Piping	2.92	1	2.92	1	2.92
Well	0.00	0	0.00	1	0.00
Pump	4.86	0	0.00	1	4.86
Control structure	6.14	0	0.00	1	6.14
Depreciation on existing capital	43.80	1	43.80	1	43.80
Others (professional fees, etc.)	7.35	1	7.35	1	7.35
Total Fixed Costs			**54.07**		**65.07**

Source: Repair and maintenance costs from Evans et al. (1996), Crabbé et al. (2012), Agri Drain Corporation (2019), wage rates from ESDC (2019), depreciation data and other fixed costs from OMAFRA (2019f).

Operating Costs

OMAFRA (2019f) Field Crop Budgets were used to estimate the operating costs associated with corn and soybean farms in Ontario. Table 5.11 shows a summary of the cost of production corresponding to the growth of both products corn and soybean, in both technologies.

Both technologies have similar costs except for the cost of additional labor for irrigation. As noted in the previous study case, it was assumed that under the Base Technology, the producer used a sprinkler irrigation system in dry seasons which required more labor. This cost was based on two hours of work ($18.5/h) per acre per year (Buchanan and Cross, 2002). On the other hand, when the producer adopted the BMP, the additional irrigation cost is not incurred due to the subirrigation component of the system.

5.4.3 Sherrington, Quebec

For the Sherrington site, data were collected for the irrigation system used along with details on dryland production practices.

Investment Costs

The cost of investment in this study site was related only to the hand moved sprinkler irrigation system. As Table 5.12 shows, the total cost is $7,107.09 per acre in 2018 prices.

The details of the components and their quantities were obtained from the BMP´s layout described in Bogdan (2019) based on an area of 12.7 ha (or 31.3 acres). The costs of the aluminum piping, fittings, and sprinklers were derived from the price guideline publication by CRAAQ (2016), updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019i). The same price index was used to update the cost of the well, which was derived from CRAAQ (2008) based on a 6,000 m^3 well suitable to irrigate 40 ha (~100 acres) at a cost of $15,000. An electrical pump costing $4,565 was considered enough to irrigate 4 ha (10 acres) as suggested by CRAAQ (2016).

Table 5.11. Operating Costs of Corn and Soybean Growth under the Base Technology and the BMP Technology in Harrow ($/acre)

Item	**Corn**		**Soybean**	
	Base Technology ($/acre)	**BMP Technology ($/acre)**	**Base Technology ($/acre)**	**BMP Technology ($/acre)**
Inputs				
Seed	120.70	120.70	95.00	95.00
Fertilizer	133.20	133.20	42.65	42.65
Insecticides	1.60	1.60	0.00	0.00
Herbicides	26.10	26.10	70.00	70.00
Farming Operations				
Fertilizer application (mixing and delivery)	11.15	11.15	11.15	11.15
Pesticides application	11.15	11.15	11.15	11.15
Planting (tractor and machine fuel)	25.05	25.05	17.95	17.95
Trucking	39.75	39.75	11.05	11.05
Harvesting	32.95	32.95	33.85	33.85
Marketing				
Drying	75.25	75.25	0.00	0.00
Storage	38.30	38.30	11.20	11.20
Marketing board and financial protection fees	1.80	1.80	1.85	1.85
Others				
Repair and maintenance: machinery	20.85	20.85	21.00	21.00
Risk management program	7.30	7.30	1.25	1.25
Production insurance	10.90	10.90	9.15	9.15
Additional labor (Irrigation)	37.00	0.00	37.00	0.00
Total Operating Costs	**593.05**	**556.05**	**374.25**	**337.25**

Source: Operating costs for corn and soybean production from OMAFRA (2019f), fertilizer costs from Essien (2016), details on irrigation system from Buchanan and Cross (2002) and wage rates from ESDC (2019).

Revenue

For this site, carrot and onion prices from 2016 to 2018 were obtained from the Quebec fruit and vegetable price report developed by CRAAQ (2019a), while historical prices were obtained from the daily commodity price summary for Montreal by AAFC (2019b). The yield data were obtained from secondary sources since for this case study information on yields could not be obtained from the farm under consideration. Carrot and onion average yields per acre from 2011 to 2017 were collected from the report published by CRAAQ (2019b), which was an average estimate of farms with good technical and economic production efficiency in Quebec. The jumbo size of both commodities were taken into account when collecting the required data. These estimates were considered in this study as the carrot and onion yields delivered in the non-irrigation base scenario. The crop yields for the BMP Technology were calculated based on the results of studies (Lada and Stiles, 2004; Rekika et al., 2014; Seidazimova et al. (2016); Bogdan, 2019) that assessed the effect of the adoption of sprinkler irrigation on the productivity of horticultural crops in the same region.

Table 5.12. Cost of Investment for BMP Technology in Sherrington ($/acre)

Item	Unit	Cost ($/unit)	Quantity (per acre)	Total Cost of BMP Tech. ($/acre)
Cost of the components[a]:				
Aluminum lateral pipes (76 mm diam. x 9 m length)	Metre	13.03	345	4,493.04
Aluminum mainline pipes - manifold (152 mm x 11 m)	Metre	27.05	5	133.06
Valve-tee, couplers, stopper, and other fittings	Unit	381.98	0.5	183.00
Sprinkler head, nozzle, riser pipe (25 mm diam.)	Unit	42.44	38	1,626.65
Well (6,000 m^3)	Unit	210.04	1	210.04
Electrical Pump and fittings	Unit	461.30	1	461.30
Total Investment Cost				**7,107.09**

Source: Details and required quantity of the components involved in the technology from Bogdan (2019), unit costs of pipe, fittings and pump from CRAAQ (2016) and cost of the well from CRAAQ (2008). Prices were updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019i).

[a] All costs were calculated in 2018 prices and included installation and assembly costs (CRAAQ, 2016).

Nagaz et al. (2017) compared carrot yields under dryland conditions with yields under irrigation. These data were for 2007 to 2009 for different levels of soil moisture with low organic matter. When the land was completely irrigated (no deficit irrigation), carrot yields were 29.5, 29.7 and 26.8 t/ha, in each year respectively, compared to approximately 20 t/ha when there was no irrigation. This indicates an increase in yields by approximately 47.5, 43.5 and 34%, respectively for each year. Similar results have been reported by Lada and Stiles (2004) based on a study of irrigated carrot yields in Truro, Nova Scotia. Seidazimova et al. (2016) reported an increase of 12.3% and 16.3% in carrot productivity in 2014 and 2015 growing seasons, respectively, when the conventional surface irrigation was changed to a sprinkler system on a high organic matter soil. Recently, Bogdan (2019) estimated a 20% increase in carrot yields from dryland and irrigated carrots for the same study site. All of these studies reported a significant increase in carrot yields under irrigation. The financial analysis in this study was based on the most conservative increase of 12.3% -- the smallest increase reported by these studies.

Rekika et al. (2014) evaluated onion yield response to a sprinkler irrigation treatment during the bulbing stage and compared it with the yields of unirrigated onion crops (i.e., rainfed crop) in a muck soil field in southwestern Quebec in 2008 and 2009. Their results indicated that in the 2008 growing season, the yield of non-irrigated onions was 73,500 kg/ha, while that under irrigation was 78,800 kg/ha. This shows an increase of approximately 7.2% in yields under irrigation over dryland. Similarly, in the 2009 growing season, yields with no irrigation were 65,100 kg/ha, and with irrigation were 71,000 kg/ha, which is an increase of about 9.1%. These yield increases were used by Bogdan (2019) for the evaluation of the sprinkler irrigation system.

In this study, increases in onion yields were based on the review of the mentioned studies, since they were conducted in the region and on the same type of soil. However, a conservative yield increase of 7.2% over the dryland yields was used in the financial analysis.

Table 5.13 shows the revenues of this study site from 2011 to 2017, taking into account prices and yields according to the description noted previously. As suggested by CRAAQ (2008), the wholesale discount of 5% of the revenue was also considered since the reported market prices are derived from a selected group of Montreal market wholesalers, who are required by the retailers for the respective discount. The crop yields for each product were reported for half of an acre due to the intercropping system, assuming that half of the production is carrot and the other half is onion in the evaluated field in the same growing season.

Table 5.13. Revenues with Base Scenario and BMP Technology in Sherrington ($/acre)

			Base Technology			**BMP Technology**		
Year	**Crop**	**Price ($/kg)**	**Yield (kg/acre/2)***	**Whole-sale disc. (5%)**	**Gross Revenue ($/acre/2)**	**Yield (kg/acre/2)***	**Whole-sale disc. (5%)**	**Gross Revenue ($/acre/2)**
2011	Carrot	0.46	7,227	361	2,984.42	8,116	406	3,351.50
	Onion	0.95	6,053	303	5,448.53	6,488	324	5,840.82
2012	Carrot	0.49	6,943	347	3,020.46	7,797	390	3,391.97
	Onion	0.86	6,984	349	5,655.50	7,487	374	6,062.69
2013	Carrot	0.74	7,773	389	5,352.27	8,729	436	6,010.60
	Onion	0.84	8,057	403	6,346.69	8,637	432	6,803.66
2014	Carrot	0.65	6,923	346	4,156.36	7,775	389	4,667.59
	Onion	0.93	9,717	486	8,511.16	10,416	521	9,123.97
2015	Carrot	0.91	6,761	338	5,847.82	7,593	380	6,567.10
	Onion	0.74	9,433	472	6,495.21	10,112	506	6,962.86
2016	Carrot	0.62	7,247	362	4,120.74	8,138	407	4,627.59
	Onion	1.02	8,846	442	8,577.56	9,483	474	9,195.14
2017	Carrot	0.57	7,308	365	3,823.39	8,207	410	4,293.67
	Onion	0.65	9,130	456	5,436.77	9,787	489	5,828.21

Sources: 2016 to 2017 prices for carrot and onion from CRAAQ (2019a), 2011 to 2015 prices for carrot and onion from AAFC (2019b) and average carrot and onion yield from CRAAQ (2019b).

* The yields were divided by 2 since each crop takes half the area of field -- alternate rows.

Fixed Costs

Table 5.14 shows that the total annual fixed cost of the study site for the base scenario (non-irrigation) was $1,022.93 per acre, while that for the site BMP Technology was $1,187.55 per acre. These values were estimated in accordance with the operating budget of a farm with good technical and economic efficiency that produces carrots and onions in an intercropped modality (CRAAQ, 2008). These values were updated to 2018 prices using the Farm Input Price Index (Statistics Canada, 2019j) for Quebec for different cost categories: machinery repairs, depreciation on machinery and vehicles, and general business.

The main difference between the two values was the annual maintenance cost of the sprinkler irrigation system, which was calculated as 2% of the investment cost of $7,107.09/acre (Martin et al., 2007). Except for machinery and equipment insurance cost, all other costs were identical between the two systems (Base and the BMP Technology). These costs also included the depreciation on the existing capital assets -- shed, warehouse with refrigeration, and machinery and equipment of the farm, with depreciation rates of 3%, 3.6%, and 7%, respectively, as suggested by CRAAQ (2008). The total costs reported were: $656.67/acre for the shed, $1,440.28/acre for the warehouse with refrigeration and $5,199.29/acre for machinery and equipment of the farm, which were updated to 2018 prices using the Farm Input Price Index (Statistics Canada, 2019j) for depreciation on machinery and equipment in Quebec.

Table 5.14. Fixed Costs under Base Technology and BMP Technology in Sherrington ($/acre)

Item	**Base Technology ($)**	**BMP Technology ($)**
Maintenance and repair:		
Irrigation system	0.00	142.14
Buildings	73.09	73.09
Machinery and equipment	13.06	13.06
Maintenance of land	8.63	8.63
Machinery and equipment insurance	35.07	38.05
Buildings insurance	41.86	41.86
Liability insurance	2.86	2.86
Professional fees and consulting services	121.84	121.84
Electricity, phone, internet, etc.	30.46	49.95
Net property taxes	37.68	37.68
Miscellaneous	9.87	9.87
Depreciation on existing capital:		
Shed of machinery and equipment (3%)	29.29	29.29
Warehouse with refrigerated section for carrot (3.6%)	77.22	77.22
Machinery and equipment (7%)	542.01	542.01
Total Fixed Costs	**1,022.93**	**1,187.55**

Source: Maintenance and repair costs for irrigation system from Martin et al. (2007) and other fixed costs from CRAAQ (2008). Prices were updated to 2018 prices using the Farm Input Price Index (Statistics Canada, 2019j).

Operating Costs

Table 5.15 shows in detail the operating costs under no irrigation and BMP Technology, They were estimated based on the operating budget of a farm with good technical and economic efficiency that produces carrots and onions in an intercropped modality (CRAAQ, 2008), then updated to 2018 prices using different components (seeds, fertilizers, pesticides, production insurance, etc.) of the Farm Input Price Index (Statistics Canada, 2019j) for Quebec. The costs corresponded to growing of both products: carrots and onions, which were reported on a half-acre basis due to intercropping.

For both carrots and onions, operating costs were higher under the BMP Technology since additional labor costs were associated with irrigation. The hand moved sprinkler irrigation is a system that does not require very expensive equipment or assembly of infrastructure as the other types of sprinkler irrigation, but that is the one that demands the greatest amount of labor (Tam and Petersen, 2014a; Martin et al., 2007). A normal irrigation activity consisted of 2 workers for a maximum of 3 hours per field of 31.3 acres to be irrigated. Additionally, for the removal and transfer of the system to another area, 5 workers are needed for approximately 5 hours each (Bogdan, 2019). Therefore, assuming a total of 31 hours of labor needed, it amounted to approximately 1 hour per acre at a cost of $16.72 per hour (ESDC, 2019).

5.4.4 Holland Marsh, Ontario

As noted in section 5.2.4, the Base Technology for the Holland Marsh was the subsurface drainage while the BMP added controlled drainage to it. Both of these technologies were analyzed in this study.

Investment Costs

Table 5.16 shows detailed initial investment costs associated with both the technologies. These costs were $2,483.71 per acre for the Base Technology and $2,682.20 per acre for the BMP Technology. Thus, to install a controlled tile drainage system on an existing subsurface tile drainage system cost $198.49 per acre more.

The remaining costs of subsurface drainage on both the farms were very similar. The only additional cost was for the water control structure and its installation. The current price quoted by Agri Drain Corporation for the water control structure, suitable for an area of 4 hectares, was US $1,094.34, which was converted in Canadian funds using an exchange rate of 1.296 CAD/USD (Bank of Canada, 2019). The installation and transportation costs of the control structure were obtained from Kitchen and Kitchen (2017), which included 2 hours of labor (including materials and equipment) necessary to connect the structure to the drainage system that already exists, plus the float fee based on Ontario contractor quotes.

The prices of the four types of pipes were obtained from the 2019 retail price list through a quote to Soleno Inc -- a drainage tile contractor listed in OMAFRA. The total price of the accessories (the joints, tees, tapes, etc.) was obtained as a 3% of the piping cost, suggested by CRAAQ (2010), as well as the cost of the land preparation, which was updated to 2018 prices using the Machinery and Equipment Price Index (Statistics Canada, 2019i). The same price index was used to update the costs of the well and the water pump at 2018 prices based on the information given in Essien (2016). The well was adequate for about 20 ha (~50 acres) of farmland and the pump could serve approximately 4 ha (~10 acres) (Essien, 2016).

Table 5.15. Operating Costs of Carrot and Onion Growth under the Base Technology and the BMP Technology in Sherrington ($/acre)

Item	Carrot		Onion	
	Base Technology ($/acre/2)[a]	**BMP Technology ($/acre/2)***	**Base Technology ($/acre/2)***	**BMP Technology ($/acre/2)***
Inputs				
Seed	316.43	316.43	464.63	464.63
Fertilizer	53.33	53.33	59.67	59.67
Herbicide[a]	51.33	51.33	60.58	60.58
Insecticides	25.87	25.87	33.01	33.01
Fungicides	30.25	30.25	73.46	73.46
Cover crop	13.90	13.90	13.90	13.90
Winter soil protection	6.95	6.95	6.95	6.95
Farming Operations				
Chisel plow	9.37	9.37	9.37	9.37
Rotary digger	13.90	13.90	7.46	7.46
Seeding of cover crops	0.90	0.90	0.90	0.90
Carrot/Onion seeds plantation	20.73	20.73	20.73	20.73
Fertilizer application (tractor)	1.44	1.44	2.87	2.87
Agrochemical spraying	18.23	18.23	25.12	25.12
Mechanical weed control[a]	0.00	0.00	5.02	5.02
Swathing	0.00	0.00	4.58	4.58
Irrigation (tractor and pump)	0.00	4.80	0.00	18.00
Harvesting	46.68	46.68	21.62	21.62
On-farm transportation	36.79	36.79	18.43	18.43
Marketing				
Storage (plus electricity and forklift)	48.80	48.80	26.77	26.77
Packing	1,332.75	1,332.75	1,159.91	1,159.91
Transportation	131.40	131.40	156.14	156.14
Others				
Crop Insurance	34.16	34.16	53.41	53.41
Land screening	42.66	42.66	42.66	42.66
Hired labor for irrigation	0.00	16.72	0.00	16.72
Total Operating Costs	**2,235.87**	**2,257.39**	**2,267.19**	**2,301.91**

Source: Operating costs for carrot and onion production from (CRAAQ, 2008), detail on labor characteristics from Bogdan (2019) and wage rates from ESDC (2019). All prices updated at 2018 prices using different components (seeds, fertilizers, pesticides, production insurance, etc.) of the Farm Input Price Index (Statistics Canada, 2019j).

* The costs were divided by 2 since each crop takes half of the total area of the field -- alternate rows.

[a] The costs of herbicides and weed control are both included in this budget. It was assumed that the former is related to the cost of the input itself, while the second one is related to the additional labor and equipment costs for weed control.

Table 5.16. Cost of Investment for Base Technology and BMP Technology in Holland Marsh ($/acre)

Item	Unit	Cost ($/unit)	Quantity (per acre)	Total Cost of Base Technology ($/acre)	Total Cost of BMP Technology ($/acre)
<u>Cost of the components</u>:				**1,919.37**	**2,061.16**
Piping:					
100 mm diameter lateral tile	Metre	3.30	244	805.20	805.20
150 mm diameter main tile	Metre	9.39	39.75	373.25	373.25
200 mm diameter non-perforated pipe	Metre	19.82	0.6	12.04	12.04
Split couplings, tees, tapes, etc.	Unit	35.71	1	35.71	35.71
Outlet (250 mm)	Unit	69.70	1	69.70	69.70
Water table control:					
Control structure	Unit	1,417.94	0.1	0.00	141.79
Well	Unit	6,787.34	0.02	137.40	137.40
Pump	Unit	4,860.67	0.1	486.07	486.07
<u>Cost of installation</u>:				**514.49**	**571.18**
100 mm diameter lateral tile	Metre	1.71	244	417.32	417.32
150 mm diameter main tile	Metre	2.39	39.75	95.18	95.18
200 mm diameter non-perforated pipe	Metre	3.28	0.6	1.99	1.99
Control structure (Inc. Transport)	Unit	566.92	0.1	0.00	56.69
<u>Cost of land preparation</u>:	**Acre**	**49.86**	**1**	**49.86**	**49.86**
Total Investment Cost				**2,483.71**	**2,682.20**

Source: Details and required quantity of the components involved in the technologies from Essien (2016), unit costs of pipe from Soleno.Inc (2019), accessories and land preparation from CRAAQ (2010), installation and transportation costs from Kitchen and Kitchen (2017) and unit costs for components of the water table control system from Essien (2016). Prices were updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index (Statistics Canada, 2019i).

Revenue

All available price and yield data are shown in Table 5.17. Data on carrot yield for the growing season 2015 and 2016 for the experimental fields that were obtained from De Sena (2017). Average prices for those years were obtained from the annual average price of the horticultural crops report (OMAFRA, 2018a).

Table 5.17. Carrot Revenues with Base Technology and BMP Technology in Holland Marsh ($/acre)

Year	Price ($/kg)	Base Technology		BMP Technology	
		Yield (kg/acre)	Gross Revenue ($/acre)	Yield (kg/acre)	Gross Revenue ($/acre)
2015	0.2316	34,452	7,979.46	28,564	6,615.73
2016	0.2281	23,944	5,461.88	24,855	5,669.58

Sources: Carrot yield from De Sena (2017) and carrot prices from OMAFRA (2018a).

With respect to onion production, it was not possible to obtain any information on actual yield from the farm under study. These had to be estimated using a horticulture report by OMAFRA (2018b). Prices for onion were also obtained from this source. Due to a lack of evidence regarding the performance of onion productivity when switching from conventional drainage systems to controlled drainage, this study assumed that there was no difference in yield between onions grown under the Base Technology or the BMP Technology.

Fixed Costs

Fixed costs were estimated as the sum of the cost of various items for maintenance and repair for both the water management systems, plus the depreciation of existing machinery and equipment on the farm. The total annual fixed cost of the Base Technology was estimated at $641.57 while that for the BMP Technology at $647.71 per acre (Table 5.18). Like in the previous case studies, the difference between the two systems was the cost of the control structure maintenance.

The maintenance and repair costs of the pipe system and the water pump were estimated as a fixed percentage, 0.25% and 1% respectively, of their initial investment cost (Table 5.16), following Evans et al. (1996). No cost was assumed for the well as suggested by Evans et al. (1996). The maintenance cost of the control structure was estimated as the result of two lubrications of the stoplogs per year, which meant two hours of work at $18.50 per hour (ESDC, 2019) plus the lube that costs of USD $9.41 (~CAD $12.20) per tube for each application. Depreciation of existing machinery and equipment were estimated in accordance with the operating budget of a farm with good technical and economic efficiency that produces carrots and onions in an intercropped modality (CRAAQ, 2008).

