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Economic Analysis of the Hand Moved Sprinkler Irrigation System: A Case Study of a Vegetable Farm in Quebec

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Abstract

Irrigation has been promoted as one of the best adaptation measure under climate change. In Eastern Canada, average temperatures are expected to increase, coupled with variable precipitation that may not exceed the evaporation rate. Frequency of dry situation during crop growth period is expected to be higher. This study was developed to examine the financial performance of irrigation on a vegetable farm in Quebec to cope with such a situation. The analysis was undertaken from a producer's accounting stance. Three measures of financial performance - Net present value, Benefit-cost ratio, and Payback period, were used. Two types of technologies were included in this evaluation: One, Base technology where there was no irrigation provided to the crops; and Two, Beneficial Management Practice of providing irrigation water to the crops using an overhead sprinkler system of a hand-move type. The farm grew carrots and onions in an intercropping system - half the field was for devoted to carrots, and the other half for onions. Results suggest that irrigating vegetables crops (such as carrots and onions) provided higher net present value over the 15 year life. The irrigation technology generated an additional $10,932 per ha over the life of the project, coupled with a benefit-cost ratio of 2.1. The payback period for the initial investment was estimated to be very short - only 1.2 years. These results were found to be robust as under most of the changes (change in price of products, discount rate, cost of initial investment) irrigation maintained its higher level of net returns over no irrigation situation. The only exception was that under the prediction that vegetable yields would be reduced under climate change, irrigation loses its financial attractiveness.

Keywords: *Irrigation; Vegetable Production; Net Present Value; Benefit-Cost Ratio; Financial Performance*

Introduction

The continuous increase in global greenhouse gas (GHG) emissions has been credited to having significant effect on climate conditions throughout the world [1]. Increases in average temperatures and changes in precipitation distribution are consequences of climate change and are expected to affect many economic activities, including crop production, due to the occurrence of frequent extreme events such as floods and droughts [2]. In Canada, water availability variations have an overall negative impact on crop yields since are mostly unpredictable [3]. In Eastern Canada, producers usually have to deal with water excess during planting and water shortage during the growth period [4]. Either way, changes in climatic conditions have an effect on crop production since photosynthesis, respiration rate, water use efficiency and soil potential depends directly on temperature levels and water availability [5]. However, the agricultural sector is not only one of the most affected by global warming but is also responsible for contributing to GHG emissions from farm practices.

In 2017, 72 megatonnes of carbon dioxide equivalent (Mt CO_2-eq) GHGs were emitted by the agricultural production activities, which constituted approximately 10% of the total Canadian GHG emissions [6]. Crop production contributes to increases in nitrous oxide (N_2O) emissions by the application of both organic and inorganic fertilizer. The former (i.e. manure) has a higher contribution through releasing mainly methane (CH_4), although application of inorganic nutrients boosts the potential emissions of N_2O through denitrification when soil moisture increases, although denitrification prevents the loss of nutrients from the crop field [7]. Nitrogen leaching and runoff are also indirectly related to total N_2O emissions. The eutrophication of water bodies, for example, produces death and decomposition of living beings that inhabit the water, which contributes to CH_4 released into the atmosphere [8]. Similarly, carbon dioxide (CO_2) can be emitted through decomposition of crop residue and soil organic matter when the soil is dry or in conditions of water scarcity. As water through either with irrigation or rainfall is added, the CO_2 emission slows down [9].

Canada, as a member of the United Nations Framework Convention on Climate Change (UNFCCC), has made a new commitment at the recently held Paris Conference, to reduce by 30% its current national GHG emissions by 2030. Reducing GHG emissions from all sectors has been a priority, although it poses a challenge for both federal and provincial governments to develop appropriate measures to reach this goal. With regard to the agricultural sector, Agriculture and Agri-Food Canada (AAFC) is undertaking research to develop Beneficial Management Practices (BMPs) through the Agricultural Greenhouse Gases Program that might lead to mitigation of agricultural GHG emissions and, at the same time, improving farm production yielding in higher economic returns of Canadian producers [10]. The agricultural water use efficiency area is one of the priorities in this effort. The management of the agricultural water resource has always been a subject of study and interest for researchers, decision-makers and producers, with the aim of promoting water use efficiency and improving its quality to increase agricultural production [11]. However, lately, the need has been added to deal with the availability of water, due to changes in precipitation patterns. The studies foresee that the consequences will be more severe if GHG emissions continue to increase [4].