Table 5.18. Fixed Costs under Base Technology and BMP Technology in Holland Marsh ($/acre)

Item	Base Technology ($)	BMP Technology ($)
Repair and maintenance:		
Piping	3.24	3.24
Well	0.00	0.00
Pump	4.86	4.86
Control structure	0.00	6.14
Depreciation on existing capital:		
Shed of machinery and equipment (3%)	28.61	28.61
Warehouse with refrigerated section for carrot (3.6%)	75.43	75.43
Machinery and equipment (7%)	529.44	529.44
Total Fixed Costs	**641.57**	**647.71**

Source: Repair and maintenance costs from Evans et al. (1996), Crabbé at al. (2012), Agri Drain Corporation (2019), depreciation data from CRAAQ (2008) and wage rates from ESDC (2019).

Operating Costs

Since there are no recent vegetable budgets prepared for Ontario[11], operating costs in this study site were estimated using data obtained from different sources. Table 5.19 shows detailed operating costs for the Base and the BMP technologies. For the two technologies, costs were very similar, except for fertilizer cost. The fertilizer cost was lower under the controlled tile drainage system because the control structure was effective to retain the chemicals in the field and avoid additional application of fertilizer throughout the growth stage (De Sena, 2017).

Table 5.19. Operating Costs of Carrot and Onion Growth under the Base Technology and the BMP Technology in Holland Marsh ($/acre)

Item	**Carrot**		**Onion**	
	Base Technology ($/acre)	**BMP Technology ($/acre)**	**Base Technology ($/acre)**	**BMP Technology ($/acre)**
Inputs				
Seed	773.38	773.38	787.34	787.34
Fertilizer	285.59	164.81	164.81	95.11
Insecticides	50.40	50.40	51.97	51.97
Herbicides[a]	100.04	100.04	103.14	103.14
Fungicides	58.95	58.95	60.77	60.77
Cover crop	9.88	9.88	0.18	0.18
Farming Operations				
Chisel plow	8.94	8.94	8.94	8.94
Rotary disc	13.81	13.81	8.11	8.11
Seeding of cover crops	2.11	2.11	2.11	2.11
Fertilizer application	1.31	1.31	2.62	2.62
Seeding	31.17	31.17	31.17	31.17
Agrochemical spraying	14.94	14.94	24.90	24.90
Irrigation	2.83	2.83	4.25	4.25
Weed control[a]	60.73	60.73	2.87	2.87
Harvesting	149.30	149.30	149.30	149.30
Miscellaneous	122.00	122.00	122.00	122.00
Hired labor	166.50	166.50	166.50	166.50
Total Operating Costs	**1,851.87**	**1,731.09**	**1,690.97**	**1,621.27**

Source: Carrot and onion seeds from Stokes Seeds.Inc, (2019), required quantities and prices of fertilizers and micronutrients from De Sena (2017), McDonald et al. (2018) and Zandstra et al. (1986b) and U of G (2018), required quantities and prices of insecticides, herbicides, and fungicides from CRAAQ (2008), labor required from CRAAQ (2008) and other operating costs from (OMAFRA, 2018c).

[a] The costs of herbicides and weed control are both included in this budget. It was assumed that the former is related to the cost of the input itself, while the second one is related to the additional labor, machinery and equipment costs for applying herbicides.

The type of carrot and onion seeds considered in this study are those that had the best marketable performance in the Holland Marsh (Tesfaendrias et al., 2010; Zandstra et al., 1986a; Zandstra et al., 1986b). The quantities used and their prices were obtained (based on their

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[11] The last vegetable budgets provided by OMAFRA are incomplete data collections from 2000 (Van Dyk, 2019).

quote) from Stokes Seeds Inc, a vegetable seed company listed in OMAFRA. Details on fertilizers and micronutrients used were obtained from the on-site study by De Sena (2017) for carrots. For onions, suggestions of McDonald et al. (2018) and Zandstra et al. (1986b) for muck soils were followed. In this study, the input prices were obtained from the survey of farm supply stores conducted by the University of Guelph in Ontario in order to collect retail prices (U of G, 2018). Given that the majority of carrot and onion production occurs in Ontario and Quebec, they also share the same problems regarding pests (AAFC, 2018b). For this reason, in this study, the amounts of insecticides, herbicides, and fungicides, and their reference prices for carrots and onions were obtained from the guideline provided by CRAAQ (2008) for Quebec, and updated to 2018 prices using the farm input index price for pesticides (Statistics Canada, 2019j).

The hours of labor required for farming operations were taken from the publication for vegetable farms in Quebec (CRAAQ, 2008). Then, costs per hour of charging for chiselling, sowing of main crop seeds, application of fertilizer and spraying of agrochemicals, weed control, miscellaneous as snow removal, etc., were obtained from the Ontario´s custom farmwork rates survey (OMAFRA, 2018c). Although these costs were for general activities, they were considered a good approximation for the production of horticultural crops.

5.5 Financial Analysis

The financial evaluation of the desirability of the technologies was carried out using an Excel-based model. As noted previously, the financial analysis for the selected BMP Technology in a site was undertaken with a “private” accounting stance and a “with and without” criterion (Gittinger, 1982). In this sense, the private economic net benefits to the producer through the adoption of new water management technologies were estimated by calculating the benefits and costs related to the selected BMP Technology and comparing them with the situation where the BMP Technology has not been adopted – a situation called Base Technology. Thus this comparison is based on the incremental net benefit of the BMP Technology for a given study site.

In all four case studies, the economic performance of investing in the BMP Technology was estimated over the BMP Technology´s life span through the use of financial indicators, such as net present value (NPV) and benefit-cost ratio (BCR), as well as the pay-back period. These indicators take into account the time value of future benefits and costs and compare them to the investment cost of the technologies; therefore, all benefits and costs were in present-day (discounted) values. The effect of inflation was not considered because it was assumed that it affects both inputs and outputs prices equally (Singh and Christen, 2000).

5.5.1 Net Present Value

The NPV analysis in this study was carried out using the data presented in Section 5.4. The analysis was conducted for the useful life of the BMP Technology. The useful life of BMP Technology that involved a controlled drainage system, with and without subirrigation, was 20 years (Agri Drain Corporation, 2019; Crabbé et al., 2012). In the case of sprinkler irrigation, the useful life of the assets was assumed to be 15 years (Buchanan and Cross, 2002; Ortiz et al., 2006). Accordingly, the Base Technology was also assumed to have the same useful life. Actual data were not available for all costs and revenue items for the entire duration of the useful life of the project, so, the random number generator tool of the R-Project program was used to estimate project costs, prices and returns over the life of each technology. For this purpose, statistical distributions were estimated for each data group. More details are provided in Section 5.5.3.

The NPV calculation method for this analysis was taken from Boardman et al. (2018), which consists of subtracting the present value of the costs, $PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$, from the present value of the benefits, $PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t}$, resulting in the value estimated using equation (5.1). This is a decision-making indicator showing the financial desirability of the investment.

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{5.1}$$

Where: B_t and C_t represents the streams of benefits and costs, respectively, occurred in the time period t for $t = 1, 2, \ldots, n$ (time frame); and i implies the discount rate.

Another indicator used for this study is the benefit-cost ratio (BCR), which was calculated by dividing the present value of benefits, $PV(B)$, by the present value of costs, $PV(C)$, as shown in equation (5.2).

$$BCR = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} \bigg/ \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{5.2}$$

A BCR value of greater than 1 indicates that the benefits outweigh the costs and the project is worthy of investing. The decision criterion followed was: the higher the BCR, the more attractive is either the Base Technology or BMP Technology (Gittinger, 1982).

In addition, another indicator was used: the pay-back period. This break-even analysis as a time-based measurement was undertaken to determine the time period required for the investment in the Base Technology and the BMP Technology so that net positive gains start to accrue to pay for itself (Singh and Christen, 2000). The longer the period when investment cost is returned, the riskier the investment is considered to be. This criterion leads to selecting the most financially attractive technology based on a shorter period of time.

5.5.2 Discount Rate

The discount rate was determined using the weighted average cost of capital suggested by Boehlje and Eidman (1984), which consists of establishing a combination of debt and equity funds that the producer will use to finance the investment by assigning weights to the cost of debt and the cost of equity, according to equation (5.3).

$$d = K_e W_e + K_d(1 - t)W_d \tag{5.3}$$

Where, d is the discount rate, K_e is the rate of return on equity capital, W_e is the proportion of equity capital (equity/asset ratio), K_d is the interest rate on debt, t is the income tax rate, and W_d is the proportion of debt (debt/asset ratio). This method of determining the discount rate evaluates the investment after taxes (Olson, 2011).

The return on equity (ROE) used in this study was 10.2%, which is the planned performance for the 2018-2019 fiscal year of the Canadian farming sector ROE developed by Farm Credit Canada (FCC, 2018). An interest rate on debt of 3.64% was assumed, calculated as the monthly average of the prime business loan rate in 2018 (Zhang, 2019). The income tax rate used was 20%, which is the rate in Quebec for a taxable income between $43,055 and $86,105 in 2018 (Revenu Québec, 2018). For the Ontario study site, the same income tax rate was used to make results comparable, although, in reality, it is 20.5% for taxable income greater than $46,605 but less than $93,208 in 2018 (CRA, 2018).

A debt/asset ratio of 19.5% and an equity/asset ratio of 80.5% were used, which were obtained as the 10-year average for the period between 2008 and 2017 for Quebec and Ontario (Statistics Canada, 2019k). This resulted in the estimated discount rate used for this study of 8.78%. This rate is comparable to that used in Kitchen and Kitchen (2017) when analyzing the on-farm costs and benefits of controlled drainage systems in Ontario with the objective of measuring the probability of adoption among producers. However, this study used an 8% discount rate, which is also comparable to the 8.47% used by Essien (2016). Singh and Christen (2000) also used a discount rate of 8% because it is assumed to be the expected rate of return for the most attractive alternative use of producers' capital, and suggests its opportunity cost.

5.5.3 Forecasting of Costs and Revenue Elements

The benefits and costs calculated for each case studied were projected over the life span of the project. This was determined on the basis of technical reports and literature. A controlled drainage system life span is usually determined in 20 years because the expected life of the water control structure is 20 years (Agri Drain Corporation, 2019; Evans et al., 1996; Crabbé et al., 2012; Kitchen and Kitchen, 2017). For a sprinkler irrigation system, it is common to use a life of 15 years based on the expectancy on the aluminum sprinkler heads (Buchanan and Cross, 2002; Ortiz et al., 2006).

In all four cases, 2018 was assumed to be the investment year. For those study sites that involved controlled drainage with or without subirrigation systems, given their project life is 20 years, data from 2019 to 2038 were generated. While for the site that used the sprinkler irrigation system, data from 2019 to 2033 were generated corresponding to its project life. Additionally, the salvage value of every component associated with both technologies was calculated at the end of its useful life and was included as a negative cost in the last year of the cost stream (assuming that each asset installation was in the year the project began). In this calculation, the annual depreciation on piping was estimated in 2% with an expected life of 50 years, the depreciation on the well was assumed in 2% with an expected life of 30 years, and the annual depreciation of the pump was assumed in 5% with an expected life of 20 years (Crabbé et al., 2012).

As noted previously, all benefits and costs were projected using the statistical program R-Project and its random data generation tool. The random number generation analysis tool delivers a range with independent random numbers that are drawn from a specific distribution. Given a distribution and its properties, random numbers were generated to forecast prices and crop yields, as well as the operating costs of production.

There are several studies that have attempted to find out the statistical distribution of prices and yields of agricultural products in order to predict them by using different methods of analysis. Some studies have found normal distribution at least in the case of distribution of yields (Just and Weninger, 1999). However, this conclusion is not agreed by other researchers as agriculture is influenced by many unpredictable situations such as droughts, floods, pests, etc. (Allen, 1994). Several studies have concluded non-normality of the distributions of crop yields and prices, indicating that they have a marked skewness and kurtosis (Trautman et al., 2012; Ramírez et al., 2003; Atwood et al., 2003; Ramírez, 1997; Day, 1965). Based on this review, in this study, the stochastic forecast method was used in order to take into account the positive or negatively skewed distributions for various variables historically. Details on the procedure followed and data that could have been collected depending on the particular study case were different for each case study and is described later on in this section.

The skew-normal probability distribution is an extension of the normal probability distribution (Gaussian) that allows the presence of skewness in the analyzed data. This skew-normal distribution extends the normal distribution by adding a shape parameter to regulate the skewness (Ghorbanzadeh et al., 2017). The probability density function for a random variable (vector) x can be expressed as shown in equation 5.4.

$$f(x) = 2\emptyset(x)\varphi(\alpha x) \tag{5.4}$$

Where: $\emptyset(x) = \frac{\exp(-x^2/2)}{\sqrt{2\pi}}$ is the standard Normal density function and $\varphi(\alpha x) = \int_{-\infty}^{\alpha x} \emptyset(t)\, dt$ is the distribution function evaluated at point αx. The component α is the shape parameter that regulates the density function. When $\alpha = 0$ the skewness disappear and equation (5.4) reverts back to the standard Normal density function; however, when $\alpha \neq 0$ the skewness of the distribution increases towards the right side (positive skew if $\alpha > 0$) or left side (negative skew if $\alpha < 0$) (Azzalini and Capitanio, 2014).

The parameters for a skew-normal distribution are described by $SN(\varepsilon, \omega^2, \alpha)$, where ε is referred to the location, ω is scale, and α is the shape. Those parameters are referred to as the mean, standard deviation and skewness (that would be zero) derived from a normally distributed set of data (Azzalini, 2005). In this study, the skew-normal distribution family "SN" package of the R-Project in the univariate case (Azzalini, 2018), was used for the generation of random values for prices and crop yields.

The operating costs were forecasted assuming a normal distribution, based on results of risk analysis (for agricultural insurance) studies (Jacques, 2014; Ozaki et al., 2014; Sossou et al., 2014). In particular, this assumption is satisfied for fertilizer and fuel price distribution (Jacques, 2014). In this case, a random number generation analysis tool was used assuming that the data are drawn from a normal distribution, $N(\mu, \sigma^2)$ with parameters μ and σ referred to the mean and standard deviation, respectively. The shape of the function is determined by the probability density function shown in equation (5.5).

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2} \tag{5.5}$$

The required data for forecasting operating costs were taken from the 2018 partial budget that was collected for each study site. These costs were projected until 2027 using the Farm Input Price Index Projections provided by AAFC (AAFC, 2018c). Therefore, having the mean and standard deviation of 10 years of data (2018-2027) in each case, values for the rest of the years were forecasted using the random data generation tool provided of R-Program. The procedure of how the projections were reached at each study site is described below for each case study.

St. Emmanuel, Quebec

For this study site, historic corn and soybean market prices were obtained from FADQ (2018). These data were available for the 1980-2016 period for corn and for the 1990-2016 period for soybean. Regarding crop yield data, 12 years of historical corn yield (as shown in Table 5.5) collected from the study farm for both Base Technology and BMP Technology in St. Emmanuel were used. Since there were only two years of soybean yield data for both technologies (1995 and 1996) at this study site, the average annual yields for the province, as provided by FADQ (2018), were used for the 1990-2016 period.

Three parameters were estimated for each historical data vector: mean, standard deviation and the skewness coefficient, using the R-Program (Table 5.20). To estimate these parameters in soybean yields, the mean was calculated from the 2 years on-site data obtained for both technologies, while the standard deviation and skewness were estimated from the historical average yields of the province.

Table 5.20. Parameters of Skew-Normal/Normal Distribution of Crop Prices and Yields and Operating Costs (St. Emmanuel)

Crop	**Item**	**Crop Price**	**Base Technology**		**BMP Technology**	
			Yield	**Operat. Costs**	**Yield**	**Operat. Costs**
Corn	Mean	161.750	3.722	604.995	3.840	569.609
	Stand. Dev.	40.782	0.753	24.674	0.673	23.231
	Skewness	1.008	0.335	-	-0.138	-
Soybean	Mean	344.940	1.120	373.353	1.355	337.733
	Stand. Dev.	93.811	0.071	25.341	0.071	22.923
	Skewness	0.667	0.402	-	0.402	-

Note: Output obtained from R-Project Statistical Program.

Using the random data generation tool with skew-normal distribution in the R-Program for crop prices and yields, the values were obtained for 20 years (2019-2038) according to the useful life of the project that was established. Since producers followed a 5-year rotation, this study assumed four years of corn followed by one year of soybeans. Table 5.21 shows these values as well as the calculation of the gross revenue from the projected values.

Table 5.21. Forecast of Corn and Soybean Prices and Yields, along with Gross Revenue, for Base Technology and BMP Technology (2019-2038) in St. Emmanuel

Year	**Corn**					**Soybean**				
	Crop Price ($/t)	**Yield Base Tech. (t/acre)**	**Yield BMP Tech. (t/acre)**	**Gross Revenue**		**Crop Price ($/t)**	**Yield Base Tech. (t/acre)**	**Yield BMP Tech. (t/acre)**	**Gross Revenue**	
				Base Tech. ($/acre)	**BMP Tech. ($/acre)**				**Base Tech. ($/acre)**	**BMP Tech. ($/acre)**
2019	241.68	3.34	3.19	808.36	769.87					
2020	214.59	3.27	3.40	701.76	730.09					
2021	189.47	4.78	4.87	905.66	922.45					
2022						479.77	1.09	1.37	522.90	656.74
2023	180.67	3.96	4.05	716.34	731.68					
2024	207.10	3.82	4.63	791.36	958.29					
2025	193.26	4.27	4.23	825.38	818.03					
2026	184.57	4.14	3.56	763.48	656.99					
2027						575.68	1.05	1.34	606.34	771.47
2028	209.41	3.59	3.46	750.78	724.65					
2029	219.45	4.66	4.80	1021.77	1053.10					
2030	276.64	4.35	4.55	1202.37	1259.58					
2031	219.33	2.31	2.40	506.59	526.90					
2032						396.09	1.06	1.40	421.83	554.83
2033	236.60	3.23	4.56	763.16	1078.74					
2034	140.03	2.41	3.68	337.99	514.82					
2035	222.14	3.13	4.35	696.01	965.27					
2036	209.33	3.36	4.19	704.04	878.02					
2037						517.51	1.16	1.36	597.96	701.68
2038	190.98	3.61	4.01	689.08	765.66					

Note: Output obtained from R-Project Statistical Program.

As mentioned earlier, the operating costs of growing corn and soybean with Base Technology and BMP Technology were forecasted until 2027 using the projected Agricultural Input Price Index provided by the Medium-Term Outlook for Canadian Agriculture (AAFC, 2018c). After that year, the values were generated using the random number generator of R-Project and assuming a normal distribution until 2038. These values are shown in Table 5.22.

Harrow, Ontario

Historic corn and soybean market prices were obtained from OMAFRA (2019b; 2019c) for the period 1981-2017. Regarding crop yield data, seven and six years of historical corn and soybean yield data, respectively, were collected for both Base Technology and BMP technologies (see Table 5.9). However, since there were only a few past years with corn and soybean yield data for both technologies in Harrow, the average annual yields of the province provided by OMAFRA (2019b; 2019c) for the period 1981-2017 were used.

Table 5.22. Forecasts of Operating Costs of Corn and Soybean for Base Technology and BMP Technology (2019-2038) in St. Emmanuel

	Corn		**Soybean**	
Year	**Base Technology ($/acre)**	**BMP Technology ($/acre)**	**Base Technology ($/acre)**	**BMP Technology ($/acre)**
2019	581.94	547.90		
2020	587.05	552.71		
2021	595.22	560.41		
2022			368.97	333.77
2023	613.62	577.73		
2024	620.26	583.98		
2025	628.43	591.68		
2026	641.72	604.18		
2027			400.60	362.38
2028	643.22	575.24		
2029	573.37	599.98		
2030	630.06	582.17		
2031	632.79	546.60		
2032			383.76	362.72
2033	595.00	580.96		
2034	598.74	602.67		
2035	577.64	547.93		
2036	639.24	586.93		
2037			411.78	344.40
2038	604.92	576.15		

Note: Output obtained from R-Project Statistical Program.

In order to use the R-program for each historical data series, three parameters were estimated: mean, standard deviation and skewness coefficient. These are shown in Table 5.23. To estimate them for corn and soybean yields, the mean was calculated from the on-farm collected data for both technologies, while the standard deviation and skewness were estimated from the historical average yields performance from the province.

Table 5.23. Parameters of Skew-Normal/Normal Distribution of Crop Prices and Yields and Operating Costs (Harrow)

Crop	**Item**	**Crop Price**	**Base Technology**		**BMP Technology**	
			Yield	**Operat. Costs**	**Yield**	**Operat. Costs**
Corn	Mean	148.430	3.080	630.060	3.347	590.751
	Stand. Dev.	41.795	0.634	31.711	0.634	29.733
	Skewness	0.920	0.327		0.327	
Soybean	Mean	329.584	1.283	395.722	1.324	356.599
	Stand. Dev.	87.956	0.163	17.985	0.163	16.207
	Skewness	0.753	-0.573		-0.573	

Note: Output obtained from R-Project Statistical Program.

The random data generation tool in the R-Program was used with the specification of a skew-normal distribution for crop prices and yields. The projected values were estimated for the 20 years period (2019-2038). Since a 2-year rotation cycle was assumed, the data were arranged by crops accordingly, as shown in Table 5.24. Using these data, gross revenues for each year and crop were derived.

Table 5.24. Forecast of Corn and Soybean Prices and Yields, along with Gross Revenue, for Base Technology and BMP Technology (2019-2038) in Harrow

Year	Corn					Soybean				
	Crop Price ($/t)	Yield Base Tech. (t/acre)	Yield BMP Tech. (t/acre)	Gross Revenue		Crop Price ($/t)	Yield Base Tech. (t/acre)	Yield BMP Tech. (t/acre)	Gross Revenue	
				Base Tech. ($/acre)	BMP Tech. ($/acre)				Base Tech. ($/acre)	BMP Tech. ($/acre)
2019	223.45	4.04	4.15	902.88	926.66					
2020						498.57	1.10	1.36	550.39	678.37
2021	219.85	4.09	4.39	899.70	964.59					
2022						482.18	1.49	1.52	719.02	732.00
2023	253.34	3.57	3.75	903.79	949.49					
2024						488.49	1.55	1.15	757.80	559.60
2025	248.08	2.34	2.76	580.20	684.68					
2026						495.80	1.47	1.45	728.63	719.92
2027	198.33	3.98	4.00	788.88	793.34					
2028						483.16	1.14	1.36	548.96	657.71
2029	282.21	2.92	2.92	824.87	823.49					
2030						574.87	1.19	1.85	686.51	1065.87
2031	255.10	3.35	3.78	855.73	963.05					
2032						450.86	1.22	1.46	548.25	656.65
2033	250.42	3.33	4.42	832.83	1,107.89					
2034						418.60	1.51	1.18	631.76	492.62
2035	265.11	2.63	3.00	696.37	794.20					
2036						513.61	1.43	1.51	735.15	773.66
2037	234.21	3.20	3.67	749.21	860.32					
2038						523.81	1.10	1.24	576.64	650.60

Note: Output obtained from R-Project Statistical Program.

As mentioned previously, the operating costs of growing corn and soybean with Base Technology and BMP Technology were forecasted until 2027 using the projected Agricultural Input Price Index provided by AAFC (2018c). After that year, the values were generated using the random number generator of R-Project and assuming a normal distribution until 2038. These values are shown in Table 5.25.

Sherrington, Quebec

For this site, historic carrot and onion market prices were obtained from the Infohort system of the AAFC (AAFC, 2019b). Carrot prices were available for the period 1996-2000 and 2010-2019, while onions prices were available for the period 1994-2019. For crop yield data, seven years (2011-2017) of historical carrot and onion yield data were obtained from CRAAQ (2019b) for both Base Technology and BMP Technology (see Table 5.13). Table 5.26 shows the estimated parameters: mean, standard deviation and the skewness coefficient that were estimated with the R-Project program from each historical data vector described before.

Table 5.25. Forecast of Operating Costs of Corn and Soybean for Base Technology and BMP Technology (2019-2038) in Harrow

Year	Corn		Soybean	
	Base Technology ($/acre)	BMP Technology ($/acre)	Base Technology ($/acre)	BMP Technology ($/acre)
2019	603.65	565.99		
2020			384.28	346.29
2021	617.43	578.91		
2022			393.98	355.03
2023	636.51	596.80		
2024			406.02	365.88
2025	651.88	611.21		
2026			420.07	378.54
2027	677.85	635.56		
2028			387.46	366.98
2029	599.32	562.37		
2030			394.79	359.74
2031	635.15	567.61		
2032			379.58	352.39
2033	652.89	590.66		
2034			394.51	366.95
2035	619.37	538.33		
2036			375.60	363.07
2037	593.17	605.16		
2038			446.61	339.12

Note: Output obtained from R-Project Statistical Program.

Table 5.26. Parameters of Skew-Normal/Normal Distribution of Crop Prices and Yields and Operating Costs (Sherrington)

Crop	Item	Crop Price	Base Technology		BMP Technology	
			Yield	Operat. Costs	Yield	Operat. Costs
Carrot	Mean	0.676	7,168.884	2,383.732	8,050.656	2,406.676
	Stand. Dev.	0.207	334.555	104.412	375.706	105.417
	Skewness	1.272	0.625		0.625	
Onion	Mean	0.783	8,316.946	2,417.120	8,915.766	2,454.139
	Stand. Dev.	0.179	1,361.223	105.875	1,459.231	107.496
	Skewness	0.265	-0.655		-0.655	

Note: Output obtained from R-Project Statistical Program.

For the 15-year period (2019-2033), using the R-Program, crop prices and yields were estimated. This provided all the data needed for the designated useful life of the project. Since it was assumed that the producer would follow an intercropping system (half of the production under carrots and the other half under onions in the same growing season), yield values were arranged on a half of an acre (acre/2) basis for both crops, as shown in Table 5.27. This resulted in gross revenues for half an acre. Both crop gross revenues were added to obtain per acre value.

As mentioned previously, the operating costs of growing carrots and onions with Base Technology and BMP Technology were forecasted until 2027 using the projected Agricultural Input Price Index provided by the Medium-Term Outlook for Canadian Agriculture (AAFC, 2018c). After 2027 year, the values were generated for the 2028-2033 period using the random number generator of R-Project and assuming a normal distribution until 2033 using the mean and standard deviations shown in Table 5.26. The estimated operating costs are presented in Table 5.28.

Table 5.27. Forecast of Carrot and Onion Prices and Yields, along with Gross Revenue, for Base Technology and BMP Technology (2019-2033) in Sherrington

Year	**Carrot**					**Onion**				
	Crop Price ($/kg)	**Yield Base Tech. (kg/acre/2)**	**Yield BMP Tech. (kg/acre/2)**	**Gross Revenue**		**Crop Price ($/kg)**	**Yield Base Tech. (kg/acre/2)**	**Yield BMP Tech. (kg/acre/2)**	**Gross Revenue**	
				Base Tech. ($/acre/2	**BMP Tech. ($/acre/2)**				**Base Tech. ($/acre/2**	**BMP Tech. ($/acre/2)**
2019	0.73	7,221	7,487	5,253	5,447	0.82	7,781	8,065	6,347	6579
2020	0.83	7,673	7,955	6,363	6,596	0.59	6,799	10,939	3,990	6,420
2021	1.01	7,393	7,971	7,445	8,028	1.08	9,808	7,402	10,601	8,001
2022	0.75	7,524	8,397	5,645	6,300	1.07	9,295	7,894	9,942	8,443
2023	0.84	6,973	8,207	5,847	6,882	0.93	5,608	10,389	5,194	9,622
2024	0.77	6,920	8,546	5,319	6,569	0.78	7,401	8,395	5,767	6,541
2025	0.81	6,582	8,756	5,300	7,051	0.89	9,831	9,207	8,715	8,161
2026	0.91	7,134	7,543	6,508	6,881	0.54	7,467	7,656	4,006	4,107
2027	0.61	7,309	8,064	4,453	4,913	1.09	6,461	8,605	7,024	9,356
2028	0.77	7,110	8,273	5,500	6,399	0.92	8,498	8,743	7,837	8,063
2029	0.82	7,461	7,544	6,105	6,173	1.04	7,084	7,148	7,339	7,404
2030	0.66	7,153	8,082	4,686	5,294	1.03	9,207	8,154	9,510	8,423
2031	0.69	8,010	7,726	5,546	5,349	1.26	5,813	7,164	7,313	9,012
2032	0.85	7,489	8,706	6,337	7,367	0.88	8,511	11,462	7,461	10,049
2033	0.85	7,052	8,255	5,989	7,010	0.93	6,920	10,636	6,424	9,873

Note: Output obtained from R-Project Statistical Program.

Holland Marsh, Ontario

For the Ontario site of Holland March, historic (for the period 1979-2018) carrot and onion market prices were obtained from OMAFRA (2018a; 2018b). With respect to crop yields, unfortunately, there were only two years (2015 and 2016) of comparable carrot yield data available for both technologies at this study site. Furthermore, there was no information available on onion yields. Therefore, the average annual yields of both crops for the period 1979-2018 were obtained from OMAFRA (2018a; 2018b).

For forecasting purposes, the above data sets were used to estimate various parameters needed for generating missing data -- mean, standard deviation and the skewness coefficient. Estimates for the project's useful life were made using the R-Program. In order to estimate these parameters for carrot yields, the mean was calculated from the 2 years on-site data obtained for both technologies, while the standard deviation and skewness were estimated from the historical average yields of the province. For onion yields, all parameters were estimated from the provincial average data. Estimated parameters are shown in Table 5.29.

Table 5.28. Forecast of Operating Costs of Carrot and Onion for Base Technology and BMP Technology (2019-2033) in Sherrington

Year	Carrot		Onion	
	Base Technology ($/acre/2)	**BMP Technology ($/acre/2)**	**Base Technology ($/acre/2)**	**BMP Technology ($/acre/2)**
2019	2,275.83	2,297.74	2,307.71	2,343.05
2020	2,295.82	2,317.91	2,327.97	2,363.63
2021	2,327.79	2,350.19	2,360.39	2,396.54
2022	2,353.76	2,376.42	2,386.73	2,423.28
2023	2,399.72	2,422.81	2,433.33	2,470.60
2024	2,425.69	2,449.04	2,459.67	2,497.34
2025	2,457.66	2,481.32	2,492.09	2,530.25
2026	2,509.61	2,533.77	2,544.76	2,583.74
2027	2,555.57	2,580.17	2,591.36	2,631.05
2028	2,378.74	2,307.01	2,403.52	2,489.96
2029	2,371.69	2,335.60	2,471.17	2,279.54
2030	2,236.13	2,370.46	2,371.32	2,476.27
2031	2,511.18	2,423.70	2,395.89	2,475.83
2032	2,284.03	2,250.92	2,324.86	2,540.56
2033	2,210.62	2,468.20	2,465.90	2,195.02

Note: Output obtained from R-Project Statistical Program.

Table 5.29. Parameters of Skew-Normal/Normal Distribution of Crop Prices and Yields and Operating Costs for the Holland Marsh, Ontario Site

Crop	Item	Crop Price	Base Technology		BMP Technology	
			Yield	**Operat. Costs**	**Yield**	**Operat. Costs**
Carrot	Mean	0.152	29,210.530	1,955.656	26,720.650	1,836.283
	Stand. Dev.	0.043	4,072.434	82.921	4,194.607	82.884
	Skewness	0.189	0.245		0.245	
Onion	Mean	0.255	14,470.360	1,804.682	14,470.360	1,715.927
	Stand. Dev.	0.070	2,140.741	103.565	2,140.741	99.564
	Skewness	-0.195	-0.341		-0.341	

Note: Output obtained from R-Project Statistical Program.

The estimated parameters and using the R-Program, prices and yields of onion and carrots were estimated for the project life (2019-2038) assuming a skew-normal distribution. In addition, since 3-year cycle rotation (2 years of carrots followed by one year of onions) for the Base Technology and a 4-year cycle (3 years of carrots followed by one year of onion production) for the BMP Technology were assumed, these data were arranged accordingly. Table 5.30 shows these values as well as the calculated value of the gross revenues for each crop.

Table 5.30. Forecast of Carrot and Onion Prices and Yields, along with Gross Revenue, for Base Technology and BMP Technology (2019-2038) in Holland Marsh

	Carrot					**Onion**				
				Gross Revenue					**Gross Revenue**	
Year	**Crop Price ($/kg)**	**Yield Base Tech. (k/acre)**	**Yield BMP Tech. (kg/acre)**	**Base Tech. ($/acre)**	**BMP Tech. ($/acre)**	**Crop Price ($/kg)**	**Yield Base Tech. (k/acre)**	**Yield BMP Tech. (kg/acre)**	**Base Tech. ($/acre)**	**BMP Tech. ($/acre)**
2019	0.2119	26,815	32,547	5,683	6,898					
2020	0.1468	27,706	28,304	4,066	4,154					
2021	0.2016		29,780		6,005	0.1787	13,163		2,353	
2022	0.0875	23,508		2,057		0.1900		13,163		2,501
2023	0.1721	29,078	27,245	5,005	4,690					
2024	0.0702		25,902		1,819	0.2725	16,161		4,404	
2025	0.1336	36,132	22,484	4,826	3,003					
2026	0.1438	26,168		3,764		0.2011		16,161		3,250
2027	0.1700		27,668		4,702	0.3000	14,009		4,202	
2028	0.1956	28,446	38,183	5,564	7,469					
2029	0.1563	22,844	31,652	3,570	4,946					
2030						0.2319	14,333	14,333	3,324	3,324
2031	0.2018	30,366	22,944	6,127	4,629					
2032	0.1494	30,810	30,668	4,603	4,582					
2033	0.1295		32,431		4,201	0.0844	15,593		1,316	
2034	0.1715	33,524		5,751		0.3328		15,593		5,190
2035	0.1805	32,519	24,807	5,871	4,479					
2036	0.1718		28,558		4,907	0.1946	13,556		2,638	
2037	0.1611	23,098	28,402	3,722	4,577					
2038	0.0976	33,024		3,222		0.2461		13,556		3,336

Note: Output obtained from R-Project Statistical Program.

As mentioned previously, the operating costs of growing carrot and onion with Base Technology and BMP Technology were forecasted until 2027 using the projected Agricultural Input Price Index provided by the Medium-Term Outlook for Canadian Agriculture (AAFC, 2018c). After that year till 2038, these values were generated using the random number generator of R-Project assuming a normal distribution (Table 5.31).

5.6 Sensitivity Analysis

The financial viability of a BMP Technology could be related to changes in certain parameters due to uncertainties associated with future economic and non-economic events. To test for the robustness of results of economic desirability from the producers’ perspective, further sensitivity analysis was undertaken for key parameters. The parameters that were used for this analysis were: crop prices, change in climate patterns in future affecting crop yield, investment cost, discount rate, and project life span.

Table 5.31. Forecasting Operating Costs of Carrot and Onion for Base Technology and BMP Technology (2019-2038) in Holland Marsh

Year	Carrot		Onion	
	Base Technology ($/acre)	**BMP Technology ($/acre)**	**Base Technology ($/acre)**	**BMP Technology ($/acre)**
2019	1,884.97	1,762.03		
2020	1,901.52	1,777.50		
2021		1,802.25	1,760.48	
2022	1,949.51			1,706.75
2023	1,987.57	1,857.94		
2024		1,878.05	1,834.53	
2025	2,035.57	1,902.80		
2026	2,078.59			1,819.76
2027		1,978.61	1,932.75	
2028	1,889.73	1,866.17		
2029	2,123.76	1,897.42		
2030			1,833.99	1,771.28
2031	1,944.16	1,897.85		
2032	1,852.31	1,928.09		
2033		1,716.52	1,988.16	
2034	1,970.06			1,919.22
2035	1,883.75	1,788.39		
2036		1,712.80	2,023.74	
2037	2,048.81	1,877.97		
2038	1,953.80			1,632.58

Note: Output obtained from R-Project Statistical Program.

5.6.1 Change in Crop Prices

Variations in crop prices were created by characteristics of the markets for each commodity, as well as by the volatility and future trends. For example, in the medium term, it is foreseen an increase in the prices of grain and oilseeds due to positive macroeconomic factors, such as the increase in the demand of agricultural products by developing economies; however, since Canada is a price taker for those commodities and since world markets are overwhelmed by the growing world supply and high stocks, the forecasts for the increase in prices are conservative. Therefore, prices of corn and soybeans were projected to rise by 2.5% and 0.7%, respectively, by 2027 (AAFC, 2018c). For the grain-producing sites of this study, these values were taken into account when selecting the sensitivity analysis price increases. Additionally, reductions in the prices of both commodities were assumed in the same magnitude as noted above, in case of a pessimistic scenario. Finally, a break-even analysis was carried out in terms of the price level at which the present value of the benefits would equal the present value of the costs under both Base Technology and BMP Technology -- in other words the point at which NPV is zero.

For the vegetable prices, the medium-term outlook suggests an increase of 1.8% by 2027, which would be a slow recovery to the reduction in the fruit and vegetable market in 2017, when prices declined in 1.9% (AAFC, 2018c). However, due to the creation of new and more reliable horticultural production systems, such as tests and trials on varieties according to the characteristics of the farm (Wilton et al., 2018; Tesfaendrias et al., 2010) and pest control programs (Canadian Horticultural Council, 2019), the production of vegetables would be increasing, and the increase in supply could bring prices down. For the vegetable producing sites of this study, sensitivity analysis prices were selected for the period ending 2033 (for Sherrington) and 2038 (for Holland Marsh). First, for the optimistic scenario, a price increase of 1.8% was assumed. For the pessimistic scenario, reductions of 1.9%, 5% and an extreme value of 50% in the price of carrot and onion each were assumed.

5.6.2 Change in Crop Yields

In this study, it was assumed that variations in crop yields are mainly related to changes in climatic conditions in the growing region. In this study, interest was focused on the effects that high temperatures and different rainfall regimes in southern Quebec and Ontario on yields of various crops.

According to historical (1969 to 2003 period) data, temperatures in southern Quebec have progressively increased by 0.5°C to 1.2°C in the southwestern and southcentral regions, and by less than 0.5°C in the southeastern area (Bourque and Simonet, 2008). For these regions, the average daily temperature has been increased by 0.2°C for maximum temperatures, and by 0.4°C for minimum temperatures, per decade, resulting in shorter frost seasons and longer growing seasons (Ouranos, 2010). Additionally, the accumulation of heat during the growing season (growing degree days) has increased by 4 to 20% (Bourque and Simonet, 2008). With regard to precipitation, southern Quebec has received more frequent but low-intensity rainfall (Ouranos, 2010).

Some studies have projected the potential impact of changes in temperature and precipitation in southern Quebec on corn yields (and occasionally of soybean) in the coming decades (Qian et al., 2019; Ouranos, 2010). By 2050, a warmer climate is expected with an increase in temperature in the growing season from 1.9°C to 3.0°C (Ouranos, 2010). There is high uncertainty in precipitation projections, with scenarios of increases and decreases in rainfall, so no significant changes are expected for 2050 (Ouranos, 2010, Bourque and Simonet, 2008; Li et al., 2018). However, forecasts have varied from decreases to significant increases in corn and soybean yields (Ouranos, 2010; Warren and Lemmen, 2014).

Brassard and Singh (2007) studied the potential effects of climate change on corn and soybean yields in eight regions of Quebec for the period 2040-2069, using two experimental models (scenarios) of the Canadian Center for Climate Modeling and Analysis (CCCma) for different climatic variables -- variability in temperature and precipitation. The results showed both increases and decreases in corn yields in different scenarios and regions. For instance, in the southwest region of Quebec, a reduction of -1.7% in corn yields was predicted for the period 2040-2069 in one of the scenarios due to moisture stress. In contrast, a significant increase of 19.1% was predicted for the time period under another scenario, due to more growing degree days. With respect to soybean, in both scenarios, there were significant increases were predicted for the same period in the southwest region, ranging from 25.7 to 95.8%.

For Southern Quebéc, there have not been any predictions of significant increases in rainfall, but it is possible that some years will have floods as a result of climate change, which would create asphyxiating conditions for the roots of the crop if the excess of water is not drained (Ouranos, 2010; Warren and Lemmen, 2014). Although, the increase in rainfall may not exceed the increase in the rate of evaporation that always occurs with high temperatures, the probability of water stress in the growing season is high (Ouranos, 2010; Bourque and Simonet, 2008). This prediction of yields for future precipitation scenarios in Quebec have some degree of uncertainty; however, the BMP Technology is seen as a solution to substantially counteract the possible problems of water scarcity, with the subirrigation technique, as well as the possibility of flooding, with the drainage technique (Lepage et al., 2012).

In Ontario, the temperatures are also expected to increase. During the period between 1948 and 2016, the annual temperature has risen by 1.3°C on average. These increases were more severe during winters, when the temperature rose in some years up to 2°C, and less severe during falls, when temperatures raised up to 1°C (Cohen et al., 2019). With that variation in the climate condition, it is projected that it will lead to longer growing seasons. According to the estimates by Morand et al. (2017), the growing season will last 196 days by 2050 compared to an average of 172 days currently. While, on average, the growing season begins around May 12, by 2050, it is predicted to start around May 7; likewise, if the end of the growing season is average around October 30 now, by 2050 it will be close to November 18.

In some areas of southern Ontario, annual average precipitation has declined by about 225 mm in the last 20 years (Tan and Reynolds, 2003); furthermore, in the southwest region, since 1950s, it has become more variable and associated with intense events (Chiotti and Lavender, 2008). Thus, high temperatures in some areas will increase evaporation and evapotranspiration, resulting in water stress for crops. In other areas, the intensity of rainfall will create excess moisture, which usually occurs in poorly drained soils. Therefore, crop yields will be affected in both situations.

Morand et al. (2017) obtained the projection of climate data for the decades of 2020s, 2030s, 2040s and 2050s, based on the Canadian Gridded Temperature and Precipitation (CANGRD) model for the period 1981-2010. The average temperature in the growing season (May-October) of southwest Ontario is projected to increase to 17.8, 18.3, 18.9 and 19.6°C in each decade, respectively, compared to the historical value of 16.3°C in the base period (1981-2010). Precipitation is projected for the growing season as well, to an average of 477, 476, 480, 480 mm, respectively for the above period, as against its historical (1981-2010) value of 474 mm. As a result, annual corn yields in Southern Ontario are expected to increase by 21, 30, 39, and 50%, in the respective decades, relative to the average base yield of 5,948 kg/ha.

As reported above, rainfall for the growing season is predicted to remain stable by 2050. Additionally, greater evaporation in the following decades has also been predicted, which would result in moisture stress in the future (Qian et al., 2019). The study by Morand et al. (2017) assumed that the problem of water stress is currently being addressed with the development of new adaptation technologies, such as hybrid corn seeds or new irrigation technologies. In that sense, in order to obtain the projection of corn yields in the coming decades, Morand et al. (2017) did not take into account moisture availability but only the increase in temperature that is associated with higher crop heat units.

Bootsma et al. (2005) studied the potential impacts of climate change on corn and soybean production for the period 2040-2069, based on the output from a Canadian General Circulation Model experiment (CGCMI-A) and used agroclimatic indices (temperature and precipitation) and annual average yield from Quebec, Ontario and the Atlantic Provinces. According to the results, the increase in the estimated temperature for the region, measured through the increase in crop heat units, would result in a potential increase in corn yields of 40 to 115% and in soybean yields of 21 to 54% for the period 2040-2069. The study concluded that the effect of rainfall does not have a significant effect mainly due to the consideration that hybrid grains have already adapted to water stress. However, they did point out that excess moisture might have negative effects on the yields of both crops.