The warming rate in Canada is faster than the global rate [12]. It was estimated that over the period 1948 - 2016, the annual temperature in Canada has increased in average by 1.7°C compared to the global average of 0.8°C, in the same period. In Quebec specifically the annual temperature has increased to 1.1°C [13]. Changes in climatic conditions are already affecting agricultural practices and will likely have adverse effects on crop yields, hence the need to develop technologies for adapting to future warming conditions [14]. High temperatures will lead to longer growing seasons and probable issues regarding water availability since, although periods of heavy rain will be experienced, the evaporation rate will be higher as the temperature becomes higher [14].

The beneficial practices for water management are related to irrigation, drainage and water table management (WTM) practices/systems. Several studies [15-27] have identified relevant characteristics of the BMPs, that should be able to give the plant all the water required in the different stages of growing to get better yields and improve the quality of the product, minimize water losses due to evaporation or runoff, control the water table level, control the application of fertilizer, improve nutrient efficiency, control and balance of GHG emissions, among others effects [28]. The BMPs could also help mitigate GHG emissions by reducing their emission or taking advantage of soil sequestration capacity. Through irrigation systems (sprinkler, drip, subsurface) for example, since water is used efficiently (through reduced wastage) by the crop, water does not leave the crop field carrying nutrients that may cause eutrophication and then the emission of CH_4 [7]; it also prevents the emission of CO_2 from organic matter or decomposition of crop residues in dry conditions, allowing more carbon sequestration [9].

The BMP considered in this study is the adoption of irrigation by the producer. For its performance to be successful, it is necessary to take into account certain relevant factors with respect to the characteristics of the farm, such as water sources (i.e. distance from surface or underground water source), the type of soil (i.e. hydraulic conductivity or ability to retain moisture), the slope of the land, or easy access to the crop field, among others [29], which needs further investigation as key factors that influence its adoption by producers.

Furthermore, knowledge of potential environmental benefits of adoption of irrigation may also be a motivation for the government to encourage their adoption by producers.

Studies on the adoption of new agricultural practices [30-33] suggest that producers' decision making is based primarily on the economic objectives of their farm business. Naturally, what farmers expect is to have higher returns with the adoption of the new technology compared to the situation without it. Thus, it is necessary for them to be aware of the financial benefits that would result from the adoption of the new technology (such as irrigation) prior to committing investment. Therefore, in order to encourage adoption of irrigation by producers, it is important to develop knowledge of its economic impacts on the farm. This is not to rule out the possibility of some type of government intervention assisting producers adopt the new technology if the adoption leads to some environmental benefits, such as reduced GHG emissions or improved water quality.

Objective of the Study

The objective of this study is to measure the economic effect of adopting irrigation on a vegetable producing farm in Quebec. This is accomplished through estimating the direct benefits and costs associated with this practice. It is equally important that robustness of the results need to be evaluated under a varying set of economic and non-economic conditions.

Materials and Methods

Study site and description of the beneficial management practice

The study site for this analysis belongs to a commercial farm located in Sherrington, Montérégie in southern Quebec, 60 km south of Montreal. The farm has a total area of 607 ha, within which lie the study field consisting of 142 ha or about 350 acres [34]. The soil is muck type, an organic soil with high content of organic matter and nutrients, suitable for growing vegetables [9,35]. This farm produces mainly carrots, onions, spinach and lettuce in rotation, changing fields every year to avoid diseases, and in turn, adopts the intercropping system alternating carrot-onion or lettuce-spinach. The former was of interest in this study [9]. The farm is located in an area of Montérégie known as the black lands of Jardins de Napierville. According to the 2016 census of agriculture, this area contributes more than 60% and 80% of the Quebec's total production of carrots and onions, respectively [36]. In general, Quebec is a major vegetable production region in Canada. In 2018, it accounted for 38% of total vegetable production in Canada, which was 2.4 billion tonnes [37,38]. In 2018, the most produced vegetable nationwide was carrot, generating a farm gate value of $ 129.9 million, with Quebec contributing $ 50.1 million (or 39% of the total). In Canada, dry onion was the third most-produced vegetable, after tomato, generating a farm gate value of $ 94.6 million, with Quebec representing $35.1 million (or 37% of the total) [37].