Qian et al. (2019) calculated the impact of four levels of global warming (1.5, 2.0, 2.5 and 3.0°C above the global mean temperature over the 1850-1990 period) on corn yields for the southwestern regions of Quebec and Ontario. The study used twenty simulations of the Global Climate Model to determine the effect on yields under the aforementioned warming levels that are reached in the year 2025, 2040, 2052 and 2063, respectively. As a result, with an assumption of moisture stress, the percent changes in corn yields (with respect to the yields of the period 2006-2015) were quite variable: ranging from a reduction of 0.7% to an increase of up to 5.6% with a warming level of 1.5°C. Similar projections for an increase of 2.0°C ranged from a decrease of 2.2% to an increase of up to 13.8%. Under the increase in the global mean temperature of 2.5°C, the range was from a reduction of 3.4% to an increase of up to 17.7%, if global temperature increased by 3.0°C, corn yields would change from a decrease of 5.6% to an increase of up to 19.0%. Table 5.32 shows a summary of studies reviewed so far in this section regarding the effect that the undeniable climate change will have on corn and soybean yields.

The studies report heterogeneous results depending on the scenario used in the simulations, mainly in the case of corn, which ranges from yield reductions of -5.6% to increases in 115%, for the next 4 decades. Two studies addressed the effects on soybean yields, which only showed increases of between 21 and 95.8% for simulations in the period 2040-2069.

Contrary to climate-induced changes in grain production, horticultural crops are more sensitive to periods of hot days and the number of days during the growing season with precipitation (McKeown et al., 2005). Therefore, horticultural crop production is at risk of losses due to the consequences of climate change in terms of the increase in temperature and water stress. For example, high temperatures produce sunscald and crown canker in carrots (Ouranos, 2010). Moreover, many times small variations in temperature or humidity results in poor quality production, because it is damaged and leads to a lower amount of marketable yield. McKeown et al. (2005) reported a yield loss in many vegetables when they were exposed to temperatures above 30°C coupled with fewer days with rainfall.

Several studies observed that growth, maturity and marketable yield of carrots and onions are influenced by weather conditions. Rekika et al. (2014) indicated that abundant humidity (including availability of water especially for the development of the bulb) and fertile soils are critical factors for the growth of onions. Sorensen et al. (1997) reported a reduction of up to 28% in marketable carrot yields during drought periods in experiments conducted in sandy loam soils. Hussain et al. (2008) stated that the optimum good-quality carrots grow with a temperature not greater than 21°C. In fact, for the best onions production, no higher than 26°C is ideal (De Ruiter, 1986). However, according to the climate forecasts indicating higher temperatures during the growing season, water stress and variability in rainfall patterns, the production of carrots and onions would be at risk, since soil moisture is decisive for their growth and quality. Therefore, it is expected vegetable yields would decrease in a future climate change scenario.

Table 5.32. Summary of Projected Variations in Corn and Soybean Yields Related to Climate Change

Study	**Region Studied**	**Assumed Scenario**	**Projection Year**	**Projected Change in Corn Yield**	**Projected Change in Soybean Yield**
Brassard and Singh (2007)	Quebec	Scenario 1: Moisture stress.	2040-2069	**-1.7%**	+25.7%
		Scenario 2: More growing degree days.		+19.1%	+95.8%
Morand et al. (2017)	Ontario	Higher crop heat units (1°C more per decade) and no significant changes in precipitation.	2020	**+21%**	---
			2030	+30%	---
			2040	+39%	---
			2050	+50%	---
Bootsma et al. (2005)	Quebec and Ontario	Increase in crop heat units and no significant variation in precipitation.	2040-2069	+40% to +115%	+21% to +54%
Qian et al. (2019)	Quebec and Ontario	Temperature increase in 1.5°C and moisture stress.	2025	-0.7% to **+5.6%**	---
		Temperature increase in 2°C and moisture stress.	2040	-2.2% to +13.8%	---
		Temperature increase in 2.5°C and moisture stress.	2052	-3.4% to +17.7%	---
		Temperature increase in 3°C and moisture stress.	2063	**-5.6%** to +19%	---

Although the change in climatic conditions may be favourable for the corn and soybean production, those conditions could also aggravate collateral agricultural risks, such as crop pests and erosion of soils (Vincent et al., 2018). Likewise, the increase in the atmospheric CO_2 concentration would increase the growth of the crop by increasing photosynthesis (Ouranos, 2010). In this analysis, none of these aspects were taken into account because the interaction of all or some of these factors is unpredictable and the results in terms of their implication in the increase or decrease of crop yields depend on several aspects.

In summary, the assumptions and results of various reviewed studies were considered for selecting the yield sensitivity analysis for this study. For the grain-producing sites, corn yield variability was simulated at -5.6% (Qian et al., 2019), -1.7% (Brassard and Singh, 2007), 5.6% (Qian et al., 2019) and 21% (Morand et al., 2017). Although these results of increase in corn yields are much higher than those reported by the reviewed studies, it was assumed that the robustness of the financial indicators will be fairly well represented with a moderate increase of up to 21%, since the conclusions will have the same tendency to a higher percentage of yield increase (see Table 5.32). With respect to variations in soybean yields, studies indicated significant increases, but only a few studies supported it (Brassard and Singh, 2007; Bootsma et al., 2005). For this reason and for convenience in the analysis, the same percent variation in soybean yields (as assumed for corn yields) was assumed for sensitivity analysis.

In contrast to grains, for vegetable-producing sites, carrot and onion yields were considered to have decreased by a maximum of 28%, according to the study by Sorensen et al. (1997). Although there is very little existing literature in relation to the impacts of variation of the climatic conditions on vegetable crops, all of them conclude negative effects on their yields. Therefore, in addition to the -28% mentioned above, this study also simulated reductions of 7 and 14% in the carrot and onion yields for the sensitivity analysis. Moreover, for the optimistic scenario, a 7% increase in the yields of both crops was considered.

5.6.3 Change in Investment Costs

Another parameter of interest for the sensitivity analysis was a change in the investment cost of the new technology, and how that affects the result of the financial analysis. Changes in investment costs were estimated through the use of cost-share programs, loans and incentives granted by provincial governments.

The provincial government of Québec, through the Farm Business Development program of La Financière Agricole du Quebec, provides financial support to farms to encourage investments related to increased production, yield or profitability. However, the project must include the construction, renovation or improvement of a building or cropland including improvement equipment, such as drainage, new crop production in fallow land, etc. Projects are eligible for a $13.33 grant for every $100 of eligible funding from a loan of at least $150,000. This subsidy is equivalent to a repayment of interest at a rate of 3% for five years. The maximum financial assistance per farm is $20,000 and is paid in two installments per year for a five year period (FADQ, 2019a).

A program that is attractive to younger producers in Quebec is the Financial Support Program for Aspiring Farmers, also given by La Financière Agricole du Québec, whose objective is to help producers that count at least one year's relevant experience in agriculture to establish themselves in an existing farm or start a new business through training, improvement projects for the land, equipment installation, among others. The requirement for having the financial support to carry out a project that has a business plan which indicates that it is a potentially profitable project. The grant is financially supported by up to $50,000 (FADQ, 2019b).

In Ontario, producers, who have plans to install a subsurface drainage system, are eligible for the Tile Loan Program offered by OMAFRA. The program finances up to 75% of the value of the investment in the installation of the system performed by a licensed contractor. The loan is repaid in 10 years with annual repayments and can be fully paid at any time without penalty. Interest rates are fixed over the entire term of the loan regardless of fluctuations in market interest rates (OMAFRA, 2007). The provincial government set this rate at 6% for a ten-year term for the 2018/2019 fiscal year (OMAFRA, 2018d).

Since 2003, five year federal-provincial/territorial agriculture policy framework agreements have provided the primary mechanism for programs designed to support the sustainable growth of the sector. The Canadian Agricultural Partnership (Partnership), launched on April 1, 2018, is the latest five-year policy framework (2018-2023). Under the Partnership, an estimated allocation of up to $3 billion is available to support federal/ provincial/territorial cost-shared environmental stewardship programs (AAFC, 2019c). The cost-shared programs are delivered by provinces, including identifying BMPs eligible for incentives to support on-farm adoption (Shakeri, 2019).

In Ontario, the Ontario Soil and Crop Improvement Association (OSCIA) administers cost-share funding programs to producers. The programs support projects in three areas: i) economic development, ii) environmental stewardship, and iii) protection and assurance (OMAFRA, 2019g). The first two are of interest to this study. The first program -- economic development program, encourages productivity improvement by funding the adoption of best practices and technological innovation (AAC, 2019). Table 5.33 details this project category.

Table 5.33. Cost-share Funding Program in Economic Development Area in Ontario

Project Category	Cost-share Percentage	Project Cap	Description
Technology and Equipment to Improve Labor Productivity	25%	$100,000	“Projects focused on the execution of a comprehensive plan to implement new and novel technologies and equipment to enhance labor productivity”.

Source: OSCIA (2019).

The second program -- the environmental stewardship program, funds the adoption of on-farm management practices and technologies that improve water quality, especially the reduction of nutrients loss, such as phosphorous from agricultural production into Ontario Great Lakes. Table 5.34 details this programme category.

Table 5.34. Cost-share Funding Program in Environmental Stewardship Area in Ontario

Project Category	Cost-share Percentage	Project Cap	Description
Tillage and Nutrient Application Equipment Modifications	45%, 55%	$20,000	“Projects focussing on supporting equipment modification for no-till, fertilizer and residue management, adjustment of new or existing equipment to reduce soil erosion and nutrient loss, […].

Source: (OSCIA, 2019).

In the sensitivity analysis, access to loans and subsidies for the installation of technologies and beneficial management practices were taken into account for estimating the investment of the technologies. For study sites in Quebec, a subsidy of $13.33 was assumed for every $100 loan of the total investment cost in each technology analyzed. The interest rate considered was the one for a long-term debt at 4.92% in 2018 (Zhang, 2019). Moreover, it was assumed that the producer was listed as an "aspiring farmer" and was granted a subsidy of up to $50,000 of the total cost of investment in the technology.

For study sites in Ontario, a loan for 75% of the initial cost in the installation work was assumed, at 6% interest rate for 10 years for both sites using subsurface drainage systems. Additionally, grants from the cost-share program of 25% and 50% of the total investment cost for both technologies were assumed. In all the case studies, a pessimistic scenario of a 5% increase in the cost of investment for some reason, such as an increase in transport costs, was also taken into account in this sensitivity analysis.

5.6.4 Change in Discount Rates

The literature shows that there is a high variation in discount rates used by different studies in agricultural projects (Trautman et al., 2012; Tyndall and Roesch-McNally, 2014; Essien, 2016; Kitchen and Kitchen, 2017; Bogdan, 2019). This is because the discount rate is a way of taking into account the relative risk that may affect the investment analysis (Selvavinayagam, 1991). In this study, a conservative discount rate of 8.78% was used for the main analysis. Trautman et al. (2012) involved a less risky investment with a 10% discount rate. Essien (2016) linked risk levels with the experience of producers and used a discount rate as low as 3.75% for young farm operators, same as Tyndall and Roesch-McNally (2014). Bogdan (2019) reported a 5% discount rate according to estimates with the weighted average cost of capital. Therefore, these values were used in the sensitivity analysis with respect to discount rates.

5.6.5 Change in the Project Life Span

Another parameter of interest that affects the value of financial indicators is the useful life of the technology. The estimated amount of years establishes the timeframe to calculate annualized costs and benefits and may affect the financial viability of both Base Technology and BMP Technology. Although several studies report the life span of a controlled drainage system at 20 years (Crabbé, 2012; Essien, 2016; Kitchen and Kitchen, 2017), based on the useful life of the water control structure (AgriDrain Corporation, 2019). At the same time, there are other studies that perform the evaluation assuming 40 years of useful life (Tyndall and Bowman, 2016). In this study, the impact of a longer useful life assumption of 30 and 40 years, was considered for each drainage technology (subsurface drainage, controlled drainage with/without subirrigation) as well as a hypothetical life span of 10 and 15 years in the research sites of St. Emmanuel, Harrow and Holland Marsh.

Similarly, studies usually report the lifespan of 10 to 15 years for the sprinkler irrigation system (Buchanan and Cross, 2002; De Oliveira et al., 2016; Bogdan, 2019). Other studies agree that with good care and in the case of aluminum pipe, the system could have a useful life of 20 years (Ortiz et al., 2006; Phocaides, 2007) and even up to 25 years (OMAFRA, 2002). Therefore, in this study 10, 20 and 25 years were used as sensitivity analysis parameters for the life span of irrigation investment at the Sherrington site. This resulted in the recalculation of salvage values for each of the four study sites.

Chapter 6

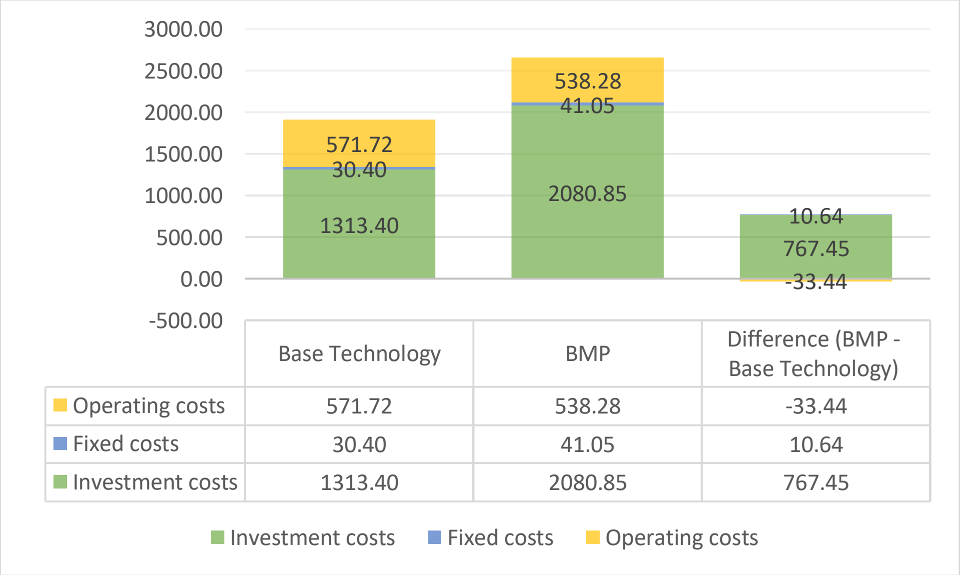
RESULTS AND DISCUSSION

This chapter shows the results of the economic desirability of selected BMPs for the four study sites. As noted in the analytical framework, these results are based on the economic indicators, namely NPV, BCR and pay-back period. Comparison of the BMP Technology with the base technology using a ‘with and without’ framework provides the marginal contribution of the BMP Technology (positive or negative). This chapter also presents the results of the sensitivity analysis undertaken for these sites. The parameters used for these simulations included: crop price, crop yield, investment cost, discount rate and project life span. These results are arranged by each research site.

6.1 St. Emmanuel, Quebec

6.1.1 Financial Evaluation

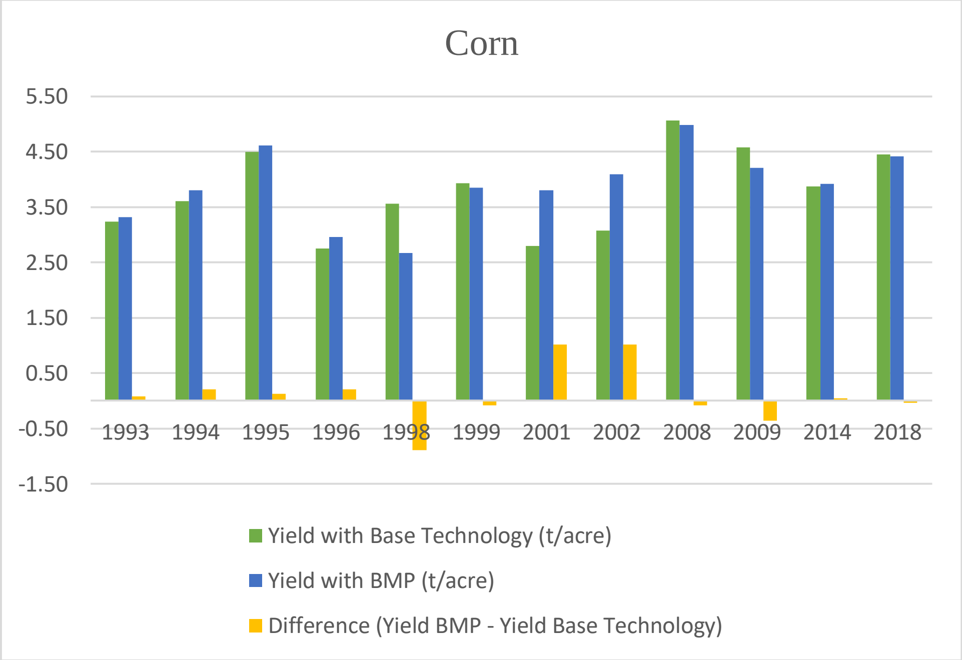
At the St. Emmanuel site, the base technology was subsurface drainage, and the BMP Technology was controlled drainage with subirrigation. Total investment cost to implement Base and the BMP Technology along with fixed and operating costs of producing corn under both systems in 2018 are shown in Figure 6.1. The BMP Technology is slightly more expensive to install but results in lower operating costs. The difference in the investment cost for the two technologies is $767.45 per acre, resulting from additional components needed for the controlled drainage with subirrigation, such as deep well, pump and control structure. During the operations period, fixed costs for the BMP Technology were also higher by about $11 per acre, due in part to maintenance and repair costs. The operating costs, on the other hand, were lower with the BMP Technology by $33.44 (assuming that corn was grown in 2018), since there were no extra irrigation costs that were required when using the Base Technology. This was based on two hours of labor cost for the sprinkler irrigation for the entire growing season.



	Base Technology	BMP	Difference (BMP - Base Technology)
🟨 Operating costs	571.72	538.28	-33.44
🟦 Fixed costs	30.40	41.05	10.64
🟩 Investment costs	1313.40	2080.85	767.45

Figure 6.1. Difference in Investment, Fixed and Operating Costs of corn production under Base Technology and BMP Technology in St. Emmanuel 2018 ($/acre)

Gross revenues for the two technologies in 2018 were $957.82 and $949.11 per acre, respectively with the Base Technology and BMP Technology, which resulted in farm net returns of $355.70 and $369.78, respectively. Thus, growing corn using the BMP Technology in that year had a 3.96% advantage over the situation using the Base Technology. However, this is not a situation that is repeated every year. Figure 6.2 shows that historical corn yields under the BMP Technology exceed the yields under the Base Technology in more than half of the years in which the data were collected. This variability was also reflected in the stochastic projection, as shown in Table 5.21.



Source: Corn yield data from Ekwunife (2019).

Figure 6.2. Comparison of Base Technology and BMP Technology on Corn Yields in St. Emmanuel

As noted in Chapter 5, the financial viability of both technologies (subsurface drainage as the Base Technology and controlled drainage with subirrigation as he BMP Technology) was carried out using an estimated useful life 20 years and a discount rate of 8.78%. Table 6.1 presents the results of the financial indicators for the two technologies.

Table 6.1. Financial Indicators of the Desirability of Base Technology and BMP Technology in St. Emmanuel

Indicator	**Base Technology (Subsurface Drainage)**	**BMP Technology (Controlled Drainage with Subirrigation)**
Net Present Value at r=8.78% ($/acre)	64	104
Benefit-Cost Ratio (gain for every $1 spent/acre)	1.009	1.014
Pay-back Period (years)	19.3	19.2

The results show that both technologies are financially desirable at the 8.78% discount rate and lasting over a 20 year period (2019-2038). The positive value of their NPVs, and a BCR greater than 1. The pay-back period for them, is very similar, between 19 and 20 years. However, the BMP Technology was found to be slightly more attractive on financial grounds than the Base Technology. In fact, over the life of the project, the BMP Technology generated $40 per acre higher profits relative to the Base Technology. This means that for the entire study field, that spans 4.2 ha (~10 acres), the difference in profitability is approximately $400 in favour of the controlled drainage with subirrigation system. The results are not significantly different between the two technologies as a producer would only gain approximately 1 cent for every $1 per acre spent, as illustrated by the BCR results.

The results of this analysis suggest that the production of corn-soybean rotation using the BMP Technology is economically attractive. These results can be compared with those of Essien (2016), which had undertaken the economic analysis of both technologies analyzed in this study, in the same research field at St. Emmanuel, Quebec. As in this study, the project´s life span considered by Essien (2016) was 20 years (2015-2034), the forecasted values were assumed to be normally distributed, and a similar discount rate at 8.47% was selected. However, the Essien (2016) study differs from this study in that only continuous corn production was considered (no rotation with soybean). The results reported net present values of $545 and -$3003 per acre for the Base Technology and BMP Technology, respectively. Thus, Essien´s (2016) conclusion about the BMP Technology´s performance is opposite of that obtained in this study.

Kitchen and Kitchen (2017) had similar results to those found in this study, although it was carried out in another location and using the controlled drainage technique as BMP Technology instead of the controlled drainage with subirrigation. The economic analysis of the controlled drainage system was carried out on a farm in Ontario that produced corn and soybean in a rotation. The reported NPV was $36.56 per acre using a discount rate of 8% over a project life of 20 years.

6.1.2 Sensitivity Analysis

A sensitivity analysis of the financial indicators was undertaken with the objective of checking the robustness of the results obtained. As noted above, the parameters involved were: crop price, crop yield, investment cost, discount rate and project lifespan.

Change in Crop Prices

The impact of price increases of 2.5% for corn and 0.7% for soybean had a considerable impact on the financial attractiveness of the controlled drainage with subirrigation (BMP Technology), especially in terms of the pay-back period. This period was reduced by almost 8 years for the Base Technology and by 2-3 years for the BMP Technology. The values of the NPV and BCR improved marginally for the BMP Technology relative to the Base Technology. Thus, the increased prices of these two crops improved the financial desirability for the BMP Technology slightly over the Base Technology. On the other hand, if a decrease of similar magnitude occurs in crop prices (2.5% lower for corn and 0.7% lower for soybean), both technologies would become financially unattractive (Table 6.2). Table 6.2 also shows the break-even point in the prices level at which the present value of benefits and costs are equal, that is, systems´ NPV zero. The price of corn would have to decrease by 0.54% and that of soybean by 3.5%, so that the Base Technology ceases to be financially viable; however, the BMP Technology remains profitable with a positive NPV. Similarly, if the price of corn falls a little more at 0.83% and that of soybean by 4.56%, the BMP Technology would no longer be a viable option (as its NPV approaches a value of zero), and the Base Technology would exhibit losses.