Regardless of whether it is a growing season with or without rainfall, under the new technology, fields of the farm are irrigated once per year using the hand moved sprinkler irrigation system [9,34]. It is also reported that irrigation practices are becoming more frequent in southern Quebec [39]. The main consideration for this is the change in weather conditions, as reported earlier. Still the magnitude of irrigation relative to total area is small (less than one percent). In 2018, the total artificially irrigated area in Quebec was 17,228 ha [40], of which only 21.2% was assigned to field crops, 26.3% to fruits and 52.5% to vegetables [41]. Much of the water for irrigation (about 84% of total) comes from surface on-farm water sources and 15% from on-farm groundwater sources [42]. Different irrigation practices, such as sprinkler and drip irrigation systems, have been developed to increase crop yields and reducing water use through the timely application of water that improves plant nutrition in the crop's root zone [20,43]. In addition, such practices also maintain water quality of these sources since, the rate of application of water is equal to the rate of infiltration of the soil, resulting in no over-application and no runoff [12,15,18,20,21].

The BMP Technology analyzed for this study site involved providing water to the crop using irrigation in some fields and compare it against a no irrigation situation (fields no irrigated at all) as the base technology. That BMP technology consisted of an overhead sprinkler system in a hand moved type, which consisted of 3 inches (~76 mm) aluminum lateral pipes with 30 feet (~9m) in length, which were arranged on the surface of the land with sprinkler heads for each lateral pipe. Water was supplied through an underground 3 inches diameter PVC pipeline system that was brought from a deep well. This system had a 6-inch diameter aluminum (~152 mm) main pipe, with a length of 37 feet (~11m) length. Water was obtained using two 200 hp and 60 hp electrical pumps. One of the characteristics of this system is that, except for underground pipes, it is perfectly movable [31].

This farm used this system to irrigate 12.7 ha (or 31.3 acres) at a time. The base design consisted of 14 main pipelines, 1200 lateral (15 rows of 80 laterals each) and 1200 sprinklers, covering an area of 720m (80 laterals x 9m) long by 154m (14 main pipelines x 11m) wide [31]. With the aim of guaranteeing a uniform irrigation throughout the area, the sprinklers were installed so that when the water is thrown to the air, it falls to the ground in an overlapping manner [9]. This prevents the greatest amount of water from falling into the radius near the sprinklers only [44-47].

The economic desirability of the selected BMP Technology was undertaken in a financial analysis framework and based on the incremental net benefit of the new technology. It means, from the perspective of a private accounting stance and using a "with and without" the project principle. Therefore, the private economic net benefits to the producer of adopting the BMP Technology was calculated by estimating the direct benefits and costs associated with it and comparing it with the situation when the BMP has not been adopted (Base Technology). Furthermore, it was assumed that onions and carrots are grown in an intercropping system every year. Thus, half the field.

Sources of data and analysis of the beneficial management practice

The specifications of the quantity of each component that was used for the installation of the sprinkler irrigation system were obtained from the study by Bogdan [31]; however their prices were collected from various other sources. The costs of the piping, fittings, and sprinklers set were derived from the price guideline publication by the Centre de Référence en Agriculture et Agroalimentaire du Québec [48], updated to 2018 prices using the Machinery and Equipment for Crop and Animal Production Price Index [49]. This price index was also used to update the cost of the well, which was derived from CRAAQ [50] based on a well with 6,000 m3 of capacity adequate to irrigate 40 ha (or about 100 acres) at a cost of $15,000, as well as an electrical pump costing $4,565, enough to irrigate 4 ha [49]. The sum of these costs resulted in the total cost of investment in the sprinkler irrigation system, $17,561.97 per ha. Detail of components´ costs are summarized in table 1, all of them were calculated at 2018 prices and included installation and assembly costs [49].

Item	Unit	Cost ($/unit)	Quantity (per ha)	Total Cost of BMP Tech. ($/ha)
Cost of the components				
Aluminum lateral pipes (76 mm diam. x 9m length)	Meter	13.03	852.5	11,102.53
Aluminum mainline pipes - manifold (152 mm x 11m)	Meter	27.05	12.4	328.80
Valve-tee, couplers, stopper, and other fittings	Unit	381.98	1.2	422.20
Sprinkler head, nozzle, riser pipe (25 mm diam.)	Unit	42.44	93.9	4,019.53
Well (6,000 m^3)	Unit	210.04	2.5	519.02
Electrical Pump and fittings	Unit	461.30	2.5	1,139.90
Total Investment Cost				17,561.97

Table 1: *Cost of investment for BMP Technology ($/acre).*

Carrot and onion prices from 2016 to 2018 were obtained from the Quebec fruit and vegetable price report developed by CRAAQ [51], while historical prices were obtained from the annual summary wholesale to retail market prices for Montreal by AAFC [52]. Carrot and onion average yields were collected from CRAAQ [53] for the period 2011 - 2017, which was an average estimate of farms with good technical and economic production efficiency in Quebec. These data were used in this study as the crops' yield under the Base Technology.