Table 6.2. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Corn and Soybean Prices Variation for the Study Site St. Emmanuel

Financial Indicator	**System**	**% Change in Crop Prices***				
		C: +2.5% & S: +0.7%	**0%**	**C: -2.5% & S: -0.7%**	**Break-Even Prices**	
					C: -0.54% & S: -3.5%	**C: -0.83% & S: -4.555%**
NPV[1]	Base Tech.	218	64	-90	**0**	-27
	BMP Tech.	268	104	-61	30	**0**
BCR[2]	Base Tech.	1.032	1.009	0.987	1.000	0.996
	BMP Tech.	1.037	1.014	0.992	1.004	1.000
Pay-back Period[3]	Base Tech.	11.4	19.3	26.5	20.0	25.8
	BMP Tech.	16.8	19.2	42.0	19.8	20.0

* C refers to corn price and S to soybean price.

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Yield Changes under Climate Change

An increase of 5.6% and 21% in corn and soybean yields, would result in the BMP Technology being a more attractive option financially. The NPV of the BMP Technology over the Base Technology increases by $110 per acre. However, this a somewhat marginal increase as demonstrated by a very close BCR for the two technologies (Table 6.3). Under this scenario, the major improvement is in the pay-back period which is reduced from 19.3 years in the base simulation to 8.9 years. This is a significant change in the financial attractiveness of the BMP Technology. For example, with the 5.6% increase in yields, the pay-back period for the Base Technology investment is reduced by approximately half (10 years) compared to the initial scenario in which the pay-back period of 19.3 years. However, with the same percentage of variation in yields, the pay-back period for the BMP Technology is reduced only by 5 years -- from 19.2 to 14.2 years. Therefore, under the assumption of yields increases, the controlled drainage with subirrigation technology (BMP Technology) is superior to the Base Technology.

Table 6.3 also shows the changes in financial indicators as a result of assuming yield reductions (1.7 and 5.6% reductions in corn and soybean yields). Under this situation, NPV for both the technologies becomes negative and the BCR is less than one. This implies that neither of these technologies would be economically viable for the producer. The break-even yield simulation indicates that the investment in the BMP Technology would continue to be worthwhile even if there is a reduction in the yields of both corn and soybean crops by 1.075%, but the Base Technology would no longer be a viable alternative. On the other hand, when the percent decrease in crop yields is as low as 1.65%, the BMP Technology starts showing losses.

Table 6.3. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Corn and Soybean Yields Variation in St. Emmanuel

Financial Indicator	**System**	**% Change in Crop Yield**						
		+21%	**+5.6%**	**0%**	**-1.7%**	**-5.6%**	**Break-Even Yield**	
							-1.075%	**-1.65%**
NPV[1]	Base Tech.	1,308	396	64	-37	-268	**0**	-34
	BMP Tech.	1,418	454	104	-3	-247	36	**0**
BCR[2]	Base Tech.	1.193	1.058	1.009	0.095	0.960	1.000	0.995
	BMP Tech.	1.194	1.062	1.014	1.000	0.966	1.005	1.000
Pay-back Period[3]	Base Tech.	6.0	10.7	19.3	26.2	38.5	20.0	25.9
	BMP Tech.	8.9	14.2	19.2	20.1	31.3	19.7	20.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Change in Investment Cost

A reduction in investment costs would invariably make the NPVs higher than base simulation. Two separate scenarios were investigated. Scenario one included a decrease in investment cost by 20.27% (as shown in Table 6.4) corresponds to a situation where a producer receives the Farm Business Development program subsidy consisting of the payment of $13.33 for every $100 dollars of loan requested, payable in 5 years. The interest rate assumed was the 5-year long-term debt at 4.92%, as reported by AAFC for 2018 (Zhang, 2019)[12]. The second scenario was based on a total elimination of the investment cost (100%) under the assumption that the producer was eligible for the Financial Support Program for Aspiring Farmers and that the investments were less than $50,000. This made the producer eligible for the elimination of the total investment cost of both technologies. In both scenarios, the sensitivity analysis of the investment cost resulted in the BMP Technology continuing to be the most financially viable option.

The break-even investment cost analysis at which the present value of benefits and costs are equal, that is, technologies' NPV zero, shows that if the investment costs would increase by 4.9%, the Base Technology ceases to be financially viable; however, the BMP Technology remains profitable with a slightly positive NPV. Such increase may be from higher installation cost, freight costs, or by other reasons, Likewise, if the investment cost increases by 5%, the BMP Technology would no longer be the most viable option with an NPV equal to zero, and Base Technology would exhibit losses (Table 6.4).

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[12] The interest rate reported by AAFC was used in this study site since the La Financière Agricole du Quebec (FADQ) does not have a fixed rate, but rather the interest rates are customized to each customer based on their financial position (Stangier, 2019).

Table 6.4. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Investment Cost Variation in St. Emmanuel

Financial Indicator	**System**	**Change in Investment Cost**					
		+5%	**0%**	**-20.27%**	**-100%**	**Break-Even Inv. Cost**	
						+4.9%	**+5.0%**
NPV[1]	Base Tech.	-2	64	330	1,377	**0**	-2
	BMP Tech.	0	104	526	2,185	2	**0**
BCR[2]	Base Tech.	1.0	1.0	1.1	1.3	1.0	1.0
	BMP Tech.	1.0	1.0	1.1	1.4	1.0	1.0
Pay-back Period[3]	Base Tech.	20.5	19.3	10.6	0.0	20.0	20.5
	BMP Tech.	20.0	19.2	11.7	0.0	20.0	20.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Change in Discount Rate

As noted previously, other studies have used discount rates different than the study rate of 8.78%. In fact, a discount rate of 3.75% (Essien, 2016) and 5% (Bogdan, 2019) have been suggested. The federal government has recommended projects to be calculated using a discount rate of 10%. Both increase and decrease in discount rates were used for undertaking the sensitivity analysis for the two technologies. Table 6.5 shows that the NPV indicators of both technologies increase as the discount rate decreases. Likewise, the BCR showed slight increases in these scenarios as well. However, the most sensitive indicator resulting from a decrease in the discount rate was the pay-back period. It was estimated that the technologies will payback investment cost in around 19 years with a discount rate of 8.78% was reduced 10 or 11 years with a lower discount rate. Nonetheless, with lower discount rates both the technologies remain attractive, but the controlled drainage with subirrigation (BMP Technology) had a better financial performance than the Base Technology. These results differ from those obtained by Essien (2016)[13] who obtained a better NPV for the subsurface drainage system (Base Technology) than for the controlled drainage with subirrigation system.

Table 6.5. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Discount Rate Variation in St. Emmanuel

Financial Indicator	**System**	**Change in Discount Rate**					
		10%	**8.78%**	**5%**	**3.75%**	**Break-Even (IRR)**	
						9.5%	**9.4%**
NPV[1]	Base Tech.	-42	64	507	705	**0**	8
	BMP Tech.	-93	104	948	1,336	-16	**0**
BCR[2]	Base Tech.	0.993	1.009	1.059	1.075	1.000	1.001
	BMP Tech.	0.986	1.014	1.105	1.136	0.998	1.000
Pay-back Period[3]	Base Tech.	33.2	19.3	10.8	10.5	20.0	19.9
	BMP Tech.	29.0	19.2	11.7	11.3	23.5	20.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

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[13] As mentioned in section 6.1.1, Essien (2016) performed the economic analysis of the same technologies and in the same field of research as this study, during the 2015-2034 lifespan with a discount rate of 8.47%.

On the other hand, when the discount rate is increased from 8.78% to 10%, it resulted in negative NPV for both technologies. The break-even discount rates (Table 6.5), referring to the internal rate of return (IRR), was estimated to be 9.5 and 9.4% for the base and BMP technologies, respectively. This indicates that at a discount rate greater these values the investment would not yield any profitability, and would become financially non-viable.

Change in Project Lifespan

Table 6.6 shows the sensitivity analysis with respect to variations in the length of life span of the technologies. When evaluating financial indicators with a 10-year life span of the technologies (half the time of the initial scenario), neither of the two technologies were found to be a viable option, since their respective NPVs were negative (Table 6.6). This is attributed to the fact that the period of time is short enough for the accumulated net benefits to pay the entire investment cost. The following simulation of a life expectancy of 15 years shows positive indicators in both technologies, but with the Base Technology as the most financially attractive option.

Table 6.6. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Project Life Span Variation in St. Emmanuel

Financial Indicator	**System**	**Change in Project Life Span (years)**				
		10	**15**	**20**	**30**	**40**
NPV[1]	Base Tech.	-100	137	64	45	76
	BMP Tech.	-313	20	104	145	163
BCR[2]	Base Tech.	0.980	1.023	1.009	1.006	1.010
	BMP Tech.	0.941	1.003	1.014	1.018	1.019
Pay-back Period[3]	Base Tech.	10.6	14.3	19.3	24.2	24.2
	BMP Tech.	11.6	16.2	19.2	19.7	19.7

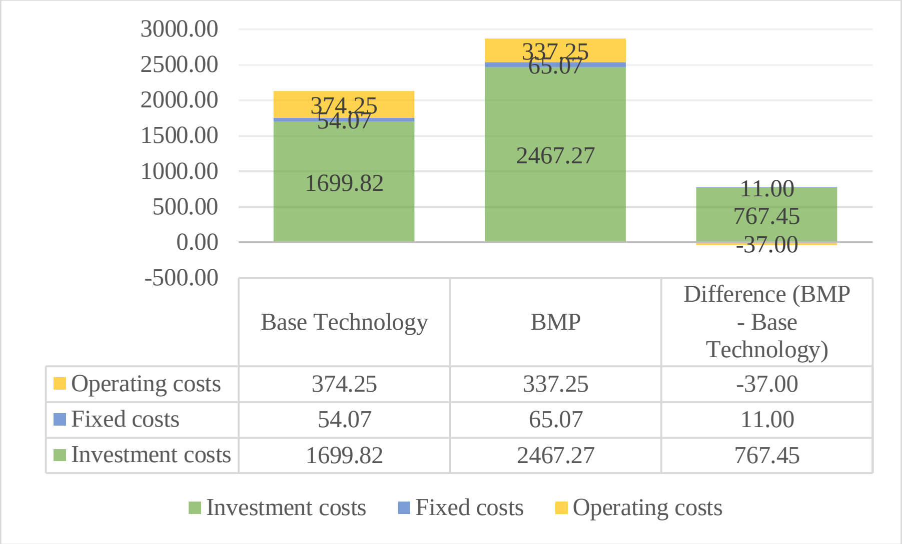
[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Both technologies would continue to show financial attractiveness if their useful life would increase by 50 and 100% of the time (30 and 40 years respectively). However, the controlled drainage with subirrigation system (BMP Technology) was still the most financially desirable option but only marginally. The BCR for the two technologies improves but changes are rather small. With respect to the pay-back period, as project life increases, so does the pay-back period.

6.2 Harrow, Ontario

6.2.1 Financial Evaluation

The technologies investigated for the Harrow site were exactly the same as those at the St. Emmanuel site. Figure 6.3 shows the total investment cost of installing the Base Technology and the BMP Technology, fixed costs and the operating costs of growing soybeans under both systems on a per acre basis in 2018. The difference in the investment costs indicated that installing a controlled structure with subirrigation system in an existing conventional subsurface drainage system would cost an additional $767.45 per acre, due to additional components, such as deep well, pump and control structure needed. Fixed costs for the BMP Technology were also higher by $11 per acre, caused by higher maintenance and repair costs. However, the operating costs of the BMP Technology (assuming that soybean was grown in 2018) were lower by $37 per acre, resulting from no extra irrigation required as compared to the Base Technology.



	Base Technology	BMP	Difference (BMP - Base Technology)
🟨 Operating costs	374.25	337.25	-37.00
🟦 Fixed costs	54.07	65.07	11.00
🟩 Investment costs	1699.82	2467.27	767.45

Figure 6.3. Difference in Investment, Fixed and Operating Costs of soybean production under Base Technology and BMP Technology in Harrow 2018 ($/acre)

Gross revenues for 2018 were estimated at $717.56 per acre under both technologies because soybean yields were the same under the Base Technology and the BMP Technology[14]. Therefore, the farm net returns were $289.24 and 315.24 per acre these technologies, respectively. Thus, in 2018, growing soybeans had an 8.99% advantage if BMP Technology was used. However, historically there is a large variability over time in both corn and soybean yields. Both the yields were in several years greater using the BMP Technology than using the Base Technology, but also lower in other years, as shown in Figure 6.4. This variability was also reflected in the stochastic projection, as shown in Table 5.24.

As noted above, the financial analysis of both technologies was carried out assuming a useful life of 20 years and a discount rate of 8.78%. Table 6.7 presents the estimated financial indicators based on a per acre basis.

Both technologies were financially desirable at the 8.78% discount rate and the project life of 20 years (2019-2038). In both cases, the NPV was positive, and the BCR was greater than one. In addition, the pay-back period was less than 20 years. Between the two technologies, the BMP Technology was more financially attractive than the Base Technology, with additional profits of $28 per acre. This means that at the entire study field level that spans 1.6 ha (~4 acres), the difference in profitability would amount to approximately $112 in favour of the controlled drainage with subirrigation system. In terms of how much the producer will earn for his investment, the results are not significant, as approximately 1 cent is returned for

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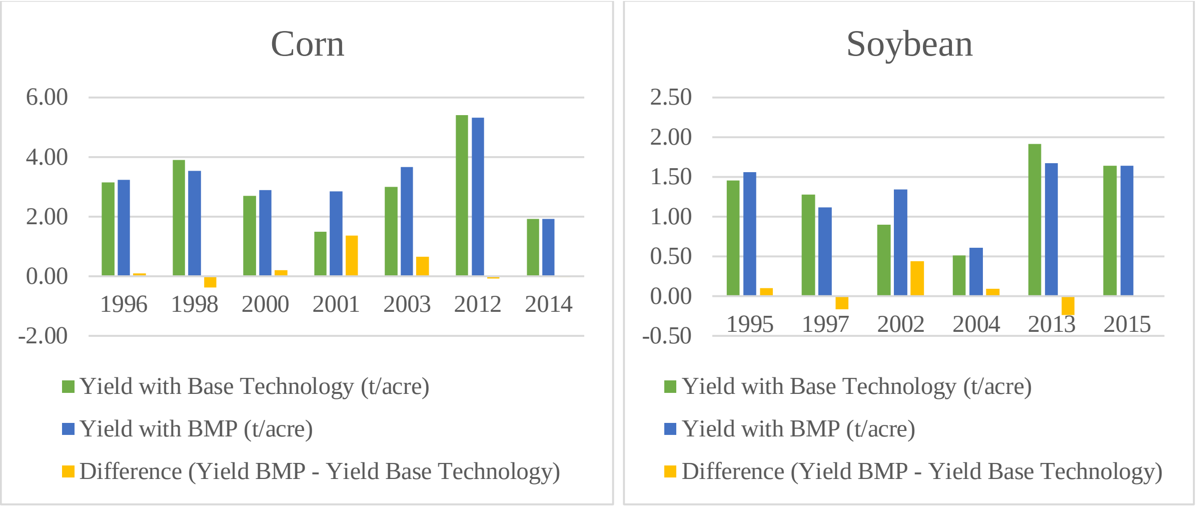
[14] The soybean yields considered for 2018 were actually from 2015, since this was the last year from which performance data were available in the literature (Abbasi et al., 2018).

every $1 spent per acre (as shown by the BCR results). In both cases, the time required to earn back the investment is almost entirely the life of the project.



Source: Corn and soybean yield data from Tan et al. (2007), Drury et al. (2009) and Abbasi et al. (2018).

Figure 6.4. Comparison of Base Technology and BMP Technology on Corn (left) and Soybean (right) Yields in Harrow

Table 6.7. Financial Indicators of the Desirability of Base Technology and BMP Technology in Harrow

Indicator	**Base Technology (Subsurface Drainage)**	**BMP Technology (Controlled Drainage with Subirrigation)**
Net Present Value at r=8.78% ($/acre)	10	38
Benefit-Cost Ratio (gain for every $1 spent/acre)	1.00	1.01
Pay-back Period (years)	19.9	19.8

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

The results of this analysis suggest that the production of corn-soybean rotation using the BMP Technology is the most economically attractive option. This result is consistent with that reported by Kitchen and Kitchen (2017), as noted above in the context of St. Emmanuel's results. However, these results are different than those reported by Essien (2016) as that study indicated the Base Technology to be more attractive on financial grounds.

6.2.2 Sensitivity Analysis

A sensitivity analysis of the results on financial indicators was carried out on the basis that some factors could affect the economics of the water management systems differently. The factors selected in this analysis were: crop prices, crop yield, investment cost, discount rate and project lifespan.

Change in crop market prices

Table 6.8 shows that when corn and soybean prices increase by 2.5% and 0.7%, respectively, over the level assumed in the base simulation, the BMP Technology remains the most financially attractive option. Conversely, when prices fall hypothetically by the same amounts (2.5% for corn and 0.7% for soybean), both technologies became economically unattractive. With respect to the break-even price, the results indicate that a reduction in corn prices by 0.13% and soybean prices by 0.17%, would make the Base Technology a not viable option, but the BMP Technology would continue to be financially attractive. But if prices fall more than 0.45% in corn and by 0.62% in soybean, then the BMP Technology would also no longer be the most financially attractive option.

Table 6.8. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Corn and Soybean Prices Variation for the Study Site Harrow

Financial Indicator	**System**	**% Change in Crop Prices***				
		C: +2.5% & S: +0.7%	**0%**	**C: -2.5% & S: -0.7%**	**Break-Even Prices**	
					C: -0.13% & S: -0.17%	**C: -0.45% & S: -0.615%**
NPV[1]	Base Tech.	130	10	-110	**0**	-26
	BMP Tech.	168	38	-91	28	**0**
BCR[2]	Base Tech.	1.019	1.001	0.984	1.000	0.996
	BMP Tech.	1.023	1.005	0.988	1.004	1.000
Pay-back Period[3]	Base Tech.	19.1	19.9	24.9	20.0	21.3
	BMP Tech.	19.1	19.8	21.7	19.9	20.0

* C refers to corn price and S to soybean price.

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Yield Changes under Climate Change

As in the previous case study, financial indicators are sensitive to the effects that climate change could have on corn and soybean yields. Table 6.9 shows that given the simulated increases in crop yields of 5.6 and 21%, the NPVs of both technologies increase in the same direction and the BCRs also increase, although slightly. Thus the previous conclusion remains unchanged. The results of the pay-back period indicator show that the higher the yield increase, the period of recovery of the initial capital becomes somewhat lower with the subsurface drainage system (Base Technology). For example, if there would be an increase in yields of 21%, the returns of the Base Technology would be able to recover the investment in a little more than 9 years, while those of the BMP Technology in almost 12 years. However, as suggested by the NPV indicators, it can be concluded that in an increased crop yield scenario, the controlled drainage with subirrigation system (BMP Technology) is still the best option financially.

Table 6.9 also shows the change in financial indicators resulting from a reduction in corn and soybean yields by 1.7 and 5.6%. These reductions led to negative NPVs for both technologies, and consequently undesirable BCR and pay-back period indicators. This indicates that neither of the two alternatives is financially viable under these conditions. The break-even results of this yield sensitivity analysis show that the investment in the BMP Technology would continue to be worthwhile even if there is a reduction in the yields of both corn and soybean crops by 0.25%, but the Base Technology would no longer be a viable alternative. On the other hand, when the percentage of decrease in crop yields is as low as 0.9%, then at this point even the BMP Technology would be starting to show losses.

Table 6.9. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Corn and Soybean Yields Variation in Harrow

Financial Indicator	**System**	**% Change in Crop Yield**						
		+21%	**+5.6%**	**0%**	**-1.7%**	**-5.6%**	**Break-Even Yield**	
							-0.25%	**-0.9%**
NPV[1]	Base Tech.	846	233	10	-58	-213	**0**	-26
	BMP Tech.	942	279	38	-35	-203	28	**0**
BCR[2]	Base Tech.	1.123	1.034	1.001	0.992	0.969	1.000	0.996
	BMP Tech.	1.128	1.038	1.005	0.995	0.972	1.004	1.000
Pay-back Period[3]	Base Tech.	9.3	17.1	19.9	23.2	31.0	20.0	21.3
	BMP Tech.	11.7	17.4	19.8	20.6	26.5	19.9	20.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Change in Investment Cost

Assuming a scenario in which the producer is eligible for the Tile Loan Program offered by OMAFRA, there is a significant increase in the NPVs of both technologies, but the BMP Technology remains to be the most financially attractive. Table 6.10 shows that under this scenario there is a reduction in the investment costs of the Base Technology and BMP Technology of 7.35 and 5.6%, respectively, which are derived from the 75% financing of the installation cost (including land preparation) payable for 10 years at an interest rate of 6% for a ten-year term. When the cost-share program scenarios are assumed, subsidies of 25 and 50% of the total cost of investment in each technology are available. On the other hand, an increase in the investment cost by 5% results in both technologies no longer viable financially. As Table 6.10 shows, NPVs are quite sensitive to these changes, increasing in large amounts. It is also shown that the BMP Technology would continue to be the most economically viable under the scenario that the producer be granted the subsidy.

The break-even investment cost analysis, at which the present value of benefits and costs are equal, shows that if the investment costs would slightly increase for some reason by 0.6%, then Base Technology ceases to be financially viable; however, the BMP Technology remains profitable with a positive NPV. Likewise, if the investment cost increases 1.55%, the BMP Technology would be no longer the most viable option with an NPV equal to zero, and Base Technology would exhibit losses.

Table 6.10. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Investment Cost Variation in Harrow

Financial Indicator	**System**	**Change in Investment Cost**						
		+5%	**0%**	**BT: -7.35% BMP: -5.6%**	**- 25%**	**-50%**	**Break-Even Inv. Cost**	
							+0.6%	**+1.55%**
NPV[1]	Base Tech.	-75	10	135	435	860	**0**	-16
	BMP Tech.	-85	38	177	655	1,272	24	**0**
BCR[2]	Base Tech.	0.989	1.001	1.020	1.07	1.14	1.000	0.998
	BMP Tech.	0.989	1.005	1.024	1.10	1.21	1.003	1.000
Pay-back Period[3]	Base Tech.	23.9	19.9	19.1	11.7	5.1	20.0	21.1
	BMP Tech.	21.6	19.8	19.0	12.2	6.0	19.9	20.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Change in Discount rate

Sensitivity analysis for discount rates included these rates to be as low as 3.75% (Essien, 2016) and 5% (Bogdan, 2019), and as high as 10%, in addition to the rate of 8.78% used for the base simulation. Table 6.11 shows that the NPV indicators of both technologies increase as the discount rate decreases. BCR indicators had a slight increase in these scenarios as well; however, the most sensitive indicator was the pay-back period, which decreased from more than 19 years with a discount rate of 8.78% to about 12 or 13 years with lower discount rates. As reported in the St. Emmanuel study site, this probably occurs because the initial investment is not very high. With discount rates of 3.75 and 5%, the technologies are both viable, but the controlled drainage with subirrigation remains to have the best financial performance. As in the previous study site, increasing the discount rate from 8.78% to 10% resulted in losses on both subsurface drainage and controlled drainage with subirrigation systems.

Table 6.11. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Discount Rate Variation in Harrow

Financial Indicator	**System**	**Change in Discount Rate**					
		10%	**8.78%**	**5%**	**3.75%**	**Break-Even (IRR)**	
						8.861%	**8.98%**
NPV[1]	Base Tech.	-132	10	623	908	**0**	-15
	BMP Tech.	-182	38	992	1,434	23	**0**
BCR[2]	Base Tech.	0.980	1.001	1.073	1.098	1.000	0.998
	BMP Tech.	0.974	1.005	1.111	1.149	1.003	1.000
Pay-back Period[3]	Base Tech.	26.7	19.9	13.8	12.3	20.0	21.1
	BMP Tech.	27.7	19.8	13.4	12.3	19.9	20.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Likewise, Table 6.11 also shows the break-even discount rates, referring to the internal rates of return (IRR). At about 8.86 and 8.98% discount rate, the Base Technology and the BMP Technology, respectively, have a zero NPV. This means that at a discount rate greater than these levels, the investment would not produce any profitability, thus making them financially non-viable options.

Change in project lifespan

Table 6.12 shows the effect of change in the length of the technologies' life span on the financial attractiveness of the BMP Technology. Relative to the base scenario value of 20 years, a 10 and 15-year life spans are reductions of 50% and 25%, respectively. Under these conditions, neither of the two technologies is financially attractive, since their NPV values are negative and the BCR is less than one. This perhaps is because the period of time is short for the net benefits to pay for the total investment costs.

Table 6.12. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Project Life Span Variation in Harrow

Financial Indicator	**System**	**Change in Project Life Span (years)**				
		10	**15**	**20**	**30**	**40**
NPV[1]	Base Tech.	-154	-44	10	120	193
	BMP Tech.	-380	-31	38	176	296
BCR[2]	Base Tech.	0.969	0.993	1.001	1.016	1.024
	BMP Tech.	0.930	0.995	1.005	1.022	1.035
Pay-back Period[3]	Base Tech.	12.0	15.9	19.9	25.1	25.1
	BMP Tech.	12.6	16.3	19.8	21.9	21.9

[1] Net Present Value at r=8.78% (\$/acre), [2] Benefit-Cost Ratio (gain for every \$1 spent/acre), [3] No. of years.

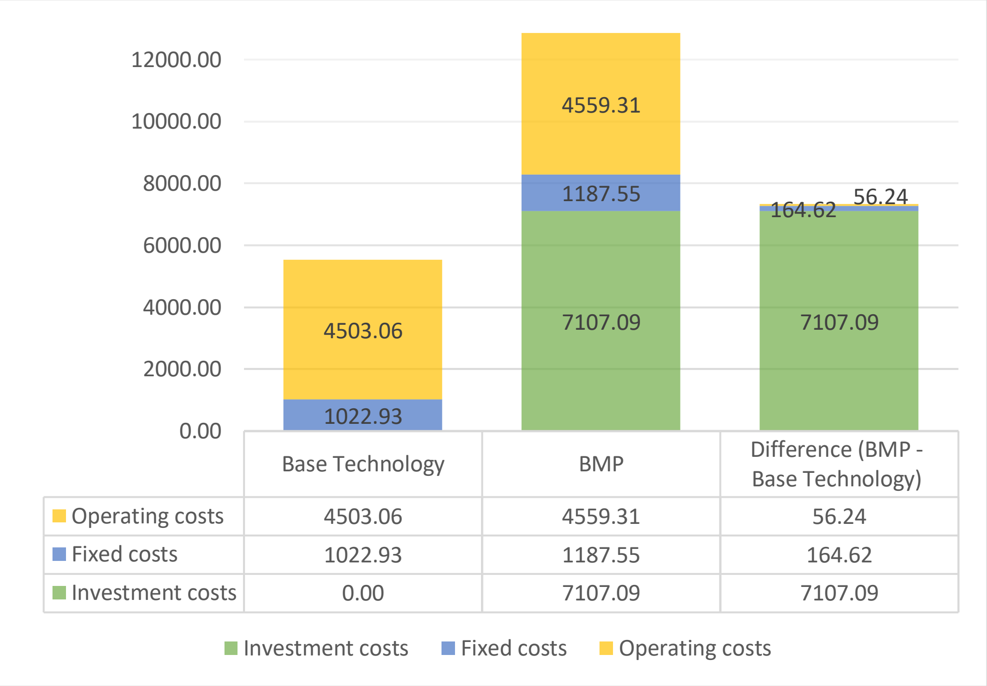
Conversely, both the Base Technology and the BMP Technology continue to be financially attractive if their useful life would increase by 50% and 100% (30 and 40 years, respectively) with respect to the 20 years period under the base simulation. The controlled drainage with subirrigation system (BMP) showed better financial performance compared to the conventional subsurface drainage system (Base), making it the most financially attractive option.

6.3 Sherrington, Quebec

6.3.1 Financial Evaluation

As noted in Chapter 5, Sherrington is a site producing vegetables (onions and carrots). Here the BMP involved an irrigation of the crop while the Base Technology was production under rainfed conditions. Figure 6.5 shows the total investment cost of implementing the BMP Technology, as well as fixed and operating costs of producing carrots and onions in an intercropping system for the two technologies. These results are for the year 2018 on a per acre basis. Installing a hand moved sprinkler irrigation system cost the producer \$7,107.09 per acre. This resulted in higher fixed costs by about \$164.62 per acre resulting from maintenance and repair costs of the irrigation system. The operating costs were also higher with the BMP Technology by \$56.24 per acre, as more labor was required for irrigation.

Gross revenues from the production of these crops for 2018 were $9,260.16 and $10,121.88 per acre with Base Technology and BMP Technology[15], respectively, resulting in farm net returns of $3,734.17 and $4,375.02 per acre, respectively. Thus production in 2018 year had a 19.43% advantage using the sprinkler irrigation system over the rainfed conditions.



	Base Technology	BMP	Difference (BMP - Base Technology)
🟨 Operating costs	4503.06	4559.31	56.24
🟦 Fixed costs	1022.93	1187.55	164.62
🟩 Investment costs	0.00	7107.09	7107.09

Figure 6.5. Difference in Investment, Fixed and Operating Costs of carrot and onion production under Base Technology and BMP Technology in Sherrington 2018 ($/acre)

As noted previously, the financial viability of both rainfed production (Base Technology) and hand-moved sprinkler irrigation (BMP) was carried out considering the estimated useful life of the technology for 15 years and the discount rate of 8.78%. Table 6.13 presents the results of the financial indicators calculation per acre. The three indicators: NPV, BCR and pay-back period, represent the measure of the financial desirability of the Base Technology and BMP Technology.

Table 6.13. Financial Indicators of the Desirability of Base Technology and BMP Technology in Sherrington

Indicator	**Base Technology (No Irrigation)**	**BMP (Hand Moved Sprinkler Irrigation)**
Net Present Value at r=8.78% ($/acre)	57,930	62,354
Benefit-Cost Ratio (gain for every $1 spent/acre)	2.2	2.1
Pay-back Period (years)	0	1.2

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[15] The carrot and onion yields considered for 2018 were actually from 2017, since this was the last year from which we obtained data in the literature (CRAAQ, 2019a; 2019b).

Results show that both technologies are financially desirable at the 8.78% discount rate with a lifespan of 15 years (2019-2033). The NPV in both cases was positive and the BCR was greater than one. The payback period for the BMP Technology was estimated to be significantly less than 15 years (only between 1 to 2 years). The marginal financial gains in present day prices was $4,424 (7.6%) per acre over the life of the technology above that under the Base Technology. This BMP Technology provides 7.6% higher profits relative to the no irrigation situation. If the entire study field, that spans about 31.3 acres, with this technology, producer is set to receive approximately $138,471 over the life of the project. In terms of the benefit-cost ratio, both are equally financially attractive with a gain of more than double per $1 spent per acre.

The results suggest that a carrot-onion production with a sprinkler irrigation system is preferable on economic grounds. These results can be compared to the results by Bogdan (2019), which was undertaken in the same research field. Using a 5% discount rate and a project life of 15 years (2015-2029). Bogdan (2019) concluded that sprinkler irrigation is financially more attractive than rainfed production, with a difference in NPVs of more than 7% in favour of the BMP Technology.

6.3.2 Sensitivity Analysis

As in the other case studies, the robustness analysis of the financial indicators was carried out for different levels of changes in the following factors: crop prices, crop yield, investment cost, discount rate and project lifespan.

Change in Crop Market Prices

Table 6.14 shows that if prices were assumed to increase by 1.8% (as suggested by the forecasts), the financial desirability of the BMP Technology does not change. On the other hand, if prices were to decrease by 1.9 or 5%, the BMP Technology continues to be the most financially desirable option. However, in the hypothetical case that the prices of carrots and onions decline by 50%, then the BMP Technology is no longer the best financially viable option since its NPV would be lower than that of the Base Technology, although they continue to remain positive. With respect to the break-even point, Table 6.14 shows that the crop prices have to decline by more than 55% for the NPV of the Base Technology to become zero, whereas that for the BMP Technology the change would be 53.7% of the prices used for the base simulation.

Yield Changes under Climate Change

As discussed in Chapter 5, the future climate could bring some adverse effects on the yield of vegetable crops. Table 6.15 shows the change that the BMP Technology financial indicators would have if the experienced reduction in carrot and onion yields is 7, 14 or 28% of the base simulation. As expected, a yield reduction decreases the attractiveness of the Base Technology and the BMP Technology in terms of its NPV and also of the other indicators. However, both Base and BMP technologies continue to remain viable on financial grounds. It is necessary to note that given a reduction in yields as low as 7%, sprinkler irrigation (BMP) is no longer the best alternative in financial terms and is replaced by the dry land scenario (Base). In the case of a 28% less carrot and onion yields, the NPV resulting from the Base scenario is reduced by approximately 70%, from $57,930 to $17,700, while the NPV associated with sprinkler irrigation (BMP) is reduced by almost 90%, from $62,354 to $6,452 values. Thus BMP Technology is more sensitive to yield changes. On the other hand, an increase in yields of both crops by 7% maintains the BMP Technology as the most desirable option compared to the Base Technology.

Table 6.14. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Carrot and Onion Prices Variation for the Study Site Sherrington

Financial Indicator	**System**	**% Change in Crop Prices***						
		+1.8%	**0%**	**-1.9%**	**-5%**	**-50%**	**Break-Even Prices**	
							-54.996%	**-53.718%**
NPV[1]	Base Tech.	59,826	57,930	55,928	52,663	5,262	**0**	1,346
	BMP Tech.	64,444	62,354	60,149	56,550	4,316	-1,483	**0**
BCR[2]	Base Tech.	2.3	2.2	2.2	2.1	1.1	1.0	1.0
	BMP Tech.	2.2	2.1	2.1	2.0	1.1	1.0	1.0
Pay-back Period[3]	Base Tech.	0	0	0	0	0	0	0
	BMP Tech.	1.2	1.2	1.3	1.4	12.5	15.5	15.0

* The percent change was applied to the prices of both carrots and onions in the same proportion.

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Table 6.15. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Carrot and Onion Yields Variation in Sherrington

Financial Indicator	**System**	**% Change in Crop Yield**						
		+7%	**0%**	**-7%**	**-14%**	**-28%**	**Break-Even Yield**	
							-42.6315%	**-31.969%**
NPV[1]	Base Tech.	69,292	57,930	47,090	36,771	17,700	**0**	12,674
	BMP Tech.	79,174	62,354	46,672	32,128	6,452	-15,520	**0**
BCR[2]	Base Tech.	2.5	2.2	2.0	1.8	1.4	1.0	1.3
	BMP Tech.	2.4	2.1	1.8	1.6	1.1	0.7	1.0
Pay-back Period[3]	Base Tech.	0	0	0	0	0	0	0
	BMP Tech.	1.0	1.2	1.6	2.2	8.7	25.6	15.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

The break-even yield level for this site indicates that the dryland scenario (Base) would continue to be worthwhile even if there is a reduction in the yields of both carrot and onion by 31.97%, but the sprinkler irrigation would no longer be a viable alternative. On the other hand, when the percentage of decrease in yields is as low as 42.63%, the Base scenario would produce losses as well. The break-even yield level for this site indicates that the dryland scenario (Base) would continue to be worthwhile even if there is a reduction in the yields of both carrot and onion by 31.97%, but the sprinkler irrigation would no longer be a viable alternative. On the other hand, when the percentage of decrease in yields is as low as 42.63%, the Base scenario would produce losses as well.

Change in Investment Cost

Reduction in the investment cost through government policies would affect the BMP Technology in a more positive manner. The sensitivity analysis of the BMP Technology´s investment cost decrease makes its NPV higher (Table 6.16). These results were generated under two scenarios: One, a reduction of 11.93% (which corresponds to a producer receiving Farm Business Development program subsidy consisting of the payment of $13.33 for every $100 dollars of loan requested, paid in 5 years).

Two, government policy measure cover 22.48% of the total cost of investment (corresponds to assuming that the producer was eligible for the Financial Support Program for Aspiring Farmers). Since the total investment cost in the sprinkler irrigation system is about $222,451.92 ($7,107.09 x 31.3 acres), it was considered that the producer was granted just the maximum amount of $50,000. This resulted in the reduction in investment cost per acre of 22.48% -- from $7,107.09 to $5,509.65 per acre. On the other hand, an increase of 5% of the investment cost results in just a slight reduction of the NPV of the BMP Technology, but it is still the most desirable option. The break-even analysis indicated that the investment cost for the BMP Technology would have to increase by more than 800% for BMP Technology ceases to be financially viable.

Table 6.16. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Investment Cost Variation in Sherrington

Financial Indicator	**System**	**Change in Investment Cost***				
		+5%	**0%**	**-11.93%**	**-22.48%**	**Break-Even Inv. Cost**
						+877%
NPV[1]	Base Tech.	57,930	57,930	57,930	57,930	57,930
	BMP Tech.	61,999	62,354	63,054	63,952	**0**
BCR[2]	Base Tech.	2.2	2.2	2.2	2.2	2.2
	BMP Tech.	2.1	2.1	2.1	2.2	1.0
Pay-back Period[3]	Base Tech.	0	0	0	0	0
	BMP Tech.	1.3	1.2	1.0	1.0	15.0

* Changes corresponding to the investment cost of the BMP only.

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Change in Discount Rate

Table 6.17 shows that increasing the discount rate from 8.78% to 10% results in a decrease of NPV values by 6.9% and 7.6%, respectively, for the Base and BMP technologies. However, the BCR and pay-back period indicators remain the same. With lower discount rate of 3.75%, the NPV values in both cases are higher, increasing up to 38% with the baseline scenario, and up to 43.4% with the BMP Technology. These results show that with all the discount rates analyzed, sprinkler irrigation (BMP) maintains its better financial performance compared with the dryland technology. This sensitivity analysis reveals conclusions quite similar to those found in Bogdan (2019) for this site[16]. With discount rates of 5 and 10%, her study concluded that sprinkler irrigation is the best alternative financially.

Table 6.17. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Discount Rate Variation in Sherrington

Financial Indicator	**System**	**Change in Discount Rate**					
						Break-Even (IRR)	
		10%	**8.78%**	**5%**	**3.75%**	**2 mill. %**	**150.9%**
NPV[1]	Base Tech.	53,957	57,930	73,631	80,276	**0**	4,256
	BMP Tech.	57,586	62,354	81,314	89,385	-4,619	**0**
BCR[2]	Base Tech.	2.2	2.2	2.2	2.2	2.1	2.1
	BMP Tech.	2.1	2.1	2.2	2.2	0.4	1.0
Pay-back Period[3]	Base Tech.	0	0	0	0	0	0
	BMP Tech.	1.2	1.2	1.2	1.2	---	15.0

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

The break-even discount rates showed in Table 6.17, referring to the internal rate of return (IRR), indicates that the discount rate would have to be greater than 150% for sprinkler irrigation to cease to be financially viable. On the other hand, a misplaced discount rate of two million percent would be necessary for the NPV indicator in the Base scenario to be zero. This unlikely value of IRR is justified because the amount of investment in the no irrigation base scenario, where there is no technology, is zero, compared to more than $7,107/acre that is invested in sprinkler irrigation.

Change in Project Life Span

Table 6.18 shows the effect of a change in the length of life span of the two technologies on their financial attractiveness. With a reduction of 15 to 10 years, NPV indicators are reduced by about 22% for the Base Technology and 27% for the BMP Technology. On the contrary, as life expectancy increases (say from 20 to 25 years), NPV values also increase. When the useful life of the technologies increased from 15 to 25 years, the NPV indicators increased by about 18% (for the Base Technology) and 20% (for the BMP Technology). The other financial indicators (BCR and pay-back period) had no major changes. The results in Table 6.18 also show that both technologies are financially attractive when their life span is between 10 and 25 years; however, in all scenarios sprinkler irrigation (BMP Technology) is the best option on financial grounds.

6.4 Holland Marsh, Ontario

6.4.1 Financial Evaluation

In Holland Marsh site, the Base Technology used was subsurface drainage, while the BMP Technology involved controlled drainage. Figure 6.6 shows the total investment cost of installing the Base Technology and the BMP Technology, the fixed costs and the operating

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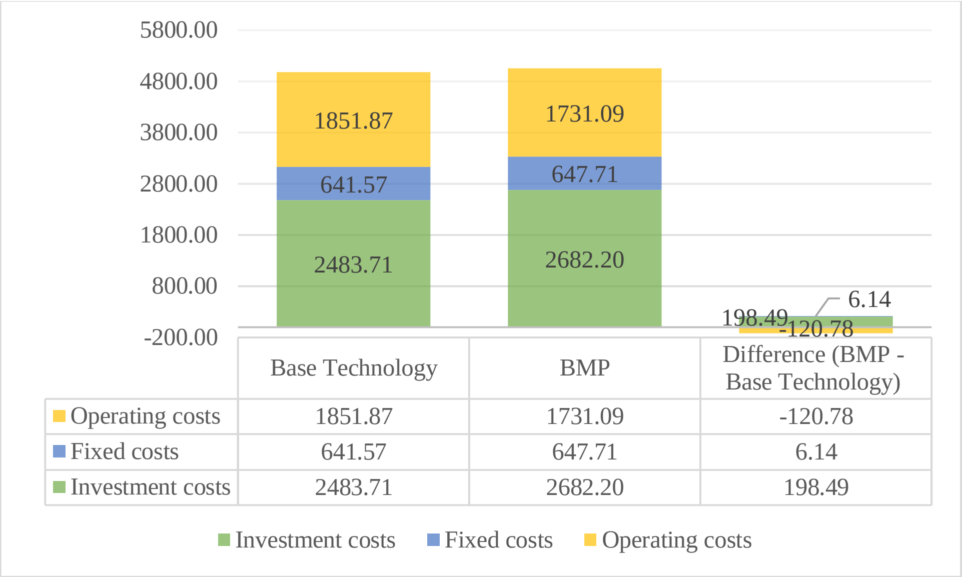
[16] As mentioned in section 6.3.1, Bogdan (2019) undertook the economic analysis of the same technologies and in the same field of research as this study, during the 2015-2029 lifespan with a discount rate of 5%.

costs of growing carrots under both systems on a per acre basis in 2018. The difference in the investment costs indicates that installing a controlled drainage system in a field with an existing conventional subsurface tile drainage system has an additional cost of $198.49 per acre. This increase is due to components required for controlled drainage, such as the control structure.

Table 6.18. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Project Life Span Variation in Sherrington

Financial Indicator	**System**	**Change in Project Life Span (years)**			
		10	**15**	**20**	**25**
NPV[1]	Base Tech.	45,073	57,930	63,529	68,359
	BMP Tech.	45,363	62,354	69,435	74,886
BCR[2]	Base Tech.	2.2	2.2	2.2	2.2
	BMP Tech.	2.0	2.1	2.1	2.1
Pay-back Period[3]	Base Tech.	0.0	0.0	0.0	0.0
	BMP Tech.	1.2	1.2	1.2	1.2

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.