For the BMP Technology, the yields were calculated based on the results of previous studies that assessed the effect of the adoption of sprinkler irrigation on the productivity of horticultural crops in the same region. For carrot yields, one study compared carrot yields under dryland conditions with yields under irrigation during the growing seasons of 2007, 2008 and 2009, for different levels of soil moisture and low organic matter. The results reported carrot yields of 29.5, 29.7 and 26.8 t/ha, in each year respectively, when the land was completely irrigated (no deficit irrigation), 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 [54]. Similar results have been reported in a study of irrigated carrot yields in Truro, Nova Scotia [55]. Another study [56] 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, a 20% increase in carrot yields from dryland and irrigated carrots for the same study field at Sherrington was estimated [31]. All of these studies reported a significant increase in carrot yields under irrigation. The analysis in this study used a conservative increase of 12.3%, the smallest increase reported by the literature.

Regarding onion yield responses to water applications, Rekika., *et al.* [36] analyzed the effect of a sprinkler irrigation treatment during the bulbing stage and compared it with the yields of unirrigated onion crops in a muck soil field in southwestern Quebec in 2008 and 2009. The 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% [36]. In this study, a conservative onion yield increase of 7.2% over the dryland yields was used in the analysis, based on the review.

The revenues of this study farm were estimated from CRAAQ [50]. In estimating the price, 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 a hectare (ha/2) 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.

The operating budget of a farm with good technical and economic efficiency that produces carrots and onions in an intercropped modality [50] was used to estimate the production costs for this study farm. As detailed in table 2, the total annual fixed cost of the study site for the base scenario (no irrigation) was $2,527.71 per ha, while that for the site BMP Technology was $2,934.58 per ha. All reported costs were updated to 2018 prices using the Farm Input Price Index [57] for Quebec for different cost categories (machinery repairs, depreciation on machinery and vehicles, and general business). The main difference between the fixed costs of the technologies was the annual maintenance cost of the sprinkler irrigation system, which was calculated as 2% of the investment cost [47]. Thus, except for machinery and equipment insurance cost, all other costs were identical between the two technologies. These costs also included the depreciation on the existing capital assets - shed (with a depreciation rate of 3% of the total cost of $1,622.63/ha), warehouse with refrigeration (with a depreciation rate of 3.6% of total cost of $3,558.93/ha, and machinery and equipment of the farm (with depreciation rate 7% of the total cost of $12,847.45/ha), as suggested by CRAAQ [50]. They were updated to 2018 prices using the Farm Input Price Index [57] for depreciation on machinery and equipment in Quebec.

Item	Base Technology ($/ha)	BMP Technology ($/ha)
Maintenance and repair		
Irrigation system	0.00	351.24
Buildings	180.61	180.61
Machinery and equipment	32.37	32.37
Maintenance of land	21.23	21.23
Machinery and equipment insurance	86.66	84.22
Buildings insurance	103.44	103.44
Liability insurance	7.07	7.07
Professional fees and consulting services	301.07	301.07
Electricity, phone, internet, etc.	75.27	123.43
Net property taxes	93.11	93.11
Miscellaneous	24.29	24.29
Depreciation on existing capital		
Shed of machinery and equipment (3%)	72.38	72.38
Warehouse with refrigerated section for carrot (3.6%)	190.81	190.81
Machinery and equipment (7%)	1,339.33	1,339.33
Total Fixed Costs	2,527.71	2,934.50

Table 2: *Fixed costs under base technology and bmp technology.*

The detail of operating costs under no irrigation and BMP Technology were estimated based on the operating budgets developed by CRAAQ and updated to 2018 prices using different components (seeds, fertilizers, pesticides, production insurance, etc.) of the Farm Input Price Index [57] for Quebec. The costs corresponded to producing carrots and onions, reported on a half-ha basis under intercropping. For both crops, 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 an 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 [47,51]. 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 [31]. Therefore, assuming a total of 31 hours of labor needed, it amounted to approximately 2.47 hour per ha at a cost of $16.72 per hour, calculated as the average agricultural work wage in Quebec [59].

Financial analysis

The evaluation of the financial desirability of the hand-moved sprinkler irrigation system (BMP Technology) was conducted using an Excel-based spreadsheet model. The incremental net benefit of the selected BMP was calculated by comparing its net benefits and those of the Base Technology (no irrigation scenario). All net benefits were based on a budgeting technique used for estimating costs and returns for both technologies. In addition, the salvage value (at the end of the life of the project) of the investment component (piping, well, pump) associated with both technologies was also included as a negative cost in the last year of the cost stream. This justifiable since an assumption was made that each investment component was purchased at the beginning of the project. Based on a review of the literature, the life of a sprinkler irrigation system was assumed to be 15 years [44,60]. Thus, the project was assumed to have stated in 2019 and the final year of operation was 2033.