	Base Technology	BMP	Difference (BMP - Base Technology)
🟨 Operating costs	1851.87	1731.09	-120.78
🟦 Fixed costs	641.57	647.71	6.14
🟩 Investment costs	2483.71	2682.20	198.49

Figure 6.6. Difference in Investment, Fixed and Operating Costs of carrot production under Base Technology and BMP Technology in Holland Marsh 2018 ($/acre)

Fixed costs for the BMP Technology were higher by $6.14 per acre, resulting from higher maintenance and repair costs of the structure. Conversely, the operating costs (assuming that carrot was grown in 2018) were lower for the BMP Technology by $120.78 per acre, since there were no extra fertilizer applied under the Base Technology.

Gross revenues for 2018 were estimated at $5,736.20 and $5,954.34 per acre under the Base Technology and the BMP Technology[17], respectively. Therefore, the farm net returns were $3,242.76 and $3,575.54 per acre using both technologies. In that year, growing carrots had a 10.26% advantage using the BMP Technology. Figure 6.7 shows the carrot yields

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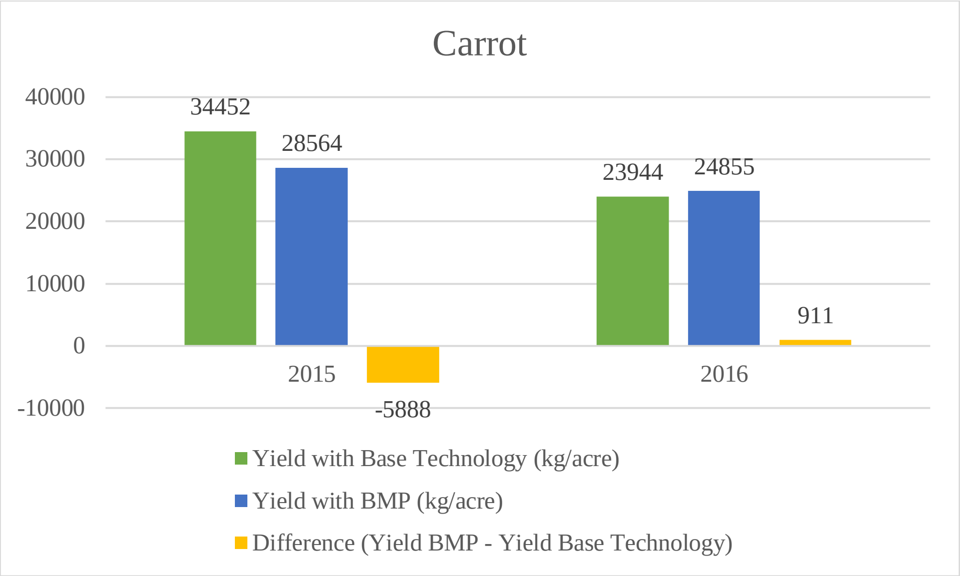
[17] The carrot yield considered for 2018 were actually from 2016, since this was the last year for which performance data from the literature could be obtained (De Sena, 2017).

obtained from this study site for the 2015 and 2016 growing seasons. Production in the first year was higher with the Base Technology, at approximately 20.6%; however, in the following year, the yields under the BMP Technology exceeded 3.8% of those produced under the Base Technology. This variability was also reflected in the stochastic projection, as shown in Table 5.30.



Source: Carrot yield data from De Sena (2017)

Figure 6.7. Comparison of Base Technology and BMP Technology on Carrot Yields in Holland Marsh

As noted in Chapter 5, the financial analysis of subsurface drainage (Base Technology) and controlled drainage (BMP Technology) was carried out considering the estimated useful life of the technology of 20 years and the discount rate of 8.78%. Table 6.19 presents the results of the financial indicators calculation on a per acre basis. Like the above evaluations, indicators such as NPV, BCR and pay-back period were used.

Table 6.19. Financial Indicators of the Desirability of Base Technology and BMP Technology in Holland Marsh

Indicator	**Base Technology (Subsurface Drainage)**	**BMP (Controlled Drainage)**
Net Present Value r=8.78% ($/acre)	11,984	16,147
Benefit-Cost Ratio (gain for every $1 spent/acre)	1.5	1.6
Pay-back Period (year)	0.9	0.7

Both technologies were found to be financially desirable at the study discount rate and the lifespan. In both situations, the NPV was greater than zero, a benefit-cost ratio was greater than 1 and the pay-back period was less than 20 years in duration. However, the BMP Technology was the most financially attractive, with its profitability of $4,163 (34.7%) per acre being higher than that for the Base Technology. The producer earns for his investment about 60 cents for every $1 spent per acre as shown by the BCR results and the time required to earn back the investment is less than a year. The results of this analysis suggest that producing carrots and onions in a rotation system using the BMP Technology is economically attractive.

6.4.2 Sensitivity Analysis

A sensitivity analysis of the results on financial indicators was carried out considering that some factors could affect the economics of the selected technologies. The parameters selected for this analysis were: crop prices, crop yield, investment cost, discount rate and project lifespan.

Change in crop market prices

Results for the simulated financial indicators suggest that in spite of change in the price level for carrots and onions, the better performance of the controlled drainage technology does not change (Table 6.20). Even if the prices for these commodities were to decrease to as low as 1.9% or 5% of the base simulation, the BMP Technology continues to be the most financially desirable technology. Likewise, in the hypothetical case that the prices of carrots and onions decline by 50%, then both technologies are no longer viable. With respect to the break-even point, Table 6.20 shows that the crops prices would have to decline by about 31.4% for the Base Technology to become financially unattractive. For the BMP Technology, this change was estimated to be a decrease of 38.8% of base simulation levels.

Table 6.20. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Carrot and Onion Prices Variation for the Study Site Holland Marsh

Financial Indicator	**System**	**% Change in Crop Prices***						
		+1.8%	**0%**	**-1.9%**	**-5%**	**-50%**	**Break-Even Prices**	
							-31.4%	**-38.824%**
NPV^1	Base Tech.	12,671	11,984	11,259	10,076	-7,098	**0**	-2,833
	BMP Tech.	16,896	16,147	15,357	14,068	-4,648	3,088	**0**
BCR^2	Base Tech.	1.5	1.5	1.4	1.4	0.7	1.0	0.9
	BMP Tech.	1.7	1.6	1.6	1.6	0.8	1.1	1.0
Pay-back Period^3	Base Tech.	0.8	0.9	0.9	0.9	26.3	10.9	28.3
	BMP Tech.	0.6	0.7	0.7	0.7	23.8	3.1	20.0

* The percent change was applied to the prices of both carrots and onions in the same proportion.

^{1} Net Present Value at r=8.78% ($/acre), ^{2} Benefit-Cost Ratio (gain for every $1 spent/acre), ^{3} No. of years.

Yield Changes under Climate Change

As was reviewed in Section 5.6.2, climate change can have severe and significant impacts on yields of vegetable crops, which in turn could affect the economics of a technology. Table 6.21 shows changes that financial indicators associated with a reduction in carrot and onion yields by 7, 14 and 28%. As expected, a yield reduction decreases the financial attractiveness of technologies in terms of various economic indicators. When there is a yield reduction of 14%, the NPV indicator decreases by around 83% and 67% with the Base Technology and BMP Technology, respectively. However, for both the technologies the NPV remains to be positive. In all these cases the controlled drainage has a better financial performance than the subsurface drainage. If the crop yields were to be reduced by 28%, both the technologies become unattractive on financial grounds. On the other hand, as expected, an increase in yields of both crops by 7% maintains the BMP Technology as the most desirable option compared to the Base Technology.

Table 6.21. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Carrot and Onion Yields Variation in Holland Marsh

Financial Indicator	**System**	**% Change in Crop Yield***						
		+7%	**0%**	**-7%**	**-14%**	**-28%**	**Break-Even Yield**	
							-17.175%	**-21.784%**
NPV[1]	Base Tech.	17,514	11,984	6,828	2,046	-6,396	**0**	-2,832
	BMP Tech.	22,174	16,147	10,528	5,317	-3,883	3,088	**0**
BCR[2]	Base Tech.	1.7	1.5	1.3	1.1	0.8	1.0	0.9
	BMP Tech.	1.9	1.6	1.4	1.2	0.8	1.1	1.0
Pay-back Period[3]	Base Tech.	0.7	0.9	4.3	8.5	48.8	20.0	43.4
	BMP Tech.	0.5	0.7	0.8	1.4	40.7	8.2	20.0

* The percent change was applied to the yields of both carrots and onions in the same proportion.

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

The break-even yield level, as shown in Table 6.21, indicates that the controlled drainage system (BMP Technology) would continue to be the preferred option even if there is a reduction in carrot and onion yields of 17.18%; but at that point the conventional subsurface drainage system (Base Technology) would no longer be a viable alternative. But, if yields would decline by 21.78%, then the BMP Technology would not be viable anymore.

Change in Investment Cost

Assuming a scenario in which the producer is eligible for the Tile Loan Program offered by OMAFRA, there is an increase in the NPVs of both technologies, but the BMP Technology remaining the most financially attractive option. Table 6.22 shows that under this scenario there would be a reduction in the investment costs of both technologies by 5.44%, which are derived from the 75% financing of the installation cost (including land preparation) payable for 10 years at an interest rate of 6% for a ten-year term. When the cost-share program scenarios are assumed with subsidies of 25 and 50% of the total cost of investment in each technology, then the BMP Technology would continue to be the most economically viable under the scenario that the producer has received the subsidy.

On the other hand, an increase of 5% of the investment cost results in just a slight reduction of the NPV values of both technologies, but the BMP Technology is still the most desirable option. The break-even analysis for the investment costs, at which the present value of benefits and costs are equal, shows that the Base Technology would cease to be financially viable if the investment cost is more than five times the real amount; however, even in that case, the BMP Technology remains profitable with a positive NPV. Likewise, the BMP Technology would be no longer the most viable option with an NPV equal to zero if its investment cost increases are more than 7 times the cost in base simulation. At this point, the Base Technology would exhibit losses (Table 6.22).

Table 6.22. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Investment Cost Variation in Holland Marsh

Financial Indicator	System	Change in Investment Cost						
		+5%	0%	-5.44%	-25%	-50%	Break-Even Inv. Cost	
							+583%	+702%
NPV[1]	Base Tech.	11,860	11,984	12,177	12,605	13,226	**0**	-2,968
	BMP Tech.	16,063	16,147	16,293	16,818	17,489	3,206	**0**
BCR[2]	Base Tech.	1.5	1.5	1.5	1.5	1.5	1.0	0.9
	BMP Tech.	1.6	1.6	1.6	1.7	1.7	1.1	1.0
Pay-back Period[3]	Base Tech.	0.9	0.9	0.7	0.6	0.4	20.0	49
	BMP Tech.	0.7	0.7	0.5	0.5	0.3	13.7	20

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Change in Discount rate

Table 6.23 shows that the NPV indicators of both technologies increase as the discount rate decreases or increases. No large changes in the indicators, such as the BCR and pay-back period, were noted with the change in the discount rates. However, under all discount rates, both the technologies are economically attractive. At the same time, the BMP Technology remains to be the most attractive option. On the other hand, the break-even discount rates, referring to the internal rates of return (IRR), are about 76.9% and more than 125% for the Base Technology and the BMP Technology, respectively, which implies that the investment in both technologies is profitable, and in the BMP Technology even more. Discount rates would have to increase by a very large magnitude before these technologies become economically unattractive.

Table 6.23. Sensitivity of Financial Indicators of the Base Technology and BMP Technology to Discount Rate Variation in Holland Marsh

Financial Indicator	System	Change in Discount Rate					
		10%	8.78%	5%	3.75%	Break-Even (IRR)	
						76.89%	125.6%
NPV[1]	Base Tech.	10,799	11,984	16,963	19,201	**0**	-744
	BMP Tech.	14,691	16,147	22,346	25,170	1,221	**0**
BCR[2]	Base Tech.	1.4	1.5	1.5	1.5	1.0	0.8
	BMP Tech.	1.6	1.6	1.7	1.7	1.2	1.0
Pay-back Period[3]	Base Tech.	0.9	0.9	0.8	0.8	18.8	47.8
	BMP Tech.	0.7	0.7	0.6	0.6	1.3	10.3

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

Change in Project Life Span

Table 6.24 shows the effect of a change in the project's life span on various financial indicators. When the project lifespan is reduced from 20 years to 10 years, the NPV values for the Base Technology were reduced by 30% (from $11,984 to $8,396), and by 31% (from 16,147 to 11,159) for the BMP technology. However, both technologies remain financially viable with NPV values greater than zero.

Table 6.24. Sensitivity of Financial Indicators of Base Technology and BMP Technology to Project Life Span Variation in Holland Marsh

Financial Indicator	System	Change in Project Life Span (years)				
		10	15	20	30	40
NPV[1]	Base Tech.	8,396	10,206	11,984	13,312	14,014
	BMP Tech.	11,159	13,974	16,147	17,775	18,738
BCR[2]	Base Tech.	1.5	1.4	1.5	1.5	1.5
	BMP Tech.	1.6	1.6	1.6	1.6	1.6
Pay-back Period[3]	Base Tech.	0.9	0.9	0.9	0.9	0.9
	BMP Tech.	0.7	0.7	0.7	0.7	0.7

[1] Net Present Value at r=8.78% ($/acre), [2] Benefit-Cost Ratio (gain for every $1 spent/acre), [3] No. of years.

On the other hand, when there is an increase in the lifespan of the project to 30 and 40-year, an increase in the NPV value was noted. When the useful life of the technologies increased by 100% (from 20 to 40 years), NPV values increase by approximately 14% for both Base and BMP technologies. With respect to the BCR and pay-back period indicators, no significant changes were recorded with any of these changes. It should be noted that in all the scenarios analyzed, the controlled drainage system (BMP) remains the most financially attractive alternative, surpassing the conventional subsurface drainage system (Base).

6.5 Summary of Results

6.5.1 Grain Producing Farms

In the St. Emmanuel, Quebec, study site, economics of an investment in the controlled drainage with subirrigation system was selected as the BMP Technology and was compared with the Base Technology -- free subsurface drainage system. The analysis was conducted on corn and soybean production in a five-year cycle rotation, with four consecutive years of corn followed by one year of soybean production, over a period of 20 years (2019-2038). The main difference between the two technologies was that the BMP Technology required the installation of components to manage the water table level according to the crop needs.

Assuming that investment was made in 2018, the marginal cost of investing in the BMP Technology was $768/acre. Fixed costs totalled $11/acre more with the BMP Technology, as a result of additional cost of maintenance and repair of water control structures. In addition, under the assumption that in 2018, corn was grown on this farm using the BMP Technology, the resulting operating costs were lower by about $33/acre. This reduction was caused by a lack of need for additional irrigation costs which were not necessary with the BMP Technology. In total, production costs for 2018 were $23/acre less with the BMP Technology than with the Base Technology. On the other hand, gross revenues were $957.82 and $949.11 per acre with Base Technology and BMP Technology, respectively, resulting in farm net returns of $355.70 and $369.78. A slight increase of 3.96% in the net returns was estimated with the adoption of the BMP Technology.

At the Harrow, Ontario, study site, the same technologies as investigated for the St. Emmanuel study site were evaluated. The controlled drainage with subirrigation system was the BMP Technology and the subsurface drainage was the Base Technology. Also, the same crops but in a different rotation were grown at this site. The rotation was a two-year rotation with corn followed by soybean. Similar to the St. Emmanuel site, the life span of the technology was assumed to be 20 years (2019-2038).

Since in these two sites the same technologies were considered, the marginal cost of investment for the BMP Technology was also the same – estimated at $768/acre (although the investment costs are higher in Ontario than in Quebec). Fixed costs were $11/acre more with the BMP Technology, due to additional cost of maintenance and repair of water control structures. With respect to operating costs, these have been calculated assuming that in 2018 soybeans were grown on this site. These costs were estimated to be $37/acre less with the BMP Technology relative to the Base Technology. This was a result of no additional irrigation was required when BMP Technology was used (note that this cost is higher than that for the previous case because irrigation labor costs are higher in Ontario). In total, fixed plus operating costs in 2018 were $26/acre less with the BMP Technology relative to the Base Technology. The gross revenues of the farm from corn and soybean production in 2018 were estimated at $717.6 under the two technologies, but farm net returns were different. These were estimated at $289 and $315 per acre under Base Technology and BMP Technology, respectively. Thus, the BMP Technology generated 9% higher net revenue from corn and soybean production relative to the Base Technology.

The financial analysis indicators in both the grain-producing farms were estimated using a discount rate of 8.78% and the project lifespan of 20 years (see the comparison in Table 6.25). For the St. Emmanuel study farm, the NPV calculated resulted in a 62.5% increase over the life of the project, from $64 to $104 per acre, under the controlled drainage with subirrigation technology. The BCR for each technology was estimated to be 1.009 (Base) and 1.014 (BMP), while the pay-back period indicators were 19.3 years (Base) and 19.2 years (BMP). While for the Harrow study site, the NPV for using the BMP Technology generated an increase of 280% over the Base Technology, it was $10 per acre for the Base Technology and increased to $38 per acre under the controlled drainage with subirrigation system. The BCRs for each technology were very close -- 1.001 (Base) and 1.005 (BMP), and so were the payback periods -- 19.9 years (Base Technology) and 19.8 years (BMP Technology). The results of these case studies indicate that both technologies meet the criteria of being financially attractive. However, the BMP technology had higher values of these indicators and thus more attractive on financial grounds.

Table 6.25. Comparison of Financial Indicators of the Desirability of Base and BMP Technologies in Grain Producing Sites (St. Emmanuel and Harrow)

Indicator	**St. Emmanuel, Qc**		**Harrow, On**	
	Base Technology	**BMP Technology**	**Base Technology**	**BMP Technology**
NPV ($/acre)	64	104	10	38
BCR (gain for every $1 spent)	1.009	1.014	1.001	1.005
Pay-back Period (years)	19.3	19.2	19.9	19.8

The results of the crop price (corn and soybeans) sensitivity analysis for both study sites lead to very similar conclusions (see the comparison in Table 6.26). The estimations indicated that under the scenario of an increase in crop prices, the value of financial indicators improved in favor of the BMP Technology. For example, the NPVs of the BMP Technology improved by $268 and $168 per acre for St. Emmanuel and Harrow, respectively, when corn prices increased by 2.5% of the base simulation values and soybean prices increased by 0.7%. However, with price reductions of the same magnitude, both technologies were unprofitable.

Table 6.26. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Corn and Soybean Prices Variation in Grain Producing Sites (St. Emmanuel and Harrow)

Financial Indicator	**System**	**St. Emmanuel, Qc**			**Harrow, On**		
		C: +2.5% & S: +0.7%	**0%**	**C: -2.5% & S: -0.7%**	**C: +2.5% & S: +0.7%**	**0%**	**C: -2.5% & S: -0.7%**
NPV ($/acre)	Base Tech.	218	64	-90	130	10	-110
	BMP Tech.	268	104	-61	168	38	-91

These results reveal that the desirability indicators are very sensitive to variations in crop prices, since it only takes a small drop in them to make the technologies unprofitable. Results of the price break-even analysis conducted for St. Emmanuel (shown in Table 6.2), revealed that a price decrease of only 0.5% in corn and 3.5% in soybeans, would result in Base Technology no longer being financially viable, but the BMP Technology would still remain the best alternative. However, if these prices were to fall by more than 0.8% in corn and 4.6% in soybean, even the BMP Technology would lose its financial attractiveness. Similar results were observed in the case of Harrow (Table 6.8). If crop prices were to decrease by 0.13% for corn and 0.17% for soybeans, the Base Technology will no longer be financially viable, but the BMP Technology would still remain the best alternative until prices fall by 0.45% for corn and 0.62% for soybeans.

Similar conclusions were reached when variations in crop yields were simulated. Increases in corn and soybean yields by 5.6% resulted in higher NPVs of both technologies in both the study sites. However, a reduction of yields of a similar magnitude resulted in negative NPVs, as shown in Table 6.27. As in the case of price sensitivity analysis, the indicators are very sensitive to variations in crop yields. For example, for St. Emmanuel, a reduction of approximately 1.1% in the yields of both crops, kept the BMP Technology financially attractive but such was not the case with the Base Technology. When the yield decreases of about 1.7% were experienced, even the BMP Technology became financially unattractive (Table 6.3). Similarly for Harrow, a yield reduction of 0.25% for both crops maintained the financial attractiveness of the BMP Technology, but such was not the case with the Base Technology. However, if the yields were to decrease by 0.9%, the BMP Technology would cease to be financially viable (Table 6.9).

Table 6.27. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Corn and Soybean Yields Variation in Grain Producing Sites (St. Emmanuel and Harrow)

Financial Indicator	**System**	**St. Emmanuel, Qc**			**Harrow, On**		
		+5.6%	**0%**	**-5.6%**	**+5.6%**	**0%**	**-5.6%**
NPV ($/acre)	Base Tech.	396	64	-268	233	10	-213
	BMP Tech.	454	104	-247	279	38	-203

With respect to the investment cost sensitivity analysis, as one would expect, any reduction in this cost through a cost-share program from the Ontario and Quebec provincial governments, made the BMP Technology more attractive on financial grounds, with the BMP Technology being the most desirable option at all times in both study sites, as shown in Table 6.28. This high sensitivity in the NPV indicators could be of interest for decision-makers if they would want to encourage producers to adopt innovative practices.

Table 6.28. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Investment Cost Variation in Grain Producing Sites (St. Emmanuel and Harrow)

Financial Indicator	**System**	**St. Emmanuel, Qc**			**Harrow, On**		
		0%	**-20.27%**	**-100%**	**0%**	**BT: -7.35% BMP: -5.6%**	**-25%**
NPV ($/acre)	Base Tech.	64	330	1,377	10	435	860
	BMP Tech.	104	526	2,185	38	655	1,272

In contrast, moderate increases in investment costs led to not-so-attractive results, as shown in the output when the break-even analysis was conducted (see Tables 6.4 and 6.10). For example, in St. Emmanuel, if the investment costs were to increase by only 5%, neither of the two technologies would remain financially viable (Table 6.4). In Harrow, even a slight increase in this cost (say only 1.6%) would make both technologies financial unattractive (Table 6.10).