The indicators used for the financial performance of each technology included: net present value (NPV), benefit-cost ratio (BCR) and pay-back period. More details on these criteria are shown in table 3. Since the net present value analysis takes into account the time value of future benefits and costs, they were expressed in present-day values (discounted), and compared to the investment cost of the technologies (in the BMP Technology scenario). The discount rate was estimated at 8.78% using the weighted average cost of capital [61] and using equation 1:

$$r = K_e W_e + K_d(1 - t)W_d \qquad \text{-(1)}$$

Where, r is the discount rate, 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.

The estimation consisted of a combination of debt and equity funds used by the investor to finance investment in the BMP Technology by assigning weights to the cost of debt and the cost of equity. This method of determining the discount rate evaluates the investment after taxes [62]. The return on equity used was 10.2%, which was obtained from the planned performance for the 2018 - 2019 fiscal year of the Canadian farming sector return on equity (ROE) developed by Farm Credit Canada [63]. The interest rate on debt used was 3.64%, which was based on the monthly average of the prime business loan rate in 2018 (X. Zhang, personal communication, June 6, 2019). The proportions of equity capital and debt used were established in 80.5% and 19.5%, respectively, based on a 10-year average (2008 - 2017) of the equity/asset and debt/asset ratios calculated for Quebec [35]. The income tax rate used was 20%, as a reasonable rate of taxable income in the province [64].

Indicator	Formula	Decision criteria	Unit
Net present value (NPV)	$\sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$		$/ha
Benefit-cost ratio (BCR)	$\sum_{t=0}^{n} \frac{B_t}{(1+i)^t} / \sum_{t=0}^{n} \frac{C_t}{(1+i)^t}$		$ gained for every $1 spend
Pay-back period			No. of years

***Table 3:** Indicators used for financial evaluation.*

The revenue and cost data for the 15 years of life span (2019 - 2033) were generated based on a stochastic simulation using the random number generation tool of the R-Project program. To forecast prices and crop yields, a skew-normal distribution was assumed, which was based on past studies that found marked skewness and kurtosis in commodity prices and crop yield distributions [65-69]. Therefore, the mean, standard deviation, as well as the positive or negative skewness coefficients were calculated from the historical set of data of these variables (price and yield). Carrots and onions market prices were obtained from the horticultural wholesale report managed by AAFC [52]. Data available for carrots were obtained for the periods 1996 - 2000 and 2010 - 2019, while for onions the prices were available from 1994 to 2019.

Similarly, the operating costs were forecasted using a normal distribution, based on results of risk analysis (for agricultural insurance) studies [70-72]. The Farm Input Price Index outlook provided by AAFC [73] was used to estimate operating cost data for 10 years (from 2018 to 2027), which were the basis to estimate mean and standard deviation needed for forecasting values for the period until 2033.

Table 4 summarizes the three coefficients obtained for each technology. Projections of revenues and operating costs throughout the 15-year life span (2019 - 2033) took into account the intercropping system - half the filed was under carrots and the other half under onions.

Crop	Item	Crop Price ($/kg)	Base Technology (Per ha)		BMP Technology (per ha)	
			Yield in kg	Oper. Costs in $	Yield	Oper. Costs
Carrot	Mean	0.676	17,714.7	5,890.3	19,893.6	5,972.0
	Stand. Dev.	0.207	826.7	258.0	928.4	260.5
	Skewness	1.272	0.625		0.625	
Onion	Mean	0.783	20,551.6	5,972.8	8,915.766	5,947.0
	Stand. Dev.	0.179	3,363.7	261.6	1,459.231	265.6
	Skewness	0.265	-0.655		-0.655	

Table 4: *Coefficients of skew-normal and normal distributions of crop yields, prices and operating costs.*

Sensitivity analysis

The financial performance of the BMP Technology may be affected in the future through changes in bio-physical and economic parameters used in the base simulation. The robustness of the financial performance of the BMP technology was evaluated in this study using changes in crop price, crop yield, investment cost, discount rate and project life span. Each one of these is described further. In addition, break-even analyses were carried out in each parameter at which the NPV is zero under both Base Technology and BMP Technology.

Changes in product price

The AAFC has reported an increase of 1.8% for vegetable prices by 2027, in spite of the fact that the fruit and vegetable market in Canada has experienced a decrease in these prices in 2017 of 1.9% [73]. However, due to the creation of new and more reliable horticultural production practices, such as tests and trials on varieties according to the characteristics of the farm [32,74] and pest control programs [75], the production (supply) of vegetables would be increasing, which may bring their prices down in the future. In this study, however, a price increase of 1.8% was assumed in an optimistic scenario; while reductions of 1.9%, 5% and an extreme value of 50% in the price of carrot and onion each were assumed as pessimistic scenarios for the sensitivity analysis.

Changes in crop yields

This study assumed that the main reason for variation in carrot and onion yields will be the change in future climate patterns. Past data indicates that for the period 1969 to 2003, the average daily temperature in southern Quebec increased by 0.3°C on average, which has been causing shorter frost seasons and longer growing seasons, while precipitation has been more frequent but of low intensity [76]. By 2050, a warmer climate is predicted associated with increases in temperatures during the growing season of 1.9°C to 3°C. At the same time, there is a high level of uncertainty in these predictions. Rainfall increases would be expected in some periods [77], although this increase would not exceed the evaporation rate that usually occurs when there are high temperatures, so the possibility of water stress in the growing season is high [37,76,78].

Based on the literature, some studies have projected the potential impact of changes in climatic conditions on vegetable yields. Horticultural crops are more sensitive to periods of hot days and the number of days during the growing season with precipitation [79].

Therefore, vegetable 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 [76]. Moreover, many times small variations in temperature or humidity result in poor quality production, which leads to a lower amount of marketable yield. Studies have reported yield losses in many vegetables when they were exposed to temperatures above 30°C coupled with fewer days with rainfall [79]. The growth, maturity and marketable yield of carrots and onions are also influenced by weather conditions. High humidity (including availability of water especially for the development of the bulb) and fertile soils are critical factors for the growth of onions [36]. The optimum good-quality carrots grow with a temperature not greater than 21°C [80]. In fact, for the best onion production, no higher than 26°C is ideal [81]. 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. A reduction of up to 28% in marketable carrot yields was reported during drought periods in experiments conducted in sandy loam soils [82]. This change in yields was used in the sensitivity analysis. In addition to this decrease, reduction of 7 and 14% in the carrot and onion yields were also simulated. For an optimistic scenario, a 7% yield increase was used.

Change in investment costs

This study assumed that change in investment costs will take place mainly due to the granting of incentives and convenient loans by the government through cost-share programs. For example, the provincial government of Quebec, through the Farm Business Development Program as managed by La Financière Agricole du Quebec (FADQ), provides financial support to farms to encourage the increase in their livestock and crop production through the construction, renovation or improvement of buildings or croplands (e.g. drainage systems). Projects are eligible for a $13.33 grant for every $100 of eligible funding from a loan of at least $150,000. The maximum financial assistance per farm is $20,000 and is paid in two installments per year for a five year period [83].

Another program in Quebec is the Financial Support for Aspiring Farmers of the FADQ. The objective of this program is to support (younger) farmers that count at least one year´s relevant experience in agriculture to establish themselves in an existing farm or a new business through training, improvement projects for the land, equipment installation, among others. The eligibility requirement is to have a business plan which ensures that it is a potentially profitable project. The grant is financially supported by up to $50,000 [84].

In this sensitivity analysis, the producer´s access to these programs for the installation of a hand-moved sprinkler system irrigation was assumed, by simulating variations in investment of the new technology. In one scenario, a subsidy of $13.33 was assumed for every $100 loan of the total investment cost in each technology analyzed. The interest rate used was the one for long-term debt of 4.92% in 2018. The second scenario 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.

Change in discount rates

Based on a literature review of different discount rates used in previous studies of financial or economic analysis of agricultural projects, this sensitivity analysis has analyzed the impact on the desirability indicators of adopting the BMP Technology using other discount rates: 3.75% [85,86], 5% [31] and 10% [65].

Change in the project life span

The effect that change in the project life span would have on the financial indicators was also analyzed. In this study, it was assumed that the project life span could be of 10 years [45] under a pessimistic scenario, 20 years [44] and 25 years [26] in a more optimistic scenarios. In all these simulations, recalculation of the salvage value of the investment was required.