In the case of sensitivity results to a change in discount rate, a decrease in it led to improvements in the NPVs for both the technologies. Table 6.29 shows that a discount rate at 3.75% for both study sites, maintained the BMP Technology with desirable values. However, if the discount rate were to increase to 10%, neither of the technologies is financially viable.

Table 6.29. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Discount Rate Variation in Grain Producing Sites (St. Emmanuel and Harrow)

Financial Indicator	**System**	**St. Emmanuel, Qc**			**Harrow, On**		
		10%	**8.78%**	**3.75%**	**10%**	**8.78%**	**3.75%**
NPV ($/acre)	Base Tech.	-42	64	705	-132	10	908
	BMP Tech.	-93	104	1,336	-182	38	1,434

As results in Table 6.5 and 6.11 for St. Emmanuel and Harrow, respectively, show, neither of these technologies are finally attractive if the discount rate were to increase to 9.5% or higher.

For both study sites, when it was assumed that the life span of the BMP is twice the baseline scenario (40 years), both technologies were financially viable, with the BMP Technology being the best alternative. However, when the life span decreased to 10 years, neither of the two technologies retained their financially attractiveness (see Table 6.30).

Table 6.30. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Project Life Span Variation in Grain Producing Sites (St. Emmanuel and Harrow)

Financial Indicator	**System**	**St. Emmanuel, Qc**			**Harrow, On**		
		10	**20**	**40**	**10**	**20**	**40**
NPV ($/acre)	Base Tech.	-100	64	76	-154	10	193
	BMP Tech.	-313	104	163	-380	38	296

6.5.2 Vegetable Producing Farms

In the Sherrington, Quebec, study site the economics of an investment in a hand moved sprinkler irrigation system (BMP) were evaluated against a situation where no irrigation technology was used, called the Base Technology. The analysis was included carrot and onion production as an intercropping system every year, over a 15 year period (2019-2033). Assuming that the year of the investment is 2018, the marginal cost of investing in the BMP Technology was estimated to be $7,107/acre. Fixed costs were $165/acre more with the BMP Technology resulting from additional cost of maintenance and repair of the irrigation system's components. Moreover, the operating costs in 2018 of the BMP Technology were higher by about $56/acre, since more labor to operate the irrigation system was required. Therefore, production costs for 2018 were $221/acre more with the BMP Technology than those with the Base Technology. On the other hand, gross revenues were $9,260 and $10,122 per acre with Base Technology and BMP Technology, respectively, resulting in farm net returns of $3,734 and $4,375, respectively, for these two technologies. This indicated that the BMP Technology resulted in 17% higher net returns relative to the Base Technology.

At the Holland Marsh study site, the controlled drainage system was the BMP Technology and the conventional free subsurface drainage was the Base Technology. Two separate one each the two technologies were the source of data for this analysis. The analysis was conducted on carrot and onion production in a 3-year rotation (2 years of carrots followed by one year of onions) for the Base Technology and a 4-year cycle (3 years of carrots followed by one of onion) for the BMP Technology, over a period of 20 years (2019-2038). The main difference between the two technologies is that the BMP Technology required the implementation of the water control structure. Thus, assuming that investment was made in 2018, the marginal cost of investing in the BMP Technology was $199/acre. Also, the fixed costs were $6/acre more with the BMP Technology because of the additional cost of maintenance and repair of the control structure. Operating costs were calculated assuming that carrots have been grown in both research farms in 2018, which accounted for $121/acre less with BMP Technology than with Base Technology. This was due to no extra fertilizer application was required with the BMP Technology. In total, production costs in 2018 were $115/acre less with the BMP Technology than with the Base Technology.

The gross revenues generated from the production of these crops in 2018 were estimated at $5,736 and $5,954 with Base Technology and BMP Technology, respectively. Taking into account the respective cost of production, this yielded farm net benefits of $3,243 and $3,576 per acre for the two technologies, indicating that the BMP Technology adoption would result in an increase in net returns of 10.3% over the Base Technology.

The financial analysis indicators for the vegetable producing farms (see the comparison in Table 6.31) were estimated using a discount rate of 8.78%. Moreover, a project life span of 15 years was used for Sherrington and 20 years for Holland Marsh. The estimations for Sherrington resulted in a 7.6% increased contribution for the BMP Technology over the Base Technology. This value increased from $57,930 per acre for the no irrigation scenario (Base Technology) to $62,354 per acre for the Hand-Moved Sprinkler Irrigation (BMP Technology). The BCR for each technology were close to each other – being 2.2 (Base) and 2.1 (BMP), while the pay-back period for the BMP Technology was 1.2 years. For the Holland Marsh study site, the financial analysis indicators suggested that the NPV for the controlled drainage (BMP Technology) was 35% higher than that for the free subsurface drainage (Base Technology). The increase was from $11,984 for the Base Technology to $16,147 with the controlled drainage system. The BCR for each technology were close -- 1.5 (Base) and 1.6 (BMP), while the pay-back period indicators were estimated at 0.9 (Base) and 0.7 (BMP). The new investment is recovered within a year of production activity. Although these results show that both technologies are financially viable, the BMP Technology is more attractive on financial grounds.

Table 6.31. Comparison of Financial Indicators of the Desirability of Base and BMP Technologies in Vegetable Producing Sites (Sherrington and Holland Marsh)

Indicator	**Sherrington, Qc**		**Holland Marsh, On**	
	Base Tech. (No Irrigation)	**BMP Tech. (Sprinkler Irrigation)**	**Base Tech. (Subsurface Drainage)**	**BMP Tech. (Controlled Drainage)**
NPV ($/acre)	57,930	62,354	11,984	16,147
BCR (gain for every $1 spent)	2.2	2.1	1.5	1.6
Pay-back Period (years)	0	1.2	0.9	0.7

The results for sensitivity analysis in both study sites reveal that the financial desirability indicators are less sensitive to variations in the selected parameters. For example, the sensitivity analysis of the two technologies with respect to commodity price change indicated that an increase in carrot and onion prices would support the conclusion that the BMP Technology is superior to the Base Technology. Moreover, price reduction yielded lower but positive NPVs. Even though the prices of both crops decrease by 5%, the values are still positive and the BMP the most desirable alternative (see the comparison in Table 6.32).

Table 6.32. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Carrot and Onion Prices Variation in Vegetable Producing Sites (Sherrington and Holland Marsh)

Financial Indicator	**System**	**Sherrington, Qc**			**Holland Marsh, On**		
		+1.8%	**0%**	**-5%**	**+1.8%**	**0%**	**-5%**
NPV ($/acre)	Base Tech.	59,826	57,930	52,663	12,671	11,984	10,076
	BMP Tech.	64,444	62,354	56,550	16,896	16,147	14,068

According to the results of break-even analysis, the indicators are not very sensitive to price variations. This is shown by a price drop of 53% for Sherrington when both technologies would no longer be financially attractive (see Table 6.14). While for the Holland Marsh site, if crop prices were as low as 31% of the level in the base simulation, the Base Technology would no longer be a viable option, although the BMP Technology would continue to be attractive until the prices of carrots and onions are reduced by around 39%. At that point, neither of the two technologies would have a positive NPV.

The sensitivity analysis with respect to crop yields showed that the NPV will decrease further if yields continued to decrease. A yield increase of approximately 7% would make the BMP Technology better than the Base Technology, as reflected in their respective NPVs in Table 6.33. However, a reduction of carrot and onion yields by 28% had different results for each study site. In Sherrington, the results showed still positive NPVs for both technologies, but the BMP Technology is no longer the most desirable option, while in Holland Marsh, neither of the two technologies are viable anymore (Table 6.33).

Table 6.33. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Carrot and Onion Yields Variation in Vegetable Producing Sites (Sherrington and Holland Marsh)

Financial Indicator	**System**	**Sherrington, Qc**			**Holland Marsh, On**		
		+7%	**0%**	**-28%**	**+7%**	**0%**	**-28%**
NPV ($/acre)	Base Tech.	69,292	57,930	17,700	17,514	11,984	-6,396
	BMP Tech.	79,174	62,354	6,452	22,174	16,147	-3,883

At the Sherrington study site, further reduction of approximately 31% would make the BMP Technology to be no longer an attractive option, while a yield reduction of 43% would make neither option financially viable (Table 6.15). However, the indicators are more sensitive in Holland Marsh than at Sherrington. With a yield reduction of as low as 17%, the Base Technology would no longer be a desirable alternative, but the BMP Technology would remain to be desirable until carrot and onion yields were to be as low as 22% of the base simulation values (Table 6.21).

In the investment cost sensitivity analysis, as expected, any reduction in the investment cost through using a cost-share program of the provincial governments would increase the values of the financial indicators for the BMP Technology, making it more financially attractive, as shown in Table 6.34. The BMP Technology in each study site would become financially unattractive if this cost were to increase by more than 8 and 7 times the investment cost estimated in the baseline, for Sherrington and Holland Marsh, respectively (Tables 6.16 and Table 6.22). These results are explained by the high net returns that the BMP Technologies yield in these vegetable producing sites.

Table 6.34. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Investment Cost Variation in Vegetable Producing Sites (Sherrington and Holland Marsh)

Financial Indicator	**System**	**Sherrington, Qc**			**Holland Marsh, On**		
		0%	**-11.93%**	**-22.48%**	**0%**	**-5.44%**	**-25%**
NPV ($/acre)	Base Tech.	57930	57,930	57,930	11,984	12,177	12,605
	BMP Tech.	62354	63,054	63,952	16,147	16,293	16,818

The discount rate sensitivity analysis showed that regardless of how much these rates may change, both alternatives remain viable. Naturally, as the rate decreases, the values of the NPV indicators increase. At all times the BMP Technology was the best financially viable alternative. This is shown in Table 6.35 for both study sites.

Table 6.35. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Discount Rate Variation in Vegetable Producing Sites (Sherrington and Holland Marsh)

Financial Indicator	**System**	**Sherrington, Qc**			**Holland Marsh, On**		
		10%	**8.78%**	**3.75%**	**10%**	**8.78%**	**3.75%**
NPV ($/acre)	Base Tech.	53,957	57,930	80,276	10,799	11,984	19,201
	BMP Tech.	57,586	62,354	89,385	14,691	16,147	25,170

Similar results were found for the changes in the life span of the technology in both the Sherrington and Holland Marsh study sites. In all simulated scenarios, the NPV indicators were positive, with the BMP Technology being the most financially attractive option. These results are summarized in Table 6.36.

Table 6.36. Comparison of Sensitivity of the NPV Financial Indicators of Base and BMP Technologies to Project Life Span Variation in Vegetable Producing Sites (Sherrington and Holland Marsh)

Financial Indicator	**System**	**Sherrington, Qc**			**Holland Marsh, On**		
		10	**15**	**25**	**10**	**20**	**40**
NPV	Base Tech.	45,073	57,930	68,359	8,396	11,984	14,014
	BMP Tech.	45,363	62,354	74,886	11,159	16,147	18,738

Chapter 7

SUMMARY AND CONCLUSION

7.1 Summary

Climate change has long become one of the main concerns for the world as a whole. Global warming already constitutes a threat for future generations, while its main cause, the GHG emissions, continues to increase. Changes in the atmospheric properties resulting from the high concentration of GHG are the ones that have the greatest impact on agricultural production, since crop yields are affected by an increase in average temperature, as well as by the imbalance in precipitations that entails often to flooding in croplands, due to the excess of water during the growing season, while other times result in the incidence of droughts and poor water availability for the plant. Undoubtedly, agricultural activity is affected by the high concentration of GHG; however, crop production is also a source of GHGs. In this context, as Canada has joined the global goal of reducing GHG emissions, it has committed to reducing its GHG emissions by 30% from the level of 2005 by 2030. This has resulted in federal and provincial governments taking action to reduce GHG agricultural emissions by promoting responsible agricultural activity, but at the same time developing programs for adaptation to climate change. Such adaptation measures have included supporting the development of technologies in irrigation and drainage, BMPs, which among others, promote efficiency in the use and quality improvement of water, and ensure the production of optimal agricultural products to protect the interests of Canadian producers.

Producers in eastern Canada often have to deal with excess water during planting as well as poor availability of water during the plant growth period. The beneficial water management practices involve the provision of an appropriate quantity of water to crops, as well as management of the water table. As these measures affect crop yields, they are of interest to most producers. But the real question is whether such practices will be adopted by the producer. Studies have suggested that the willingness of producers to adopt any BMP is associated with their perception of its profitability either through increasing yields or by reducing production costs. In addition, the proposed BMPs must be perceived as being superior to the practice(s) in use currently. In short, the producer will invest in the BMP if it increases his profits in relation to the pre-investment situation. It is precisely this discussion that has been addressed in this study.

The objective of this study was to evaluate the farm level economic effects of adopting BMPs at four study sites located in Quebec and Ontario. The economic desirability of the BMPs selected in this study was assessed using a financial analysis framework, taking into account the direct costs and benefits of the farm (from a private accounting stance) when the BMP was adopted and when it was not (with and without criterion). This last situation was called Base Technology and corresponded to the practice that the producer had been using traditionally. To compare both situations and finally assess the financial desirability of the new BMP, the net benefits (costs subtracted from benefits) were compared through three financial indicators: net present value, benefit-cost ratio and pay-back period. As long as financial benefits over the selected life span exceed costs, the investment is determined to be economically desirable.

In addition to the above objective, the study also evaluated the robustness of economic desirability results associated with BMPs, through simulation of economic indicators that could be affected by change in important parameters. In addition, such results may also provide the policy-makers with some idea of how much these parameters may influence the producer's decision to adopt a BMP on his farm. The chosen parameters were: commodity prices, investment costs, discount rates, the useful life of the BMP, and crop yields. The level of changes in the crop yields was determined through a review of previous studies, particularly those related to impacts of climate change. Such studies included those for grain production as well as vegetable production.

The on-farm financial analysis was carried out by identifying the costs and benefits associated with the adoption of the selected BMP in each case study site, and subtracting the discounted costs stream from the discounted benefits stream, resulting in the estimation of the farm level net present value. In sum, this process began by identifying the design of the Base and BMP Technologies, their components and the investment capital costs. Then a partial budget of the study farms was developed, which among other things included revenues, fixed and operational costs. The useful life of the BMPs was then established and forecasted values of costs and revenues were obtained. The estimation of the financial indicators mentioned above was carried out, to show the robustness of the results.

This study focused on two types of enterprises on farms: One, grain enterprises, which comprised of production of corn in rotation with soybean; and, Two, vegetable enterprises, which included production of carrots intercropped with onions. For both of the enterprises, production characteristics and rotation patterns of each of the case study farms were taken into account, along with agricultural characteristics of the average farm in these provinces.

The economies of both provinces are favoured with the high contribution made by corn production, which is listed as the major grain crop in the region. In 2018, Ontario obtained 63% and Quebec 26% of their respective total contribution from corn production, valued at $2.26 billion. Soybean production is also of high importance in these provinces, representing $3.05 billion worth of total farm cash receipts in 2018, of which approximately 74% came from production in both provinces.

With respect to the production of vegetables within Canada, Ontario is recognized as the largest producer of these crops, with the largest crop area in the country. In 2018, carrot was the largest vegetable crop produced crop in Canada and onions held the third place after tomatoes. The provinces of Ontario and Quebec accounted for 72% and 80% of the national carrot production (values at $129.9 million) and onion production (valued at $94.6 million), respectively. This demonstrates the relative importance of these crops in these regions.

7.2 Conclusions

This study performed the farm-level analysis using four case study farms, two in Quebec and two in Ontario. Budgets corresponding to the average costs estimated for a profitable farm with good performance were used in each of the regions, according to the estimates of the ministries of agriculture of each. Additionally, all possible data available on the relevant characteristics of each farm studied were taken into consideration, such as cultural practices (most commonly rotation patterns, fertilizer application, amount of labor, etc.), design and characteristics of both water management systems, the existing one (Base Technology) and the experimental one (BMP Technology).

The farm-level economic evaluation, as undertaken in this study, indicated that the selected BMP Technology for each of the four case studies was a more desirable alternative when compared to the respective Base Technology. This would imply that producers from Quebec and Ontario who are engaged in grain and vegetable production, may be interested in adopting innovative water management practices based on the fact that such practices are an alternative that will allow them to generate higher net returns than those generated by the cultural practices/technology they are currently using. Although for grain production sites (St. Emmanuel and Harrow) time to recover is longer, for vegetable production sites (Sherrington and Holland Marsh) this period is very short, which makes them even more attractive. However, depending on whether they are grain or vegetable producers, producers' interest may be affected since these financial indicators are very sensitive to changes in key parameters. Among these crop prices and their yields seem to be playing a more important role. The role of climate change becomes even more vital for the adoption of these technologies.

On grain (corn and soybeans) producing farms, the BMP Technology of controlled drainage with subirrigation system, generated low economic net returns. In these sites, even the profitability of the Base Technology was almost on the edge. Sensitivity analyses carried out suggested that both commodity prices and crop yields of corn and soybeans do not have to be reduced much for these producers experiencing losses, regardless of the technology used. Similarly, in these sites, a small increase in investment costs is detrimental. This impact was noted to be much greater in Ontario since materials and labor costs here are higher than in Quebec.

Although the incremental benefit of adopting the water management practice compared to the conventional free drainage system was high, the year to year variability in yields may make producers less enthusiastic in adopting the BMP Technology. Furthermore, the BMP Technology may become financially unattractive under changes in key parameters that affect the financial indicators. However, at the same time, the adoption of BMP technology may produce high benefits to the rest of society. Two such benefits may include water quality improvements and reduction of GHG emissions. If the studies being conducted reach conclusive results that these innovative water management practices have the ability to reduce impact of the release of contaminants from farmland to water bodies and mitigate the GHG emissions through reducing emissions or increasing their capacity to sequester them (which are finally the main reason why they were created), then the government would have a role to play in the adoption of BMPs by grain producers.

Depending on the magnitude of the social benefits, governments may consider developing incentives for grain produces in the two provinces. High social net benefits and low private net benefits could be an argument to promote adequate cost-sharing programs. An incentive from the government, such as those mentioned in the sensitivity analysis of investment costs, can help the producer make a decision with more confidence and can make a difference in the likelihood of adoption of BMP technology. Additionally, among these incentives, technology development may be included through research on improving crop yields under those BMPs.

In comparison to the grain-producing sites, results are different for the vegetable-producing sites. For these sites, the BMP Technology produces higher net economic returns with a shorter payback period. Therefore, it would appear that the probability of their adoption is higher than that of the grain producers. Sensitivity analyzes in this case show much more robustness as well. The prices of crops in the market (for carrots and onions) could vary without affecting the financial attractiveness of the BMP Technology. Similar results were obtained with respect to changes in crop yields. In fact, the incidence of future climate change is expected to reduce the yield of vegetable crops. These farms are less sensitive to changes in investment costs. A shorter period to recover investment costs may have more appeal to the producers in these regions. Therefore, for vegetable production, no intervention from the government is needed since, even if the social net benefits are very high, the private benefits are high enough so that farms are able to capture all the economic benefits from the investment.

In this context, even though there are variations and uncertainty in key factors associated with investment in innovative practices, the BMP Technology proposed for these farms are an economically desirable option and are likely considered to be adopted (with some public incentive in some cases) since the profit that assures producers is the main factor that impacts their adoption decisions.

7.3 Limitations of the Study

Although every effort was made to collect the best possible data and information in assessing the financial desirability of the BMP Technologies for the study sites, it is necessary to be cautious when generalizing results for all corn-soybean and carrot-onion producers within Quebec and Ontario. The economic viability analysis of a technology assumes that it is technically feasible. In reality, several different factors on farms, such as the slope of the soil, type of soil, existence of a nearby water source, access to the farm for the installation of technologies, etc. may affect the relative financial attractiveness of the BMP Technology. Nonetheless, the results of this study can serve as a reference for producers in the surrounding regions on the economic benefits of alternative technologies that are available.

The production costs used in this study for vegetable producing sites – Sherrington, Quebec and Holland Marsh, Ontario, were obtained from carrot and onion production costs budgets developed by CRAAQ in 2008 and updated to current prices by using the Farm Input Price Indexes in its different aspects. This was due to a lack of updated budgets as far as vegetables are concerned in those provinces. This situation is more serious in Ontario, where the last vegetable budgets provided by OMAFRA was based on incomplete data collection from 2000. In the future, if such data can be made available, it would be possible to have more precise results of financial analysis, which would be more useful for producers in their decision-making to adopt new beneficial management practices.

The sensitivity analyses conducted were important means to measure the uncertainty regarding those economic and non-economic factors that could influence the financial viability of the BMP Technology and, consequently, the possible adoption by the producer. Although important parameters were included in these analyses, other factors may also be important to producers and need to be investigated. Furthermore, in this study, the changes in these parameters were analyzed individually, although, in reality, one could make a case for combined evaluation or two or more parameters.

7.4 Suggestions for Further Research

Future research could continue to explore applying the model in other regions throughout Canada where corn, soybean, carrot and onion are produced, with their diverse soil characteristics, climatic conditions, etc. to measure the performance of the new technologies selected in different contexts. Likewise, the performance of BMPs could also be analyzed in other crops or with other rotational patterns that could be more responsive to the innovative practices

On the other hand, this study provides the basis for a more comprehensive analysis of the on-farm economic desirability of the selected BMP, which captures the producer's willingness to adopt it, but excludes the off-site benefits and costs. Knowledge of these off-site impacts may be instrumental in changing producers' mind about the adoption of the BMP Technology. These associated benefits could two types -- social and environmental. Within the first one, could be considered changes in labor patterns for the successful operation of the new technology, while in the environmental impacts, soil salinization, subsidence of the crop field, etc. could be considered as being important considerations.

Impact of climate change on yields was based on climate models, which do not differentiate between the study technologies. More effort is needed to develop this information, since it is crucial for the economic outcomes of the BMP Technologies.

This study may also constitute the starting point for conducting a benefit-cost analysis (BCA), which would not only evaluate the impact of adoption of BMPs at the farm level, but also would be capable of measuring the impact on the society as a whole, and involve all interested parties in a successful environmental management.

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