Results and Discussion

Financial evaluation

In the base simulation, the financial viability of both dryland production (Base Technology) and hand-moved sprinkler irrigation system (BMP Technology) was undertaken using an estimated life span of 15 years (2019 - 2033) and a discount rate of 8.78%. Results revealed that both technologies are financially desirable since their NPVs are positive and the BCRs are greater than one (Table 5). The pay-back period for the BMP Technology was estimated to be significantly less than 15 years (only between 1 to 2 years). The incremental net benefits for the BMP Technology in present-day prices is $10,932 per ha relative to the Base Technology, over the entire life span of the project. It means, the hand-moved sprinkler irrigation system provides 7.6% higher profits relative to the no irrigation situation. In terms of the entire study field, that spans about 12.67 ha, the producer would receive approximately $138,471 over the life of the project. The BCRs both are equally financially attractive with gain of more than twice per each $1 invested per acre. Therefore, results suggest that carrot-onion production in an intercropping system with a sprinkler irrigation system is preferable on economic grounds. These results can be compared to the findings by Bogdan [31], which was undertaken in the same research fields in the Sherrington study site. Using a 5% discount rate and a project life of 15 years, Bogdan [31] concluded that sprinkler irrigation in onion production is financially more attractive than rainfed (no irrigation) production, with a difference in NPVs of more than 7% in favour of the BMP Technology.

Indicator	Base Technology (No Irrigation)	BMP Technology (Hand Moved Sprinkler Irrigation)
Net Present Value at r = 8.78% ($/ha)	143,148	154,080
Benefit-Cost Ratio (gain for every $1 spent/ha)	2.2	2.1
Pay-back Period (years)	0	1.2

***Table 5:** Financial indicators of the desirability of base technology and BMP technology.*

Sensitivity analysis

As noted above, five different sensitivity analyses were undertaken to test the robustness of the superiority of the irrigation (over no irrigation) technology. Under the price change sensitivity analysis, the better financial performance of the BMP Technology does not change if the carrot and onion prices increase by 1.8% (as suggested by the forecasts) relative to the baseline scenario (Table 6). Even when prices were to decrease by 1.9 or 5%, the BMP Technology continues to be a more financially attractive option. Given these scenarios, the other indicators (BCR and pay-back period) show almost no variation. However, in the hypothetical case that the prices of carrots and onions decline by 50%, then the BMP Technology is no longer financially viable, since its NPV becomes lower than that of the Base Technology, although they continue to remain positive. The break-even point estimates reveal that crop prices have to decline by 55% for the NPV of the Base Technology to become zero, whereas that for the BMP Technology the change would be 53.7% less than the prices used for the base simulation.

Financial Indicator	System	% Change in Crop Prices*						
		+1.8%	0%	-1.9%	-5%	-50%	Break-Even Prices	
							-54.99%	-53.72%
NPV[1]	Base Tech.	147,833	143,148	138,201	130,133	13,003	0	3,326
	BMP Tech.	159,244	154,080	148,631	139,738	10,665	-3,665	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	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

***Table 6:** Sensitivity of financial indicators of the base technology and BMP technology to carrot and onion price variation.*
**: Percent of Base Simulation Prices; [1]: Net Present value; [2]: Benefit-cost Ratio.*

Production of carrots and onions could be adversely affected under a future climate scenario. In this sensitivity analysis, yield of carrot and onion crops were reduced by 7, 14 or 28% of the base simulation level. These reductions decrease the financial attractiveness of both Base Technology and BMP Technologies, although they continue to remain financially viable (Table 7). However, in all of these situations, the BMP technology is no longer better than the base technology. Therefore, the BMP Technology is more sensitive to yield changes. In the case of a 28% less carrot and onion yields, the NPV resulting from the Base scenario is reduced by approximately 70%, from $143,148 to $43,737, while the NPV associated with the BMP Technology is reduced by almost 90%, from $154,080 to $15,943 level. On the other hand, an increase in yields of both crops by 7% maintains the superiority of the BMP Technology over the Base Technology. 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.

Financial Indicator	System	% Change in Crop Yield						
		+7%	0%	-7%	-14%	-28%	Break-Even Yield	
							-42.63%	-31.97%
NPV[1]	Base Tech.	147,833	143,148	138,201	130,133	43,737	0	31,318
	BMP Tech.	195,643	154,080	115,329	79,390	15,943	-38,351	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

Table 7: *Sensitivity of financial indicators of the Base Technology and BMP Technology to carrot and onion yield variations.*
**: Percent of base simulation yield level; [1]: Net Present value; [2]: Benefit-cost Ratio.*

As expected, results of sensitivity analysis for investment costs indicated that the BMP technology is positively affected with the government intervention. As investment cost for the producer decreases, the NPV values increase (Table 8). These results were generated under two variants of the intervention. The first one was 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). The second scenario is a 22.48% decrease in the total cost of investment (corresponds to assuming that the farmer 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 (for a 12.67ha field), under this program only $50,000 could be granted. However, it resulted in a reduction in investment cost per ha by 22.48% -- from $17,562 to $13,614 per ha. 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 still remains as the most desirable alternative. The break-even analysis indicated that the investment cost for the BMP Technology would have to increase by more than eight times for BMP Technology ceases to be financially viable.

Financial Indicator	System	Change in Investment Cost*				
		+5%	0%	-11.93%	-22.48%	Break-Even Inv. Cost
						+877%
NPV[1]	Base Tech.	143,148	143,148	143,148	143,148	143,148
	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

Table 8: *Sensitivity of financial indicators for the Base and BMP Technologies to change in project investment cost.*
**: Percent of Base Simulation Investment Cost; [1]: Net Present Value; [2]: Benefit-Cost Ratio.*

The discount rate sensitivity analysis showed 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 unchanged. With a 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. At the same time, regardless of the discount rate level, sprinkler irrigation (BMP) maintains its better financial attractiveness compared with the dryland technology. These results are quite similar to those by Bogdan [31]. With discount rates of 5 and 10%, her study concluded that sprinkler irrigation is the best alternative financially. The break-even discount rates, also referred to the internal rate of return (IRR), indicate that the discount rate would have to be greater than 150% for the BMP to cease to be financially viable. On the other hand, an arbitrary very high discount rate of two million percent would make the NPV indicator in the Base Technology to be zero, whereas for the BMP technology a discount rate higher than 150% would make it unprofitable.

Financial Indicator	System	Change in Discount Rate				Break-Even (IRR)	
		10%	8.78%	5%	3.75%	2 mill. %	150.9%
NPV[1]	Base Tech.	133,330	143,148	181,946	198,360	0	10,517
	BMP Tech.	142,298	154,080	200,931	220,875	-11,414	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

Table 9: *Sensitivity of financial indicators for the Base and BMP Technologies to change in discount rates.*
[1]: Net Present Value; [2]: Benefit-cost Ratio.

The results on the project life span sensitivity analysis revealed that the financial indicators are almost non-sensitive to changes in the length of the project's life. As shown in table 10, with a reduction of project life from 15 to 10 years, the NPV indicators are reduced by about 22% for the Base Technology and 27% for the BMP Technology. On the contrary, as life expectancy increases, 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. In all situations, the BMP technology was found to be more attractive financially, as suggested by higher NPV values.

Financial Indicator	System	Change in Project Life Span (years)			
		10	15	20	25
NPV[1]	Base Tech.	111,378	143,148	156,983	168,919
	BMP Tech.	112,094	154,080	171,577	185,047
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	Base Tech.	0.0	0.0	0.0	0.0
	BMP Tech.	1.2	1.2	1.2	1.2

Table 10: *Sensitivity of financial indicators for Base and BMP Technologies to a change in project life span.*
[1]: Net Present value; [2]: Benefit-cost Ratio.

Conclusion

This study conducted a farm-level economic analysis of a commercial vegetable producing farm in Quebec. Budgets developed by Quebec Reference Center for Agriculture and Agri-Food were used, which corresponded to the average costs estimated for a profitable farm with good performance in the region where the greatest production of vegetables is concentrated. Furthermore, all possible data available on the relevant characteristics of the study farm (such as cultural practices including most commonly rotation patterns, irrigation patterns, fertilizer application, amount of labor, etc.) were taken into consideration. The BMP for this farm was use of hand moved sprinkler irrigation, which was compared with that of no irrigation situation.

This farm-level economic evaluation suggested that the hand moved sprinkler irrigation system is a more financially attractive alternative when compared to the dry land situation (no irrigation at all). This would imply that producers from Quebec, who are involved in vegetable production and that do not use irrigation of any kind for their crops, may be interested in adopting the innovative water management practice since it is an alternative that will allow them to generate higher net returns than those generated by the current farming practices. Besides, the time to recover the investment is very short, which makes the technology even more attractive to adopt.

The BMP Technology performance is robust to changes in the several factors. The prices of crops in the market (for carrots and onions) could vary without affecting the financial attractiveness of the BMP Technology. However, climate change could play an important role in determining the yields of horticultural crops (notably carrots and onions). A reduction in the yield of these crops would make the sprinkler irrigation less attractive to producers. The production of these crops is less sensitive to changes in investment costs, as the adoption of irrigation could be financed through internal resources.

Declaration of Interest

The authors report no conflicts of interest. The authors alone are responsible for the contents and writing of this article.

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